Research Technical Completion Report

# DETERMINATION OF SUSTAINED YIELD FOR THE SHALLOW BASALT AQUIFER IN THE MOSCOW AREA, IDAHO

by

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Submitted to

Pullman-Moscow Water Resources Committee

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ABSTRACT

The cities of Moscow, Idaho and Pullman, Washington, the University of Idaho, and Washington State University meet almost all their water needs by pumpage from ground water. Water use by the four entities has increased as the population of the cities and enrollment at the universities have increased. The increase in water use has led to an increase in pumpage from shallow and deep aquifers underlying the Pullman-Moscow area. Water levels in the aquifers have declined in response to this pumpage. The general objective of this study is to estimate a sustained yield from the shallow aquifer in the Moscow area and compare the estimate of sustained yield with recharge figures in Lum and others (1990).

Pumpage records and water level data from the Moscow area are analyzed to obtain estimates of sustained yield for the shallow aquifer using the Hill method and the zero water level change method. A maximum estimate of sustained yield for the shallow aquifer is about 500 to 520 million gallons per year with a water level close to 2479 feet. The estimate of sustained yield is probably 50 to 70 million gallons per year less than the average annual recharge into the Wanapum Basalt. Decreased downward leakage to the deep aquifer balances much of the pumpage from the shallow aquifer. Continued monitoring of pumpage rates and water levels should be done in support of ground water management in the basin.

# INTRODUCTION

## Statement of Problem

The cities of Moscow, Idaho and Pullman, Washington, the University of Idaho, and Washington State University meet almost all their water needs by pumpage from ground water. Water use by the four entities has increased as the population of the cities and enrollment at the universities have increased. The increase in water use has led to an increase in pumpage from aquifers underlying the Pullman-Moscow area. Water levels in the aquifers have declined in response to this pumpage. The decline in water levels has prompted concerns about the ability of the aquifers to meet future water needs.

Ground water for the city of Moscow and the University of Idaho is pumped from two separate but interconnected aquifer systems, designated in this report as the shallow and deep aquifers. The shallow aquifer is from about 100 to 350 feet below land surface in the Wanapum Basalt of the Columbia River Group. The deep aquifer is from about 750 to 1250 feet below land surface in the Grande Ronde Basalt. The shallow aquifer receives recharge from the overlying Palouse loess and discharges to streams and the underlying Grande Ronde Basalt. The deep aquifer receives recharge from the overlying Wanapum Basalt with most discharge to the Snake River Canyon and the Columbia River Basin (Lum and others, 1990). Concerns have been raised about what effect pumpage from the shallow aquifer has on water levels in, and recharge to, the deep aquifer.

Pumpage by the City of Moscow and the University of Idaho from the shallow aquifer in the Wanapum Basalt caused water level declines of about 100 to 130 feet from 1900 to the early 1960's. Since the early 1960's, water levels have recovered to 1930's levels because of decreased pumpage from the shallow aquifer. The decreased pumpage is the result of the development of the deep aquifer as a primary water supply source. Determination of pumping rates which would result in stable water levels in the shallow aquifer would be useful in the combined management of the shallow and deep aquifers in the Moscow area.

## Purpose

The purpose of this study is to improve understanding of the relationship between yearly pumpage volumes, water levels in, and recharge to the shallow aquifer in the Moscow area to aid formulation of water management plans for the Pullman-Moscow area.

## Objectives

The general objective of this study is to estimate a sustained yield from the shallow aquifer in the Moscow area. Specific objectives are:

1. Summarize geology and hydrogeology of the Pullman-Moscow area.
2. Collect, compile, and present water level and pumpage data in the form of hydrographs, bar graphs, and tables.
3. Extrapolate annual pumpage volumes for years prior to the

period of record by estimating per capita water use.

4. Analyze relationships between pumpage and water levels in the shallow aquifer in the Moscow area.

5. Estimate the sustained yield of the shallow aquifer in the Moscow area and compare to recharge estimates by Lum and others (1990).

6. Evaluate the effect of pumpage from the shallow aquifer in the Moscow area on water levels in the shallow aquifer and in the deep aquifer in the Moscow area.

## Location of Study Area

The Moscow area is located on the border of Washington and Idaho, in Latah County (Figure 1). The study area is bounded on the north, east, and south by outcropping crystalline basement rock (Palouse Range, Paradise Ridge, Tomer Butte, Bald Butte). The western limit of the study area is defined by an estimate of the area influenced by pumpage from the shallow aquifer by the city of Moscow and the University of Idaho. The estimate is based on Lum and others (1990, fig. 12) who show an area around Moscow where more than 25 closely spaced wells completed in the Wanapum Basalt had water level increases of 0 to 9 feet from 1974 to 1985.

## Precipitation

Average annual precipitation increases west to east in the Pullman-Moscow area. Average annual precipitation is 20 inches in Colfax, 21 inches in Pullman, 23 inches in Moscow,

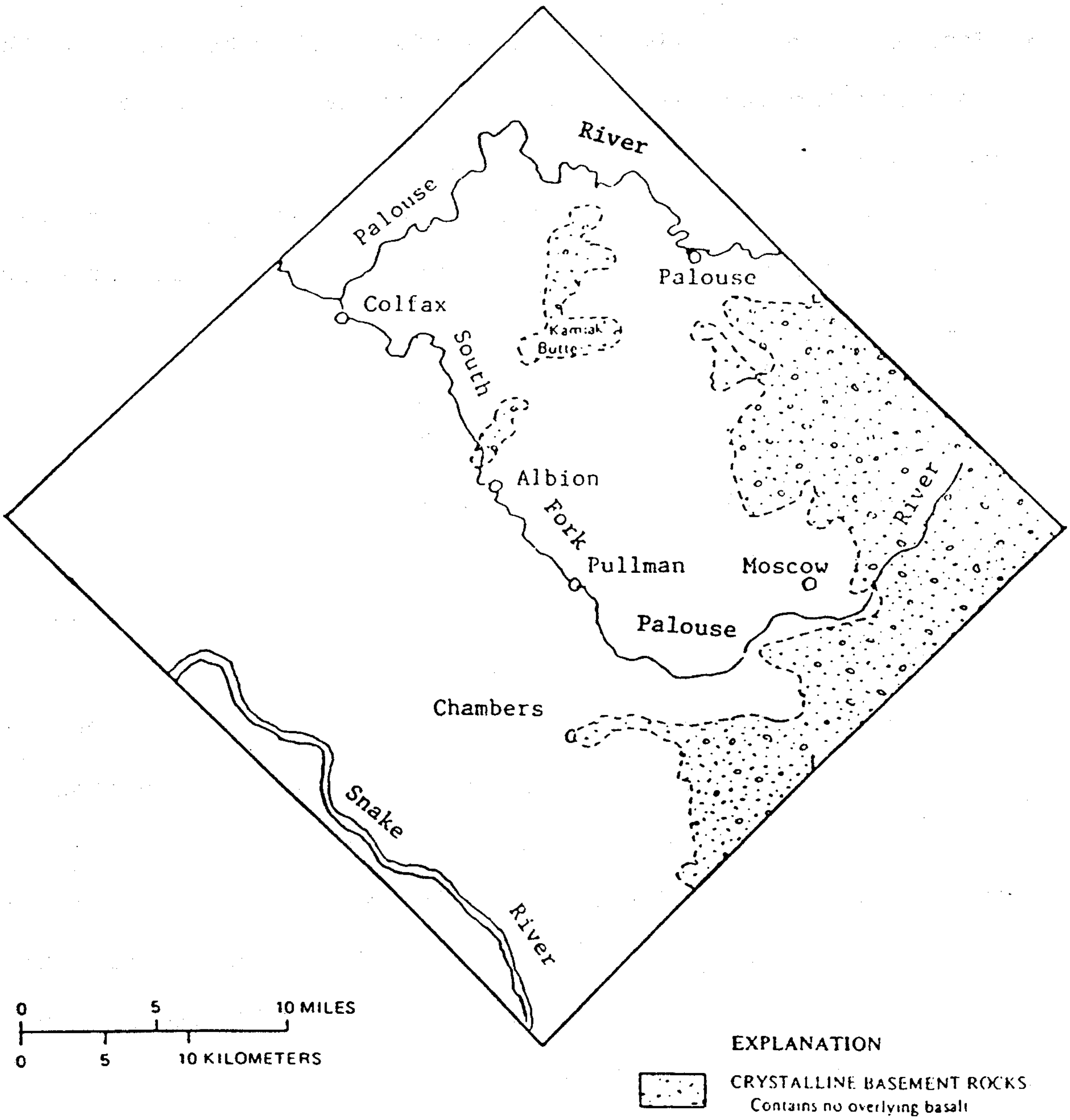


Figure 1. Location map of Moscow area.

and close to 40 inches in watersheds located on Moscow Mountain (Bloomsburg, 1959; Cherry, 1986; U.S.N.O.A.A., 1989a, 1989b; personal communication, Idaho State Climatologist Office, 1991). Most precipitation falls between November and April and is generally of low intensity.

## Population

According to the 1990 U. S. census, the population of Moscow is 18,519. On-campus student enrollment at the University of Idaho for the 1989-1990 school year was almost 10,000. Both the city population and the university enrollment have shown a general increase since the early 1900's.

## Previous Studies

No previous studies have presented a sustained yield for the shallow aquifer in the Moscow area. However, previous studies in two areas are of interest to this study: 1) literature on hydrogeology and recharge in the Pullman-Moscow area, and 2) literature pertaining to the determination of sustained yield.

### Hydrogeology

Russell (1897) conducted the first investigation of the hydrogeology of the Pullman-Moscow area and found flowing artesian wells in Pullman and reported flowing wells in Moscow. Foxworthy and Washburn (1963), Ross (1965), Walters and Glancy (1969), and Jones and Ross (1972) all described the basic hydrogeology of the area.

Laney and others (1923), Stevens (1959; 1960), and Crosthwaite (1975) authored reports that contain data concerning various aspects of water supply in the Pullman-Moscow area such as geologic well logs, well construction data (well depth, well diameter, use of well, casing depth, etc.), water levels in observation wells, and brief overviews of the geology and hydrogeology of the Moscow area. Jones and Ross (1972), Barker (1979), Smoot and Ralston (1987), and Lum and others (1990) have developed mathematical models of ground-water flow in the area.

## Recharge

Lin (1967) studied factors affecting recharge in the Pullman-Moscow area. Williams and Allman (1969) analyzed factors affecting infiltration and recharge through loess.

Laney and others (1923), Stevens (1959; 1960), Foxworthy and Washburn (1963), Ross (1965), and Jones and Ross (1972) estimated or discussed recharge in the Pullman-Moscow area. Barker (1979) estimated yearly recharge into the Grande Ronde Basalt based on results of a computer simulation of the aquifer system in the Pullman-Moscow basin.

Bauer and Vaccaro (1990) developed a model for recharge in various basins within the Columbia Plateau regional aquifer system, including the Pullman-Moscow basin. Lum and others (1990) constructed a 3-D computer model of ground water flow in the Pullman-Moscow basin. Their estimate of recharge for the model is based on work by Bauer and Vaccaro (1990).

Bloomsburg (1959), Davis (1971), and Cherry (1986) studied small watersheds near Moscow. Each study determines the percentage of annual precipitation that infiltrates to the water table.

## Sustained Yield

The concept of sustained yield, (also called safe yield), of a ground water basin was defined by Meinzer (1932, pg 99) as " the practicable rate of withdrawing water ..... perennially for human use". In the 1940's and 1950's, the definition of safe yield was modified to be that quantity of water which could be extracted each year without producing undesirable results. (See for example Conkling, 1946; Banks, 1953; Todd, 1959). The undesirable results might include but are not limited to: excessive pump lifts because of lower water levels, degradation of water quality, and legal considerations such as interference with other water rights.

During the late 1950's and early 1960's, other concepts of yield were introduced because of dissatisfaction with use of the term safe yield. Since the 1960's, safe yield generally has been called sustained yield or perennial yield (A.S.C.E., 1961 and 1972; Walton, 1970; Todd, 1980; Mandel and Shiftan, 1981). Todd (1980) and Domenico (1972) pointed out that sustained or perennial yield can and usually does vary with time. This is because any estimate of sustained yield is based on specific conditions and a change in any of these conditions will modify the estimate of sustained yield. Some of these conditions include but are not limited to: annual rainfall, infiltration rates, natural recharge and discharge, ground water boundaries, pumpage volumes, water levels, well locations, ground water-surface water interactions, well construction, economics, and legal considerations.

This study uses Todd's (1980, p. 363) definition of sustained yield: "the rate at which water can be withdrawn perennially under specified operating conditions without producing an undesired result". The "undesired result" is defined later in this study.

Methods of determining sustained yield are outlined in Conkling (1946), Todd (1959; 1964), Bear and Levin (1967), Domenico and others (1968), Walton (1970), Domenico (1972), and Hamill and Bell (1986). Todd (1980) also contains many references pertaining to the determination of sustained yield.

Two of the more accepted methods of determining sustained yield are the Hill method and the zero water level change method. These methods are based on a simplified form of the equation of hydrologic equilibrium given as follows: net inflow minus pumpage equals change in storage. A change in one of the terms in the equation must be equaled by a change in one or both of the other two terms. The temporal pattern of water levels in an aquifer is an indicator of the balance in this equation. A long-term rise in water levels generally indicates that the total ground water recharge (natural and artificial) exceeds the total discharge (natural and pumpage) from the ground water system. A long-term decline in water levels generally indicates that discharge exceeds recharge. However, if the pumpage continually increases, the drawdown will increase whether or not the pumpage exceeds the recharge. No long-term change in water levels generally indicates that the ground water system is in an equilibrium state.

The Hill method was first presented in Conkling (1946) and is summarized in Todd (1959; 1964; 1980), ASCE (1961), and Domenico (1972). The Hill method consists of plotting the average annual water level change versus average annual pumpage for a given time period. Using moving 5 year time periods reduces the effects of yearly variations in pumpage, recharge, and other factors. The data should plot near a straight line if there is a relationship between water level change and yearly pumpage and if net inflow (recharge from all sources minus natural discharge) is fairly constant. Points that fall on the line correspond to periods when net inflow equals the average net inflow. Points that fall to the right of the line correspond to periods when net inflow exceeds the average net inflow. Points which fall to the left of the straight line correspond to periods when net inflow is less than average net inflow. Figure 2, an example taken from Conkling (1946), illustrates an application of the Hill method. This example is of a hypothetical ground water basin with an average net inflow of 15,000 acre feet per year.

The horizontal departure of the points from the straight line equals the difference between net inflow and average net inflow. The x intercept of the line (corresponding to zero water level change on the y axis) is an estimate of sustained yield (average net inflow for the period in question).

The zero water level change method is based on the following premise; if water levels are the same at the beginning and end of a long period of pumping, the average pumpage over the period is an estimate of sustained yield. This method was first described by Haley (1955) and summarized by ASCE (1961), Todd (1959, 1964), and Domenico (1972). Figure 3 is a hypothetical example of an application of the zero water level change method. The straight line connects two years of equal water level. The average yearly pumpage during this time period is an estimate of sustained yield.

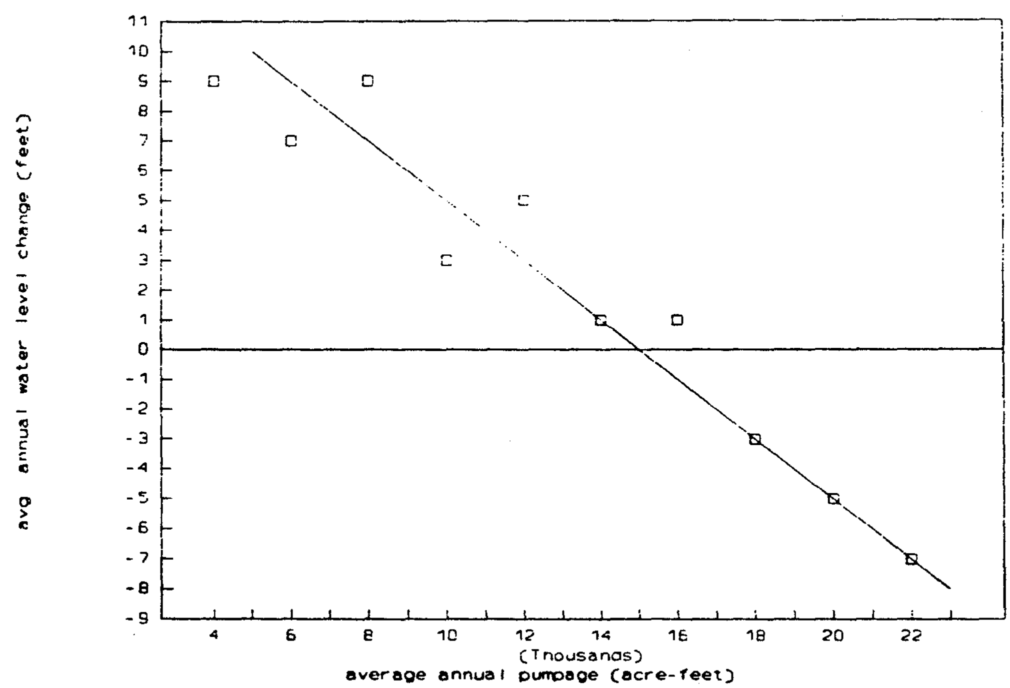


Figure 2. Example of Hill method for hypothetical ground water basin (from Conkling, 1946).

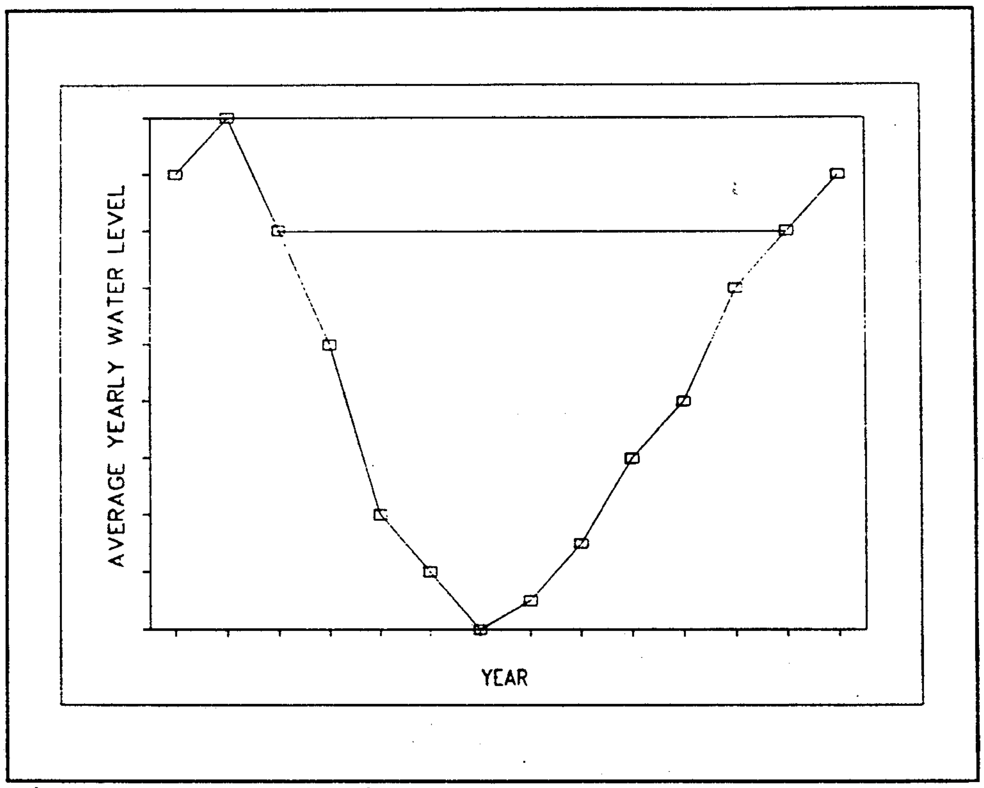


Figure 3. Hypothetical example of zero water level change method.

# HYDROGEOLOGY

## Geology

The generalized geology of the Pullman-Moscow area consists of a sequence of basalt flows with interbedded sediments. This sequence is capped in most places by the Pleistocene Palouse Loess and underlain by an eroded surface of pre-Tertiary crystalline rocks. The crystalline rocks are primarily granitic with some metamorphic rocks at scattered localities. Figure 4 shows the generalized stratigraphy of geologic units in the Pullman-Moscow area and figure 5 shows the location of outcropping crystalline basement rock.

The basalts in the Moscow area are part of the Miocene Columbia River Basalt (Swanson and others, 1980). The Columbia River Basalt is a thick sequence of basalt flows which erupted over millions of years. The basalt flows cover much of eastern Washington and Oregon, and parts of northern Idaho. Total thickness of the basalts in the Pullman-Moscow area ranges from 1,300 feet at Moscow to over 3,000 feet west of Pullman (Walters and Glancy, 1969). Individual flows are from 50 to 200 feet thick locally.

Basalt flows in the Pullman-Moscow area are classified into the Wanapum and Grande Ronde Basalts of the Yakima Basalt Subgroup of the Columbia River Basalt Group (Swanson and others, 1979). The Wanapum and Grande Ronde Basalts can be differentiated geochemically and stratigraphically. The Wanapum contains higher concentrations of titanium and lower concentrations of magnesium; the Grande Ronde contains higher

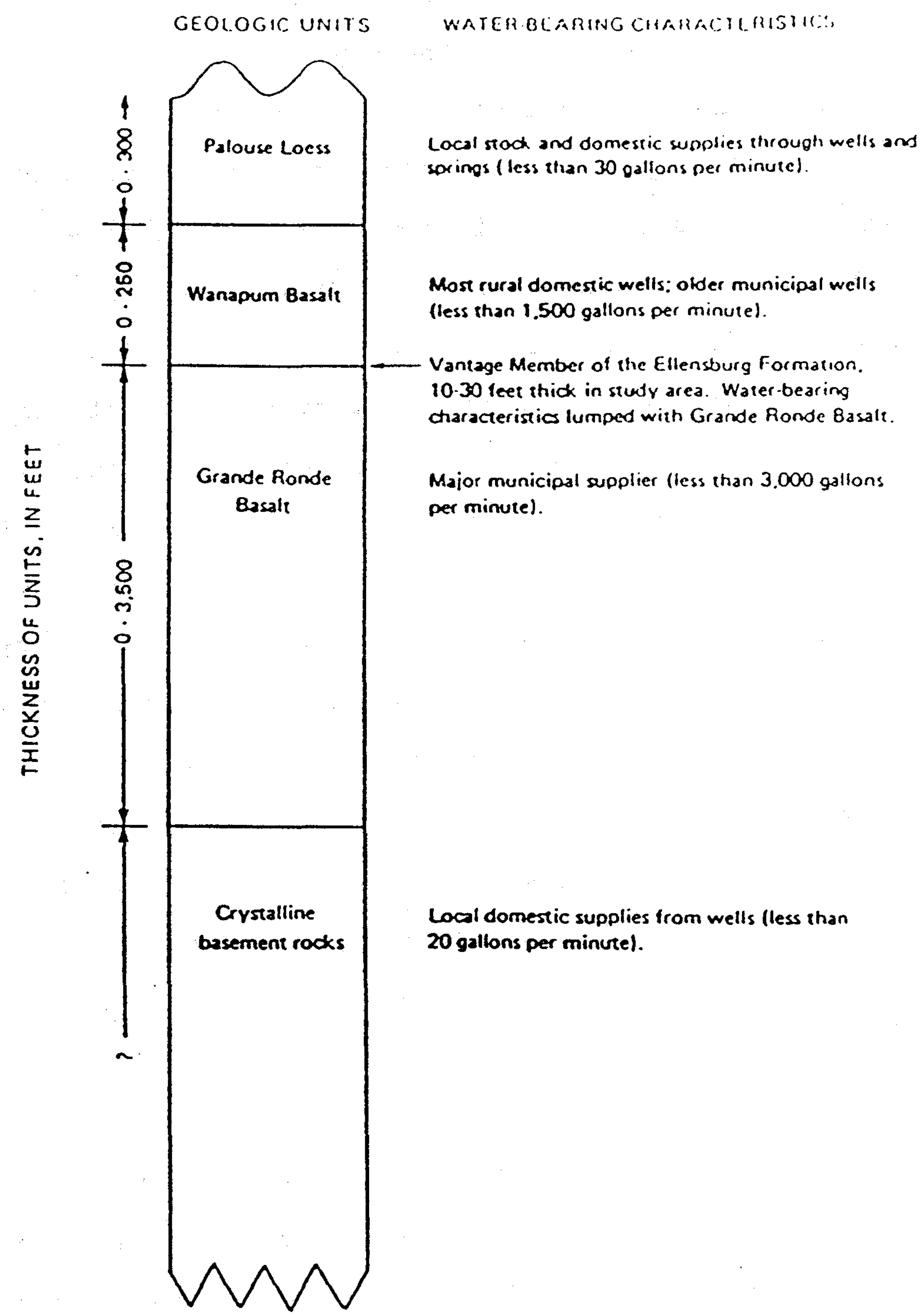


Figure 4. Generalized stratigraphy of geologic units in the Pullman-Moscow area. (From Lum and others, 1990)

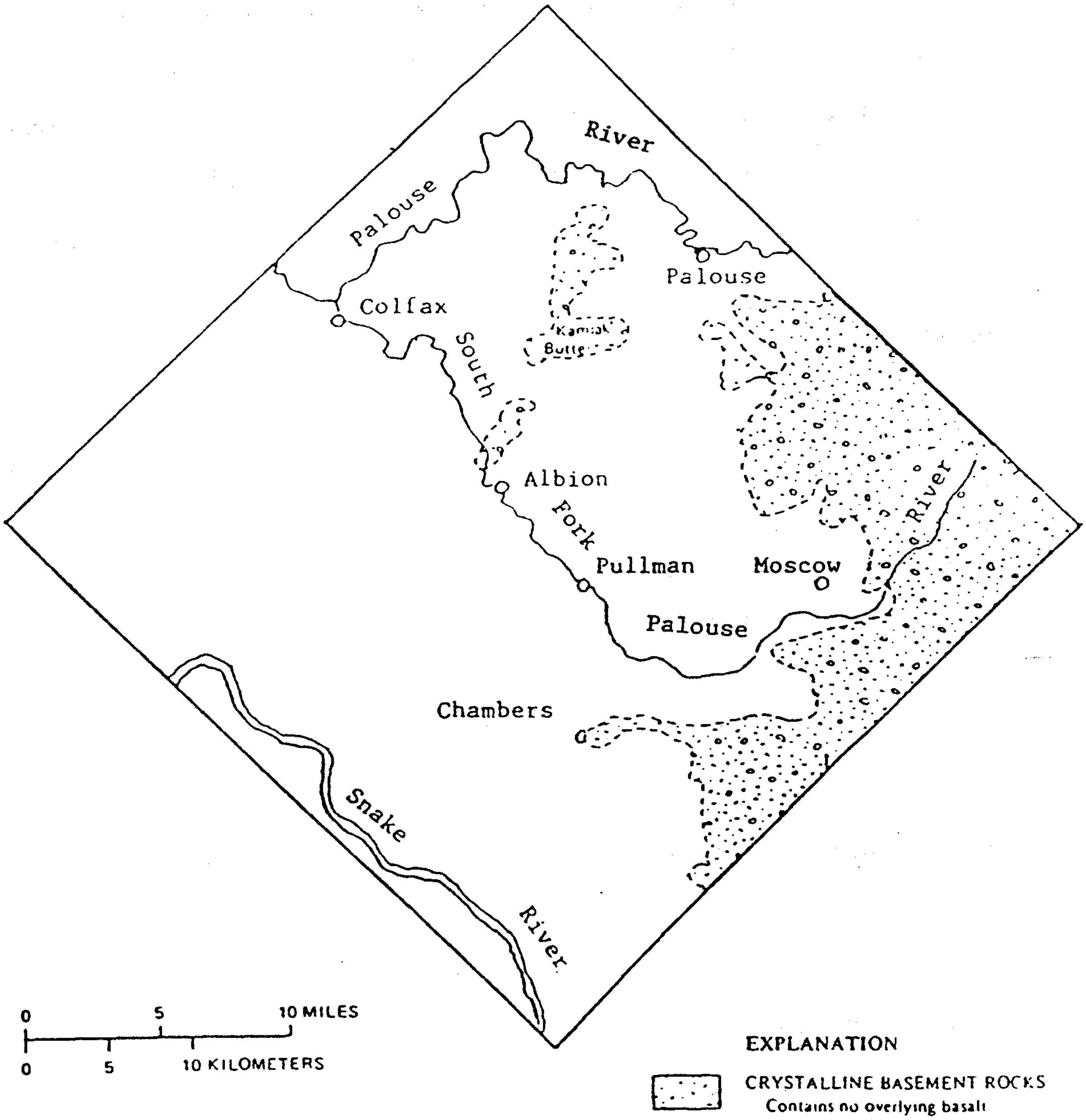


Figure 5. Location of outcropping crystalline basement rocks in Pullman-Moscow area. (After Lum and others, 1990)

concentrations of magnesium and lower concentrations of titanium. The Wanapum Basalt overlies the Grande Ronde Basalt although there is at least one location in southeast Washington state where the basalts are inter-layered (Swanson and others, 1979). The Vantage Member of the Miocene Ellensburg Formation separates the Wanapum and Grande Ronde Basalts. The Vantage Member is composed of siltstone, claystone, and tuffaceous rocks (Swanson and others, 1979).

Sedimentary interbeds make up a large part of the stratigraphy in the Moscow area, particularly at and east of Moscow. These beds consist of clay, sand, and some gravel interbedded in the Wanapum and Grande Ronde Basalt. Drillers logs indicate that the thickness of layers of sedimentary beds uninterrupted by basalt flows can be more than 300 feet. The interbeds probably become more fine-grained and thin to the west of Moscow but their distribution is not well known (Smoot and Ralston, 1987; Lum and others, 1990).

Many of the sedimentary interbeds were probably deposited as the result of lava flows damming pre-existent streams (Walters and Glancy, 1969). The dammed streams formed lakes in which sediments were deposited. Subsequent lava flows covered the sediments while creating new lakes.

The Palouse Loess blankets the Wanapum Basalt and associated interbeds in most places in the Pullman-Moscow area. The Palouse Loess consists of eolian silt transported from central and eastern Washington during the Pleistocene Epoch. The loess was deposited as large dunes which form the rolling topography that is characteristic of the Palouse. Thickness of the loess ranges from 0 to 150 feet but locally the loess can be up to 300 feet thick (Walters and Glancy, 1969; Foxworthy and Washburn, 1963). Alluvium deposits occur in the stream valleys and along the basin margins.

The crystalline basement rocks are composed of Cretaceous granitic and Pre-Cambrian metamorphic rocks. The crystalline rocks outcrop at the higher elevations in the area such as the Palouse Range, Paradise Ridge, and Kamiak Butte. Valleys in the rugged topography of the crystalline rocks were flooded by invading basalt flows.

## Ground-Water Flow Systems

Ground water generally flows to the west and northwest in the Pullman-Moscow area. Recharge to the ground-water system is derived primarily from deep percolation from precipitation and streams (Smoot and Ralston, 1987; Lum and others 1990; Foxworthy and Washburn, 1963). Recharge probably is greater in the eastern portion of the area because precipitation is higher.

Although ground-water flow in the Pullman-Moscow area can be viewed as one complete flow system, three separate but interconnected sub-systems can be distinguished on the basis of geology, water level data, and recharge and discharge characteristics. These three sub-systems are discussed in the following sections. All figures for water yield are from Lum and others (1990).

Loess and Surficial Deposits

The loess and surficial deposits receive recharge primarily from precipitation and streamflow with discharge to seeps, springs, streams, evapotranspiration, and the underlying Wanapum Basalt. The loess and surficial deposits yield up to 30 gallons per minute to wells.

Depth to water in wells completed in the loess generally ranges from 0 to 60 feet but can be deeper at the top of hills underlain by a thick layer of loess (Lum and others, 1990; Crosthwaite, 1975). Shallower depths to water generally occur in the stream valleys and other low lying areas. Water levels in the loess respond to seasonal variations in precipitation and climate.

Wanapum Basalt

The Wanapum Basalt receives recharge primarily from infiltration of precipitation through the loess and from streams with discharge to streams and the underlying Grande Ronde Basalt. Water is pumped from the Wanapum Basalt in Moscow from wells completed in the depth interval of about 150 to 350 feet. Wells completed in the Wanapum Basalt yield up to 1,500 gallons per minute.

The present depth to water in the Wanapum Basalt is about 50 to 60 feet. Russell (1897) reported that wells probably completed in the Wanapum Basalt flowed at land surface. Water levels in the Wanapum declined to as much as 130 feet below land surface from the 1890's until the early 1960's.

Grande Ronde Basalt

The Grande Ronde Basalt receives almost all of its recharge from the overlying Wanapum Basalt with most discharge to the Snake River Canyon and the Columbia River Basin west of the Pullman-Moscow area (Lum and others, 1990). Water is pumped from the Grande Ronde Basalt at a depth interval of about 750 to 1250 feet. Some wells fully penetrate the basalt sequence to the contact with the crystalline basement rocks. Wells completed in the Grande Ronde Basalt yield up to 3,000 gallons per minute. Static depth to water in the Grande Ronde Basalt is about 300 feet in Moscow.

# DATA PRESENTATION

## Introduction

Pumpage and water level records were obtained from the city of Moscow and the University of Idaho for use in this study. Water level records were provided by the U.S.G.S. Data were obtained for the period of 1936 to 1990. This time period is used because water level data before 1936 are scanty or non-existent.

Pumpage by other private water users in the Moscow area was not considered large enough to be used in the analysis of sustained yield for the following reasons:

1. Pumpage rates from most of the private wells probably do not exceed 20-30 gallons per minute with the pumps on only a small percentage of the time.
2. The volume of water pumped from private wells is not significant relative to city and university use.

## Pumpage

### Moscow

The city of Moscow currently obtains water from three wells completed in the Grande Ronde Basalt and two wells completed in the Wanapum Basalt. Table 1 summarizes completion data for each well. Moscow wells #2 and #3 obtain water from the Wanapum Basalt and wells #6, #8, and #9 obtain water from the Grande Ronde Basalt.

Pumpage records are available on a well-by-well basis for the city of Moscow from 1947 to present. Figure 6 and table 2

| Well Name | Well number | Elevation (feet) | Depth (feet) | Casing Depth (feet) | Year completed or first pumped |
|---|---|---|---|---|---|
| Moscow#2 | T39NR05W07DAD2 | 2568 | 240 | 77? | about 1925 |
| Moscow#3 | T39NR05W07DAD3 | 2568 | 261.5 | 40? | 1936 |
| Moscow#6 | T39NR05W08BDB1 | 2588 | 1305 | 905 | 1960 |
| Moscow#8 | T39NR05W07BDA2 | 2617 | 1458 | 1047 | 1965 |
| Moscow#9 | T39NR06W12DBA1 | 2557 | 1242 | 1242 | 1983? |
| UI#1 | T39NR05W18BAD1 | 2601 | 330 | 98 | 1921 |
| UI#2 | T39NR05W07CDC1 | 2553 | 354 | 354 | 1951 |
| UI#3 | T39NR05W07CBB1 | 2567 | 1337 | 891 | 1964 |
| UI#4 | T39NR06W12DAA1 | 2554 | 747 | 671 | 1976 |

Table 1. Well completion data.

show the combined yearly pumpage of wells #2 and #3. Figure 7 and table 3 show separate yearly pumpages for wells #2 and #3.

Yearly pumpage from wells #2 and #3 before 1947 is estimated on a per capita use basis with population data from census figures. A linear yearly increase in population is used from one census to the next. Yearly pumpage before 1947 is estimated by multiplying the estimate of Moscow's population in a given year by the estimated per capita consumption for Moscow. 1936 is chosen as the first year of estimates because this is the earliest year of water level records. The per capita consumption is determined in this report by dividing the average yearly pumpage in the 1950's by the average yearly population in Moscow during the 1950's. Average yearly population in Moscow during the 1950's is determined by taking the average of the 1950 and 1960 census. Per capita consumption determined from 1950's water use, (37,000 gallons per person per year), is probably a better approximation of per capita consumption before 1950 than per capita consumption determined from decades later than the 1950's. Records for 1947 are available for only the last 8 months of the year so pumpage for this year is an estimate based on the last 8 months of 1947.

Pumpage by the city of Moscow from the shallow aquifer (wells #2 and #3) was greatly reduced in 1966 (figure 6) because the city of Moscow completed two wells in the deep aquifer. Moscow well #6 started pumping in 1960 and Moscow well #8 started pumping in 1965. These wells were drilled to

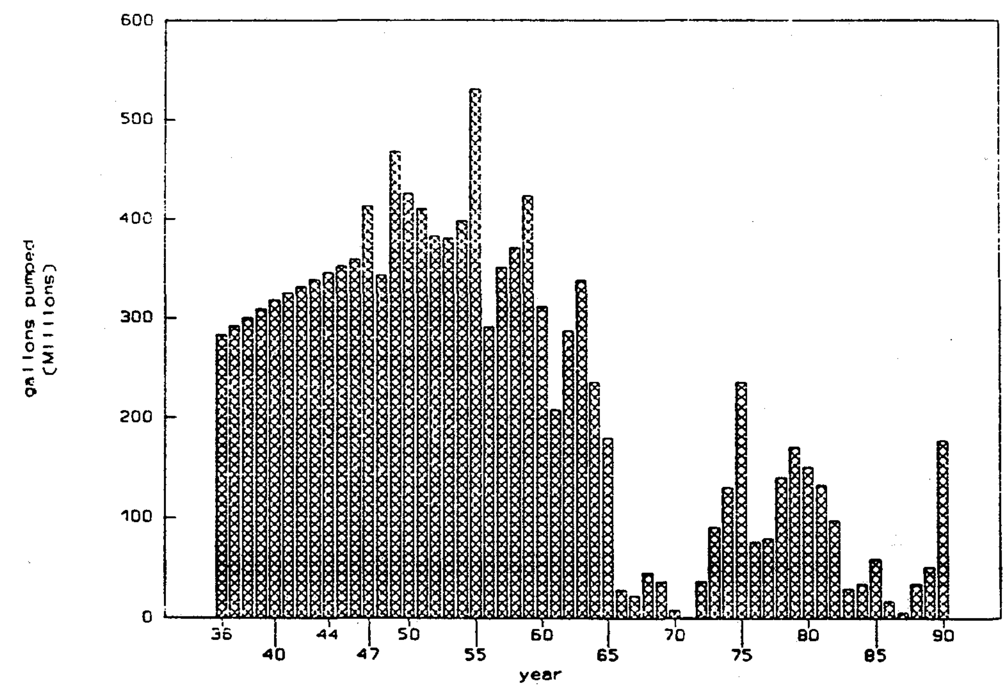


Figure 6. Combined yearly pumpage, Moscow wells #2 and #3.

| year | gallons pumped | year | gallons pumped |
| --- | --- | --- | --- |
| 1936 | 2.83E+08 | 1964 | 2.36E+08 |
| 1937 | 2.92E+08 | 1965 | 1.80E+08 |
| 1938 | 3.01E+08 | 1966 | 2.86E+07 |
| 1939 | 3.10E+08 | 1967 | 2.26E+07 |
| 1940 | 3.18E+08 | 1968 | 4.50E+07 |
| 1941 | 3.25E+08 | 1969 | 3.69E+07 |
| 1942 | 3.32E+08 | 1970 | 8.26E+06 |
| 1943 | 3.39E+08 | 1971 | 9.42E+05 |
| 1944 | 3.46E+08 | 1972 | 3.69E+07 |
| 1945 | 3.53E+08 | 1973 | 9.04E+07 |
| 1946 | 3.60E+08 | 1974 | 1.30E+08 |
| 1947 | 4.13E+08 | 1975 | 2.36E+08 |
| 1948 | 3.44E+08 | 1976 | 7.61E+07 |
| 1949 | 4.68E+08 | 1977 | 7.93E+07 |
| 1950 | 4.26E+08 | 1978 | 1.41E+08 |
| 1951 | 4.10E+08 | 1979 | 1.71E+08 |
| 1952 | 3.83E+08 | 1980 | 1.51E+08 |
| 1953 | 3.81E+08 | 1981 | 1.33E+08 |
| 1954 | 3.99E+08 | 1982 | 9.80E+07 |
| 1955 | 5.31E+08 | 1983 | 3.01E+07 |
| 1956 | 2.91E+08 | 1984 | 3.45E+07 |
| 1957 | 3.51E+08 | 1985 | 5.89E+07 |
| 1958 | 3.72E+08 | 1986 | 1.73E+07 |
| 1959 | 4.23E+08 | 1987 | 5.75E+06 |
| 1960 | 3.12E+08 | 1988 | 3.47E+07 |
| 1961 | 2.09E+08 | 1989 | 5.11E+07 |
| 1962 | 2.87E+08 | 1990 | 1.77E+08 |
| 1963 | 3.39E+08 | | |

Table 2. Combined yearly pumpage, Moscow wells #2 and #3.

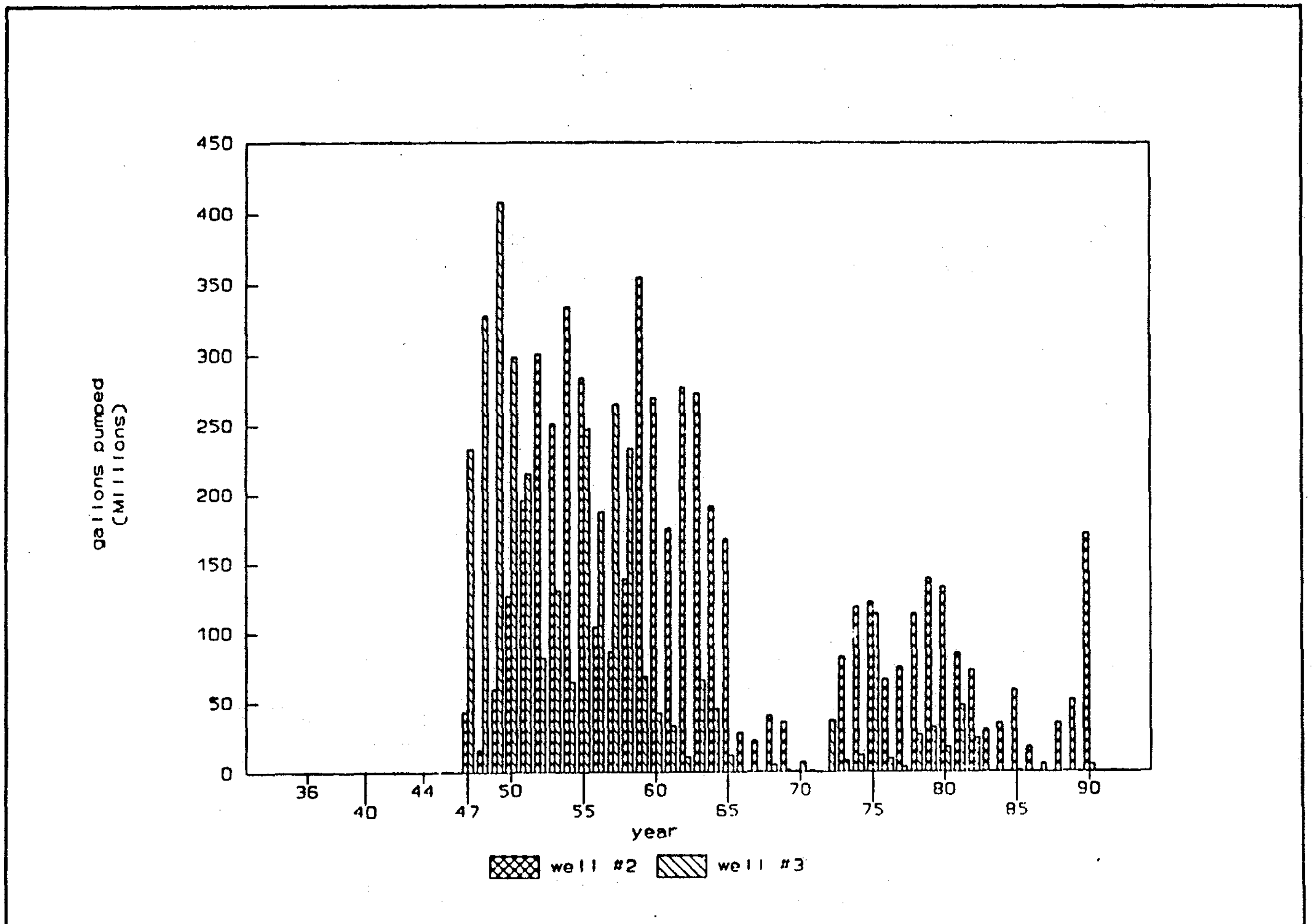


Figure 7. Yearly pumpage, Moscow wells #2 and #3.

| year | gallons #2 | pumped #3 |
|---|---|---|
| 1947 | 42844500 | 232422000 |
| 1948 | 15943500 | 327708000 |
| 1949 | 59697000 | 408198000 |
| 1950 | 127188000 | 298512000 |
| 1951 | 195870000 | 214595550 |
| 1952 | 300466500 | 82812600 |
| 1953 | 250904250 | 130504800 |
| 1954 | 333701925 | 64863705 |
| 1955 | 283440125 | 247437450 |
| 1956 | 103762900 | 187648100 |
| 1957 | 86913300 | 264572200 |
| 1958 | 138713000 | 233326900 |
| 1959 | 354280500 | 69041000 |
| 1960 | 269479270 | 42323120 |
| 1961 | 175452800 | 33068900 |
| 1962 | 276290400 | 10826900 |
| 1963 | 272692300 | 66158500 |
| 1964 | 191359300 | 45132900 |
| 1965 | 167974490 | 12070700 |
| 1966 | 28293900 | 338600 |
| 1967 | 22221200 | 421900 |
| 1968 | 39758000 | 5274900 |
| 1969 | 35783500 | 1164600 |
| 1970 | 858800 | 7398188 |
| 1971 | 941800 | 0 |
| 1972 | 0 | 36857500 |
| 1973 | 82432000 | 8002000 |
| 1974 | 118407200 | 11997600 |
| 1975 | 122454900 | 113876800 |
| 1976 | 66440900 | 9632300 |
| 1977 | 75665200 | 3682000 |
| 1978 | 113819400 | 26703400 |
| 1979 | 139051000 | 32110700 |
| 1980 | 132835700 | 17912800 |
| 1981 | 85282900 | 47567100 |
| 1982 | 73462100 | 24515000 |
| 1983 | 30042600 | 66000 |
| 1984 | 34244700 | 256100 |
| 1985 | 58110300 | 778200 |
| 1986 | 17257500 | 0 |
| 1987 | 5746900 | 0 |
| 1988 | 34713600 | 0 |
| 1989 | 51121100 | 24500 |
| 1990 | 171572200 | 5428000 |

Table 3. Reported yearly pumpage for Moscow wells #2 and #3.

expand the water supply for the city of Moscow and because of water quality concerns from wells #2 and #3.

University of Idaho

The University of Idaho currently pumps from two wells completed in the lower aquifer (Grande Ronde Basalt). However, the university water supply was obtained from two wells completed in the shallow aquifer (Wanapum Basalt) prior to 1965. Table 1 summarizes completion data for each well. U. I. wells #3 and #4 pump from the Grande Ronde Basalt; U. I. wells #1 and #2 are completed in the Wanapum Basalt and are no longer pumped.

Pumpage records for the University of Idaho are available from 1955 to present. Figure 8 and table 4 show the combined yearly pumpage of U. I. wells #1 and #2. Pumpage before 1955 is estimated on a per capita basis as described below. Figure 9 and table 5 show separate yearly pumpages for U. I. wells #1 and #2.

Before 1964, the university pumped all water from well #1 and #2. In 1964 the university started pumping from a third well which was completed in the Grande Ronde Basalt (well #3). Well #3 was drilled to expand the water supply for the University and because of sedimentation problems and water quality concerns about wells #1 and #2. Neither of the two wells completed in the Wanapum Basalt has been pumped since 1965. The pump has been removed from well #1, and a cap has been placed on the well.

Yearly pumpage before 1955 for the University of Idaho is estimated by multiplying estimated per capita use by fall semester enrollment figures. Estimated yearly pumpage for the war years of 1942 through 1945 is probably low because there were several military training programs conducted on campus and dormitories were filled with military personnel (personal communication, George Bloomsburg, University of Idaho). Estimated per capita consumption is determined by taking the average per capita consumption from 1955 to 1964. These years are used because they are the only years of record where the University of Idaho pumped all or most of its water from the Wanapum Basalt. Estimated per capita consumption for pumpage before 1955 by the University of Idaho is about 42,000 gallons/student/year.

Combined Pumpage

Combined yearly pumpage by the city of Moscow and the University of Idaho from the Wanapum Basalt is shown in figure 10 and table 6. As has been already discussed, pumpage was greatly reduced in 1965. Since 1965 pumpage has exceeded 200 million gallons a year only once. Not considering small users, only the city of Moscow has pumped from the Wanapum Basalt since 1965.

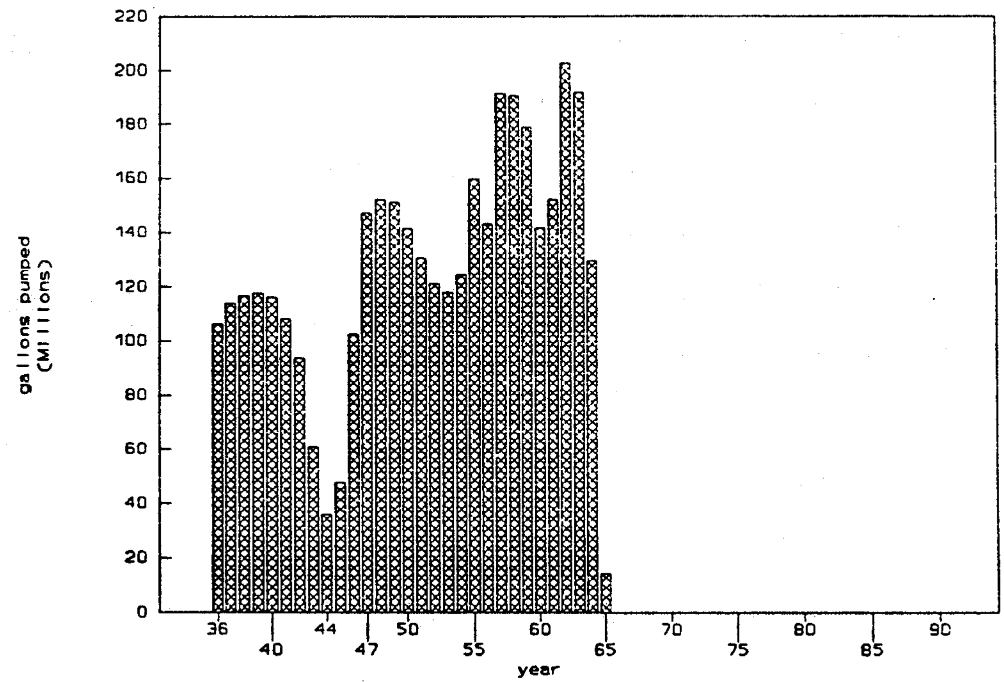


Figure 8. Combined yearly pumpage, U. I. wells #1 and #2.

| year | gallons pumped |
| --- | --- |
| 1936 | 1.06E+08 |
| 1937 | 1.14E+08 |
| 1938 | 1.17E+08 |
| 1939 | 1.18E+08 |
| 1940 | 1.16E+08 |
| 1941 | 1.08E+08 |
| 1942 | 9.41E+07 |
| 1943 | 6.10E+07 |
| 1944 | 3.62E+07 |
| 1945 | 4.78E+07 |
| 1946 | 1.03E+08 |
| 1947 | 1.47E+08 |
| 1948 | 1.52E+08 |
| 1949 | 1.51E+08 |
| 1950 | 1.42E+08 |
| 1951 | 1.31E+08 |
| 1952 | 1.21E+08 |
| 1953 | 1.18E+08 |
| 1954 | 1.25E+08 |
| 1955 | 1.60E+08 |
| 1956 | 1.43E+08 |
| 1957 | 1.91E+08 |
| 1958 | 1.90E+08 |
| 1959 | 1.79E+08 |
| 1960 | 1.42E+08 |
| 1961 | 1.52E+08 |
| 1962 | 2.03E+08 |
| 1963 | 1.92E+08 |
| 1964 | 1.29E+08 |
| 1965 | 1.44E+07 |

Table 4. Combined yearly pumpage, University of Idaho wells #1 and #2.

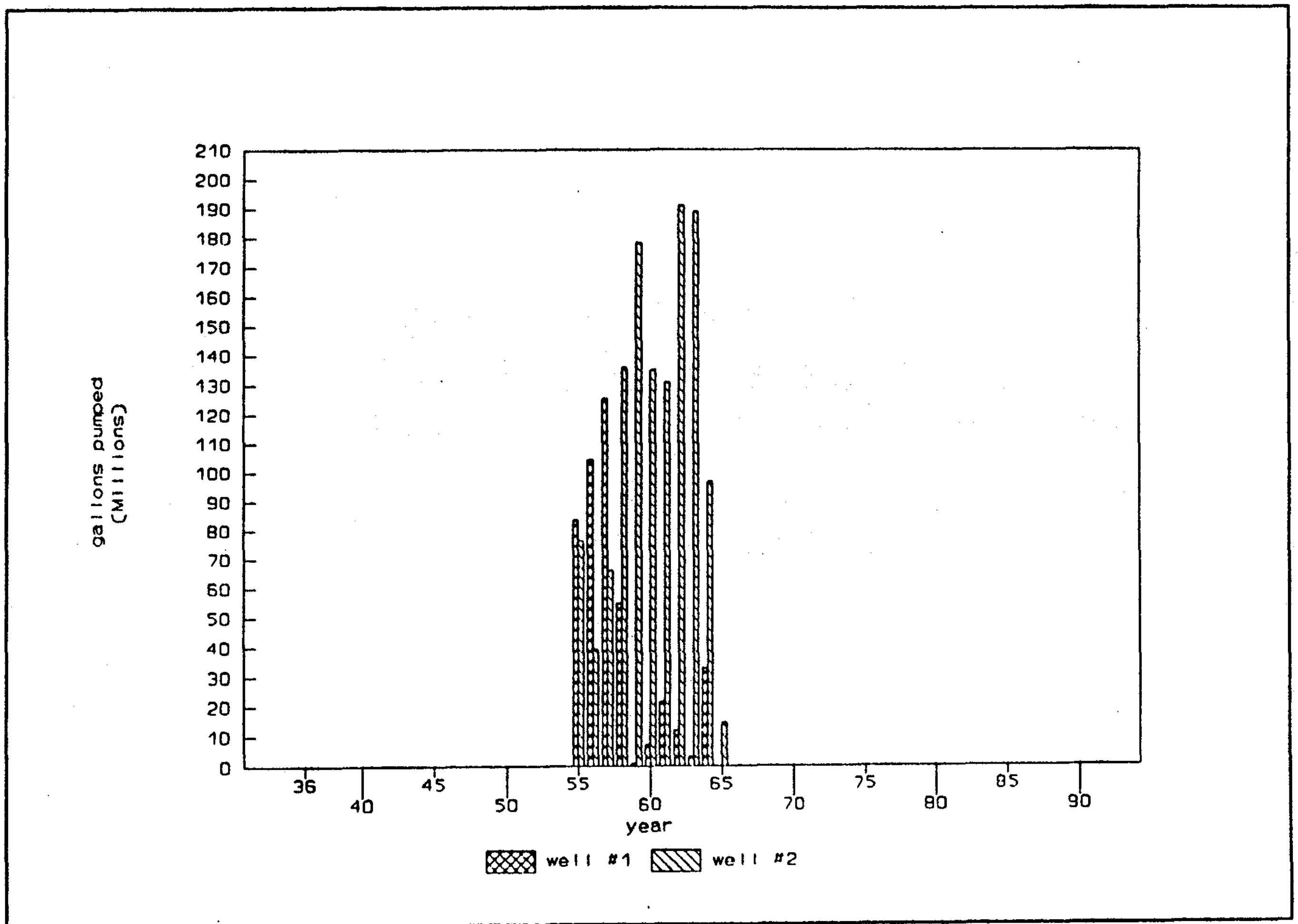


Figure 9. Yearly pumpage, U. I. wells #1 and #2.

| year | gallons #1 | pumped #2 |
| --- | --- | --- |
| 1955 | 83307050 | 76506273 |
| 1956 | 104031600 | 39261694 |
| 1957 | 125256825 | 65930924 |
| 1958 | 54939450 | 135433983 |
| 1959 | 864000 | 178007048 |
| 1960 | 7137000 | 134662564 |
| 1961 | 21522460 | 130620755 |
| 1962 | 11952245 | 190687367 |
| 1963 | 3096750 | 188573060 |
| 1964 | 32852245 | 96561083 |
| 1965 | 0 | 14428100 |

Table 5. Reported yearly pumpage, U.I. wells #1 and #2.

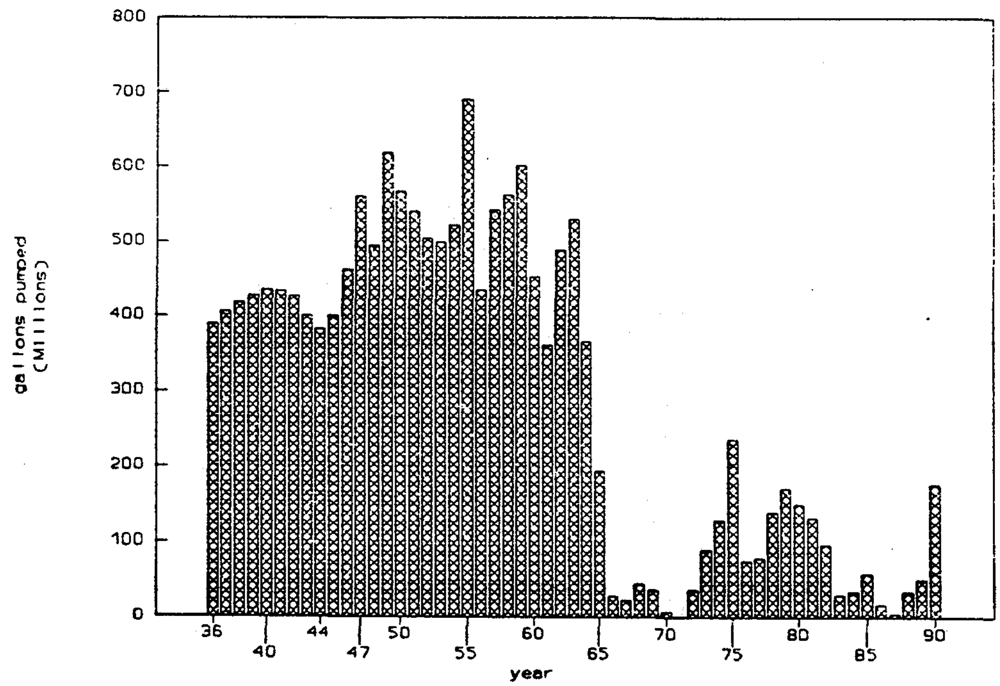


Figure 10. Combined yearly pumpage from Wanapum Basalt, Moscow and University of Idaho.

| year | gallons pumped | year | gallons pumped |
|---|---|---|---|
| 1936 | 3.89E+08 | 1964 | 3.66E+08 |
| 1937 | 4.06E+08 | 1965 | 1.94E+08 |
| 1938 | 4.17E+08 | 1966 | 2.86E+07 |
| 1939 | 4.27E+08 | 1967 | 2.26E+07 |
| 1940 | 4.35E+08 | 1968 | 4.50E+07 |
| 1941 | 4.34E+08 | 1969 | 3.69E+07 |
| 1942 | 4.26E+08 | 1970 | 8.26E+06 |
| 1943 | 4.00E+08 | 1971 | 9.42E+05 |
| 1944 | 3.82E+08 | 1972 | 3.69E+07 |
| 1945 | 4.01E+08 | 1973 | 9.04E+07 |
| 1946 | 4.62E+08 | 1974 | 1.30E+08 |
| 1947 | 5.60E+08 | 1975 | 2.36E+08 |
| 1948 | 4.96E+08 | 1976 | 7.61E+07 |
| 1949 | 6.19E+08 | 1977 | 7.93E+07 |
| 1950 | 5.67E+08 | 1978 | 1.41E+08 |
| 1951 | 5.41E+08 | 1979 | 1.71E+08 |
| 1952 | 5.04E+08 | 1980 | 1.51E+08 |
| 1953 | 4.99E+08 | 1981 | 1.33E+08 |
| 1954 | 5.23E+08 | 1982 | 9.80E+07 |
| 1955 | 6.91E+08 | 1983 | 3.01E+07 |
| 1956 | 4.35E+08 | 1984 | 3.45E+07 |
| 1957 | 5.43E+08 | 1985 | 5.89E+07 |
| 1958 | 5.62E+08 | 1986 | 1.73E+07 |
| 1959 | 6.02E+08 | 1987 | 5.75E+06 |
| 1960 | 4.54E+08 | 1988 | 3.47E+07 |
| 1961 | 3.61E+08 | 1989 | 5.11E+07 |
| 1962 | 4.90E+08 | 1990 | 1.77E+08 |
| 1963 | 5.31E+08 | | |

Table 6. Combined yearly pumpage from Wanapum Basalt, Moscow and University of Idaho.

## Water Levels

Water level records for the USGS observation well are available for 1937-1940 and 1947-1987 (figure 11, table 7). The USGS observation well has not been measured since 1987 because of obstructions in the well (personal communication, U.S.G.S. office, Boise Idaho). Water levels in the USGS observation well were measured at various times by the U.S.G.S., the University of Idaho, and the Idaho Geological Survey. Water level measurements by the U.S.G.S. were made by steel tape (personal communication, U.S.G.S. office, Boise Id.). Water levels measured by the University of Idaho and the Idaho Geological Survey probably were made using a steel tape or electric tape. All of these records are believed to be comparable. Available information indicates that the USGS well was not pumped during the period when water level records are available.

The USGS observation well is located about one block northeast of the University of Idaho, near Paradise creek. The well is at an elevation of 2561 feet and is 231 feet deep. The well has a diameter of 8 inches; the casing depth is unknown.

The average yearly water level was determined by finding the mean of the average monthly water levels available for a given year. Average water levels were calculated for all years even though some years contained records for less than 12 months. The annual averages for years with partial records compared well with full record years.

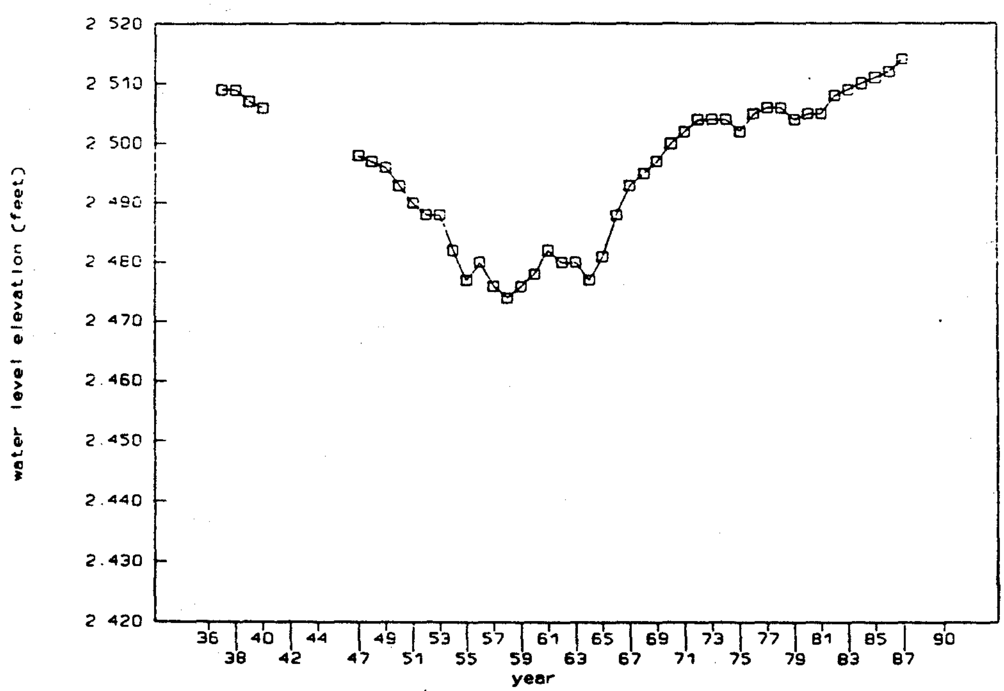


Figure 11. Average yearly water levels, U.S.G.S. observation well (39N 05W 07DDC1).

| year | water level Moscow #2 | water level Moscow #3 | water level USGS | year | water level Moscow #2 | water level Moscow #3 | water level USGS |
|---|---|---|---|---|---|---|---|
| 1936 | | 2508 | | 1964 | 2468 | 2430 | 2477 |
| 1937 | | 2505 | 2509 | 1965 | 2468 | | 2481 |
| 1938 | 2504 | 2507 | 2509 | 1966 | 2477 | 2486 | 2488 |
| 1939 | 2504 | 2504 | 2507 | 1967 | 2482 | 2485 | 2493 |
| 1940 | 2502 | 2503 | 2506 | 1968 | 2484 | | 2495 |
| 1941 | | | | 1969 | 2480 | | 2497 |
| 1942 | | | | 1970 | | | 2500 |
| 1943 | | | | 1971 | 2499 | 2500 | 2502 |
| 1944 | | | | 1972 | | | 2504 |
| 1945 | | | | 1973 | | | 2504 |
| 1946 | | | | 1974 | 2491 | 2503 | 2504 |
| 1947 | | | 2498 | 1975 | 2491 | 2507 | 2502 |
| 1948 | | | 2497 | 1976 | 2494 | 2508 | 2505 |
| 1949 | | | 2496 | 1977 | 2502 | 2494 | 2506 |
| 1950 | | | 2493 | 1978 | 2505 | 2496 | 2506 |
| 1951 | 2484 | 2485 | 2490 | 1979 | 2505 | 2484 | 2504 |
| 1952 | 2485 | 2485 | 2488 | 1980 | 2506 | 2482 | 2505 |
| 1953 | 2484 | 2483 | 2488 | 1981 | 2506 | 2483 | 2505 |
| 1954 | 2486 | 2484 | 2482 | 1982 | 2507 | 2483 | 2508 |
| 1955 | 2482 | 2473 | 2477 | 1983 | 2509 | | 2509 |
| 1956 | 2473 | 2470 | 2480 | 1984 | 2511 | 2488 | 2510 |
| 1957 | 2472 | 2470 | 2476 | 1985 | 2512 | | 2511 |
| 1958 | 2474 | 2469 | 2474 | 1986 | 2511 | | 2512 |
| 1959 | 2457 | 2461 | 2476 | 1987 | 2510 | 2514 | 2514 |
| 1960 | 2459 | 2440 | 2478 | 1988 | 2512 | 2514 | |
| 1961 | | | 2482 | 1989 | 2514 | 2516 | |
| 1962 | 2451 | 2438 | 2480 | 1990 | 2507 | 2515 | |
| 1963 | 2451 | 2431 | 2480 | | | | |

Table 7. Average yearly water levels for Moscow wells #2, #3, and U.S.G.S. observation well.

Discontinuous water level records are available for city of Moscow wells #2 and #3 for 1936 to 1940 and 1951 to present. Measurements were made using an air line. Figures 12, 13, and table 7 show the average yearly water levels for Moscow wells #2 and #3.

Discontinuous water level records are available for University of Idaho well #1 for 1921 to 1963 and University of Idaho well #2 for 1951 to 1983. Measurements were probably made using a steel tape (personal communication, Larry Kirkland, U. I. physical plant, 1991). Figure 14 and table 8 show water level data for U.I. wells #1 and #2. In table 8, years without the avg. abbreviation in front had only one measurement.

Water level records from the city of Moscow and the University of Idaho wells are not used in the analysis of sustained yield because: 1) water level measurements were affected by pumping, and reliable measurements of static water level could not be obtained; 2) the accuracy of some of the water level measurements based on air line readings for the city of Moscow is questionable (personal communication, Dean Weyen, Assistant City Engineer, city of Moscow, 1991) and 3) water level records from the USGS well are more complete and continuous than water level records from the Moscow or University of Idaho wells. Measurements of water levels in the USGS observation well have less error because better trained personnel used a steel tape for measurement.

Three trends can be seen in the plot of the USGS observation well hydrograph (Figure 11). The first trend is from 1937 to 1953 where the yearly decline in water level appears to be fairly constant, about 1.4 feet per year; and pumpage averaged 486 million gallons per year. The second trend is from 1955 to 1964 where water levels varied between 2470 and 2480 feet, and pumpage averaged 504 million gallons per year. The third trend is from 1964 to 1987 where water levels generally increased every year at about 1.5 feet per year, and pumpage averaged 91 million gallons per year.

Water levels in the city wells and the USGS observation well in the late 1980's have recovered to 1930's conditions. This indicates that pumpage since the 1930's has not been greater than net recharge since the 1930's. An analysis of water levels in the USGS observation well and pumpage from Moscow and University of Idaho wells is given in the following sections.

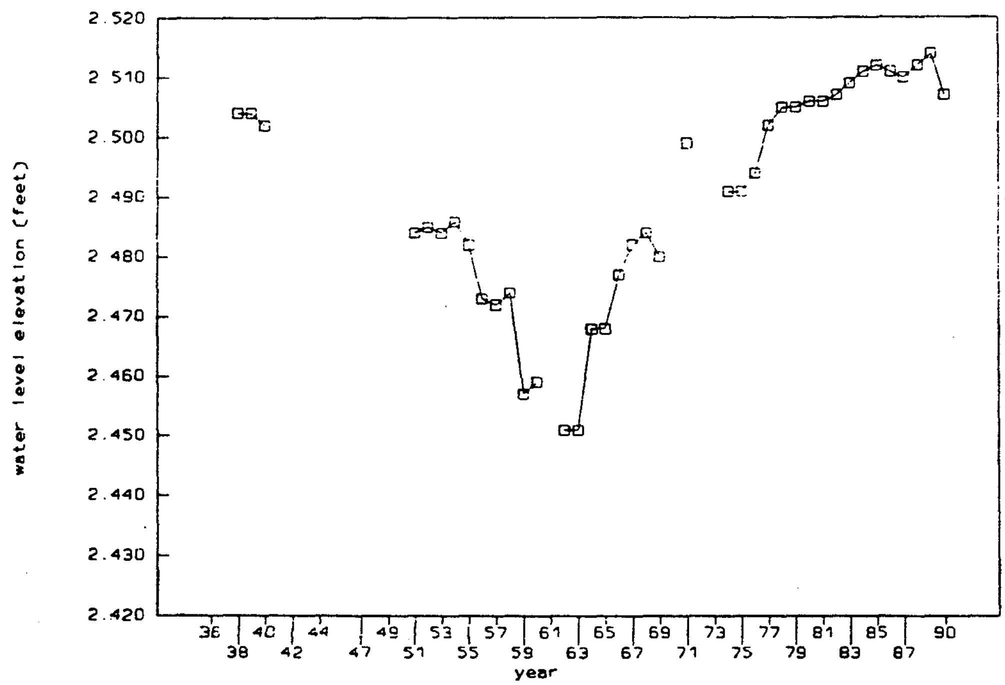


Figure 12. Average yearly water levels, Moscow well #2 (39N 05W 07DAD2).

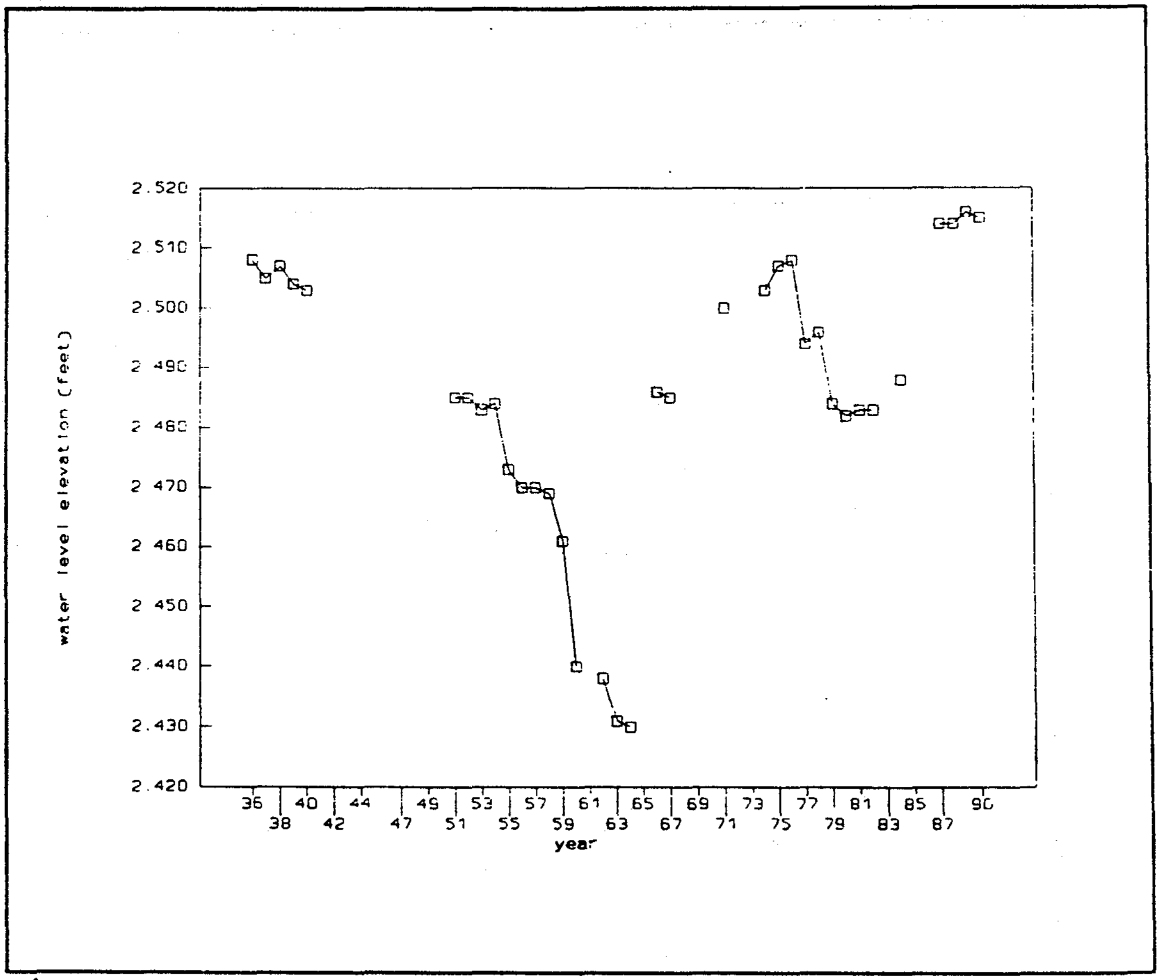


Figure 13. Average yearly water levels, Moscow well #3 (39N 05W 07DAD3).

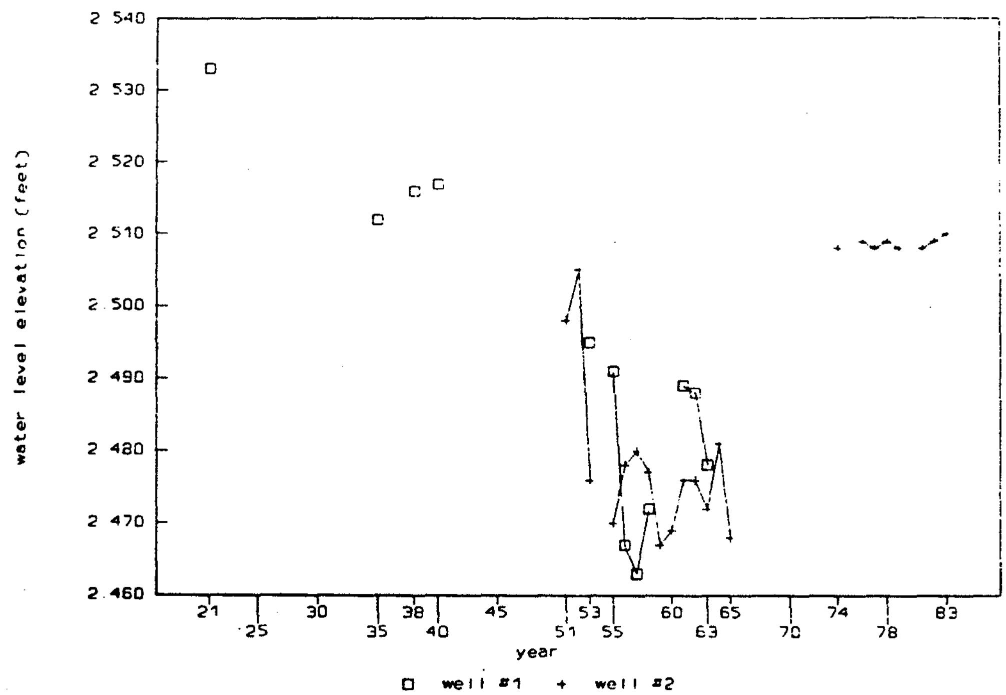


Figure 14. Average yearly water levels, U. I. wells #1 (39N 05W 18BAD1) and #2 (39N 05W 07CDC1).

| UI #1 | |
|---|---|
| year | water level |
| 1921 | 2533 |
| 1935 | 2512 |
| 1938 | 2516 |
| 1940 | 2517 |
| 1953 | 2495 |
| 1955 | 2491 |
| avg. 1956 | 2467 |
| avg. 1957 | 2463 |
| avg. 1958 | 2472 |
| avg. 1961 | 2489 |
| avg. 1962 | 2488 |
| avg. 1963 | 2478 |

| UI #2 | |
|---|---|
| year | water level |
| 1951 | 2498 |
| 1952 | 2505 |
| avg. 1953 | 2476 |
| avg. 1955 | 2470 |
| avg. 1956 | 2478 |
| avg. 1957 | 2480 |
| avg. 1958 | 2477 |
| avg. 1959 | 2467 |
| avg. 1960 | 2469 |
| avg. 1961 | 2476 |
| avg. 1962 | 2476 |
| avg. 1963 | 2472 |
| avg. 1964 | 2481 |
| avg. 1965 | 2468 |
| avg. 1974 | 2508 |
| 1976 | 2509 |
| avg. 1977 | 2508 |
| 1978 | 2509 |
| 1979 | 2508 |
| avg. 1981 | 2508 |
| 1982 | 2509 |
| 1983 | 2510 |

Table 8. Water level data U.I. wells #1 and #2.

## DATA ANALYSIS

Pumpage records and water level data from the Moscow area were analyzed to obtain estimates of the sustained yield for the shallow aquifer. Sustained yield, as used for this study, is defined as the rate of yearly pumpage which will not draw the static water level in the Moscow area below an elevation of about 2479 feet. This elevation is the average yearly water level in the USGS well during a 12-year period when water levels in the USGS well were at their lowest.

### Hill Method

The Hill Method of determining sustained yield was applied to data from the Moscow area. Figure 15 is a plot of average yearly water level changes for 5-year moving periods in the USGS observation well versus average yearly pumpage for 5-year moving periods from the Wanapum Basalt by the University of Idaho and the City of Moscow for the years 1955 to 1987. These data are tabulated in table 9. Five-year moving periods were used to smooth out yearly variations in pumpage and water levels. Pumpage before 1955 was not considered because pumpage records are not complete before 1955. Three equilibrium conditions, (points where the lines cross zero water level change), can be seen from the plot. A linear regression line is plotted for each condition and is shown on figure 15 by straight lines.

The first equilibrium condition corresponds to the time period 1955 to 1963 when pumpage was close to or above 500

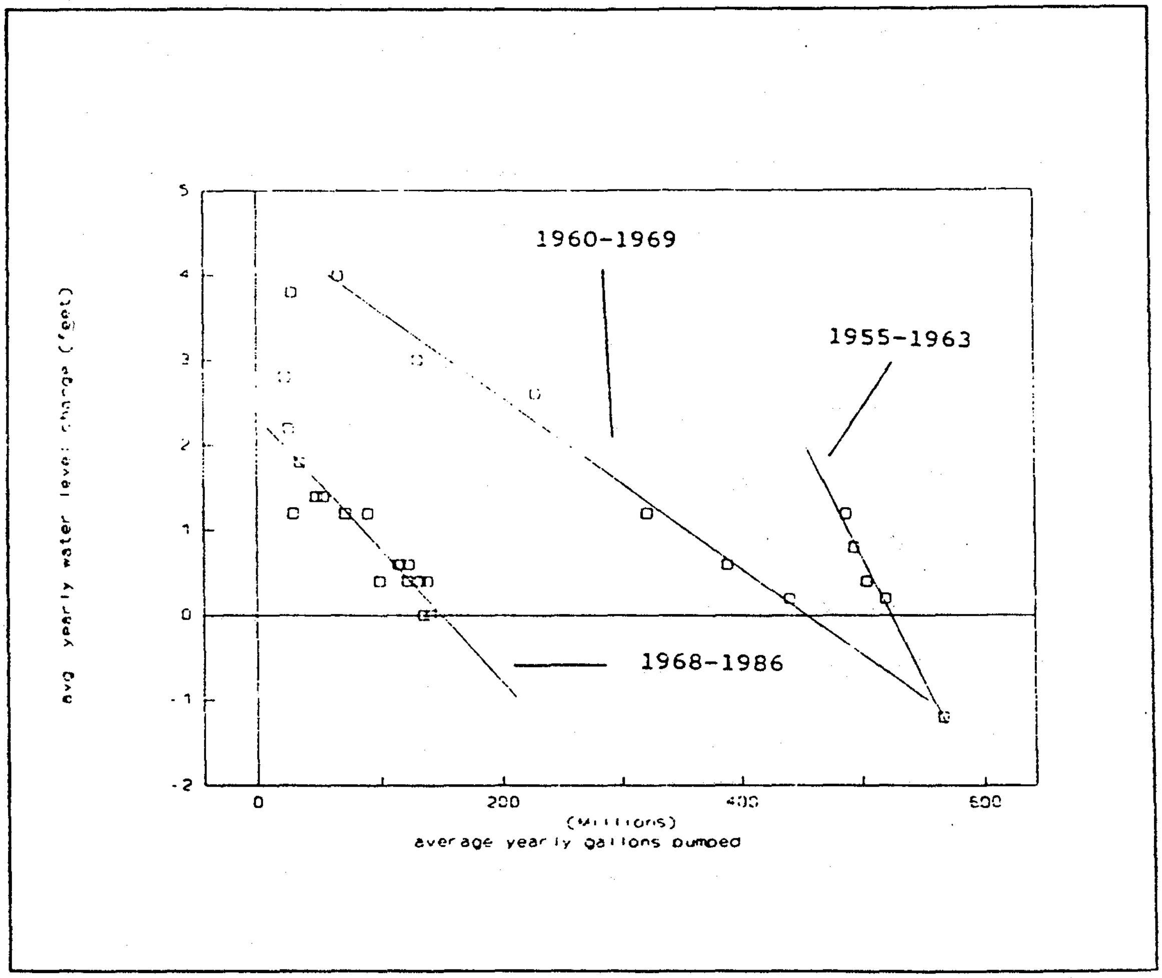


Figure 15. Plot of average yearly water level decline in U. S. G. S. observation well versus average yearly pumpage from Wanapum Basalt for 5 year moving periods, 1955-1987.

| 5 year period | average yearly pumpage (gallons) | average yearly water level change |
|---|---|---|
| 1955-1959 | 5.67E+08 | -1.2 |
| 1956-1960 | 5.19E+08 | 0.2 |
| 1957-1961 | 5.04E+08 | 0.4 |
| 1958-1962 | 4.94E+08 | 0.8 |
| 1959-1963 | 4.87E+08 | 1.2 |
| 1960-1964 | 4.40E+08 | 0.2 |
| 1961-1965 | 3.88E+08 | 0.6 |
| 1962-1966 | 3.22E+08 | 1.2 |
| 1963-1967 | 2.28E+08 | 2.6 |
| 1964-1968 | 1.31E+08 | 3.0 |
| 1965-1969 | 6.55E+07 | 4.0 |
| 1966-1970 | 2.83E+07 | 3.8 |
| 1967-1971 | 2.28E+07 | 2.8 |
| 1968-1972 | 2.56E+07 | 2.2 |
| 1969-1973 | 3.47E+07 | 1.8 |
| 1970-1974 | 5.34E+07 | 1.4 |
| 1971-1975 | 9.90E+07 | 0.4 |
| 1972-1976 | 1.14E+08 | 0.6 |
| 1973-1977 | 1.23E+08 | 0.4 |
| 1974-1978 | 1.33E+08 | 0.4 |
| 1975-1979 | 1.41E+08 | 0.0 |
| 1976-1980 | 1.24E+08 | 0.6 |
| 1977-1981 | 1.35E+08 | 0.0 |
| 1978-1982 | 1.39E+08 | 0.4 |
| 1979-1983 | 1.17E+08 | 0.6 |
| 1980-1984 | 8.92E+07 | 1.2 |
| 1981-1985 | 7.09E+07 | 1.2 |
| 1982-1986 | 4.77E+07 | 1.4 |
| 1983-1987 | 2.93E+07 | 1.2 |

Table 9. Average yearly water level change and average yearly pumpage for 5 year moving periods.

million gallons per year. Water level elevations during this time period averaged about 2478 feet. The second equilibrium condition corresponds to the time period 1960 to 1969. This is a transitional period between the high pumpage volumes of the 1950's and early 1960's, and the low pumpage volumes after 1965 (figure 10). Yearly water level elevations during this time averaged 2485 feet. The third equilibrium condition corresponds to the time period 1968 to 1986. This is a period where pumpage was below 200 million gallons every year except one. Yearly water level elevations during this time averaged 2505 feet.

Using the Hill Method, data from the 1955-1963 period indicate a sustained yield of about 520 million gallons a year. Data from the 1960-1969 period indicate a sustained yield of about 450 million gallons a year. Finally, data from the period 1968 to 1986 indicate a sustained yield of about 150 million gallons a year.

Static water levels in the USGS observation well during the 1955-1963 time period were at their lowest point during the period of record. The water levels during this time averaged about 2478 feet, which is close to 2479 feet. Therefore, the estimate of sustained yield from this time period (520 million gallons per year) is the maximum estimate of sustained yield as defined previously in this study.

The relationship between average water levels and sustained yield is well illustrated by the analysis using the Hill Method. Lower water levels correspond to higher sustained yield estimates and vice versa.

The fact that all of the data do not fall on a single line might be explained by changes in pumping rates during the period of record. As pumpage decreases, rises in water levels change recharge and natural discharge rates so there is a continual trend to re-establish equilibrium with the new pumpage rates. New equilibrium conditions are reflected in the three lines, shown on figure 15. A case involving more than one equilibrium condition is described in Conkling (1946).

## Zero Water Level Change Method

Estimates of sustained yield for a given time period and a constant water level elevation based on the zero water level change method are given below.

| Year | water level elevation (feet) | average pumpage ($10^6$ gallons per year) |
|---|---|---|
| 1937-1983 | 2509 | 324 |
| 1940-1981 | 2506 | 330 |
| 1947-1969 | 2498 | 420 |
| 1950-1967 | 2493 | 440 |
| 1952-1966 | 2488 | 452 |
| 1954-1965 | 2482 | 479 |
| 1956-1963 | 2480 | 497 |

As expected, higher estimates of sustained yield correspond to lower water level elevations. This reflects changing recharge and discharge conditions.

## Discussion

Sustained Yield estimates obtained from the Hill Method and the zero water level change method agree reasonably well. The maximum estimate of the Hill Method is 520 million gallons a year with a water level of 2478 feet. The maximum estimate of the zero water level change method is 497 million gallons a year with a water level of 2480 feet. Both of the estimates cover nearly the same time period. Because of the close agreement between the two methods, the maximum sustained yield is estimated to be about 500 to 520 million gallons per year based on maintaining a water level elevation close to 2479 feet.

## Comparison to Recharge Estimates

In this section, the estimates of sustained yield are compared to recharge estimates for the Moscow area published by Lum and others (1990). The recharge estimates by Lum and others are chosen because they represent the best estimates for the Pullman-Moscow area (personal communication, Dale Ralston, 1991). Recharge estimates by other authors do not try to divide the recharge into the different units and thus cannot be used to compare sustained yield from the Wanapum Basalt. Comparison of estimates of recharge to sustained yield entail knowledge of the area of influence of pumpage by Moscow and the University of Idaho. Division of the sustained yield estimates by the area of influence of pumping gives an equivalent depth of water over the area of influence which can be compared to recharge estimates.

Crystalline basement rocks limit the area influenced by pumpage to the north, east, and south. As discussed previously, the western limit of the area influenced by pumpage is estimated to be a radius of 3 to 5 miles west of Moscow (figure 16). If the western limit is a radius of 5 miles then the estimated area of influence of pumpage is about 41 square miles. If the western limit is a radius of 3 miles then the estimated area of influence of pumpage is about 20 square miles.

The Lum and others (1990) estimation of recharge in the Moscow area, based on work by Bauer and Vaccaro (1990), varies from 1.5 to 4.5 inches per year depending on land use (namely farming practices) in a given area (Figure 17). Lum and others (1990) concluded that recharge is an average of 2.8 inches per year over the modeled area with 2 inches per year reaching the Grande Ronde Basalt. This leaves 0.8 inches for natural discharge from the loess and Wanapum Basalt. Because the amount of natural discharge from the loess is unknown (personal communication, W. E. Lum, 1991), a maximum estimate of 0.8 inches of recharge into the Wanapum Basalt is used to compare the Lum and others (1990) estimate of recharge with this study's estimates of sustained yield.

The recharge rate of 0.8 inches per year over an area of 41 square miles (5 mile radius) is about 570 million gallons per year. This recharge rate over an area of 20 square miles (3 mile radius) is about 280 million gallons per year.

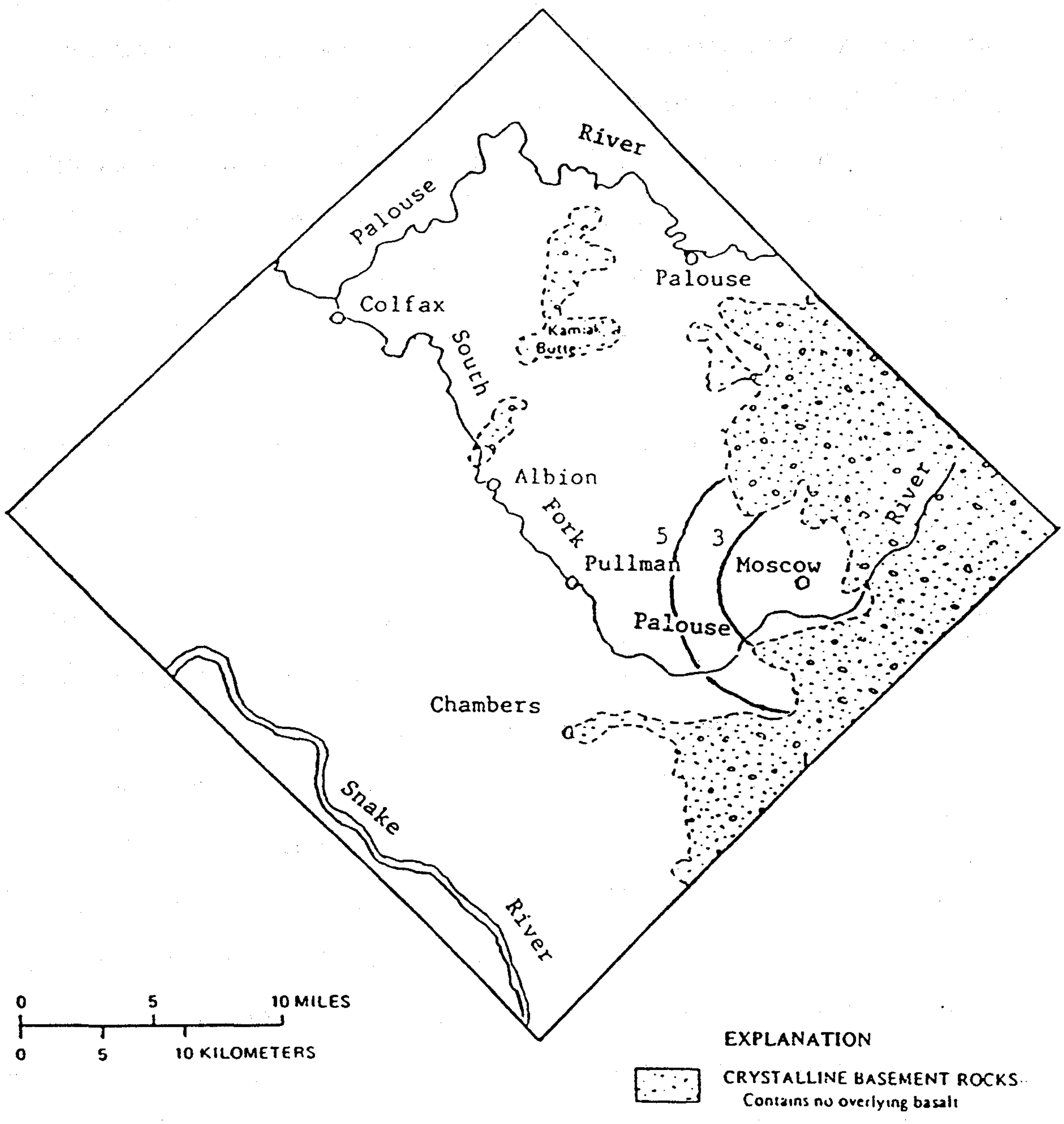


Figure 16. Area of influence of pumpage from Wanapum Basalt by Moscow and U. of I. given radius of 3 and 5 miles

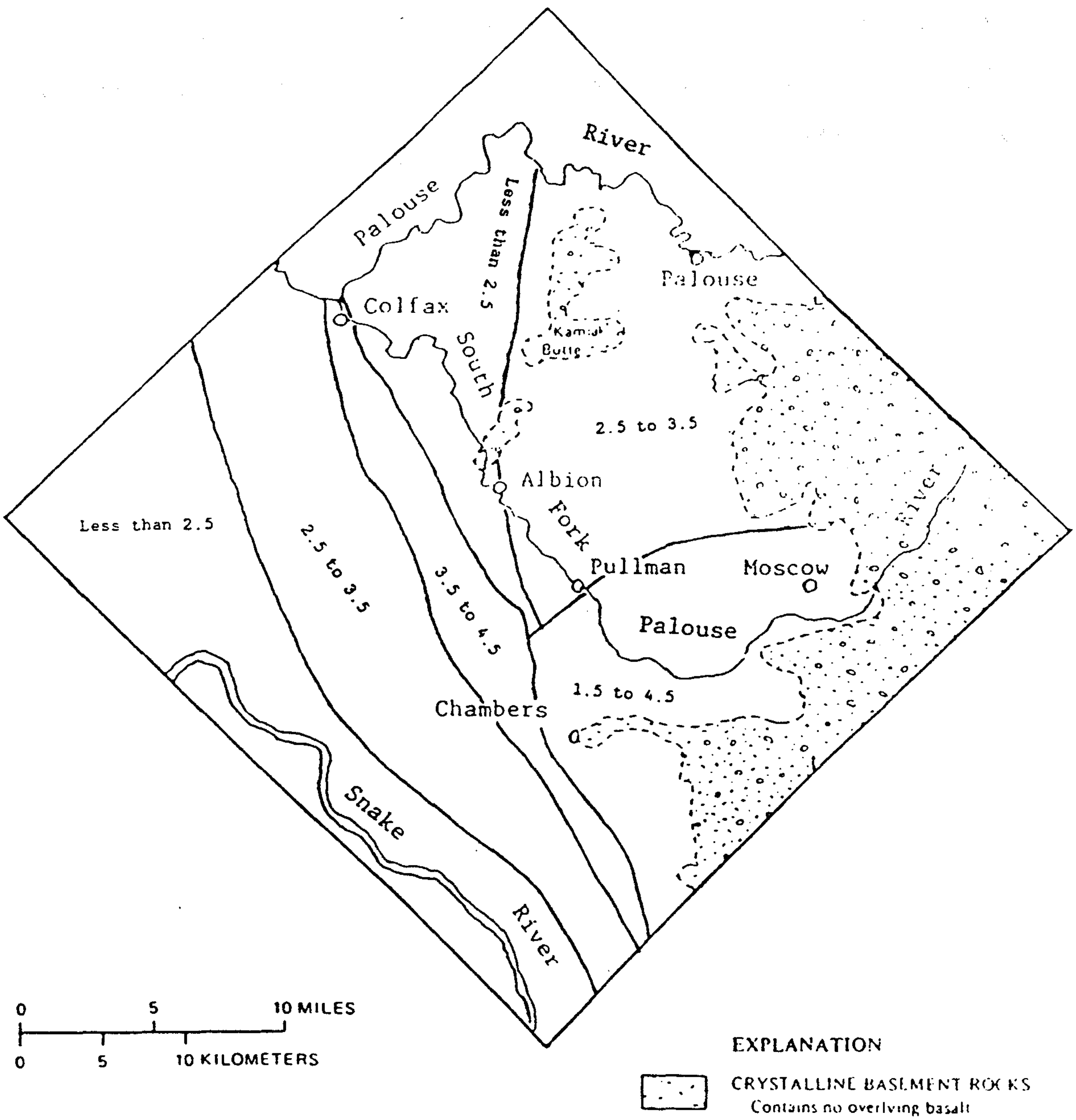


Figure 17. Recharge map of Pullman-Moscow area based on Lum and others, 1990.

The calculated recharge of 0.8 inches per year over 41 square miles is about 50 to 70 million gallons greater than the sustained yield estimated in this report. The 5 mile radius area of influence of pumping appears to be a reasonable figure because the estimates of sustained yield and recharge differ by about 10 percent.

## EFFECT OF SHALLOW AQUIFER PUMPAGE ON THE DEEP AQUIFER

Water level changes in the Wanapum Basalt affect the magnitude of downward leakage into the Grande Ronde Basalt through the aquitard that separates the two aquifers. An estimate of intra-aquifer pumpage effects may be obtained using Darcy's Law. For example, the difference in depth to water between the Wanapum Basalt (DTW=@60 feet) and the Grande Ronde Basalt (DTW=@300 feet) is about 240 feet. The vertical distance between the two aquifers is about 400 feet (350 feet versus 750 feet). This gives a vertical hydraulic gradient of about .60 (240 ft/400 ft). Lowering the water level in the Wanapum Basalt by 20 feet decreases the downward gradient and leakage by about 8 percent. Similarly, raising the water level in the Wanapum Basalt by 20 feet increases the downward gradient and leakage by about 8 percent. The 8 percent change in gradient and leakage is equivalent to about $1.1 \times 10^8$ gallons per year based on a recharge rate of 2 inches per year for the Grande Ronde Basalt over 41 square miles.

The changes in downward leakage to the Grande Ronde Basalt caused by water level declines in the Wanapum Basalt may be estimated using historic water level data. Pre-development water levels in the Grande Ronde Basalt in the Moscow area were probably about 275 feet below ground. Water levels in the Wanapum basalt in the late 1930's were about 50 feet below ground. This gives a vertical hydraulic gradient of .56 (225 ft/400 ft). Water levels in the Wanapum had declined to about 85 feet below ground by the period of lowest water levels during the late 1950's-early 1960's. This gives a hydraulic gradient of .48 (190 ft/400 ft). This is a difference of -14% in downward leakage.

During the low water level period of 1956-1963, the decrease in downward leakage was about 200 million gallons per year (.14 times 2 inches per year of recharge over an area of 41 square miles) as compared to the average yearly pumpage of 497 million gallons per year. These data indicate that much of the pumpage from the Wanapum Basalt was balanced by a decrease in downward leakage to the Grande Ronde Basalt.

The estimated change in downward leakage may be compared to the difference in estimates of sustained yield by the zero water level change method presented previously. The difference between the sustained yield estimates at water level elevations of 2509 feet and 2480 feet is about 170 million gallons per year. The sustained yield estimate is higher with a lower water level elevation because of decreased downward leakage and decreased discharge to surface streams. The 200 million gallon estimated decrease in downward leakage is comparable to the 170 million gallon decrease in downward leakage estimated from sustained yield figures.

## CONCLUSIONS

1. A relationship exists between static water levels and pumpage in the shallow confined aquifer in the Moscow area. Static water levels stabilize at different elevations depending on pumpage rates. Higher yearly pumpage volumes correspond to lower water level elevations and vice versa.

2. Based on an analysis of available data, a sustained yield for the shallow aquifer in the Moscow area is estimated to be 500 to 520 million gallons per year. This estimate is based on the condition that static water levels in the shallow aquifer in the Moscow area are not drawn below an elevation of 2,479 feet.

3. The estimate of sustained yield (500 to 520 million gallons per year) is probably 50 to 70 million gallons less than the average annual recharge into the Wanapum Basalt over the area of influence of present wells.

4. Much of an increase in pumpage from the Wanapum Basalt is balanced by a decrease in downward leakage to the Grande Ronde Basalt.

## RECOMMENDATIONS

Continued monitoring of pumpage rates and water levels should be done in support of continued ground water management in the basin.

1. Water levels in Moscow wells #2 and #3 and any new wells drilled into the Wanapum Basalt by the University of Idaho or the city of Moscow should be regularly monitored on at least a monthly basis.

2. Accurate continuous pumpage records should be kept for Moscow wells #2 and #3 and any new wells drilled into the Wanapum Basalt by the University of Idaho or the city of Moscow.

3. U. I. well #2 should be monitored on at least a monthly basis for use as an indicator of static water level conditions in the shallow aquifer. An attempt should be made to re-establish water level measurements in the former USGS observation well. This would be an invaluable addition to the data base and it would help define water table conditions in the shallow aquifer.

4. Water levels and pumpage from the Moscow cemetery well and the U. I. Parker Farm well should be monitored in the same manner as described in recommendation #1 and #2.

5. Water levels in wells outside Moscow city limits but in the Moscow area should be monitored at least quarterly to determine the extent of the cone of depression in the Moscow area.

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