WASHINGTON STATE DEPARTMENT OF ECOLOGY

Decreasing Streamflow and Possible Ground Water Depletion

in the Sinking Creek Watershed, Lincoln County, Washington

82-6

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DECREASING STREAMFLOW AND POSSIBLE GROUND WATER DEPLETION IN THE SINKING CREEK WATERSHED, LINCOLN COUNTY, WASHINGTON

By

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Abstract

The baseflow of Sinking Creek in Lincoln County, Washington has declined in recent years. The magnitude of this decline is not known because historical records of streamflow are not available. Ground water discharge to several lakes in the watershed has also declined during recent years. This study concludes that these declines are due to interference and increased vertical leakage of ground water by pumpage from deep irrigation wells, below average precipitation, and downhole leakage in uncased wells.

The geologic setting for the watershed includes surface soils and alluvium of varying depths overlying three basalt aquifer zones (Upper, Middle, and Lower). The Upper and Middle Zone basalts are the principal source of water for maintaining lake levels and baseflow in Sinking Creek. The Middle and Lower Zone basalts are the principal source of ground water for irrigation in the watershed.

Ground water pumpage from deep irrigation wells has increased twenty-fold in the period 1968 to 1979. This pumpage lowers the hydrostatic head in the Middle and Lower Zone basalts and increases the rate of vertical leakage from the Upper Zone during the irrigation season although water levels in all zones recover during the winter recharge period. Pumpage roughly equals the average yearly recharge from precipitation and water levels have not changed significantly since 1968.

Precipitation for the period 1960-1980 was slightly below average but would not singularly account for the observed declines in surface water discharge. Uncased wells in the watershed continually drain water from the Upper Zone. Although the amount of this leakage is relatively small, it may be contributing to the baseflow declines.

Acknowledgments

The author is indebted to Ted Olson, Jim Lyerla, and Cindy Christian of the WDOE Eastern Regional Office for their assistance with water-level monitoring, aquifer testing, and the assembling of water right information.

Bechtel Corp. geologists and Walter Loo of Tera Corp. supplied data and reports on the geohydrology of the Washington Water Power Creston Generating Station site in the upper watershed.

INTRODUCTION

Statement of the Problem

Local farmers believe that the flow of Sinking Creek in north-central Lincoln County has drastically decreased over the past 15 years. The decreasing flow of springs and creek water and declining lake levels is decreasing livestock drinking supplies and grass yields of naturally irrigated pasture in bottom lands. Ranchers with vested rights and claims to the surface water believe that ground water pumpage from large irrigation wells is causing the problem. The farmers furthermore correlate the first noticeable flow declines with the drilling of the first high-production (greater than 500 gpm) irrigation wells around 1968. Prior to this time, wells in and near the Sinking Creek watershed were relatively shallow, low-volume producers used for only small irrigated plots, livestock, and domestic supplies.

Scope of Study

This investigation was begun in 1978 at the request of the Washington State Department of Ecology (WDOE) Water Resource Management personnel in the Eastern Regional Office. The scope of this study was limited to gathering additional baseline data on stream flow, water levels in wells, and aquifer characteristics and to interpreting the general geologic and hydrologic processes of the study area.

REGIONAL HYDROLOGIC SETTING

Study Area Location

The study area includes the Sinking Creek watershed and portions of adjoining watersheds and occupies approximately 150 square miles in Townships 25 and 26 North, Ranges 32-35 East of east-central Washington (Figure 1). The towns of Creston and Wilbur are located along the northern edge of the study area.

Previous Studies

There are no previous publications concerning details of the ground water situation in the Sinking Creek watershed, although Luzier and Burt (1974) briefly discussed water-level records for a single well in the watershed (well 26/33-34P). For the period 1967-69, they correlated a 4-foot water-level drop in this well with increased ground water pumpage in the area south of Wilbur. The ground water withdrawals in the area had increased from 1,100 acre-feet in 1966 to 2,300 acre-feet in 1968.

Well logs and water level data were available from the U.S. Geological Survey (USGS), Tacoma, and from the Washington State Department of Ecology, Olympia and Spokane. USGS water-level measurements taken from 1966 to 1968 are among the most important data used in this investigation because they enable one to check whether ground water levels have declined in the 15 years since large irrigation wells were first drilled in the watershed.

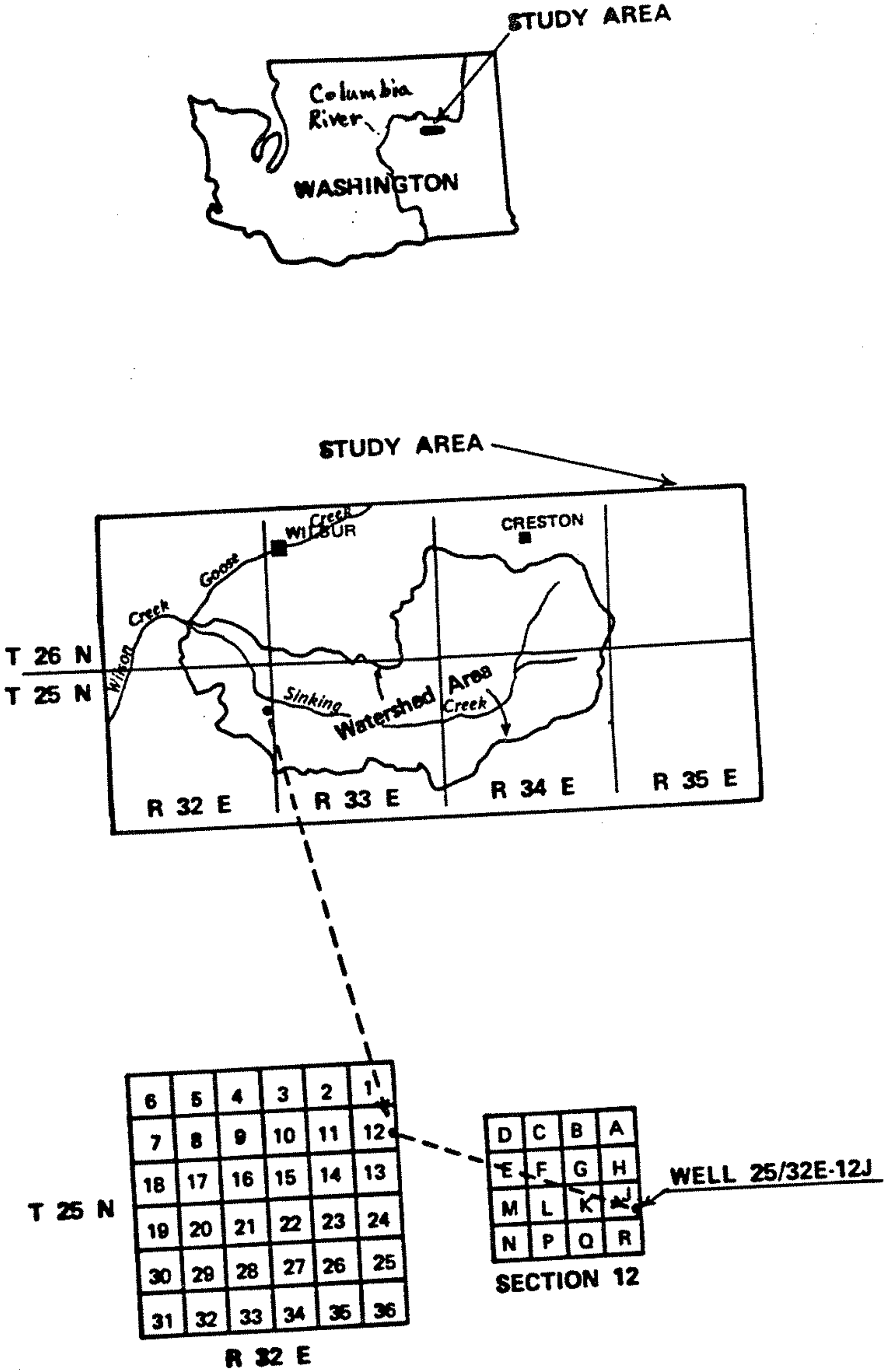


FIGURE 1 INDEX MAP OF STUDY AREA AND DIAGRAM SHOWIN[G] WELL NUMBERING SYSTEM.

A few miscellaneous streamflow measurements for Sinking Creek were available from the U.S. Geological Survey.

Topography and Drainage

The Sinking Creek watershed lies at the northern edge of the Columbia Plateau. Topography is generally low rolling hills forming uplands surrounding the narrow Sinking Creek valley. Except for Creston Butte, the land surface elevation ranges from 2,010 feet at the mouth of the creek to 2,465 in the upper watershed. Whereas the main Sinking Creek channel is cut into bedrock, the uplands are mantled by thick soils and drained by tributary valleys which are, in some cases, dissected to the bedrock. These tributary valleys carry water only during the spring snowmelt or after heavy rain storms. Sinking Creek, as indicated by its name, has perennial flow only along certain portions of its channel, usually at the mouth and along portions of its middle reaches. The reach between Greenwood Slough (T26N/R34E-27) and Marquette Spring (T25N/34E-4) flows only during the most severe flooding. The gaining and losing reaches of Sinking Creek are related to ground water levels, as will be discussed later.

Sinking Creek flows south and then west through a bedrock valley eroded during the tremendous glacial melt-water floods of the Pleistocene glacial epochs (Bretz, 1959). Sinking Creek joins Goose Creek to form Wilson Creek at the west end of the watershed (Figure 1). Surface waters northeast of the watershed flow northward to Franklin D. Roosevelt Lake on the Columbia River.

The southeast corner of the watershed is scabland, an area of thin soils and extensive bedrock exposures that was scoured by the glacial melt-water floods.

Occasional ponds with no outflow (potholes) occur in the scabland, in parts of the bottomland near the main channel, and on the uplands just north of the creek.

Geology and Soils

Plate 1 illustrates the general surficial geology of the study area. The uppermost bedrock area is basalt of the Columbia River Group. The basalt is comprised of an undetermined number of nearly horizontal flows which are in places separated by interflow zones of broken or weathered basalt and rarely sedimentary sand or gravel. Creston Butte, lying on the northern edge of the watershed, is a pre-Tertiary quartzite steptoe. Outcrops of Mesozoic granitic rocks are found on the northeast edge of the watershed. These intrusive rock types underlie the basalts at depths of a few feet (near outcrops) to perhaps several thousand feet. No wells have penetrated through the basalt to these basement rocks within the study area. Increased exposure of granitic rocks to the north also indicates that the basalt flows thin northward. Granite is exposed beneath the basalt along the banks of FDR Lake (eight miles north of Sinking Creek) where the basalt is only 800 feet thick.

Basalt is exposed along Sinking Creek on valley margins and only a few feet of stream-laid sediments (alluvium) cover the main valley floor. The adjoining scabland has thin soils, usually less than two feet in thickness, and numerous basalt exposures. The uplands have a surface soil of wind-blown silt, called loess, which forms rich cropland. Subsoils often include sand and gravel flood deposits. The upland soils range from a few feet to more than 90 feet in thickness, but are generally less than 20 feet thick.

GROUND WATER OCCURRENCE

Alluvial Aquifers

Shallow excavations and test drilling in the upper watershed by Bechtel Corporation and Tera Corporation for the proposed Washington Water Power electric generating station, together with numerous logs of wells throughout the watershed (WDOE files), reveal that ground water is rarely encountered in deposits overlying the basalt, except in the thin alluvium along Sinking Creek. Infiltrating water apparently does not accumulate in the basalt rubble on top of the uppermost flow but seeps through one or more interflow zones before accumulating in quantities necessary for well production.

Basalt Aquifers - Description and Correlation

In the valley walls along Sinking Creek, one can see the basalt layers extending nearly horizontally for a mile or more. This is similar to exposures in other parts of the Columbia Plateau, such as Grand Coulee, Banks Lake, and Moses Coulee where the individual basalt flows can be seen for many miles along canyon walls and where individual flows have been mapped over areas of several hundred square miles. The basalt layers dip gently to the southwest at an angle of 1 or 2 degrees. Sinking Creek cuts through successively deeper and older basalt layers as it flows down the valley so the stream channel gradient is somewhat steeper than the dip of the basalts. The more resistant basalt layers occasionally form a stairstep arrangement along the valley floor, causing the stream gradient to flatten to the angle of dip of the basalt flow and then to steepen rapidly as the stream descends over the downstream edge of the flow.

The contact zones between basalt flows (interflow zones) contain highly fractured basalt or basalt rubble, sometimes partially weathered to clay. The unweathered interflow zones tend to be very permeable and act as the principal reservoir and conduit (aquifers*) for ground waters. The weathered interflow zones contain clay which fills the fractures and drastically reduces permeability.

*Note: Throughout this report the term "aquifer" will be used to represent any water-bearing zone, even if the zone does not yield significant amounts of water to a well.

The interior of each flow tends to be massive with fewer vertical and horizontal fractures than in the interflow zones. Thus, the interior portions of the basalt flows store considerably less water than the interflow zones but nonetheless slow seepage occurs through the widely spaced fractures. At depths of several thousand feet, these fractures tend to close due to the weight of rock above, with the result that ground water movement is increasingly impeded.

Identification of individual flows from borehole samples is generally not possible because the basalt is quite homogeneous. Fortunately, geophysical logging conducted by lowering remote sensing "tools" such as calipers, flow meters, thermometers, and gamma and neutron radiation recorders into boreholes has made identification of certain groups of basalt flows possible with interpretive techniques developed in the last 15 years. Only two wells have been geophysically logged within the study area but these provided useful information when compared with geophysical logs for many other wells throughout the northern Columbia Plateau.

The uppermost basalt in the study area has been identified from outcrop samples as the Priest Rapids member of the Wanapum Basalt Formation (Miocene age, approximately 14 million years old; Swanson _et_ _al_., 1979). The geophysical logs from well 25/33-7B1 indicate the top of the Grande Ronde Formation (Miocene, approximately 15 million years old) at a depth of 180 feet (Brown, 1978) below the surface.

Hydrostatic Head Relationships

Water levels in wells represent the hydrostatic head in one or more aquifers. Wells open to several aquifers will have a composite head that is at some level between the highest and lowest head of the individual aquifers. Water flows up or down the borehole toward the lowest head and the flow can be detected with a down-hole flow meter.

Hydrostatic head usually decreases with depth in the Columbia Plateau basalts. That is, the heads are highest in the shallowest aquifer and become lower in the deeper aquifers (Luzier and Burt, 1974). Because heads commonly are lower in the deeper aquifers, downhole flow generally occurs in the uncased wells of the study area. In situations where the head of the lower aquifers is at an elevation below the overlying aquifers, water will cascade down the open well bore and this flow often can be heard at the well head.

Three basalt aquifer zones were identified in the study area. Each aquifer zone consists of several aquifers which have the same or similar hydrostatic heads. The zones were distinguished by constructing detailed hydrogeologic cross-sections. Correlation of water levels for the zones was based on the water level elevation and the elevation at the bottom of the well. Water level elevations for most of the known wells in the study area and the map locations of hydrogeologic cross-sections are plotted on Plate 2. The hydrogeologic cross-sections illustrated on Plate 3 show the relative positions of the three aquifer zones.

In the Sinking Creek area, well records show very similar hydrostatic heads in the uppermost two or three basalt aquifers. This group of aquifers will be referred to as the Upper Zone. Wells completed in the

Upper Zone usually produce less than 100 gpm but may produce up to 300 gpm. Specific capacities range from 0.6 to 14 gpm per foot of drawdown (Appendix I).

Below the Upper Zone the next few basalt aquifers have a head approximately 50 feet lower than in the Upper Zone and have generally higher production (275 to 2600 gpm). This group of aquifers will be referred to as the Middle Zone. This zone is the principal source of water for most of the large diameter wells (12 inches or more) drilled since 1968. Specific capacities range from 2 to 54 gpm per foot of drawdown (Appendix I).

Several hundred feet below the top of the Middle Zone another basalt aquifer zone is encountered with an additional head drop of approximately 100 feet. This will be referred to as the Lower Zone. Only ten wells have been drilled to this zone in the study area. Production ranges from 350 to 2600 gpm and specific capacities range from 1.3 to 103 gpm per foot of drawdown (Appendix I).

The Upper Zone may correspond stratigraphically to the Wanapum Formation, whereas the Middle and Lower Zones may correspond to the Grande Ronde Formation. However, additional geophysical logging and chemical analysis will be needed to substantiate this correlation.

Previous hydrologic studies of the Columbia River basalts in Washington have recognized the importance of geologic materials and structure to the movement of ground water in the layered volcanic sequences. That is, the thickness, aereal extent and permeability characteristics of both the basalt flows and the intervening weathered horizons control the vertical and horizontal movement of ground water. Studies by Luzier and Burt (1974), MacNish and Barker (1976), Brown (1978, 1980, 1981) and Barker (1979) have all identified at least two aquifer groups or zones characterized by significant hydrostatic head changes with depth between the zones. According to Barker (1979, p. 20):

> "The shallower aquifers [in the Pullman-Moscow basin] are cut locally by canyons or other surface depressions so that their areal extent is limited and they are not generally connected to significant sources of lateral recharge. The deeper aquifers are generally continuous areally over greater distances than are the shallower aquifers and are usually the more productive. These deeper aquifers typically comprise the regional flow system;..."

Brown (1980) has recognized similarities in the hydrologic characteristics of the basalt flows in diverse and widely separated study areas throughout the Columbia River Plateau region. In each area he found only one major head change with depth in the various sequences of basalt flows. He interpreted this to indicate that basalt flows are not impermeable and that individual flows do not behave as isolated aquifers as earlier investigators had thought. He further explained the sudden head change between the two aquifer zones as follows (Brown, 1980, p. 16):

"The apparent importance of the Vantage interbed in the Pullman and Central Basin areas and the Mabton interbed in the Horse Heaven Hills area in controlling head changes indicates that these interbeds, perhaps in combination with the basalt flow immediately underlying, are responsible for significant vertical head loss rather than the basalt flows themselves."

Brown (1978; 1981) has also noted that the uppermost basalt aquifer zone has some characteristics of an unconfined aquifer wherein the potentiometric surface more-or-less mirrors the land surface. This occurs because higher elevations act as recharge areas while lower elevations along streams are discharge areas. The hydraulic head of the Upper Zone and possibly the Middle Zone, in the Sinking Creek area also follows this pattern. In addition, the storage capacity of these aquifers is somewhat larger than usually found in confined aquifers.

The hydrologic data from the basalts in the Sinking Creek area generally fit within Brown's framework of interpretation. However, well logs for the Sinking Creek area do not show continuous sedimentary or weathered basalt layers at depths corresponding to the head changes between the three identified aquifer zones. Such layers are rarely listed by drillers because they are often less than 10 feet thick and may be missed during routine sampling. Considering the proximity of the study area to the Odessa-Lind and Grand Coulee areas where the interbeds have been found, it seems reasonable to assume that the interbeds are also present in the Sinking Creek area.

An obvious difference between the Sinking Creek area and those studied by Brown is that three rather than two aquifer zones were found in the former. It may be that the Upper and Middle Zones of Sinking Creek are equivalent to the "upper zone" in other areas. On the other hand, Brown (1980) found downhole flow in one well located deep in his "lower zone" in the Odessa-Lind area and this may have indicated a third aquifer zone deep in the Grande Ronde formation as seems to be the case at Sinking Creek.

Elevation contours for the top of the Middle Zone (Plate 4), were drawn using the geohydrologic cross-sections and water level data. The contours show the approximate elevations at which the first major head change occurs and could be used as an estimate of the depth of drilling required to obtain high yields. The top of the Middle Zone may also correspond stratigraphically to the base of the uppermost basalt flows of the Grande Ronde Formation.

Ground Water Movement

The potentiometric map (Plate 5) for the Middle Zone aquifers illustrates the regional hydraulic gradient and direction of ground water flow. The potentiometric surface represents the change in hydrostatic head across the aquifer. Data points shown on the map were hydrostatic water levels (heads) for wells assigned to the Middle Zone during the hydrogeologic cross-section interpretations. Most of these wells are not cased through the Upper Zone and may have composite heads representing some level between the Upper Zone and Middle Zone heads. However, it is believed that the heads are only slightly higher in elevation than the true Middle Zone heads. Ground water flow is at right angles to the contours, toward lower head contours.

Several hydrologic studies of the Columbia Plateau basalt aquifers (Luzier and Burt, 1974; Garrett, 1968; Brown, 1980) have found that regional movement of ground water in the northern Columbia Plateau area is generally toward the lower elevations to the southwest. The generalized map of ground water levels (Plate 5) in wells of the Sinking Creek watershed also indicates southwestward regional flow.

The regional ground water flow in the Middle Zone of the study area is somewhat independent of watershed boundaries and may be in a distinctly different direction than the principal surface drainage. The direction of ground water flow in the Upper Zone is probably toward the nearest surface drainage, either a tributary valley or the main Sinking Creek valley.

GROUND WATER DISCHARGE TO STREAMS

General Observations

The most obvious source of ground water outflow to Sinking Creek is from the water table in the alluvium of the main valley. Ground water is stored in the alluvium during rain storms and spring snow melt. This ground water discharges to the creek so long as the water table is above the creek level. The Upper and Middle Zone basalt aquifers also contribute water to the creek through several springs. This ground water moves to the springs through portions of the interflow zones, which are more highly fractured, whenever the hydrostatic head in the basalt is higher than the elevation of the spring. Perennially or seasonally dry reaches of the creek bed (thus the name Sinking Creek) are at elevations above the water levels in both the basalt aquifer zones and the alluvium, and hence receive no ground water discharge. The dry reaches occur where erosion resistant basalt flows form ledges, 5 to 15 feet high, across the valley floor and channel. For several thousand feet upstream from the ledge the stream gradient is quite flat, corresponding to the dip of the upper surface of the basalt flow. The creek disappears midway through the low gradient reach and then reemerges as a large spring at the base of the ledge. In most instances, this occurs seasonally (approximately May to November) during low flow conditions. However, the reach extending approximately one mile above Marquette Spring (25N/34E-9B; see Plate 1) is almost perennially dry with flows only during major flooding. Most of the other springs along Sinking Creek occur at some distance from the channel, unusually near the edge of the valley but not necessarily at the base of small cliffs or ledges. A few springs occur in the tributary valleys but none of these flow during the summer and fall. Throughout the length of Sinking Creek, springs appear to be the principal source of ground water from the basalt. Slow seepage from basalt into the alluvium along reaches between springs does not add much water to the creek.

Except during periods of heavy rain or snowmelt runoff, ground water flow from springs is the only source of water for the creek. This ground water baseflow maintains the creek during the dry season from approximately June through October. Disruption of this baseflow is apparently causing the creek to dry up.

Discharge from Alluvium and Upper and Middle Zone Basalt Aquifers

Direct precipitation, runoff from tributary valleys, and ground water from the basalt aquifers recharges the ground water in the valley alluvium. This ground water storage is depleted by late spring or early summer and creek flow decreases rapidly. Thereafter creek flow depends principally on the baseflow contributed through springs from the Upper and Middle Zone basalt aquifers.

Ground water storage in the basalt aquifers varies both seasonally and yearly as evidenced by fluctuating water levels in wells. After several years of low precipitation, ground water storage and creek flow derived from these sources are also decreased.

The geohydrologic cross-sections (Plate 3) show that the Upper Zone water levels are usually above the creek channel elevation throughout the watershed. Conversely, the water levels for the Middle Zone are usually below the creek channel elevation except along the central reaches of the creek in T25N/R34E - Sections 8, 17, and 18 and T25N/R33E - Section 13, where several large springs occur (see cross-section A-A' on Plate 3). In this area the hydrostatic head of the Middle Zone is higher than the head in the Upper Zone.

The owner of two springs in the aforementioned area reported that he first noticed diminished flow from the springs in 1978. The smaller of the two springs, 25/34-18Rs, is at present only a trickle during the spring but the owner reported that it once maintained Baring Lake, 25/34-17E, a shallow lake with an outlet to Sinking Creek. (See cross-sections A-A' and B-B', Plate 3). The second spring, 25/34-8Ns, produces enough water (several cfs) to form a significant tributary to the creek. In 1978, and again in 1980, this large spring ceased flowing by midsummer, while during 1979, 1981, and 1982 the flow declined substantially.

The water level in an excavated sump at the larger spring, 25/34-8Ns, was monitored during two irrigation seasons (1980 and 1981). A Stevens Type A continuous water-level recorder and staff gage were installed to measure water level fluctuations at the spring (Figure 2). Although the recorded water-level fluctuations were very slight (a few hundredths of a foot), there was a very definite correlation with water-level fluctuations in the Houger abandoned well 25/34-9F, also equipped with a continuous recorder. The well fluctuations, in turn, were directly related to irrigation pumping in Houger well 25/33 -2G; that is, when the irrigation well was pumped the water-level in the recorder-equipped observation well would begin to decline within less than one-half hour and would continue to decline as long as the pumping continued. Conversely, when the irrigation pump stopped, the observation well water-level would begin rising in less than one-half hour. The correlation of the observation well and irrigation well was established during an aquifer test (described later in this report). Thus, the water-level fluctuation in the spring may also be correlated with the starting and stopping of the pump in Houger well 25/33-2G. Figure 2 illustrates the correlation between the spring water level records, the observation well water level records, and the pumping of the irrigation well. Each July the irrigation well was shut off for two or three weeks during alfalfa harvest and the

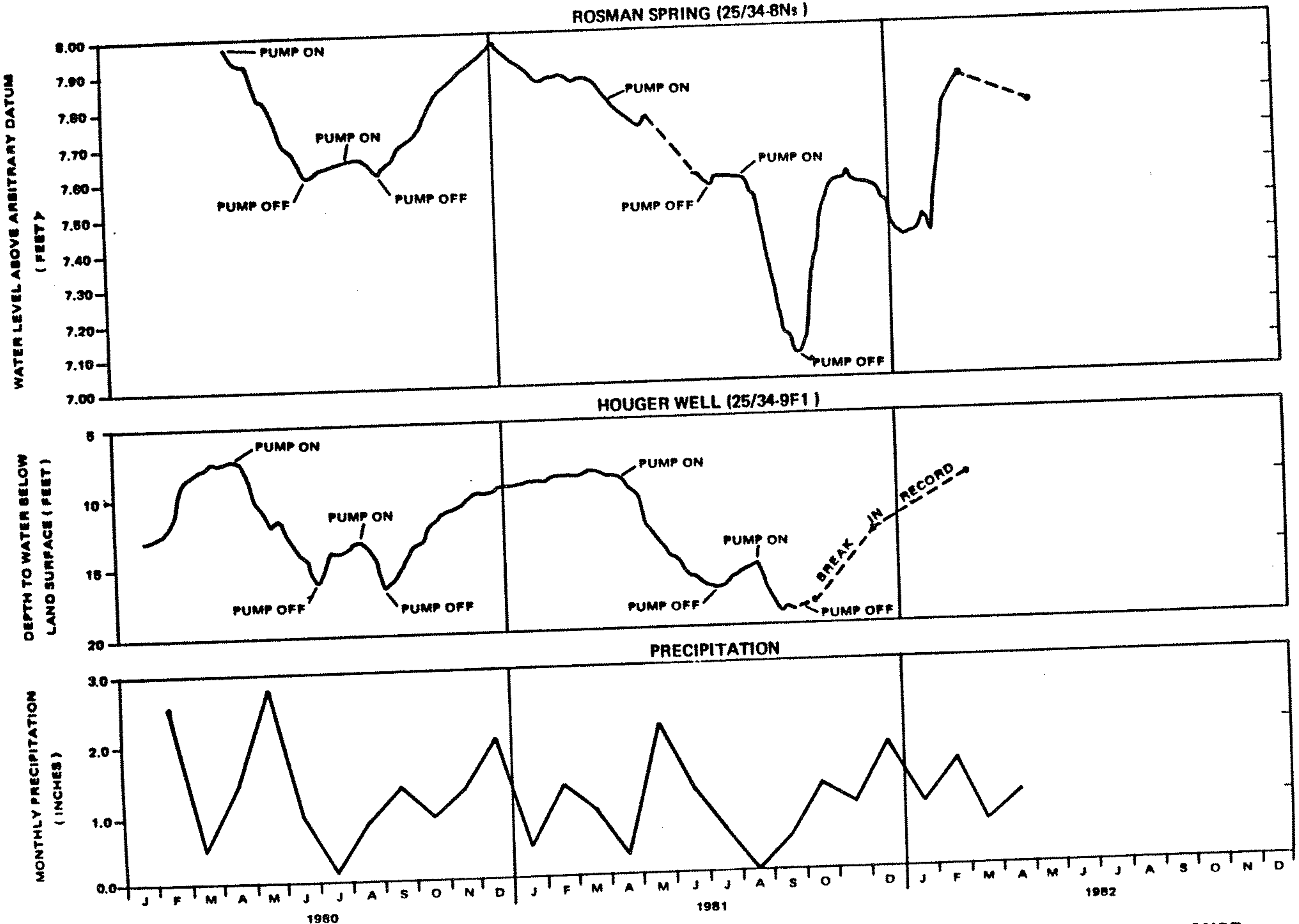


FIGURE 2. HYDROGRAPHS OF HOUGER WELL, 25/34-9F1, AND ROSMAN SPRING, 25/34-8Ns, SHOWING CORRESPONDENCE OF WATER LEVEL CHANGES TOGETHER WITH MONTHLY PRECIPITATION, FOR WILBUR.

water-levels rose at the spring and in the observation well. In early August the irrigation pumping resumed and water levels immediately declined. Then in late September, the irrigation pumping ceased for the year and water levels again rose. These water-level fluctuations were not related to ground water recharge from summer rain during those years and do not correlate well with monthly precipitation totals.

The other large irrigation wells in the study area are used for growing wheat and are pumped on a different schedule than the Houger irrigation well which is used for growing alfalfa. These wheat farm wells are generally shut off in early July and do not resume pumping until late August. Therefore, no other irrigation well pumping schedule can be correlated with the spring's water-level fluctuations.

Hydrogeologic cross-section A-A' on plate 3 illustrates a possible explanation for the spring's response to pumping from the Middle Zone. The water must be rising along a narrow fracture zone which passes through both springs and cuts vertically across several Upper Zone basalt flows to a depth of at least 200 feet where it intersects the uppermost Middle Zone aquifer. Based upon horizontal projection of the Middle Zone hydrostatic head from Houger irrigation well 25/34-2G through Houger observation well 25/34/-9F and then westward to the area of the spring, the hydrostatic head could be expected to extend above ground surface at the spring. The Upper Zone hydrostatic head, as measured in Dreger well 25/33-18F, located near the spring, is not above ground surface. Thus, only a highly permeable hydraulic connection such as a linear fracture zone between the land surface and the Middle Zone aquifers could explain the behavior of the two springs. This fracture zone would also explain why several other springs in the immediate vicinity (see Plate 2) have not been affected by pumping. The large Blenz Spring, 25/33-13Ms, in particular, has not been affected according to the owner. These unaffected springs must be fed entirely from the Upper Zone and alluvial aquifers.

Further evidence for a linear fracture zone was found on a photolineament map (Plate II-24 in Sandness et al., 1979). The map shows a two-mile long lineament oriented NNE to SSW and passing precisely through the two affected springs (see Plate 1). The lineament was located with a U-2 type, high-altitude air-photo. Photolineaments are caused by a variety of features on the earth's surface but in this case the occurrence of a fracture zone is strongly supported by the hydrologic evidence.

Aside from the two springs discussed above, no others have been found which have a direct hydraulic connection with the Middle Zone aquifers. The hydrogeologic cross-sections (Plate 3) show no other area where the Middle Zone hydrostatic head projects above ground surface. Therefore, all the other springs along Sinking Creek are assumed to be fed by the Upper Zone aquifer. For instance, Marquette Spring, 25/34-4Rs, appears to be a reemergence of water that disappears into the channel bed just downstream from Greenwood Slough at the south end of Section 34 (T26N/R34E). The owner of another spring, 25/34-11Gs, believes that irrigation pumping has directly decreased the flow from the spring. However, the Middle Zone head in that area is not high enough to reach ground surface. Furthermore, an aquifer test (described later in this report) of Houger well 25/34-2G also demonstrated that there is no direct effect on the spring due to irrigation pumpage from the Middle Zone.

Sinking Creek Flow Records

There are no continuous records of streamflow in Sinking Creek available to establish a correlation between stream flow and precipitation and to accurately record the decrease in baseflow. A staff gage for measuring streamflow is now being established by the U.S. Geological Survey and monthly measurements are in progress.

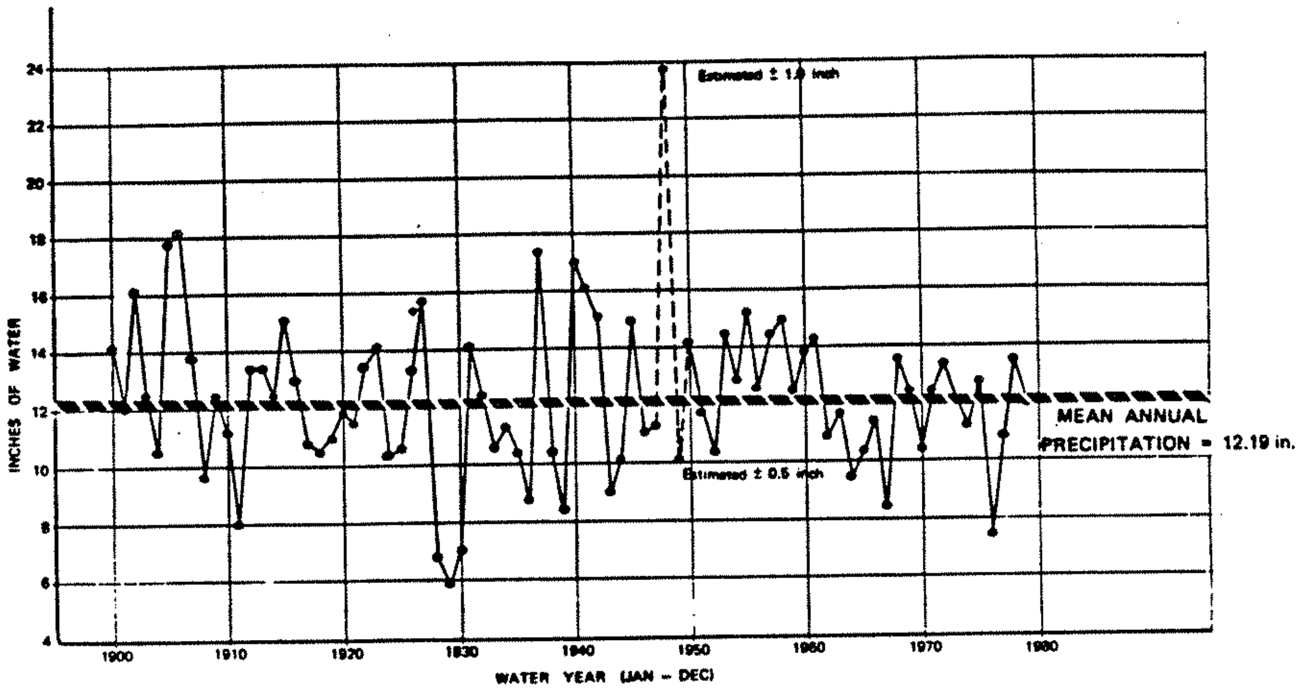
In spite of this lack of flow data, there appears to be a consensus among local residents, many with no economic interest in the creek, that Sinking Creek no longer flows like it used to. Some of the residents recall catching native trout which could only have survived if the flow continued all year. Monthly measurements in 1981 and 1982 found no flow from July through October in 1981 and no flow after early June in 1982, except in the vicinity of the largest springs.

PRECIPITATION, EVAPOTRANSPIRATION, AND RECHARGE PROCESSES

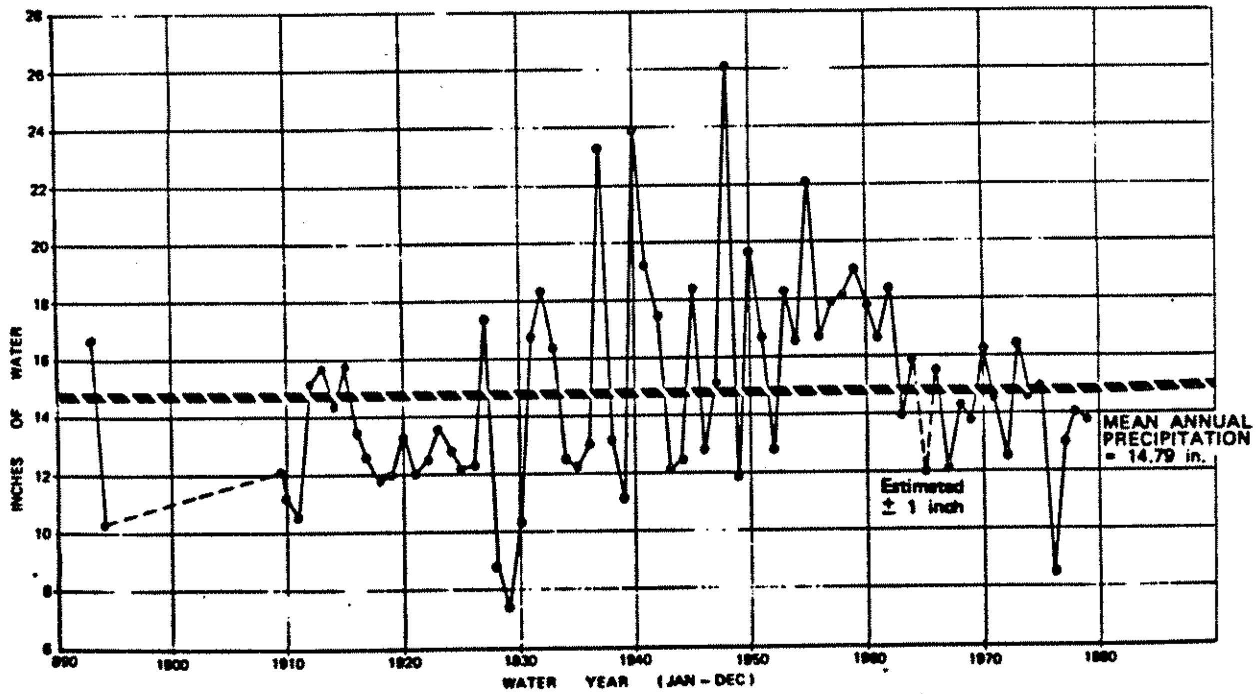
There are two permanent weather stations near the study area, one in Wilbur and one in Davenport (Figure 1). Precipitation data for the Wilbur station from 1900 to 1981 and for the Davenport station from 1893 to 1894 and 1909 to 1981 are presented in Figure 3. These data are also tabulated in Appendix II. The two stations show similar patterns in yearly precipitation although Davenport averages 2.6 inches higher per year (14.79 inches at Davenport versus 12.19 inches at Wilbur). Since 1962, precipitation at Wilbur has averaged 7 percent below the 81-year mean and 16 percent below the previous 20 years (1942-1961). At Davenport, the precipitation since 1962 has averaged 4 percent below the 75-year mean and 17 percent below the previous 20 years. However, the 20-year period from 1917 to 1936 had 10 percent below average precipitation at Wilbur and 13 percent below average precipitation at Davenport. Local farmers claim there was no streamflow problem during those years, but there are no streamflow records to verify this claim.

Figures 4 and 5 depict the average monthly precipitation and calculated evapotranspiration (evaporation due to wind and heat and transpiration by plants) for the Wilbur and Davenport weather stations (Washington State University, 1965). Actual evapotranspiration is shown for soils with two inches and six inches of water holding capacity in the root zone. This is the probable range of soil moisture storage capacities in the study area. Actual evapotranspiration occurs at the "potential" rate so long as the water losses are immediately replenished by precipitation or capillary moisture movement at both the topsoil surface and around plant roots. Actual evapotranspiration falls below the "potential" rate when the moisture replenishment rate can no longer replace the losses as fast as they occur. The actual evapotranspiration rate falls farther and farther below the "potential" rate as the season progresses and soil moisture storage is depleted. Actual evapotranspiration is much less in the soil with the lower moisture storage capacity.

Figures 4 and 5 also show that most of the precipitation in the study area occurs from October through June. Once the rain or snowmelt replenishes soil moisture lost to evapotranspiration (highest during the growing season) and the soil profile is saturated, any additional rainfall



Wilbur, Wa. *YEARLY PRECIPITATION 1900-1979*



Davenport, Wa. *YEARLY PRECIPITATION 1893-94, 1909-79*

FIGURE 3

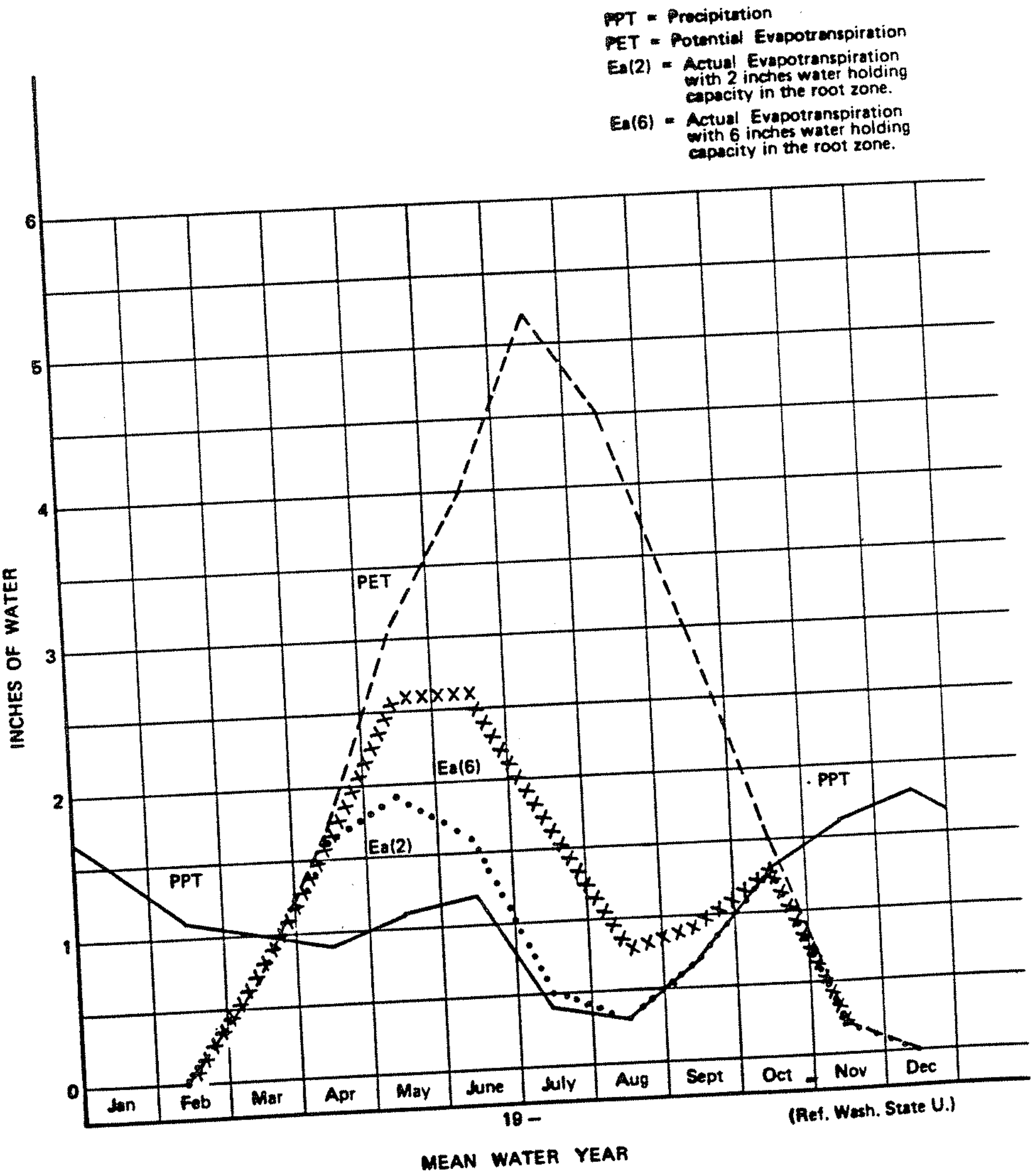


FIGURE 4. Wilbur – Annual Water Budget

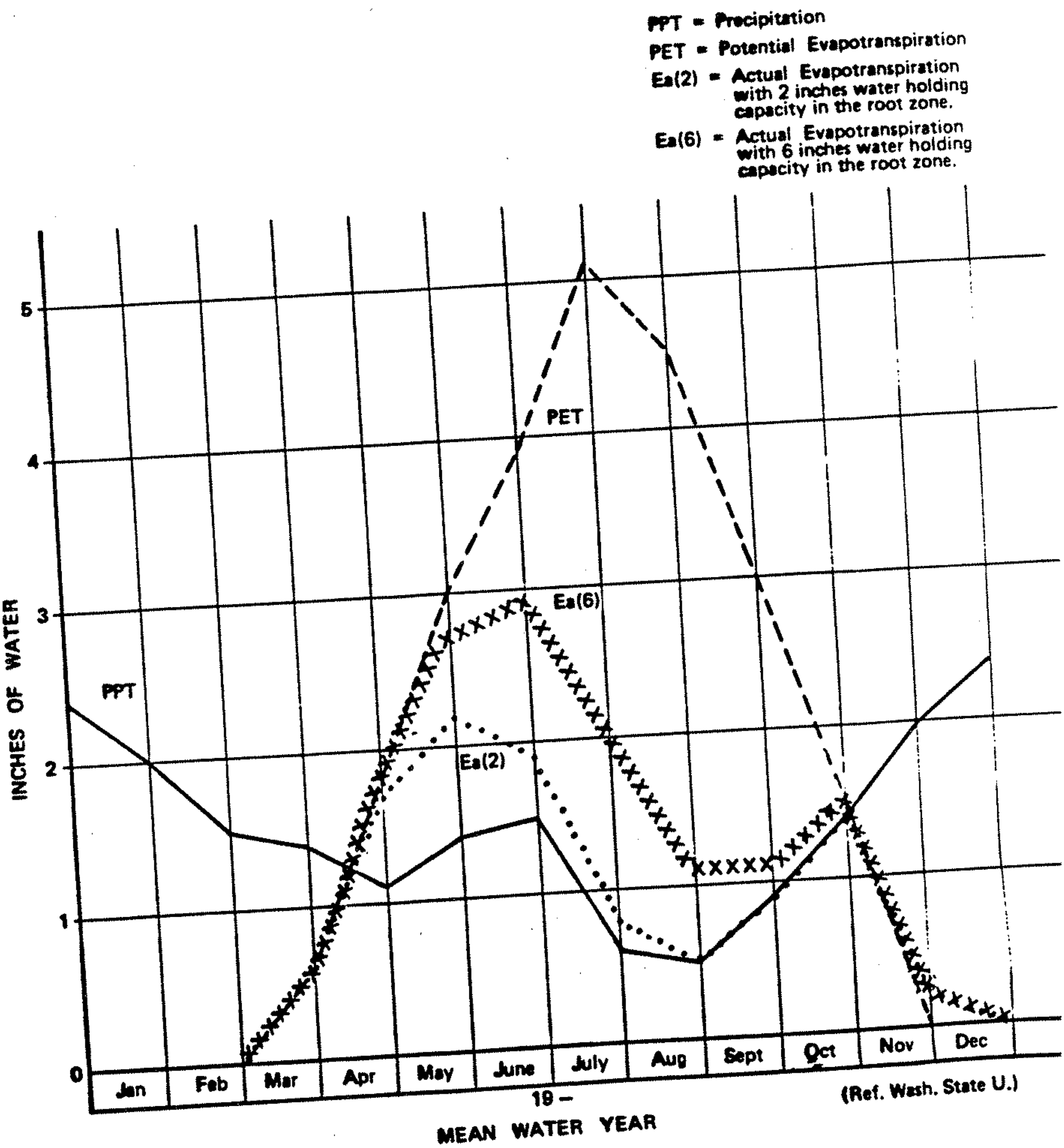


FIGURE 5. Davenport – Annual Water Budget

or snowmelt will pass through the soil and recharge the aquifers. Therefore, recharge is more likely to occur from November through March, when average precipitation exceeds average actual evapotranspiration. For a given amount of precipitation more recharge will occur under the soil which stores only two inches of water than under the soil storing six inches of water because less is captured and retained.

Basalt aquifers in the study area are recharged primarily in the scablands, in the Sinking Creek valley, and in tributary valleys. In these areas, the basalt is at or within a few feet of the surface and soil moisture storage is low. The upland areas with thicker soils rarely generate recharge. This has been documented by Stephenson and Zuzel (1981) in a study of a similar geologic and climatic setting in southwest Idaho. They found that the amount of recharge from a given amount of precipitation was dependent upon soil depth. Areas of basalt outcrop generated recharge from all storms; whereas, in areas of soil cover, as the soil depth increased, progressively greater amounts of rainfall in an individual storm were required to generate recharge.

Evidence of recharge in the Sinking Creek area is found in the well hydrographs (Figures 7 to 16). A few of the hydrographs which were not affected by irrigation pumping show a cycle of rising water levels from approximately November to April, due to recharge, followed by decline from approximately May through October, when precipitation and recharge is less likely. This demonstrates that water levels (and water storage) in the Upper and Middle Zones respond to the seasonal variations in recharge from precipitation.

The hydrographs also demonstrate the effects of year-to-year variations in precipitation. For instance, rainfall in 1980 was 1/3 greater than in 1979 and the water level in Nelson well 25/34-11G (Figure 12) dropped to 17.9 feet at its lowest point in 1979, but only dropped to 12.6 feet in 1980. This suggests that the below-average rainfall for the period 1962-1979 is possibly a factor in decreasing the base flow of Sinking Creek.

GROUND WATER IRRIGATION

Ground Water Pumpage

Figure 6 illustrates the estimated yearly increase in ground water pumpage for the study area. This includes all irrigation wells within approximately two miles of the Sinking Creek watershed, an area of approximately 96,000 acres (150 square miles). Major development of well irrigation started in 1968. These large wells draw water principally from the Middle and Lower Zones, although many have not been cased entirely through the Upper Zone. Estimates of actual pumpage were based on comparisons with irrigated acreage served by each well according to a relationship developed by H.H. Tanaka (personal communication) for the nearby Odessa area.

Total estimated pumpage in 1979 was 15,000 acre-feet/year or 54 percent of permitted pumpage allotted by State of Washington permits or certifi-

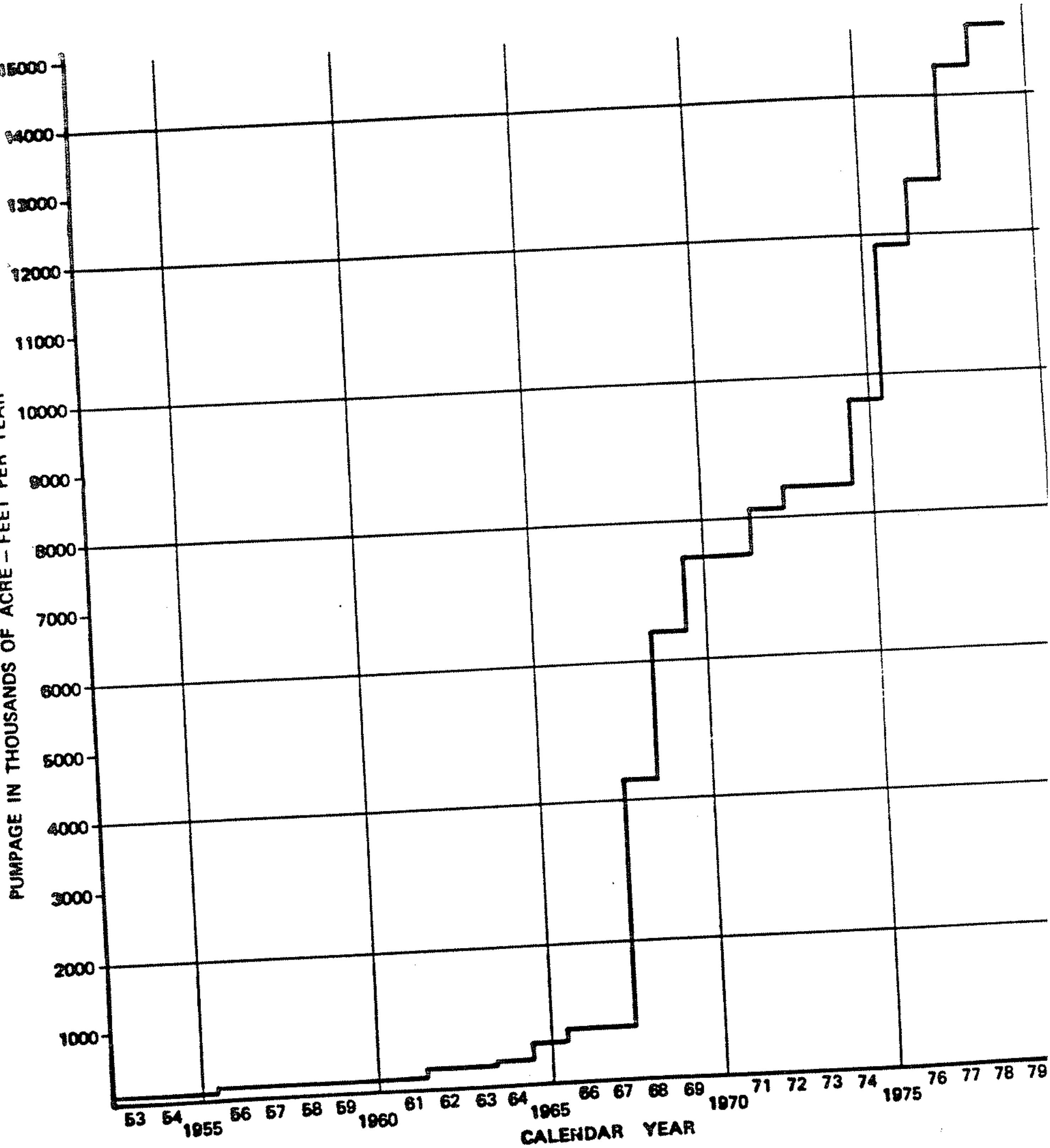


FIGURE 6 Annual Pumpage of Ground Water 1953 - 1980
Sinking Creek Watershed

cates for the irrigation wells. This estimated pumpage averaged over all the acreage of the study area is equivalent to 0.16 feet or 1.9 inches of water. Thus the pumpage amounts to 15 percent of the estimated average precipitation of 13 inches per year for the study area. Natural recharge in the Quincy Basin, approximately 50 miles southwest of Sinking Creek, was estimated by Tanaka et al. (1974) to be approximately one inch per year. Precipitation is approximately 60 percent higher in the Sinking Creek area than in the Quincy area (13 inches versus 8 inches) so that recharge at Sinking Creek may be correspondingly higher. Recharge in the study area may, therefore, be estimated at approximately 1.6 inches per year. Thus, the estimated irrigation pumpage of 1.9 inches per year only slightly exceeds the natural recharge. Taking account of the possible inaccuracies in both estimates it would appear that pumpage does not greatly exceed natural recharge. Therefore, significant water level declines would not be expected in the basalt aquifers due to irrigation pumpage.

Records of Water Levels In Wells

Water level records from previous surveys were available for many wells throughout the study area. Most of these measurements were made during the period 1965-1969. These were supplemented by measurements taken during the present study from 1978 through 1981. Despite the relatively large amount of irrigation pumpage, a careful examination of the successive water-level measurements for the best documented wells in the study area does not indicate steadily declining heads as was suggested in an earlier report (Luzier and Burt, 1974). Hydrographs (Figures 7 to 16) for these wells do not show a downward trend in water levels. Although water levels in certain wells seemed to show a gradual decline during the first few years of measurements, readings taken in recent years indicate that water levels have not appreciably changed since the mid 1960s.

Water levels measured from January through April are the most useful for detecting long-term declines because this period is least affected by pumping. Water levels have mostly recovered from early fall pumping effects by January and recharge from snowmelt and winter rains is largely complete by April.

Spring pumping begins either in late April or May, so early April water levels are closest to natural of any month, given the four- or five-month recovery from the previous fall pumping. The detailed discussions of the individual hydrographs which follow are pertinent to depletion of streamflow because the wells are open to the Upper Zone which supplies base flow to Sinking Creek.

Well 25/32-12J1: (Figure 7) Depth: 165 feet. Owner: C. Wagner. This well is finished in the Upper Zone. Recent measurements show that the water levels in May 1982 are equal to the original water level taken in April of 1954. Thus, there has been no long-term depletion. Pumping in nearby Middle Zone wells appears to cause a large amount of seasonal drawdown in this well but complete recovery occurs each winter.

Well 25/33-5C1: (Figure 8) Depth: 270 feet. Owner: W.F. Dreger. This well is finished in the Upper Zone. Measurements in early 1981 show that some long-term depletion may have occurred but the decline is only 2 or 3 feet. Measurements in early 1982 reflect late winter pumping which did not allow the well to fully recover as in 1981. It is not known whether this well is affected by pumping from the Middle Zone.

Well 25/34-2G1: (Figure 9) Depth: 320 feet. Owner: M. Houger. This well is open to both the Upper and Middle Zones, with the major production from the Middle Zone. The water level is a composite head for the two zones. March and April measurements show only two feet of decline from 1967 to 1980. Although the spring 1982 measurements did not show complete recovery there is little likelihood of long-term decline because the quantity of water pumped has not changed. This was the pumping well for the Houger aquifer test described later in this report.

Well 25/34-7N: (Figure 10) Depth: 200 feet. Owner: W.F. Dreger. This well is finished in the Upper Zone. Recent measurements show that the water level in May is one foot above the original water level measured in October 1967. There has been no long-term depletion.

Well 25/34-9F1: (Figure 11) Depth: 211 feet. Owner: M. Houger (former owner, O. Mangis). Information on the well's construction is limited, but the Houger aquifer test indicates penetration into the Middle Zone. The hole also may be open to the Upper Zone. This is the best-documented well in the watershed, with nearly continuous water-level recordings since May 1978, in addition to bimonthly measurements from 1967 through 1970. April 1980 water levels were one foot higher than in April 1968. Long-term decline is ruled out. Continuous recording still is in progress.

Well 25/34-11G: (Figure 12) Depth: 80 feet. Owner: C. Nelson. This well is open to the uppermost aquifer in the Upper Zone. Recent measurements show the water levels in the spring season are approximately equal to the water level when the well was drilled (original water level reported by owner, no WDOE measurements prior to 1979).

Well 25/34-29C1: (Figure 13) Depth: 96 feet. Owner. E.F. Dreger. This is a low-production stock well completed in the Upper Zone. The summer 1980 levels were two feet higher than in 1967, ruling out long-term depletion.

Well 25/34-30K1: (Figure 14) Depth: 266 feet. Owner: E.F. Dreger. This well is open to both the Upper and Middle Zones. April 1982 measurements were at or above 1969 levels. Long-term decline is ruled out.

Well 25/34-30K2: (Figure 15) Depth: 560 feet. Owner: E.F. Dreger. This well lies 50 feet from and is twice as deep as well 30K1. The well is open to both the Upper and Middle Zones. All measurements were made at the same time as for Well 30K1. Measurements in 1982 were 10 to 15 feet higher than in 1967.

Well 26/33-34P1: (Figure 16) Depth: 450 feet. Owner: R. Dreger. This well is open to both the Upper and Middle Zones. A measurement in February 1977 was approximately the same as the water level in the springs of 1967 and 1968. Thus, there was no change for 10 years. Although water levels from 1978 through 1981 appear to be declining, the measurements were all taken after early spring pumping and so do not reflect the true hydrostatic water level.

Water-level data are available for many additional wells, but the measurements were too sporadic to permit analysis of possible aquifer depletion. Average water levels for all wells are listed in Appendix I. Although the present analysis of well hydrographs does not indicate aquifer depletion, we believe it could occur in the Middle or Lower Zones, as has occurred in the Odessa area located 20 miles to the south, if pumping were to increase substantially.

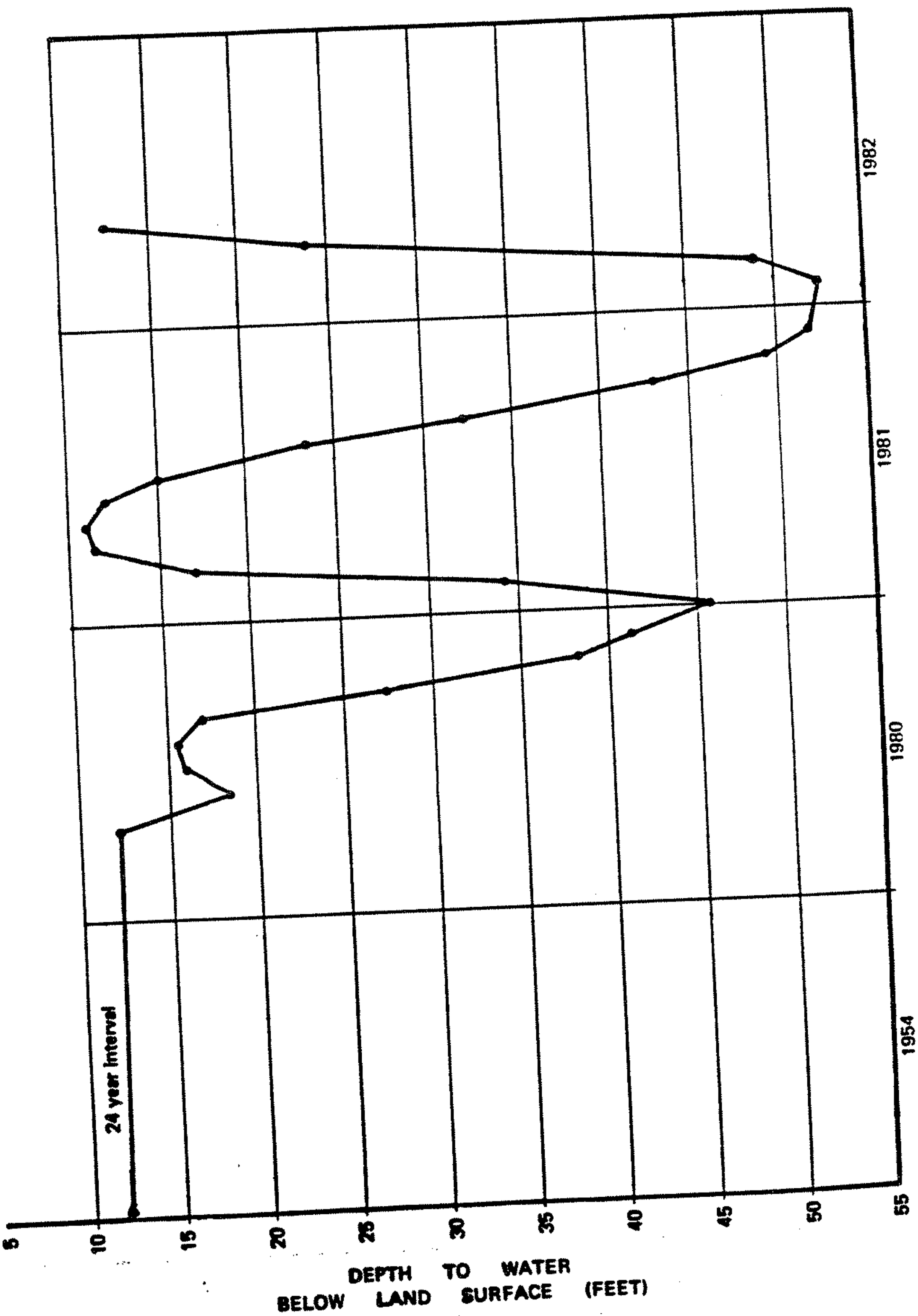


FIGURE 7

25N/32E - 12J1 C. WAGNER', DEPTH: 165', UPPER ZONE

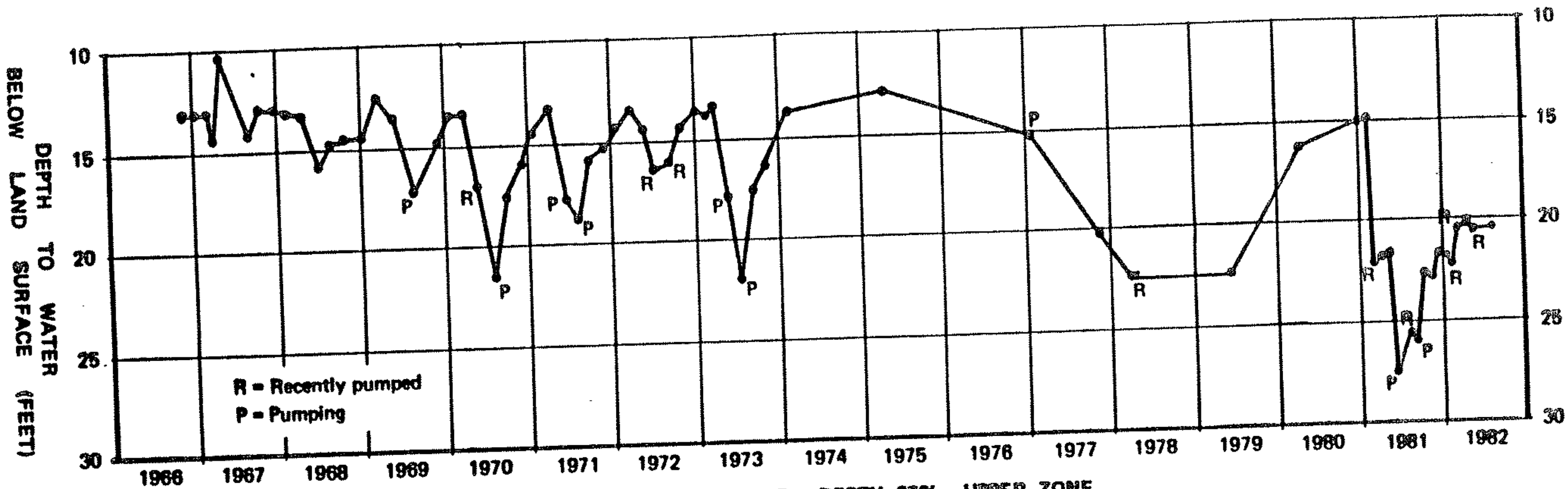


FIGURE 8 25N/33E - 5C1 W. F. DREGER DEPTH: 270' UPPER ZONE

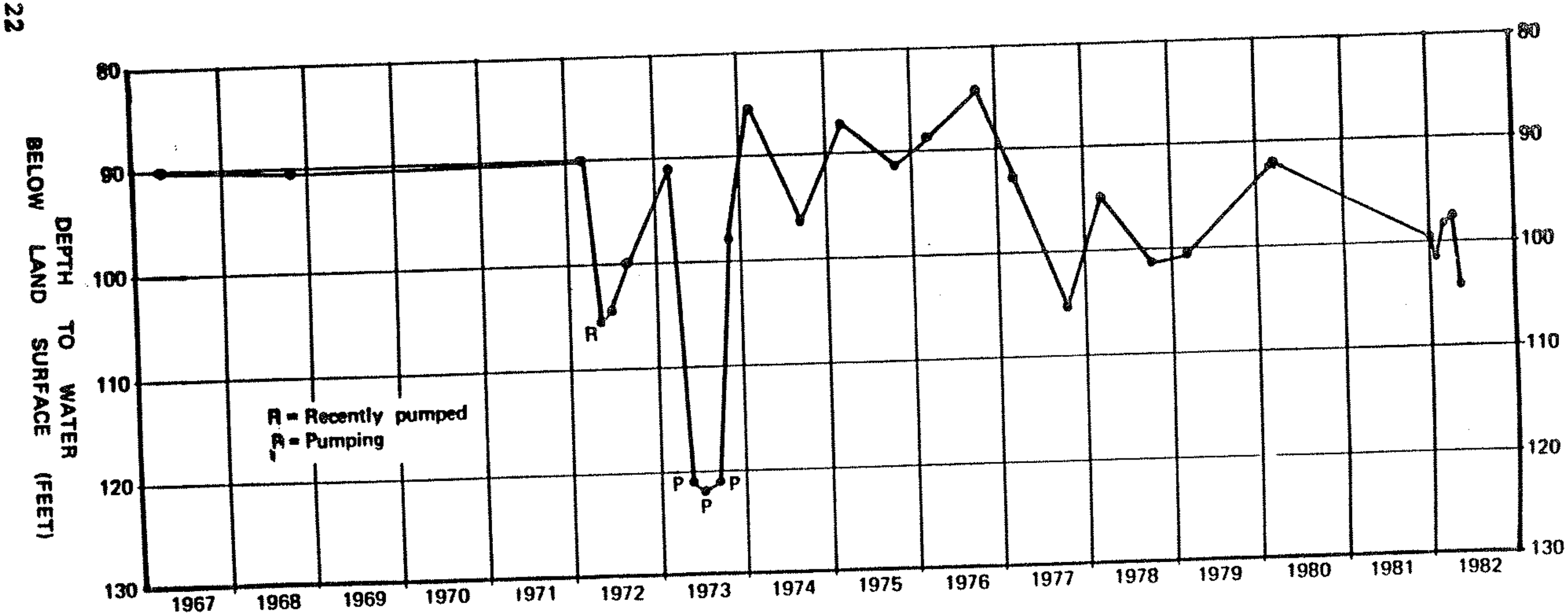


FIGURE 9 25N/34E - 2G1 M. HOUGER DEPTH: 320' UPPER AND MIDDLE ZONES

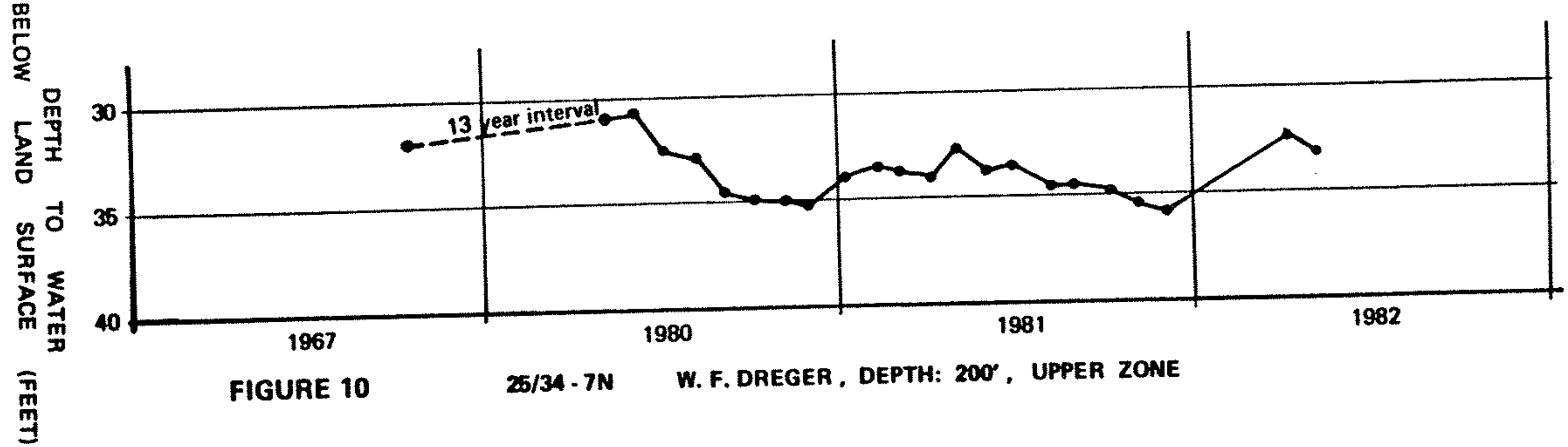


FIGURE 10 25/34 - 7N W. F. DREGER, DEPTH: 200', UPPER ZONE

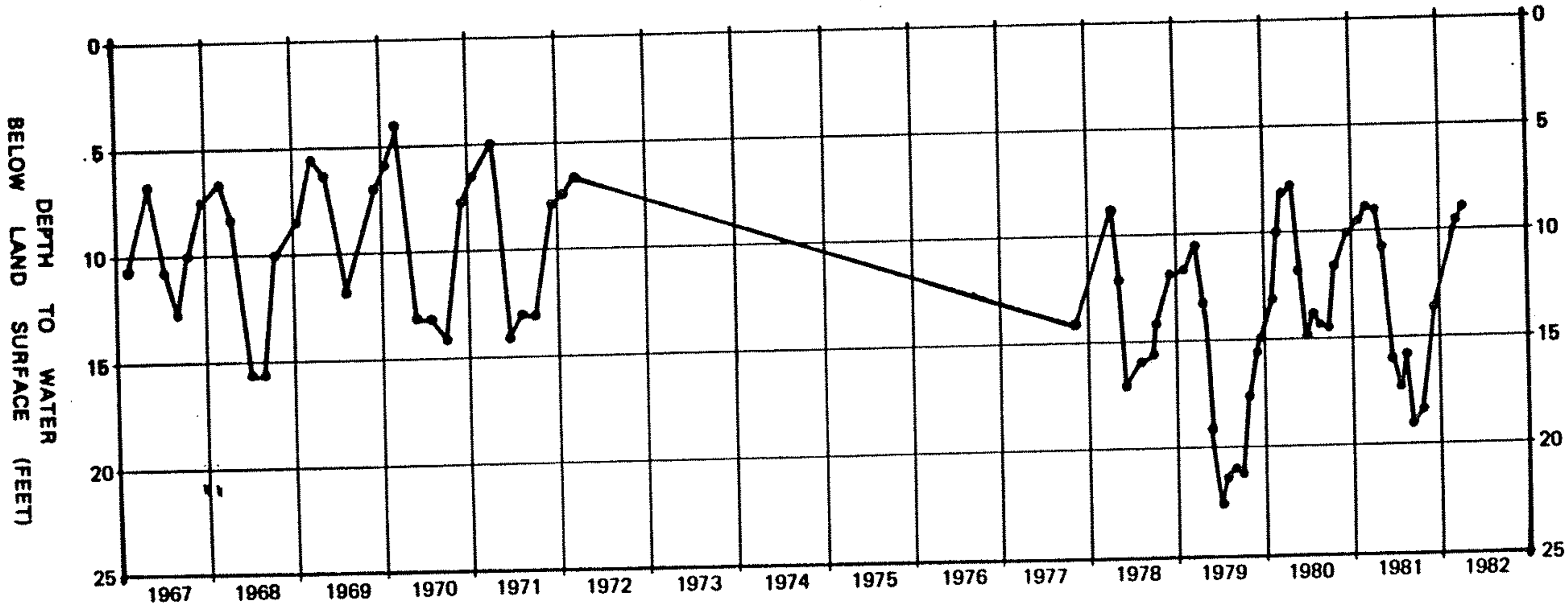


FIGURE 11 25N/34E - 9F1 M. HOUGER (formerly O. MANGIS) DEPTH: 211' UPPER AND MIDDLE ZONES

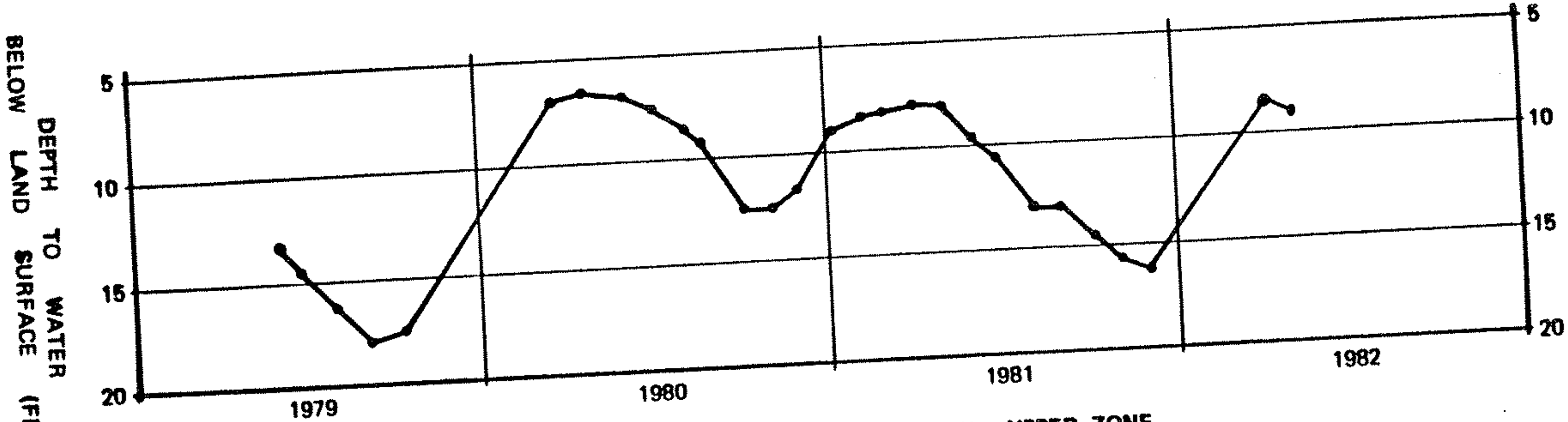


FIGURE 12 25/34 - 11G C. NELSON DEPTH: 80' UPPER ZONE

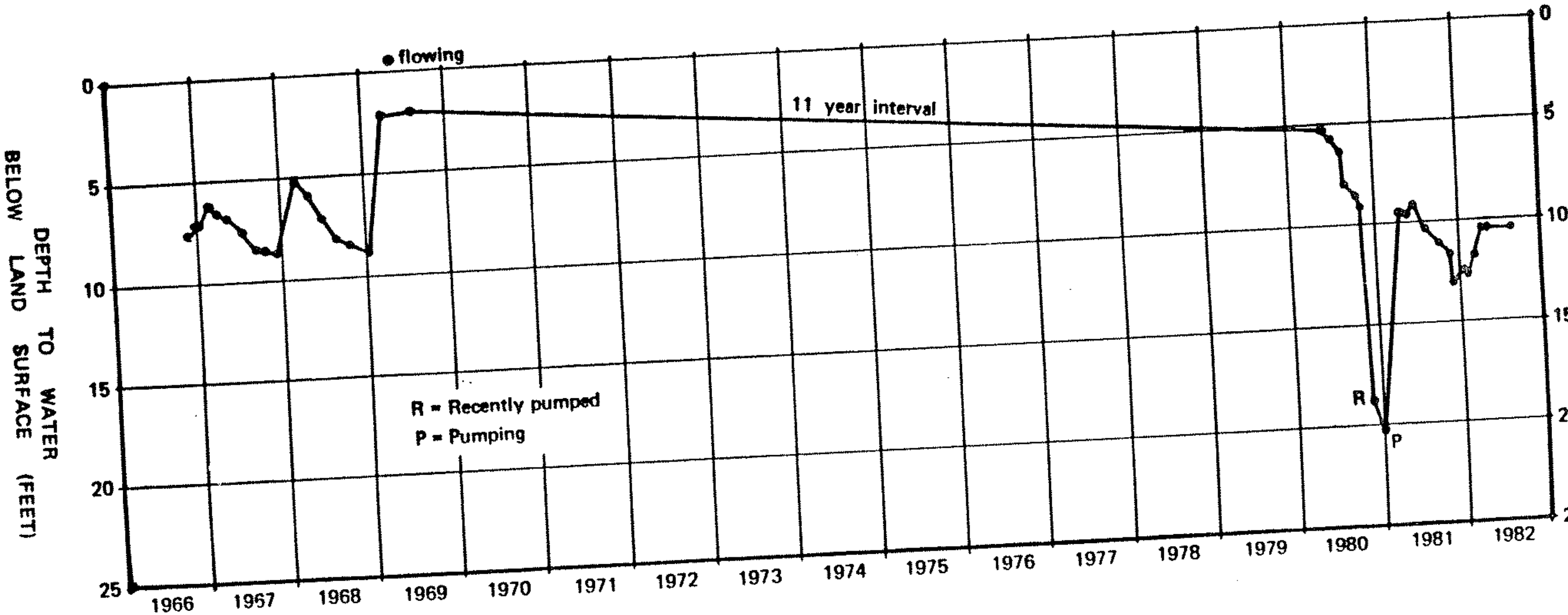


FIGURE 13 25N/34E - 29C1 E. F. DREGER DEPTH: 96' UPPER ZONE

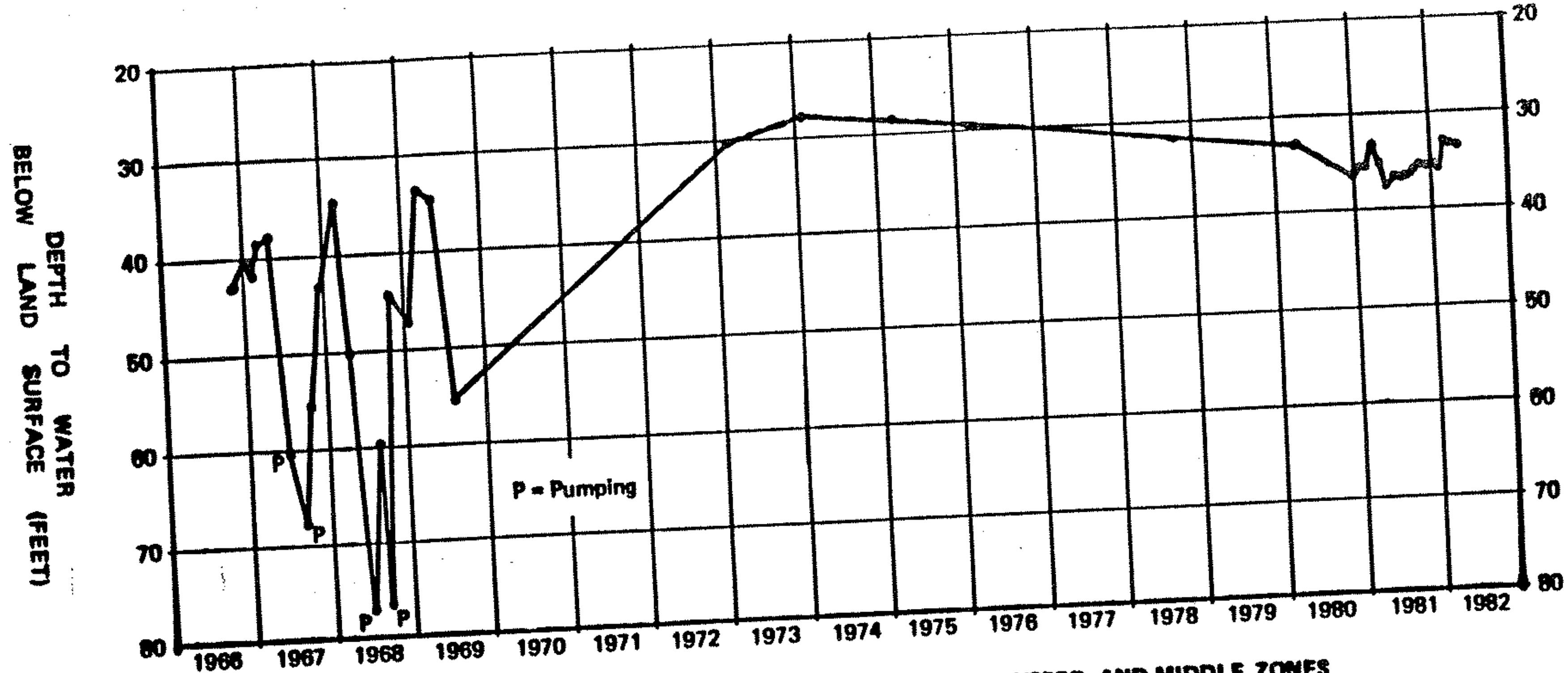
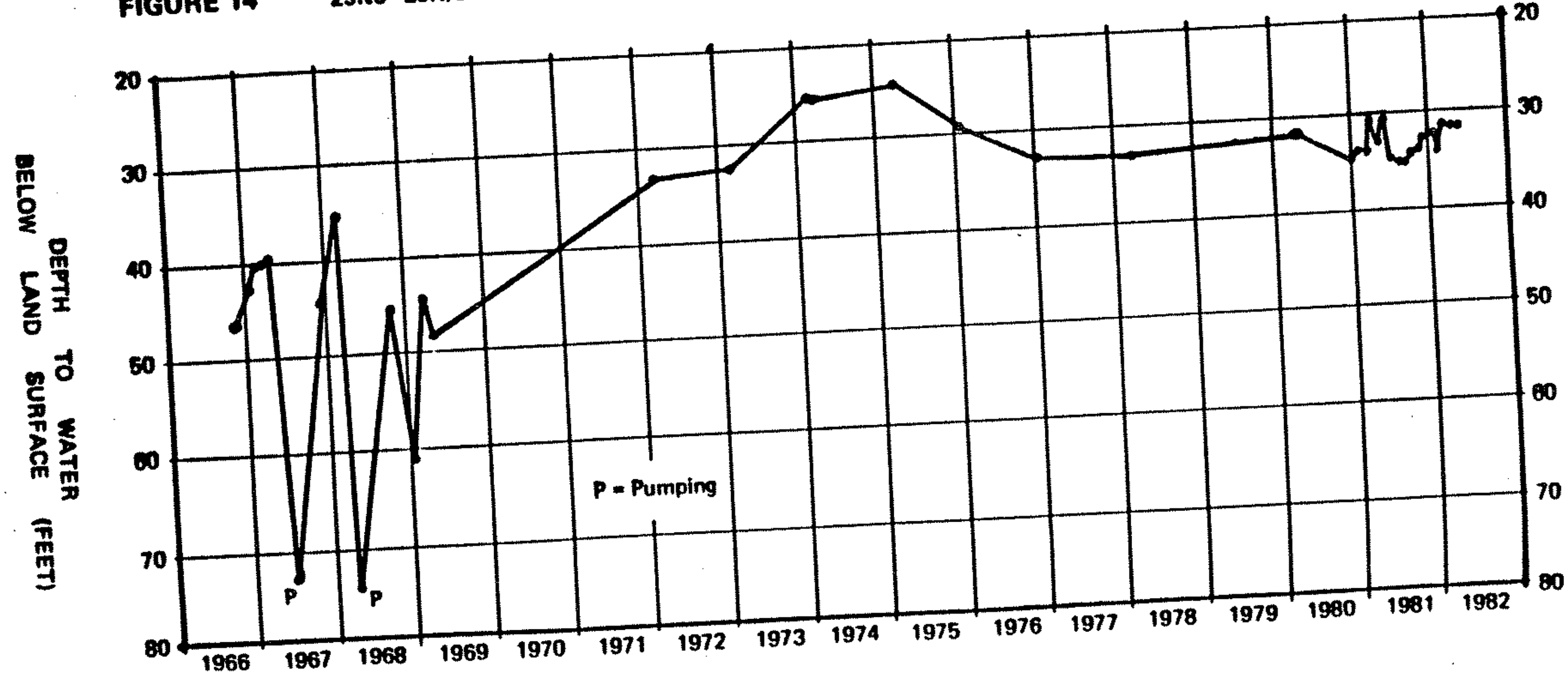


FIGURE 14 25N6 25N/34E - 30K1 E. F. DREGER DEPTH: 206' UPPER AND MIDDLE ZONES



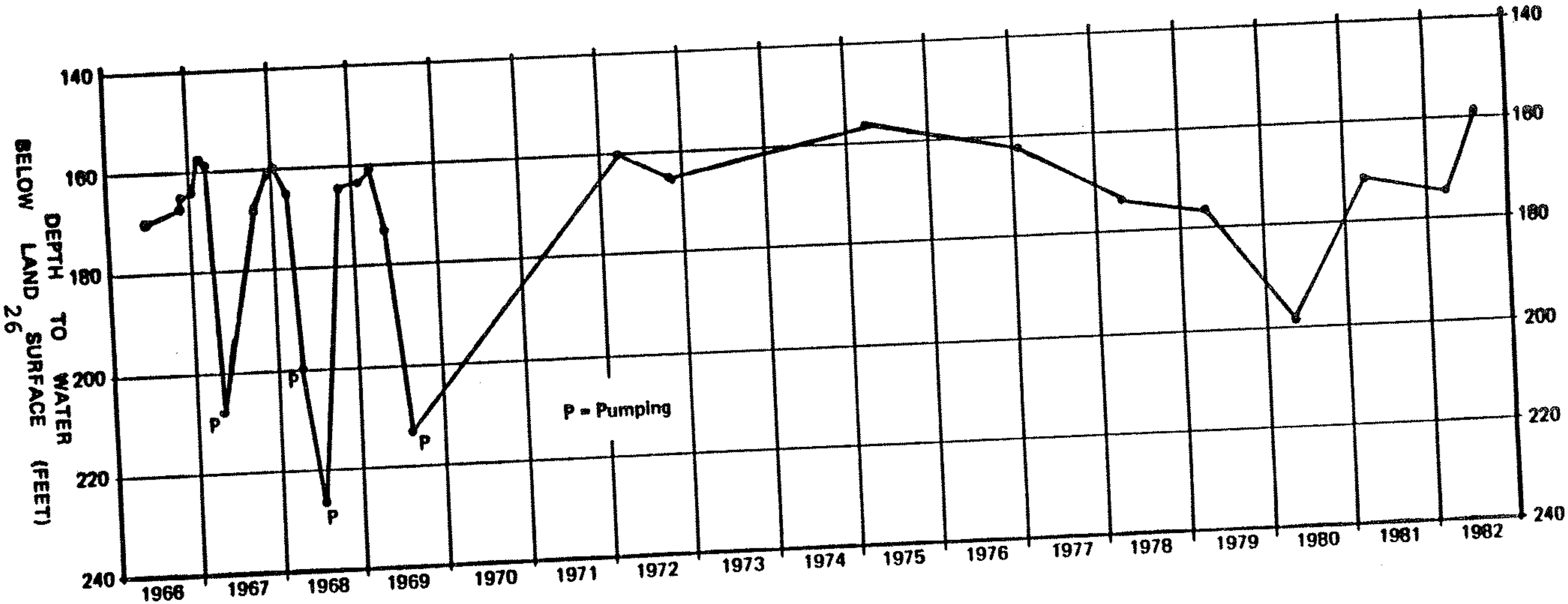


FIGURE 16 26N/33E - 34P1 R. DREGER DEPTH: 450' UPPER AND MIDDLE ZONES

AQUIFER TESTING

Storage Coefficient

The storage coefficient of an aquifer represents the volume of water that is released from a unit volume of rock when the head is lowered by pumping. For the Odessa area, Luzier and Burt (1974) calculated the volume of water pumped versus the resulting water-level decline in what they designated as the "lower" aquifer zone. They calculated storage coefficients of 2.5 x 10^{-3} and 6.5 x 10^{-3} in two portions of their study area. The usual range of values of the storage coefficient for artesian aquifers is 10^{-3} to 10^{-7}, and for water table (unconfined) aquifers is 2x10^{-1} to 10^{-3}. Brown (1981) interprets Luzier and Burt's storage coefficient values to indicate that over the long-term (several years) the basalt aquifers behave somewhat like water table aquifers.

Transmissivity

Transmissivity (T) is a measure of an aquifer's ability to transmit water and is equal to the hydraulic conductivity (or permeability) multiplied by the thickness of the saturated portion of the aquifer. Transmissivity often is indirectly estimated from the specific capacity of wells. Specific capacity is the yield of the well in gallons per minute (gpm) per foot of drawdown. For example, a well pumping 120 gpm with a resulting 20 feet of drawdown (measured in the well) has a specific capacity of 6 gpm/foot of drawdown. Luzier and Burt (1974) used the approximation that transmissivity (in feet squared per day) equals the specific capacity in GPM per foot of drawdown multiplied by 270. Based on data from Lincoln County, they estimated an average transmissivity of 1,600 ft^2/day for their "lower zone" (equivalent to the combined Middle and Lower Zones as designated in this report) in the Sinking Creek area.

Houger Aquifer Test

A more direct method of obtaining the aquifer storage coefficient and transmissivity is the aquifer test. An aquifer test of the older Houger irrigation well, 25/34-2G1 (Figure 9), was conducted during this study and is described in detail in the following text.

The older Houger irrigation well, 25/34-2G1, has caused considerable concern among the nearby ranchers. The well is 320 feet deep, with casing to only 60 feet. Thus the well is open to both the Upper and Middle Zone aquifers. The farmers believe Houger's pumping (approximately 550 gpm or 1.1 cfs, 5 months per year) is sufficient to dry up the upper creek. As a straightforward test of this concern, an aquifer test was conducted which involved pumping the Houger well, measuring drawdown within the well and, at the same time, monitoring water levels in several other wells. These observation wells included another Houger irrigation well, 25/34-2C (Middle Zone only); Washington Water Power (hereinafter abbreviated WWP) well OW-1, 25/34-3A (Upper Zone); WWP well OW-8, 26/34-34A (Upper Zone); WWP well OW-4, 26/34-36M (Upper Zone); Carl Nelson well, 25/34-11G (Upper Zone); and abandoned Houger well, 25/34-9F1 (Upper and Middle Zones). The WWP wells each contain two piezometers finished in separate aquifers within the Upper Zone. Hydrographs for pumped well 25/34-2G1 and observation wells 25/34-9F1 and 25/34-11G were previously described and can be seen in Figures 8, 10, and 11.

From March 25 to March 28, 1980 the Houger well, 25/34-2G1, was pumped at an average rate of 560 gpm for a total of 72 hours. Flow rate was measured with a Sparling flow-meter mounted in a 10-foot length of 10-inch diameter irrigation pipe. The water then was conducted through irrigation pipes to a nearby field where it was spread over the ground with 104 sprinkler heads. Barometric changes were recorded with a microbarograph and clock-driven chart recorder. Water level readings accurate to plus or minus 0.05 feet were taken with Olympic Well Probe "electric tapes." A Stevens Type-F continuous water-level recorder was used on the Houger well, 25/34-9F1.

During the test, drawdown occurred in the pumping well and in the two Houger observation wells, both completed in the Middle Zone. There was no drawdown in the Washington Water Power wells or the Carl Nelson well. The unaffected wells were all completed in the Upper Zone, so the test demonstrates that these aquifers are not in direct hydraulic communication with the Middle Zone. This does not rule out the possibility of slow leakage from the Upper Zone to the Middle Zone which might be induced by lowering the hydrostatic head in the Middle Zone during the irrigation pumping season.

Mathematical analysis of the Houger aquifer test utilized the Theis equation curve-matching and the Jacobs semi-log procedures (Lohman, 1979) to obtain the transmissivity (T) and storage coefficient (S). These calculations yielded an aquifer transmissivity = 12,000 ft^2/day and storage coefficient = 4×10^{-5}, for the Middle Zone north of observation well "2G1". Similar calculations for observation well "9F1" yielded transmissivity = 78,000 ft^2/day and storage coefficient = 1×10^{-5}, for the Middle Zone west of well "2G1".

The Houger aquifer test demonstrated that pumping well "2G1" has an almost immediate effect on well "9F1" for which we have several years of nearly continuous water-level data (Figure 11). Thus, the large water-level declines during spring, summer, and fall each year in well "9F1" may be attributed to irrigation pumpage by well "2G1". Water-level data from well "2G1" for April 20 to June 16, 1979 (57 days) was analyzed with the Theis equation in the same manner as for the three-day Houger aquifer test. Calculations yielded an "effective long-term" transmissivity = 1,000 ft^2/day and storage coefficient = 2×10^{-4}. This transmissivity value is quite close to the 1,600 ft^2/day estimated by Luzier and Burt (1974). The lower transmissivity and higher storage coefficient for the 57-day aquifer test compared to the 3-day test indicates that slow leakage is probably occurring from the Upper to the Middle Zone.

Four additional aquifer tests in the Upper Zone were carried out by Tera Corp. (1981). Four wells, drilled under Tera supervision, were individually pumped: WWP well P4, 25/34-2N2; WWP well P3, 25/34-3K1; WWP well P1, 26/34-27Q1; and WWP well P2, 26/34-34J1. Observation wells included the Washington Water Power wells drilled previously and Nelson well 25/34-11G. These aquifer tests demonstrated that pumping as little as 25 gpm from an Upper Zone well causes measurable drawdown within hours in other Upper Zone wells located more than a mile away. Average transmissivity and storage coefficient for the Upper Zone as determined by these tests were 5700 ft^2/day and 2×10^{-4}, respectively.

One of the Tera Corporation tests was of particular interest: WWP well P4, 25/34-2N2 (Upper Zone) was pumped at 25 gpm and caused measurable drawdown in Nelson well 25/34-11G (Upper Zone) in 38 hours. On the other hand, recall that pumping the Houger well 25/34-2G1 (Middle Zone) at 560 gpm for 72 hours produced no measurable drawdown in the Nelson well. This further substantiates the results of the Houger aquifer test which demonstrated that pumping from the Middle Zone has no short-term effect on water levels in the Upper Zone.

Further evidence that pumping the Houger well has no immediate effect on the Nelson well and the nearby spring can be seen in Figure 7. The water level in the Nelson well did not rise when the Houger well was shut down for alfalfa harvest from July 16 to August 16, 1979 and from July 13 to August 14, 1980. Instead, the water level declined steadily during the two periods because of the lack of natural summer recharge.

Effect of Downhole Flow in Uncased Wells

Houger well 25/34-2C, cased through the Upper Zone, has a water level some 20 to 30 feet below the levels for nearby WWP wells OW-1, 25/34-3A, and well P4, 25/34-2N2, both finished in the Upper Zone. With such a large head difference, one might expect downhole flow from the Upper Zone to the Middle Zone. However, the Houger aquifer test demonstrated that the uncased Houger well 25/34-2G1 is not pumping much water from the Upper Zone. This may indicate that vertical leakage to the Middle Zone via the well bore is very slow.

Throughout the study area, the majority of Middle and Lower Zone wells drilled prior to 1975 are uncased through the Upper Zone and probably cause down-hole flow at varying rates. Compared to total pumpage from the Middle and Lower Zones, down-hole flow is probably not a significant source of recharge to these zones. However, this steady leakage might be a significant loss from storage in the Upper Zone. Thus, even though winter precipitation completely replenishes the Upper Zone each year, the down-hole flow losses could contribute to seasonal declines in the Upper Zone head and reduce flow from springs.

Because downhole flow in uncased wells may have some effect on the Upper Zone water levels, it would be prudent to require casing through the Upper Zone in wells which tap the Middle and Lower Zones. Plate 4 provides a preliminary indication of the necessary casing depths but needs refinement based on additional geophysical logging and chemical analysis of the basalt. Until this is accomplished, the casing requirement might be to simply case off the uppermost aquifers which do not provide significant production to a given well.

Seasonal Depletion of Upper Zone by Induced Leakage

Both water-level data from wells and aquifer testing indicate that deep-well irrigation pumping has not caused long-term water level declines in the aquifers. However, irrigation pumping could be reducing the flow of springs fed by Upper Zone aquifers by causing induced leakage of ground water from the Upper to the Middle Zone. Irrigation pumping lowers the Middle Zone head over a large area thereby increasing the head difference across the lower boundary of the Upper Zone. This may induce increased downward flow through the basalt to the Middle Zone. Ground water flow from springs is "head-sensitive." In some cases a head drop of only a few feet could result in cessation of flow from a spring. Because the storage coefficient in the Upper Zone is small (2×10^{-4}) only a small volume of water need be lost to lower the head ten or more feet. Thus, the Upper Zone wells experience water level declines of from 5 to 50 feet during the irrigation season but the water levels fully recover during the winter recharge season when the induced leakage has ceased. The induced leakage process is too slow to show up during pumping tests, such as the Houger test, lasting only a few days. Thus, we only have indirect evidence (hydrographs) that the process is occurring.

Summary and Conclusions

Farmers and ranchers living along Sinking Creek in north-central Lincoln County believe that ground water pumping from large irrigation wells has caused a substantial decrease in the baseflow of the creek. They have noticed in particular that several perennial springs used for cattle watering in the upper (east) half of the watershed now dry up early in the summer. Two shallow lakes, Wagner Lake and Baring Lake, both less than five feet deep, have disappeared completely and a somewhat deeper lake (H Lake) has decreased 5 or 6 feet in depth since 1972.

Three distinct sets of hydrostatic heads were identified from well logs and water level measurements. These are thought to represent Upper, Middle, and Lower aquifer zones in the basalt bedrock. Each aquifer zone consists of several water-bearing basalt flows each with nearly the same hydrostatic head. Between aquifer zones the hydrostatic head decreases several tens of feet, apparently because of an intervening weathered layer of relatively lower hydraulic conductivity. All of the large irrigation wells in the watershed draw water principally from the Middle and Lower Zones.

Water level measurements in wells have not indicated any substantial decline in hydrostatic head in the Middle aquifer zone during the 17 years since large volume ground water pumping began. Water level data for the Upper and Lower aquifer zones is less conclusive because of the scarcity of data; however, there are no indications of large head declines in these zones. The water table in the alluvium along Sinking Creek has apparently declined resulting in both large shrinkage cracks in the soil in one area and drying up of a shallow lake (Wagner Lake).

A pumping test of an irrigation well open to both the Upper and Middle Zones produced no drawdown in wells open only to the Upper Zone. However, subsequent continuous water level measurements in a large spring and a nearby abandoned well (which had been affected during the pumping test) showed that pumping from the irrigation well is causing seasonal decreases in the flow of the spring. Since 1978 the spring has either dried up or the flow has diminished substantially during each irrigation season. This spring and another nearby are unusual in that they are probably fed by the Middle Zone aquifers along a localized fracture zone. All the other springs in the watershed are fed by the Upper Zone aquifers and these would not be as quickly affected by irrigation pumping. However, increased leakage from the Upper Zone to the Middle Zone, induced by irrigation pumping, may cause seasonal decreases in the flow from the Upper Zone springs.

Nearly all the wells in the area are uncased. Water is probably flowing down the well bores between aquifer zones due to the decrease in hydrostatic head with depth. This downhole leakage may be contributing to seasonal decreases in the flow from the Upper Zone springs.

Precipitation has been approximately 5 percent lower than average during the period from 1962 to 1981. However, yearly precipitation for the period 1917 to 1936 averaged 10 percent below normal and yet local farmers claim there was no streamflow problem during those years. Nonetheless, decreased precipitation could be partly responsible for declining baseflow in the creek.

It is concluded that a combination of induced vertical leakage due to irrigation pumping, downhole flow in uncased wells, and below average precipitation seasonally lower the Upper and Middle aquifer zone hydrostatic heads. As a result, spring flow to the creek has diminished and lakes fed by ground water have dried up and not refilled in recent years. Induced vertical leakage due to irrigation pumping may be the most significant of these factors.

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APPENDICES

APPENDIX I

RECORDS OF WELLS

Explanation:

Well locations shown on Plate 2.

Well Number: see Figure 1 for well numbering system

Elevation LSD: Elevation of land surface datum in feet above mean sea level, interpolated from topographic maps.

Depth to Water: Average depth below land surface datum. Measured in feet.

Aquifer Depth: Depth below land surface datum to the top of each water-bearing zone encountered.

Specific Capacity (SC): Production capacity in gallons per minute (gpm) per foot of drawdown as measured within the well bore. In most cases this was calculated from test data provided by drillers.

APPENDIX 1 - RECORDS OF WELLS (Continued)

Well Number	Owner	Well Depth	Elevation LSD	Elevation Bottom Well	Depth to Water	Elevation Water Level	Casing Depth	Aquifer Depths	Drill Log Available	Remarks
					T.25N, R.32E					
12J1	C. Wagner	165	2105	1940	12	2093	0-16	159	Yes	86 GPM w/155' drawdown SC = 0.6. Upper Zone
12J2	D. Wagner	427	2105	1678	73	2032	0-65	365, 400	Yes	400 + GPM. Middle Zone
17J	T. Quirk	300	2070	1770	200	1870	0-28	103	Yes	10-12 GPM.
26C2	P. Quirk	900	2216	1316	311	1905	0-62	867	Yes	450 GPM w/260' drawdown SC = 1.7. Lower Zone
26G1	P. Quirk	650	2250	1600	352	1898	0-76	371,622	Yes	1585 GPM w/22' drawdown SC = 72. Lower Zone
28R	A. Schroeder	417	2131	1714	115	2016	0-11	85,168, 248, 369	Yes	300 + GPM. Middle Zone
					T.25N, R.33E					
1B	W. Tiegs	60	2310	2250	4	2306	0-24	55	Yes	140 GPM w/10' drawdown SC = 14. Upper Zone
4D	W. Dreger	925	2305	1380	249	2056	0-75	165, 226, 270, 465, 570, 620, 664, 688, 803, 803, 916	Yes	2400 GPM permitted. Water level dropped from 2125' to 2056' elevation when well was deepened from original depth of 355'. Lower Zone
5C	W. Dreger	270	2229	1959	15	2214			No	100 GPM. Upper Zone
7B	W. Dreger	>500	2150	<1650	145	2005	0-30	42, 72, 178, 204, 251, 294, 367, 376	Yes, partial	Geophysical logs available from USGS. Lower Zone
7H	W. Dreger	225	2165	1940	14	2151	0-19	85, 225	Yes	Originally 100' deep, water level rose when deepened. Upper Zone
8D	G. Watson	335	2179	1844	126	2053	0-57	328	Yes	Water dropped 22' at 328' depth during drilling. 800 GPM w/190' drawdown SC = 4.2. Middle Zone
9B1	A. Eagle	390	2252	1862	160	2092	0-11	196, 362	Yes	275 GPM w/106' drawdown SC = 2.6. Middle Zone

AV/W17(A2,4-5)

APPENDIX 1 - RECORDS OF WELLS (Continued)

Well Number	Owner	Well Depth	Elevation LSD	Elevation Bottom Well	Depth to Water	Elevation Water Level	Casing Depth	Aquifer Depths	Drill Log Available	Remarks
T. 25N, R. 33E (Continued)										
9B2	A. Eagle	325	2257	1932					No	
10B	R. Rosman	362	2355	1993	90	2265	0-12	150, 175,215, 330	Yes	220 GPM w/216' drawdown SC = 1.0. Upper Zone
12K	W. Dreger	202	2241	2039	7	2234	0-23		No	Abandoned. Upper Zone
20B	R. Bauer	235	2170	1935	144	2026	0-18	55, 145, 160, 220	Yes	80 GPM. Middle Zone
20D	Wyborney	?	2205	?	180	2025			No	
24K	W. Tiegs	?	2270	?	173	2097			No	Abandoned windmill
27A1	E. Rettkowski	850	2318	1468	289	2029	0-21 452-500		Yes	Geophysical logs by USGS 2565 GPM w/103' drawdown SC = 24.9 Well has collapsed. Lower Zone
27A2	E. Rettkowski	865	2320	1455	291	2029	0-27 389-572	561, 842?	Yes	2500 GPM w/24' drawdown SC = 104. Lower Zone
27R	E. Rettkowski	525	2200	1675	232	1968	0-55	249, 366, 502	Yes	Lower Zone
31G	Wilbur Securities	495	2120	1625	215	1905	0-23 365-386	475	Yes	Lower Zone
T. 25N, R. 34E										
2C	M. Houger	610	2370	1760	127	2243	0-52	89, 163, 308, 358, 597	Yes	450 GPM w/128' drawdown SC = 3.5. Middle Zone
2G	M. Houger	320	2336	2016	90	2246	0-60	215, 303	Yes	1500 GPM w/28' drawdown SC = 54. Middle Zone
6D	W. Rosman	?	2330	?	13	2317			No	Abandoned windmill. Upper Zone
7N	W. Dreger	200	2270	2070	31	2239	0-30		Yes	Abandoned. Upper Zone
9F1	M. Houger	211	2240	2029	8	2232			No	Poor production, abandoned. Middle Zone
9F2	M. Houger	105	2235	2130	1	2235	0-38	30, 50, 95	Yes	70 GPM. Upper Zone

AV/W17(A3,6-7)

APPENDIX 1 - RECORDS OF WELLS (Continued)

Well Number	Owner	Well Depth	Elevation LSD	Elevation Bottom Well	Depth to Water	Elevation Water Level	Casing Depth	Aquifer Depths	Drill Log Available	Remarks
T. 25N, R. 34E (Continued)										
11G	C. Nelson	80	2275	2190	10	2265	0-10	40	No	Windmill, formerly a perennial spring. Upper Zone.
18F	W. Dreger	42	2200	2158	10	2190	0-42		No	Water table in alluvium.
20P2	Dreger	340	2270	1930	79	2191	0-23	54, 280, 312, 328	Yes	500 GPM. Middle Zone Cascading.
29C1	Ed. Dreger	96	2258	2168	6	2252			No	70 GPM. Upper Zone
29J	Ed. Dreger	550 (1225)	2285	1735 (1060)	255 (7500)	2030 (<1785)	0-? & 470-680		No	Lower Zone. Original depth 550', deepened to 1225'.
30K1	R. Dreger	266	2247	1542	30	2117	0-77	670	Yes	725 GPM w/290' drawdown SC = 2.5. Middle Zone
30K2	R. Dreger	705	2247	1542	30	2217	0-70		Yes	Middle Zone. Lower section may have collapsed
30K3	R. Dreger	500	2260	1760	65	2195	0-63	470	Yes	2150 GPM w/256' drawdown SC = 8.4. Middle Zone
T. 25N, R. 35E										
20D	E. Cole	410	2250	1840	21	2229	0-5	35, 270, 295, 312, 384?, 800, 890, 980	Yes	Originally drilled to 1440' depth by Delta Gas and Oil. Back-filled to present depth.
T. 26N, R. 32E										
20L	R. Sheffels	290	2040	1750	30	2010	0-75	147, 270	Yes	Upper Zone
21J	G. Anderson	453	2082	1629	145	1937	0-21	142, 350, 426	Yes	425 GPM w/224' drawdown SC = 1.9. Middle Zone
26D	J. Rosman	166	2060	1894	1/	2108		153	Yes	Upper Zone

AV/W17(A3,8-9)

1/ Flowing (-) 48'

APPENDIX 1 - RECORDS OF WELLS (Continued)

Well Number	Owner	Well Depth	Elevation LSD	Elevation Bottom Well	Depth to Water	Elevation Water Level	Casing Depth	Aquifer Depths	Drill Log Available	Remarks
T. 26N, R. 33E										
18C2	City of Wilbur	900	2245	1345	82	2163	0-17		Yes	350 GPM w/270' drawdown SC = 1.3. Lower Zone
18J1	E. Angstrom	308	2253	1947	49	2206	0-33	265, 280	Yes	180 GPM w/137' drawdown SC = 1.3. Upper Zone
19D	A. McInroy	233	2175	1942	1/	2198	0-40	233	Yes	150 GPM flow. Upper Zone
29N	F. Rux	120	2195	2075	20	2175	0-120		Yes	Upper Zone
29P1	H. Rux	288	2209	1921	Flowing	?	0-8	120, 250, 280	Yes	Upper Zone
29P2	H. Rux	160	2209	2049	Flowing	?			Yes	
31	D. Piper	120	2246	2126	20	2226	0-10		No	Upper Zone
32A	Ed. Dreger	34	2240	2206	28	2212	0-34		No	110 GPM. Windmill pump.
32D	W. Dreger	308	2185	1877	12	2173	0-18	301	Yes	Middle Zone
32K	Ed. Dreger	426	2303	1877	85	2218	0-34		Yes	2575 GPM w/230' drawdown SC = 11.2. Middle Zone
33A	Ed. Dreger	160-200?	2280	2080	13	2267	0-36		No	Upper Zone
33B	Ed. Dreger	37	2255	2218	Flowing		0-34	24, 27	Yes	55 GPM. Upper Zone
34P	R. Dreger	450	2382	1932	160	2222	0-62		Yes	1700 GPM w/64' drawdown SC = 26.6. Middle Zone
36A	W. Rosman	285	2398	2113	86	2312	0-50		No	Upper Zone
36N	A. Dreger	350	2305	1955	81	2224	0-72	304	Yes	880 GPM w/122' drawdown SC = 7.2. Middle Zone
T. 26N, R. 34E										
21D	R. Krause	250	2440	2190	130	2310	0-53		Yes	30 GPM
22A	E. Rosman	248	2435	2187	144	2291	0-15		No	
30M	J. Rosman	?	2385	?	73	2312			No	Upper Zone
32J	R. Nelson	307	2390	2083	105	2285	0-38		No	Upper Zone

AV/W17(A3,10-11)

1/ Flowing (-) 23'

APPENDIX 1 - RECORDS OF WELLS (Continued)

The following wells were all drilled for site evaluation by Washington Water Power (WWP) for the Creston coal-fired electric power generation station.

Well Number	Owner	Well Depth	Elevation LSD	Elevation Bottom Well	Depth to Water	Elevation Water Level	Casing Depth	Aquifer Depths	Drill Log Available	Remarks
T. 25N, R. 34E										
2N1	WWP, B-1	85	2346	2261	68	2278	0-45	?	Yes	
2N2	WWP, P-4	140 (220)	2319	2179 (2099)	47	2272	0-19	70, 120, 164	Yes	Originally 220' deep Backfilled to 140' deep
3A	WWP, OW-1	164	2348	2183	73-upper 74-lower	2265 2264	0-31	128, 156	Yes	2 Piezometers; screens at 128-135' and 156-161'
3K	WWP, P-3	150 (220)	2335	2185 (2115)	61	2274	0-23	96, 140, 195	Yes	Originally 220' deep Backfilled to 150' deep
4B	WWP, OW-5	165	2315	2150	25-upper 43-lower	2280 2272	0-42	55, 151	Yes	2 Piezometers; screens at 73-83' and 152-162'
9E	WWP, OW-2	117	2238	2121	10-upper 12-lower	2228 2226	0-19	24, 40, 57, 90	Yes	2 Piezometers; screens at 48-62' and 90-117'
T. 26N, R. 34E										
27C	WWP, OW-3	180	2383	2203	51-upper 91-lower	2332 2292	0-18	70, 170	Yes	2 Piezometers; screens at 65-74' and 161-177'
27K	WWP, B-9	115	2343	2228	60	2283	?	?	Yes	
27Q	WWP, P-1	214 (248)	2370	2156 (2122)	68	2302	0-40	65, 150, 240	Yes	Originally 248' deep. Backfilled to 214' deep
34A	WWP, OW-8	120	2314	2194	32-upper 32-lower	2285 2284	0-17.5	55, 100, 115		2 Piezometers; screens at 60-75' and 100-116'
34J	WWP, P-2	142 (273)	2295	2153 (2022)	16	2279	0-40	75, 112, 221	Yes	Originally 273' deep Backfilled to 142' deep

AV/W17(A12-14)

APPENDIX II

YEARLY PRECIPITATION RECORDS FOR DAVENPORT AND WILBUR, WASHINGTON

Year	Precipitation (in.) Davenport	Wilbur
1893	16.67	--
1894	10.32	--
1900	--	14.25
1901	--	12.11
1902	--	16.20
1903	--	12.55
1904	--	10.53
1905	--	17.80
1906	--	18.20
1907	--	13.87
1908	--	9.70
1909	12.09	12.40
1910	11.18	11.19
1911	10.48	7.99
1912	15.10	13.45
1913	15.68	13.41
1914	14.36	12.44
1915	15.81	15.12
1916	13.54	13.05
1917	12.53	10.76
1918	11.77	10.54
1919	11.99	11.00
1920	13.34	11.92
1921	12.03	11.50
1922	12.53	13.38
1923	13.60	14.10
1924	12.76	10.29
1925	12.16	10.59
1926	12.34	13.38
1927	17.41	15.66
1928	8.89	6.81
1929	7.30	5.80
1930	10.32	7.11

Year	Precipitation (in.) Davenport	Wilbur
1931	16.83	14.06
1932	18.31	12.18
1933	16.25	10.50
1934	12.47	11.34
1935	12.22	10.42
1936	12.97	8.67
1937	23.29	17.32
1938	13.25	10.40
1939	11.11	8.37
1940	23.87	17.00
1941	19.25	16.10
1942	17.36	15.07
1943	12.08	8.95
1944	12.47	10.07
1945	18.42	14.88
1946	12.77	11.10
1947	15.11	11.27
1948	26.06	23.7(E)
1949	11.93	10.1(E)
1950	19.70	14.23
1951	16.81	11.90
1952	12.75	10.26
1953	18.29	14.53
1954	16.46	12.77
1955	22.09	15.16
1956	16.72	12.56
1957	17.86	14.38
1958	18.17	14.96
1959	19.05	12.54
1960	17.85	13.85
1961	16.61	14.22
1962	18.27	10.94
1963	13.93	11.68

Year	Precipitation (in.) Davenport	Wilbur
1964	15.92	9.37
1965	12.0(E)	10.29
1960	15.55	11.36
1967	12.10	8.42
1968	14.27	13.60
1969	13.76	12.29
1970	16.20	10.41
1971	14.54	12.42
1972	12.54	13.42
1973	16.46	12.25
1974	14.62	11.23
1975	14.93	12.85
1976	8.51	7.37
1977	13.05	10.83
1978	14.10	13.54
1979	13.77	12.10
1980	17.33	16.74
1981	13.37	11.34
Mean	14.79	12.19

(E) = Estimated