2 Data Resource Information

2.1 Introduction

Existing literature contains a large amount of data and information related to the Spokane Aquifer. Recent investigations conducted as part of the City of Spokane Wellhead Protection Project provided several new discoveries that enhanced and modified the previous conceptual model of the Spokane Aquifer developed for the City's program. Building upon these new findings, a multi-faceted field data collection program was developed for the SAJB wellhead protection project. This data collection process was intended to further enhance the knowledge base about the aquifer, and to refine the original hydrogeologic conceptual model.

Field data collection activities were focused on three somewhat discrete geographic regions of the Spokane Aquifer: the state-line area; the central Spokane Valley; and portions of North Spokane near the interface of the Hillyard Trough and Little Spokane River Valley. In those areas a more extensive body of hydrogeologic data (e.g., the Spokane Valley area), were intended to refine the existing hydrogeologic conceptual model. In areas where a more limited data set exists (e.g., North Spokane area), the newly acquired geologic and hydrogeologic data serves as a baseline for developing a preliminary conceptual model.

The following principal activities were performed for the SAJB data collection process.

- Developed an expanded (to the City of Spokane) water level monitoring network.
- Installed fifteen new monitoring wells.
- Conducted conventional land surveys to establish horizontal and vertical control for wells and geophysical survey stations.
- Performed aquifer tests using existing production wells and existing or newly installed monitoring wells.
- Conducted a discrete groundwater level-monitoring event near the state-line area.
- Conducted continuous water level monitoring of a Washington-Idaho state-line monitoring well.
- Conducted a seismic reflection survey to map bedrock depth and structure in the central Spokane valley.
- Evaluated drillers' logs and other available hydrogeologic information to confirm or refute the presence of a deep confined aquifer system in the north Hillyard Trough and Little Spokane River Valley.
- Conducted a microgravity gradiometry survey in the north Hillyard Trough area to evaluate basement bedrock depth and structure.

- Performed a Transient Electro-magnetics (TEM) field evaluation in an area of North Spokane.
- Established a network of river stations, creek stations, and water supply wells to assess hydrologic conditions within a portion of the Little Spokane River Basin between Dartford Creek and Little Deep Creek.

A Field Data Collection Plan and QA/QC Plan (Appendix B) was prepared to help guide and direct the data collection efforts of the project. The Plan describes both the rationale for the respective data collection activities, and the general methodologies used for data collection and reduction. The following principal data quality objectives were established for collecting the hydrogeologic and geologic data required for the SAJB's wellhead protection planning work.

- Collect sufficient hydrogeologic data to potentially refine the existing regional groundwater flow model. The model is used to delineate wellhead protection areas for wells and well fields operated by SAJB members and for proposed future wells.
- Apply methods and procedures generally consistent with standard practices and applicable state regulations during drilling, well installation, and other hydrogeologic data collection activities.
- Obtained easement to wells and properties were applicable.

The following sections describe the major data collection tasks performed to support the SAJB wellhead protection program. The conceptual model of the study area's geology and hydrology that was developed by synthesizing existing literature resources and new information generated by this project is presented in Chapter 3.

2.2 Water Level Monitoring Network

Data collection efforts conducted in support of the City of Spokane WHP program established a water level monitoring network consisting of approximately 120 wells located in the Spokane Aquifer from the Washington-Idaho border to the Nine-Mile Dam. To refine the existing Spokane Aquifer model and conduct simulation/calibration and wellhead delineation near SAJB members' pumping wells, it was necessary to collect additional water level data within approximately five miles of the state-line, both in Washington and Idaho. For this purpose, a water level monitoring network was established that totaled 35 existing wells, 22 wells located in Washington between Sullivan Road and the state-line, and 13 wells in Idaho located west and northwest of Post Falls.

The 22 wells located in Washington included 19 which were previously part of the City of Spokane's WHP network and three new monitoring wells installed by the SAJB (see Chapter/Section 2.3).

The following description briefly summarizes the method used to select the 13 Idaho wells included in the SAJB program.

- Well log records (obtained from the Idaho Division of Environmental Quality [IDEQ]) and U. S. Geological Survey reports identified over 100 wells located within about five miles of the state-line.
- This list of over 100 wells was reduced to approximately 30 potential locations to provide a data point density of about one well per square mile.
- The owners of these wells were identified, contacted by telephone, and asked for their cooperation in the project.
- A field reconnaissance trip was made to each of the well locations to verify the location, review operational status, assess its accessibility for manual water level measurements, and secure owner permission (either verbal or written) to monitor water levels in the Fall of 1996.

Each of the wells selected for the SAJB monitoring network were given a unique well identification number pertaining to the well's township, range, section, and quarter/quarter section. The well identification numbering system is similar in convention to that used by the USGS and other agencies, but it was modified for this project to a seven-digit alphanumeric code. For example, the ID code for a new monitoring well drilled at the CID #4 well field is 5517D05. The first number indicates the township in which the well is located (i.e., 5 represents Township 25 North; and 6 represents Township 26 North). The second number represents the range (i.e., 5 represents Range 45 East and 4 represents Range 44 East). The third and fourth numbers identify the section in which the well is located (i.e., Section 17). The letter in the fifth position represents the quarter/quarter section in which the well is located. This follows the USGS well-numbering system. The last two numbers also follow USGS conventions and identify wells in a particular quarter/quarter section. The ID codes for Idaho well locations follow the same naming system. An example ID code for a well located in Post Falls is 1534B03, where the 1 represents Township 51 North (or 0 represents Township 50 North) and the 5 represents Range 5 West (or 6 as the second digit represents Range 6 West).

Whenever possible wells that appeared in existing USGS databases or reports were assigned the same quarter/quarter section identification as in the existing USGS database/report.

Table 2-1 lists the wells selected for the SAJB water level monitoring network.

2.3 Monitoring Well Installation

As part of the data collection program, 15 new monitoring wells were installed at strategic locations, 13 in the Spokane Valley and two in North Spokane. The new monitoring wells were designed and sited to meet the following objectives:

- Characterize the geologic nature of the aquifer using soil samples collected while drilling.
- Provide representative groundwater level data for the Spokane Aquifer.
- Serve as observation wells for aquifer tests performed on selected SAJB production wells.

- Serve as sentinel wells for future assessment of water quality in areas hydraulically up-gradient of SAJB member wells.

Table 2-1: SAJB Water Level Monitoring Network

State	Well ID	Owner	Well Name
Idaho	1625H01	Yung	Domestic
	0606Q01	Jacklin Seed	10-inch domestic
	1534B03	City of Post Falls	#5
	1533E01	Schneidmiller	USGS monitoring well
	1531Q01	Greenacres Plant Food Ctr.	#1
	1531E01	Beck, Don	#1
	1530N01	POE Asphalt	Domestic near office
	1528R03	East Greenacres ID	3C
	1528N03	East Greenacres ID	1C
	1527F01	Guy	Domestic
	1522D02	East Greenacres ID	2B
	1521M01	Wolkenhaur	Domestic
	1519K02	Hauser Lake Water Assoc.	#1
Washington	6631M07	Spokane County	SAJB #3
	6619N01	Spokane County (208)	Idaho Rd #1 (Near Trent)
	6536N02	Boshears	Domestic
	6532J02	Schmidt	Domestic
	6526H03	Pentler	Domestic
	5517Q01	Spokane Gun Club	Domestic
	5517D05	Spokane County	SAJB #1
	5516C01	Inland Empire Paper	USGS Monitoring Well
	5515R01	Liberty Lake Sewer District	Sprague well
	5514F01	Liberty Lake Sewer District	Schultz well
	5511M01	Kennert (North Well)	North Well
	5511G01	Bryant Motors	Domestic
	5510F01	Delp	Domestic
	5507A04	Spokane County	SAJB #2
	5506D02	Borjessan	Domestic
	5503N01	Coen	Irrigation
	5503D02	Otis Orchards School	Domestic
	5501H03	Washington State Patrol	Domestic
	5414J01	Vera Water and Power	#2 Test Well
	5412M01	Central PreMix	SPK Co (208) - Sullivan
	5401R01	Spokane Industrial Park	Well #4
	5401D01	Trentwood ID	Trentwood #5

The locations of the new monitoring wells are shown in Figure 2-1. All wells consisted of 2-inch-diameter polyvinyl chloride (PVC) screens and riser pipes. All wells were drilled and installed in accordance with Ecology's requirements for resource protection (monitoring) wells. Spokane-based Fogle Pump and Supply used air rotary drilling methods to drill the wells between July 1996 and September 1998. Each of the wells were drilled and installed approximately 25 to 35 feet into the saturated zone of the aquifer. This depth was used to accommodate the range of expected seasonal water level fluctuations (levels typically fluctuate from 5 to 15 feet) and depth-sampling requirements of the Spokane County Water Quality Management Program.

Well construction diagrams and soil-boring logs for each new monitoring well are provided in Appendix C. The lithology at each well site was logged in accordance with the Unified Soil Classification System (USCS). After construction, each well was developed by surging, bailing, and pumping to remove excess fines from around the filter pack and to improve the hydraulic connection between the aquifer and the well.

2.4 Discrete Water Level Monitoring Event

The primary objective of this one-day water level monitoring event was to provide a water table configuration for the expanded study area into Idaho. The results of this monitoring event was used to refine the calibration of the regional groundwater flow model.

2.4.1 Water Levels

The discrete one-day water level monitoring event was performed on October 30, 1996. The monitoring was conducted at this time to provide water level information when groundwater withdrawal rates were low and water levels were near seasonal lows. Water levels were manually measured at the thirty-five wells described in Chapter/Section 2.2 and at six additional sites along the Spokane River between Lake Coeur d'Alene and Sullivan Road in the Spokane Valley.

Table 2-2 lists the well ID, well owner and number, and water level information for the October 30, 1996 monitoring event, including measured river stage elevations. Reference point elevation data for each of the wells, which were determined by engineering surveys completed by the City of Spokane (1994-95), CH2M HILL, Inc. (1996) for Washington wells, by the USGS (date unknown) and Meckel Engineering (1996) for Idaho locations are included in Table 2-2. Appendix D provides field reconnaissance describing locations, reference points, and depth-to-water measurements sheets for each of these well monitored.

A water table contour map showing groundwater elevations and the locations of wells monitored during the October 30, 1996 monitoring event is presented in Figure 2-2.

2.4.2 Pumping

Pumpage data were gathered from private and industrial water purveyors whose high capacity production wells were in service for a 72-hour period that included the one-day monitoring event. Data was evaluated on the average of the total hours. These data are presented in Table 2-3.

Figure 2-1: Wellhead Protection Area Monitoring Wells

Figure 2-2: Data Collection Points and water table map for the Discrete Monitoring Event

Table 2-2: Water Level Data - October 30, 1996 Monitoring Event

Table 2-3: Data for Pumping Wells Operating During the Water Level Monitoring Event
(Located in the vicinity of the monitoring network)

State	Well ID	Owner	Well Name	Average Pumping Rate (gpm)
Idaho	1534B02	City of Post Falls	#3	300
	1534B01	City of Post Falls	#1	500
	1528N03	East Greenacres ID	1C	200
	1519K02	Hauser Lake Water Assoc.	#1	100
Washington	6534L01	CID	East Farms, 7A	1,175
	6525C01	Moab Irrigation District	#1	120
	5518R01	CID	Corbin, 2A	830
	5515D01	Liberty Lake Imp. Dist.	Kenney Well, S02	330
	5515C01	Liberty Lake Imp. Dist.	Mission Well, S03	75
	5423J01	Vera Water and Power	#8	1,600
	5415E02	Modern Electric	#1	700
	5412M02	Central PreMix	Pit Well	550
	5412D01	Spokane Industrial Park	#3	950
	5411B01	Kaiser Trentwood	Domestic	250
	5410A01	Kaiser Trentwood	WW-EW-1	4,500
	5402P01	Kaiser Trentwood	Extraction Well (OH-EW1)	1,000
	5401R01	Spokane Industrial Park	Well #4	815
	5401D01	Trentwood ID	Sullivan #5	520
River	Lake CDA		2840 cfs river flow	1,274,600
Inflows	Liberty Lake	Treatment Plant		275
	Post Falls	Treatment Plant		1,200

2.5 Continuous Water Level Monitoring

An electronic data logger and pressure transducer were installed to provide relatively “continuous” water level monitoring of the new monitoring well (Well ID 6631M07) drilled at the CID well field #11 located near the state-line. The data logger was set to collect water level readings at regular four-hour intervals for three periods beginning in February 1997 and ending in February, 1998. Several breaks in the data collection record occurred as a result of this data logger and pressure transducer being used to support other data collection efforts during aquifer testing in the Summer, 1997.

Figure 2-3 displays a hydrograph of the data showing water level elevation changes throughout the monitoring period. The continuous water level data provides a detailed record of short-term and long-term water level changes. Even though this well is only about 1/2 mile north of the Spokane River, the hydrograph data shows that at this location precipitation events and/or river stage fluctuations do not generally appear to directly affect water level changes in the aquifer.

2.6 Aquifer Testing

Multiple well tests were conducted at four locations in the Spokane Aquifer for this project. The purpose of these tests was to provide additional estimates of aquifer transmissivity at several locations to confirm and refine modeling parameters. Initial estimates of aquifer transmissivity used to calibrate the groundwater flow model for the City of Spokane's WHP program were largely derived from a limited data set which included thirty-one single-well specific capacity tests and five multiple-well pumping tests.

Four well sites were selected for use during aquifer water level tests because of their locations, the presence of nearby observation wells, and the fact that they are all high-capacity production wells. Three water level tests were performed in the Spokane Valley at the following locations: 1) Vera Water and Power's #2-1 well near Sullivan Road and Springfield Avenue, 2) CID's #11 well north of Wellesley Avenue on Idaho Road, and 3) CID's #4 well near Mission Avenue and Barker Road. One test was performed in the Hillyard Trough at North Spokane Irrigation District's #3 well located northeast of Francis Avenue and Market Street.

At each test site, a data logger and pressure transducer were installed in one observation well several days in advance of testing to monitor background water level changes. During the actual testing, water levels were monitored using the data logger and transducer and monitored manually in other wells using electronic water level indicators or airline gauges. Each of the four aquifer tests is briefly summarized below. The summaries describe test duration, pumping rates, wells monitored, observed draw-down, and difficulties encountered during the data collection. During all four tests one problem that occurred was the inability to pump a wells for a period of more than eight hours. This was largely due to system capacity restraints and/or difficulties in distributing large quantities of water during periods when system demands fell below seasonal norms.

2.6.1. Aquifer Test Summaries

2.6.1.1 Vera Water and Power Well #2-1 Aquifer Test

An eight-hour aquifer test was conducted at Vera's #2-1 well on June 10, 1997. Both production wells at this well-field were removed from service for 21 hours prior to the start of the aquifer test. During the aquifer test, well #2-1 produced an average of 2,500 gpm. Table 2-4 summarizes observed draw-down responses.

Table 2-4: Draw-down Response from Vera #2-1 Aquifer Test

Well	Distance from Well #2-1	Draw-down after 8 hours
Well #2-1	Pumping well	No access - could not measure
Test Well #2	16 feet	0.26 feet
Well #2-2	16 feet	No access - could not measure

2-3.dwg 1/98

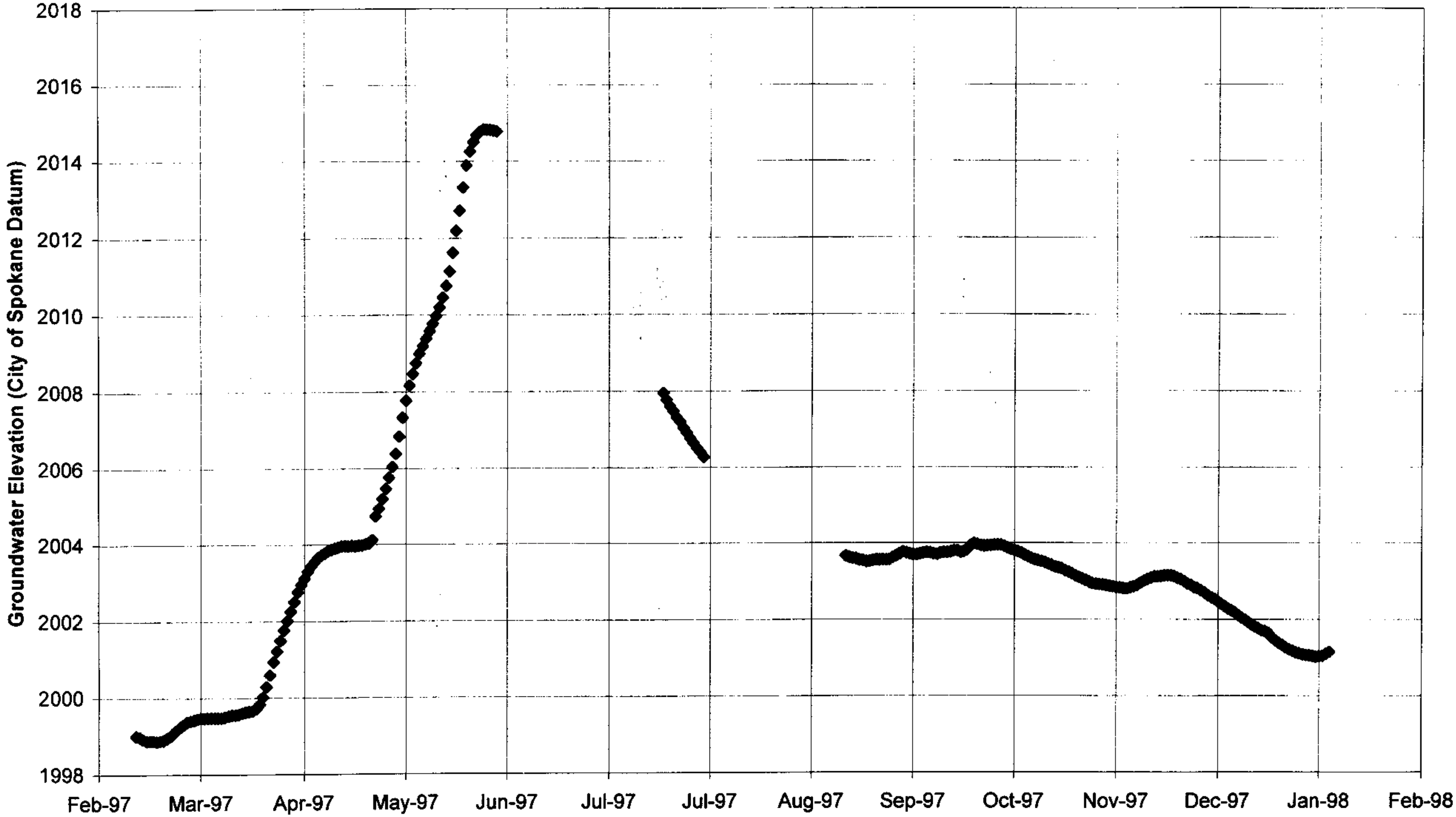

FIGURE 2–3

IDAHO ROAD MONITORING WELL
GROUNDWATER ELEVATIONS
FEBRUARY 1997 – FEBRUARY 1998

SPOKANE AQUIFER JOINT BOARD
FEBRUARY 1998

CH2MHILL

- Water levels in the pumped well and one observation well (well #2-2) could not be monitored because access ports were unavailable. Water levels at test well #2 showed instantaneous response when the pump was started and stopped, draw-down remained consistent at 0.26 feet during the entire pumping period.

2.6.1.2 North Spokane Irrigation District Well #3 Aquifer Test

A 6.5-hour aquifer test was conducted at NSID's well #3 on July 16, 1997. No pumping had occurred for approximately 3 hours prior to testing. During the testing, well #3 was pumped at an average rate of 800 gpm. Table 2-5 summarizes observed draw-down responses during the testing.

Table 2-5: Draw-down Response from NSID Well #3 Aquifer Test

Well	Distance from Well #3	Draw-down after 6.5 hours
Well #3	Pumping well	4.04 feet
Well #2	170 feet	0.37 feet
SAJB #4 monitoring well	2300 feet	No measurable response observed

The purveyor's system capacity would not allow for pumping beyond the 6.5 hours of testing.

2.6.1.3 CID #11 Aquifer Test

A 7-hour aquifer test was conducted at CID's #11 well-field on August 8, 1997. During the testing, well #11A was pumped at an average rate of 3,400 gpm. Table 2-6 summarizes observed draw-down responses during the testing.

Table 2-6: Draw-down Response from CID Well #11A Aquifer Test

Well	Distance from Well #11A	Draw-down after 7 hours
CID Well #11A	Pumping well	1.8 feet
SAJB #3 monitoring well	59 feet	0.03 feet
CID Well #11B	72 feet	1.1 feet (measured with air-line, located 72 feet from another pumping well.

Well (#11A) was shutdown three hours prior to testing. However, due to system demands and the inability of the purveyor to provide service to the local area from another pumping station caused well #11C to operate when Well #11A was turned off (prior to testing). Well #11C also operated intermittently during the testing period when well #11A could not meet the purveyor's system demands. Well #11C is located approximately 145 feet south of Well #11A. Water levels in wells #11A and #11B were monitored with air-lines.

2.6.1.4 CID #4B Aquifer Test

A 4-hour aquifer test was conducted at CID's #4 well-field on August 29, 1997. Due to a lack of purveyor system capacity, the pumped well (#4B) cycled on and off during the test, operating steadily for about 35 minutes then stopping for about 20 minutes. When pumped, Well #4B produced at an average of 1,975 gpm. Table 2-7 summarizes observed draw-down responses during the testing.

Table 2-7: Draw-down Response from CID Well #4B Aquifer Test

Well	Distance from Well #4B	Draw-down after 0.5 hours
CID Well #4B	Pumping well	0.7 feet
SAJB #1 monitoring well	90 feet	0.1 feet

Water levels in Well #4A and #4C could not be monitored with confidence as their airlines gave unreliable readings.

2.6.2 Data Analysis

Analyses of the aquifer test data collected during the four tests summarized above are presented in Appendix E.

Draw-down data at selected wells were adjusted to remove artificial influences on draw-down resulting from the partially penetrating nature of the well. This analysis was based on methods developed by Butler (1957) and Walton (1962). Analytical methods using time-draw-down and recovery, distance-draw-down, and specific capacity data were used to analyze the aquifer test data.

Table 2-8 summarizes the transmissivity values and hydraulic conductivity values determined from the four aquifer tests and compares the results to the transmissivity input for the existing groundwater flow model. In general, the results from the SAJB testing gave somewhat lower estimates of transmissivity and hydraulic conductivity compared to the existing flow model parameters. However, they generally fall in the same range as the existing model parameters.

2.7 Spokane Valley Geophysical Investigation

Historically, several types of surface geophysical methods have been used to investigate the thickness and subsurface characteristics of the Spokane Valley-Rathdrum Prairie Aquifer, including gravity (Purves, 1969), seismic refraction (Newcomb et al., 1953; Hart-Crowser, 1994) and seismic reflection (WA State DNR, 1994; City of Spokane, 1997). Shallow seismic reflection profiling was used during the SAJB field investigation to better define aquifer thickness and bedrock topography for a selected portion of the study area. Specifically, the SAJB seismic reflection survey data, used in conjunction with other subsurface information obtained from previous investigations and drillers' logs, can help constrain previous estimates of aquifer thickness and improve definition of the bedrock geometry in the mid-Spokane Valley area. These parameters are of particular importance to model construction and estimates of aquifer through-flow.

Seismic reflection profiling was used during the data collection phase of the City of Spokane's Wellhead Protection Program and found to be a cost effective and minimally intrusive tool for defining the thickness of the glaciofluvial and alluvial deposits, and the configuration of the underlying bedrock basement. This surface geophysical tool was shown to be especially useful where deep lithologic data from wells or borings were sparse or non-existent.

For the SAJB data collection program, a north-south trending seismic traverse was completed along Sullivan Road (north of river) and Progress Road (south of river). This five-mile long seismic traverse extended across the entire width of the Spokane Valley. Cultural features and vehicular traffic required that the traverse be broken into three separate segments (Lines 1, 2, and 3). An offset gap of approximately 2000 feet was required between Lines 2 and 3 (see Figure 2-4). A fourth line (Line 4), was completed parallel to line 3 and provides additional definition of the bedrock contact near the northern margins of the valley. Elevation control for the underlying bedrock basement was provided through local drillers' logs and a seismic refraction survey (Hart-Crowser, 1994) conducted approximately one-half mile west of the Sullivan Road profile in the vicinity of the Kaiser-Trentwood facility. A gravity survey transect along Sullivan Road (Purves, 1969) also provided a qualitative measure of geologic control.

Interpre'Tech/SeisPulse, LLC of Lacey, Washington, used its patented SeisPulse Near Offset method of seismic surveying to perform the seismic reflection survey. A vehicle-mounted impulsive seismic source, two or three geo-phones (positioned within five feet of the seismic source), and a Bison six-channel stacking seismograph were used to acquire the seismic reflection data. Most shot point intervals were set at one hundred foot spacings; some 50-foot spacings were used near the valley margins, and some 200-foot spacings were used near the north end of the transect. Typically, six to eight summed shots were used per station.

The entire Sullivan Road seismic profile, including horizontal shot point distribution, two-way travel time, surface topography, well control, assumed water table elevation of 1940 feet (USGS datum) and calculated bedrock elevation is shown in Figure 2-5. A copy of the Interpre'Tech/SeisPulse seismic reflection survey report is included in Appendix F. The seismic reflection data indicate the presence of a prominent, coherent reflector that is believed to represent the top of bedrock in contact with glaciofluvial and alluvial valley fill deposits. The reflector appears to define a valley-like profile, with its deepest point (location of greatest travel time) in the vicinity of the present-day Spokane River. It is not known, however, whether the valley fill materials at depth have a water-bearing capacity that is similar to the upper portion of the aquifer. Application of these data to the current groundwater flow model is discussed in more detail in Chapter 3.

Table 2-8: Summary of Aquifer Testing Calculations

Aquifer Test	Location	Estimated Saturated Thickness (ft)	SAJB Aquifer Testing			Existing Groundwater Model Input	
			Data Analysis Methods	Estimated Transmissivity Range (ft^2/day)	Estimated Hydraulic Cond.(ft/day)	Estimated Transmissivity Range (ft^2/day)	Estimated Hydraulic Cond. (ft/day)
Vera #2	Valley, Sullivan and Broadway	400	Distance-drawdown	380,000	950	2,000,000 - 3,000,000	5,000
No. SPK Irr. Dist.	North Spokane, Francis and Market	200	Time-drawdown, time-recovery, specific capacity	100,000 - 700,000	500 - 3,500	< 1,000,000	2,000
CID #11	Idaho Road and Wellesley	400	Distance-drawdown Specific capacity	800,000 - 1,700,000	2,000 - 4,200	3,000,000 - 4,000,000	7,000
CID #4	Valley, near Barker and Mission	450	Distance-drawdown Specific capacity	1,900,000 - 2,500,000	4,200 - 6,200	3,000,000 - 4,000,000	7,000

Figure 2-4: Location of Seismic Reflection Survey Line

Figure 2-5: Sullivan Road North-South Seismic Reflection Profile

2.8 North Spokane Hydrogeologic Evaluation

2.8.1 Introduction

Data collection activities in the north Spokane area were directed at the northern portion of the Hillyard Trough and the Little Spokane River valley downstream of the Highway 395 bridge crossing at Dart Hill. Additional baseline hydrogeologic data also were collected for the Pine River Park area where two SAJB water purveyors (Whitworth Water District and Water District No. 3) obtain water from a groundwater system that appears to lie outside the main body of the Spokane Aquifer system. The data collection activities in this area were designed to support a reassessment and refinement of the existing hydrogeologic conceptual model for the "down-gradient" portion of the Spokane Aquifer. Specifically, the goals of the data collection program were to:

- provide an improved understanding of aquifer thickness and bedrock basement topography within the north end of the Hillyard Trough;
- evaluate the suspected occurrence of a deep, confined water-bearing unit near the base of the Hillyard Trough and the lower reach of the Little Spokane River valley using existing drillers' logs and other available hydrogeologic information;
- summarize known characteristics of groundwater quality for the deep, confined water-bearing unit;
- conduct a cursory evaluation of hydrologic conditions within the Pine River Park area of north Spokane sufficient to support the development of WHP capture zones for several production wells that lie outside the main body of the Spokane Aquifer.

Both active field data collection and a literature/drillers' log review were used to achieve the goals of the north Spokane hydrogeologic evaluation.

Two different surface geophysical methods, seismic reflection and microgravity gradiometry, were used to collect representative subsurface hydrogeologic information within the WHP study area. A third surface geophysical method, transient electromagnetics (TEM) also was pilot tested; results from the TEM pilot test were inconclusive, and therefore will receive only a limited discussion herein. As discussed in Chapter/Section 2.7, seismic reflection profiling was used effectively within the central portion of the Spokane Valley to assess aquifer thickness and bedrock basement topography. An alternative method, microgravity gradiometry, was used to define similar characteristics of the north Hillyard Trough where lithologic conditions limited the application of seismic reflection methodologies.

The northern end of the Hillyard Trough was targeted as an area of interest to the SAJB wellhead protection project for several reasons. It serves as a primary groundwater discharge zone for the Spokane Aquifer, being located at the down-gradient end of the aquifer system.

Increasing land development and population growth have prompted the need for additional groundwater development, and created a potential conflict over the ability to secure water rights within WRIA 55.

A deep, laterally extensive water-bearing zone appears to be present at the base of the glacio-alluvial sediment sequence; the degree of hydraulic interconnection between this deep aquifer unit and the "upper" Spokane Aquifer and/or the Little Spokane River is thought to be limited due to the apparent thickness of the overlying glaciolacustrine silt/clay aquitard.

2.8.2 Microgravity Gradiometry Survey

A microgravity gradiometry (gravity) survey was conducted at the northwestern end of the Hillyard Trough, where the Spokane Aquifer groundwater system merges with the Little Spokane River Valley. The gravity survey, including data collection, processing, and analysis and reporting, was performed by Northwest Geophysical Associates, Inc. (NGA) of Corvallis, Oregon. This north Hillyard Trough/Mead area was selected for additional study based on its unique hydrogeologic setting, and because of limited but compelling evidence that a deep, confined aquifer unit was present at the base of the unconsolidated glacio-alluvial sediment sequence. Full details of the gravity survey are presented in Appendix G. The following discussion provides a brief summary of the preliminary setup and findings from the NGA gravity survey.

2.8.2.1 Conventional Land Survey

The microgravity gradiometry methodology requires a high degree of vertical elevation control to maximize the resolution of subsurface structures such as the contact between the basement bedrock and the overlying sediments. To achieve the desired degree of vertical control, J. Paul Ramer and Associates, Inc., Spokane, Washington conducted a conventional land survey. Gravity stations were established at spacings of generally 200 to 300 feet to produce a southwest-northeast trending transect approximately two miles long. The location of the survey transect is shown on Figure 2-6. Each gravity station actually included three discrete measurement points that formed a gradiometry triplet. The three measurement points, spaced approximately 20 feet apart, were laid out in a triangular array, and served as the basis for establishing the apparent near-surface gravity gradient.

Each gravity station was surveyed to a vertical accuracy of 0.05 feet and a horizontal accuracy of better than 0.1 foot. Elevations were referenced to the Spokane County datum (USGS datum). Positions of the second and third points of the gradiometry triplets were measured relative to the surveyed base station of the triplet. NGA personnel using a fiberglass tape and a Brunton compass, respectively obtained distance and azimuth for the second and third measurement points of the triplet. Relative elevations were measured to the nearest 0.05 feet using a laser level. The survey data are tabulated in Appendix G.

2.8.2.2 Data Processing and Geologic Control

Processing of the raw gravity data requires application of several standard corrections before the data set is usable for analysis and interpretation. The following corrections were made to the SAJB gravity data set:

- earth tide correction;
- instrumental drift correction;
- latitude correction including spheroid and centrifugal effects;

- free air (elevation) effect;
- simple Bouguer correction;
- terrain effects (complete Bouguer).

Details of these data processing steps and assumptions are provided in Appendix G. After applying these standard data corrections, the corrected data were gridded and modeled using NGA's modeling software, GM-SYS™.

Some geologic control was available to constrain the subsurface interpretation provided by the gravity modeling software. Lithologic data from three area wells and field observations of known bedrock outcrops were used as constraints on the gravity model. Specifically, two area wells located near the margins of the transect encountered bedrock: a 180- foot deep Whitworth Water District well at the southwest end of the gravity transect, and an abandoned 277-foot deep Water District No. 3 test well (Dakota Well) at the northeast end of the transect. A 465-foot deep Whitworth Water District test well (Mayfair Well) located along the interior of the gravity transect near the intersection of Highway 395 and Hastings Road, served as an additional control well. Basement bedrock was not encountered in the Mayfair Well according to drillers' log records.

2.8.2.3 Findings

The gravity data have been interpreted to show the thickness of sediments along the gravity transect across the north end of the Hillyard Trough. Figures 2-7 and 2-8 show two interpretations of the gravity data using assumed densities for the trough sediments of 1.95 gm/cm^3 and 2.10 gm/cm^3, respectively. An assumed sediment density of 1.95 gm/cm^3 produces a modeled trough sediment thickness of approximately 490 feet (basement bedrock at elevation 1315 feet above MSL). An assumed sediment density of 2.10 gm/cm^3produces a modeled trough sediment thickness of approximately 590 feet (basement bedrock at elevation 1215 feet above MSL). A previous gravity survey of the Spokane Valley by Purves (1969) used a density of 2.10 gm/cm^3 .

The drillers' log reports the presence of water-bearing materials in the lower 50 to 70 feet of the Mayfair test well. The gravity data suggest that an additional 30 to 100 feet of trough sediments may be present below the terminal depth of the Mayfair Well. The geologic, hydrogeologic, and water supply implications of the north Hillyard Trough gravity survey findings are further discussed in Chapter/Section 2.8.1.

2.8.3 TEM Field Test

A field test was made at a site in north Spokane to determine if transient electromagnetic (TEM) surface geophysical methods could be used effectively for exploration of subsurface geological conditions in this portion of the study area. TEM is a non-intrusive, electrical geophysical method that measures the electrical properties of soil and rock materials, and can provide representative subsurface lithologic information at a variety of depths within the geologic column. The TEM test site was a wooded parcel located immediately north of Mead High School. The test study was designed to build on a previous TEM investigation

Figure 2-6: Microgravity Gradiometry Survey Transect

Figure 2-7: Gravity Model Profile #1: Trough Sediment Density of 1.95 gm/cm^3

Figure 2-8: Gravity Model Profile # 2: Trough Sediment Density of 2.10 gm/cm3 that was conducted in August 1995 for Water District No. 3, as part of a focused evaluation of a candidate site for a new water supply well. This previous TEM study specifically had been used to help identify and differentiate the depth and location of water-bearing strata, low permeability glaciolacustrine sediments, and basement bedrock in the vicinity of Highway 395 and Hastings Road in north Spokane. TEM data can be especially useful where vertically adjacent geologic units have distinctly different electrical resistively properties (e.g., gravel vs. clay). Based on a review of limited drillers' log data, such conditions were believed to be present in the north Hillyard Trough area.

The TEM field test was conducted in early February 1997. A Zonge Engineering receiver and transmitter were used to collect data from this field test. A total of seven TEM soundings were made at four adjacent instrument locations. Both 50 meter and 100 meter square loops were used, employing in-loop and coincident-loop configurations. The corrected TEM data were to be used to generate a geologic pseudo-section of the investigated area. A pseudo-section (i.e., generalized geologic cross-sectional profile) can display various stratigraphic units having different electrical resistively characteristics.

Mineralogy, porosity and permeability, and the amount and type of pore fluid can influence electrical geophysical properties and equipment responses. In addition, cultural interference such as power transmission lines, buried piping, metal fencing, and buried metallic debris can influence the response of the geophysical equipment.

Evaluation of the SAJB TEM test data revealed that cultural interference and/or an unresolved instrumentation problem were producing data of unreliable quality. As a result, it was determined that additional TEM studies would not be performed as part of the WHP data collection program. An alternative geophysical technology (microgravity gradiometry) instead was selected to investigate the north Hillyard Trough/Little Spokane River valley interface as described above in Chapter/Section 2.8.2.

2.8.4 North Spokane Deep Aquifer Evaluation

An extensive review and analysis of drillers' logs and existing hydrogeologic reports was conducted as part of the SAJB WHP study to gain a better understanding of possible water-bearing strata at or near the base of the north Hillyard Trough and Little Spokane River valley areas. CH2M HILL performed a limited review of north Spokane well log information during the data collection phase of the City of Spokane's Wellhead Protection project. This previous evaluation suggested that a confined aquifer system, having only a limited degree of hydraulic interconnection with the main body of the Spokane aquifer, was present within the north-central portions of the Hillyard Trough. A more focused and detailed evaluation was undertaken during the SAJB Wellhead Protection study to confirm the presence and approximate lateral extent of a deep, confined aquifer system in this area.

Traditionally, groundwater development within the north Hillyard Trough has been limited to the unconfined sand and gravel deposits located within the upper 200 feet of the geologic column. Lithologic information from a 780-foot deep exploration well, drilled in 1962 as part of a Washington Water Power gas reservoir siting program, suggested that a fairly thick sequence of water-bearing sediments were present near the base of the north Hillyard Trough. A copy of the WWP well log is included in Appendix H. The permeable, granular sediments were overlain by silt/clay materials believed to be of glaciolacustrine origin. At least one flowing artesian well (indicating confined hydraulic conditions) also is known to have been drilled along the southern flanks of the Little Spokane River valley near the transition zone between the valley and the Hillyard Trough. The lithologic and hydrologic evidence from the flowing artesian well and the deep WWP gas reservoir exploration well provided the basis for advancing the hypothesis that a deep confined aquifer system exists beneath the Hillyard Trough and Little Spokane River valley. Results of this analysis, and the lines of evidence supporting this concept are presented below.

Drillers' logs for wells in the North Spokane area were used, along with known bedrock occurrences, to construct four hydrogeologic cross-sections as shown on Figure 2-9. Cross section A-A′ provides an east-west profile of the Hillyard Trough. Cross section B-B′ provides a north-south profile from the Hillyard Trough, through the Wandermere Springs channel, and into the Pine River Park area of the Little Spokane River valley. Cross sections C-C′ and D-D′ are developed within the lower reaches of the Little Spokane River valley. The C-C′ cross section originally was generated by John Covert of the Washington State Department of Ecology. A portion of cross section D-D′ extends into the Down-river region of the Spokane River valley above Nine Mile Falls.

Along the A-A′ profile (Figure 2-10), the Hillyard Trough is approximately three miles wide. The 780-foot deep WWP gas reservoir exploration well (6320J02) is located near the middle of the trough. The basement bedrock contact occurs at an elevation of approximately 1250 feet above MSL. Subsurface knobs of basement bedrock are observed along the eastern margins of the Hillyard Trough, as evidenced by wells 6321J01 and 6321J02. A distinct silt/clay unit is present at an elevation of approximately 1500 to 1600 feet above MSL. This low permeability unit is believed to serve as the aquitard that hydraulically separates the deep aquifer system from the upper unconfined Spokane Aquifer system. Additional discussion on the lateral extent and inferred origin of this thick silt/clay unit is presented under subsequent discussions of cross sections B-B′, C-C′ and D-D′.

The north-south B-B′ profile (Figure 2-11) extends from the WWP gas reservoir test well northward to the Pine River Park area of the Little Spokane River valley. A second deep well, the 465-foot deep Whitworth Water District #2 Mayfair test well, penetrated both the upper aquifer, and approximately 180 feet of low permeability silt/clay/fine sand materials. Below the silt/clay unit, from an approximate elevation of 1400 to 1315 feet above MSL, the Mayfair Well encountered granular, water-bearing materials that are thought to correlate to materials encountered in the WWP well.

Boese and Buchanan (1996) provide a regional overview of the hydrogeologic conditions that are present in the north Spokane County area. Their study describes two water-bearing hydrostratigraphic units within the Pleistocene deposits, termed "upper sand and gravel aquifers" and "lower sand and gravel aquifers". These terms, while useful at a broad regional level, are not used herein. An alternative nomenclature is suggested to describe the confined water-bearing unit that is found as a distinct, laterally correlatable hydrostratigraphic unit below an elevation of approximately 1500 feet above MSL within the north Hillyard Trough and Little Spokane River valley. It is suggested that this unit be called the *North Spokane Aquifer*. The suggested nomenclature will help to differentiate this deeper confined aquifer system from the portion of the Spokane Aquifer (i.e., the upper unconfined aquifer) that has been simulated by the groundwater flow model constructed for the SAJB and City of Spokane wellhead protection projects.

East of Dart Hill, cross-section B-B′ passes through a channel-like feature where over 200 feet of low permeability sediments overlie a confined water-bearing strata. Silt/clay materials are found between an elevation of approximately 1440 and 1670 feet above MSL near the Lafferty domestic well. Water level data from the Mayfair and Lafferty wells suggest that groundwater in the North Spokane Aquifer maintains a potentiometric head level that is 30 to 40 feet lower that the water table elevation in the upper aquifer. The silt/clay unit extends further northward into the Little Spokane River valley, where it overlies, and serves to confine, a water-bearing sand and gravel aquifer utilized by Water District No. 3 and Whitworth Water District #2. The strikingly consistent stratigraphic position of the silt/clay unit within both the Hillyard Trough and Little Spokane River valleys suggests strongly that this unit is of glaciolacustrine origin. Chapter/Section 2.9 provides additional details of a focused hydrologic assessment of the Pine River Park area that was performed to support the delineation of wellhead capture zones for this separate hydrogeologic system.

Profiles C-C′ and D-D′ (Figures 2-12 and 2-13) demonstrate that the silt/clay aquitard extends well into the lower reaches of the Little Spokane River valley where it maintains its stratigraphic position within the general range of elevation 1400 to 1600 feet above MSL. The aquitard overlies a water-bearing sand and gravel of undetermined thickness. Except for wells completed along the margins of the valley, no deep wells within the Little Spokane River valley have been drilled through the basal sand and gravel unit to the underlying basement bedrock. As discussed above in Chapter/Section 2.8, results of a gravity survey across the trough between Five Mile Prairie and Dart Hill show that basement bedrock occurs somewhere between elevation 1215 and 1315 feet above MSL. Further south (up-trough) at the WWP gas reservoir test well, basement bedrock was encountered at an approximate elevation of 1250 feet above MSL. From these data, it can be inferred that water-bearing valley fill sediments (i.e., North Spokane Aquifer) within the central portion of the Little Spokane River valley could be as much as150 to 200 feet thick. Equally important is the fact that the silt/clay aquitard, having a thickness of at least 75 to 100 feet, likely restricts hydraulic interaction between the Little Spokane River and the North Spokane Aquifer.

Identification of the North Spokane Aquifer may have important implications for future groundwater withdrawals, water rights decisions and groundwater development within portions of the North Hillyard Trough and Little Spokane River valley that are part of the Department of Ecology's Water Resource Inventory Area (WRIA) 55. The current evaluation provides an improved understanding of the stratigraphic position and inferred area extent of this little-used groundwater resource. Three important, yet unresolved, considerations affecting decisions to develop the groundwater resource from the North Spokane Aquifer are (1) water quality characteristics, (2) hydraulic properties – especially transmissivity and sustainable well yield, and (3) the degree of hydraulic connection between this deep aquifer and the upper Spokane Aquifer groundwater system and/or the Little Spokane River.

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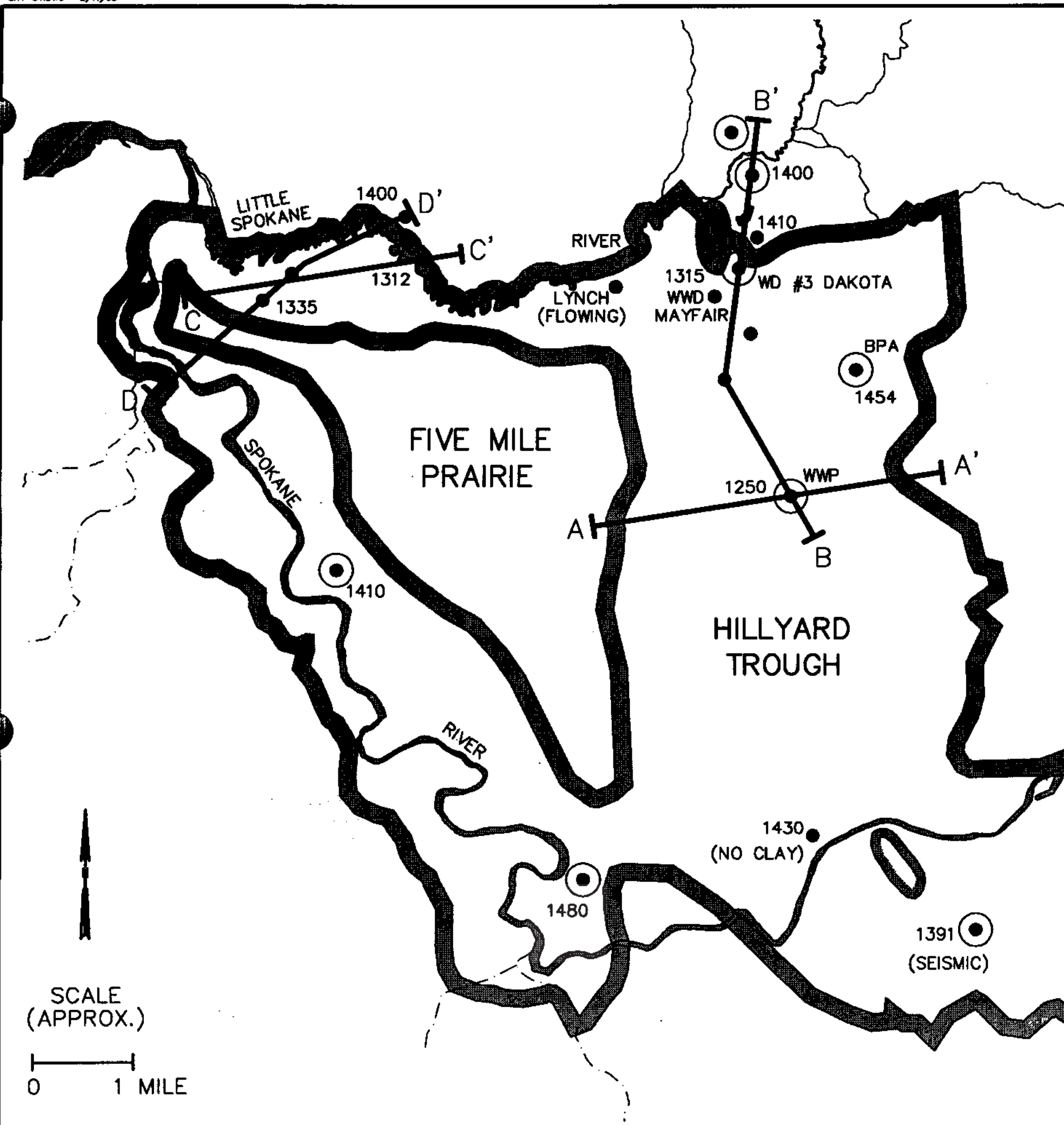

⦿ DEEP WELL – BEDROCK ENCOUNTERED

● DEEP WELL – BEDROCK NOT ENCOUNTERED

FIGURE 2–9

LOCATION OF DEEP WELLS AND NORTH SPOKANE GEOLOGIC CROSS SECTIONS

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Figure 2-10: Geologic Cross Section A-A'

Figure2-11: Geologic Cross Section B-B'

Figure2-12: Geologic Cross Section C-C'

Figure 2-13: Geologic Cross Section D-D'

2.8.5 North Spokane Aquifer Water Quality

No sampling and analysis of groundwater from the North Spokane Aquifer was conducted as part of the SAJB Wellhead Protection project. However, some limited water quality data have been obtained during the past two years by other agencies and investigators. These data are presented herein to provide a preliminary indication of groundwater quality in the North Spokane Aquifer. Personnel from Spokane County Utilities collected water samples from the Whitworth Water District #2 Mayfair test well in June 1997. A summary of these data is presented in Table 2-9. In addition, Boese and Buchanan (1996) sampled and analyzed groundwater from a domestic well (6204N02) located in the lower reach of the Little Spokane River valley. The results of this water quality analysis also are provided in Table 2-10. These two analyses suggest that groundwater quality in the North Spokane Aquifer is of good quality, and appears to meet the general criterion for potability.

Table 2-9: Summary of North Spokane Aquifer Groundwater Quality Results

Parameter	Whitworth WD#2 Mayfair Test Well	Domestic Well (6204N02)
Alkalinity (as $CaCO_3$)	116	-
Hardness (as $CaCO_3$)	-	134
Chloride	1.5	2.5
Sulfate	15	-
Iron	0.04	0.18
Calcium	29	-
Magnesium	14.5	-
Sodium	2.9	-
Potassium	1.7	-
Nitrate + Nitrite as N	0.99	<0.01
Orthophosphate as P	<0.01	-
Conductivity (µmhos/cm)	-	257
pH (units)	-	8.09

Notes:
All units in mg/L unless noted otherwise.
"-" indicates parameter not included for analysis.

2.9 Pine River Park Evaluation

2.9.1 Data Collection Network

A focused assessment of the Pine River Park and lower Dartford Creek areas of the Little Spokane River Basin was conducted in support of the SAJB wellhead delineation activities. Specifically, water levels in the Little Spokane River were measured along with water levels from selected water supply wells to better estimate the localized groundwater flow pattern within two hydraulically distinct groundwater production zones in this region of north Spokane County. Using the hydrologic data obtained from these focused data collection activities and from the existing literature, groundwater capture zones were developed for five SAJB-member production wells that lie outside the main body of the Spokane Aquifer. The specific data collection activities and data analysis procedures are discussed below.

Hydrogeologic data from drillers' logs and the existing literature show that three active Whitworth Water District #2 wells (Wells #8A1, 8A2, 8B) and the Water District No. 3 Pine River Park well all draw groundwater from a similar confined aquifer unit (see Figure 2-14). The geologic cross section B-B', presented in Chapter/Section 2.8.4, displays a portion of this aquifer system, just north-northeast of Lake Wandermere. This 40- to 100-foot thick water-bearing sand and gravel unit is developed at the base of the Little Spokane River valley. The groundwater system in this portion of the Little Spokane River valley is believed to be hydraulically separate from, or maintains only limited hydraulic connection with, those aquifer units that have been identified at the north end of the Hillyard Trough. This conclusion is based on apparent differences in hydraulic head, known basement bedrock boundaries, and comparison of stratigraphic relationships between different water-bearing units.

One inactive well (Shady Slope Well) owned by Whitworth Water District #2 also was included as part of the hydrologic data collection network (see Figure 2-14). This well lies between the drainage of Little Deep Creek and Deadman Creek.

The Whitworth Water District #2 Rivilla Well is a shallow-dug well less than 15 feet deep located downstream of the Pine River Park area near the mouth of Dartford Creek (see Figure 2-14). This well is thought to utilize groundwater from a shallow, unconfined alluvial aquifer system, given its depth, construction characteristics, and location near the confluence of Dartford Creek and the Little Spokane River.

Personnel from CH2M HILL conducted a level loop survey of this portion of the Little Spokane River basin in order to establish reference elevations for a series of hydrologic monitoring stations that included (1) bridge crossings, (2) river/creek staff gauges, and (3) local production wells. Benchmarks on record with the Spokane County surveying department were used to establish elevation control for the level loops. After completion of the level loop survey, a water level monitoring round was conducted on May 21, 1997. Data from the water level measurement event were used to evaluate the apparent hydrologic relationships between the river, tributary creeks, the shallow unconfined aquifer system, and the deeper confined aquifer system. Water level elevation data from the May 21, 1997 monitoring event are shown on Figure 2-14. Water level elevations and surveyed reference point data are presented in Table 2-10. Some production wells did not include a water level measurement port, which prevented collection of representative groundwater level measurements. Air tube pressure gauge readings were recorded when available.

Figure 2-14: Little Spokane River Basin Focused Investigation Area

Table 2-10: Little Spokane River Valley Data Collection Network Survey Data and Water Level Measurements

Station Name	Ref. Pt. Elevation	Water Level Elevation	Comments
Whitworth WD#2 Rivilla Well	1580.83	NM	RP is top corner of pump pad
Dartford Creek	1579.99	1577.29	RP is top of concrete headwall behind green house
Dartford Drive Bridge over L. Spokane River	1590.96	1576.21	RP is "X" in concrete on north side of boardwalk
Greenleaf Bridge over L. Spokane River	1608.76	1599.51	RP is "X" near center of bridge on downstream side
River Staff Gauge near Whitworth Well #8B	1612.16	1611.61	RP at top of #4 rebar
WD No. 3 Pine River Park Well	1615.00	1595 +/-	RP is concrete pad at S. end of pump station. WL measured via air tube on 10 hp pump.
Little Spokane Drive Bridge	1624.14	1615.19	RP is paint mark at center of bridge - downstream side
Shady Slope Road Bridge over Little Deep Creek	1634.66	1626.73	RP is "X" on downstream side of bridge
Shady Slope Road Bridge over Deadman Creek (north)	1639.99	1631.47	RP is "X" on downstream side of bridge
Shady Slope Road Bridge over Deadman Creek (south)	1640.78	1633.78	RP is "X" on downstream side of bridge
Whitworth WD #2 Shady Slope Well	1633.88	1617.76	RP is orange paint on concrete pump motor pad
Whitworth WD #2 Well 8A1	1649.66	NM	RP is orange paint on concrete pump motor pad
Whitworth WD #2 Well 8A2	1650.31	1584.66	RP is orange paint on pump motor casing. WL measured through vent line. Pump was on.
Whitworth WD #2 Well 8B	1636.54	NM	RP is orange paint on top of steel pump plate (NE corner)

Notes:
Elevation data in feet above MSL (USC&GS 1929 NGVD)
NM - not measured

2.9.2 Data Evaluation and Capture Zone Analysis

A routinely applied analytical equation for uniform groundwater flow was used to generate WHPA capture zones for the three Whitworth Water District wells (8A1, 8A2, 8B) and the Spokane County Water District No. 3 Pine River Park well. Application of the Uniform Flow analytical equation requires use of the following input parameters:

- Well Pumping Rate (Q)
- Aquifer Hydraulic Conductivity (K)
- Aquifer Saturated Thickness (b)
- Horizontal Hydraulic Gradient (i)

For this analysis, the well pumping rate was derived from the annual water right. Hydraulic conductivity was estimated from specific capacity data (Driscoll, 1986) obtained from the drillers' logs. Saturated thickness was estimated from lithologic descriptions on the drillers' logs and known well construction characteristics. Water level elevation data from the river/creek monitoring stations and accessible wells were used to approximate a horizontal hydraulic gradient (and inferred direction of groundwater flow) for the confined aquifer. A summary of the input values used to estimate the dimensions of the capture zones for this selected suite of outlying wells is presented in Chapter 3, along with the resulting WHPA delineations.

A calculated fixed radius (CFR) method was used to establish a capture zone for the Whitworth Water District #2 Rivilla Well as described in Chapter 3. The CFR method was chosen because of uncertainties over the nature and extent of the shallow alluvial aquifer system that provides groundwater to the Rivilla well.