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A Review Of Water-Well Data From The Unconfined Aquifer In The Eastern And Southern Parts Of The Pasco Basin

Randall E. Brown

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Rockwell International

Rockwell Hanford Operations
Energy Systems Group
Richland, WA 99352

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A REVIEW OF WATER-WELL DATA FROM THE UNCONFINED AQUIFER IN THE EASTERN AND SOUTHERN PARTS OF THE PASCO BASIN

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September 1979

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STATEMENT OF AUTHOR

I hereby acknowledge that, during the preparation of this report, the staff of Rockwell Hanford Operations (Rockwell) has provided assistance in the form of retyping my final manuscript, redrafting illustrations, and editing the manuscript. This assistance was provided pursuant to a prior arrangement between Rockwell and myself and was intended solely as a means of supplementing and extending the support resources of my professional practice for this single effort. I further state that this assistance provided by Rockwell has in no way amended the technical content or intent of my original manuscript and drawings.

Randall E. Brown
Author

2/5/81
Date

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ABSTRACT

An overview of the post-Columbia River basalt geology and shallow hydrogeology of the Pasco Basin for areas adjacent to the Hanford Site is presented. The lithostratigraphic units described include the surface of the Columbia River basalt; the basal gravels, silts and clays, and conglomerates of the Ringold Formation; and the Hanford formation (informal name). Discussions regarding the occurrences, hydraulic properties, and flow characteristics of the shallow (unconfined) groundwater systems are described for six subareas within the study region. Empirical transmissivity values are tabulated for 209 wells and 14 plates provide geologic and hydrologic data at a 1:62,500 scale for the study area. This work has been performed in supplement to ongoing studies within the Hanford Site by Rockwell Hanford Operations.

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INTRODUCTION

PURPOSE

This study was undertaken for Rockwell Hanford Operations (Rockwell) to better determine the occurrences of groundwater in the area peripheral to the Hanford Site, specifically on the east and south sides of the Pasco Basin. The data from the large number of wells in this area would considerably increase our knowledge of the geology and hydrology.

The emphasis of the work was to characterize the unconfined or water-table aquifer, and the relevant late Cenozoic stratigraphic units that bear on and control the flow of those shallow groundwaters.

AUTHORIZATION

This study was authorized by Rockwell on January 8, 1979.

ACKNOWLEDGMENTS

I wish to acknowledge the full cooperation and assistance of Rockwell personnel in expediting the work and in aiding its completion, especially the technical editing of B. V. Johnston and illustration work of D. B. Mill. This assistance greatly enhanced the final report and helped me clarify the points being made. I also wish to thank those members of Rockwell who provided comments and discussions bearing on geologic questions that arose during the work. I wish to especially thank Leo S. Leonhart, technical liaison for Rockwell, with whom many aspects of the work were discussed and who provided considerable aid and assistance.

The work, of course, would have been impossible without the long-term help of a great many well drillers, too numerous to name here. They have, in the interests of improving knowledge of the region and simultaneously improving their own skills, consistently supplied data where data were needed; to them, I give many thanks.

LOCATION AND SETTING

The area of study encompasses approximately 800 square miles, as shown on Figure 1 and on the plates accompanying this report. The area extends from the west end of Wahluke Slope southward through the South Columbia Basin Irrigation District to Wallula Junction, from there, westward to Benton City and north to Horn Rapids. It borders the Hanford Site on the north, northeast, east, southeast, and south. It is an area in which an estimated 3,000 wells have been drilled.

The study area was divided for purposes of the discussion into six geographically smaller areas, as shown in Figure 1. All six areas are characterized by distinguishing hydrologic properties that reflect the geologic conditions. They are as follows:

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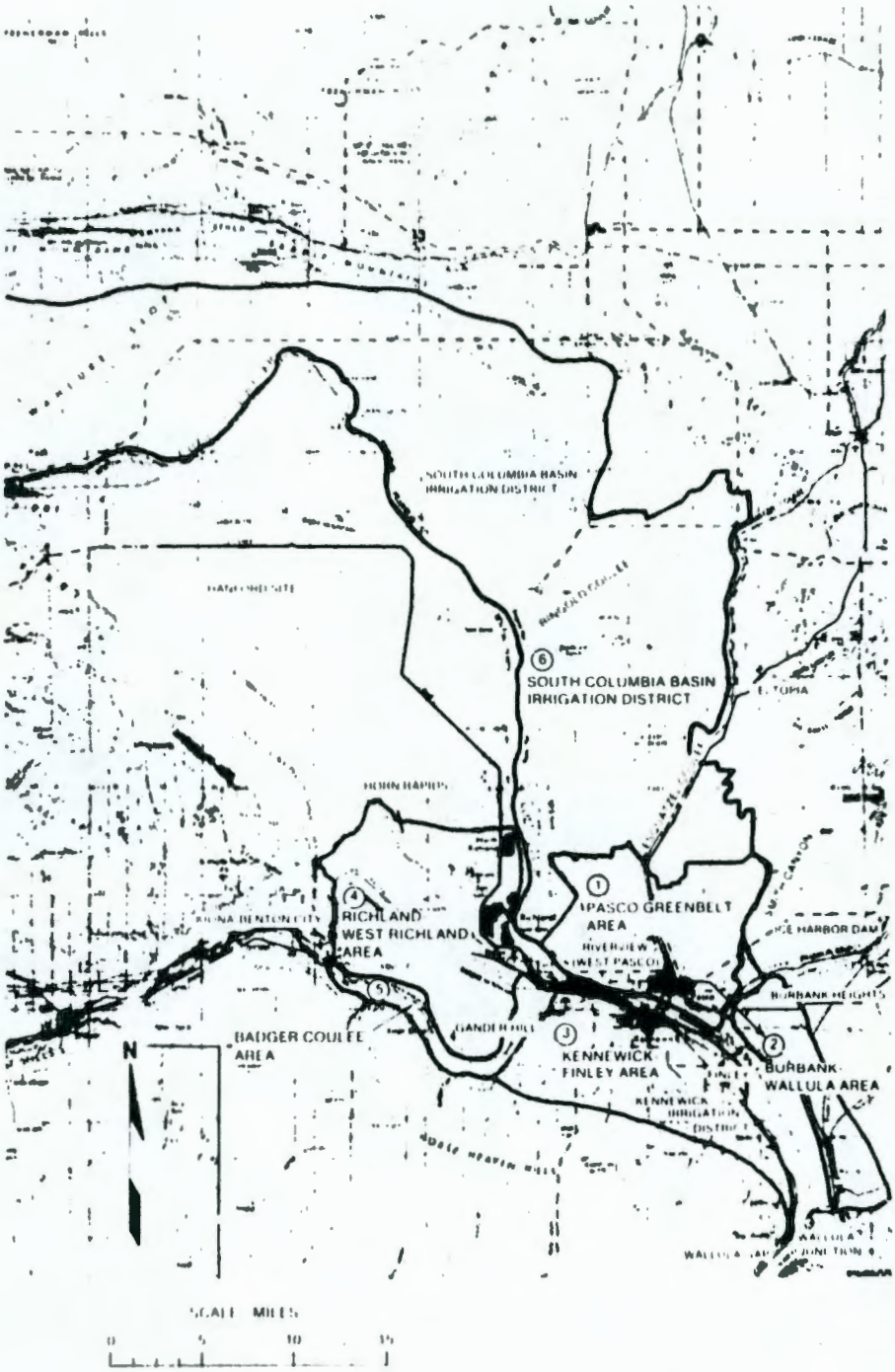

FIGURE 1. Index Map of the Location of the Study Area.

1. The Pasco Greenbelt Area
2. The Burbank-Wallula Area
3. The Kennewick-Finley Area
4. The Richland-West Richland Area
5. The Badger Coulee Area
6. The South Columbia Basin Irrigation District Area (including Wahluke Slope).

The Pasco Greenbelt Area, so called because of extensive irrigation from wells, is recharged from the Columbia Basin Irrigation Project. Geologic conditions, later summarized, and the recharge permit the drilling of high-yield wells in favorable sites. Drainage problems are present in some locales.

The Burbank-Wallula Area, on the east bank of the Columbia River southeast of Pasco, is characterized by low- to only moderate-yield wells in the unconfined aquifers. Yields from the basalts are low to very low. The unconfined aquifers are in direct contact with the Snake, Columbia, and Walla Walla Rivers, with little to probably no significant recharge from the east.

The Kennewick-Finley Area is one where small farms abound. It lies between the Columbia River and the Horse Heaven Hills. The unconfined aquifers consequently pinch out upslope. A thin and shallow-depth, water-table aquifer is adequate generally only for domestic and small-scale irrigation water supplies. Much of the groundwater is derived from two irrigation districts within the area.

The Richland-West Richland Area (to Kiona-Benton City and to Horn Rapids) lies where basalt is close to or above the water table, except in the City of Richland. Consequently, most of the area has an unconfined or water-table aquifer only where irrigation practices or the deliberate raising of the water table have created one. Wells commonly are several hundreds of feet deep and produce from the basalts.

Badger Coulee lies where basalt is sharply and deeply folded, and probably faulted. Coulee-fill sediments, even though relatively low in permeability, permit high-yield wells owing to the fact that the aquifer is up to more than 200 feet thick. The thickness reflects recharge from irrigation within the Kennewick Irrigation District which has resulted in a water-table rise of more than 100 feet. The coulee evidently is a major recharge site for the aquifers in the upper part of the Wanapum Basalt.

The South Columbia Basin Irrigation District, including Wahluke Slope and the part of the Hanford Site north of the Columbia River, is by far the largest subarea of the overall study area. Throughout the district, groundwaters commonly lie deep in the Ringold Formation and more commonly

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in the underlying basalts. Yields, with few exceptions, are low to very low; hence, irrigated agriculture requires irrigation via the Columbia Basin Project rather than by wells.

The low permeabilities of the Ringold Formation and the underlying basalts, with their perching tendencies, have induced extensive drainage southward into the Pasco Greenbelt Area. Drainage problems have developed, resulting in wetlands and extensive areas of landsliding along the White Bluffs and Ringold Coulee.

PREVIOUS WORK

Many persons have studied portions of the current study area, with the greatest attention given to the area between the Horse Heaven Hills and the Rattlesnake Hills, especially between Kennewick and Benton City. Those studies, however, were restricted almost wholly to field mapping, even in locales such as Badger Coulee where the basalt structures are hidden beneath thick fill sediments. Workers in such areas did not benefit from the abundant well data that, in numerous instances, are not only necessary to adequately understand the structures, but in many locales are the only data.

Newcomb (1948), Brown and McConiga (1960), Walters and Grolier (1960), Newcomb (1965), Newcomb, Strand, and Frank (1972), Molenaar (1968), Mundorff, Reis, and Strand (1952), and Grolier and Bingham (1971, 1978) are among those who have reviewed some aspects of the data from wells in the study area. The most detailed study of the geology of the post-basalt sediments through the use of wells was by Newcomb (1965) in the Walla Walla Basin, which study barely reached Wallula Gap. Tanaka, Hansen, and Skrivan (1974) developed a digital groundwater model for the Columbia Basin Irrigation Project using largely the data of Walters and Grolier (1960) and Grolier and Bingham (1971, 1978). This groundwater model has been used for part of the study area. Most of the studies identified only the gross characteristics of the geology and did not attempt to use all the well data available.

In 1978, the author contributed to a study for the U.S. Army Corps of Engineers of the Pasco Greenbelt Area that lies between the South Columbia Irrigation District and Pasco, and from the Snake River to the Columbia River. The study, using all the well data then available, identified the geology and the hydrology of the area in considerably more detail than prior studies. A model study by Battelle-Northwest (no report issued), using the Corps-supplied data, permitted predictions of groundwater behavior resulting from certain pumping and recharge situations. Events in 1978 and 1979 proved the applicability of the method of model use, and, consequently, of the correctness of identification of the geologic parameters.

The procedures used by Brown in the Corps study have been applied to local problems in well siting and to the solution of drainage problems. As a result, a data base has accumulated that is increasingly providing guidance for well drilling and answers to hydrologic questions.

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PROCEDURES

This hydrologic study is a paper study based nearly wholly on data obtained from existing water wells drilled by others. Field work was limited to procurement of data from wells then being drilled.

The data are supplemented and verified where possible by correlation to published or otherwise available data from other sources.

Huge areas are blanketed by the Pleistocene flood deposits and often thick eolian soils (loesses); hence relevant outcrops are often rare to absent. Thus, the well data are peculiarly important. In addition to the geologic data, the wells often provide important hydrologic data that often corroborate the geology and, in turn, are explained by the geology.

Summers and Weber (1978) indicate that about 7,000 wells have been drilled in the Pasco Basin, about 4,000 of which lie on the Hanford Site. Hence about 3,000 wells lie outside the Hanford Site dominantly within the study area. About 1,300 wells, whose records are most readily available, were used for this study. It is readily evident that they constitute a tremendous bank of data.

Wells were initially plotted on available topographic base maps at a scale of 1:24,000 (1 inch equals 2,000 feet). Surface altitudes were determined by map inspection and were checked against the altitudes recorded for the wells. Discrepancies were resolved if possible.

The depths to the geologic features of interest were determined from the well logs and their altitudes recorded on the map at the well location. If anomalies appeared between two or more adjacent wells, the logs of the affected wells were reexamined and a consistency sought.

Contour intervals were chosen to maximize the detail that could be shown for relevant features, but also to indicate the probable accuracy of the contours. Generally, 100-foot intervals indicate few data points and considerable generalization. Contours at closer intervals indicate more data points and closer control over the features shown.

The minimum contour intervals are: 50 feet for the basalt, 5 feet (2 feet locally) for the basal gravels of the Ringold Formation, 50 feet for the lowermost silts and clays, 20 feet for the conglomerate, and 10 feet for the water table. The greater number of wells in the shallower units permits more detailed contouring. The probable error, empirically determined, is about ±50% of the contour interval.

The contours were transferred to base maps on a scale of 1:62,500 (1 inch equals about 1 mile). They were adjusted to match the contours of adjoining areas and to provide consistency in patterns. The maps then were checked against previously drawn geologic cross sections (from prior studies of local areas) and additional cross sections were sometimes drawn. Minor adjustments were made as necessary.

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THE DATA BASE

COMPLETENESS OF THE DATA

The estimated 3,000 wells in the Pasco Basin external to the Hanford Site represent an average well density of nearly four wells per square mile for the approximate 800-square-mile study area. However, only about 1,300 wells were reviewed for this study for an average density of about one to two wells per square mile. The density varies greatly, from appreciably less than one per square mile on Wahluke Slope to several score per square mile in parts of West Pasco (Riverview) and Finley. Simultaneously, the detail, accuracy, and reliability of the conclusions vary, even if the logs can be accepted at face value.

The very low density in certain areas is less serious for several reasons: (1) concepts and relationships developed in one locale are applicable elsewhere; thus, demonstration that the Ringold Formation is tectonically deformed in one site of close control indicates that it is most likely deformed at other sites although poor control at these other sites does not permit such a determination; (2) most wells are drilled where water is readily available, hence few wells indicate difficulty in water procurement and probably an area of less hydrologic interest; and (3) the wells tabulated include the more recently drilled wells, oftentimes more carefully logged (often by geologists) and the data are correspondingly more reliable than the logs of wells drilled tens to scores of years ago.

About 1,700 wells currently are untabulated, if the 3,000 wells external to Hanford as estimated by Summers and Weber (1978) are correct. Probably the bulk of the 1,700 wells is domestic wells of low yield, many stopping short of basalt and with poor logs, if logs are even available. However, many logs of wells have been found to date that are not recorded in Washington State Department of Ecology files and hence were not tabulated by Summers and Weber (1978). These unrecorded wells included more than 130 which penetrated to or into basalt. Some of those were abandoned wells, some were drilled subsequent to Summers and Weber's (1978) tabulation, and many were existing domestic wells for which logs evidently never were filed.

DATA QUALITY

A tabulation shows that more than 130 different well drillers are known to have drilled wells in the Pasco Basin external to Hanford, subsequent to 1909, the apparently oldest well in the region. A review of the tabulated about 1,300 wells shows the expected complete spectrum of detail and quality, ranging from a recording only of location and depth to highly detailed, complete, and analytical logs.

Both the quality and detail of each of the logs were reviewed and assessed. This included comparison to the logs of adjacent wells

(especially by other drillers) and a determination of how the well fitted into the broad geologic picture or pattern.

It is significant that even basalt cannot always be identified with certainty. Thus, it may occur as breccia, often logged as "gravel," palagonite, sometimes logged as "clayey gravel," or highly weathered basalt logged in a variety of ways. Nests of large basalt boulders and even compact basalt sand have been logged as basalt bedrock. Where any of those materials occur above true basalt bedrock, the log may or may not reflect the true material.

Another problem is the location and altitude of the well collar. If the well is not accurately located, the altitude of the well cannot be determined accurately even with detailed topographic maps. If the altitude is incorrect, both the depth to and consequent altitude of the water table and the altitudes of the respective geologic units are in error.

Commonly the altitudes of wells can be determined from topographic maps that are available to an accuracy of probably no more than 20 feet, if the well location is known to the nearest 40 acres (a quarter-quarter section). In some sites, wells are drilled in canyon bottoms or in unusual topography such that precise locations are needed. Hence, if water levels or geologic features appear to be anomalously high or low, field checking for the well location is necessary.

Random samples of water levels were examined, where numerous wells were in close proximity. Discrepancies in the water table altitude, as recorded by the drillers, of as much as 40 feet were noted. Discrepancies of 10 to 20 feet were more common. Contour intervals of 10 feet thus are meaningful only where consistency between wells prevails or where accurate altitudes of wells were determined.

A high degree of accuracy is desirable in the altitude of the wells, but the large number of variables present makes that high degree unrealistic. The following summarizes the situation:

1. Depths at time of drilling are measured from the ground surface. Following drilling, the land may be graded to unspecified depths. Once the well is in use, the casing top is a more usable reference point. The well altitude is seldom changed to reflect those conditions.

2. Depths to formation changes are dependent upon the driller. If drilling is proceeding rapidly, the driller may miss the depth by several feet, or may miss it entirely unless operating conditions change.

3. Depth-to-water readings oftentimes are merely approximated, or may be measured with electric tapes, air lines, depth of wetting on cables, bailer and tools, air pressure (for air rotary equipment), or other methods. Errors of 5 to 10 feet easily can be expected.

Water levels, as used here, are the levels recorded by the driller at the time of well completion. In parts of the Pasco Greenbelt and in Badger Coulee, water levels have changed appreciably owing to irrigation and drainage practices. Consequently, the water-table map in many locales reflects out-of-date data, corrected only if and where wells recently were drilled. Thus, water levels in the Pasco Greenbelt have changed several tens of feet in a 20-year period, and lowering by as much as 10 to 15 feet has occurred in a year's time owing to drainage practices and the pumping of many large irrigation wells. In the Badger Coulee Area, the levels have risen more than 100 feet since the 1950's when the Kennewick Irrigation District began operations there. Changes have been at a rate of about 5 feet a year. On Wahluke Slope, no new wells have been drilled in many years and the water level data are seriously out of date.

Irrigation wells usually are tested by pumps prior to placing the well in service. The tests commonly include a short-term step-drawdown test, followed by a short-term (commonly 4 hours) maximum rate test. In only three reported instances in the Pasco Basin (external to the Hanford Site) were observation wells used in the classical manner to determine the permeability and the transmissivity of the unconfined aquifer. They included two tests by the U.S. Bureau of Reclamation (currently known as the Water and Power Resource Service) near Smith Canyon, and one test by the Ranney Method Western Corporation for the City of Kennewick, near Finley. In no other instances, according to local pump companies and well drillers, were observation wells used to determine the aquifer properties. In about six known instances, nearby wells were checked to determine if interference existed.

Only one instance is recorded in which a well into the confined (basalt) aquifers was tested by using an observation well. Insufficient drawdown was noted in the observation well to permit an aquifer analysis.

Tests accordingly provide specific capacity data pertinent to sizing of the pump and depth of installation. Most domestic wells are tested by bailing (if the well is drilled by cable-tool rigs) or by the amounts of water blown from the well (if air-drilled). In the first instance, the bailing rate is normally only estimated; in the latter case, the drawdown is unknown and the amount of water blown from the well is estimated (seldom measured).

Transmissivities of the formations can be calculated from the specific capacities as indicated by Theis (1954) and Bierschenk (1959). Probably the inaccuracies in that calculation are no more than the combined inaccuracies in well location, altitude, depth to water, depth to formation changes, well construction, and other elements.

QUALITY ASSURANCE

The well log data used were verified by: (1) a review for obvious inconsistencies; (2) comparison of the materials as recorded to those recorded for adjacent wells; (3) determination of whether the data were

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consistent with the regional pattern or picture (is the log a meaningful sample); and (4) whether the altitudes of the respective units were consistent and logically explainable.

The use of obviously incorrect names for the units or materials encountered was of no concern, although cause for some suspicion. Realistically speaking, the presence of and depth to changes were the most important. The actual materials encountered in most instances were deduced from knowledge of the stratigraphic section, familiarity with the driller's use of terms, and by relationship to other, nearby wells.

Consistency from well to well was important, but changes from well to well were sought as a means of identifying trends. Hence decisions were made on whether indicated changes were valid, whether they were due to altitude or location errors, or to a difference in the use of words. The decisions often were made on a probability basis.

The principal problem in the post-basalt sediments was and is differentiation of the Ringold Formation conglomerate from the Pasco gravels, which commonly include reworked Ringold Formation conglomerates. Differentiation is important, both because of appreciably different hydrologic properties (permeability), but also because the interpretation of the development of the Pasco Basin subsequent to early Pliocene time hinges on that differentiation.

Newcomb, Strand, and Frank (1972) tabulated criteria for differentiating the two units. Even in many outcrops, however, the distinction is far from clear-cut. The differences in wells are much less evident and often are totally unrecognizable.

The stratigraphic relationships were and are helpful in an analysis of well logs. The basal gravels of the Ringold Formation are thin in the study area. They are restricted to the center of the Pasco syncline. They are everywhere overlain by the lowermost silts and clays of the Ringold Formation. The conglomerates, in turn, lie above the silts and clays in all but a few outlying areas where overlap evidently occurred. Hence, if a significant thickness of Ringold-type gravels occurs directly above basalt in the structurally low areas, the gravels likely are Pasco gravels derived by reworking of the Ringold Formation conglomerate.

The locale of the gravels accordingly is a site of extensive erosion that has to be logically explainable; in other words, other evidence has to indicate the cause of erosion and the patterns.

The in-place Ringold Formation conglomerates are low to only moderately permeable (Bierschenk, 1959). If well yields are high, the probability is high that the gravels are the Pasco gravels. This is due largely to the poorer sorting of the Ringold Formation conglomerates than the Pasco gravels and to cementation, more prevalent in the Ringold Formation conglomerates. Those features commonly are noted by drillers.

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In some locales, the Ringold Formation conglomerates conceivably could yield large volumes of water. This requires an adequately thick section, development of the total aquifer, and probably special well construction; hence well yield is still only indicative.

Work over the years with a variety of geologic and hydrologic problems has resulted in many analyses of conditions bearing on water procurement, drainage, soil stability, geologic structure, and stratigraphy. From those studies, patterns have developed. The current study is a review and coordination of those local studies supplemented by new data and a final evaluation of the conclusions.

Additional local data, particularly in areas such as Wahluke Slope, are expected to significantly modify the interpretations presented here. In most locales, most of the changes will result only in refinement of the present understanding.

STRATIGRAPHY AND STRUCTURE

The current study is oriented dominantly toward understanding the unconfined or water-table aquifer system. It is not primarily a study of either stratigraphy or structure. However, as pointed out, the different geohydrologic units have markedly different permeabilities; hence, stratigraphic identification in large part identifies the hydrologic properties. Moreover, structure is important, in that it identifies the position of the aquifers, consequently of recharge and discharge sites, and also can determine barriers to groundwater flow.

A review and analysis of the data from about 1,300 wells disclosed stratigraphic and structural features of possibly appreciable importance that were not otherwise detectable. The discussion relates dominantly to the findings of the well log analysis and as little as possible to background information and conclusions by others. The reader is referred to the earlier work insofar as necessary.

THE BASALT SURFACE

The current study deals dominantly with the post-basalt sediments. Complete dissociation from the basalts is, however, impossible and is not requested. Thus, the Ringold Formation (see Figure 2) sediments, the major part of the current study, interfinger with the uppermost basalt flows that locally pinch out (WPPSS, 1974). Interchange of water thus is possible between aquifers in those sites, as well as in some other geologic environments in the basin.

For practical purposes, the basalt surface is the lower limit of the current study. Plate 2, Structural Contour Map, Surface of the Basalt Sequence is the base map to which other maps are constructed and to which they relate.

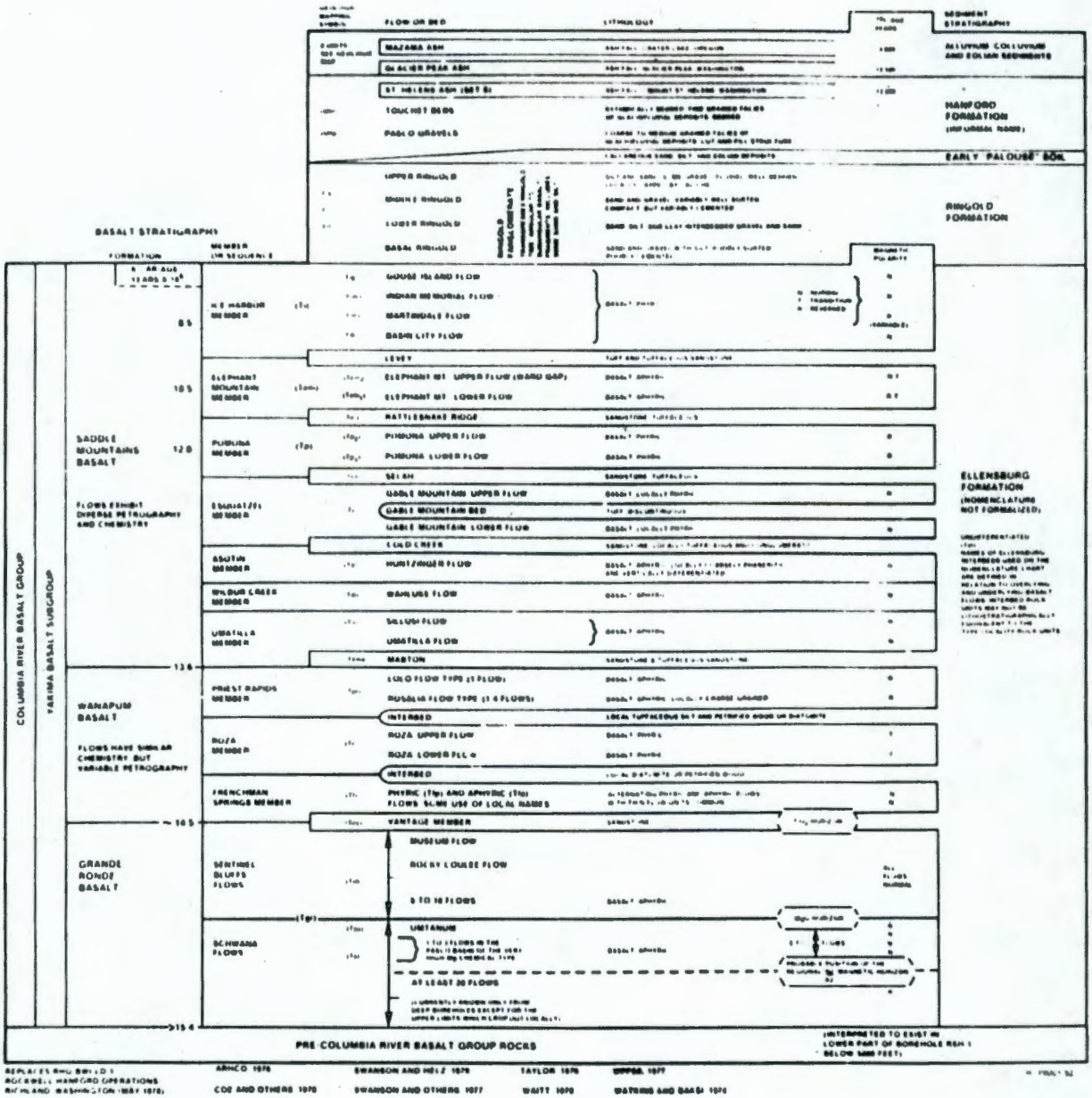

FIGURE 2. Pasco Basin Stratigraphic Nomenclature.

Construction of the basalt surface map served three principal purposes. First, it is approximately the division between the confined and unconfined aquifers, modified as later discussed. Second, it is a stratigraphic horizo that is readily recognizable by most well drillers although not always without error; hence it is the least likely horizon to be misidentified. Third, it is dominantly a structural as well as a stratigraphic surface. It is locally and importantly modified by erosion; moreover flow pinchout results in local step-down in the stratigraphic section toward the older flows.

The basalt surface is an excellent reference plane by which to identify such events as post-basalt deformation through the folding of later sediments.

Basalt generally dips radially inward at a low angle toward the basin center and low point under the Hanford Site. The radially inward dip is altered in the southern and southeastern parts of the study area by a series of northwest-southeast-trending anticlinal, synclinal, and monoclinal folds. Most of those folds are earlier identified, mapped, and studied (Bond and Others, 1978). They elongate the basin in an east-southeastward direction now followed by the Columbia River along the structural low from Richland to Wallula Gap. That low is the Pasco syncline, a major linear structure of the study area.

Between the Pasco syncline and the Horse Heaven Hills that bound the basin to the south is a series of parallel structures that repeatedly have been studied, though not by the use of data from wells. They are most distinct in the Horn Rapids "peninsula" (the McWhorter Canal bench of Bond and Others, 1978). They become less prominent and distinct southeastward. They include, from north to south: (1) the Horn Rapids lineament, an alignment of elongate domes or doubly terminated anticlines, and intervening, local, monoclinal folds that may be faulted and are extensively eroded; (2) the Lewis and Clark (L-C) Angus Ranch syncline, the axis of which follows the McWhorter Canal of Bond and Others (1978); (3) the Rattlesnake-Wallula lineament, another group of elongate domes, some faulting, and some monoclinal folding; (4) a minor syncline trending nearly east-west south of Badger Mountain; (5) the Goose Hill anticline, Badger Coulee monocline and fault axis; and (6) the Badger Coulee syncline. All the above structures converge and become less prominent southeastward. At Finley, only the Rattlesnake-Wallula lineament persists north of the main Horse Heaven Hills.

The combined Badger Coulee syncline and the adjoining Goose Hill anticline-Badger Coulee monocline and fault axis are the least well known of the listed features; potentially, it is highly significant overall.

The coulee has been considered (Bond and Others, 1978) to be largely erosional; hence it is comparable to some of the coulees of the Channeled Scabland. Outcrops substantiate considerable erosion. Well data, however, show that from Gander Hill (named by Bond and Others, 1978), in Section 8, Township 8 North, Range 28 East, westward the basalts are profoundly downwarped and probably down faulted beneath the coulee fill into the Badger Coulee syncline.

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Eastward and northeastward from Gander Hill and particularly beyond the coulee bend to the northeast, folding is less significant and erosion was of increasingly greater impact in forming the coulee.

Normal stream erosion and the impact of the glacial Lake Missoula floods eroded much of the north limb of the Badger Coulee syncline. Following the erosion, up to about 300 feet of sediments buried the critical parts of the structures.

The Badger Coulee syncline is sharply asymmetrical with a south limb that rises gently toward the crest of the Horse Heaven Hills. The north limb is nearly vertical and probably is faulted because of the very sharp folding that occurred. Total stratigraphic offset is about 400 feet (see Plates 2 and 11, Cross Section C-C'). The monoclinal fold on the north limb of the syncline probably passes into the Goose Hill anticline to the west, to the east into the Badger Coulee faults identified by Bingham and Others (1970) adjacent to Gander Hill, and in the Coyote Canyon area to the east.

The coulee evidently served as the course of the ancestral Yakima River prior to diversion of the river northward to Horn Rapids. Probably diversion was caused by one of the glacial Lake Missoula floods that swept westward up the coulee into the lower Yakima Valley. As floodwaters ebbed, the coulee-fill sediments were laid down, blocking the coulee and making the Yakima water gap near Horn Rapids the preferred course. Bond and Others (1978) consider, on the basis of their interpretation of the morphology of Badger Coulee and certain gravels, that the course was that of the Columbia River. It presumably flowed south to Benton City, then eastward nearly to Richland.

Data from wells south and southwest of Badger Mountain suggest that several of the basalt flows and aquifers are exposed in the north wall of the coulee and are subject to recharge beneath the coulee-fill materials. The most logical site for recharge is near Gander Hill. The potential is later discussed.

Several features on the basalt surface north and northeast of Pasco are geologically and hydrologically important. The axis of the Pasco syncline in this area lies about a mile north of and parallel to the Columbia River. Its location bears on the yields of wells in the Kennewick and Pasco areas. Rising southward toward the Horse Heaven Hills (within 3 miles of the river), basalt rises above the water table; hence yields of wells in Kennewick are generally low, with the best wells close to the river. Northward, in the Pasco Greenbelt, the basalts rise at a gentler angle and rise above the water table 5 and more miles north of the synclinal axis. The axis location, the lower altitude of the basalt with distance northward compared to the southward rise, and the abundant supply of irrigation water that recharges the greenbelt aquifer assure a water table above the basalt to the north. This is later discussed.

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Four miles north of the Columbia River, a single line of small, subsurface buttes was suggested by well data (see Plate 2A). The line trends north 78 degrees west, nearly parallel to the axis of the Pasco syncline and the north face of the Horse Heaven Hills. Each of the buttes is indicated by a single well, suggesting domes akin to those along the Horn Rapids and Rattlesnake-Wallula lineaments. The orientation of the line and its form imply a possibly significant tectonic axis.

The buttes are structurally too high for their presence to be due solely to errors in altitude, especially where the topography has little relief. An examination of the well logs shows no record of the driller of three wells. The driller of the fourth well is one whose well logs commonly are somewhat unreliable. Possibly several of the buttes are non-existent and their location along a presumed tectonic axis fortuitous.

The basalt surface is gently undulating eastward to the Jackass Mountain axis of folding. There the basalts were gently folded, as a very low and broad anticline northward (beyond Eltopia). Southward, toward Pasco, the fold appears to be a gentle monocline. The west side, toward the basin center, dips steeper than the east side, though only at a slope of about 50 feet per mile. Well data also suggest that the basalt section thickens markedly westward from the fold axis, with the younger basalt flows restricted to the west side of the fold.

The axis of folding apparently extends nearly from the east end of the Saddle Mountains possibly to Newcomb's (1965) Divide anticline that separates the Walla Walla and Pasco Basins. The flexure thus borders the Pasco Basin on the east.

The Jackass Mountain flexure evidently helped localize the ancestral Columbia River west of the axis of folding. During the glacial Lake Missoula floods, the flexure may have helped divert the floods down Smith Canyon that parallels the fold axis immediately to the east. Smith Canyon now crosses the fold axis about 5 to 7 miles north of the Snake River. The east branch of the canyon (see Plate 2) closely follows the basalt that rises on the east bank. This sharply bounds the water-table aquifer on the east. Farther east, only confined waters in the basalts are available.

The floods down the west fork of Smith Canyon entered what is now the Pasco Greenbelt. Scouring of channels in the Ringold Formation sediments and their filling with the permeable Pasco gravels provide the basis for high-yield wells there.

Esquatzel Coulee is a similar, though much smaller, coulee that nearly pinches out across the axis of the flexure about 3 miles south of Eltopia. The coulee increases in size from that point southward, probably reflecting increasing convergence of runoff southward from lands inundated by the Missoula floods.

Smith Canyon and Esquatzel Coulee currently are important drainages for the South Columbia Basin Irrigation District, as later discussed.

THE RINGOLD FORMATION

The precise range and extent of the Ringold Formation are not laterally or vertically defined. For practical purposes, in the Pasco Basin the type locality of the formation is considered to extend to the underlying basalt (Newcomb, 1958; Brown and McConiga, 1960). The formation as considered here represents a period of sedimentation continuing beyond the emission of the latest basalt flows.

The Ringold Formation sediments, however, lie atop several different basalt flows. In the southern part of the Pasco Basin, they lie atop the Ice Harbor flows; elsewhere, they lie atop basalts successively lower in the section. Grolier and Bingham (1971), for instance, mapped the Ringold Formation overlying the Priest Rapids and Roza Members in the Quincy Basin.

The lowermost part of the formation in the center of the Pasco Basin thus may be considered as interfingering with the later basalt flows (WPPSS, 1974). If, however, we use the latest basalt flow as terminating the formation downward, a workable sequence can be considered present.

Newcomb (1958) divided the formation into three members, a lower "blue clays," a conglomerate, and an upper silt and sand. Although somewhat arbitrary and atypical as later noted, the division is useful.

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The Basal Gravels

Throughout the current central part of the basin, the sediments immediately overlying the basalt are sands and gravels; in this report, they are referred to as the Ringold Formation basal gravels (see Plates 3, 4, 10, and 11). The isopach map of that member of the formation and the geologic cross sections show that the basal gravels in the study area extend south and southeastward along the east side of the Hanford Site along the axis of the Pasco syncline. They are traceable to the Pasco area where they evidently pinch out and grade into finer sediments.

Their presence along the axis of the Pasco syncline indicates that the syncline was already in existence and controlling the course of the Columbia River.

The basal gravels, because they lie beneath silts and clays of the lower part of the formation, commonly contain confined and locally artesian water. In the area from the 300 Area of the Hanford Site through North Richland, Richland, West Richland, and the Island View area of Richland, wells drilled through the confining silts and clays into the basal gravels commonly flow at low heads and low rates (generally a few gallons per minute). The aquifer is later discussed.

The Silts and Clays

Drillers' logs, as far back as 1909, have recorded silts and clays overlying the basalts in the Pasco Basin. They are referred to as "blue clays," although they are largely silts and siltstones that are blue-gray to gray and gray-green. Where they are weathered and have been exposed to air, they are tan to buff or brown. The transition in some sites reflects a one-time water table or even a ground surface level.

Stratigraphically higher silts and clays, though tan in color, in many sites are identical to the lowermost silts and clays, but merely have been in an oxidizing environment.

The lowermost silts and clays are best known from wells, but outcrops occur along the Columbia Irrigation District canal between Kennewick and Finley, near Meadow Springs, and at a few locales along the Yakima River near Richland. In this report, they are referred to as the lowermost silts and clays to differentiate them from the stratigraphically higher units later discussed.

The lowermost silts and clays occur as a major part of the Ringold Formation in the basin center. There, as shown on the structural contour map and the cross sections, the silts and clays are warped and folded with the underlying basalts along the axis of the Pasco syncline and over the folds toward the Horse Heaven Hills. The structural contour map of the silts and clays, the isopach map, and the geologic cross sections show less deformation in those silts and clays than in the underlying basalts; hence were deposited during deformation that continued for an unknown time period, perhaps to the present.

The isopach map of the silts and clays shows a near symmetry in thickness of the unit across the Pasco syncline. The edge of the unit north of Pasco is about 350 feet in altitude; whereas south of Kennewick and to West Richland, it is up to about 650 feet in altitude. It suggests that deformation following deposition of the unit was greater between the Pasco syncline and the Horse Heaven Hills than from the syncline to the Jackass Mountain axis. This affects the yield of wells in the Kennewick area just as does the basalt, compared to the Pasco Greenbelt Area.

Deposition of the lowermost silt and clay probably resulted from basining. Basining continued, as indicated by the mild deformation of the beds along the east side of the Pasco Basin, away from the anticlinal structures. Subsequent anticlinal uplift, especially of the Horse Heaven Hills, then warped those silts and clays. Probably, the anticlinal uplift in turn aided deposition of the later Ringold Formation sediments as first suggested by Flint (in Waters, 1955).

The pattern of distribution of the basal gravels as well as the later silts and clays also suggests that the Columbia River already was flowing in a course that would take it to the structural low in the Horse Heaven Hills at Wallula Gap.

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The sediments above the "blue clays" are gravels. Newcomb (1958) referred to them as conglomerates, owing to the partial-to-effective cementation. That practice is followed here. They are overlain by buff colored silts and sands of the upper part of the formation.

If the lowermost silts and clays were deposited largely as a result of basining, the Ringold Formation conglomerate then conceivably may mark a hiatus in deformation, as suggested by Newcomb (1959). The hiatus then probably was terminated by the beginning of uplift or alternatively by a more rapid uplift of the Horse Heaven Hills.

The three-fold division of the formation, as suggested by Newcomb (1959), although workable, is arbitrary. First, the division ignores the basal gravels that, though thin, are a significant artesian aquifer. Second, the "blue clays" (which are largely silts) lie in the basin low and pinch out, especially northward and eastward. Additional silts and clays are present at stratigraphically higher positions (see Plates 5, 6, 10, and 11). Those higher silts and clays are facies variants of coarser grained sediments in the White Bluffs that lie above the lowermost silts and clays. Third, the type section near Ringold evidently lies on the edge of the basin and, hence, is somewhat atypical of the entire formation. Conclusions based on that atypical nature are not necessarily valid overall.

The principal locales of the higher silts and clays are adjacent to the Jackass Mountain flexure and on Wahluke Slope. Both sites evidently were on the basin margins at the time of deposition of the Ringold Formation and northeastward of the main-stream Columbia River. That main-stream course is now marked by the conglomerate that lies south of Sentinel Gap (see Plate 10, Cross Section A-A') and by the abundance of gravel beneath the Hanford Site at many different horizons.

We can conclude that the formation is largely a floodplain deposit in which the gravels mark the main-stream deposits through the basin center and low, and the finer sediments to the northeast mark the quieter water and overbank deposits. This agrees with the initial findings of Merriam and Buwalda (1917), McKnight (1923), and with the findings of Gustafson (1978) based on the fossil record and the habitat indicated by those fossils. It differs from the concept of Newcomb (1958), who proposed a lacustrine origin. The concept is further developed later in this report.

The distinction between the lowermost silts and clays and the stratigraphically higher, facies-variant silts and clays is emphasized northeast of Pasco. There, the glacial Lake Missoula floods scoured out much of the gravelly sand and sandy silt laterally intervening between the two silt-clay bodies, and physically separated them. Elsewhere, as on Wahluke Slope, the distinction is gradational and the boundaries of the higher silts and clays are only approximately located. This is a problem because the gradational contact had to be located on the basis of well logs by different drillers, potentially using somewhat different terms for the same material.

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The northeast edge of the lowermost silts and clays parallels the Jackass Mountain flexure that lies 5 to 8 miles to the east and northeast. It suggests that the flexure existed as a basalt high during the deposition of the silt and clay, thereby precluding sediment deposition farther eastward. The stratigraphically higher silts and clays were deposited farther to the east owing to the higher level of impoundment of the Columbia River; consequently they are found at least 7 miles east of Smith Canyon. In Townships 10 and 11 North, Range 32 East, several wells encountered compact silts, sands, and clays up to nearly 1,000 feet altitude, the approximate maximum altitude of the formation in the Pasco Basin.

On Wahluke Slope, the lowermost silts and clays continue upward into identical materials without a break; likewise to altitudes of nearly 1,000 feet. Wahluke Slope evidently was continuously a backwater or overbank area throughout all of Ringold Formation deposition.

The silts and clays are discontinuous downstream from the junction of the Snake and Columbia Rivers in the Finley and Burbank areas. Important deposits are present, however, from the southern part of the McNary Wildlife Refuge (Burbank Slough area) along the east side of the Columbia River south past the Boise Cascade plant, the feedlot, and packing plant area, and past Wallula to Wallula Junction. Wells indicate thicknesses of silt and clay up to about 150 feet and to altitudes of 500 to 600 feet (see Plate 5).

Silts and clays are absent on the lowlands in the east Kennewick to Finley areas. Their scattered presence on the east side of the Columbia River at Wallula suggests that floods swept down the Snake River and joined floods down Smith Canyon and Esquatzel Coulee. The resulting floods completely removed the Ringold Formation in the downstream area below the 350-foot altitude and exposed the basalt.

The bore concept is important in regard to identification of gravels in the Finley and Kennewick areas, and better determination of the properties of the resulting aquifers. It also identifies a locale where the lowermost silts and clays no longer confine deeper waters (in the basal gravels and the uppermost basalt flows). Discharge of those confined waters, hence, must occur into the Columbia River.

The Ringold Formation Conglomerate

Newcomb (1958) considered the gravel (conglomerate) of the Ringold Formation to be the middle part of the formation. This is so in the White Bluffs; elsewhere in the basin, however, the arbitrary division breaks down. Thus gravels are absent on the northeast side of the basin. On the Hanford Site, the Ringold Formation gravels are up to several hundreds of feet thick and, in the Richland area, gravels and the "blue clays" are complexly interfingered. Basically, the type locality of the formation lies a few miles east of the center and low point of the basin where presumably the most representative materials of the formation were deposited.

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Gravels can be found at nearly all stratigraphic levels somewhere in the basin. This implies that true impoundment of the Columbia River probably never occurred, that a main stream Columbia continued to flow through the basin, and that the Ringold Formation is fundamentally not a lacustrine but a floodplain and probably shallow-lake deposit.

Gravels occur directly over basalt just south of Sentinel Gap (see Plate 10, Cross Section A-A') and grade laterally eastward into the silts and clays of the lowermost part of the formation there. No silts and clays occur immediately south of Sentinel Gap, as indicated from well logs from less than 400 feet to approximately 1,100 feet in altitude.

The data suggest that the silts, clays, sands, and gravels of the Ringold Formation in the Pasco Basin were likely deposited in response to local conditions of sedimentation and their impact on a through-flowing river rather than on a truly dammed and impounded stream.

The conglomerates occur in a course trending southeastward across the Hanford Site more or less directly toward Wallula Gap (see Plate 7), as earlier indicated by Newcomb (1958). This then conflicts with the concept of Bond and Others (1978) that the Columbia River may have flowed to Benton City, then eastward through Badger Coulee. Stratigraphic evidence for that postulated, possible course is necessary.

The eastern boundary of the conglomerate is reasonably well defined. This is partly because drillers traditionally look for gravels to yield water and had no difficulty in identifying them. Also, the facies gradation from gravel to sand occurs relatively abruptly (see Plate 10, Cross Section B-B') in contrast to the boundary of the silt-clay facies variant. In addition, the facies change commonly is by interfingering of gravel and sand lenses. The silt-clay facies change occurs gradually and probably by thin interfingering beds that were not recorded (if even noted) by well drillers near the boundary.

The conglomerate boundary to the east parallels the Jackass Mountain flexure, as do the lower units already discussed. The flexure probably existed as a steepening of the basalt dip, better localizing sediment deposition.

The conglomerate overlies the lowermost silts and clays near the Jackass Mountain flexure. It indicates an accumulating basin fill resulting from the Horse Heaven Hills uplift, in contrast to the basining that caused (or contributed significantly to) deposition of the lowermost silt-clay deposits.

Conglomerates are absent in and a short distance downgradient from Esquatzel Coulee and absent to a greater distance below Smith Canyon. They are absent in the Burbank area, but occur beneath the McNary Wildlife Refuge and the Wallula area, where they are underlain by the Ringold Formation silts and clays.

The conglomerates are less extensive in the Burbank to Wallula area than those underlying silts and clays. This contrasts to the area north of Pasco, where they overlap the silts and clays. South of the Columbia River-Snake River junction, the gravels were clearly eroded by the floods. Both the gravels and underlying silts and clays were eroded in the Finley area, where the flood impact evidently was the greatest and continued the longest. In the McNary Wildlife Refuge area, the conglomerate was largely protected by higher basalt to the east and north. Moreover, the floods (sweeping down the Snake River) directly impacted the area from east Kennewick to Finley and were spreading northward and also moving to Wallula Gap.

Positive identification of the Ringold Formation conglomerate often is difficult, even in outcrops. Where the materials are encountered in wells and noted only by drillers, identification is doubly difficult, if even possible. Newcomb, Strand, and Frank (1972) cited criteria that greatly aid in identification, but each criterion oftentimes applies to the later Pasco gravels as well. In many instances, all criteria used by Newcomb (1958) may be insufficient for identification. This is particularly so where the Ringold Formation conglomerate was reworked, redeposited, and sometimes partly recemented.

The Ringold Formation conglomerate is best identified from well data if cementation were noted, if sand were cemented to the gravel surface, if the well yielded little water during drilling, and if a test with a pump showed an appropriately low-specific capacity. Because of the overlap of properties with the Pasco gravels, the presence or absence of the conglomerate still must be logically explained.

The Badger Coulee Area and the area from Kennewick to Finley are critical locales where Ringold-type materials abound and where their identification is important.

The lowermost Ringold Formation silts and clays are absent from the low bench at Finley, although they occur above the 350-foot altitude behind the Columbia Irrigation District canal, above a 300-foot altitude at Wallula, and in the river bed above the junction of the Columbia and Snake Rivers. Undoubtedly, they once existed in the intervening area where they had been deposited. Non-deposition can be ruled out. The conglomerates then were laid down atop them, also in a depositional environment. We can expect, in the structural lows, that areas lacking the lowermost silts and clays of the Ringold Formation will also, because of erosion, lack the conglomerates.

The Kennewick to Finley area, with extensive Ringold-like materials directly overlying basalt, must be considered as a locale of extensive scouring. This is because of the absence of the silts and clays, and because of the position downgradient of the Snake River and the several coulees. The Ringold-type gravels occurring there must have been eroded from the Pasco Greenbelt by the floods, and must have been transported to and deposited on the slopes rising toward the Horse Heaven Hills.

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Some true, in-place conglomerates probably occur above the Columbia Irrigation District canal in the Finley area, above the level of effective scouring and redeposition. There, the locally cemented gravels overlie the Ringold Formation's lowermost silts and clays that, in turn, lie on basalt. The gravels are overlain by the Touchet Beds silts and sands. Hopefully, additional wells will be drilled in this area to help resolve the effects and altitudes of scouring and redeposition.

The conglomerates in the Pasco Greenbelt Area are identifiable, in most instances, from the well logs. There, the transported sediments were largely derived from the basalt plateau upgradient of the greenbelt. The redeposited sediments are largely basaltic in composition, or are silts, sands, and clays derived from upstream outcrops of the Ringold Formation.

Badger Coulee is a feature where the presence or absence of the Ringold Formation conglomerates is critical to a determination of the coulee origin. Bond and Others (1978) considered that the Columbia River may have flowed southward from Horn Rapids to Benton City, thence eastward down the coulee to Richland. Part of the evidence is the presence of "late Tertiary river gravel of numerous crystalline and metamorphic lithologies" (Ringold-type gravels). Well data, which were not then available, now show that the gravels are up to 150 feet thick (see Plate 11, Cross Section C-C'). If the gravels were deposited by a normal Columbia River flowing through the coulee, then a considerable time span would be required and its absence from the main Pasco Basin and the structural low then present would also be required.

The coulee certainly was in existence at the time of the floods, probably as a Yakima River course following the Badger Coulee syncline. The undoubtedly high flow rate of the Yakima River in the Pleistocene Epoch would have been adequate to erode the course. Once the river passed Gander Hill, it flowed downdip of the basalt flows on the north slope of the Horse Heaven Hills.

Floods, pouring down the Snake River, Smith Canyon, and Esquatzel Coulee, found Badger Coulee to be the principal access to the lower Yakima Valley. As later discussed, magnitudes of the floods down the Snake River were so great that extensive scouring of the Pasco Greenbelt and the Kennewick-Finley Areas resulted. The Ringold Formation conglomerate, there stripped, likely was transported to and deposited in the coulee as the flood levels rose. As heads rose sufficiently to decrease the flow rate, the silts and sands of the Touchet Beds were deposited up to 150 feet thick. It also seems likely that the floods, initially entering the Yakima Valley through the Yakima water gap at Horn Rapids and the Badger Coulee, must have significantly scoured the coulee prior to deposition of the gravels.

More than 16 wells penetrate to basalt in the coulee. Some well logs report clays, but much of the clay appears related to the Touchet Beds, not to Ringold-type materials. Other reported clays appear patchy and discontinuous, do not continue from well to well, and are irregularly

distributed in the stratigraphic section, suggesting pulsating floods rather than slow sedimentation.

The absence of clays below the gravels helps indicate that the gravels were reworked Ringold Formation gravels rather than the conglomerates in place.

Tests on wells show yields that in six instances are too high for normal Ringold Formation conglomerates. The depth of the coulee permits deep wells, however, so that even relatively low permeabilities could convert to high yields. However, the wells are screened or perforated over limited intervals in the aquifer, rather than over the entire aquifer. The specific capacity numbers then are indicative of the Pasco gravels (see Appendix).

THE HANFORD FORMATION

The Hanford formation, a currently informal stratigraphic term, includes the Touchet Beds and the Pasco gravels. It thus includes the glaciofluvial sediments of Newcomb, Strand, and Frank (1972). It is discussed here only briefly, insofar as it affects the unconfined groundwater hydrology, principally in the Pasco Greenbelt Area. There, the greatest volumes of groundwaters of any part of the unconfined aquifer of the study area are present and flowing.

The formation was deposited by a sequence of floods, with the actual number in the Pasco Basin yet uncertain. In much of the southern part of the basin, two well-graded sequences of flood deposits are visible. Well logs commonly record one, two, and locally three such sequences. They include coarse (often boulder) gravels that grade upward into finer gravels, sands, and into the silts and sands of the Touchet Beds. Depending upon the conditions that prevailed at a given locale, gravels, sands, and the silts and sands of the Touchet Beds occur at several stratigraphic levels, as well as facies variations within a given bed.

The relative volumes of water carried by the Snake River, the Columbia River, Esquatzel Coulee, Smith Canyon, and other coulees are not known. The extent and size of Smith Canyon (see Plate 2) certainly indicate huge floods there; possibly, they approached (in orders of magnitude) the floods down the Snake River. Floods down the Columbia River, especially swollen by floods down Ringold and other coulees, were also huge; however, they spread out in the wide part of the Pasco Basin (the Hanford Site). Consequently, the greatest erosional impact from the floods in the south part of the Pasco Basin would be from the combined flows from the Snake River, Smith Canyon, and Esquatzel Coulee. This is especially the case when we consider that those floods probably significantly preceded the floods down the Columbia River, which was forced to take a more circuitous and longer path.

The floods down the Snake River had virtually no chance to dissipate their energy due to a gross enlargement of their channel size until they

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emerged from the Snake River canyon, literally in the Pasco-Burbank area. Hence, extensive erosion and deposition, probably as far upstream as Richland and West Richland, may have been dominated by the Snake River floods. This is further indicated by distribution of grain size of the flood deposits and by such features as deltaic foreset bedding and imbricate structures. This is substantiated by both well and field data.

Because the highway and railroad between the Tri-Cities and Spokane pass along the Esquatzel Coulee, its location and geology are well known. It currently drains much of the irrigation runoff water from the South Columbia Basin Irrigation District. The coulee nearly pinches out at the axis of the Jackass Mountain flexure 3 miles south of Eltopia. Hence, it could not have been a major drainage for the Missoula floods; probably, it carried water only during the peak flow.

Basalt in the floor of Esquatzel Coulee lies at a maximum altitude of nearly 600 feet. In Smith Canyon, well data indicate that basalt south of Eltopia is at a maximum altitude of about 400 feet. The depth and indicated width of Smith Canyon clearly indicate that it carried many times the flow that Esquatzel Coulee did. In addition, well data indicate several periods of canyon cutting and filling, corresponding to the noted sequences of graded deposits.

Well data also indicate that the canyon is bifurcated, with basalt septa dividing the coulee. One branch swings southward to the Snake River, following the surface expression of the canyon, and bordered on the east by the rising basalt. The other branch swings southwestward, without surface expression, toward the Pasco Greenbelt Area.

The subsurface form of the coulee is verified by geologic and hydrologic evidence. Facies-variant silts and clays are truncated by the coulee, and the conglomerate is absent downslope from the coulee. The water-table contours (Plate 8) show gradient and, thus, flow down the coulee. The transmissivity data indicate large volumes of flow along this reach (Plate 9, also in Appendix). All plates were constructed independently of each other, then integrated into a single, consistent, whole picture. Thus, geologic and hydrologic evidence corroborate the extent and location of the coulee.

The coarse-grained glaciofluvial sediments (the Pasco gravels) are by far the most permeable sediments in the Pasco Basin. Where they are present below the water table, well yields commonly are 1,000 to 3,000 gallons per minute or even more. Consequently, tracing of the scour channels filled with those gravels is important in the location of irrigation wells.

In materials such as the Ringold Formation conglomerate, yields of wells are much lower, normally a few hundreds of gallons per minute. If a thick enough section of conglomerate were saturated and penetrated by a well, yields could approach possibly 1,000 gallons per minute or even more. In most instances, however, the conglomerates are terminated at shallow depths by the silts and clays and basalt, thus precluding high yields.

GROUNDWATER HYDROLOGY

The Columbia River is the discharge location for the unconfined groundwaters in the Pasco Basin. Insofar as here determined, it is the base level for the confined aquifers in the upper part of the basalt sequence as well. To a lesser extent the Yakima, Snake, and Walla Walla Rivers act as base level, but generally only in their lower reaches where they flow over the basin-fill sediments of the Pasco Basin. Plate 8 shows gradients toward and into the Columbia River from all directions.

The Snake River above Ice Harbor Dam, the Columbia River above Priest Rapids and Wanapum Dams, and the Yakima River from its mouth increasingly upstream tend to be, at least locally, losing streams that discharge some water into the bank areas.

The water-table gradient indicates that the dominant natural recharge of at least the unconfined aquifers lies in the anticlinal ridges and higher lands surrounding the basin. Most of the natural recharge is from rain and snowmelt runoff, probably concentrated in canyons that ultimately debouch upon and into the basin-fill sediments. This is also true to some extent of the confined aquifers in the upper part of the basalt sequence.

The amount of recharge from natural sources is not yet known, but must be small owing to the deficiency of precipitation compared to evaporation. This is especially so in the dry years such as 1976-77. However, a clear-cut lowering of water tables resulting from that water-short year is not known to have been reported. Either small volumes of water are moving in the aquifers or other sources of recharge, such as irrigation must be appreciable compared to natural recharge.

The Pasco Basin is irrigated by four dominant irrigation districts, including:

1. The Columbia Basin Irrigation Project, through the South Columbia Basin Irrigation District

2. The Kennewick Irrigation District

3. The Columbia Irrigation District

4. The Franklin County Irrigation District.

Numerous private systems pump from the various rivers. The largest of these is the Lewis and Clark (L-C) Angus Ranch system that pumps from the Yakima River above Horn Rapids Dam. It irrigates more than 12 square miles in the Yakima Horn peninsula (via the McWhorter Canal of Bond and Others [1978]), and has created its own unconfined aquifer.

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In most instances, rising water levels with time as more land is irrigated and the creation of more and more drainage problems clearly indicate the importance of irrigation to recharge of the water table or unconfined aquifer. The water available for recharge includes leakage from canals and wasteways, surface runoff from irrigated land, discharge or spillover of excess irrigation water, and seepage to the water table from the irrigated land itself.

Currently, water balances in the irrigated areas have not been determined, except for the Pasco Greenbelt Area. Even there, the pumping rates are not known except for the U.S. Army Corps of Engineer's facilities. In most instances, only the pump rating is available, and the amount of water used and the amount lost at various points can only be estimated. That losses are considerable are recorded in such studies as that of the U.S. Army Corps of Engineers (1978) in the Pasco Greenbelt Area, where the onset of the irrigation season in the West Pasco (Riverview) area is marked by a 3-foot rise in the water table. Groundwater conditions within the study areas listed are discussed individually in the following sections. The reader is referred to the accompanying plates for reference geographic locations, except where other figures have been provided.

THE PASCO GREENBELT AREA

History of the Area

The Pasco gravels are most prominent and abundant in the Pasco Greenbelt Area of the study area. There, the geologic structure, stratigraphy, and impact of the glacial Lake Missoula floods have combined to provide the highest yield aquifers in the study area. An over plentiful supply of imported irrigation water recharges the aquifer and assures a water table high enough for most needs.

Irrigation development via wells and the geologic conditions present have resulted in local over-pumping in some locales, although drainage problems have developed elsewhere. Consequently, more detailed geologic and hydrologic studies have been conducted there than in any other single locale in the Pasco Basin external to the Hanford Site.

Plate 8, the unconfined water-table map, shows the approximate gradient and levels of the water table as determined from recently reported levels, largely new wells. Previous reports (for example, Walters and Grolier, 1960) show water-table levels as they were prior to irrigation recharge.

The magnitude of the change in 20 years is readily apparent. At the lower ends of Smith Canyon and Esquatzel Coulee, levels rose more than 100 feet. This is in spite of pumpage from irrigation wells in both coulees.

Farther down gradient toward the Columbia River, the levels show a progressively lesser rise until, at the Columbia River, levels are as noted in 1959.

The U.S. Army Corps of Engineers, as part of the McNary Dam project, constructed aboveground and underground levees to protect low-lying parts of Pasco and Kennewick from the waters of Lake Wallula. The levees are founded on the impermeable silts and clays of the lowermost part of the Ringold Formation. Free movement of river or groundwaters beneath the levees is precluded.

Collection ditches behind the levees collect groundwaters draining toward the Columbia River and divert them to pumping stations. There, they are lifted into the Columbia River. Automatic controls maintain levels of 330 to 332 feet altitude at the pumping stations. This is the pre-McNary Dam level of the river and water table there.

In the Pasco area, one pump station lies at Road 56 and the levee (332 feet altitude); the other at the continuation of Illinois Street and the levee (Northwest 1/4, Section 31, Township 9 North, Range 30 East). Over the years, the pumping rate at the Illinois Street station has steadily increased and is now more than double its original rate. The rate at Road 56 is nearly unchanged. The change in pumping rates reflects increasing drainage from the South Columbia Basin Irrigation District, but the lack of change at Road 56 reflects geologic barriers that divert the increased drainage away from the Road 56 station and toward the Illinois Street station. Consequently, groundwaters unable to escape to the river via their normal paths were diverted into unnatural courses and effectively ponded. By 1969, increasing irrigation runoff combined with increased pumpage into the area by the Franklin County Irrigation District resulted in the water table surfacing at Road 52 and Pearl Street. For several years, the water table rose at an annual rate of 6 inches a year.

The Walla Walla District of the U.S. Army Corps of Engineers, responsible for lands immediately adjoining Lake Wallula, constructed a pumping station at Road 52 and Pearl Street to dewater the area. A drain line was installed beneath Road 52 into the Columbia River. Pumps with a capacity of 6,000 gallons per minute began operating. The water table at the pump site was lowered about 6 feet, but only a few inches at 1,000 feet away. The data confirmed that the locale lay on the south side of a very highly permeable area.

The groundwater problem was compounded by construction of a pumping station by the Franklin County Irrigation District between the Road 56 station and the Road 52 outfall. Its purpose was to better pressurize the irrigation lines. Accurate records of the pumping rate at that station or the station at the west center of Section 18, Township 9 North, Range 29 East that feeds into the canal system are not known.

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The U.S. Bureau of Reclamation, under pressure to reduce the impact of runoff from the South Columbia Basin Irrigation District, constructed a pumping station at the junction of Selph Landing Road and Glade North Road (mouth of Esquatzel Coulee). Water that was threatening to reach the Tri-Cities Airport via surface channels was pumped into the Esquatzel Wasteway and discharged into the Columbia River. The effect of the pumping station was noted at the Illinois Street pumping station.

Ultimately, the pumping stations and extensive irrigation from wells in the Pasco Greenbelt Area resulted in falling water levels and decreasing yields of some wells. This resulted in the U.S. Army Corps of Engineers' study (1978).

Geology of the Area and Transmissivity Values

The geology of the Pasco area, centering on the greenbelt, was determined using all available well logs. Many wells had been tested for specific capacity; those specific capacity numbers then were converted to transmissivity values using the equation:

$$T = Q/s\ (1{,}700)$$

where T is transmissivity in gallons per day per foot, Q is quantity of water pumped, and s is the drawdown at that pumping rate (Theis, 1954; Bierschenk, 1959). The resulting T values are, of course, approximations that are subject to variation depending on size of the well, accuracy of measurement of pumping rate, accuracy of measurement of drawndown, efficiency of the well, and whether equilibrium was achieved. They are intended to provide relative value.

The transmissivity values were determined from about 100 wells (see Appendix) where specific capacity tests had been run. This is an average of about one value per square mile. Plotting of contours (Plate 9) clearly reflected the effect of geology there; hence, provided quality assurance of the validity of the concepts determined.

A very low-yield zone (less than 10,000 gallons per day per foot) borders and evidently underlies the Columbia River, at least from west Pasco and probably west Kennewick across from Burbank. It reflects the presence, near the water table, of the low-permeability silts and clays of the lower part of the Ringold Formation. South of the axis of the Pasco syncline, those sediments rise steadily toward the Horse Heaven Hills at a greater rate than the water table, effectively thinning the aquifer. Beyond the Snake River where the silts and clays are eroded, the underlying basalts are progressively closer to, then in, the river bed causing the aquifer to thin and pinch out downstream.

The yields are consistently higher northward from Pasco reflecting the effect of the Pasco syncline and the downfolding of the silts and clays appreciably below the water table. Beyond Selph Landing Road, the silts and clays, and ultimately the basalts, rise sufficiently high to thin and finally to terminate the unconfined aquifer.

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The geology, as confirmed by the transmissivity values, clearly shows why drainage problems have developed in west Pasco and why the pumping stations have proved inadequate in dewatering the area.

The highest yield wells, producing 3,000 or more gallons per minute, lie in a rectilinear pattern formed by zones trending north-northeast and west-northwest. Those zones are, respectively, the sub-surface continuations of Esquatzel Coulee and Smith Canyon and an ancestral Columbia River channel, all evidently cut during the glacial Lake Missoula floods. Those channels, now filled with highly permeable Pasco gravels, are the principal high-yield aquifers of the Pasco Greenbelt Area. Elsewhere, where such channels do not exist, such as west of Road 68, the permeability and transmissivity values are typical of the Ringold Formation conglomerate, and yields of wells are on the order of a few hundreds of gallons per minute.

West of Esquatzel Coulee, the water-table aquifer continues northward, where the westward-dipping basalts lie adequately below the water table. Very few wells are present and yields are low to very low (a few tens of gallons per minute). Most wells penetrate into and produce at least some water from the basalts. Specific capacity data for these wells are sparse and the accuracy of the data, especially for the unconfined aquifer, is low. Moreover, most of the wells are 20 or more years old and neither the current water-table level nor the effect of irrigation runoff and perched water tables are known.

The water-table gradient and very high-transmissivity zones trending south-southwest from Smith Canyon and Esquatzel Coulee confirm that most waters in the Pasco Greenbelt Area are derived (recharged) from those coulees. The water, upon entering the low-transmissivity zones near the Columbia River, are diverted east-southeastward either along the highly permeable zone immediately north of Pasco, or for waters at Road 52 and Pearl Street (the U.S. Army Corps of Engineers' pumping station) through the sediments of lower permeability toward the lift station on the projection of Illinois Street.

The West Pasco (Riverview) area is likened to a bathtub with the north side breached and a high south rim. Water can freely enter the "tub," but can escape with difficulty only by rising over the high south rim that has few breaches in it and by flowing through lower permeability sediments to the lift station.

Significantly, the lift station at Road 56 is ineffective because of the low-permeability sediments between it and the U.S. Army Corps of Engineers' pumping station at Road 52 and Pearl Street. Small amounts of water reach the lift station from the north, but most waters are derived from the west via collection ditches. Farther downstream, beyond the underground levees, groundwaters are free to flow into the Columbia River west and northeast of Sacajawea Park and no drainage problems exist there.

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The transmissivity values calculated from the specific capacity data were used as the basis of the model study of the area. Following the model study, the station at Road 52 and Pearl Street was shut down and surface water in Esquatzel Coulee was diverted into Smith Canyon. The plan then relied upon pumping from irrigation wells to protect the West Pasco (Riverview) area, and used excess water to recharge the aquifer in Smith Canyon where levels had fallen. In late 1979, water levels were below the land surface level in the low areas in West Pasco (Riverview), about as predicted by the U.S. Army Corps of Engineers' model study (1978). Recharge of Smith Canyon was inadequately effective, probably because of a too-low flow, a too-short recharge time, and possibly channeling of the water away from the areas needing recharge.

The Pasco area study demonstrated that relatively complex and detailed geology can be identified from water well logs. In addition, usable transmissivity values can be determined from the specific capacity tests. The values then can help explain the geology and, in turn, be explained by the geology.

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THE BURBANK-WALLULA AREA

Subsequent to the Pasco area study for the U.S. Army Corps of Engineers, a smaller but similar study was conducted for them in the Burbank area. The purpose was to determine if sites existed in which yields of wells could meet or exceed 1,000 gallons per minute. Test drilling had failed to disclose any locales. No computer modeling was planned.

The available logs of wells were examined in the same manner as for the Pasco area. A geologic map and transmissivity map were constructed, coordinating the geology and the transmissivity values. Plates 5 and 9 contain updated versions of those earlier maps.

More than 100 wells are recorded from Burbank to Wallula Junction. This is an average of more than two wells per square mile into or through the unconfined aquifer. Yields of wells commonly are a few tens of gallons per minute.

Only one limited zone was found in which high yields are possible. It is a northwest-trending zone that appears to be the continuation of a similar zone in the Pasco area (see Plate 9). A review of well logs indicated the presence of a scoured channel in the Ringold Formation surface that was filled with Pasco gravels. The data and conclusions agreed with the general findings of the more experienced drillers who have worked in the area. Plans for a proposed project were dropped.

Expansion of the Boise Cascade plant at Wallula called for a water supply increase by 5,000 gallons per minute desirably from groundwater sources. Following the drilling of several test wells that yielded about 300 gallons per minute each confirmed Ringold Formation conglomerates.

The water-table gradient in the Burbank or Wallula area, is shown (Plate 8) is being nearly flat. Hence, probably no significant recharge occurs from the east. Because the area lies in a square bounded by the Snake, Walla Walla, Touchet, and Columbia Rivers with no upland, no significant surface drainage exists. Basalts dip gently westward and will perch what waters may reach them. Agricultural development locally may cause slight recharge, but most farming operations use giant circle sprinklers and make efforts to minimize water use.

The lack of gradient then implies that recharge is by the Snake and Columbia Rivers, with negligible groundwater flow and poorly defined flow directions. The concept of a well field was abandoned because it would have to be an inordinately long, single line of wells.

Stagnation of the groundwaters increases the potential of contamination of those groundwaters. Nitrate concentrations, in excess of the standards of the Washington State Department of Social and Health Services, are reported in numerous wells. Engineering consultants attribute this to septic tank use, but other evidence implicates local irrigation practices.

Walla Walla County officials anticipate that a research study may be funded to identify the locales and causes of the contamination and the flow patterns of the groundwaters.

Following completion of Ice Harbor Dam, several residents of the area reported that water levels rose in their deep basalt wells. The observation confirms recharge of the uppermost basalt aquifers by the reservoir pool and westward flow. Data indicate, as noted, that the basalt aquifers are low in yield to wells.

THE KENNEWICK-FINLEY AREA

Many domestic and small irrigation wells exist in the east Kennewick to Finley area. The well location map (Plate 1) shows a sampling of typical wells, with the total number shown estimated at no more than 30-40% of the probable total in existence. Many shallow wells are known to be dug wells, and many others are drilled wells that are old and/or were not recorded.

Few wells exist farther west, short of Badger Coulee, or upslope on the Horse Heaven Hills. Wells are now being drilled at an increasing number of sites into the basalt aquifers to obtain higher yields or assuredly purer water below the locally contaminated water-table aquifer. More wells also are being drilled upslope, beyond the reach of city water and irrigation water or to supplement those sources. South of the Rattlesnake-Wallula lineament, basalt lies above the static water level, as it also does west of the northeast end of Badger Coulee. Transmissivity values could be calculated only for the area between Kennewick and Finley.

The groundwater table lies generally only a few feet above the Ringold Formation silts and clays or, where they have been eroded, above the basalt. Well yields consequently are consistently low to only moderate, and commonly a few tens of gallons per minute. In most of the area, the Kennewick and Columbia Irrigation Districts supply irrigation water, but wells supplement that supply and provide domestic sources. Groundwaters are not used to the extent they are in the Pasco area.

Transmissivities are generally consistent from site to site across the total area, unlike the Pasco area. Values normally are less than 50,000 gallons per day per foot. This appears to confirm the general stripping of the area by floods, and deposition of reworked Ringold Formation gravels as a uniform, blanket-like deposit over the area.

The water table slopes northward from the rse Heaven Hills to the Columbia River. As in the Pasco area, surface d underground levees protect low-lying parts of the Finley and Kennewick areas from the waters of Lake Wallula. Several pumping stations of the U.S. Army Corps of Engineers pump water from a network of drain ditches into the Columbia River. They maintain a groundwater level at the river of about 332 feet altitude.

Very few water-level records were available for wells in the Kennewick-Finley area; however, the indicated areal uniformity of the aquifer gravels suggests that the water table is a relatively uniform and regular slope toward the pumping stations (northward). This is so indicated on Plate 8.

Recharge is to the south. Natural recharge is from rain and snowmelt runoff down canyons where the runoff can be concentrated (e.g., Zintel Canyon, Coyote Canyon, etc.) The lack of runoff in many years indicates that natural recharge probably is minor to possibly almost non-existent in dry years. Undoubtedly, a major source of recharge is from imported irrigation water.

To date, the Columbia Irrigation District, operating since the early 1900's, has been a major contributor to artificial recharge. The water is derived by leakage from canals, spillage of excess water, and seepage from irrigated land that lies only a few feet above the water table. A steadily increasing amount of water now is being added by the Kennewick Irrigation District. That system, operating since the mid-1950's, is contributing significant amounts of water to the groundwaters, once the irrigated land became adequately saturated to begin draining. The Kennewick Irrigation District irrigates land below an altitude of about 650 feet in most of the district, but land up to 850 feet in altitude is irrigated in west Kennewick. The increasing contribution of water from the Kennewick Irrigation District is noted in rising water tables (especially in Badger Coulee) and in a greater number of drainage problems below the canal system (downslope). Initially, this occurred where geologic conditions concentrated runoff and precluded ready drainage. Subsequently, drainage problems became more widespread.

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In addition to drainage problems, the development of the area has resulted in a corresponding increase in contaminated groundwaters. Currently, a hazard does not appear present (Wood, 1977), but time and an increasing amount of development are likely to result in further pollution. A better understanding of the sources of water, the flow-paths, and flow rates, particularly in the Finley area, is important.

No attempts have been made to date to achieve a water balance.

THE RICHLAND-WEST RICHLAND AREA

About 65 wells are tabulated in the Richland-West Richland Area, roughly 2 per square mile (Plate 1). Most are concentrated in West Richland where they provide domestic and small-scale irrigation supplies. Relatively few wells are known to have been tested. Well yields are known to be low, generally a few tens of gallons per minute. Many of the wells penetrate into and produce at least some water from the underlying basalt. The yield of any one aquifer then is uncertain owing to a common lack of information on well construction.

A score or more wells along Van Giesen Street tap the basal gravel aquifer of the Ringold Formation and commonly reflect low artesian heads (flowing wells). The basal gravel aquifer, however, is over-developed so that heads decrease during the irrigation season when the wells are pumped to capacity. In winter, wells are used solely for domestic and stock water uses and heads recover.

Recharge of the basal gravel aquifer is from the Yakima River, evidently from Horn Rapids. This is indicated by the head of wells along Van Giesen Street. At Horn Rapids, the basalts and the silts and clays overlying the basalt were upwarped and eroded. Recharge of the aquifer is evidently low and ineffective, based on seasonal differences in the static water levels of local wells.

The unconfined aquifer also is recharged from the Yakima River, but probably in a longer strip north of Van Giesen Street where the water table lies within the Ringold Formation conglomerate (see Plate 11, Cross Section C-C'). Farther south, the water table drops in response to a lowering of the level of the Yakima Rive[illegible]ly, it lies within the silts and clays most of the distanc[illegible] of [illegible] Giesen Street.

Groundwaters in the unconfined aqu[illegible] flow beneath Richland, generally east-southeastward toward and into the Columbia River. Yields of most wells are low, with the maximum yield a few hundred gallons per minute, even with full penetration and development of the aquifer.

A half mile west of the Columbia River, the Ringold Formation conglomerate is trenched by north-south-trending channels (see Cross Section D-D'). Adjacent to the Columbia River, the Ringold Formation surface drops into the river bed. Wells in both those areas commonly yield large supplies. Flow in the inland channels appears to be southward into the Yakima River south of South Richland, especially when artificial recharge occurs.

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The City of Richland in past years (between the 1940's and 1960's) extensively recharged the the groundwater table aquifer in the vicinity of Wellsian Way, as well as those in North Richland (Hart, 1958). Water was supplied by gravity flow from the Yakima River at Horn Rapids to the North Richland basins. A pump station on the Yakima River in South Richland supplied water for the Wellsian Way field.

The naturally filtered water raised the water table at both locales into the Pasco gravels. Wells around the recharge basins thus were able to pump large volumes of water into the city system. Upon construction of the North Richland filter plant, the canal system was discontinued; however, Columbia River water from the filter plant is periodically pumped into the North Richland recharge basins for supplemental supplies.

Industrial development of the Horn Rapids triangle has been proposed several times by various developers. Studies that have been made and the few test wells that have been drilled indicate probable yields of only a few hundred gallons per minute, typical of the Ringold Formation conglomerate.

Transmissivities in the water-table aquifer are about 44,000 gallons per day per foot. Yields, however, change dramatically when the recharge basins are operated.

Meaningful patterns of the transmissivity values are not evident, other than that north-south-trending channels are present. The scarcity of wells in key sites and the complications induced by artificial recharge preclude better data.

A perched water table formed from artificial sources lies west of West Richland in the structural and topographic low occupied by the Lewis and Clark (L-C) Angus Ranch.

The ranch lies along the axis of the Lewis and Clark (L-C) Angus Ranch syncline that extends from near Horn Rapids southeastward to the northeast end of Badger Coulee. It parallels the McWhorter Canal of Bond and Others (1978).

The area, bordered on three sides (east, west, and north) by the Yakima River and on the south by Badger Coulee, is underlain by basaltic lava flows that lie above the natural static water level of the basalt aquifer. No surface drainage is into the area and upward leakage is believed to be trivial. Hence all unconfined groundwaters are strictly locally derived. Occasional rain and snowmelt runoff from Red Mountain, Badger Mountain, and other isolated buttes locally may create a temporary water-table aquifer. The major source of recharge to the unconfined aquifer is irrigation.

Virtually all wells produce from the basalt, with a few in the southern and southeastern parts of the area tapping small amounts of water in the sediments overlying the basalt. Those locales are where irrigation is practiced, using water dominantly from the Badger Lateral Canal of the Kennewick Irrigation District. It terminates north of "Candy Mountain" and south of the Tri-Cities Raceways at Lost Lake.

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An order of magnitude of water recharging the water-table aquifer was estimated. Seepage rates were measured from Lost Lake, and from the Columbia Irrigation District canal in a portion along Harrington Road during the winter of 1977-78. Losses ranged from 0.25 to 1 gallon per square foot in sediments of the exposed Touchet Beds and encountered in numerous wells.

Total losses to the groundwater system from surface ponds, canals, and land irrigated by circle sprinklers using the above values are in the range of 1,000 gallons per minute. The waters perch on the underlying basalt surface and migrate to several breaches along the northeast side of the syncline. In two of the breaches, tile drains carry the water either into the Columbia Irrigation District canal or beneath it into the Yakima River. Flow rates measured at various times indicate perhaps 1,000 gallons per minute draining via the drains.

Seepage from the Columbia Irrigation District canal is confirmed by the owners of wells adjacent to the canal along Harrington Road. They report rises in the water level in their wells from 5 to 8 feet shortly following the filling of the canal in spring.

Water balances probably can be determined for the area if accurate figures can be obtained for the water pumped by the Lewis and Clark (L-C) Angus Ranch, water reaching the end of the Badger Lateral Canal, and evapotranspiration losses.

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THE BADGER COULEE AREA

Nearly 50 wells in the Badger Coulee Area between Kennewick and Kiona are recorded as tapping the water-table aquifer. This is an average concentration of about three wells per square mile for the about 15 square miles of the coulee. About a third of the wells penetrate to or into the basalt. About 30 are known to have been tested for specific capacity.

The average transmissivities calculated from the specific capacity of the wells tested are about 15,000 gallons per day per foot; the range is about 3,000 to 30,000 gallons per day per foot. The wells providing data, however, are concentrated in the east end of the coulee so that patterns are not evident.

The higher yield wells lie along the north side of the coulee. The reason is that basalt along the synclinal axis is there at its maximum depth and rises steadily southward. The gravel that overlies basalt and that evidently was flood-deposited thins southward. Along the south side of the coulee, the unconfined aquifer thins and the gravels, in fact, pinch out. Many wells to the south pass from the Touchet Beds directly into basalt (see Plate 11, Cross Section C-C'); probably the gravels grade into the silts and fine sands and interfinger with them.

water levels at the Badger Station well (Section 7B, Township 8 North, Range 28 East) in Badger Coulee were lying at an altitude of about 325 feet in 1952 when the well was completed. Subsequently, the Kennewick Irrigation District was completed and irrigation began by using water from the Yakima River at Chandler.

In 1966, the water had risen to about 491 feet in altitude, a rise of 5 feet per year. In 1975, the level at Badger Station was up to 538 feet, an additional rise of 5 feet per year. That level is the one plotted on the water-table map (Plate 8). If the rise has continued at the same rate, the water table now stands at about 560 feet in altitude. Consequently, the groundwater flow rate is increasing both westward toward Kiona and eastward and northward toward Meadow Springs. This trend can be expected to continue for an indefinite period.

Wells drilled in the last several years on the Badger Plateau (the high bench south of Badger Mountain) encountered static water levels in the Priest Rapids Member aquifer (Bond and Others, 1978) at about 550 feet in altitude (refer to Cross Section C-C' on Plate 11). The potential gradients slope generally north-northeast to east-northeast (see Figure 3), and appear to radiate from Gander Hill. The data suggest recharge of the basalt aquifer in the scoured-out part of Badger Coulee where the Priest Rapids Member aquifer is exposed in the coulee walls below the upper level of the coulee-fill sediments.

Gander Hill crests at 1,317 feet. The basalt in the coulee floor is slightly higher than 400 feet, for an altitude difference of nearly 900 feet. Bond and Others (1978) show that the top of the Priest Rapids Member is at an altitude of about 500 feet, or about 100 feet above the coulee floor. It thus is in an excellent position for recharge there and to the west for an undetermined distance.

If the water-table level in the coulee is 560 feet altitude (on the basis of Figure 3), the gradient to the nearest wells is about 5 feet per mile; a low gradient compared to that farther north. A high permeability thus is inferred, compared to that farther north. If so, it suggests that the Badger Coulee fault and monoclinal fold do not act as subsurface barriers to lateral groundwater movement, but rather as permeable conduits. If so, water may flow into the Frenchman Springs Member aquifers at still greater depth, thereby recharging them.

The actual flowpath of groundwaters in the Priest Rapids Member aquifer undoubtedly varies greatly, at least locally, from the indicated path shown on Figure 3. In Badger Mountain, the Priest Rapids Member locally lies far above the static water level and is dry. Water flowing in the tabular zones between basalt flows is diverted around the mountain, in addition to following the more permeable zones in the aquifer.

Stratigraphically higher aquifers undoubtedly are recharged in Badger Coulee where they lie below the water table. Flow in them is considerably more complex because the aquifers are closer to the surface and likewise folded with the basalts in a complex pattern of saturated and dry locales. Specific head data and specific capacity numbers are

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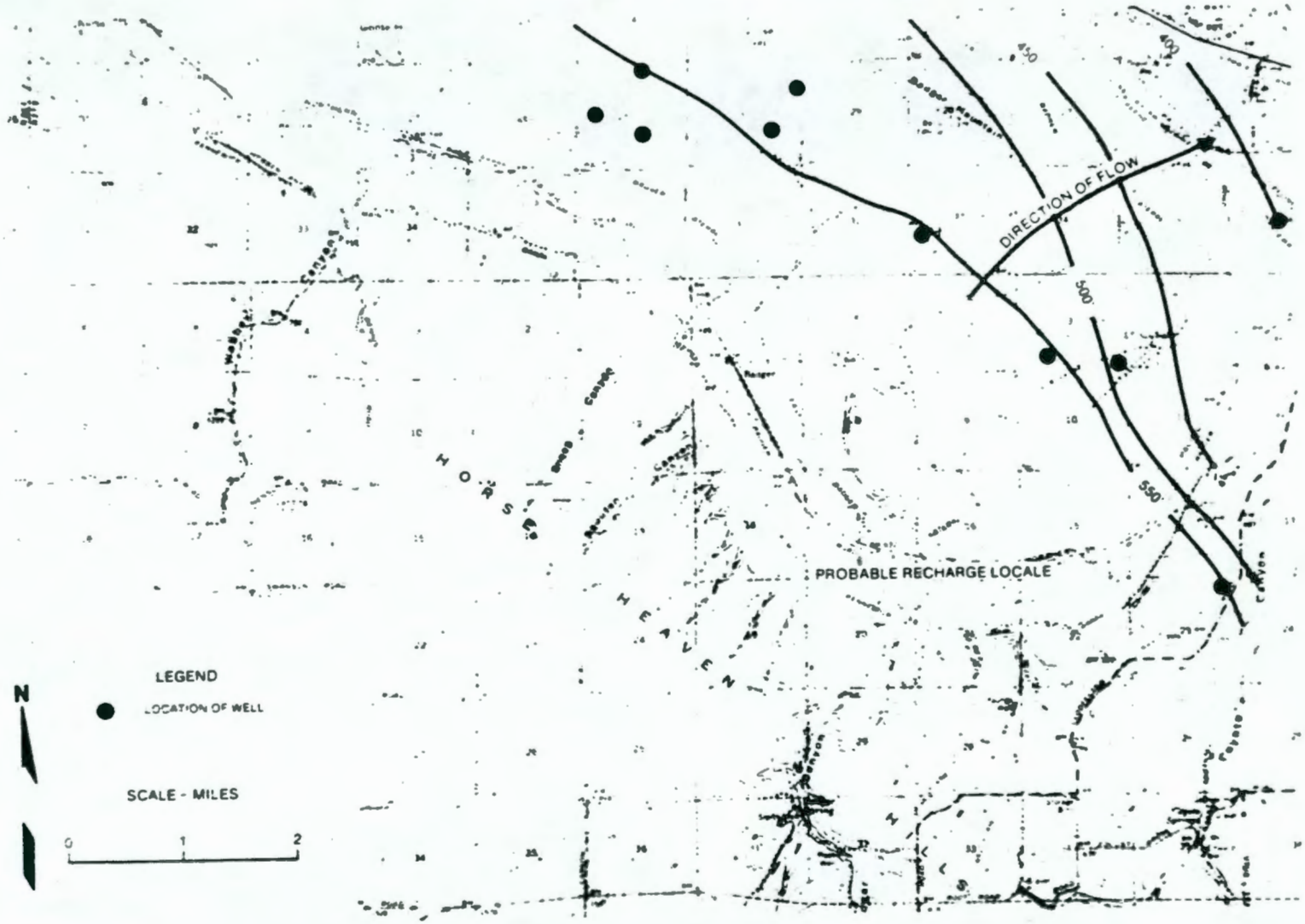

FIGURE 3. Map of the Badger Plateau Area (showing wells penetrating the Priest Rapids Member aquifer and static water levels [piezometric heads] in that aquifer). Direction of flow indicated. Levels are feet above sea level.

largely lacking. Well data do show, however, that the Yakima River north of Benton City is a gaining stream on its left (west) bank, but is a losing stream on its right (east) bank. On the east bank, waters are moving eastward in flow breccias in the Umatilla Member as shown by wells in Section 32, Township 10 North, Range 27 East. The water then is moving toward and beneath the Harrington Road area. The waters there pass beneath the Yakima River and Richland, and turn southeastward and south.

Stratigraphically higher basalt aquifers are more affected by local irrigation practices and local runoff across the eroded or upturned and exposed edges of the aquifers. Wells, however, commonly tap several basalt aquifers so that the heads measured, in many instances, are integrated values of the heads in several different aquifers.

The area is one in which careful measurements of heads during and following drilling are important. Positive identification of the aquifers and the potential yields of each need be made before more quantitative conclusions can be derived.

The Badger Plateau Area is one of the few sites in the Pasco Basin where all wells so far drilled over a linear distance of 7.5 miles tap the same aquifer (the Priest Rapids Member); hence heads are readily relatable to each other. Ten of the 11 wells drilled to date produce water from flows of the Priest Rapids Member; the remaining tap the Frenchman Springs Member at evidently the same head.

Only five of the wells have so far been tested. Only four of the 11 fully penetrate the aquifer, and two of those are not yet tested. The transmissivity values that can be determined from the specific capacity values vary 25-fold. This reflects both changes in the aquifer and, in one instance, different procedures in drilling and development.

Transmissivity values for the aquifer are of questionable use. If we use intermediate values of 16,000 gallons per day per foot, an aquifer width of 8 miles, and a gradient averaging 1 foot per 100 feet, the water flowing through the aquifer is roughly 6,700,000 gallons per day. This is equivalent to less than five wells each pumping 1,000 gallons per minute. It indicates the importance of monitoring water levels during pumping, determining rates of water use, and the careful spacing and testing of all wells.

The Priest Rapids aquifer appears to be one of the more important aquifers in the Pasco Basin. Data on it can help in an analysis of other basalt aquifers.

THE SOUTH COLUMBIA BASIN IRRIGATION DISTRICT

The South Columbia Basin Irrigation District is that part of the Columbia Basin Irrigation Project that coincides with the eastern and northern parts of the study area. It is one in which irrigated

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agriculture dominates. It is divisible into two principal parts, the east part of the basin (north of the Pasco Greenbelt Area) and the north part of the basin (Wahluke Slope).

Most wells are domestic wells, consequently of low but unrecorded yields. Only on west Wahluke Slope, in the coulees and very locally in the basalts, have higher yields been obtained.

The average well density is about one well per 2 square miles, but on Wahluke Slope large areas exist with no wells. Data hence are locally absent or nearly so, and conclusions must be derived by inference and comparison to other locales.

The conglomerates of the Ringold Formation occur in a belt along the Columbia River extending up to about 3 miles east of the river. Groundwaters are present in the conglomerate, but generally the depth to water from the crest of the bluffs is so great and the yield so low that most wells can only be afforded by communities. Yields commonly are a few tens of gallons per minute or less.

Farther east, individual, private wells exist, but must be developed in the Ringold Formation sands or silts and clays and in the underlying basalts. Still farther east, the basalt rises above the water table and all wells are drilled into and produce from the basalts.

In Ringold Coulee, many wells tap permeable Pasco gravels laid down on the coulee floor. Waters in the coulee are derived from the north. Water levels rising in the Othello to Eagle Lake and Scooteney Reservoir area in 1957 topped the axis of the Saddle Mountains anticline and drained southward. The waters were confined within the coulee by the impermeable Ringold Formation sediments that border the coulee. The waters emerged at Ringold Springs, atop the local silts and clays of the Ringold Formation that form the floor of the coulee (see Plate 10, Cross Section B-B').

Elsewhere, aquifers are recharged by irrigation waters. This is clearly demonstrated by an increasing amount of water appearing as perched water along the White Bluffs and along the walls of Ringold Coulee. Some of the water has been tapped by shallow wells.

The U.S. Bureau of Reclamation maintains a network of water-level (drainage observation) wells (see Walters and Grolier, 1960) and periodically monitors them. The levels shown on Plate 8 are based on old data, for relatively few new wells have been drilled. The newer wells generally penetrate into and produce from the basalt, both to obtain somewhat higher yields and water free from nitrate contamination. Consequently, specific capacity and numbers are meaningless. Volumes of moving water are generally low to very low, except in the mouth of Ringold Coulee where total runoff has increased from nothing in 1957 to probably more than 10,000 gallons per minute today; elsewhere, the silts and clays of the Ringold Formation preclude much water movement.

Beneath Wahluke Slope, except for the west end, the water-table altitude is poorly known. It is based on only a few wells, with most wells penetrating into and producing from the basalt.

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Recharge of the aquifers from the Saddle Mountains must be extremely low, and data suggest that much of the recharge is from the ends of the slope. Priest Rapids and Wanapum Dams at the west end of the slope and a rising water table at Ringold Coulee at the east end of the slope probably cause significant flow toward a midpoint of the slope in both the confined and unconfined aquifers. Water levels (Plate 8) reflect at least in part the heads in confined aquifers not readily distinguishable from the unconfined water-table levels.

Irrigation under way on Wahluke Slope is developing extensive perched water bodies, with some recharge of the regional water table. On the east part of the slope, the perched waters already are reaching the White Bluffs, inducing large-scale and extensive landsliding over miles of the bluffs. The problem is steadily worsening and can pollute and/or locally divert the Columbia River channel.

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RECOMMENDATIONS

Some existing water-well information might be used for addressing other hydrogeologic questions in the Pasco Basin besides those raised in this report. Future work should be guided by specific data needs and thus the items noted below are given for consideration should such information be required by the basalt project of Rockwell Hanford Operations.

Perhaps the more important consideration to data gathering is the recognition that built-in inaccuracies in water-well data (such as well locations, altitudes, and depths) do exist and there is the need to recognize and reduce these inaccuracies insofar as practicable and meaningful. In addition, new wells are being constantly drilled in the Pasco Basin and information from these may be used to expand/validate/correct previous characterization concepts.

The following items are suggested for further work on an as-needed basis:

1. Establish a long-term, low-key program for the systematic collection of data from new wells external to Hanford.

2. Continue the procurement of logs of wells already drilled, but not yet tabulated. Emphasize wells penetrating to and into basalt, but do not preclude collection of data from shallower wells. Identify areal gaps in the record and locales of stratigraphic, hydrologic, or tectonic problems; concentrate efforts there. For many sites, more data may merely duplicate existing data, but simultaneously the new data may validate data already in hand.

3. Continue to obtain the results of specific capacity tests. Those tests will largely be relied upon as the basis for a mathematical model program owing to the virtually complete lack of more exacting pumping tests on wells. This will ultimately involve the procurement of data from pump companies and may present problems regarding proprietary information (see item 6 below).

4. Improve the accuracy of well logs now in hand. This involves the more precise location of wells by field inspection and more precise determination of the altitude of the wells, both on the basis of better location and by field inspection. The work can be combined with routine procurement of more well logs.

5. Routinely monitor the water levels in key wells. Integrate the work with the programs of the U.S. Army Corps of Engineers and the U.S. Department of the Interior's Bureau of Reclamation.

6. Establish procedures to procure data from new wells as they are drilled. This will significantly improve the accuracy of the data, its reliability, and the amount obtained. This procedure may be difficult to implement; much of the data may be considered proprietary and many drillers may be reluctant to release data without the client's permission. Other drillers and some developers will be suspicious of the ultimate use of the data and the motives of the person obtaining it.

7. Continue to check, refine, and detail the maps herein included to better validate their accuracy and completeness.

8. Extend the water-well analysis program to include the basalt aquifers. Currently, too few wells have penetrated basalt into positively identified aquifers and their yields determined for meaningful results.

9. Determine meaningful water balances. This is important in assessing the relative and ultimately the absolute amounts of recharge of the respective aquifers by natural and by artificial (irrigation) practices. Locales in which water balances can be most easily achieved are: (a) the Pasco area; (b) the Kennewick to Finley area; and (c) the Badger Coulee area. The West Richland (to Benton City) area is of more immediate interest to the Hanford Site, however, owing to the extensive development of the basalt aquifers down to and including the flows of the Frenchman Springs Member. The current lack of information from wells means that more preliminary work will be needed than in the other sites.

In the Pasco area, many data are available from the U.S. Army Corps of Engineers. The data will, however, need review, updating, and possible refinement. Potentially, owners of irrigation wells may need to be canvassed to improve the accuracy of rates of extraction of water from wells.

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The Kennewick-Finley Area should permit meaningful water balances to be determined. There, most waters are believed derived from the Kennewick and Columbia Irrigation Districts, with probably minimal (if any) natural recharge from the Horse Heaven Hills. Rates of pumping from the area via the U.S. Army Corps of Engineers' pumping stations, evapotranspiration losses, and identification of sites of major diversion, loss, and use of irrigation waters should permit excellent water balances.

If the magnitude of natural recharge can be determined in that area, the recharge into confined (basalt) aquifers elsewhere will also be roughly identified.

A determination of water balances in the Badger Coulee area is important to assessing the recharge potential of the flows of the Priest Rapids Member. Losses from the Kennewick Irrigation District system, the sites of loss and magnitudes of loss, evapotranspiration losses, and sites of pumpage from wells are necessary. The data can be balanced against the recorded water-level rise. Estimates of the effective recharge of the Priest Rapids aquifers versus the anticipated pumping from wells in the Badger Plateau will then be possible.

Water balances in the West Richland-Kiona Area must await identification of aquifers yielding to each well, the total volumes so produced, and the appropriate water levels and gradients in each aquifer. Extensive well drilling will mean an appreciable level of effort to tabulate all wells, aquifers, and yields.

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REFERENCES

ARHCO, 1976, Preliminary feasibility study on storage of radioactive waste in Columbia River basalts: ARH-ST-137, Atlantic Richfield Hanford Company, Richland, Washington.

Bierschenk, W. H., 1959, Aquifer characteristics and ground-water movement at Hanford: HW-60601, General Electric Company, Richland, Washington.

Bingham, J. W., C. J. Longquist, and E. H. Baltz, 1970, Geologic investigation of faulting in the Hanford region, Washington: with a section on the occurrence of microearthquakes by A. M. Pitt: U.S. Geological Survey Open-File Report 70-0027.

Bond, J. G., J. D. Kauffman, D. A. Miller, W. Barrash, J. C. Brown, J. H. Bush, W. B. Hall, C. R. Knowles, and R. R. Reid, Geoscience Research Consultants, 1978, Geology of the southwestern Pasco Basin: RHO-BWI-C-25, Rockwell Hanford Operations, Richland, Washington.

Brown, R. E. and M. W. McConiga, 1960, Some contributions to the stratigraphy and indicated deformation of the Ringold Formation: Northwest Science, 34 (2), p. 43-54.

Coe, R. S., S. Bogue, University of California at Santa Cruz, and C. W. Myers, 1978, Paleomagnetism of the Grande Ronde (lower Yakima) basalt exposed at Sentinel Gap: potential use for stratigraphic correlation: RHO-BWI-ST-2, Rockwell Hanford Operations, Richland, Washington.

Corps of Engineers, Walla Walla District, 1978, Riverview ground water model, Pasco, Washington.

Grolier, M. J. and J. W. Bingham, 1971, Geologic map and sections of parts of Grant, Adams and Franklin Counties, Washington: U.S. Geological Survey Miscellaneous Investigations Map I-589.

Grolier, M. J. and J. W. Bingham, 1978, Geology of parts of Grant, Adams and Franklin Counties, Washington: Washington State Department of Natural Resources, Division of Geology and Earth Resources Bulletin 71.

Gustafson, E. P., 1978, The vertebrate faunas of the Pliocene Ringold Formation, south-central Washington: Museum of Natural History, University of Oregon, Bulletin 23.

Hart, D. H., 1978, Artificial recharge to ground water in Oregon and Washington: U.S. Geological Survey Open-File Report.

Ledgerwood, R. K., C. W. Myers, and R. W. Cross, 1978, Pasco Basin stratigraphic nomenclature: RHO-BWI-LD-1, Rockwell Hanford Operations, Richland, Washington.

Merriam, J. C. and J. P. Buwalda, 1917, Age of the strata referred to as the Ellensburg Formation in the White Bluffs of the Columbia River: University of California Publication Bulletin, Geological Sciences, 10, p. 255-266.

McKnight, E. T., 1923, The White Bluffs Formation of the Columbia: University of Washington thesis, Seattle, Washington.

Molenaar, D., 1968, A geohydrologic reconnaissance of northwestern Walla Walla County, Washington: Washington State Department of Natural Resources Monograph No. 1.

Mundorf, M. J., D. J. Reis, and J. R. Strand, 1952, Progress report on ground water in the Columbia Basin Project, Washington: U.S. Geological Survey/Washington State Department of Conservation and Development, Water Resources Division, Ground Water Report No. 3.

Newcomb, R. C., 1948, Ground water in the Kennewick area, Washington: U.S. Geological Survey Open-File Report.

Newcomb, R. C., 1958, Ringold Formation of Pleistocene age in type locality the White Bluffs, Washington: American Journal of Science, 256, p. 323-340.

Newcomb, R. C., 1959, Some preliminary notes on groundwater in the Columbia River basalt: Northwest Science, 33 (1), p. 1-8.

9312872028 4

Newcomb, R. C., 1965, Geology and ground water resources of the Walla Walla River Basin, Washington-Oregon: Washington State Department of Conservation, Division of Water Resources, Water Supply Bulletin No. 21.

Newcomb, R. C., J. R. Strand, and F. J. Frank, 1972, Geology and ground-water characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington: U.S. Geological Survey Professional Paper 717.

Summers, W. K. and P. A. Weber, 1978, Data for wells penetrating basalt in the Pasco Basin area, Washington: RHO-BWI-C-19, Rockwell Hanford Operations, Richland, Washington.

Swanson, D. A. and R. T. Helz, 1979, Bedrock geologic map of the vent system for the Ice Harbor member of the Saddle Mountains basalt, Ice Harbor Dam-Basin City area, southeast Washington: U.S. Geological Survey Open File Report 79-292, scales 1:62,500 and 1:24,000.

Swanson, D. A., T. L. Wright, V. E. Camp, J. N. Gardner, R. T. Helz, S. M. Price, and M. E. Ross, 1977, Reconnaissance geologic map of the Columbia River Basalt Group, Pullman and Walla Walla quadrangles, southeast Washington and adjacent Idaho: U.S. Geological Survey Open File Map 77-100.

Tanaka, H. H., A. J. Hansen, and J. A. Skrivan, 1974, Digital-model study of ground-water hydrology, Columbia Basin Irrigation Project Area, Washington: Washington State Department of Ecology, Water Supply Bulletin No. 40.

Taylor, T. L., 1976, The basalt stratigraphy and structure of the Saddle Mountains of south-central Washington: Master's Thesis, Washington State University, Pullman, Washington.

Theis, C. V., 1954, Estimating transmissibility from specific capacity: U.S. Geological Survey, Ground-Water Note No. 24.

Waitt, R. B., 1979, Late Cenozoic deposits, landforms, stratigraphy, and tectonism in Kittitas Valley, Washington: U.S. Geological Survey Professional Paper 1127, 18 p.

Walters, K. L. and M. J. Grolier, 1960, Geology and ground water resources of the Columbia Basin Project Area, Washington: Washington State Department of Conservation, Division of Water Resources, Water Supply Bulletin No. 8.

Waters, A. C., 1955, Geomorphology of south-central Washington, illustrated by the Yakima East Quadrangle: Geological Society of America, 66 (6), p. 663-684.

Watkins, N. D. and A. K. Baksi, 1974, Magnetostratigraphy and oroclinal folding of the Columbia River, Steens and Owyhee basalts in Oregon, Washington and Idaho: American Journal of Science, v. 274, p. 148.

9312872028 5

WPPSS, 1974, Preliminary safety analysis report, amendment 9, appendix 2J, page 2: Washington Public Power Supply System, Inc., Richland, Washington.

WPPSS, 1977, Preliminary safety analysis report, amendment 23, v. 1 and 2: Washington Public Power Supply System, Inc., Richland, Washington.

Wood, R. H., 1977, Ground-water quality study, Finley, Washington: School of Engineering, Walla Walla College, to Benton County Board of Commissioners.

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APPENDIX

TRANSMISSIVITY VALUES OF THE WATER-TABLE AQUIFER IN THE SOUTHERN AND EASTERN PARTS OF THE PASCO BASIN

About 200 transmissivity values for the water-table aquifer, including multiple values and ranges in some instances, are tabulated in this appendix. They include values from most of the large irrigation wells, dominantly in the Pasco Greenbelt Area. The great majority of the values, however, are from domestic and small-yield irrigation wells.

Probably another 200 or more wells have been comparably tested. Virtually all those wells are believed to be domestic and small-yield irrigation wells.

About 400 wells in that water-table aquifer probably have been tested; however, only three tests external to the Hanford Site are known in which observation wells were used. Pump companies and drillers in the Tri-Cities have verified the lack of such tests. Consequently, only the specific capacities of the wells were directly determined. In only two of the three cases when observation wells were used was the storage coefficient determined (wells 9/30-14 M and 10/31-30 A). Consequently, transmissivities were calculated solely from the specific capacities of the wells by use of the equation $T = Q/s\ (1{,}700)$ as cited by Theis (1954) and Bierschenk (1959). In that equation, T is transmissivity in gallons per day per foot, Q is the pumping rate, and s is the drawdown at that pumping rate.

Transmissivities quoted are only approximate because they ignore well efficiency, storage coefficients, and lack of full penetration of the aquifer in many cases, and generally do not account for varying lengths of pumping tests. The problem of accuracy is compounded because many wells were tested at only a single rate, basically to determine only if they were adequate for domestic use. Step-drawdown tests, when used, usually were short-term only. Maximum rate tests commonly were only for a few hours. Even the large irrigation wells in most instances were tested for less than 24 hours. The step-drawdown tests seldom resulted in straight-line functions, possibly reflecting continued well development in some instances. A range of specific capacity values often resulted.

In the Pasco Greenbelt and Burbank Areas, numerous transmissivity values were obtained and related to the known geology and hydrology. They helped explain the geology and hydrology and, in turn, were explained by the geology and hydrology; consequently, the data must be considered reliable overall within some yet-undefined limits of accuracy. It is important, however, that transmissivities be determined in the classical manner by the use of observation wells wherever possible. This will not only provide more accurate values, but will help to determine the validity of the values determined by the specific capacity method.

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A typical example of the potential error possibility is given by well 8/28-12 C. The well test by pump produced a reported 19 gallons per minute with 0.5-foot of drawdown, for a specific capacity of 38 gallons per minute per foot of drawdown and a transmissivity of 64,600 gallons per day per foot. A bailer test on the same well gave a yield of 25 gallons per minute with 2 feet of drawdown, a specific capacity of 12.5 gallons per minute per foot of drawdown, and a transmissivity of 21,250 gallons per day per foot. The latter value is comparable to values obtained in nearby wells in the same formations, but probably was less accurately determined. Greater pumping rates and, consequently, more drawdown may have given even different specific capacity and, hence, transmissivity values. This is confirmed by the specific capacity and transmissivity values obtained at well 9/30-14 M that varied by a factor of about three when it was tested by using an observation well.

Generally, only a single transmissivity value is reported owing to the unknown magnitudes of the variables affecting the values. If several tests were run at significantly different rates, the values for each test are given. Pumping rates are tabulated as a means of identifying the probable use rate and type of well. Drawdown is not tabulated. Transmissivity values range widely for wells pumped at comparable rates, but which achieved appreciably different drawdown. The tabulation is by section, township, and range to facilitate finding the values, rather than by local areas as discussed. Wells listed by such designations as "NE 1/4" generally lie in the center of the quarter section.

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Pumping Rates and Transmissivity Values for Selected Wells Tapping the Water-Table Aquifer in the Southern and Eastern Parts of the Pasco Basin

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
7/31-10 G	160	170,000
	320	127,000
	480	62,900
7/31-10 R	300	56,100
7/31-10 R	300	255,000
7/31-10 R	300	85,000
7/31-10 R	300	255,000
7/31-14 G	166	56,100
7/31-14 N	30	5,100
7/31-14 N	60	10,200
7/31-14 Q	1,300	221,000
7/31-14 R	250	35,700
	375	37,400
	530	37,400
7/31-14 R	200	13,600
	340	18,700
	460	22,100
8/27-7 D	very low	very low
8/28-6 B	1,220	20,000
8/28-6 J	1,557	23,000
8/28-7 H	75	3,000
8/28-8 D	100	5,100
8/28-11 D	250	5,600
8/28-11 J	20	10,200

*After Theis (1954) and Bierschenk (1959).

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TABLE Cont'd

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
8/28-11 J	20	13,600
8/28-12 A	50	8,500
8/28-12 B	30	3,400
8/28-12 C	20	6,800
8/28-12 C	235	8,500
8/28-12 C	19 25	64,000 21,250
8/28-12 F	20	1,100
8/28-14 SW 1/4	25	5,100
8/28-14 SW 1/4	25	5,100
8/28-14 M	25	10,000
8/28-14 N	30	10,000
8/28-15 N	30	25,500
8/28-15 Q	350	2,500
8/30-1 J	20	3,400
8/30-3 R	50	42,500
8/30-5 G	40	17,000
8/30-7 D	35	11,900
8/30-8 C	90	204,000
8/30-9 A	172	102,000
8/30-9 H	60 70 167	19,000 44,000 22,500
8/30-12 C	40-50	4,500-8,500

*After Theis (1954) and Bierschenk (1959).

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TABLE Cont'd

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
8/30-12 D	100	17,000
8/30-12 D	35	12,400
8/30-12 D	20	17,000
8/30-12 E	18	30,600
8/30-12 E	60	7,000
8/30-12 K	600	680,000
8/30-12 L	18	76,500
8/30-12 L	40-50	7,000
8/30-12 NW 1/4	230	39,100
8/30-12 ?	1,150	646,000
8/30-15 ?	20	17,000
8/30-15 A	20	17,000
8/30-15 D	35	60,000
8/30-15 D	60	34,000
8/30-15 F	25	20,400
8/30-15 N	25	20,400
8/30-15 N	25	20,400
8/30-15 R	25	42,500
8/30-15 R	25	42,500
8/30-16 J	40	22,100
8/30-16 N	15	25,500
8/30-16 P	135	17,000

*After Theis (1954) and Bierschenk (1959).

TABLE Cont'd

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
8/30-17 D	50	8,500
8/30-17 L	30	51,000
8/30-19 K	20	1,700
8/30-19 N	5-6	850
8/30-20 B	90	51,000
8/30-22 C	25	42,500
8/30-22 D	20	34,000
8/30-25 M	1,170	1,020,000
8/30-27 J	20	1,700
8/30-29 A	20	1,700
8/30-36 F	40	68,000
8/31-3 K	11	------
8/31-4 P	40	34,000
8/31-6 E	30	102,000
8/31-6 F	30	25,500
8/31-9 A	20	-------
8/31-9 H	30	-------
8/31-9 H	30	5,100
8/31-9 J	20	8,500
8/31-9 J	25	10,200
8/31-17 L	250	<27,200
8/31-17 M	20	11,900

*After Theis (1954) and Bierschenk (1959).

TABLE Cont'd

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
8/31-17 N	20	22,100
8/31-18 A	50	< 85,000
8/31-18 A	10	3,400
8/31-18 B	30	25,500
8/31-18 E	15	1,700
8/31-22 E	35	10,200
8/31-28 R	35	2,550
9/27-36 A	1,250	10,600
9/27-36 D	550 625	28,000 26,000
9/27-36 D	185	31,500
9/28-25 ?	300	73,000
9/28-34 F	400	15,500
9/28-34 ?	400	61,000
9/28-34 ?	175	27,000
9/29-1 H	40	1,700
9/29-2 F	600	510,000
9/29-3 NW 1/4	1,100	72,000
9/29-3 SE 1/4	2,000	485,700
9/29-4 J	175	13,600
9/29-4 P	300	42,500
9/29-4 Q	250	11,520
9/29-8 Q	150	13,000

*After Theis (1954) and Bierschenk (1959).

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TABLE Cont'd

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
9/29-9 SW 1/4	825	41,250
9/29-10 ?	1,500	850,000
9/29-11 ?	2,000	154,500
9/29-12 ?	3,200	680,000
9/29-14 Q	1,550	663,000
9/29-15 F	1,000	25,000
9/29-15 H	1,900	408,000
9/29-15 S 1/2	400	11,000
9/29-15 N	20	>250
9/29-16 M	45	25,500
9/29-16 M	240	6,180
9/29-21 L	30	25,500
9/29-22 A	30	10,200
9/29-22 D	20	17,000
9/29-24 H	790	767,000
9/29-25 F	13	170
9/29-27 P	30	25,500
9/29-28 C	190	610,000
9/29-28 D	45	255,000
9/29-28 E	115	2,193,000
9/29-36 E	818	310,000-869,000
9/29-26 F	230	37,000-54,000

*After Theis (1954) and Bierschenk (1959).

9 3 1 2 8 7 2 0 2 9 4

TABLE Cont'd

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
9/30-1 D	3,200	925,000
9/30-1 N	1,160	200,000
9/30-2 H	2,451	520,800
9/30-2 R	752	426,700
9/30-3 L	2,200	530,000
9/30-5 C	1,540	19,600
9/30-5 K	1,600	60,400
9/30-5 L	1,640	75,000
9/30-6 M	180	44,200
9/30-6 M	280	47,600
9/30-6 M	180	37,400
9/30-6 M	420	88,400
9/30-6 R	1,000	71,000
9/30-7 ?	800	27,200
9/30-7 E	1,700	100,000
9/30-8 A	1,600	544,000
9/30-8 Q	1,400	103,000
9/30-9 C	3,100	350,000
9/30-9 J	42	71,400
9/30-10 A	1,200	58,000
9/30-10 M	50	85,000
9/30-10 Q	1,500	85,000

*After Theis (1954) and Bierschenk (1959).

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TABLE Cont'd

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
9/30-11 NE 1/4	1,850	27,800
9/30-11 NW 1/4	1,650	233,000
9/30-11 SE 1/4	2,400	255,000
9/30-11 SW 1/4	1,150 450	26,800 12,500
9/30-12 E	1,300	-------
9/30-12 Q	170	18,700
9/30-12 Q	620	47,600
9/30-14 M Storage coefficient is 0.06-0.43; average 0.09	600 1,001 1,506 2,000 2,500 2,750	416,300 298,000 243,800 192,500 152,000 151,000
9/30-15 D	1,600	195,000
9/30-15 Q	1,200	55,000
9/30-16 K	450	25,500
9/30-17 R	1,800	85,000
9/30-19 L	40	13,600
9/30-20 F	620	4,250,000
9/30-21 F	2,000	566,000
9/30-21 J	1,800	306,000
9/30-22 E	<150	56,000
9/30-24 C	700	153,000
9/30-24 C	30	10,000

*After Theis (1954) and Bierschenk (1959).

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TABLE Cont'd

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
9/30-24 D	1,200	120,000
9/30-24 E	1,140	161,500
9/30-26 E	2,200	119,000
9/30-26 H	110	23,400
9/30-26 K	2,200	296,000
9/30-28 K	300	3,000,000
9/30-28 R	50	85,000
9/30-28 R	50	85,000
9/30-31 M	8	510
9/30-33 H	2,000	340,000
9/30-34 G	2,200	187,000
9/30-34 Q	350	2,380,000
9/30-35 A	500	40,500
9/30-35 R	215	38,000
9/30-35 R	500	850,000
9/30-36 ?	50	42,500
9/30-36 A	30	51,000
9/30-36 F	25	42,500
9/30-36 N	35	2,300
9/31-30 J	25	6,800
9/31-30 Q	50	5,100
9/31-31 M	28	47,600

*After Theis (1954) and Bierschenk (1959).

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TABLE Cont'd

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
10/28-36 G	25	14,000
10/28-36 G	25	13,600
10/29-16 C	15	650
10/29-18 P	300	255,000
10/29-21 ?	233	43,500
10/29-25 SW 1/4	1,200	127,500
10/29-27 ?	1,200	75,000
10/29-28 L	470	51,000
10/29-28 P	400	85,000
10/29-35 NE 1/4	1,250	50,000
10/29-35 H	1,600	65,000
10/30-25 P	1,225	170,000
10/30-25 R	2,600	510,000
10/30-26 M	3,300	10,000
10/30-32 P	1,500	232,000
10/30-33 N	300	17,000
10/30-33 N	2,300	170,000
10/30-33 R	1,500	425,000
10/30-33 R	1,900	357,000
10/30-35 SW 1/4	550	20,400
10/30-35 R	267	454,000
10/30-35 R	211	360,000

*After Theis (1954) and Bierschenk (1959).

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TABLE Cont'd

Well	Pumping Rate (gpm)	Calculated Transmissivity* (gpd/ft)
10/31-4 ?	2,000	425,000
10/31-5 C	2,700	2,500,000
10/31-9 M	2,200	1,500,000
10/31-30 A	1,300	931,000
Storage coefficient is 1.3×10^{-2} to 0.17; average 6.1×10^{-2}		
11/28-24 L	75	2,125
11/29-20 N	20	300
11/29-31 N	15	250
11/31-31 ?	3,500	2,400,000
11/31-31 ?	3,500	2,000,000

*After Theis (1954) and Bierschenk (1959).

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Frame 1 - Plate 6B - Isopack map Ringold formation silts and clasp north half of area.

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Frame 1 - Plate 8B - The groundwater table, north half of area.

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Frame 1 - Plate 9 - Map of transmissivity valves within the water table Aquifer.

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Frame 2 - Same as above.

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Plate 11 - Geologic cross section C-C^1 and D-D^1.