HYDROLOGIC EFFECTS OF GROUND-WATER PUMPING ON SINKING CREEK AND TRIBUTARY SPRINGS, LINCOLN COUNTY, WASHINGTON

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This Open-File Technical Report presents the results of a hydrologic investigation by the Water Resources Program, Department of Ecology. It is intended as a working document and has received internal review. This report may be circulated to other Agencies and the Public, but it is not a formal Ecology Publication.

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ABSTRACT

Much of Sinking Creek, and many of its tributary springs, dried up during the past two decades. Measurements of water levels in wells and of discharges from springs indicate that some of the flow reduction is caused by pumping in nearby wells. Other information, including drill-cuttings sampling, borehole geophysical logging, and pumping tests, further corroborates the effects of pumping on the springs by indicating that pumping disturbances propagate throughout the ground-water-flow system for many miles, both horizontally within a pumped aquifer and vertically into the other aquifers. Comparison of the pumping effects with other factors that might affect surface water - such as borehole leakage, the weather, tillage practices, and stream-channel disturbances - indicate that the pumping of irrigation wells and, to a lesser extent, borehole leakage, produce most of the reduction of the surface-water discharges.

Water levels measured prior to the irrigation season indicate a continuing decline of water levels in a portion of the study area. The decline of the water table in the alluvium along Sinking Creek continues to produce soil cracks and depressions as the soils dry out and consolidate.

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INTRODUCTION

Sinking Creek is a small, partly-intermittent stream located in north-central Lincoln County, Washington **(Figure 1)**. During each irrigation season since the late 1960's, some landowners along the creek have noted less than normal streamflow in the creek and less than normal flow from certain springs tributary to the creek. Studies by **Wildrick (1982; 1985)** indicate that ground-water pumping for irrigation reduces discharge from the springs, and thereby, reduces streamflow along several reaches of Sinking Creek. In 1990, most of the stream was dry nearly all year.

Recently, the Water Resources Program of the Washington Department of Ecology (Ecology) issued cease-and-desist orders requiring the shut-down of 28 irrigation wells serving more than 12,000 acres of cropland in the Sinking Creek area. This report presents the hydrologic interpretations which led to the regulatory orders.

The study area encompasses approximately 160 square miles in **Townships 25N through 26N and Ranges 32E through 34E**. The terrain is gently rolling with poorly developed drainage features except for the principal stream valley which is lined in places by steep bedrock cliffs. The semi-arid climate of the study area results in an average water-year precipitation of about **12.2** inches.

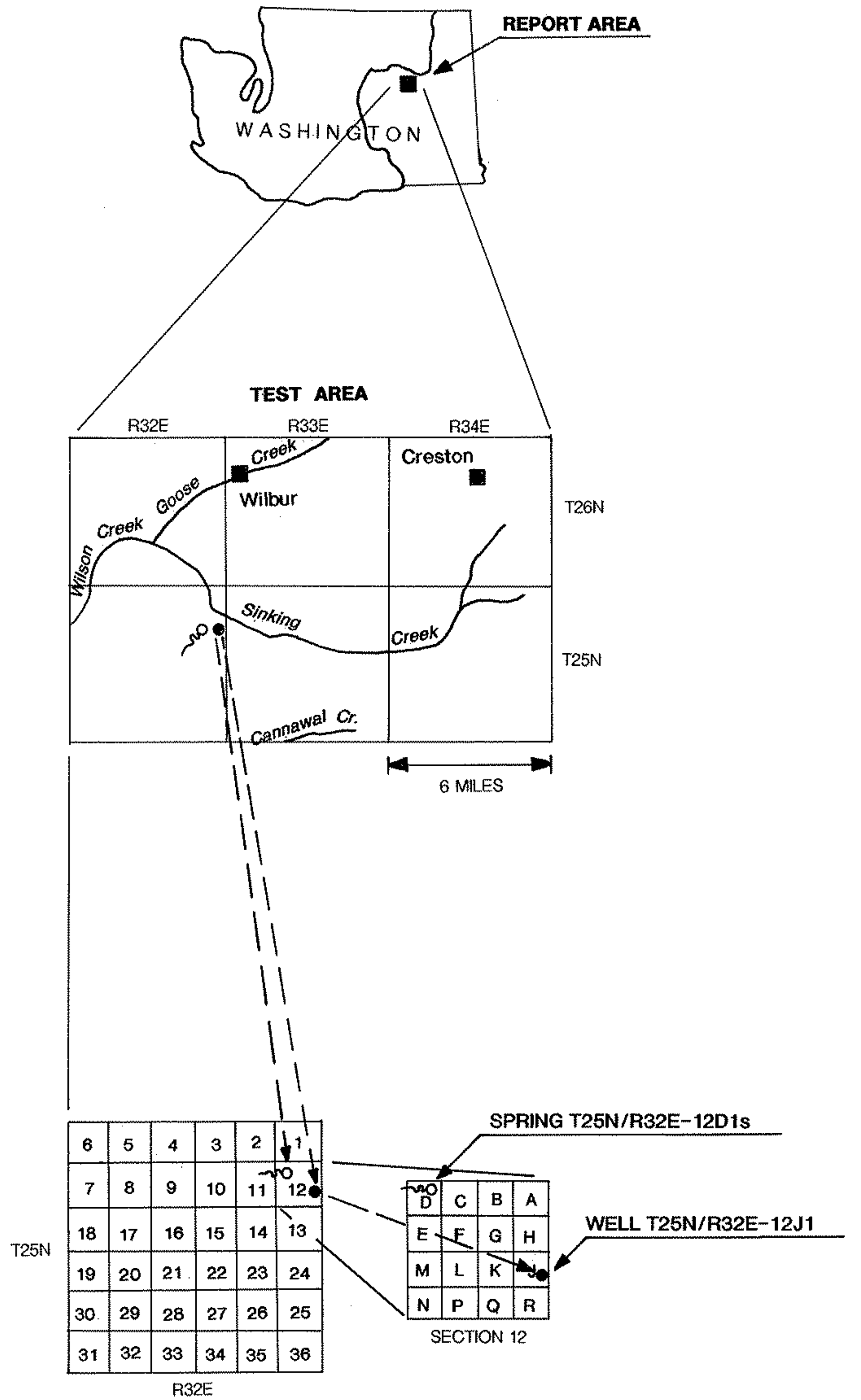

Figure 1. INDEX MAP OF REPORT AREA AND DIAGRAM SHOWING NUMBERING SYSTEM FOR WELLS AND SPRINGS.

SCOPE

This report includes analyses of:

(1) changes in water availability resulting from cyclical changes in precipitation and ground-water recharge;

(2) the effects of agricultural water use and tillage practices on discharges of Sinking Creek and tributary springs;

(3) water-level declines as evidence for long-term depletion of ground-water storage by pumping from the confined aquifers;

(4) soil cracks and shrinkage features as evidence for ground-water depletion in the unconfined, alluvial aquifer along Sinking Creek;

(5) the contribution to ground-water depletion by leakage between aquifers due to uncased wells;

(6) the reconsideration of statements in an earlier report **(Wildrick, 1982)** about the water-level-drawdown effects of pumping two irrigation wells, **T25N/R34E-02C01 and -02G01**, owned by Merwin Houger.

PREVIOUS STUDIES

Several regional-scale studies of geology, hydrogeology, ground-water use, and ground-water chemistry encompassed areas including the Sinking Creek watershed. These include **Bauer, et al., 1985; Bortleson and Cox, 1986; Cline, 1984; Drost and Whiteman, 1986; Garrett, 1968; Gephart, et al., 1979; Luzier, et al., 1968; Myers, et al., 1979; Newcomb, 1972; Silar, 1969; Swanson, Anderson, et al., 1979; Swanson, Bentley, et al., 1979; Swanson, Brown, et al., 1979; Swanson and Wright, 1978; Tanaka, et al., 1979; Waggoner, 1990; and Whiteman, 1986.**

Washington Water Power Company studied the Sinking Creek area in anticipation of the construction of a coal-fired, electric generating station by the Washington Water Power Company. During these studies, Tera Corporation, a consulting firm, drilled and tested several wells and surveyed streamflow conditions **(Tera, 1980; 1981; 1983a; 1983b).**

Wildrick (1982) reported on a study of the causes of diminished flow in Sinking Creek and from several tributary springs along the creek. The study included a pumping test of an irrigation well **(T25N/R34E-02G1)** in the Sinking Creek watershed. The present report reflects a continuation of that study.

Olson (1984) reported on the installation of six piezometers in the Dreger Observation Well **(T25N/R34E-26J2 through J7)**, a well originally drilled for irrigation supply but later abandoned. The U. S. Geological Survey (USGS) directed piezometer installation and the Washington Water Power Company funded the geophysical logging in the well.

Wildrick (1985) reported on a pumping test of another irrigation well **(T25N/R33E-27A2)** located near Sinking Creek.

Beginning in 1986, In-Situ, Inc., a consulting firm, conducted hydrologic investigations of the basalt aquifers in part of the Sinking Creek watershed **(Paschis, et al., 1988; Steele, et al., 1988; Steele, et al., 1989; Wood, 1987a, 1987b, and 1988; Wood and Poeter, 1986)**. Their work included pumping tests, geologic sampling, and borehole-geophysical logging in specially constructed wells.

Recently, Pacific Groundwater Group briefly investigated the surface-water-supply problems at Sinking Creek and prepared a short letter report of findings **(Utting, 1989)** and later prepared another letter report **(Utting, 1990)** in response to the report of **Wildrick (1990)**.

DISCHARGE CHARACTERISTICS OF SINKING CREEK

General Discharge Conditions

Under natural conditions, Sinking Creek depends entirely on ground-water discharge at springs to provide baseflow during Washington's typical dry season, usually June through September. This reliance on springs is readily observed along the creek and is further substantiated by the method of seepage runs wherein one measures flow at intervals along the creek **(Tera Corp., 1983b)**. Tera scientists found that streamflow diminishes or disappears along certain reaches and then reappears in the vicinity of springs **(ibidem, figures 3-3 and 3-7)**.

High discharge, surface-runoff events and consequent floods in the region around Sinking Creek occur infrequently (see USGS streamflow records for the region). The largest runoff events each year result from winter and spring snowmelt. Some of the larger runoff events occur when frozen ground under melting snow prevents or retards the meltwater from infiltrating the soil, thereby increasing the amount of runoff. Additionally, rain falling on melting snow can create high-discharge runoff (personal communications with many local residents).

Sinking Creek and tributary springs provide stockwater and sub-irrigation of both bottomland pasture and hay. Checkdams and ditches provide flood irrigation in small areas of bottomland. Prominent checkdams, some still in operation, some in disrepair, occur in **sections 9, 10, and 18 of T25N/R34E**; in **sections 15 and 18 of T25N/R33E**; in **section 12 of T25N/R32E**; and in **section 35 of T26N/R32E (Figure 2)**. Numerous other checkdams occupy tributary valleys and capture surface runoff from the uplands. Use of these irrigation structures probably dates back to the early part of the this century.

Intermittent Flow

The USGS topographic maps indicate intermittent flow conditions for all of Sinking Creek. However, the larger tributary springs create perennial flow for some distance downstream.

During the 1970's and early 1980's, Ecology staff observed conditions along much of the creek and noted perennially dry reaches above Marquette Spring in **T25N/R34E, Sections 3 and 4**, and below Baring Spring in **T25N/R34E, Section 18**. Ecology staff also observed that much

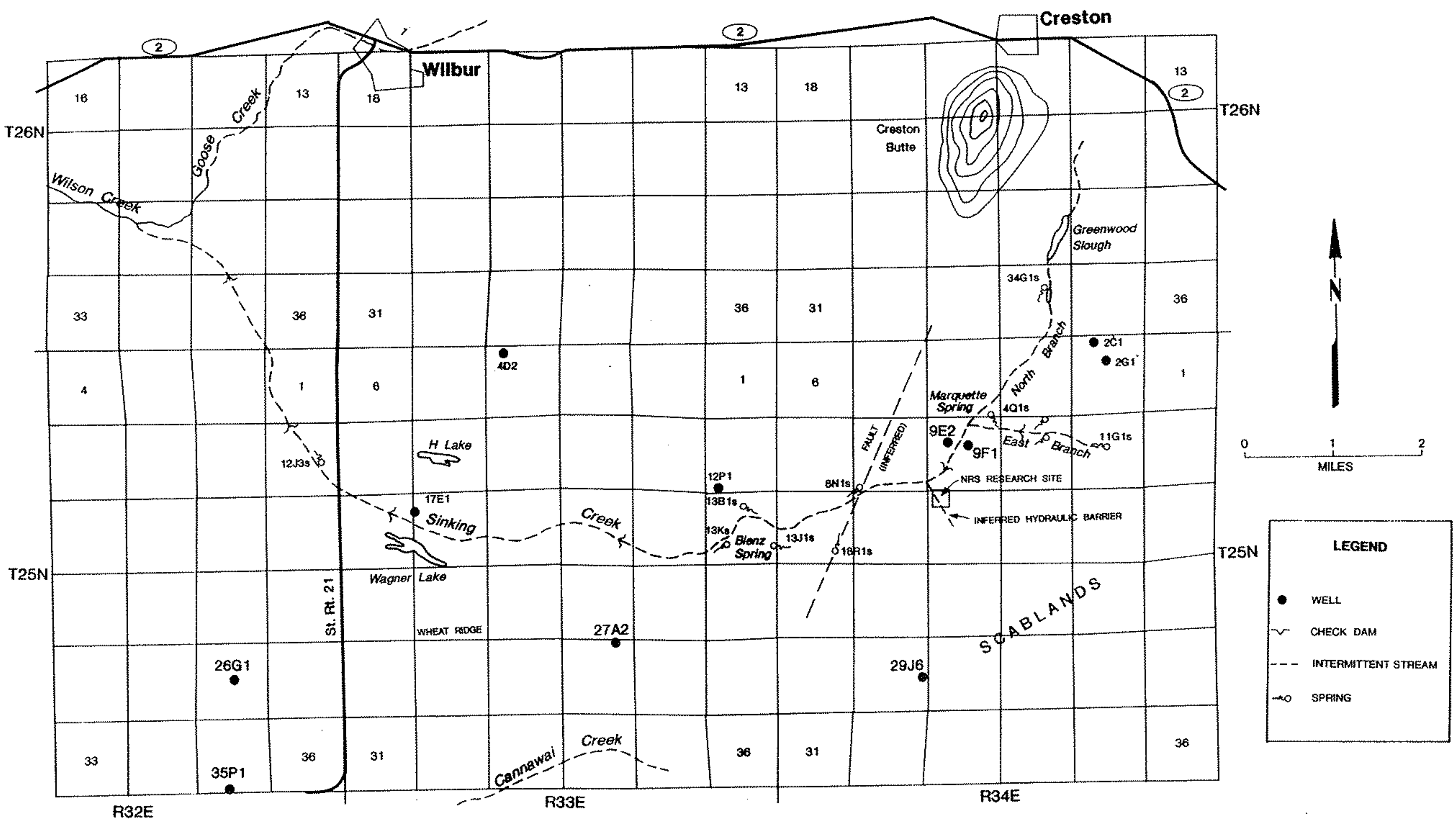

FIGURE 2. MAP OF SINKING CREEK AND SURROUNDING AREA

of the stream dried up during middle to late summer. Reaches of the stream observed to have perennial flow include those reaches immediately downstream of:

(1) the Nelson spring near Greenwood Slough **(T26N/R34E-34G01s),**
(2) the Nelson springs in **sections 10 and 11 of T25N/R34E,**
(3) the Baring spring **(T25N/34E-0801s)**; largest spring of record on Sinking Creek,
(4) the Rosman springs in **section 18, T25N/R34E,**
(5) the Blenz spring **(T25N/33E-13L01s),**
(6) the large wetland in **sections 15 and 16, T25N/R33E,** and
(7) the springs in **section 26, T26N/R32 (Figure 2).**

During the last two years (1990 through Spring 1991), at least, most reaches of Sinking Creek remained dry all year. Exceptions occurred where water from the few remaining tributary springs flowed only short distances before seeping into the channel bed. In 1991, melting of the below-average snowpack and subsequent runoff from the uplands resulted in a few weeks of stream discharge estimated to be one or two cubic feet per second (cfs). However, flow occurred only along short reaches of the channel. Runoff discharge disappeared entirely below **section 14, T25N/R33E,** downstream of the Blenz Spring.

Discharge Measurements

Historical discharge records for Sinking Creek and tributary springs consist of occasional measurements taken at irregular intervals, except for monthly measurements during 1961 at the Route 21 bridge **(T25N/R33E-07N; Table 1).** These measurements indicate that discharge continued throughout most of the year, except from mid-August to mid-September. During late summer of that year, irrigation diversions from the stream may have diverted the small amount of remaining flow and dried up parts of the stream.

For several years, the USGS also continuously measured the stage at Baring Spring, **T25N/R34E-08N01s (Wildrick, 1982).** These stage measurements indicate only the relative change in discharge from the spring. In 1983, Ecology installed a v-notch weir in the spring's discharge channel, about 250 feet below the spring and just above the confluence with Sinking Creek. Records for discharge at the weir were recorded only intermittently from 1983 through 1990 when the weir ceased functioning **(Table 1).** Otherwise, records of discharge from tributary springs along Sinking Creek are lacking.

TABLE 1. STREAM DISCHARGE IN THE SINKING CREEK AREA, LINCOLN CO.

Station: Sinking Creek at Route 21 Bridge
Location: Upstream side of highway bridge, T25N/R33E-07N
Gaging Method: Current meter
Remarks: Basalt bedrock exposed 100 yards upstream and downstream

Discharge, in cubic feet per second (cfs)

3-7-61	10.3	4-20-77	0.60	4-17-82	0.54	4-25-83	6.0
3-22-61	8.1	8-23-77	0	5-4-82	0.75	5-10-83	4.7
4-20-61	5.4	5-2-81	0.71	6-28-82	0	5-17-83	3.5
5-19-61	4.8	5-23-81	0.64	8-23-82	0	6-20-83	0.56
7-5-61	0.97	7-13-81	0	10-4-82	0	7-12-83	0.28
7-27-61	0.09	8-24-81	0	11-29-82	0	8-15-83	0
8-25-61	0	12-7-81	0	1-24-83	0	1-6-84	3.5
9-26-61	0	1-13-82	0	3-11-83	7.9	2-6-84	6.8
11-8-61	1.1	2-5-82	0	3-21-83	6.0	4-2-84	15.9
2-24-77	1.2	3-8-82	0.47	3-31-83	11.0		

Station: Sinking Creek near Blenz Spring
Location: At County Bridge 53131, T25N/R33E-13F
Gaging Method: Current meter (m); direct measurement of stage at flume (f).
Remarks: Same as Station SW7 of Tera Corp. Basalt bedrock exposed in channel, no alluvium. 1991 flows affected by beaver dam on west bifurcation, 100 yds upstream

Discharge, in cubic feet per second (cfs)

5-1-81	1.67 (m)	4-3-90	0.61 (m)	2-12-91	0.63 (f)
8-22-81	0.0	4-11-90	0.58 (m)	3-1-91	0.55 (f)
8-31-81	0.0 (m)	4-18-90	0.70 (m)	3-15-91	0.63 (f)
4-15-81	2.64 (m)	5-4-90	0.53 (m)	3-26-91	0.63 (f)
5-12-82	1.4 (m)	5-10-90	0.48 (m)	4-9-91	0.50 (f)
8-25-82	0.0	6-1-90	0.31 (m)	4-24-91	0.43 (f)
5-18-83	4.0 (m)	2-5-91	0.67 (m)	5-9-91	0.41 (f)
6-16-83	1.8 (m)	2-11-91	0.55 (f)		

TABLE 1. (Cont'd)

Station: Baring Spring, tributary to Sinking Creek
Location: T25N/R34E-08Ns. On valley edge, 100 feet north of creek.
Gaging Method: Current meter (m), v-notch weir (w), cutthroat flume (f)
Remarks: Spring's discharge channel is approximately 250 feet long. Weir positioned 3 feet above confluence with Sinking Creek. Current-meter measurements taken 10 feet downstream from spring. Stage of spring measured on staff gage mounted on stilling well at edge of spring, stage in feet above arbitrary datum. Stage at weir in feet above bottom of v-notch. Spring stage measured continuously from 4-23-80 to 8-14-83. (See Wildrick, 1982 for part of the stage data.) Weed growth raises stage at spring during summer. Stage of flume is depth of water above floor of flume at upstream end.

Discharge, in cubic feet per second (cfs)

Date	Discharge	Stage @ weir	Stage @ spring	Stage @ flume
05-17-83	1.30 (m)	--	8.08	--
05-18-83	1.25 (w)	0.76	8.04	--
05-19-83	1.25 (w)	0.76	8.04	--
06-02-83	0.99 (w)	0.69	7.98	--
06-14-83	0.76 (w)	0.62	7.94	--
06-16-83	0.76 (w)	0.62	7.94	--
07-07-83	0.51 (w)	0.53	7.87	--
08-02-83	0.51 (w)	0.53	7.96	--
09-12-83	0.54 (w)	0.54	7.93	--
10-06-83	0.40 (w)	0.48	7.95	--
11-03-83	0.59 (w)	0.56	8.06	--
12-01-83	0.88 (w)	0.66	8.08	--
01-05-84	0.82 (w)	0.64	8.00	--
01-25-84	0.92 (w)	--	--	--
03-06-84	1.91 (w)	0.90	8.31	--
03-30-84	1.91 (w)	0.90	8.34	--
05-02-84	1.91 (w)	0.90	8.36	--
05-24-84	1.71 (w)	0.85	8.34	--
07-19-84	0.88 (w)	0.66	8.10	--
05-08-85	1.61 (w)	--	--	--
10-24-84	0.22 (w)	0.38	--	--
06-20-86	0.81 (w)	0.64	--	--
12-09-86	1.30 (w)	0.77	--	--
03-16-88	1.17 (w)	0.74	--	--
07-12-88	0	--	--	--
10-12-88	0	--	--	--
02-06-90	0.20 (w)	0.36	--	--
01-29-91	0.36 (f)	--	--	0.32
02-05-91	0.48 (f)	--	--	0.37
02-11-91	0.43 (f)	--	--	0.35
02-28-91	0.34 (f)	--	--	0.31
03-15-91	0.32 (f)	--	--	0.30
03-26-91	0.36	--	--	0.32
04-02-91	0.09 (f)	--	--	--
04-03-91	0.09 (f)	--	--	0.15
04-05-91	0.14	--	--	0.19

Station:	Sinking Creek at Creston South Road bridge
Location:	T25N/R34E-09N, downstream side of bridge
Gaging Method:	Current meter
Remarks:	Same as Station SW 5 of Tera Corp.

Discharge, in cubic feet per second (cfs)

5-1-81	0.05
8-22-81	0
4-15-82	0.21
8-24-82	0

Station:	Sinking Creek below source spring for east branch
Location:	T25N/R34E-10G
Gaging Method:	Modified Parshall Flume (portable), 2" throat width
Remarks:	Small check dam upstream

Discharge, in cubic feet per second (cfs)

3-26-80	3:15 PM	0.26
3-26-80	6:00 PM	0.29
3-27-80	11:00 AM	0.32
3-28-80	12:30 PM	0.30
3-29-80	13:30 PM	0.28
3-31-80	11:30 AM	0.28
4-1-80	13:30 PM	0.28
4-3-80	10:00 AM	0.28

Streamflow Observations By Cattle Ranchers Operating Along the Creek

Cattle ranchers who have operated along the creek for many decades recall that prior to the advent of irrigation with ground water certain reaches of Sinking Creek remained perennially or seasonally dry except during floods **(Carl and Keith Nelson, Clarence Wagner, John and William Rosman, personal communications)**. Upstream of the losing reaches, water disappears into the surficial alluvium or basalt but then reappears downstream as springs in or near the channel **(Tera, 1983b)**. Hence, the creek's name. Also, according to the cattle ranchers, many reaches of the creek flowed 10 or 11 months of the year, while some reaches below springs flowed all year. Unfortunately, the small number of historical flow measurements for the creek corroborate the landowners' statements only in part.

William Rosman recalls sufficient water to form pools deep enough for swimming and to sustain native trout. The measured streamflow rates of several cfs during the spring and part of summer **(Table 1)** tend to corroborate these recollections.

According to Clarence Wagner, owner of land along Sinking Creek in the Wagner Lake area, the 1961 data for Sinking Creek at the Route 21 bridge typifies the annual discharge pattern of the decades prior to the 1970's. Mr. Wagner also noted that streamflow would usually resume in September despite the lack of rainfall. Resumption of flow probably resulted from the cessation of diversions after the growing season, as well as from diminished evapotranspiration along the stream.

GEOLOGY OF THE STUDY AREA

Surficial Geology

Sinking Creek (**Figure 2**) occupies a coulee, characteristically steep-walled in places, and flows in an underfit channel (**Tera Corp., 1983b**). The catastrophic Missoula Floods during Quaternary glacial episodes eroded the coulee into basaltic bedrock of the Columbia River Basalt Group (CRBG). These floods created the dramatic scablands (**Baker, 1981; Bretz, 1959; Swanson and Wright, 1978**) The Priest Rapids Member of the CRBG lies at the surface in the eroded portions of the stream valley (**Wildrick, 1982**). Sediments ranging from clays to gravels comprise the thin mantle of alluvium covering much of the coulee floor.

Rolling, hilly terrain with poorly developed tributary drainage (shallow draws) surrounds the stream. On the higher uplands, glacial-loess (Palouse Formation) interlayered with catastrophic-flood gravels overlie the basalt. Parts of the uplands at lower elevations and the less deeply eroded parts of the coulee are scablands with little or no soil covering the basalt.

Most areas with thicker loess soils (silt loam) support cultivation. Elsewhere, only sagebrush and grasses grow on the meager soils overlying basalt or gravel; cattle graze these areas.

Subsurface Geology

Various reports by the USGS, by Ecology, by the Department of Natural Resource's Division of Geology and Earth Resources, and by various consultants demonstrate that the Wanapum Basalt and Grande Ronde Basalt of the CRBG extend across much of the Columbia Plateau physiographic area, including the Sinking Creek area (**Bauer, et al., 1985; Drost and Whiteman, 1986; Garrett, 1968; Gephart, et al., 1979; Luzier, et al., 1968; Myers, et al., 1979; Steele, et al., 1989; Swanson, Anderson, et al., 1979; Swanson, Bentley, et al., 1979; Swanson, Brown, et al., 1979; Swanson and Wright, 1978; Tanaka, et al., 1979; Tera Corp., 1980, 1981, and 1983a; Waggoner, 1990**).

In the upper portion of the Sinking Creek watershed, the basalt flows and the sedimentary interbeds correlate over a distance of several miles, as interpreted from borehole geophysical logs (**Wood, 1987a**). **Figure 3** shows the general stratigraphy for the study area.

HYDROGEOLOGY OF THE STUDY AREA

General Description of Ground-Water Flow

Ground water moves laterally for great distances within the lava flows of the CRBG and discharges in springs where valleys cut into the basalt. Both sedimentary interbeds between basalt flows and the massive (widely-spaced fractures) centers of flows serve to impede, but not block, the vertical percolation of ground water. Furthermore, both geologic and hydrologic evidence gathered in the Sinking Creek area indicate hydraulic continuity between basalt aquifers and also between ground water and surface water (**Bauer, et al., 1985; Drost and Whiteman, 1986; Garrett, 1968; Gephart, et al., 1979; Steele, et al., 1989; Tanaka et al., 1979; Tera Corp., 1980, 1981**).

Productive water-bearing zones in the CRBG occur at the contacts between lava flows or cooling units (multiple lobes of the same flow). These contact zones are commonly called interflow zones. The term "aquifer", as applied to the CRBG for the purposes of this report, actually represents a zone of more-or-less constant (hydraulic) head comprised of one or more water-bearing, interflow zones. Hydraulic head is relatively constant (less than a few feet variation) within each aquifer, but decreases by approximately 50 to 150 feet between successively deeper aquifers.

At least three aquifers are present in the CRBG, alluvium, and catastrophic-flood gravels in the Sinking Creek area (**Wildrick, 1982**). The uppermost aquifer is unconfined and approximately occupies the Priest Rapids Member of the Wanapum Basalt, as well as the alluvium and catastrophic flood gravels. The middle and lower aquifers are confined and occupy the Roza Member of the Wanapum Basalt and upper flows of the Grande Ronde Basalt, respectively. The Quincy and Vantage Interbeds function as confining layers between the aquifers. **Figure 3** depicts the correspondence between stratigraphy and aquifers.

Both unconfined and confined basalt aquifers supply all of the baseflow in Sinking Creek, discharging as tributary springs which issue from interflow zones, vertical fractures, and, possibly, fracture or fault zones. Discharge from unconfined aquifers in the alluvium and flood gravels contribute lesser amounts of baseflow.

Research funded by the Nuclear Regulatory Commission (NRC) in the Sinking Creek watershed obtained evidence for hydrologic effects of faulting in the CRBG. **Steele et al. (1989)** conducted test drilling and pumping tests in **section 16, T25N, R34E** which revealed a local "hydraulic barrier" to ground-water flow (**Figure 2**). They also found that the thickness of the

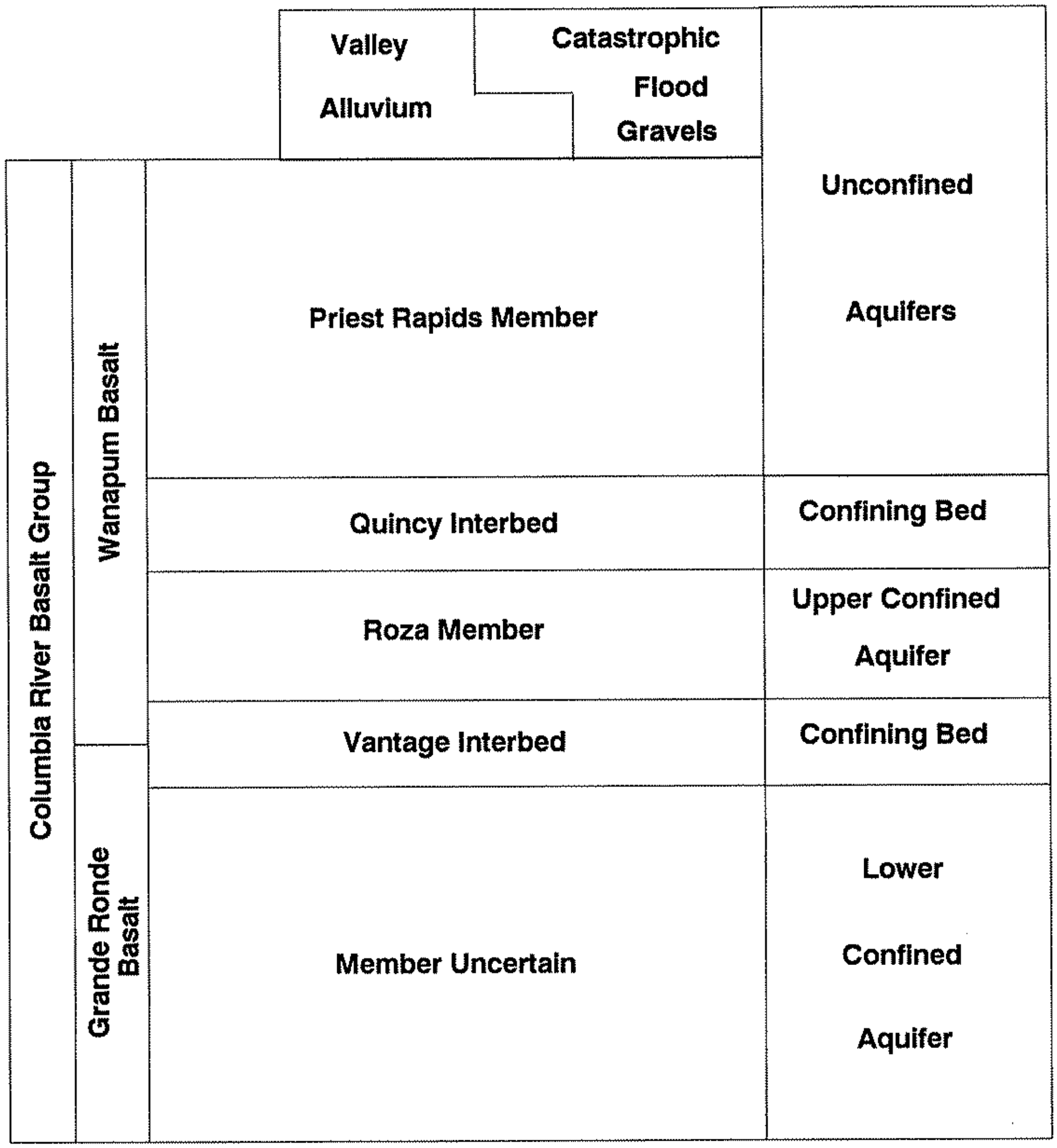

Figure 3. Hydrostratigraphy for the Sinking Creek Area (modified after Wood, 1987b)

Quincy claystone interbed varied greatly over short distances, from one foot to several feet thick.

During pumping tests of the confined aquifers (**Wildrick, 1982; 1985**), head declines propagate over great distances within a few hours. For example, when well **25N/R33E-27A02** (Rettkowski) was pumped at 2800 gallons per minute (gpm), drawdown was recorded more than four miles to the north in well **25N/R33E-04D02** after only 24 hours of pumping (**Wildrick, 1985**). At the time, both wells were uncased through both confined aquifers, although the amount pumped from each aquifer in the Rettkowski well could not be determined. Therefore, the test of the Rettkowski well indicates that pumping effects will propagate rapidly and for long distances through at least one of the two confined aquifers. Further, this pumping-test evidence, together with the geologic evidence described earlier, indicate that the water-bearing interflow zones in the basalts are continuous throughout the study area.

Irrigation Wells

Several dozen irrigation wells, located in the uplands, supply water to thousands of acres of crops. Pumping rates vary from a few hundred gpm to more than 3000 gpm. Only a few irrigation wells were used prior to the mid-1960's. The remaining wells were brought into production from the mid-1960's to the mid-1970's. Since 1979, applications for ground-water permits in the area have been denied because additional pumping would be detrimental to existing senior water rights to surface-water.

Most of the irrigation wells in the area are cased through the unconfined aquifer but are open through one or both of the underlying confined aquifers. Many of the deeper, higher production wells, therefore, pump ground water from both confined aquifers.

Deep Percolation and Ground-Water Recharge

Water percolating below the rooting zone of a soil profile (deep percolation) becomes ground-water recharge (hereinafter shortened to recharge). This tends to occur more rapidly when the amount of water moving through the soil exceeds the moisture-retention capacity of the soil (also termed field capacity or soil-moisture capacity). When soil moisture is less than the soil-moisture capacity, the water tends to drain slowly through the soil profile and very little deep percolation will occur. As the growing season progresses, evaporation and transpiration (together termed evapotranspiration or ET) return water to the atmosphere and tend deplete soil moisture to a level far below the soil-moisture capacity.

Figure 4 illustrates the estimated, average monthly soil-moisture budget for the Wilbur area, assuming that soil-moisture capacity is six inches of water in the rooting zone. Estimated potential evapotranspiration (PET) is the amount of ET that occurs when soil moisture is

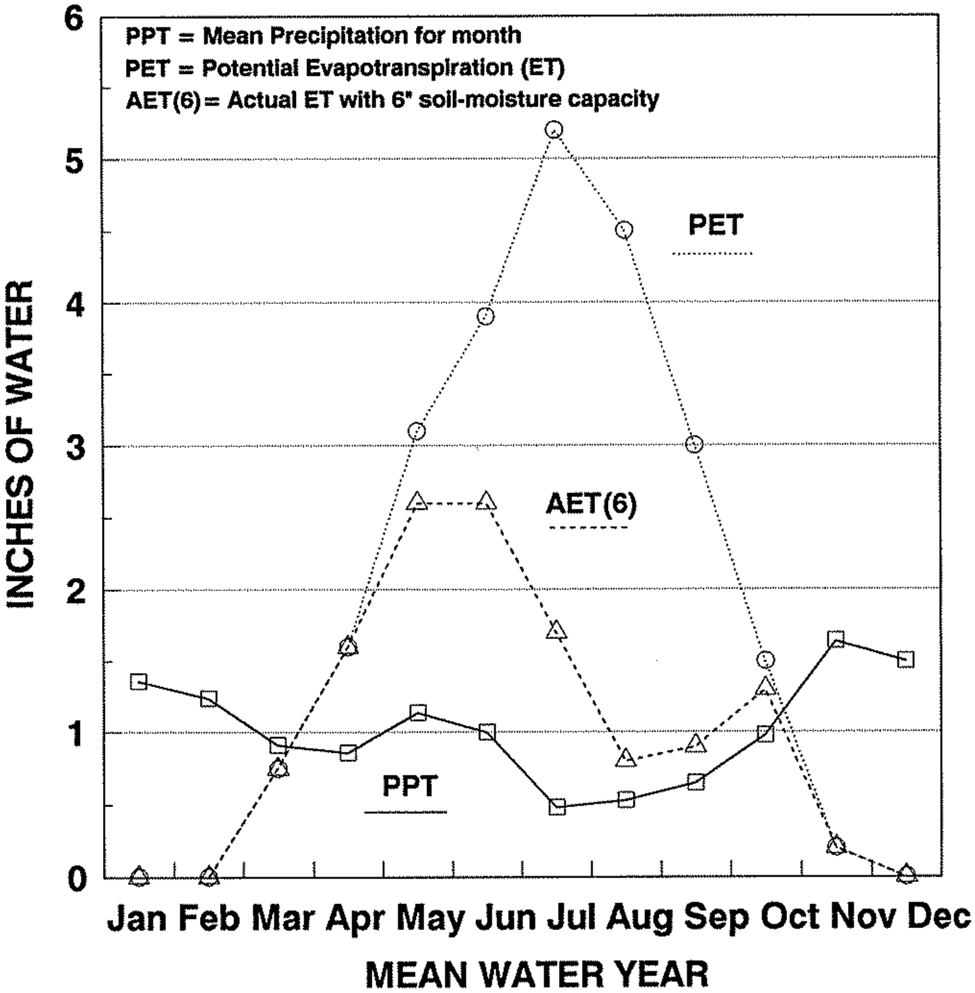

Figure 4. Soil Moisture Budget for Wilbur, Wa.

(modified from Wildrick, 1982)

plentiful and does not limit plant growth. Estimated actual evapotranspiration (AET) is the amount of ET that occurs under conditions when plant growth is limited by a lack of soil moisture, such as during the dry summers in the study area. **Figure 4** also shows that mean monthly precipitation (PPT) exceeds AET, on average, only during the months of October through March. These are the months when the amount of precipitation infiltrating down through the soil is likely to exceed soil-moisture capacity and result in deep percolation and recharge. During the months when AET exceeds precipitation, deep percolation is less likely to occur, especially late in the growing season when soil moisture is more depleted. Even during a wetter-than-average spring, such as in 1982, little recharge is generated by the spring rains except in the scablands. The silt loam soils (formed in loess) in the area have about 15 inches of soil-moisture capacity within a six-foot-thick rooting zone **(Stockman, 1977)**. In the scablands, the soil-moisture capacity is less than six inches in many places. **Figure 4,** based on a six-inch soil-moisture capacity, therefore probably underestimates AET for the loessial soils and overestimates AET for the scablands. Conversely, **Figure 4** probably overestimates the amount of moisture available for deep percolation under the loess and underestimates the moisture available for deep percolation under the scablands.

That most of the recharge originates as winter precipitation is further indicated by aquifer water levels that peak in late winter before the irrigation season begins **(Wildrick, 1982)**.

Because the loessial soils can hold so much of the average annual precipitation in the area, deep percolation through the thicker loess soils may be rare under natural, undisturbed conditions. For example, "winter" precipitation (November through April) at Wilbur averages about 7.4 inches. This much water can be temporarily stored (percolation continues although moisture content is less than the soil-moisture capacity) by about three feet of the loess soils, at 20% soil-moisture capacity, and would be lost to ET during an average growing season **(Figure 4)**. Thus, recharge through the loess probably is very small in a drier-than-average year. Instead, most of the deep percolation and recharge may occur only under the thinner loessial soils, less than one or two feet thick, which are not always cultivated, or in the scablands and coulee where fractured basalt is exposed.

Recently, the USGS **(Bauer and Vaccaro, 1990)** estimated ground-water recharge rates throughout the Columbia Plateau. For the Wilson Creek watershed, including the tributary Sinking Creek watershed, estimated recharge averages 0.9 inches per year for predevelopment conditions and 1.6 inches per year under current cultivated and irrigated conditions. For the adjacent Cannawai Creek watershed (adjacent to the Sinking Creek watershed on the south), estimate recharge averages 1.4 inches per year for predevelopment conditions and 1.2 inches per year under current cultivated and irrigated conditions.[1] Though not conclusive, these recharge

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[1]These estimates are derived from a recharge model accounting for daily rainfall, temperature, crop type, soil type, soil-moisture capacity by detailed soil classification, streamflow, evaporation, and transpiration, among other factors (Bauer and Vaccaro,

estimates for two broad regions indicate that the net result of human development, including cultivation, ranges from a small decrease to a large increase in recharge in the Sinking Creek area. Bauer and Vaccaro do not discuss the particular sources of recharge changes in these areas, but the likely source for the estimated increase in recharge for the Wilson Creek watershed is ground-water irrigation.

The following simple computation gives a comparative perspective on the volume of water pumped by irrigation versus the volume recharge to the pumped aquifer(s). At an estimated rate of 1.35 inches per year (average of post-development recharge estimates for Wilson Creek and Cannawai Creek), deep percolation through about nine acres of land is needed to produce one acre-foot of recharge. Suppose an irrigation well applies 12-inches of water to one section (640 acres) of crops during an irrigation season. One foot of water over 640 acres during one year amounts to 640 acre-feet per year of pumped water. Several of the larger irrigation wells in the study area pump that much water. Next, assuming that one acre-foot per year of recharge accumulates under nine acres, as stated above, then the hypothetical irrigation well consumes the entire amount of recharge under 9 sections, or 5,670 acres, of land and none of the recharge remains to flow toward other wells or to replenish streams.

1987). The recharge-model grid for the area is fairly detailed with cells representing one square mile.

POSSIBLE CAUSES OF STREAMFLOW REDUCTIONS IN SINKING CREEK AND ITS TRIBUTARY SPRINGS

Below-Average Precipitation

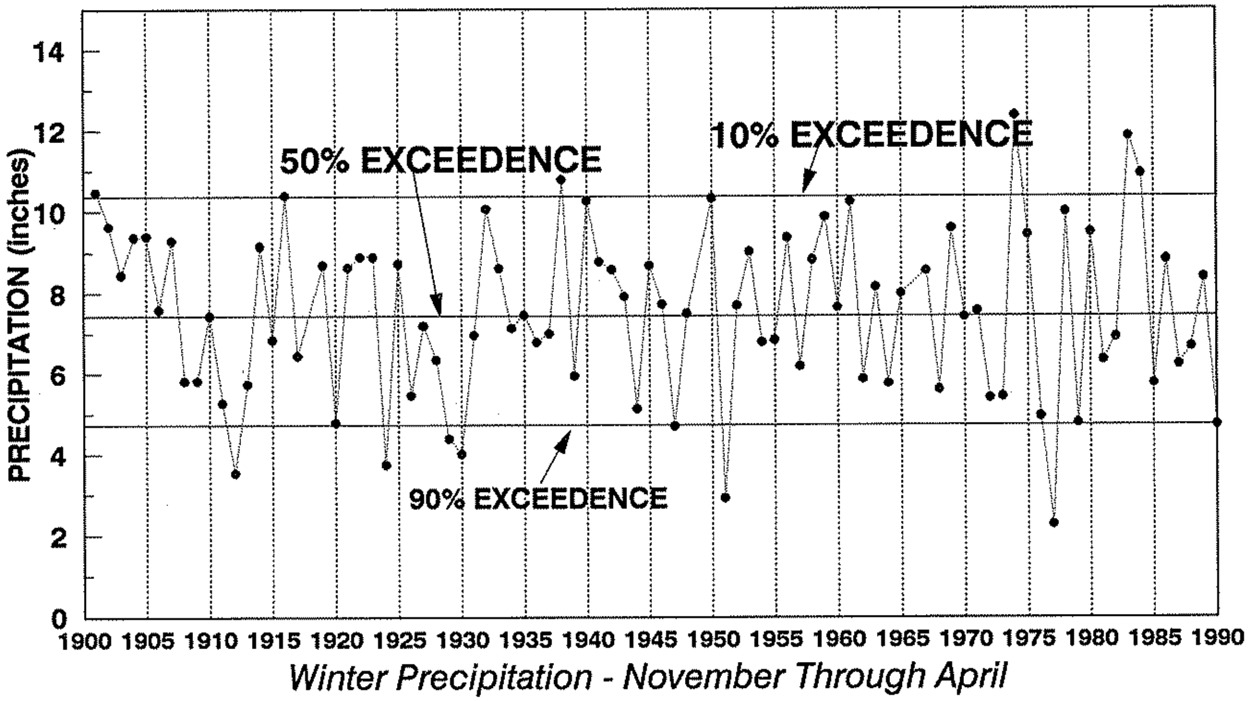
Local precipitation provides the total water supply in the Sinking Creek area. Variations in precipitation lead to variations in ground-water recharge which, in turn, lead to in variations in ground-water levels, discharge from springs, and streamflow. Obviously, prolonged periods of below-average precipitation result in reduced flow in Sinking Creek and tributary springs.

Figure 5 illustrates the record of annual water year and winter precipitation at the Wilbur weather station. The water year precipitation October through September) and winter precipitation (defined here as November through April) average about 12.2 inches and 7.5 inches, respectively.

Horizontal, solid lines drawn through the precipitation data in **Figure 5** indicate the 10%-, 50%-, and 90%-exceedence amounts. The 50%-exceedence amount equals the median precipitation (exceeded during approximately 50% or half of the years). Precipitation exceeds the 10%-exceedence amount during approximately 10% (1 in 10) of the years of records and exceeds the 90%-exceedence amount during approximately 90% (9 of 10) of the years of record. I calculated these exceedence values using regional-analysis techniques, as described by **Schaefer (1990)**, and fitted to the general-logistic distribution, as described by **Hosking (1986)**. Data included in the regional statistical analysis are National Weather Service records for the Wilbur, Coulee Dam, Davenport, Odessa, and Wilson Creek weather stations (**US West Optical Publishing, 1990**). Years of incomplete records are not included in the calculations.

Figure 5 also shows that annual and winter precipitation vary greatly from year to year. Drier and wetter periods alternate, sometimes every other year, sometimes every few years. Since the turn of the century and prior to the era of large-scale ground-water irrigation (the late 1920's, the mid-1940's, and the mid-1960's), several periods of precipitation were as dry as during the last three years. Also, the wettest two consecutive years of record occurred during the 1983 and 1984 water-years.

According to cattle ranchers along the creek, the well-above-average precipitation made little difference in Sinking Creek's flow. Unfortunately, we do not have enough surface-water-discharge information with which to compare or correlate to precipitation.



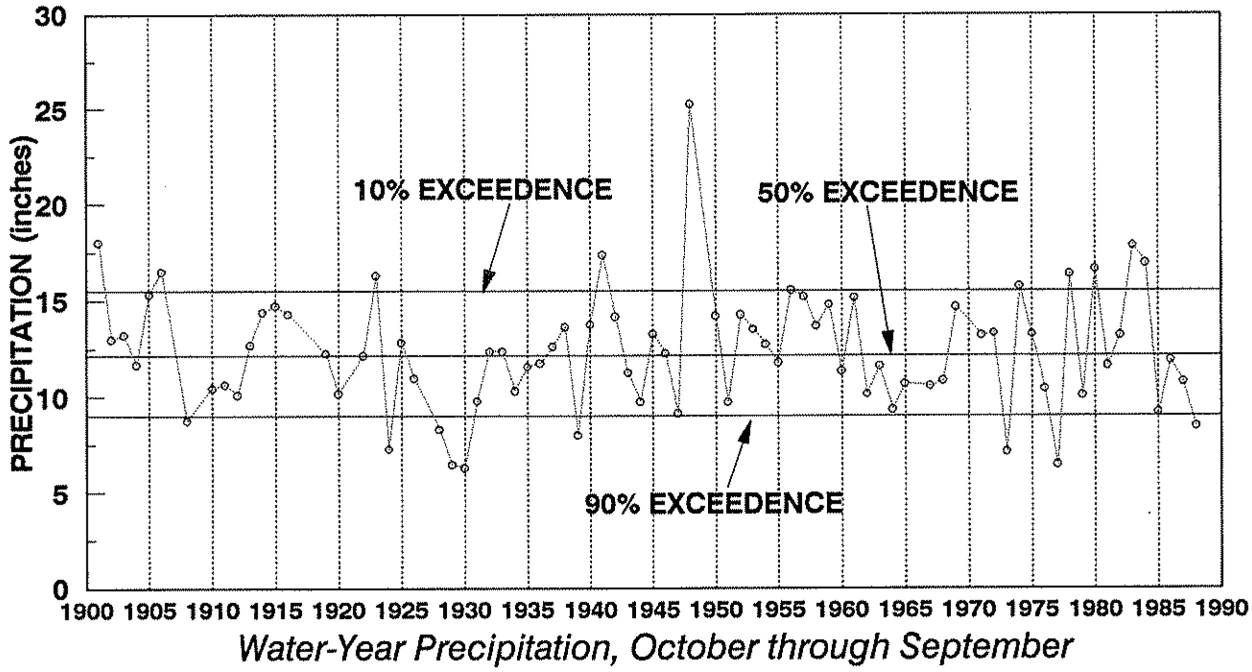


Figure 5. Winter and water-year precipitation, 1901-1989
Wilbur Station, National Weather Service
(Oct. 1988 through Sept. 1989 is the 1989 water year)

Hydrologic Effects of Tillage Practices

Soil-Moisture Effects

Tillage practices potentially can affect surface runoff, soil-moisture supply, and deep percolation (ground-water recharge). Prior to cultivation, the area's soils supported a short-grass prairie. Runoff from the undisturbed grasslands probably occurred infrequently because the natural vegetation delayed the movement of snowmelt or stormwater, allowing additional time for the water to infiltrate the soils. When cultivation commenced, runoff volumes probably increased, in particular because the bare soils offered less resistance to runoff. Current efforts by the Soil Conservation Service to reduce soil erosion by retiring cropland on steep slopes and then replanting to grasses (CRP Program) probably will restore the natural runoff conditions in small portions of the study area.

Modern tillage practices may also be restoring cultivated fields to the natural condition of infrequent runoff. **Lindstrom, et al. (1974)** found that when compared to older tillage practices such as disking, the deep-tillage practice of chiseling increases infiltration rates of soils when the ground is frozen, thereby capturing more surface runoff under certain conditions than the other tilling methods. In practice, the deep tilling creates deep grooves in the silt-loam topsoil of the area which penetrate deeper than frost normally penetrates so that water can reach and infiltrate the unfrozen soil below. However, compared to conventional disking or no tillage, chiseling is more effective at increasing soil moisture only during cold winters when snowmelt occurs while the ground is still frozen. During warmer years, with no frozen soil and no snow, the rainfall infiltrates adequately with any type of tillage or no tillage. Assuming a cold winter and frozen ground, the greater infiltration due to chiseling increases the soil moisture, at least temporarily. Soil-moisture capacity is not changed, however, so only a certain amount of extra infiltrating water can be held for the benefit of crops. The researchers recorded an increase of about four inches of soil moisture for chiseling compared to conventional disking during the cold winter. Subsoiling, another deep tillage technique, apparently tills deeper than chiseling and so may be somewhat more effective in capturing water when the frozen layer is particularly thick.

Lindstrom et al. (1974) conducted their research under conditions which resemble those around Sinking Creek. They conducted their experiments on Ritzville silt loam soil, probably loess, located near Lind, Washington. Soils there exceed 150 cm (about 5 feet) in thickness, have moisture capacities exceeding 20%, and directly overlie the CRBG. Their research, therefore, indicates that tillage practices in the Sinking Creek area affect soil-moisture infiltration and runoff only occasionally.

Other cultivation practices common to the Sinking Creek area may also affect soil moisture and surface runoff. With subsoiling, much crop stubble remains undisturbed between the widely-spaced grooves, while no tillage leaves all stubble in place for the winter. Over the winter, stubble serves to hold snow in place and, if snowfall is below average, probably reduces snowmelt runoff and retains more moisture in the upland soils.

Ground-Water-Recharge Effects

The additional soil moisture captured by deep tillage and by over-winter retention of crop stubble may benefit crop yields to some extent and may also lead to increased recharge. Recharge will occur if the water percolates below the rooting zone so that it is not lost to evapotranspiration processes. Also, on irrigated lands, deep percolation under the loess soils may be increased by the usual irrigation practice of applying enough excess water to leach salts past the rooting zone and, thereby, prevent salt buildup.

On the other hand, most of the recharge in the study area may occur in the coulee and scablands where courser, more permeable soils have higher infiltration rates, allowing soil moisture to more quickly percolate below the rooting zone and into the underlying basaltic aquifer. Also, the sparser vegetation of the scablands probably transpires less water per unit area than does the grasses of the uplands. Given the higher infiltration rate in these areas, reduction of runoff from the uplands by deep tillage might reduce recharge in these lows lying area near the creek but only during cold winters as indicated by the research of **Lindstrom, et al. (1974)**. At present, this possible effect on recharge cannot be quantified nor can the possibilities discussed in the previous paragraph.

Deep-tillage methods apparently have been in widespread use for several decades. Widespread use of stubble retention during the winter may be more recent. After so many years of deep tillage, any resultant reduction of recharge caused by these cultivation methods should have been evident many years ago as a declines in water levels in the unconfined aquifers and as reduced discharge from springs. But long-term water-level declines are only recently evident (later in this report see discussion on water-level declines). Also, owners of lands along the creek report that many smaller springs, tributary to Sinking Creek, were not noticeably diminished until the mid-to-late 1980's.

In summary, the effects of cultivation on recharge cannot be quantified at present. Until better information can be collected, further speculation about recharge effects is not warranted. However, the relative recent occurrence of changes in the ground-water system, long after the advent of these cultivation practices, suggests that cultivation has not significantly affected recharge.

Stream Channel and Floodplain Disturbance

Along many reaches of Sinking Creek, the channel has been straightened or shifted across the floodplain. Also, numerous small dikes and checkdams capture runoff for temporary flood irrigation of pasture. None of these disturbances, singly or in combination, reduce water availability in the creek during baseflow periods. Many of these irrigation works and channel changes predate the streamflow problems that developed after 1968.

Channel disturbance by checkdams probably enhances baseflow by increasing local ground-water recharge. That is, recharge to the unconfined, alluvial aquifer increases under ponds created behind the checkdams. Increased recharge raises the surrounding water table above the stream bed and increases "bank storage" of water in the alluvium. Evapotranspiration consumes some of this artificial recharge but much reappears as seepage into the channel after the farmer drains the temporary pond.

As pointed out by **Utting (1990)**, Sinking Creek is sensitive to the position of the water table. This sensitivity is expressed as gaining reaches (seepage into the stream) and losing reaches (infiltration loss through the streambed). During low-flow, all the streamflow in a losing reach may disappear underground. Farther down the coulee, the flow reappears in gaining reaches. Historically, several reaches of the creek exhibited these losing and gaining conditions. The water table in the alluvium is currently so low that most of the stream is in a losing condition.

Utting (1989) observed that Sinking Creek's channel has been shifted across the valley, in places, and, as a consequence, has been shifted up slope from the lowest point in the valley cross-section. Based partly on this observation, Utting then concluded that moving the stream channel upslope resulted in a marked and permanent reduction in the flow of Sinking Creek. Data were not provided to support either the observation or the conclusion.

Considering the physical geometry of the hydrologic system at Sinking Creek, only one hypothetical condition - namely if the water table lies below the streambed throughout its length - would lead to permanently reduced streamflow as a result of moving the creek channel to a higher elevation. This hypothetical condition probably never existed at Sinking Creek prior to human disturbances because the stream had many permanently flowing reaches. Otherwise, the stream would have resembled a wadi or arroyo with flow occurring only during runoff events. More likely, under conditions of average precipitation for the area, the water table in the alluvium and upper basalt lie above the streambed except along naturally losing reaches which comprise only a small portion of the creek. Accordingly, were a gaining reach to be shifted upslope, some of the streamflow through that reach would probably infiltrate the stream bed because the streambed would then lie above the water table, thereby changing the shifted reach to a losing condition. Water infiltrating the streambed would then recharge the alluvium and underlying basalt and flow down the valley in the subsurface, the same process as for naturally losing reaches, described above. Somewhere down the coulee, the water would reappear in undisturbed, gaining reaches of the creek.

Pumping Effects in Springs Discharging From the Columbia River Basalts

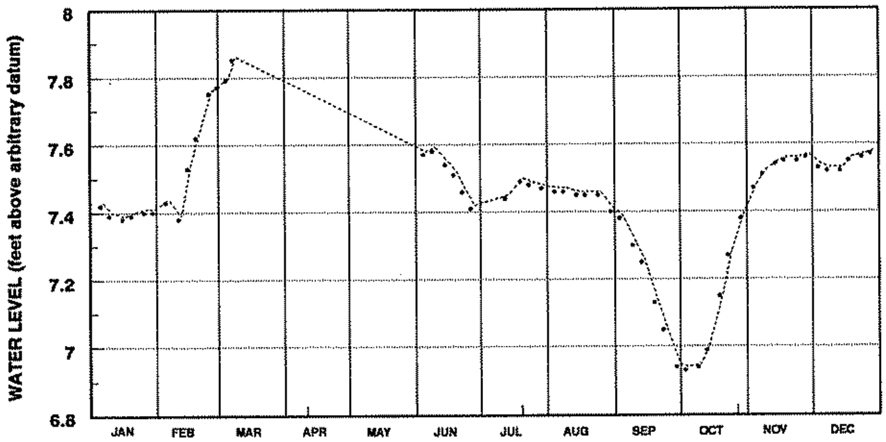
Pumping of ground water often affects the discharge of springs. Ground water discharges from springs because the aquifer head is at higher elevation than the land surface at the point of discharge. This hydraulic gradient drives ground-water flow toward the spring. Because the outlet elevation of a spring is constant, any head increase (rise) in the aquifer will increase the hydraulic gradient toward the spring, causing discharge to increase. Conversely, water-level declines in the aquifer (such as are caused by pumping from wells) decrease the hydraulic gradient and cause discharge to drop. With a sufficiently large water-level decline in the aquifer, a spring may cease to flow altogether. By this mechanism, pumping drawdown reduces discharge from springs whenever the drawdown propagates to the spring.

A pumping test of the Big Bend Golf and County Club's irrigation well in Wilbur **(T26N/R33E-07E02)** clearly demonstrated reduction of discharge from springs due to pumping from local basalt aquifers. This is an excellent example of the hydraulic continuity between ground water and surface water which applies throughout the study area. On March 24, 1965, the well pumped 400-450 gpm for 2½ hours. Following the start of pumping, the water level at a spring **(T26N/R33E-07M01s**, Town of Wilbur) drew down 0.13 feet after only 15 minutes and drawdown totaled 0.52 feet by the time pumping ceased (see water-right findings for Application No. 7295 leading to Certificate No. 5461-A, Ecology files). The spring responded to the rapid, outward propagation of water-level drawdown through the confined, basaltic aquifer.

Evidence That Irrigation Pumping Reduces the Flow of Springs Tributary to Sinking Creek

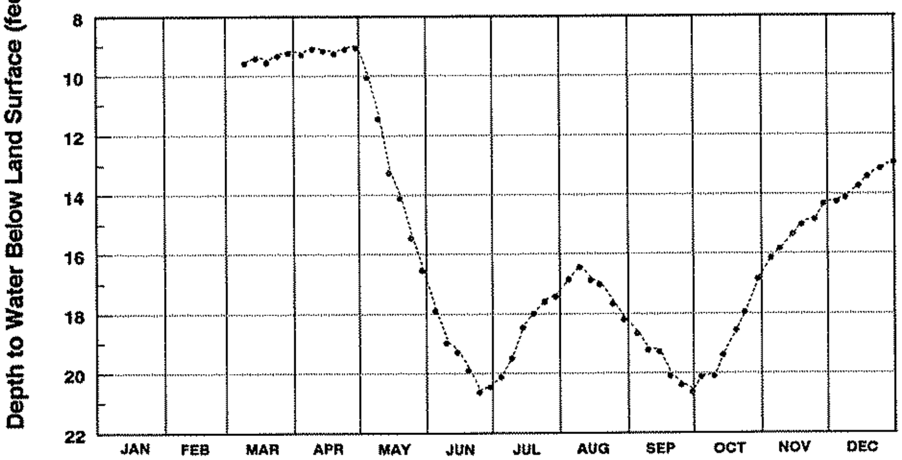
The timing of fluctuations of discharge from springs and of water levels in unpumped observation wells corresponds with the pumping schedule of many irrigation wells in the study area, particularly all those wells used to irrigate winter wheat. These wells are shut off in late June for the wheat harvest and are turned on again in August or September to pre-irrigate for the next year's crop. **Figure 6C** illustrates the water-level changes throughout the year in a typical irrigation well in the area.

Stage records for one large spring **(T25N/R34E-08N01s**, William Rosman) and discharge observations for other large springs (springs shown in **Figure 2**) correlate well with the on/off schedule of pumping from nearby wells. Each year the discharge from these springs reaches a maximum during late winter or early spring. In March or April, soon after irrigation wells begin pumping, discharge from springs begins a steady decline which lasts for approximately three months. In mid-summer, shortly after many irrigation wells cease pumping, the discharge



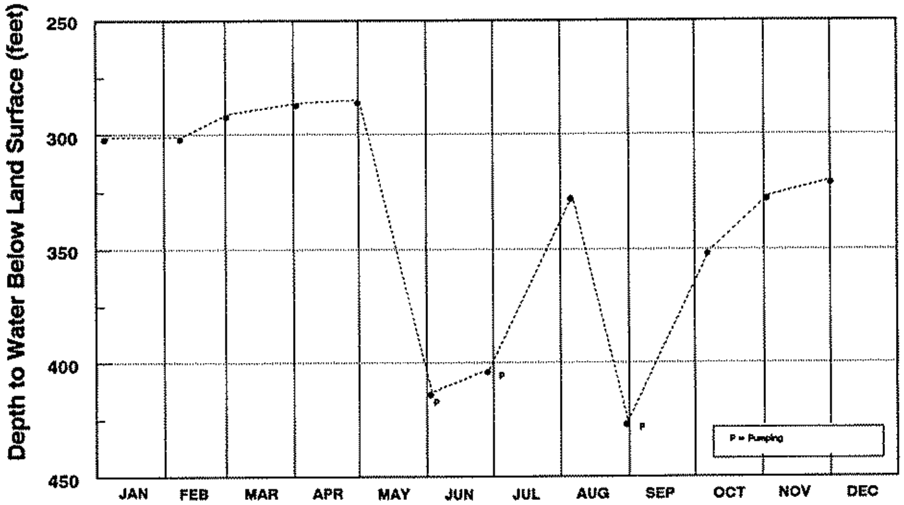
Hydrograph for Spring, T25N/R34E-8N01s, for 1982

(A)



Hydrograph for an observation well, T25N/R34E-9F01, for 1982

(B)



Hydrograph For An Irrigation Well, T25N/R33E-27A02, for 1981

(C)

Figure 6. Water Levels in a Spring and Two Wells Near Sinking Creek

from springs steadily increases. Finally, in August, soon after the irrigation wells resume pumping, the discharge from springs again steadily decreases until irrigation ceases for the winter. **Figure 6A** illustrates these pronounced changes in discharge from springs.

The on-off schedule of irrigation-well pumping also correlates well with water-level fluctuations in many wells. Water-level observations in unpumped wells throughout the area indicate that the confined aquifers are greatly affected by pumping. For example, in unpumped portions of the uppermost, confined aquifer, heads decline 15 to 20 feet during the irrigation season as indicated in observation well **25N/34E-09F01 (Figure 6B)**, located approximately 1¼ miles northeast of spring **25N/R34E-08N01s.** The same pattern of water-level fluctuations were observed in this well for several years. Note that the water level rises during July and falls again in August, in sequence with the schedule of wheat irrigation **(Figure 6C).** This observation well is located more than two miles from the nearest irrigation well.

The corresponding fluctuations of pumping schedules, water-levels in observation wells, and discharge from springs, depicted in **Figure 6**, indicate direct hydraulic continuity between ground water and surface water in the area. Changes in the ground-water system, particularly changes in water levels, lead to changes in the surface-water system, particularly the discharge from the spring. Thus, some or all of the water in the two Rosman springs appears to discharge from a heavily pumped aquifer. The only heavily pumped aquifers in the study area are the confined Roza and Grande Ronde aquifers.

During some years since 1970, spring **T25N/34E-08N01s** ceased flowing altogether, while during other years, the flow continued at greatly reduced rates. During the same period, according to John and William Rosman, the greatest discharges at this spring and at spring **T25N/R33E-13J01s** occurred during 1985 when irrigation pumping was markedly reduced by the Federal Payment-In-Kind (PIK) program. The PIK program paid farmers to reduce crop acreage so a significant percentage of the irrigated lands were not cultivated that year and perhaps for several subsequent years. Unfortunately, we were not monitoring the discharges during that year. Pumping may similarly affect other large springs located at elevations near the valley bottom, but some of those springs have gone dry and cannot be monitored. Examples of dried-up or nearly dried-up springs occur at **T25N/R32E-13J01s; several springs in the east half of section 13, T25N,R33E; T25N/R33E-16K01s; T25N/R34E-10B01s and -10H01s; and T25N/R34E-17C01s and -17E01s.**

The basalt flows of the Priest Rapids Member, an unconfined aquifer **(Figure 3)**, crop out along Sinking Creek and at the nearby tributary springs. This aquifer provides stock and domestic supplies to shallow wells in the area but cannot provide sufficient water supply for irrigation of more than a few acres. The pumping effects at the springs described above indicate that the confined basaltic aquifers might also be discharging at the spring. Prior identification of a photolineament passing through the spring **(Wildrick, 1982)**, suggests that a high-angle fault may serve as a conduit transmitting water from the upper confined aquifer (Roza Member) to the surface **(Figure 2)**. Alternatively, based on the findings of **Steele et al. (1989)** the Quincy interbed may be very thin or missing in the area beneath the affected springs. Under the latter condition, pumping effects would more easily propagate vertically upward to the ground surface where springs discharge.

In summary, the geological, geophysical, and hydrological evidence indicates that ground-water pumping reduces the discharge at springs along Sinking Creek. The evidence includes:

(1) the geological and geophysical correlation of lava flows and water-bearing zones for many miles,

(2) the correlation of irrigation-well pumping with water-level changes in distant observation wells,

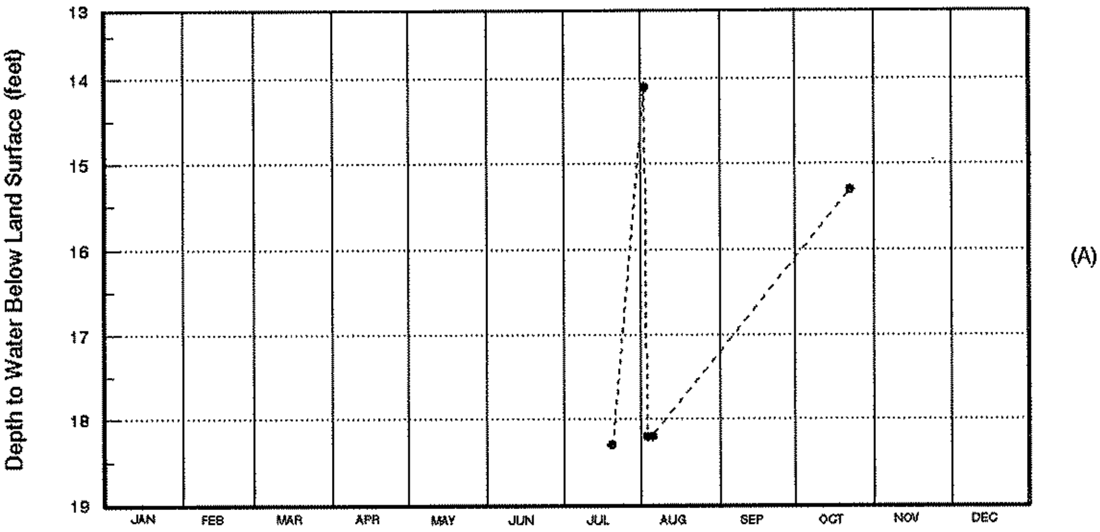
(3) the long-distance propagation of drawdown during pumping tests, and

(4) the correlation between pumping schedules for irrigation wells and fluctuations in discharge from springs.

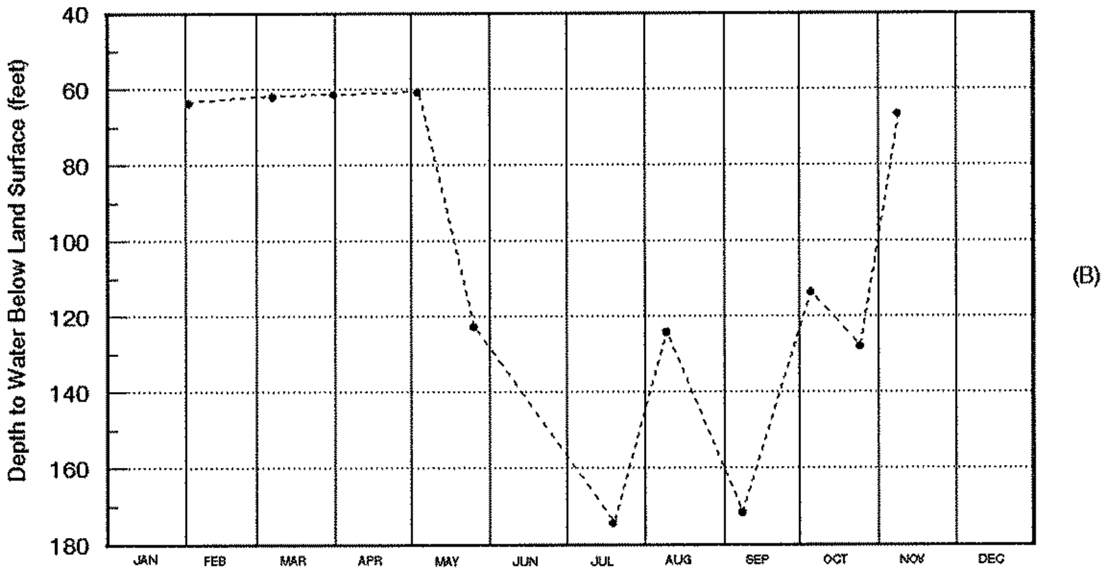
Delayed Pumping Effects On Springs Discharging From the Unconfined Basalt Aquifer

Water levels in shallow wells completed in the unconfined, basaltic aquifer **(Figure 7)** exhibit the previously described mid-summer rise and fall and correlate with the schedule of pumping for wheat irrigation. Evidently, drawdown in the confined aquifers propagates upward through the leaky confining zone and into the unconfined aquifer, though not immediately. The drawdown must first propagate upward through the Vantage and/or Quincy interbeds (claystones), if they are present, as well as through the less fractured interiors of basalt flows. The response in the unconfined aquifer may not be appreciable for several days or weeks following the start of pumping in the confined aquifer. Such a delay would account for the lack of measurable head change in the unconfined aquifer when the Houger well pumped about 600 gpm for a two-day aquifer test **(Wildrick, 1982)**.

As the head in the unconfined aquifer responds to pumping in underlying aquifers, ground water that would have discharged in springs instead leaks downward from the unconfined aquifer to the upper, confined aquifer. This can be explained in terms of the changing hydraulic gradients. On one hand, head in the underlying, pumped aquifer increases more quickly than in the overlying unpumped aquifer. This delay in response causes the vertical hydraulic gradient to increase, and, in turn, causes downward leakage to increase. Simultaneously, as the head in the unconfined aquifer declines, the hydraulic gradient toward any springs also decreases and the discharge at the springs declines. In effect, water that would have discharged at springs is captured by ground-water pumping as leakage from the unconfined aquifer into the underlying confined aquifers.



Hydrograph for Well, T25N/R34E-09E02, for 1982



Hydrograph for Well, T25N/R34E-29J6, for 1984

Figure 7. Water Levels In Two Unpumped Wells Completed In The Unconfined Aquifer, Sinking Creek Area

WATER-LEVEL DECLINES

Undisturbed aquifers usually are in hydraulic equilibrium with average recharge and discharge rates, assuming an unchanging climate. In this condition, ground-water storage and water levels in aquifers fluctuate with seasonal variations in recharge and discharge but follow similar patterns each year. Also, water levels at a given time of year are similar from year to year. But in aquifers disturbed by pumping, water levels always drop, adjusting for the increase in total discharge from the aquifer. Each year repeats the cycle of water-level decline (drawdown) during the irrigation season while wells are pumping, followed by water-level recovery after pumping ceases. The water levels will recover to undisturbed levels so long as recharge replaces the pumped water.

Confined Aquifers

Despite the growth in ground-water irrigation around Sinking Creek through the 1970's, average water levels remained stable from year-to-year. However, water levels in three irrigation wells (all located just south of Sinking Creek, and each open to one or both confined aquifers) progressively declined during the last 8 years. The water level in well **25N/32E-35P01** (Wilbur Securities) dropped about 10 feet **(Figure 8A)**. The water level in well **25N/32E-26G01** (Quirk) dropped 20 to 30 feet **(Figure 8b)**. The water level in well **25N/33E-27A02** (Rettkowski) dropped about 60 feet **(Figure 8c)**.

Apparently, the combined annual pumping from the wells in this locality now exceeds, at least temporarily, the recharge rate for the broader area within which the pumping "captures" the aquifer's discharge. Water levels will continue the year-by-year decline throughout an expanding area until the capture-area is large enough to provide influx equal to the combined pumping rates. However, with the information available at present, we cannot predict either the level at which water levels will stabilize or when this will occur.

Unconfined Aquifers

Recent evidence also indicates that water levels in wells completed in the unconfined aquifers (including the uppermost basalt, alluvium, and flood gravels) generally are declining year-by-year. This aquifer experiences considerable drawdown during the irrigation season

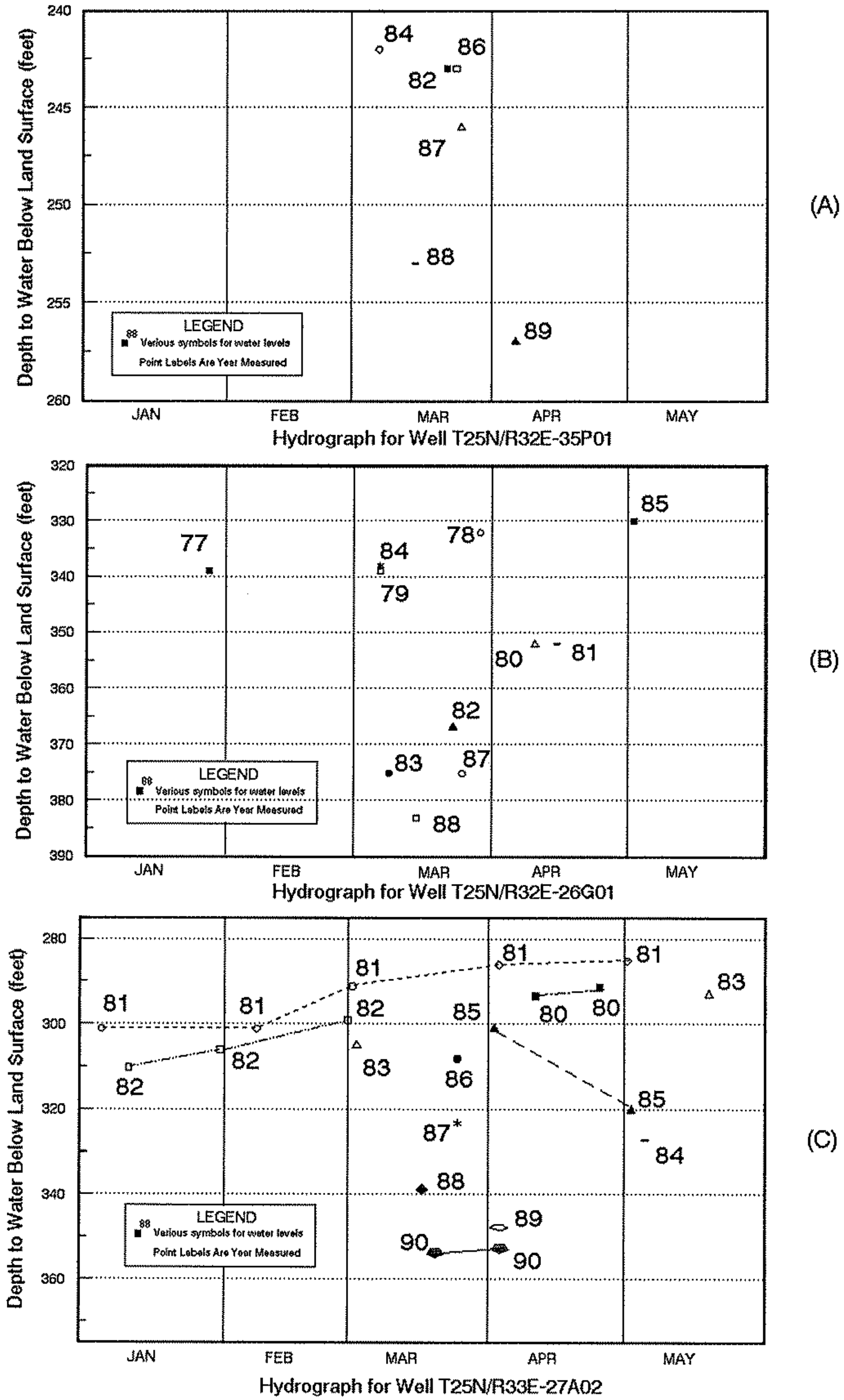


Figure 8. Water levels prior to the irrigation season in three irrigation wells near Sinking Creek.

(Figure 7), as described earlier, but water levels do not quite recover to the prior year's level during the remainder of the year.

At one locality, an unused, shallow well **(25N/33E-12P01, Tiegs)** completed in flood gravels and a nearby spring **(25N/33E-13B01s, W. Rosman)** discharging from the same gravel deposit, both dried up in the early 1980's. The well has since been abandoned. Water levels in another well **(T25N/R34E-11G01)** completed in the unconfined aquifer are also much lower now than in the early 1980's **(Figure 9)**.

Water-level data for the unconfined aquifers are sparse and most measurements are for wells located in the upper watershed. During 1991, additional wells completed in unconfined aquifers will be monitored by Ecology staff. Preliminary data indicates that water levels in other wells completed in the unconfined aquifer in the area are also experiencing yearly declines. Continuation of year-to-year water-level declines in the unconfined aquifer may reduce the discharge from any springs not already affected by the pumping of irrigation wells.

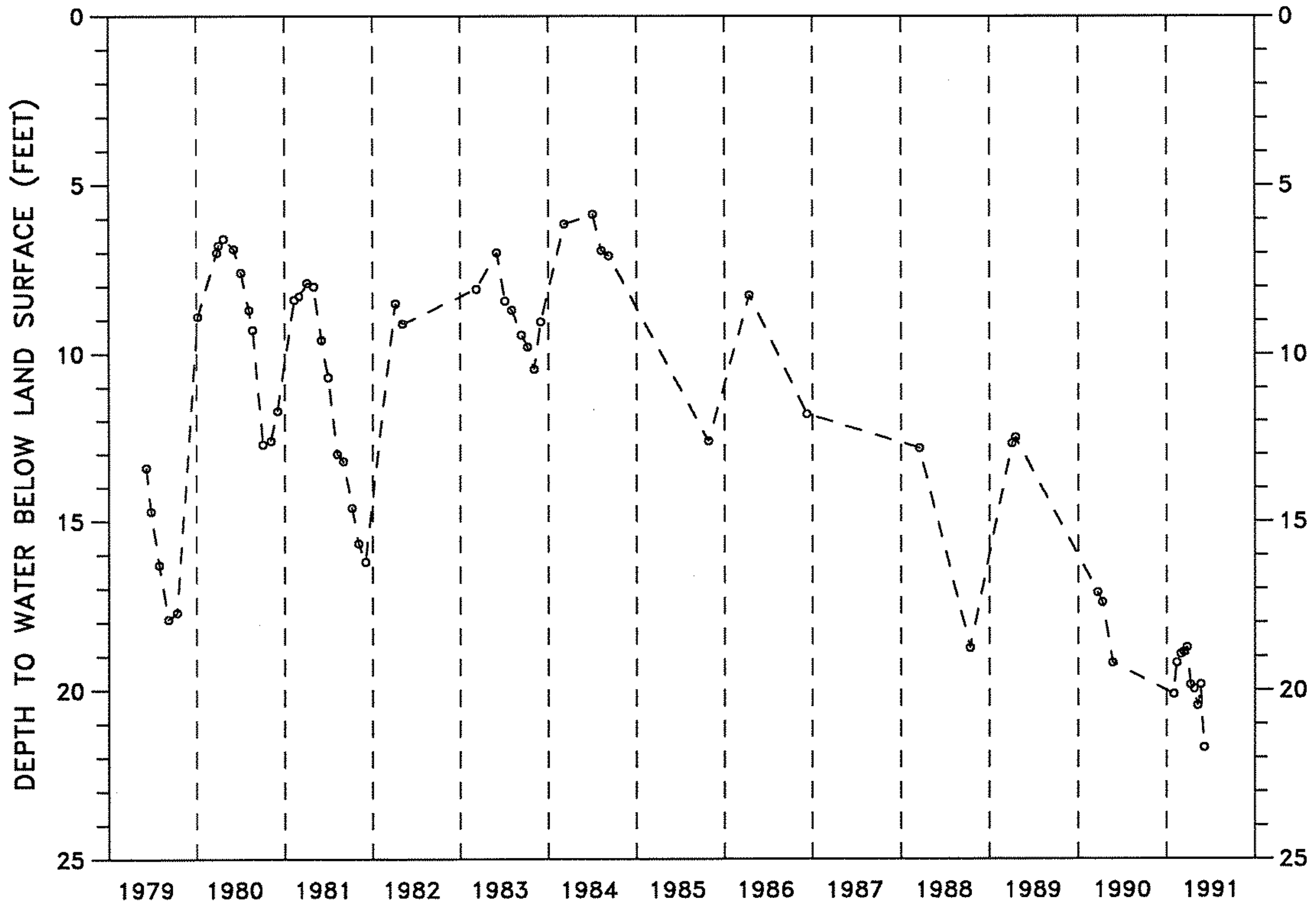


Figure 9. Water Levels in Well T25N/R34E-11G01, completed in the unconfined, basaltic aquifer, Sinking Creek area

PROGRESSIVELY DRIER CONDITIONS IN THE ALLUVIUM ALONG SINKING CREEK

Observations over the past ten years indicate that the valley alluvium and catastrophic-flood deposits along Sinking Creek have become progressively drier. In the early 1980's the cattlemen could provide stock water by digging watering holes in the alluvium after streamflow ceased for the summer. Now these excavations are dry by late spring, indicating that the water table has dropped compared to previous years.

Earliest indications of water-table decline in the alluvium were large depressions and "cracks" in the soils, first observed by Ecology staff in 1982, in the alluvium downstream of the Blenz Spring in section 13, T25N/R33E. By 1991, numerous depressions and cracks also opened up in sections 14 and 15, T25N/R33E. The larger cracks along the edge of the stream channel are about 5 to 8 feet long, 1 or 2 feet wide, and 4 to 8 feet deep. The largest depression is bowl-shaped and about 15 feet in diameter. Other depressions several hundred feet long, one to three feet deep, and a few inches wide occur along the valley's edge at the contacts between basalt outcrops and the alluvium. A few incipient cracks, tens of feet long and less than an inch wide cross the valley floor transversely and are becoming a hazard for farm vehicles. Following the brief snowmelt runoff in March 1991, water flowed past Blenz Spring to the approximate center of section 13, T25N/R33E, then disappeared into one of the large depressions.

In 1990, I observed similar cracks along the margins of the dry alluvial bed of Wagner Lake **(T25N, R33E, sections 17 and 18)**, a shallow water-table lake with no inlet or outlet. The Wagner Lake depressions also occur at the basalt/alluvium contact. The landowner, Clarence Wagner, reported the cracks to Ecology in 1989 and also stated that the lake was never completely dry during any year until the 1970's. Now the lake has been dry the year-around for several consecutive years. Near the lake, in well **T25N/R33E-17E01**, the alluvial water table now lies about five feet below the adjacent bed of Sinking Creek.

Apparently, the alluvial soils, including layers of peat, consolidate (shrink) as they dry out, resulting in the large depressions and cracks. The unprecedented occurrence of these shrinkage phenomena indicate depletion of ground water in the unconfined, alluvial aquifer. That is, the alluvium in the Sinking Creek valley no longer receives enough recharge from streamflow to become or remain saturated throughout the year. The mostly desaturated alluvium now absorbs most of the scarce snowmelt runoff and all of the baseflow from springs so that the stream is dry except for short distances downstream of the few remaining springs.

Among the sources of recharge to the alluvium - direct precipitation, surface runoff from the uplands, and ground-water discharge from springs - only the latter source has markedly decreased during the last two decades. Available evidence, discussed above, indicates that water-table depletion in the alluvium would be far less serious if the discharge of several tributary springs were not so greatly reduced by ground-water pumping.

BOREHOLE LEAKAGE IN UNCASED WELLS

Most of the irrigation wells in the Sinking Creek area are cased through only the unconfined aquifer. In some deeper irrigation wells, the uncased portions of the boreholes interconnect the two confined aquifers and are conduits for downward flow ("borehole leakage") because the head is less in the lower confined aquifer than in the upper confined aquifer. This borehole leakage occurs whenever the wells are not being pumped.[2]

The annual rates of borehole leakage cannot be quantified with available information but probably are far less than the pumping rates in the same wells. Collectively, the borehole leakage for the irrigation wells may be several hundreds of gpm, whereas the pumpage amounts to thousands of gpm. During a given year, the leakage continues for perhaps twice as long as the pumping, but even so will not amount to the cumulative, annual acre-footage pumped. Nonetheless, the borehole leakage reduces water levels throughout the ground-water flow system, by the same process as when the wells are pumped, and thereby reduces discharge from springs in some measure.

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[2]Usually pumps are set above the water-bearing zones. Thus, borehole leakage occurs below the pumps. Pumping causes the hydraulic gradient to reverse toward the pump, thereby interrupting the leakage.

CORRECTION TO PREVIOUS REPORT

Wildrick (1982) concluded that the two Houger irrigation wells **(25N/34E-02C01 and -02G01)** alone were responsible for the reduction in discharge at the Rosmans' springs. The conclusion was based on pumping-test results, on several years of daily water-levels recorded in observation well **25N/34E-09F01 (Figure 3B)**, and on limited information about Mr. Houger's irrigation schedules.

Mr. Houger has since provided corrections concerning his irrigation schedule. Apparently, the Houger wells are used mostly for irrigating alfalfa and only partly for irrigating wheat. Irrigation for alfalfa continues more-or-less constantly during the irrigation season, in contrast to the irrigation schedule for wheat. Therefore, the mid-summer's water-level rise in observation well **25N/34E-09F01 (Figure 3B)** cannot be attributed to cessation of alfalfa irrigation by the Houger wells. More probably, the water-level in the observation well rises in mid-summer when pumping ceases in more distant wells used for irrigating wheat. Nevertheless, the Houger wells cause some drawdown in the observation well and contribute to the area-wide head decline (principally in the uppermost, confined aquifer) during the irrigation season, and to the consequent reduction of discharge from tributary springs, especially from springs in the upper watershed of Sinking Creek.

SUMMARY

Pumping for irrigation is the principal cause of progressively declining streamflow and discharge from tributary springs along Sinking Creek. If pumping continues at present rates, these water-supplies will remain depleted. Borehole "leakage" through uncased wells also contributes to the surface-water depletion and will continue until the wells are properly sealed between aquifers.

Water-levels in parts of the deeper, confined aquifer are dropping progressively from year-to-year. Pumping lifts (and costs) are increasing and ground-water storage in the aquifers is being reduced. Water-levels in parts of the unconfined aquifer also are dropping progressively.

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GLOSSARY

ACRE-FOOT (Ac-ft) - A unit commonly used for measuring the volume of water or sediment; equal to the quantity of water required to cover one acre to a depth of one foot and equal to 43,560 cubic feet or 325,851 gallons.

ALLUVIUM - Soil material, such as sand, silt, or clay, that has been deposited by streams or rivers during recent time.

AQUIFER TEST - A test involving the withdrawal of measured quantities of water from or addition of water to, a well and the measurement of resulting changes in head in the aquifer both during and after the period of discharge or addition.

AQUIFER - An underground, porous or fractured layer of rock or soil capable of supplying a usable supply of water to a well.

ARTESIAN AQUIFER - Ground water under sufficient pressure to rise above the level at which the water-bearing bed is reached in a well. The pressure in such an aquifer commonly is called artesian pressure, and the rock containing artesian water is an artesian aquifer. (See "Flowing Artesian Well.")

BASEFLOW - The amount of stream discharge that is unaffected by seasonal fluctuations (changes in precipitation, consumptive use, evapotranspiration).

BOREHOLE - The uncased hole resulting from drilling or digging by any method.

BOREHOLE LEAKAGE - The movement of water between aquifers occurring within a borehole.

CASCADING WATER - Flowing water that enters a well casing at one level (aquifer zone) and travels down the well to another level.

CHANNELED SCABLANDS - A land form resulting from the Missoula Flood which left thin soils and intermittent rock outcrops.

CHISELING - A method of soil preparation whereby a chisel plow is used to prepare a seed bed. A chisel plow, as opposed to traditional moldboard plows, loosens up the upper soil layer, rather than turning over a deep swath of soil.

COLUMBIA PLATEAU PHYSIOGRAPHIC PROVINCE - The area approximately bounded by the Columbia River and Okanogan Highlands to the North, the Rocky Mountains to the east, the Blue Mountains and Central Oregon Highlands to the South, and the Cascade Mountains to the west.

COLUMBIA RIVER BASALT GROUP - Formal geologic name for the group of predominate basalt formations of the Columbia Plateau physiographic province, including the Priest Rapids and Roza Members of the Wanapum Basalt and the Grande Ronde Basalt.

CONE OF DEPRESSION - A cone-like depression of the water table or other surface that is formed in the vicinity of a well by withdrawal of water. The surface area included in the cone is known as the "area of influence" of the well.

CONFINED WATER (ARTESIAN) - Water under artesian pressure. Water that is not confined is said to be under water table conditions. (See "Artesian Aquifer.")

CONFLUENCE - The point at which one stream flows into another; or where two streams converge and unite.

COOLING UNITS - Portions of the advancing front of a lava flow cool and solidify in place but then are overridden by a breakout of lava upstream of the solidified front. By this mechanism many cooling units may result from a single lava flow. Discontinuous interflow zones also result.

COULEE - A steep-walled valley, often having a stream at the bottom. Sinking Creek occupies a coulee created by the Missoula Floods of the last glacial epoch.

CUBIC FOOT PER SECOND (CFS) - A unit expressing rate of discharge. One cubic foot per second is equal to the discharge of a stream having a cross section of one square foot and flowing at an average velocity of one foot per second. It also equals a rate of 448.8 gallons per minute.

DISCHARGE - The volume of surface water that passes through a given cross-section of a channel (or the volume of ground water pumped) during a unit of time.

DRAWDOWN - The lowering of the water level in a well and in the aquifer as a result of withdrawal by pumping.

EVAPOTRANSPIRATION - The combined losses of soil moisture by evaporation from soil surface and soil pores and by transpiration through plants. Related terms are: "potential evapotranspiration" - the maximum amount of moisture removed from the soil under given conditions of humidity, wind movement, and temperature, and when soil moisture is not limited; and "actual evapotranspiration" - the amount of moisture actually lost from the soil.

EXCEEDENCE - A statistical value denoting that the probability of an event exceeds the given value.

FAULT - A fracture or zone of fractures, along which there has been displacement of the sides relative to one another.

FLOW-SYSTEM GEOMETRY - The three-dimensional arrangement of geologic materials and structures controlling where ground water occurs, how it moves, and where it is going.

FLOWING WELL - An artesian or water-table well having sufficient head to discharge water above the land surface.

FLOWMETER - An instrument for measuring the rate of flow of a fluid. The instrument is calibrated to give volume or mass rate of flow.

FLUME - A device used to measure stream flow by forcing it to flow through a straight-sided channel.

FORMATION - A unit of rock, readily identified and mapped, usually consisting of the same kind of rock and implying the same environment of deposition.

GAGING STATION - A particular site on a stream, lake, or reservoir where systematic observations, gage height, or discharge are obtained.

GEOPHYSICAL LOGGING - A series of tests using measuring instruments lowered into a borehole to obtain information on the character of formations, effectiveness of well construction, and on the presence and chemical characteristics of groundwater.

GRANDE RONDE BASALT - The deepest of the basalt formations comprising the Columbia River Basalt Group in the study area.

GROUND WATER - Water in the pores and crevices of rock and sediments which has entered them chiefly as rain water percolating down from the surface.

HEAD, STATIC OR HYDROSTATIC - The height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point. Equal to the elevation head and the pressure head and neglecting the velocity head. HEAD, when used alone is understood to mean static head.

HEAD DIFFERENCE - The difference in head between two points in the same aquifer or in difference aquifers.

HYDRAULIC CONTINUITY - The hydraulic interconnection between ground and surface waters.

HYDRAULIC GRADIENT - The difference in head divided by the distance along the flowpath.

HYDROGEOLOGY - The study of water-bearing zones, and the movement and location of water in relation to geologic structures.

HYDROGRAPH - A graph showing stream stage or discharge, or a graph showing ground-water levels in a well, over time.

INTERBED - Geologic material between and parallel to other beds of different material (for example, sandstone interbeds between basalt flows).

INTERFLOW ZONES - Contact zones between basalt flows, usually highly fractured.

INTERMITTENT STREAM - A stream that carries runoff only part of the year and remains as a dry channel during the rest of the year.

JOINT - In geology, a crack formed along a plane of weakness (joint plane) in a mass of rock; it is unlike a fault in that little or no movement has taken place between the blocks.

LOESS - An eolian (wind) deposit, usually of silt-sized particles, formed during the last glacial period in the study area.

LOWER ZONE - In reference to the Sinking Creek area, the Lower Zone refers to the Grande Ronde Basalt Formation.

MASSIVE - Relatively thick, homogeneous rock layer with few fractures.

MEAN - Statistical term equivalent to the average of two or more values.

MIDDLE ZONE - In reference to the Sinking Creek area, the Middle Zone refers to the Roza Member of the Wanapum Basalt, CRBG.

OBSERVATION WELL - A well used for observing changing water levels.

PIEZOMETER - A pipe that extends from land surface to a predetermined depth in the well. The lower end of the pipe is open to a water-bearing zone within the borehole and is isolated from water-bearing zones above and below by sealing material.

POTENTIOMETRIC SURFACE (PIEZOMETRIC SURFACE) - A surface which represents the static head.

PUMPING LIFTS - The distance ground water must be pumped from the aquifer to the land surface, including the depth of drawdown within the well during the pumping.

RECHARGE (GROUND WATER) - The processes by which surface water percolates below the rooting zone of soils and reaches the saturated zone in aquifers.

SEEPAGE RUN - A series of discharge measurements along the course of a stream to determine approximately where water is gained or lost.

STRATIGRAPHY - The study of rock strata, especially of their distribution, composition, sequence, deposition, and age.

SUBSOILING - A method of soil cultivation whereby the seedbed is tilled with widely-spaced steel bars, usually penetrating deeper beneath the surface than is possible with a chisel cultivator.

TOPOGRAPHIC DIVIDE - A ridge, which, connected along its highest points, separates drainages.

TRANSMISSIVITY - A measure of an aquifer's ability to transmit water. Equal to the hydraulic conductivity (or permeability) multiplied by the thickness of the saturated portion of the aquifer.

UNCONFINED AQUIFER - Also called the water-table aquifer. An aquifer wherein the water surface is open to atmospheric pressure; generally the uppermost aquifer.

UNDERFIT STREAM - A stream that is too small to have the eroded the valley in which it flows.

WATERSHED - The area drained by a river or stream.

WATER YEAR - The months October through September of the following year.