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Hydrogeologic Boundary Assessment for the Pullman-Moscow Basin

by

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Pullman-Moscow Water Resources Committee

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Abstract

Hydrogeologic Boundary Assessment for
the Pullman-Moscow Basin

The hydrogeology of the local Basin has for many years been the source of interesting scientific discussion. At issue are the classic points surrounding water quantities and the sustainability of current and projected pumpages. In addressing those issues, two major contentions arise: the areal extent of the corresponding aquifer(s) and the recharge it receives. Recognizing the latter has gotten most of the more recent attention, it is the question of size of the Basin to which this work has been directed. Here, we examine the historical evidence of the reported geology and water records to postulate a fairly radical physical picture of the Grande Ronde aquifer and its western extent along the Snake River. In particular, an examination is made of the possibilty of a "no-flow" barrier in that area, wherein explaining the unusual piezometric heads known to exist in the region. For illustration, changes are made to the existing model of the Basin (given by Lum et al., 1990) to include this barrier element. Comparison are made in a before and after format, with recommendations being given for possible model and data collection improvement.

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1. Introduction

Like most of Eastern Washington and North-Central Idaho, the community within the Pullman-Moscow Basin is solely dependent on groundwater resources for its water supply. In noting that dependence, the central question raised by the controlling governmental entities within the area has been one of "safe yield" for the basin. At issue are the classic demand-tradeoffs that exist between community growth and potentially limited water resources for the region. This theme has never been more central than that expressed in recent years in response to the growing popularity of the northwestern portion of the United States.

The key element in defining the problem is really quite simple, "is there enough water available on demand at any given time to support the surrounding community?" Moreover, "what is the estimated upper limit of that supply and how long will it last under a growing demand rate?" From a technical viewpoint, the answers to these questions lie in two parts: (1) the estimate of the amount of water entering the groundwater system(s) as "recharge," and (2) the estimate the size (or aeral coverage) of the basin. Together, they quantify the amount of water that can be withdrawn from the system without producing excessive drawdown (i.e. lowering of piezometric levels) or an actual "drafting" (i.e. long-term net removal) of the regional water quantity.

Although simply posed, definitive answers to questions like these have been sought for the region for more than 30 years. The obvious question then is, "if so many studies have been performed, why haven't answers been obtained?" In response, one need only note that the domain in which the interest lie cannot been seen, nor is it readily available for study. The groundwater resources mentioned here are located deep beneath the surface. Access to these units are limited to a few wells, many of which are not located in crucial portions of the basin. Moreover, the cost of placing the number wells at the appropriate locations and depths as desired is simply beyond reasonable economics. As such, the search for answers continues under a framework of limited information, wherein postulation of reasonable solutions is the standard. As time passes and new information is made available, existing solutions are revised and new "theories" presented, until such time that the collective thought can support the bulk of information that is available.

Nevertheless, to date, sufficient information to produce the desired definitive "picture" of the region's groundwater system is not available. On one front, a recent focus has been placed on generating estimates of recharge (O'Brien and Keller, 1993), yielding what is believed to be a narrow band of appropriate values ranging from 1.5 to 3 inches per year (estimated as an average rate over the entire basin). However, the areal distribution and local variability in those numbers remain unanswered questions. Prevailing theories would place the majority of that recharge on the Moscow side of the Basin, near the mountain ranges where the corresponding aquifers of the Basin are believed to rise near the surface. On the other front, questions governing the size of the domain have varied drastically. The information and theories that do exist on this matter seem to have "oscillated" over the years, producing no justifiable consensus. Lum et al. (1990) have most recently placed its size at approximately 750 square miles, this compared to Barker (1979) who estimated it to be less than one-third of that number some ten years prior. What is clear is that without some reliable estimate of the areal extent of the Basin no estimate of available long-term water quantities can be made. It is with this latter point in mind that the work presented herein will atttempt to once again bring to the forefront the issue of boundary assessment for the Basin.

2. Background

2.1 Study Area

Located in the southeastern portion of Whitman County, WA and extending over statelines into the Latah County, ID, the Pullman-Moscow Basin is home to not only the two cities for which it were named, but also the academic institutions of Washington State

University and the University of Idaho, respectively. Physiographically described as a semi-circular, horseshoe-shaped ring, the Basin has prominent topograpic boudaries to the north (Smoot Hill and Kamiak Butte), east (Moscow Mountains and Paradise Ridge), and south (Bald Butte and a string of lower hills). To the west and northwest, lie an open area incised, in part (except for the extreme northwest portion), by the Snake River (see location map in Figure 1 bvelow).

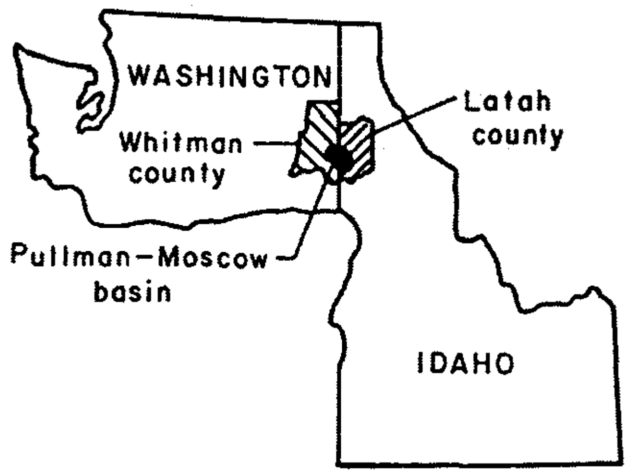

Figure 1: Location Map of Basin
(taken from Barker, 1979)

2.2 Principal Water Resources within the Area

Subject to a semi-arid rainfall, the hydrology of the Basin, along with a variety of agricultrual advances, have made the area one of the most productive dry-land farming regions within the world. Supported that agri-base are the rich clays of the Palouse loess, ranging in thickness from essentially zero to several hundred feet atop the low lying hills in the region.

The commercial and residential activities within the Basin are supported almost exclusively by waters derived from two principal underlying groundwater aquifers: the (upper) Wanapum and (lower) Grand Rhonde layers (Lum et al., 1990). Characterized as

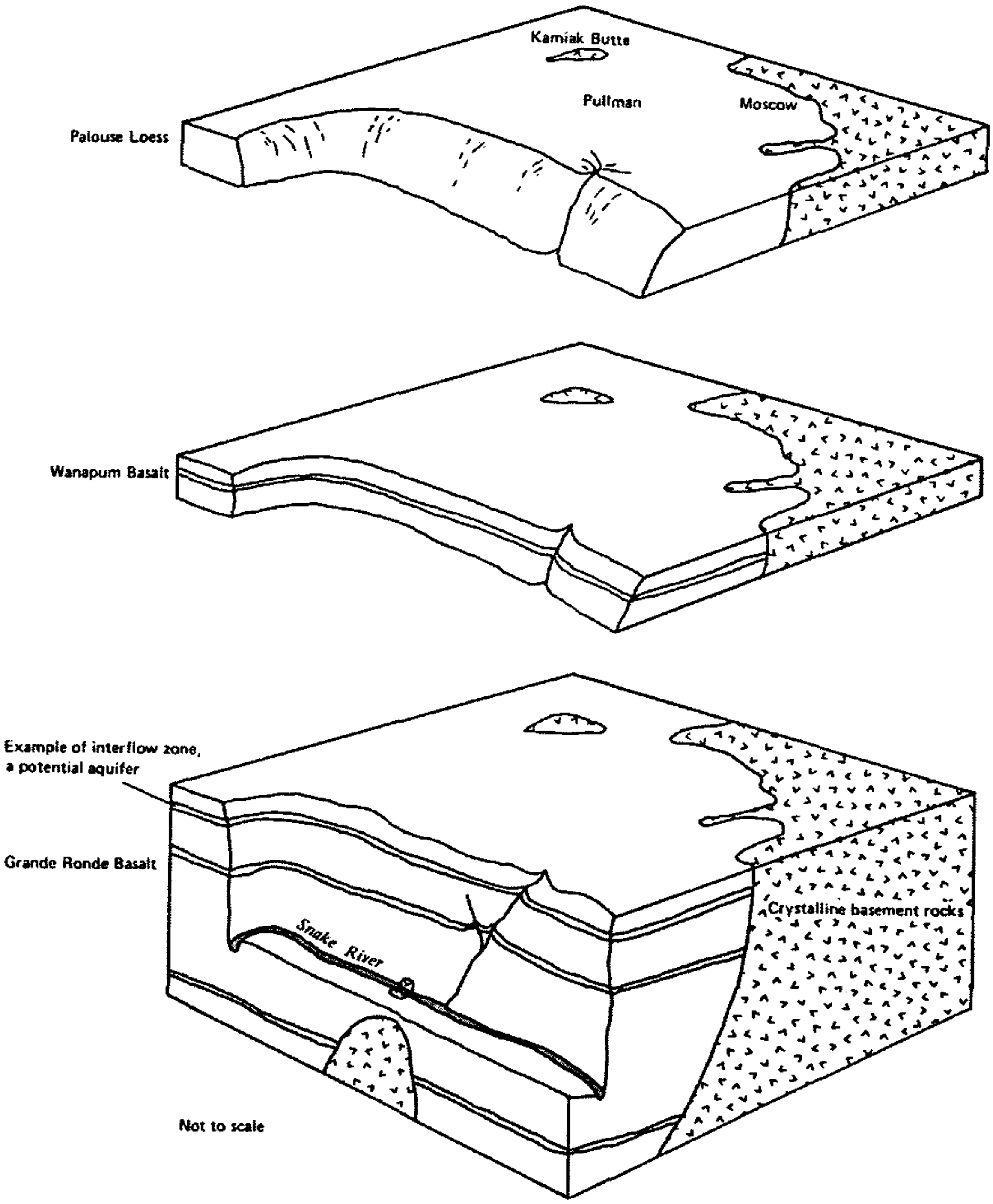

Figure 2: General Hydrogeology for the Basin

part of the Columbia River Basalt Group, these layers are formed from a collection of varying aged magmatic flows ranging from 50 to several hundred feet in thickness (Foxworthy and Washburn, 1963). Comprised almost entirely of vesicular basalt, the hydraulics of the aquifers are dominated in the vertical direction by extended joints forming deep columnar sections, while in the horizontal plane there are numerous irregularly connected interbeds comprised of clay and highly weathered basalts. A summary of the lithology of the region is illustrated in figure 2 (previous page).

2.3 Previous Research Efforts

As indicated in the opening of this report, questions regarding the long-term viability of the water rescources within the Basin have been the focus of various studies over the past 30 years. At issue are two pieces of information: (1) the rate of recharge over the Basin; and (2) the size (lateral or areal extent) of the Basin itself. These elements, when combined, permit an estimate of the 'upper bound of the safe yield' to be obtained via a simple conservation of mass relation, namely:

$$Q_{safe} = W \times A \tag{1}$$

where Q_{safe} is the maximum total pumpage which can be achieved for a given average rate of recharge (W) over the Basin's area (A). In illustrative terms (see figure 3 below), the problem resembles one of an aquifer represented as a "pop can" whose lid is letting liquid

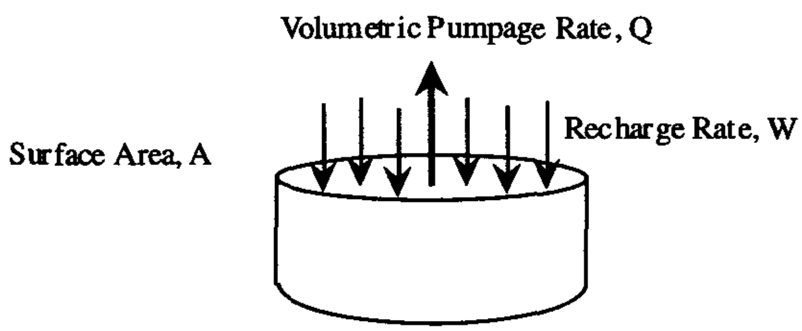

Figure 3: Illustration of Hydrogeologic Water Balance

leak in at a given rate. The question is, "how fast can you draw soda from the can without actually lowering the overall liquid level within the can itsef?" The answer to this question, at least in average terms, is expressed in Equation 1. Moreover, of the two pieces of information required, it is the second which forms the focus of this investigation, namely the Basin's lateral extent.

Although limited in scope, past efforts to define the hydrogeologic boundaries have focused on what is believed to be a "bowl-like" formation for area. To the north, east, and south, lie distinct regions of up-thrusted crytalline baserocks forming the mountainous ridges described earlier. These ridgelines and their subsurface origins are thought to outline defineable hydrogeologic boundaries for the Basin along those corresponding directions.

The question today, as it has always been, is one of the western extent of the Basin and, in particular, the possible presence of a "barrier boundary" lying to the west and northwest of the City of Pullman. As early as 1963, researchers began to cite both evidential and intuitive reasons for suspecting a fairly limited expanse for the aquifers beneath the Basin. This fact was supported by evidence of excessive drawdowns along a proposed boundary located on the western side of a line between the Washington Towns of Albion and Chambers (Foxworthy and Washburn, 1963). 'Rumors' of this barrier boundary were once again the focal point of discussion in the development of the first computer model of the Basin given by Barker (1979). To date, the existence and location of that barrier, if at all, is not known. Nevertheless, in support of various claims, numerous researchers have spectulated on the possible presence of faults (tetonic activity), intrusive features (e.g. volcanic dikes), and/or linear structural controls (e.g. folds and faults) along the western portion of the Basin. Citing Barker (1979, p. 39), we note,

> "Any one of the above-mentioned structures (dikes, basement high, folds, and faults), or a combination of these, in the area west of the basin would almost certainly retard lateral exchange of ground water between the basin area and the area of Union Flat Creek. Water movement to and from the basin across this area could be restricted to the extent that a common hydrostatic potential would exist inside the basin for aquifers among which

> hydraulic circulation in the vertical direction was reasonably good and within which lateral flow was equally retarded west of the basin."

Concern over this issue (and that of the Basin's recharge rate) has been kindled in the observation of historical drawdowns for the area. During the period from the mid-1930's to the mid-1960's, the Grande Ronde experienced an average rate of decline in piezometric head (i.e. the water level in a static well) of around 1.5 feet per year, on both the Moscow and Pullman sides of the Basin. Under drastic increases in pumpage (i.e. rate of water withdrawl) during the period bewteen 1974 and 1985, this same rate of drawdown rose to a record high of about 2 feet per year (see data given by Lum et al., 1990). Given these numbers, obvious questions have been raised regarding the long-term viability of the regions water resources. In assessing that problem, numerous investigations over the years have attempted to define the necessary hydrogeologic parameters, along with "model" the system to one degree or another (both qualitatively and quantitatively).

Yet, since the work of Barker (1979), questions governing the areal extent of the basin have seemingly been ignored. Much of the recent work on the Basin has focused on the estimation of recharge (O'Brien and Keller, 1993) and the development of a "modernized" computer model of the corresponding hydrogeology, including both lithologic reconstruction and hydraulic simulation (Lum et al., 1990). This latter work is of significance in that the boundaries included in the Lum et al. model of the Basin cover an area approximately three times larger than that previously model by Barker (1979) (see figure 4, following page). Up to 1985, specificity for the boundaries and/or the ignorance of their presence was justified given the fact that the drawdowns within the Basin were most likely not affected by lateral confinement. Such evidence is owed to the direct dependence (as observed and recognized in theory) of pumping rates on local drawdown, as given by a "laterally free" hydrogeologic domain under quasi-steady conditions. However, since Lum et al. (1990), pumpage rates within the Basin have increased over the decade following the last data used in that report. Rough estimates[1] recently computed by the author(s) here suggest that the western edge of the associated drawdown influence may have now reached a position which would place it beyond the 'barrier boundary' cited by Foxworthy and Washburn (1963) and Barker (1979). If correct, evidence supporting this postulate would only now be available. Accordingly, methods are being proposed here which will more accurately assess the possible presence of such a boundary and its location. Moreover, a review of the boundary selection used by Lum et al. (1990) will be provided, with recommendations being made for change, if needed.

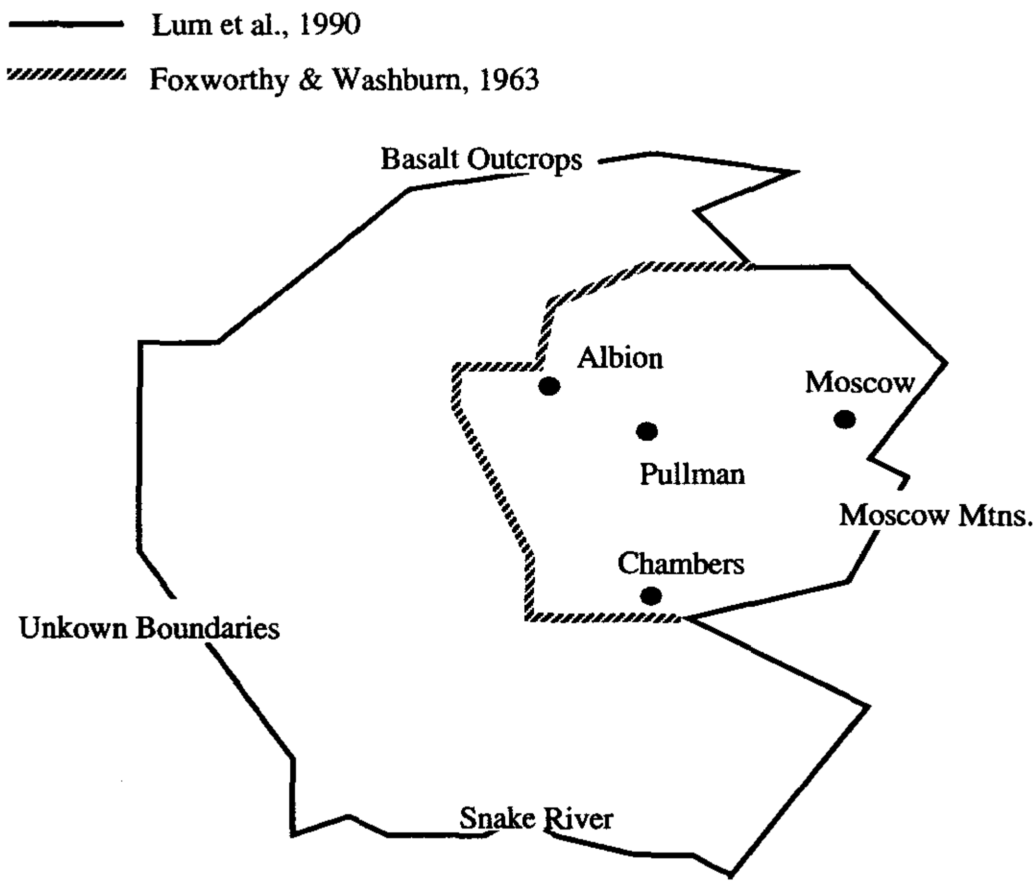

Figure 4: Sketch of Pullman-Moscow Basin Boundaries Reported by Lum et al. (1990) and Foxworthy & Washburn (1963)

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[1]Using the current estimate of deep, basalt aquifer recharge of about 2 inches/year (O'Brien, 1993) and an estimated 1985 average pumping rate of 500,000 ft^3/day for the Pullman area, one can show that the 'effective' area of groundwater influence for the Basin during that period was about 40 square miles, with a corresponding 'radius of influence' around 3.5 miles.

In short, until resolution of these hydrogeologic boundaries are known, the determination of the adequacy of existing groundwater supplies to support current and future planned water use within the Basin cannot be addressed with certainty.

2.4 Scope and Objectives of this Study

In an attempt to improve the quantification of long-term water supplies for the Pullman-Moscow Basin, work is being proposed here to:

(a) collect and analyze drawdown records within the Basin over the past ten years; and

(b) use this information in updating (through analytic means) the knowledge base concerning the areal extent of the hydrogeologic boundaries for the Basin.

In conducting this work, an emphasis will be placed on examining the question of the existence of a hydrogeologic boundary located along the western side of a line between the Towns of Albion and Chambers, WA. These results will be used (in conjunction with current estimates of recharge rates) to re-evaluate the available long-term sustainable groundwater pumpage rates for the Basin. Moreover, a review will be made and recommendations given for: (1) improving the boundary conditions within the Lum et al. (1990) computer model of the Basin and (2) the quality/quantity of data needed to justify resolution of this problem.

3. Assessment of Pumpage/Drawdown Records

3.1 Data Collection

The first step in the project was to obtain historical pumpage-drawdown data for the Basin. Here, information was sought for various candidate wells located throught the area. In that search, two types of wells were identified: primary and secondary, the former referring to wells owned/operated by one of the two major municipalities or universities in the area, while the latter referring to any other source. From the primary sources, monthly records (mostly complete) over the past decade were obtained for the following wells[2]:

Pullman: #1, #2, #3, #4, #5, and #6

Moscow: #2, #3, #6, #8, and #9

WSU: #1, #2, #3, #4, #6, and #7

UI: #2, #3, and #6

This information is summarized in the plots shown in figures 5 through 7. The secondary search yielded (single) data points from each of three locations:

Location	Static Water Elevation (msl)	Date
Town of Albion	~ 2130 ft.	May 1992
Town of Colfax	1780 ft.	May 1994
WSU Knox Farm[3]	2250 ft.	Sept. 1994

[2]Not all of which were pumping during the study period.
[3]Located approx. 4 mi south and 5 mi west of downtown Pullman.

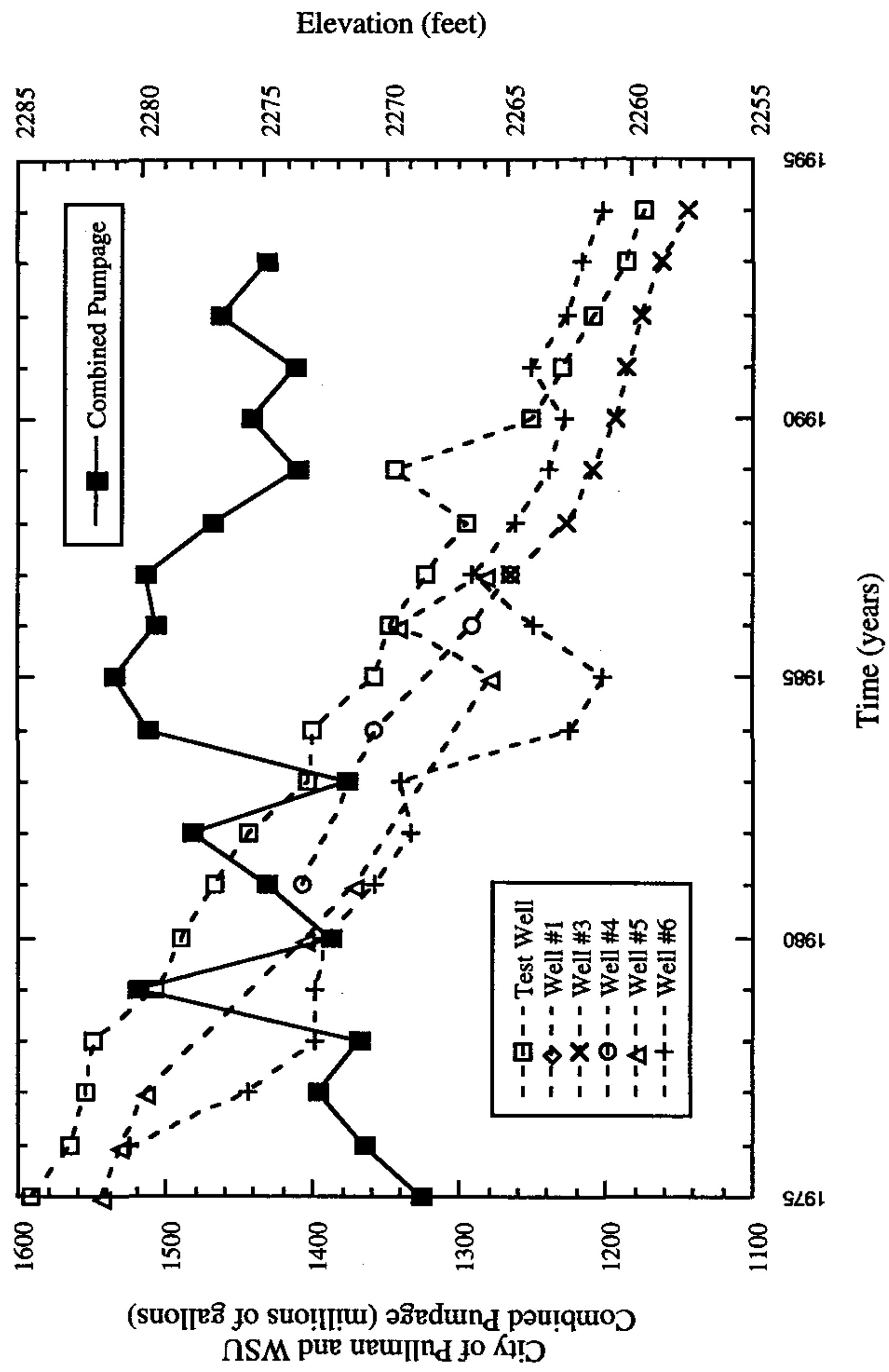

Figure 5: Summary of WSU Wells - Pumpage Versus Drawdown

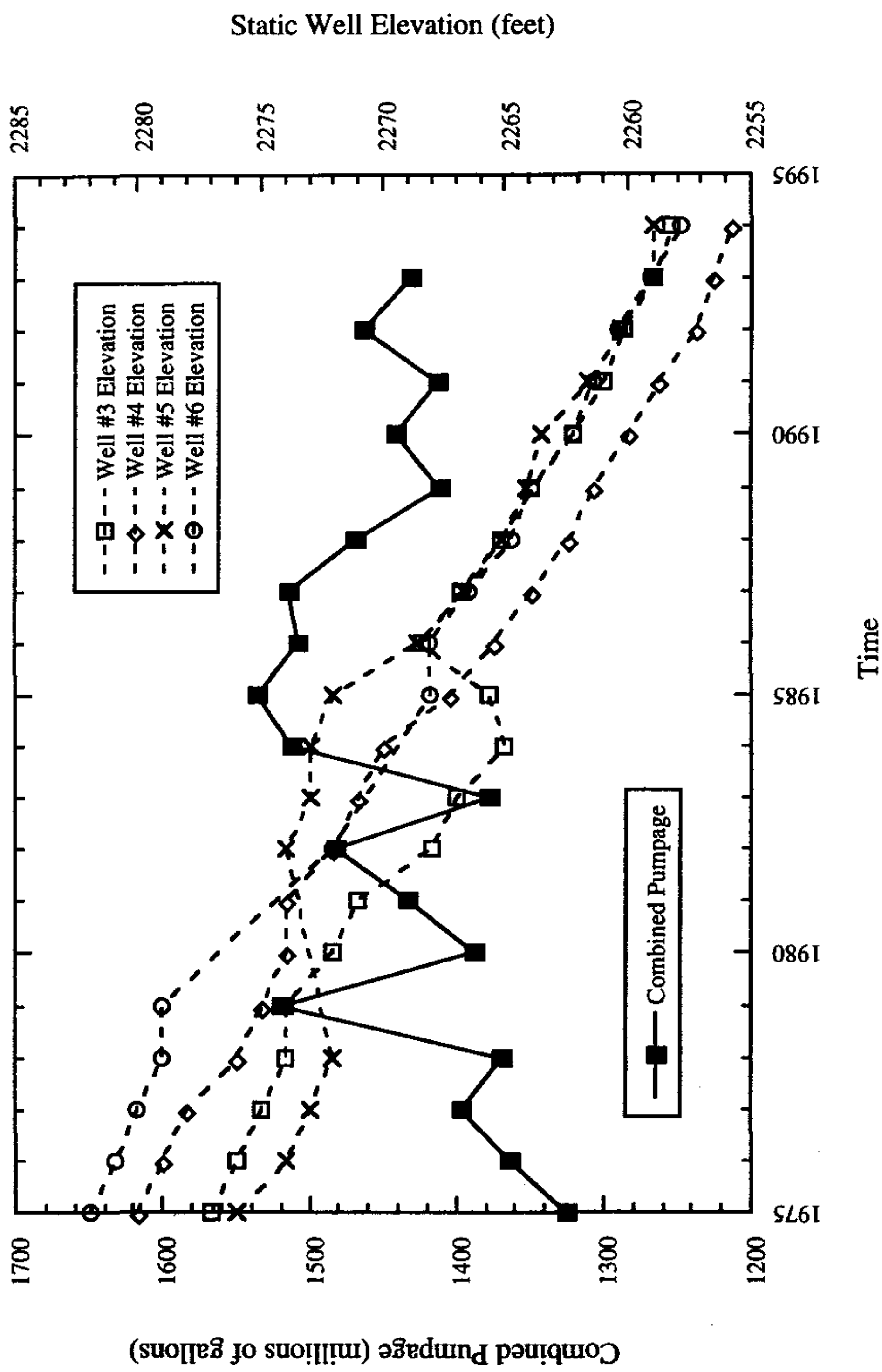

Figure 6: Summary of Pullman Wells - Pumpage Versus Drawdown

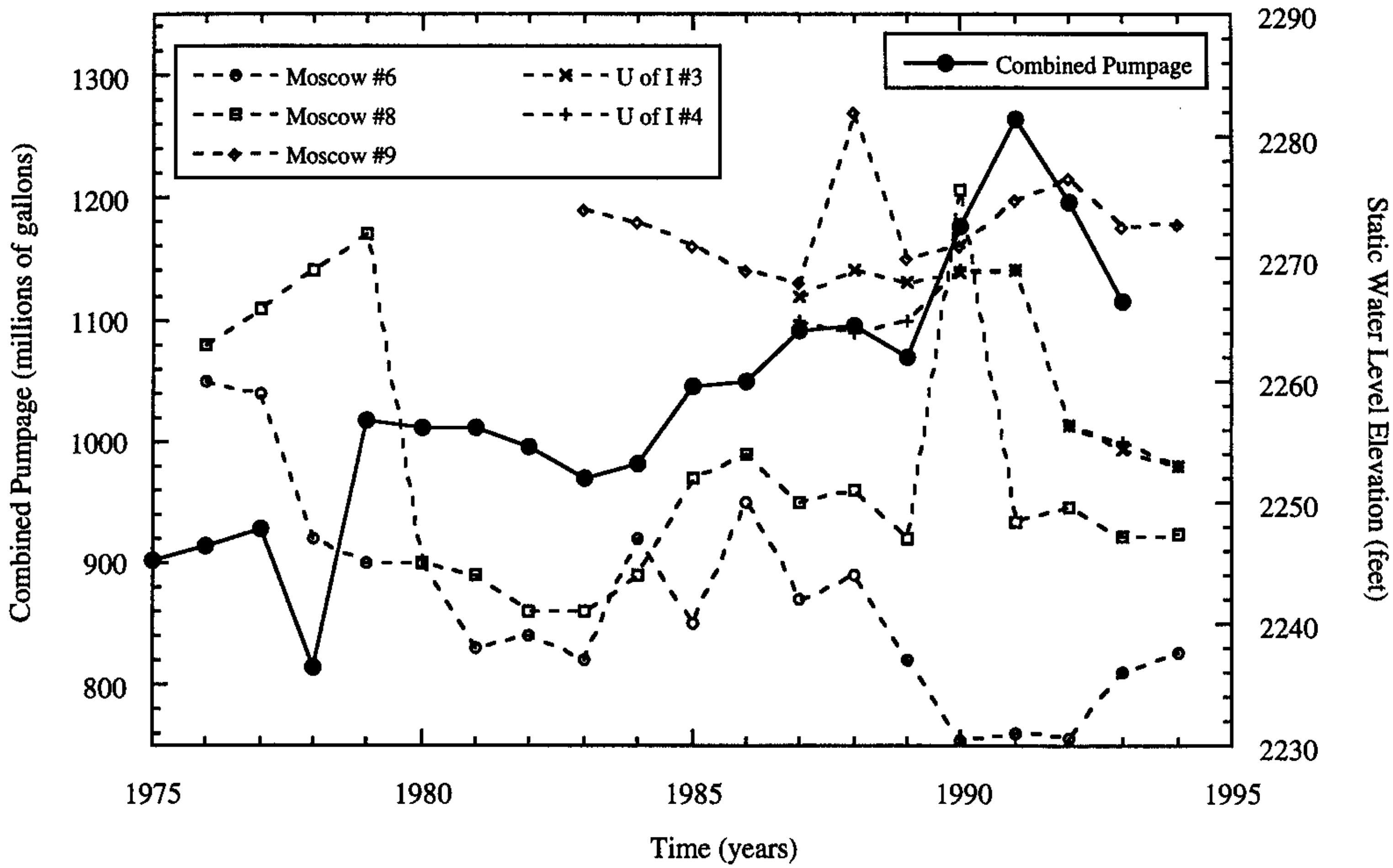

Figure 7: Summary of Moscow/UoI Wells - Pumpage Versus Drawdown

3.2 Identification of Boundaries

The second step was to examine the collected records to identify any information that would indicate the presence of a nearby barrier boundary. Here, plots like the one shown in figure 8, were generated to illustrate temporal (time) changes in pumpage versus (static well) water levels for the primary wells:

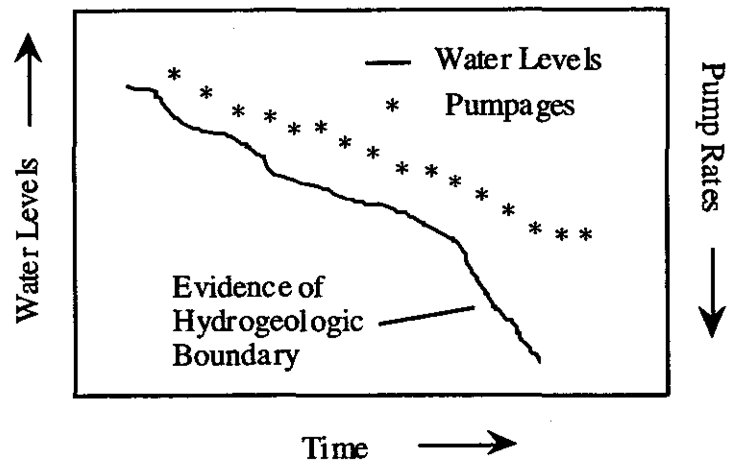

Figure 8: Generic Plot of Historical Water Levels and the Pumpages

Under the assumption of locally steady-state and homogeneous hydrogeologic behavior, theory would suggest that the two records should follow similar patterns through time, namely that as pumpage is increased the drawdown should also increase in a correlated manner in the absence of a boundary. If, however, at some point in time, the drawdown were to intercept a barrier boundary, an anomalously high drawdown would be observed for a given value of withdrawl. At this point, the two records would begin to diverge, with the observed water levels falling at a rate greater than those displayed by the continued increase in pumpage. Such evidence would suggest the presence of a "barrier or no-flow boundary" within the area of pumping influence.

The theoretical basis for this behavior can be derived from a simple manipulation of the steady state equations governing the hydraulics around a pumped well.[4] Here, one can write:

$$s = \frac{Q}{2\pi T} \ln\left(\frac{R}{r}\right) \qquad (2)$$

where s is the drawdown (or lowered water level) observed at some distance r from a well which is being pumped at a rate, Q; T is a hydrogeologic parameter (known as the transmissivity) characterizing the 'transmission capacity' of the aquifer to supply water; and R is a variable marking the maximum extent of the 'radius of drawdown influence.' Most notably in Eq. (2), however, is the direct dependence between s and Q in the absence of a boundary. In particular, as Q is increased, s is thought to increase a proportionate amount. Thus, historical records for both data should reflect a uniformly correlated trend in time, provided of course the drawdown produced by the pumpage did not impact a nearby barrier boundary.

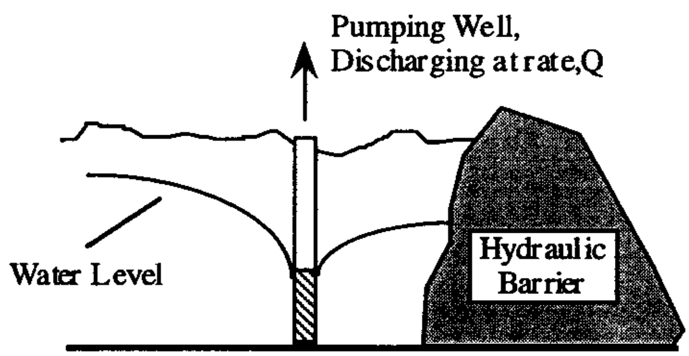

Figure 9: Illustrated Drawdown Influence in the Presence of a Barrier Boundary

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[4]Although the actual well hydraulic equations governing multiple layered aquifers (as noted for the Pullman-Moscow Basin) are much more complicated than that expressed by Eq. (2), their forms are relatively similar, particularly with respect to the main variable s, Q, T, and r (Bear, 1972; Huisman, 1972).

If, however, such a boundary were present, the drawdowns predicted by Eq. (2) would be less than those observed in the field. The noted effect is one of producing anomalously high drawdowns over a portion of the domain near that boundary. Hence, the s and Q data at some point in time (depending on the location of observation) would become divergent. Such results stem from the fact that there is a lack of water available to support a given pumpage in the face of such a boundary:

Results of the corresponding analysis yielded two main facts for the Basin[5]:

1. pumpage rates on the Moscow side (i.e. Moscow-Univ. of Idaho combined) are increasing collectively at a rate of just over 2% per year, while drawdowns remain relatively 'flat'; that is, there is no discernible increase currently in those drawdown records;
2. pumpage rates on the Pullman side (i.e. Pullman-WSU combined) are realtively 'flat,' while drawdowns continue to increase at about 1 foot per year.

In examining this information, the Moscow data would suggest an abundance of recharge is occuring on that side of the basin. In fact, the data further suggest that the rate of (net) recharge was sufficient, within a growing zone of influence, to satisfy the additional pumpage. Factors which may have produced this behavior include:

a. an actual increase in the amount of precipitation that was returning as recharge in the Moscow area; and/or
b. the induction of increased leakage from the Wanapum layers above; and/or

Nevertheless, given the reigning drought within the region over the last 5 years, item a is unlikely; hence, the observed increased in recharge may be a result of increased leakage from the Wanapum layers (above) induced by a lowering of the piezometric heads in the Grande Ronde around the Moscow area.

The Pullman data, on the other hand, suggest the presence of limited recharge (i.e. less than that observed in the Moscow area) and/or a barrier boundary in the zone of its

[5]At least in a average sense over the past 5 years or so.

pumping influence. The former could be derived from stratigraphically deeper hydrogeologic domains for Pullman, combined with smaller inputs of (net) precipitation.

On the Moscow side of the Basin, the principal hydrogeologic units are thought to be shallower, particularly against the eastern boundary marked by Moscow Mountain. This fact, combined with the likelihood of greater input from larger snowpack & precipitation at higher elevations, may establish that portion of the Basin as the most prominent in terms of overall recharge to the Moscow area. By contrast, the Pullman area (near WSU) is thought to lie atop the deepest portion of the hydrogeologic "bowl,"[6] wherein creating the largest travel time (and distance) for recharge events to occur. Moreover, the influence in precipitation (or the anonomous collection thereof) created by orographic/topographic effects which are possible on the Moscow side of the Basin are essentially non-existent in the Pullman area.

3.3 Recommendations for Future Data Collection

After reviewing the existing database of pumpage-drawdown records, the following recommendations were concluded:

1. a protocol should be developed outlining the procedures to be used in gathering "static water level" records; and
2. wells separate and distant from the main pumping centers should be sought out to act as more reliable points of observed drawdown data for the Basin.

With reference to item 1, it was noted that various inconsistencies and/or errors are present in the data collected to date.[7] To minimize its continuance, an emphasis should be placed on the adoption of a consistent "wait time" used in defining the static condition at each well, so long as the time decided upon is used equally by each of the entities collecting data. Moreover, once the data is collected, it should be reviewed for quality control prior to any subsequent readings and final cataloging.

[6]Records show a well drilled on the WSU campus which is over 2400 feet deep, the bottom of which did not intercept the crystalline baserock for the region.
[7]This is, in part, due to the highly variable hydrodynamics near a pumped (or recently shutdown) well.

To further increase the reliability of the data collected and to obtain an expanded "picture" of the regional drawdown, item 2 suggests that as many points across the Basin as possible should be established for future monitoring. Recognizing the economic constraints of this goal, there are a number of sites/wells in existence within the area which could be modified or maintained to provide crucial addtional drawdown data for the region. Candidate wells (of sufficient depth) include those located at: (i) the DOE test observation site (between Mosow and Pullman) and (ii) WSU's Knox Farm.[8] Moreover, vital information could be obtained if means were established to more regularly collect data at the pumping wells in the Towns of Colfax and Albion.[9]

4. Assessment of the Lum et al. Model

4.1 Model Review

The final task of the project was to assess and/or make recommendations for changes to current boundary conditions in the Lum et al. (1990) model, so as to more accurately reflect existing discovered for the Basin. In initiating that effort, the first step was to review exisiting elements of the model, both in terms of the current solutions it produces and the associated boundary conditions utilized. Founded on a hydrogeologic simulation obtained from the execution of the popular computer code MODFLOW (McDonald and Harbaugh, 1984), the existing model of the Basin is formed by the approximately 750 sq. mi. region defined by:

[8]To bring the DOE site "on-line," some capital expenditure would have to be made to place a recording instrument at that site and maintenance/data collection would have to performed by a representative or employee of one of the major entities/committees in the area. For the Knox Farm site, an operating (pressure) piezometer is already exisitng in the well. A simple agreement, of one form or another, need be made with WSU officials to have the well regularly measured.

[9]As before, these two facilities could be brought "on-line" with limited capital expenditure (as would be needed for Albion) and/or an agreement with the managing entity to establish a quarterly or semi-annual monitoring sequence (for example, in Colfax).

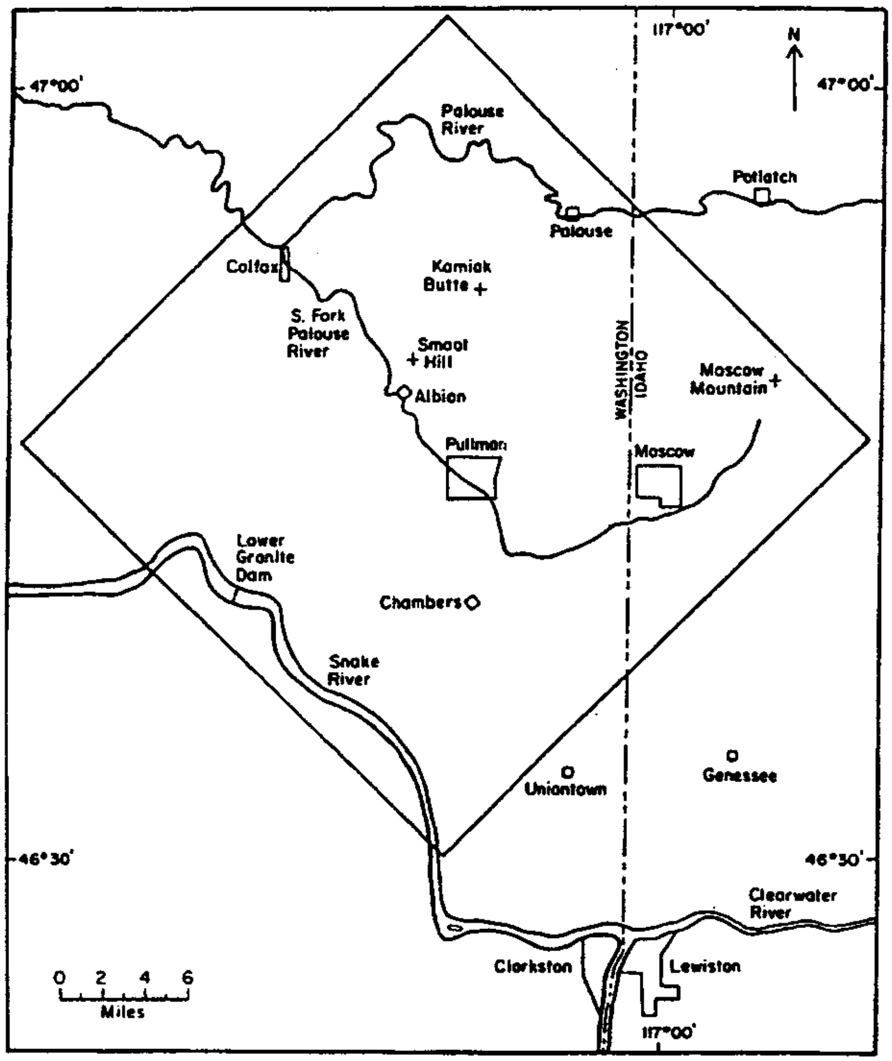

Figure 10: Current Basin Model Domain
(taken from Smoot and Ralston, 1987)

which is discretized into 3,025 (55 x 55) square grid cells, The corresponding boundary conditions are those shown in figure 11 below:

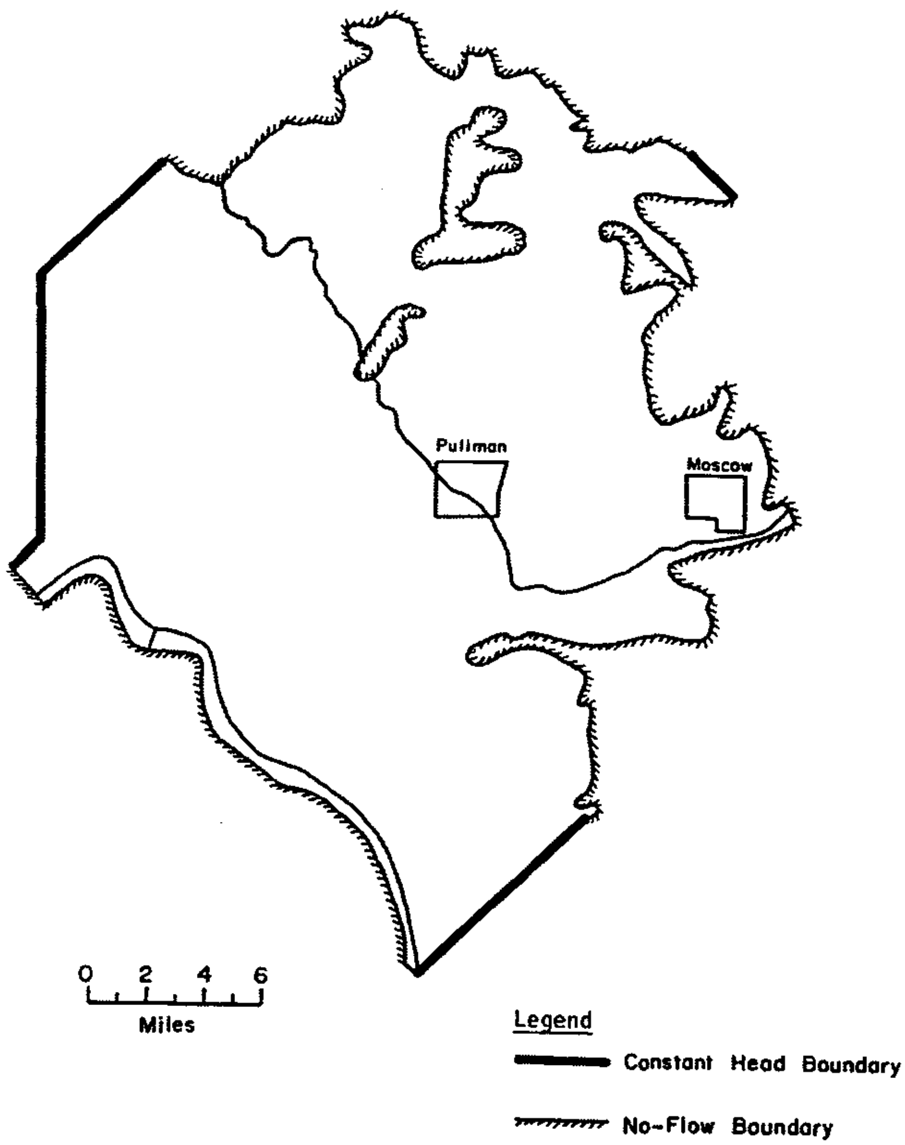

Figure 11: Lum et al. (1990) Boundary Conditions
(taken from Smoot and Ralston, 1987)

4.2 Recommended Model Changes

In reviewing the current structure/parameter selection for the model, a number of interesting items were discovered in the present input file.[10] Those items, along with review comments concerning the validity and/or errors of their selection, are listed below:

1. the constant head boundaries located northwest of Pullman and along the southeastern boundary of the modeled domain represented no "real" sources or water in those locations; moreover, the head values assigned along these boundaries were do so in arbitrary attempt to replicate the heads in the interior of the Basin; accordingly, they should be removed;

2. the transmissivity (i.e. the "conductability") values used in the Grande Ronde layer varied over two orders of magnitude; because of limited information on the formation, the selected range of numbers is thought to be unrealistic;

3. some 200 wells are in place along the Snake River and northwestern constant head boundaries to act as "sinks" in the removal of regional groundwater flow; once again, there is no justification for this approach and the wells should be removed (along with any unjustifiable no-flow conditions);

Now, in defense of Lum et al. (1990), the original development of the "model" for the Basin focused on 'head matching' near the two main pumping centers marked by Moscow and Pullman (and the two academic institutions). At that time, the use of artificial boundaries and other anamolous features external to these areas may have been justified as a means of producing the desired result on the interior of the Basin. Here, however, the authors would like to expand the "picture" of the hydrogeology for a much larger portion of the Basin in an attempt to more accurately represent those areas west and northwest of the City of Pullman. Hence, the elements of the Lum et al. model which are criticized above are not intended as negative comments of that work, rather as recommendations for improvement to the current model so as to broaden the scope of the investigated domain and to assess possible hydrogeologic linkages outside the Basin. This effort will be more clearly identified in the model executions shown in the following section.

[10]This file was obtained from Gary Johnson, whom is currently working at INEL and is an adjunct to the Univ. of Idaho. Mr. Johnson has been the 'purveyor' of the MODFLOW input files since their creation in the Lum et al. work.

4.2 Model Executions and Revisions

To begin the simulations, a "base" configuration was established using average annual pumpage rates for each of the major supply wells and the existing Lum et al. hydrogeologic configuration. The resulting contour of piezometric heads and their projections for the Grande Ronde layer are shown in figures 12 and 13. Although the solutions match the known heads in Moscow and Pullman quite well, it should not be inferred that the existing base model is all encompassing correct. In fact, similar results for the interior of the Basin were obtained via long-term projections by Barker (1979).[11] In that model, Barker's boundary conditions and physical inputs (e.g. transmissivity and recharge) differed significantly from those of Lum et al. (1990). The obvious question then is, "what is to be inferred regarding the accuracy of any of these model executions?" The answer quite honestly is nothing, unless of course the given modeling exercise can justify a solution based on the "physics" of the problem and/or other known information. Well, in this case, the exisiting model predicted the heads at the known locations, "isn't that accurate enough?" Not exactly! Explanation of this positon requires discussion of several points.

First, it should be pointed out that the so-called matching that is being performed is done using data collected at given well locations which physically represent points in the domain. Those drawdowns are then assigned (uniformly) over grid blocks within the model that are a half-mile on edge, as necessitated by the original grid assignment for the model. In so doing, the data collected at the individual wells are inadvertently being averaged over farily large block sizes in the model. As Brown (1991) reports, the result is one of insensitivity for the model predictions with respect to the selected physical parameters (e.g. transmissivity) in the domain. <u>In order to rectify this problem, the original grid assignment in the model should be modified to permit a "denser gridding" near points of known drawdown (namely those of the primary pumping wells).</u> Given various time constraints, this modification was not performed here.

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[11]Recall, in Barker's approach, the size of the domain was approx. 1/3 that used by Lum et al. (1990).

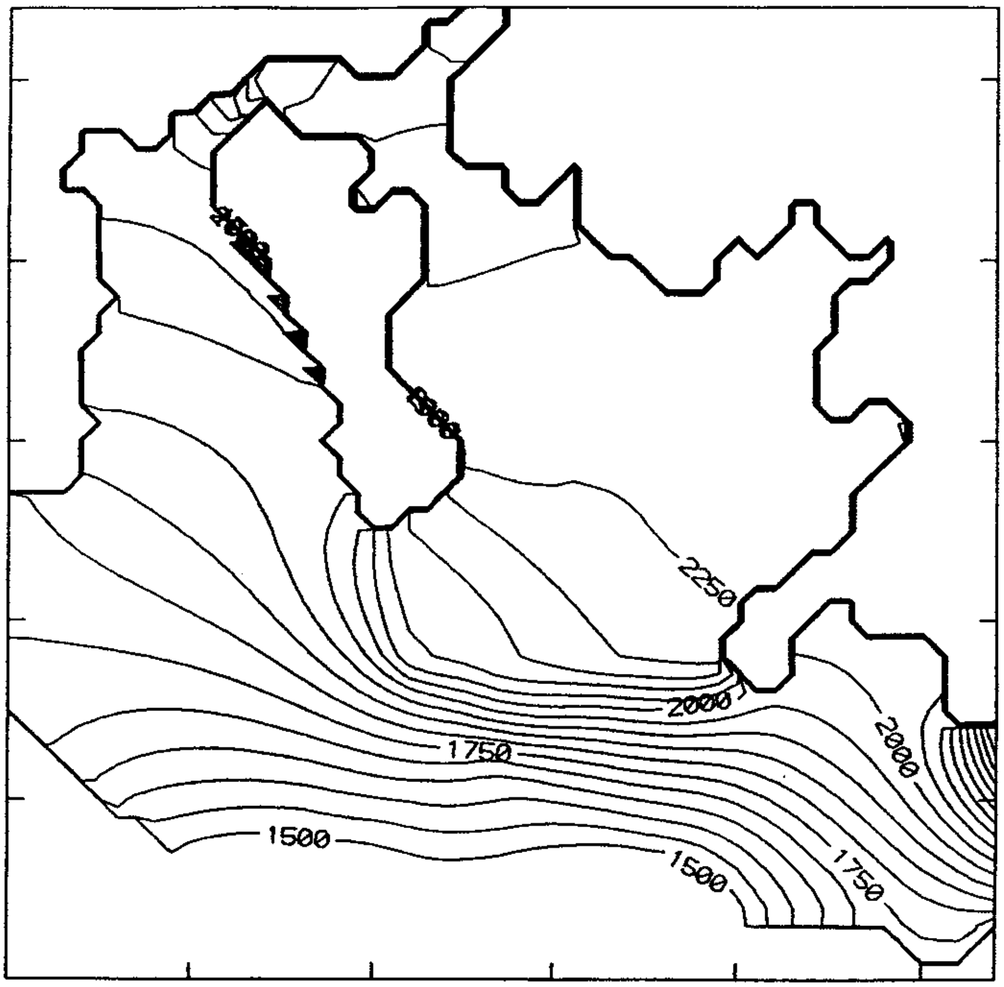

Figure 12: Piezometric Head Distribution Contours from Model Simulations Using 1993 Pump Stresses and Original Lum et al. (1990) Domain Configurations

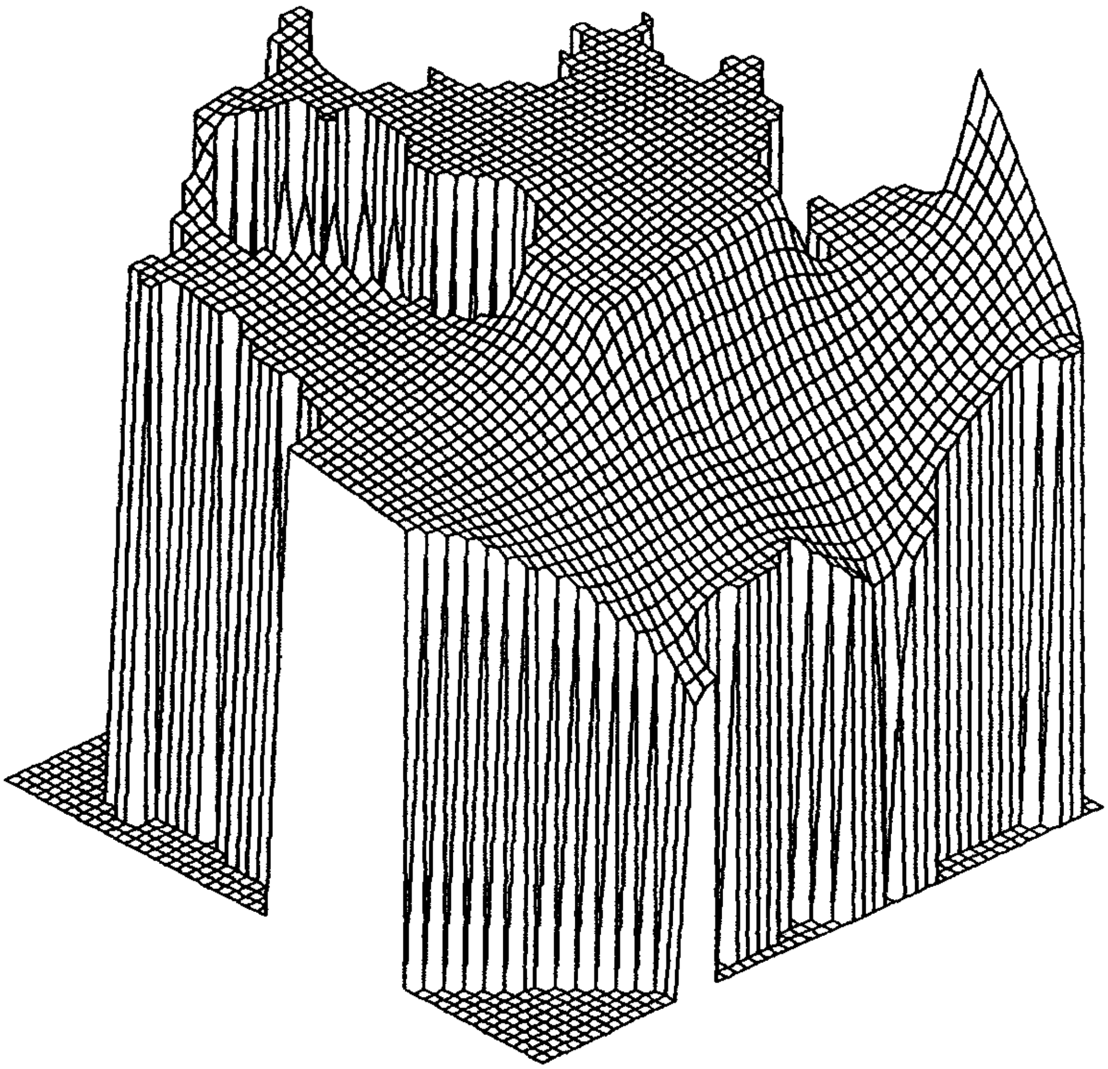

Figure 13: Areal Projection of Piezometric Heads Generated Model Simulations Using 1993 Pump Stresses and Original Lum et al. (1990) Domain Configurations

Second, the hydraulics of the solution should be assessed for its accuracy not just with respect to the heads (or drawdowns) at the main pumping wells but also at other critical locations basin-wide. Here, in particular, interest is directed at the events which are possibly occurring along the west-northwestern boundary of the Basin. In examining the typical result produced under the current version of the model, solutions (in section) of the type shown in figure 14 are obtained. That portion of the solution produced along the western edge of the Basin is, however, vastly unrealistic.[12] If correct, a "water fall" approximately 1400 feet in height would have to be occurring along the wall of Snake River canyon. Additonally, the majority of flow with Grande Ronde would be directed to this location. This, however, is most positively not the case. Moreover, the solution should be tested against other monitoring points away from the pumping wells. Unfortunately, the necessary data to that is simply not available, ergo the previous recommendation to expand data collection at the DOE test well and WSU's Knox Farm should be given serious future consideration.

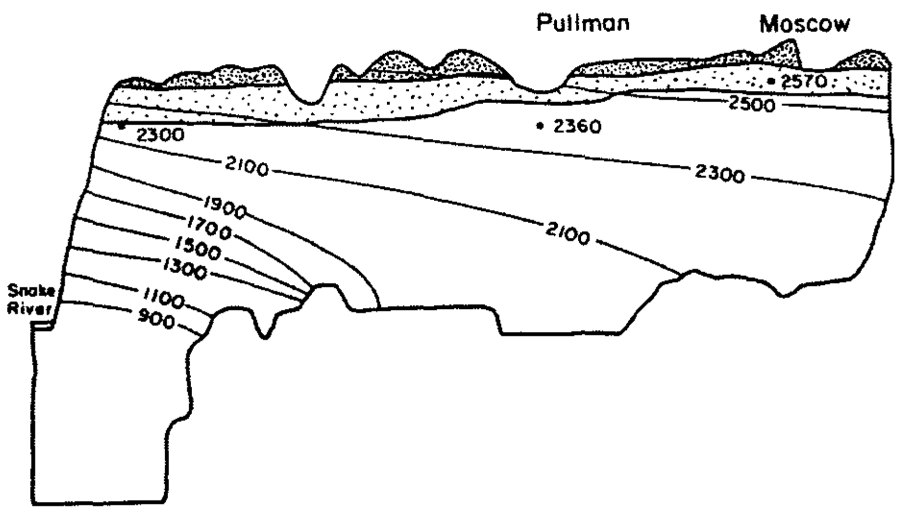

Figure 14: Illustration of Vertical Head Solution for Existing Model Configuration (taken from Smoot and Ralston, 1987)

[12]Shown in the figure is a no-flow boundary along the Snake River wall which produces a head drop of over 1400 feet in a nearly vertical direction near the river. The water shown is being removed via the placement along this boundary of some 200 artificial wells within the model and, as such, it produces the generic result shown given the amount of water that is currently being recharged into the Basin.

In addressing more directly the unresolved issue of the boundary along the Snake River canyon, the authors would be derelict in their obligations if they did not conjecture their own solution to this "mystery of the ages." In producing such a solution, the recomended changes regarding the boundary conditions were adopted[13] and the artificial wells along the Snake River were removed. In order to match the know hydraulic conditions on the interior of the Basin and permit a large head drop to occur between the Pullman area[14] and the Snake River canyon, a no-flow boundary (representing a vertical, no-transmissive, tectonic fault plane) was placed along the approximate line of Union Flat Creek, with a slot located near the Wawaiwi outfall so as to permit the known spring at that location. Justification for this "fault' has been speculated for years (Foxworthy and Washburn, 1963; Luzier and Burt, 1974; Barker, 1979). Here, we've just gone ahead and included it. The solution to this set-up is given in figures 15 and 16 (located at end of section). Interestingly enough, in examing the results, several known phenomena are explained quite well! The huge head difference between the interior of the Basin and the Snake River are appropriately resolved, along with the large head drop known to occur between the Towns of Pullman and Colfax, WA. Moreover, the relatively "flat" head surface within the interior of the Basin has been preserved and the presumed dominance of regional flow to the northwest is recovered. Unfortunately, the known heads (in absolute terms) for the Pullman and Moscow areas are not correct, nor is the presence of the no-flow boundary in northwestern most corner. The former err could, however, be easily rectified with a simple manipulation of the existing transmissivity/recharge field, while the latter is an unavoidable consequence of the default conditions in computer code.

Now, certainly the authors do not contend here that the included "fault" is the proverbial answer to "life's problems" with respect to the hydrogeologic questions governing the Basin. It does, however, appropriately address what has been over the years

[13]Namely, the constant head boundaries to the south and northwest were deleted.
[14]Moreover, the region southwest of there (e.g. in the Uniontown/Colton) where the heads are also known to be quite high.

some very interesting points of discussion. Of course, it would only be appropriate of us here to recommend that further study of the presence of such a barrier be investigated. This could be done via various geophysical methods in concert with additonal pump tests, provided a deep suitable well was in place near the boundary. These steps are, however, very costly and would prove a burden to the operating budget of the entities within the region. So, as a more cost effect solution, efforts should be direct to identify, if any, wells located on the western side of Union Flat Creek. The owners/operators of those well should be encouraged, with financial assistance, to collect water level data in those wells, even if its a single reading. Such information may be exteremely useful in proving/disproving various theories of groundwater flow for the region, particularly with respect to the western boundary of the Basin.

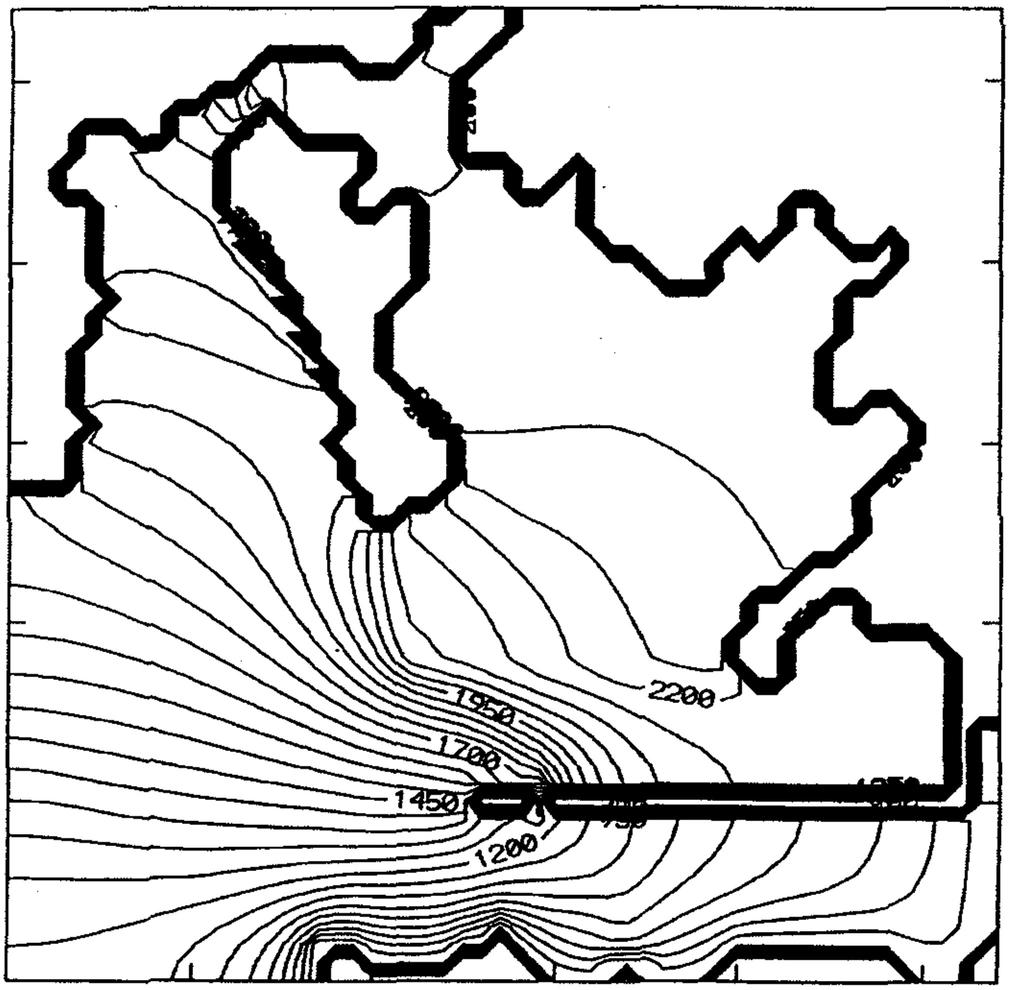

Figure 15: Piezometric Head Distribution Contours from Model Simulations Using 1993 Pump Stresses and Revised Physical Domain, Including Possible Barrier Boundary Along Union Flat Creek

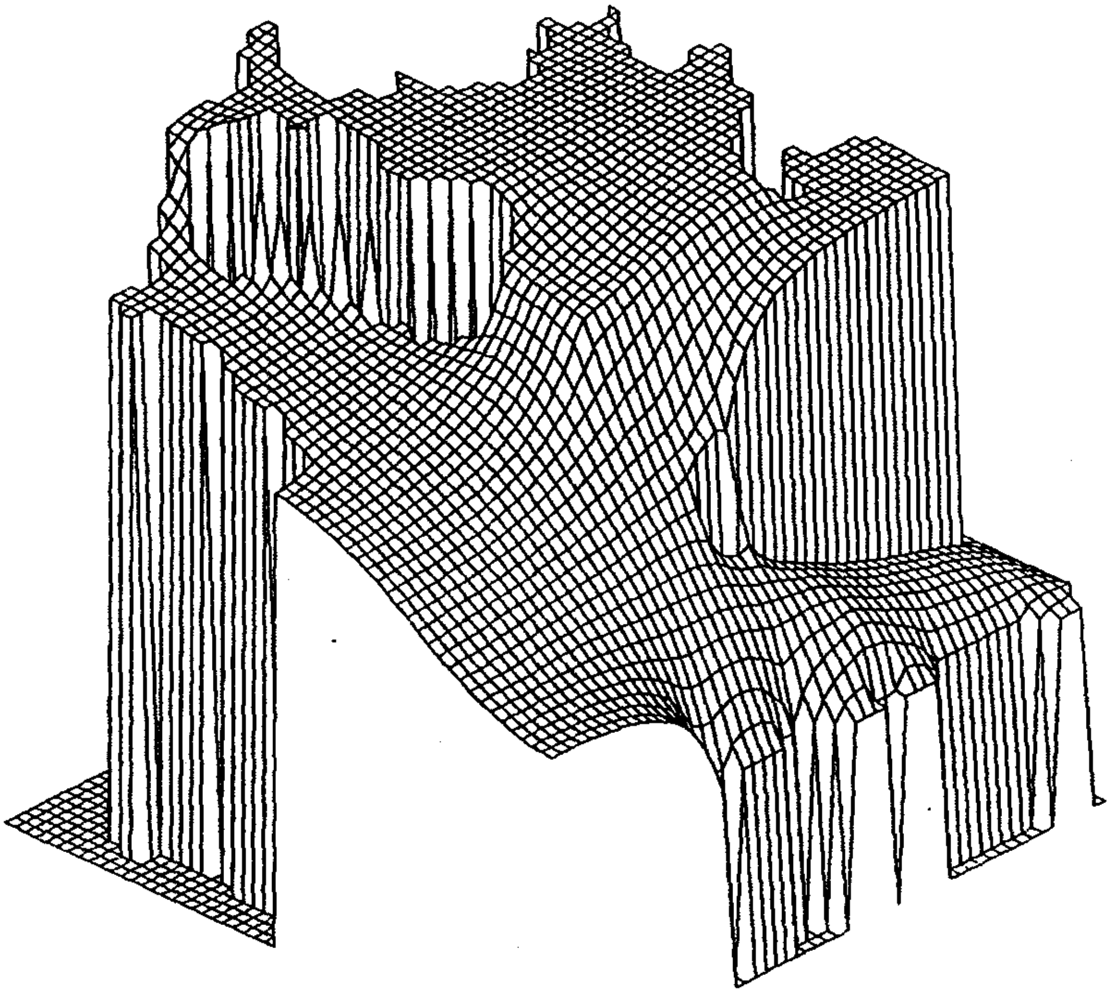

Figure 16: Areal Projection of Piezometric Heads Generated From Model Simulations Using 1993 Pump Stresses and Revised Physical Domain, Including Possible Barrier Boundary Along Union Flat Creek

5. Summary and Conclusions

5.1 Summary

The focus of the work presented here is one directed at the discovery and/or re-assessment of the theories governing the hydrogeologic boundaries for the Pullman-Moscow Basin. At issue is the resolution of a long standing debate over the extent and physical composition of the Basin along its western and northwestern boundaries. In an attempt to more clearly define those boundaries, recent drawdown data for both Pullman and Moscow were compared against temporal pumpage records gathered from several wells within the area. In short, on the Moscow side of the Basin, groundwater withdrawl rates are increasing approximately 2% per year (over the last five years); yet, the corresponding piezometric heads (i.e. well water levels with the Grande Ronde) seem to have experienced little change during that same period. By contrast, on the Pullman side, withdrawl rates have been fairly constant, while the piezometric heads continue to be lowered at a rate of about 1 foot per year. A likely explanation for these events would include a heterogeneous (spatially varying) net recharge over the Basin, the largest fraction entering on the Moscow side, combined with a limited expanse for the aquifer domain towards the west of Pullman. In further reviewing the data, the evidence suggests that the drawdown influence generated within the Pullman area has intercepted a barrier boundary or some other limiting form of hydrogeologic connection.

In pursuing the barrier concept further, an existing computer model of the Basin (Lum et al., 1991) was modified to include a "wall" in the deep basalts beneath Union Flat Creek. To investigate the presence of that structure, simulations of the of the revised domain were run in an attempt to recover several unique hydrogeologic features for the region, namely elevated piezometric heads to the west (in comparison to the Snake River) and large gradients to the northwest. Although imagnitive in its exact formation, the presence of the wall (as placed here) does in fact help to explain several of the more interesting observations for the region. In particular, the approximately 1700 foot difference in piezometric head between Union Flat Creek and the Snake River is realized without the presence of some 200 artificial wells as included by Lum et al. (1990) and the nearly 750 foot head drop known to exist between Pullman and Colfax is also recovered without the anomalous inclusion of a constant head boudary to the northwest.

5.2 Conclusions

In conclusion, there are two issues which seem deserving of additional comment. First, the question of how all this "stuff" fits into the "picture" of long-term water resources for the region. Certianly, if the combined water demands for the region placed on the Grande Ronde remain constant, little is likely to change. The drawdowns in Moscow will stabilize and remain flat, while those in Pullman will likely to continue to grow at a rate of about 1 foot per year. This conclusion, however, is obvious in that the most recent records for the Basin bear these facts out. The question then is, "are the rates of well water declines within the Pullman area something that should be considered more seriously?" The answer is probably not, provided of course that withdrawl rates do not increase drastically in the future. That portion of the Grande Ronde that is under Pullman is, as most theories would agree, the thickest part of the aquifer in the area. Moreover, if Pullman and WSU pumpages are controlled (i.e. self-limited), then the drawdowns increases that are currently being observed should stabilize within the next four or five years (as the area of influence grows to intercept a greater volume of recharge). The only covenant to this seemingly positive prognostication is that the region should not drastically increase its withdrawl rates for the deep aquifer. Conservation measures, particularly with respect to lawn watering, domestic use (such as inadequate fixtures on showers/toilets) and other more frivilous demands, should be brought to the general public's attention in a vigorous campaign. If such measures are carried out with a moderate degree of success for the area, the quantity of water for the region should be more than sufficient for many decades to come.

Finally, it is presumed here that the current assessment of the boundaries, as given by Lum et al. (1990), should be revised. It is very likely from the evidence gathered here that the Basin does in fact possess a western (barrier) boundary in the area along Union Flat Creek. The Basin is most likely hydraulically connected to other aquifers outside the area through discharge within the Grande Ronde along a line extending from Pullman to Colfax,WA. Beyond that northwest position, some of the groundwater is believed to simply return to the Snake River as it turns to the west, whilst the other is thought to pour out into the larger domain of the Eastern Columbia Plateau. In any respect, the authors believe the model modifications recommended here, including the presence of a deep wall along Union Flat Creek should be given serious consideration in all future formulations of groundwater flows for the Basin.

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