A SPREADSHEET NOTEBOOK METHOD TO CALCULATE RATE AND VOLUME OF STREAM DEPLETION BY WELLS IN THE LEMHI RIVER VALLEY UPSTREAM FROM LEMHI, IDAHO

Prepared by
Joe Spinazola

UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Pacific Northwest Region
Boise, Idaho

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CONTENTS

ABSTRACT ii

I. INTRODUCTION 1

II. PURPOSE AND SCOPE 1

III. GEOHYDROLOGIC SETTING 3

IV. STREAM DEPLETION 3
  A. Transmissivity and Specific Yield 5
  B. Distance Between Pumping Wells and Streams 9

V. USING THE SPREADSHEET NOTEBOOK 12

VI. ASSUMPTIONS AND LIMITATIONS 17

VII. CONCLUSIONS 18

VIII. REFERENCES 19

FIGURES

1. Study Area 2
2. Surface Geology 4
3. Distance Between Pumping Wells and Streams 9
4. Subbasins and Water-table Contours, June, 1996 10
5. Average Flow Line Distances Between Major Streams and Sections 11
6. Krieged Hydraulic Conductivity 12
7. Summary Notebook Page 14
8. Well Pumpage Notebook Page 15
9. Notebook Map Rendition Showing Average Flow Line Distances Between Major Streams and Sections 16

Tables

1. Well Data 6
2. FORTRAN Listing of Program to Calculate Transmissivity from Specific Capacity Data 8
3. Contents of Spreadsheet Notebook Pages 13

ABSTRACT

Local farmers and ranchers and staff from several State and Federal agencies undertook a number of activities in 1995 to simultaneously maintain traditional agricultural water uses and improve habitat and migration conditions for endangered salmon in the 1,270 square mile Lemhi River basin in east-central Idaho. Water users recognized that new ground water development in the upper part of the valley potentially could reduce surface water supplies downstream during critical periods of need for agricultural use and salmon smolt migration. A spreadsheet notebook method was developed by the Bureau of Reclamation to evaluate potential impact of wells on surface water supply. The method integrates an analytical technique to calculate stream depletion by wells (Jenkins, 1968) with a commercial spreadsheet. The spreadsheet notebook method can evaluate effects of wells in more than one location at a time. A grid of cells on one notebook page corresponds to a map rendition of individual sections where the aquifer is present, and pumping rates are input for well locations by township, range, and section. Terms required for the analytical technique— aquifer hydraulic conductivity, thickness and specific yield, distance between the stream and the well, and the equations that calculate rate and volume and residual rate and volume of stream depletion by wells are "locked" in individual spreadsheet pages to reduce potential for inadvertent changes. Calculated solutions are summarized in tabular form and depicted in map form. The method relieves the user of any need to solve complex mathematical computations, and spreadsheet summaries and map renditions eliminate the need to compile results manually. The application of the method includes a description of the approach used to convert specific capacity data from drillers' logs to distributed hydraulic conductivity values throughout the valley using a computer program developed from an analysis by Theis (1963) and the kriging statistical technique.

I. INTRODUCTION

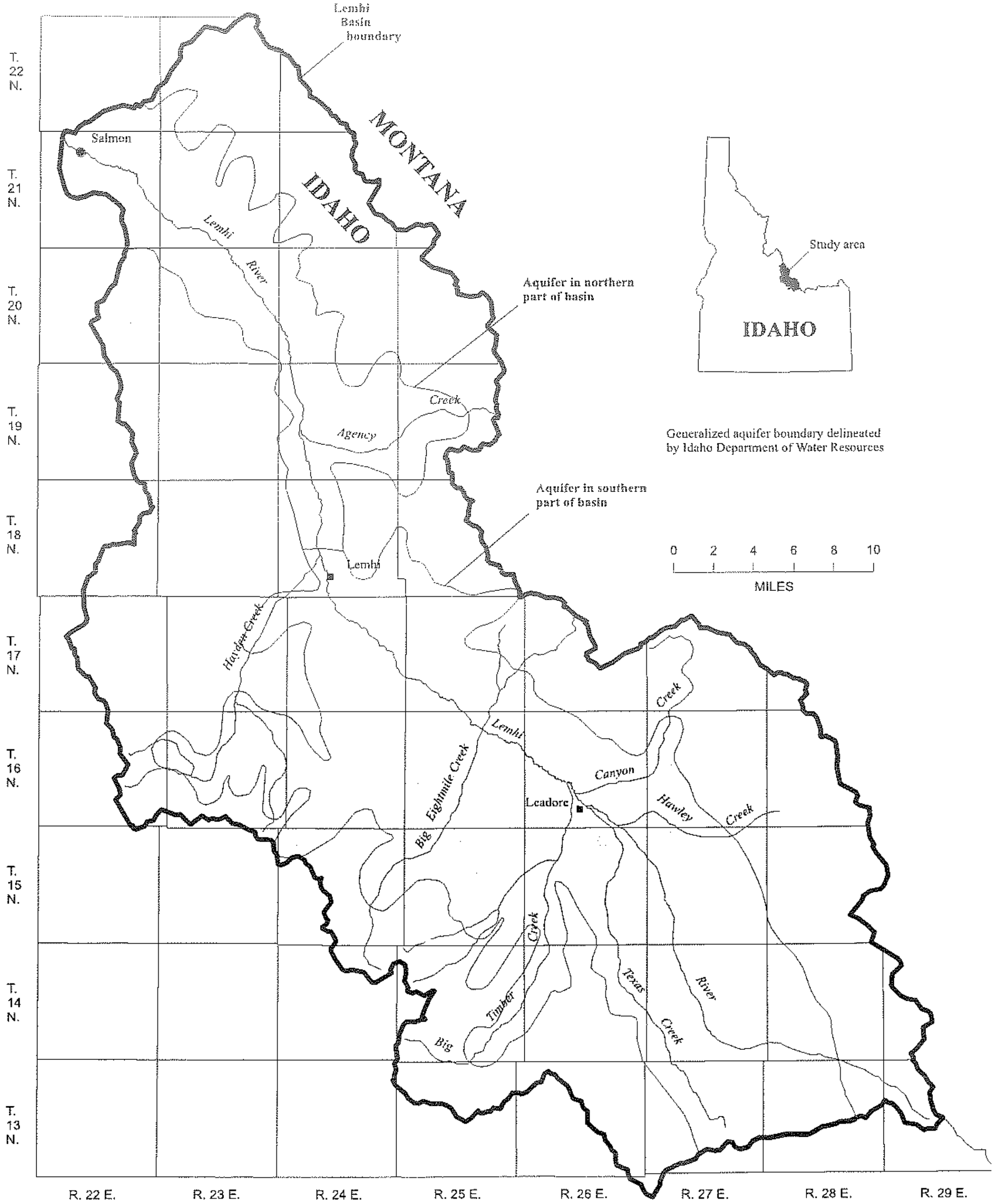
The Lemhi River basin (figure 1) is located on the Idaho-Montana border in east-central Idaho. The Lemhi River drains an area of about 1,270 square miles and flows northward about 60 miles into the Salmon River at the town of Salmon. Water from the river and tributary creeks is diverted primarily for agricultural purposes. The river and tributary creeks also serve as habitat where endangered salmon return from the Pacific Ocean to spawn before they die. Their progeny spend the first several months of life developing in the waters of the Lemhi basin before beginning their 2,000-mile trek to the sea.

Recognizing the value of the Lemhi basin to salmon restoration efforts, local farmers and ranchers and staff from Water District No. 74, the University of Idaho Research and Extension Service, Idaho Department of Fish and Game, Idaho Department of Water Resources (IDWR), Bureau of Reclamation (Reclamation), National Resource Conservation Service, Bonneville Power Administration, and U.S. Geological Survey (USGS) undertook a number of activities in 1995 that aimed simultaneously to maintain traditional agricultural water uses and to improve conditions for salmon habitat and migration. As one of those activities, this study focuses on relations between surface water and ground water. Reclamation's participation in the study was funded by Congress under the Upper Salmon River Water Optimization general investigation program.

Until recently, agricultural water use in the basin consisted of diverting the Lemhi River and some tributaries into a network of canals for irrigating crops and watering stock. Recently, ground water has been pumped in the Leadore area to supplement or replace surface-water supplies. Downstream water users who depend on diverting streamflow from the river are concerned that at some point, ground-water development upstream will reduce available surface water supplies downstream during critical periods of need for agricultural use and salmon smolt migration.

II. PURPOSE AND SCOPE

This report presents a simplified method that can be used to calculate distributed effects of ground-water pumpage in the Lemhi River Valley upstream from Lemhi on streamflow in the river and a number of its tributaries. A description of the geohydrologic setting provides the basis for the characteristics required for application of the method. Data used in this report were obtained from published reports, drillers' logs on file with the IDWR in Boise, and computerized databases maintained by the USGS in Boise.

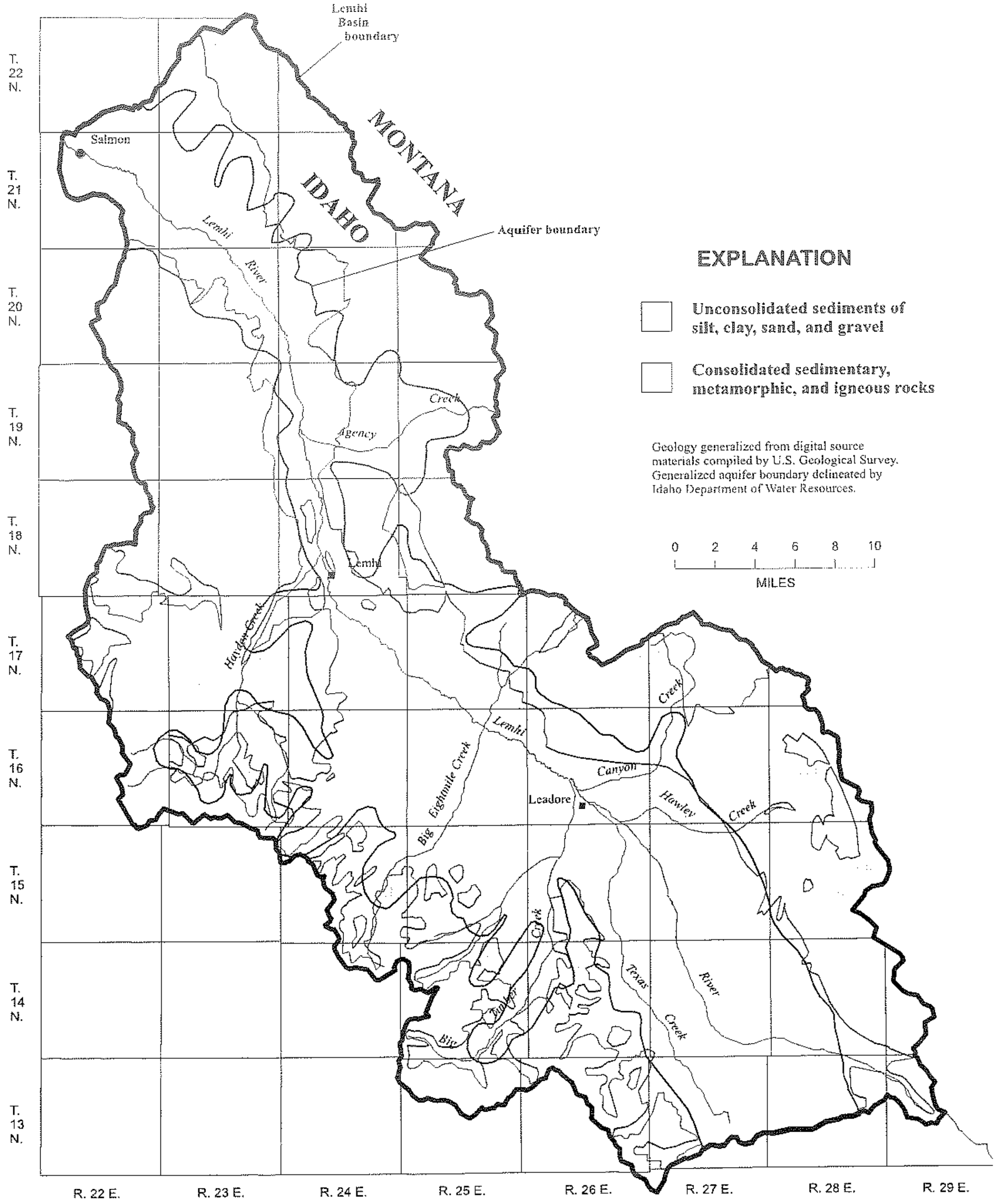

Lemhi Basin boundary
MONTANA
IDAHO
Salmon
Lemhi River
Aquifer in northern part of basin
Agency Creek
Aquifer in southern part of basin
Lemhi
Hayden Creek
Lemhi
Big Eightmile Creek
Canyon Creek
Hawley Creek
Leadore
Big Timber Creek
Texas Creek
River
Study area
IDAHO
Generalized aquifer boundary delineated by Idaho Department of Water Resources
0 2 4 6 8 10
MILES
T. 22 N.
T. 21 N.
T. 20 N.
T. 19 N.
T. 18 N.
T. 17 N.
T. 16 N.
T. 15 N.
T. 14 N.
T. 13 N.
R. 22 E.
R. 23 E.
R. 24 E.
R. 25 E.
R. 26 E.
R. 27 E.
R. 28 E.
R. 29 E.

III. GEOHYDROLOGIC SETTING

Ground water occurs predominantly in unconsolidated sediments of silt, clay, sand, and gravel associated with river and stream channels in the basin, in alluvial fans that flank the surrounding mountains, and in widely-scattered glacial deposits. Sediments are most prevalent in the valley upstream from the townsite of Lemhi (figure 2). Thickness of sediments is unknown, but drillers' logs indicate that thicknesses range from a few to about 200 feet in the valley upstream from Lemhi. The width of the valley narrows considerably downstream from Lemhi in township 18 N., range 24 E., and outcrops of consolidated rock in the narrow valley section indicate that the sediments are particularly shallow at this location. Thinning and constriction of the unconsolidated deposits in the narrows reduces the area through which ground water can flow; subsequently, almost all ground water flow from the valley upstream from the narrows discharges to the Lemhi River. Therefore, the narrows effectively separates the aquifer into independent upstream (southern) and downstream (northern) parts. Consolidated rocks that compose the mountain ranges that flank the valley and are believed to underlie sediments along stream channels, may store and transmit enough water for limited domestic or stock uses; but, consolidated rocks generally do not provide a reliable water supply throughout the basin. The remainder of this report describes ground-water conditions for the upstream part of the valley because ground-water conditions in the downstream part function independently of ground-water conditions in the upstream part.

IV. STREAM DEPLETION

Several possible approaches were considered to quantify the effects of pumping wells on streamflow-- from analytical equations and curve-matching techniques to digital ground-water flow models. However, the approach finally selected had to be relatively quick and easy to apply, require little technical training, demand no upkeep or maintenance, and provide reasonably clear, concise, and accurate results. The approach agreed upon for this study relies on an analytical technique (Jenkins, 1968) integrated with a commercial spreadsheet notebook. The analytical technique provided equations to calculate the rate and residual rate (Jenkins, 1968, p. 16, eqn. 5) and volume and residual volume (Jenkins, 1968, p. 17, eqn. 10) of stream depletion by pumping wells. Rates and volumes of stream depletion are calculated for given pumping rates and for given pumping periods to represent immediate effects of pumping on streamflow from the time pumping begins until pumping stops. Residual rates and volumes of stream depletion are calculated for a specified time after pumping stops to represent effects of pumping on streamflow that continue after the well stopped pumping. The spreadsheet notebook provides a mechanism to use the analytical technique to evaluate the effects of more than one well at a time. A grid of cells on one page in the notebook corresponds to individual sections where the aquifer is present. The cells are presented in a map rendition where pumping rates for wells are input on a township, range, and section basis. Also, calculated solutions are summarized in tabular form and depicted in map form. Integration of the analytical equations into individual spreadsheet pages in the notebook relieves the user from any need to solve complex mathematical computations, and spreadsheet summaries and map renditions eliminate the need to compile results manually.


Lemhi Basin boundary
MONTANA
IDAHO
Aquifer boundary
Salmon
Lemhi River
Agency Creek
Lemhi
Hawley Creek
Big Eightmile Creek
Lemhi
Canyon
Leadore
Hawley Creek
Creek
Big Timber Creek
Texas Creek
River
T. 22 N.
T. 21 N.
T. 20 N.
T. 19 N.
T. 18 N.
T. 17 N.
T. 16 N.
T. 15 N.
T. 14 N.
T. 13 N.
R. 22 E.
R. 23 E.
R. 24 E.
R. 25 E.
R. 26 E.
R. 27 E.
R. 28 E.
R. 29 E.
EXPLANATION
Unconsolidated sediments of silt, clay, sand, and gravel
Consolidated sedimentary, metamorphic, and igneous rocks
Geology generalized from digital source materials compiled by U.S. Geological Survey. Generalized aquifer boundary delineated by Idaho Department of Water Resources.
0 2 4 6 8 10
MILES

Specifications for six terms are required for any particular solution of the analytical equations in the notebook: pumping rate, pumping time, time after pumping stops, transmissivity and specific yield of the aquifer, and distance between the pumping well and the stream. As applied in the Lemhi Valley, the first three terms are specified by the user to obtain any particular solution. However, the last three terms were considered to be constants and were assigned permanently in separate spreadsheet notebook pages for cells that correspond to individual sections where the aquifer is present. Derivations for these last three terms are described below.

A. Transmissivity and Specific Yield

A sequential process was used to estimate a transmissivity value for each section where the aquifer is present. First, drillers' logs were reviewed to select those that contained pump test data that included pumping rate, water-level drawdown in the well due to pumping, well diameter, and pump test length (Table 1). A computer program (Table 2) was written to iteratively solve an equation (Theis, et.al, 1963, p. 332, eqn. 1) that is used to estimate a transmissivity value from pump test data reported on drillers' logs. Well diameter was used for well radius in the equation, assuming that the drilling process disturbed aquifer material beyond the well annulus and effectively increased transmissivity beyond the drill hole. For the few wells without a reported well diameter, a diameter of 8 inches was used, which is a common diameter for domestic wells in the area. A pumping time of 1 hour was used for wells where no pumping time was reported. A specific yield of 0.12 was used. No field values for specific yield were available for this area, but the chosen value falls within the range of .04 to .28 reported for alluvial sediments of silt, sand, and gravel (Johnson, A.I., 1967, p. 68). The transmissivity value obtained from the equation represented a value for the length of the well open to the aquifer during pumping and not necessarily the entire aquifer thickness. Therefore, transmissivity values were normalized by dividing by the saturated length of opening for each tested well to obtain hydraulic conductivity for the well.

A hydraulic conductivity value was estimated at each section where the aquifer is present with the kriging statistical technique using hydraulic conductivity data for wells developed from the procedure described above. GEO-EAS (Englund and Sparks, 1991) was used to develop an exponential form of the model semi-variogram from natural log-transformed hydraulic conductivity data with a nugget of 0.0, range of 2,900 meters, and contribution (sill) of 3.3. Then, the semi-variogram developed with GEO-EAS was used in GMS (Engineering Computer graphics Laboratory, Brigham Young University, 1996) to estimate a hydraulic conductivity value for each section where the aquifer is present (figure 3). The grid specified in GMS approximated section locations with 33 rows and 37 columns. GMS grid specifications included an x origin of 754,595 meters, y origin of 4,923,525 meters, a total length of 59,546.45 meters, and height of 53,109 meters. The grid was rotated 2.5 degrees in GMS to correspond with well locations and other geographic features which had been projected into UTM zone 11.

Table1. Well Data

[Data obtained from drillers' logs on file with Idaho Department of Water Resources, Boise, Idaho. Data from field-checked wells obtained from Ground Water Site Inventory database maintained by the U.S. Geological Survey, Boise Idaho. Saturated length of opening is the length of the well screen or (open) hole open to the aquifer or the difference between the pumping water level and the bottom of the opening, whichever was less. The mathematical product of estimated hydraulic conductivity values times saturated length of opening values does not necessarily equal estimated transmissivity values because of rounding to whole numbers.]

Local Well Number	Field Check Flag	Well Test Discharge Rate (Gallons per Minute)	Water Level Draw-down (Feet)	Hole Dia-meter (Inches)	Pump Test Length (Hours)	Estimated Transmis-sivity (Feet Squared per Day)	Saturated Length of Opening (Feet)	Estimated Hydraulic Conduc-tivity (Feet per Day)
15N 24E 12BA		100	40.0	8	2.00	262	34	8
15N 25E 08BB		12	19.0	6	3.00	62	42	1
15N 26E 02DDC1	*	2,280	76.0	20	16.00	4,562	92	50
15N 26E 08DC		14	50.0	6	3.00	24	10	2
15N 26E 09AD		10	84.0	6	3.00	10	30	1
15N 26E 12BCC1	*	1,600	104.0	20	1.00	1,407	80	18
15N 27E 20DCD1	*	7	7.7	6	0.00	78	10	8
16N 25E 02CDC1	*	40	25.0	6	2.00	172	3	57
16N 25E 03BCC1	*	35	22.0	6	0.00	151	2	76
16N 25E 03DAC1	*	15	6.0	6	2.00	288	33	9
16N 25E 03DBA1	*	15	6.0	6	0.00	257	27	10
16N 25E 18AA		25	40.0	6	2.00	58	4	15
16N 25E 20DB		14	40.0	6	2.00	29	7	4
16N 25E 22CDA1	*	15	10.0	6	0.00	141	7	20
16N 25E 25AAA1	*	600	20.0	6	0.00	4,375	1	4375
16N 25E 25CBB1	*	630	130.0	16	7.00	554	41	14
16N 25E 27CDA1	*	1,300	70.0	12	12.00	2,904	45	65
16N 25E 30AB		18	31.0	6	0.00	45	20	2
16N 25E 33BA		50	16.0	6	0.25	255	8	32
16N 26E 22DC		25	39.0	6	5.00	69	2	35
16N 26E 27CAC1	*	810	60.0	16	5.00	1,700	6	283
16N 26E 28DCB1	*	120	30.0	8	24.00	625	12	52
16N 26E 33AACA1	*	25	22.0	6	2.00	116	1	116
16N 26E 33ABB1	*	30	7.0	0	0.00	438	1	876
16N 26E 33ABB2	*	90	29.0	8	3.00	360	10	36
16N 26E 33ABC1	*	30	23.0	6	1.50	128	7	18
16N 26E 34AA		20	13.0	6	3.00	175	1	175
16N 26E 35BC		20	20.0	6	2.00	99	1	99
16N 27E 34AA		20	12.0	6	2.00	181	5	36
17N 23E 14ABB1	*	25	62.0	0	1.00	25	5	5

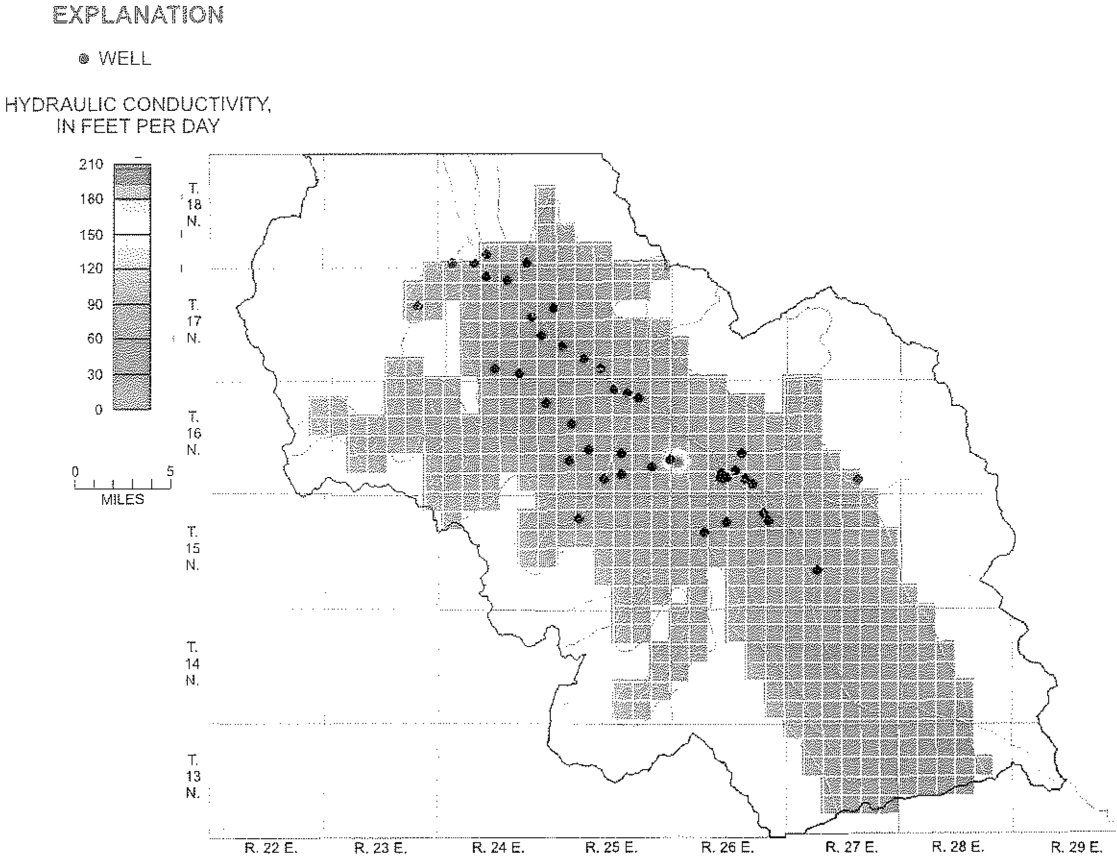
Table 1. Well Data (continued)

Local Well Number	Field Check Flag	Well Test Discharge Rate (Gallons per Minute)	Water Level Draw-down (Feet)	Hole Dia-Meter (Inches)	Pump Test Length (Hours)	Estimated Transmis-sivity (Feet Squared per Day)	Saturated Length of Opening (Feet)	Estimated Hydraulic Conduc-tivity (Feet per Day)
17N 24E 03CA		20	19.0	6	0.00	92	12	8
17N 24E 04CBA1	*	27	18.0	6	0.00	141	2	83
17N 24E 13AA		15	80.0	6	3.00	16	10	2
17N 24E 14DBA1	*	30	20.0	6	0.00	141	10	14
17N 24E 24CB		10	29.0	6	0.00	24	3	8
17N 24E 33AC		25	50.0	6	2.00	44	25	2
17N 24E 35CBB1	*	10	30.0	6	0.00	23	17	1
17N 25E 29CD		30	3.0	6	0.00	1,268	10	127
17N 25E 30BB		28	104.0	6	0.00	18	1	18
17N 25E 33BDB1	*	85	7.0	8	0.00	1,459	81	18
18N 24E 31DB		20	20.0	6	3.00	107	8	13
18N 24E 32DB		30	9.0	6	0.00	360	1	360
18N 24E 33BAC1	*	20	21.0	6	0.00	82	1	82
18N 24E 35CA		12	14.0	6	0.00	73	3	24

Transmissivity values for the Lemhi Valley upstream from Lemhi were compared with values calculated for the Pahsimeroi River basin, a tributary to the Salmon River of similar size and geologic history located immediately west of the Lemhi River basin. Average transmissivity for five irrigation wells in the Pahsimeroi Basin (Young and Harenberg, 1973, p. 43) was much greater than average transmissivity for 44 domestic and irrigation wells in the Lemhi River basin (Table 1). Because calculations made using data from small capacity wells tend to underestimate transmissivity values compared to calculations made for large-capacity wells, a multiplier was developed so that average transmissivity for the 44 Lemhi wells approximated average transmissivity for the Pahsimeroi wells. The multiplier of 12 was obtained by dividing average transmissivity of the Pahsimeroi wells (30,800 feet squared per day [Young and Harenberg, 1973, p. 36]) by average transmissivity of the Lemhi wells (2,640 feet squared per day). Average transmissivity of the Lemhi wells was calculated by multiplying average hydraulic conductivity (165 feet per day) by average open interval in the wells (16 feet).

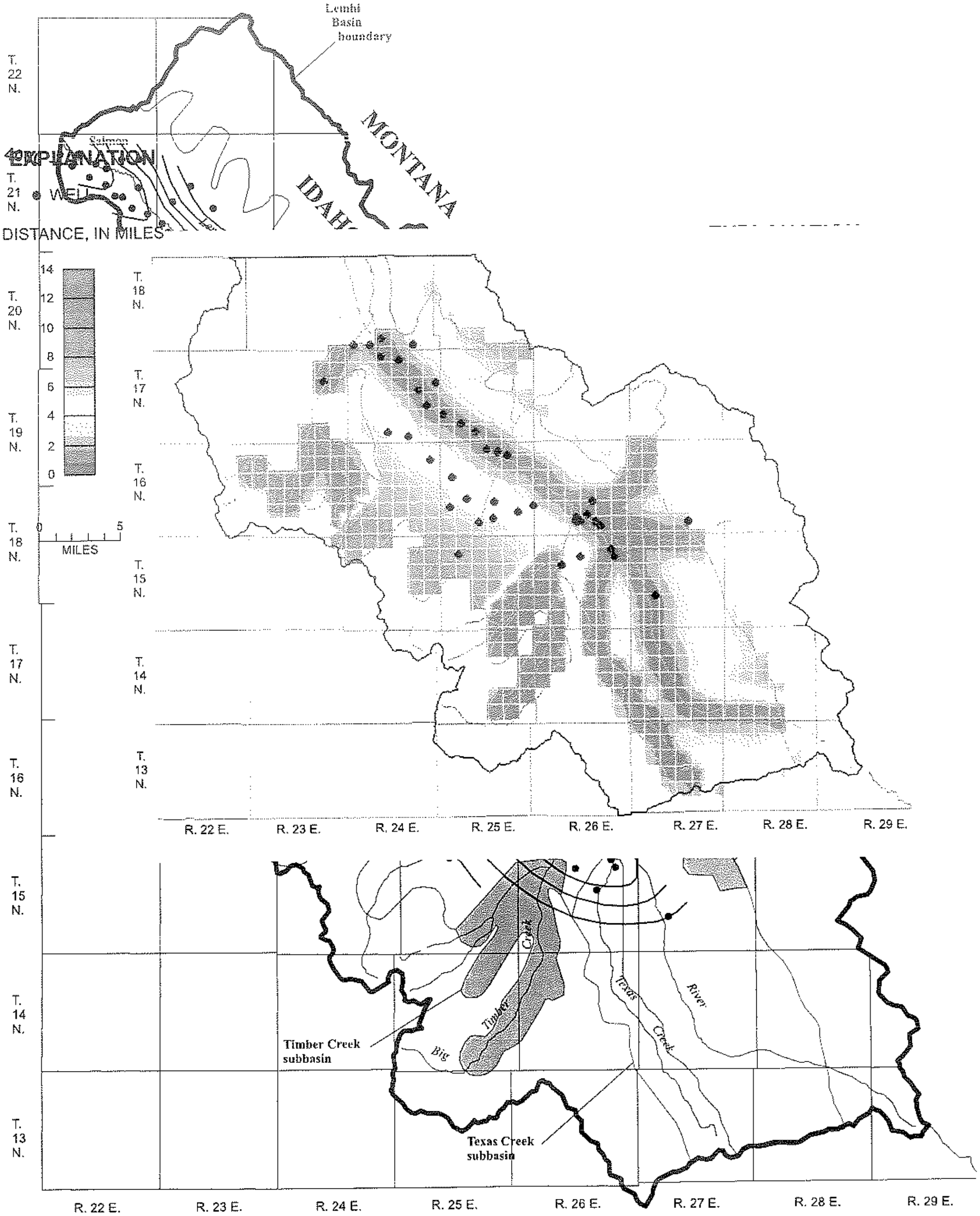
Table 2. FORTRAN Listing of Program to Calculate Transmissivity from Specific Capacity Data.

```
c       program t-est.f
c
c       calculates Theis estimate of T from specific capacity test data per USGS WSP 1535-I
c
c       inputs:
c               siteid, arbitrary site identifier
c               specific capacity (sc), in gallons per minute per foot of drawdown
c               well diameter (diam), in inches
c               pump test length (hrs), in hours
c
c       outputs
c               siteid
c               transmissivity estimate (t1), in feet squared per day
c
c       assumptions:
c               specific yield = 0.12
c               well diameter = effective radius of the well
c
        character*15 siteid
        open (7,file='sc.data')
        open (8,file='t-est.data')
5       t0= 1000.
        read (7,10,end=999) siteid, sc, diam, hrs
10      format (a15,f9.0,2f8.0)
        if (diam.eq.0.) diam= 8.
        if (hrs.eq.0.) hrs= 1.
        efrad= diam/12.
        days= hrs/24.
15      t1= 15.32*sc*(-.577-alog(efrad**2*.12/(4*t0*days)))
        diff= abs(t1-t0)
        if (diff.lt.10.) then
         write (8,20) siteid, t1
20       format (a15,f10.0)
         go to 5
        else if (t1.gt.t0) then
         t0= t0 + diff/2.
        else
         t0= t0 - diff/2.
        end if
        go to 15
999     stop
        end
```

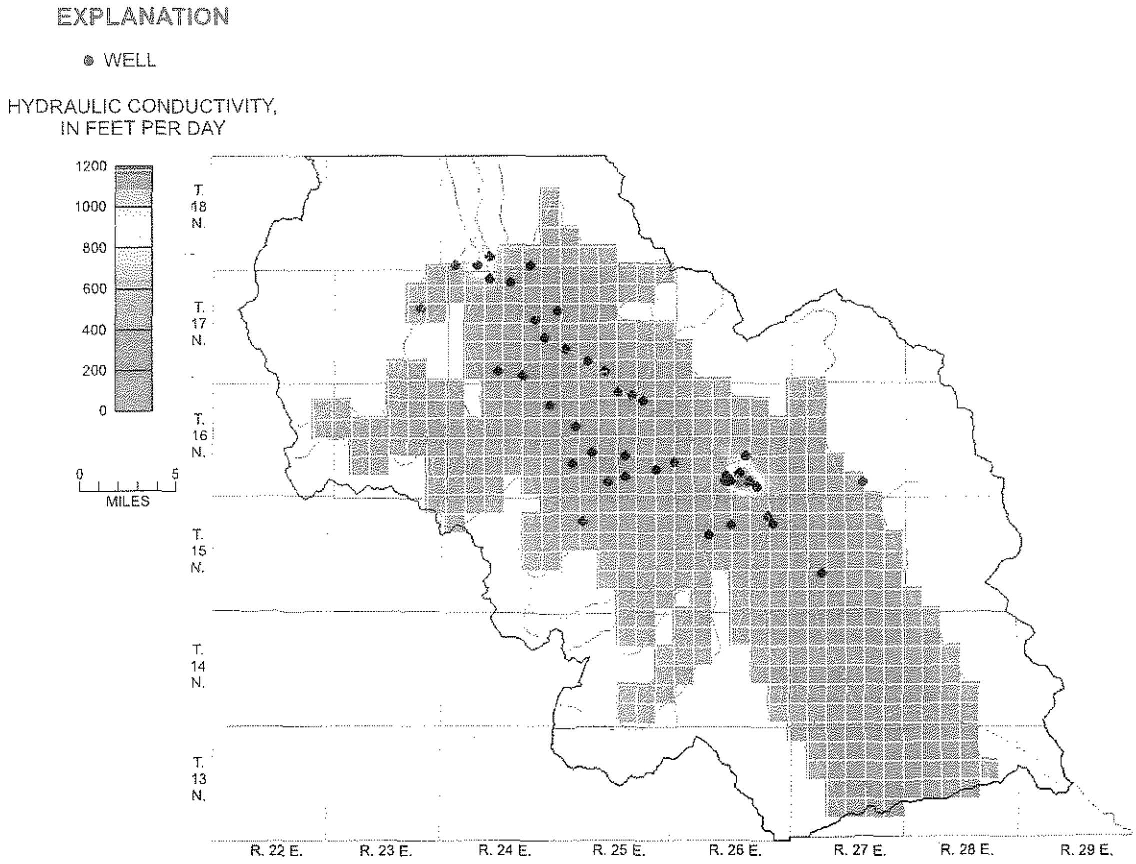


B. Distance Between Pumping Wells and Streams

The original analytical technique called for the perpendicular distance between two points, the pumping well and the stream, and uniform transmissivity between those points as two inputs required for solution. Because the spreadsheet notebook method developed for the Lemhi Valley can solve for the cumulative impacts between many paired points simultaneously and variable transmissivity values for the aquifer are represented, the perpendicular distance may not always be the actual distance that ground water moves between the stream and the section where the well is located. Therefore, flowline distance in conjunction with adjusted hydraulic conductivity, as described below, was considered to better represent field conditions in the spreadsheet notebook application. Before flowline distances were determined, sections where the aquifer is present were subdivided into 6 subbasins (figure 4) because stream depletion from ground-water pumping was likely to affect streamflow in tributary streams before affecting streamflow in the Lemhi River. The map of the water table (figure 4) was used as a basis to sketch the approximate location of flow lines in the subbasins. Flowlines depict the lateral movement of ground water and are drawn perpendicular to water-table contours. Then, the approximate average distance between a point in the section and the major stream in the subbasin along a flow line was estimated for each section (figure 5).


Lemhi Basin boundary
MONTANA
IDAHO
Salmon
EXPLANATION
WELL
DISTANCE, IN MILES
14
12
10
8
6
4
2
0
0
5
MILES
T. 22 N.
T. 21 N.
T. 20 N.
T. 19 N.
T. 18 N.
T. 17 N.
T. 16 N.
T. 15 N.
T. 14 N.
T. 13 N.
R. 22 E.
R. 23 E.
R. 24 E.
R. 25 E.
R. 26 E.
R. 27 E.
R. 28 E.
R. 29 E.
Timber Creek subbasin
Texas Creek subbasin
Big Timber Creek
Texas Creek
River

The original analytical technique also called for the average transmissivity between the well and the stream. Calculating average transmissivity values by first adjusting corrected hydraulic conductivity values to reflect average hydraulic conductivity along flowlines was considered but rejected. Stream depletion potentially could be overestimated using average hydraulic conductivity between the stream and the section with pumping wells because the lowest resultant transmissivity value in a section along a flow line should limit the analytical computation of stream depletions. Therefore, the corrected hydraulic conductivity values were adjusted so that the lowest hydraulic conductivity value on a flow line was specified for sections up hydraulic gradient on the flow line (figure 6).



V. USING THE SPREADSHEET NOTEBOOK

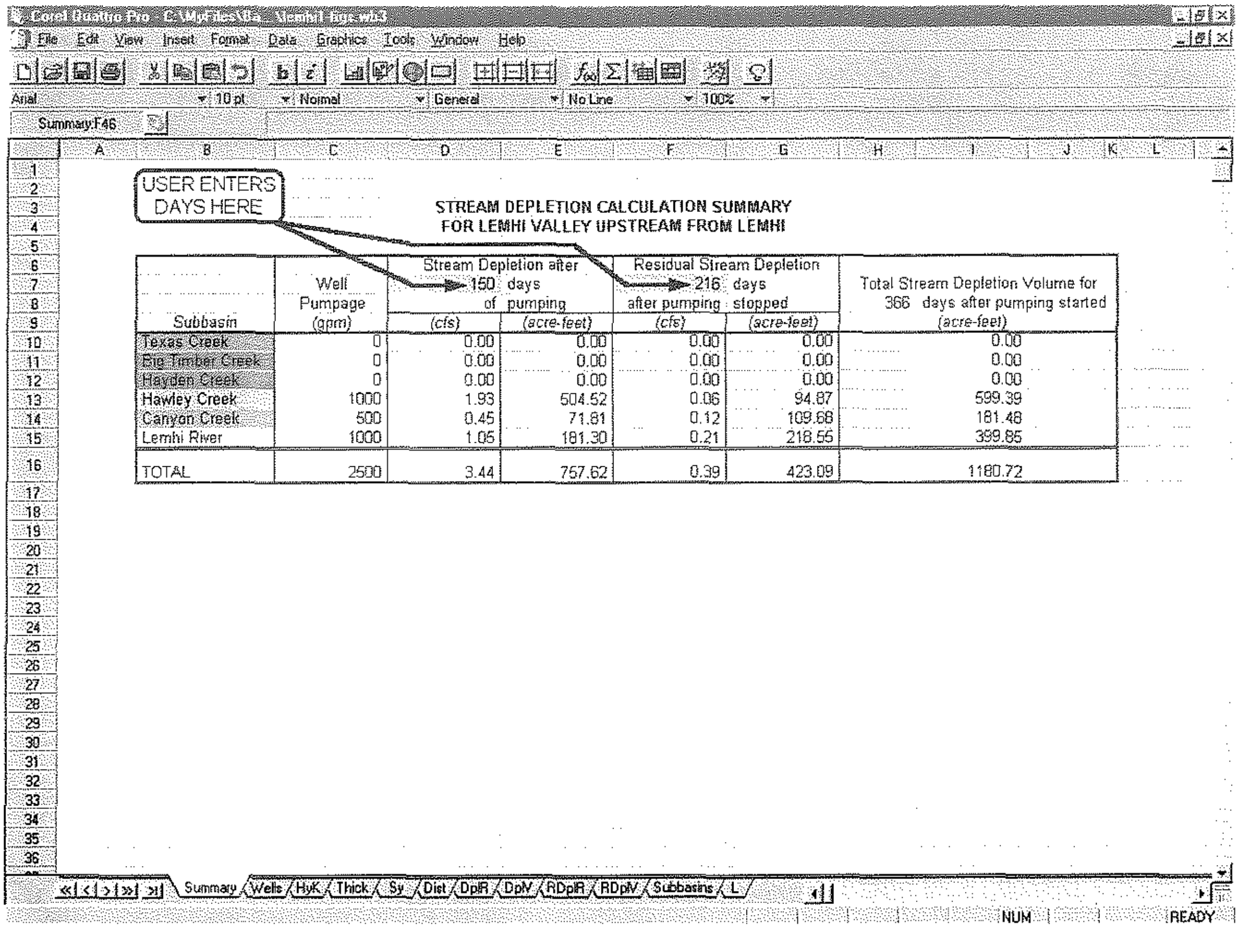
The spreadsheet notebook contains 12 pages (Table 3). The Summary and Wells pages are the only pages that require user input. The Summary page (figure 7) contains two cells where the user must specify both the number of days of pumping and the number of days after pumping stopped. These are the only cells that can be changed by the user. All other cells on the page are locked to prevent inadvertent corruption of the summary equations or page layout.

This page also presents a summary of well pumpage, stream depletion rate and volume, residual stream depletion rate and volume, and total stream depletion volume. The Summary page example (figure 7) shows the results for specifications made on the Wells page example (figure 8).

Table 3. Contents of Spreadsheet Notebook Pages.

["Yes" in the Entry column indicates that the user must enter data on the page; "No" in the Entry column indicates that the user should not change any of the contents on the page.]

PAGE NAME	ENTRY	CONTENTS
Summary	Yes	Table showing total well pumpage (in gallons per minute), rate and volume of stream depletion (in cubic feet per second and acre-feet, respectively) for a user-specified length of pumping time (in days), residual rate and volume of stream depletion (in cubic feet per second and acre-feet, respectively) for a user-specified length of time after pumping stops (in days), and total volume of stream depletion (in acre-feet) from the time pumping started until the previously-specified time after pumping stopped for six subbasins — Texas, Big Timber, Hayden, Canyon, and Hawley Creeks, and the Lemhi River. Length of pumping time and time after pumping stops is specified by the user on this page.
Wells	Yes	Map rendition of the six subbasins where the user can specify total well pumpage (in gallons per minute) in individual sections where the aquifer is present.
HyK	No	Hydraulic conductivity values (in feet per day).
Thick	No	Aquifer thickness values (in feet).
Sy	No	Specific yield values (dimensionless).
Dist	No	Distance between section and major stream in subbasin (in miles).
DplR	No	Equations that calculate stream depletion rate (in cubic feet per second) during pumping.
DplV	No	Equations that calculate stream depletion volume (in acre-feet) during pumping.
RDplR	No	Equations that calculate residual stream depletion rate (in cubic feet per second) after pumping stops.
RDplV	No	Equations that calculate residual stream depletion volume (in cubic feet per second) after pumping stops.
Subbasins	No	Index numbers for subbasins.
Objects	No	Contains charts of map renditions for hydraulic conductivity and distance from sections to major streams in subbasins and stream depletion rate and volume and residual stream depletion rate and volume.

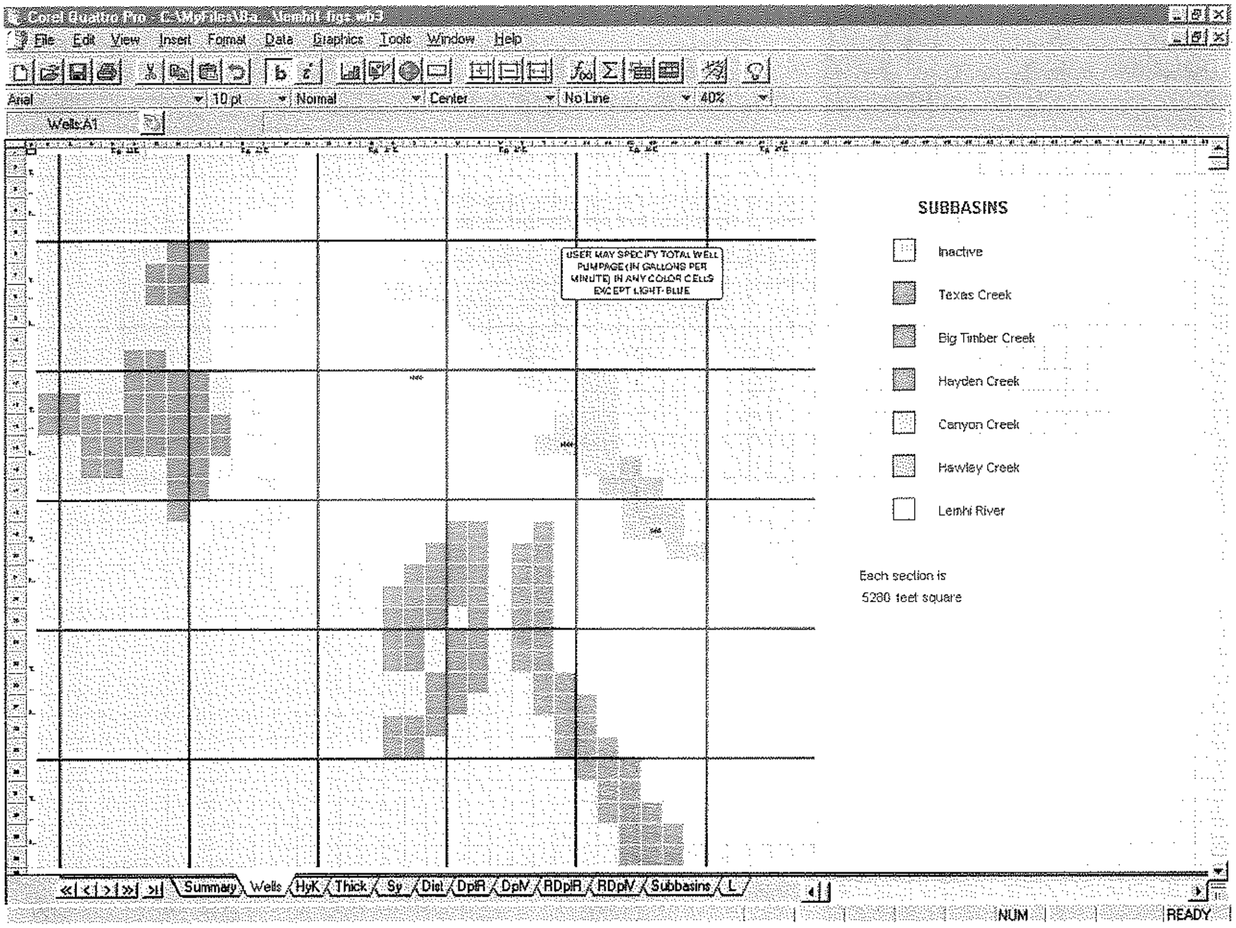


STREAM DEPLETION CALCULATION SUMMARY
FOR LEMHI VALLEY UPSTREAM FROM LEMHI

Subbasin	Well Pumpage (gpm)	Stream Depletion after 150 days of pumping (cfs)	Stream Depletion after 150 days of pumping (acre-feet)	Residual Stream Depletion 216 days after pumping stopped (cfs)	Residual Stream Depletion 216 days after pumping stopped (acre-feet)	Total Stream Depletion Volume for 366 days after pumping started (acre-feet)
Texas Creek	0	0.00	0.00	0.00	0.00	0.00
Big Timber Creek	0	0.00	0.00	0.00	0.00	0.00
Hayden Creek	0	0.00	0.00	0.00	0.00	0.00
Hawley Creek	1000	1.93	504.52	0.06	94.87	599.39
Canyon Creek	500	0.45	71.81	0.12	109.68	181.48
Lemhi River	1000	1.05	181.30	0.21	218.55	399.85
TOTAL	2500	3.44	757.62	0.39	423.09	1180.72

Figure 7.-- Summary notebook page. Example results for Lemhi River and Hawley and Canyon Creeks relate to example well pumpage shown on figure 8.

Well pumpage in gallons per minute for each section where one or more well is located is specified by the user on the Wells page (figure 8). This page also shows the sections that belong in each subbasin and provides township and range labels along the upper and left margins, respectively. Cell and label sizes were developed so that the entire valley could be displayed on a 17-inch monitor configured for a screen resolution of 1024 x 768 pixels with a magnification of 40 percent. However, township and range labels are not easily readable at this magnification. The user is encouraged to experiment to obtain a comfortable magnification level. For example, for monitor characteristics described above, 75 percent magnification shows more than 12 townships and clearly displays township and range labels.



USER MAY SPECIFY TOTAL WELL PUMPAGE (IN GALLONS PER MINUTE) IN ANY COLOR CELLS EXCEPT LIGHT-BLUE

SUBBASINS

- ☐ Inactive
- ▨ Texas Creek
- ▨ Big Timber Creek
- ▨ Hayden Creek
- ☐ Canyon Creek
- ☐ Hawley Creek
- ☐ Lemhi River

Each section is
5280 feet square

Figure 8.-- Well pumpage notebook page. Example shows 1,000 gallons per minute entered for sections in the Lemhi River and Canyon Creek subbasins and 500 gallons per minute entered for a section in the Hawley Creek subbasin.

The remaining notebook pages either hold input data, make calculations in response to user input specifications, or display map renditions of results. These pages also are locked to prevent inadvertent changes. Data and formulas in locked fields represent the analysis done for this study and should not be changed without a valid technical reason. If inadvertent changes are made to locked fields, the spreadsheet notebook can be reloaded from the original diskettes.

Spreadsheet map renditions show notebook page contents in a perspective view. Map renditions are available for hydraulic conductivity, flowline distance between major streams and sections, depletion rates and volumes, and residual depletion rates and volumes. Color shading on map renditions help illustrate relative differences in values throughout the valley. However, absolute values cannot be ascertained from the color shaded map renditions because the commercial spreadsheet was incapable of generating a color explanation for three-dimensional perspective graphs. An example map rendition of distance between sections and major streams in subbasins is shown in figure 9. This map rendition can be compared with figure 5 which shows the same information depicted as a shaded contour map and includes base map and explanatory information which could not be transferred easily to the map rendition. Map renditions may be useful to view areas of greatest impact on stream depletion.

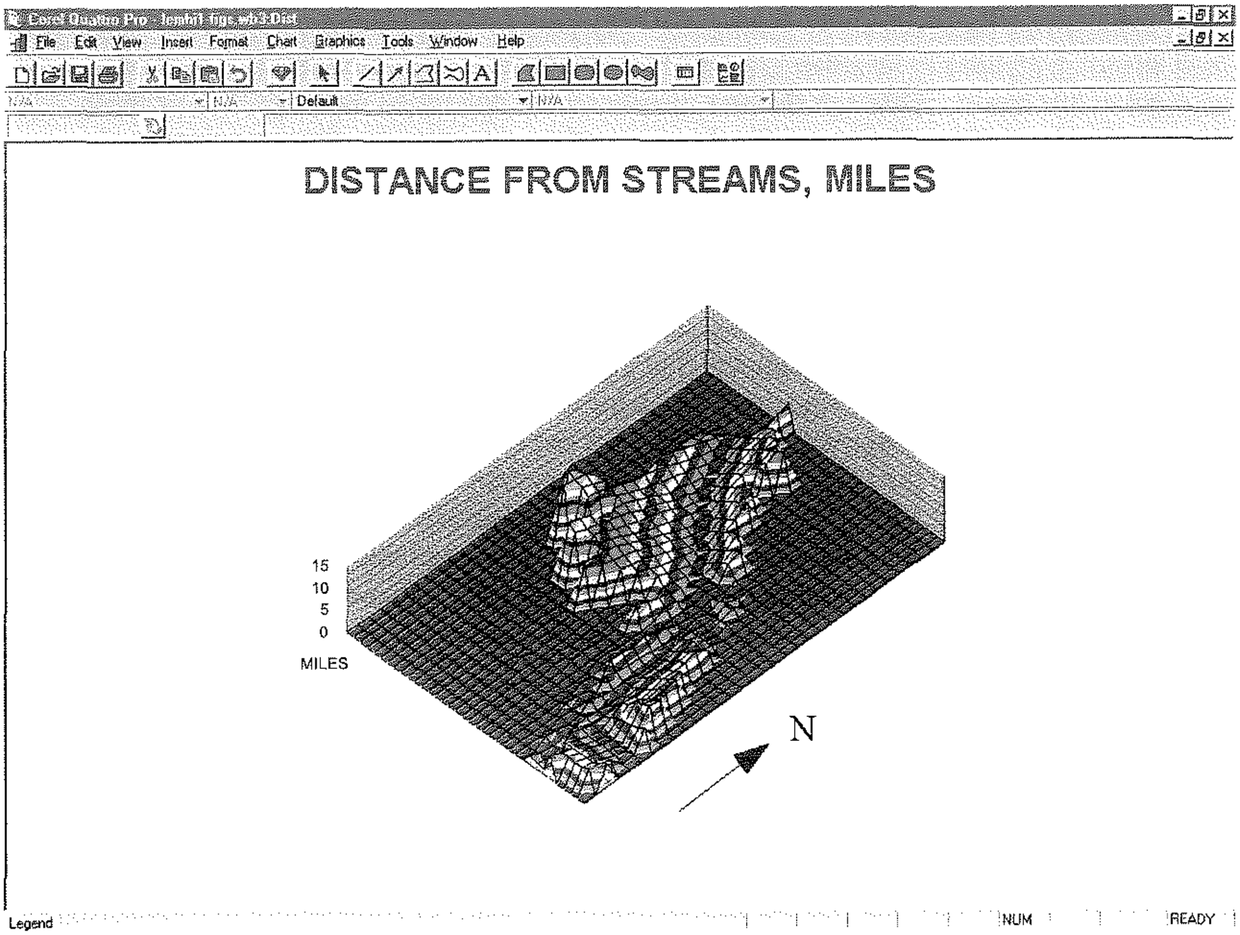


Figure 9.-- Notebook map rendition showing average flow line distances between major streams and sections. Compare to figure 5 for base map information.

VI. ASSUMPTIONS AND LIMITATIONS

Seven assumptions were specified in the report on the original analytical technique (Jenkins, 1968, p. 2) and bear repeating here:

> 1. *T* [transmissivity] does not change with time. Thus for a water-table aquifer, drawdown is considered to be negligible when compared to the saturated thickness.
> 2. The temperature of the stream is assumed to be constant and to be the same as the temperature of the water in the aquifer.
> 3. The aquifer is isotropic, homogeneous, and semi-infinite in areal extent.
> 4. The stream forms a boundary that is straight and fully penetrates the aquifer.
> 5. Water is released instantaneously from storage.
> 6. The well is open to the full saturated thickness of the aquifer.
> 7. The pumping rate is steady during any period of pumping.
>
> Field conditions never fully meet the idealized conditions described by the above assumptions.

An excellent explanation of the effects on stream depletion by pumping wells when these assumptions are not fully met follows the list of assumptions in the original publication. Jenkins (1968) summarizes these effects by stating that "[d]eparture from idealized conditions may cause actual stream depletions to be either greater or less than the values determined by methods presented in this report. Although the user usually cannot determine the magnitude of these discrepancies, he should, where possible, be aware of the direction the discrepancies take."

Assumptions 3 and 4 were addressed in a subsequent paper that compared the analytical solution for stream depletion by wells to simulated results from a numerical ground-water flow model in part of the 174,000-square-mile High Plains Regional Aquifer System in Kansas (Sophocleous, et.al., 1995). The authors reported that results from the numerical model indicated that although less stream depletion by wells was simulated in a partially-penetrating stream, greater inflow across the model boundary was simulated. A factor to correct the analytical technique for partial stream penetration for this case was presented. This correction was considered for this study, but rejected. A correction to the analytical method is appropriate as described by Sophocleous and others when representing a small study area within a large aquifer system when there is substantial ground water in storage outside of the small study area that actually can be induced to cross the study boundary in response to ground-water pumpage. However, the aquifer in the Lemhi Valley is much smaller in areal extent, and inflow across the aquifer boundary cannot increase in response to well pumpage because there is no significant aquifer opposite this boundary. Streamflow and ground-water storage within aquifer boundary in the study area are the only sources of water to wells in the Lemhi Valley. Therefore, applying the correction factor in this case was considered inappropriate.

In addition to the assumptions listed above, a few other points should be noted. Effects from well interference are not considered in this method. Total well pumpage is aggregated within each section. Significant pumping in adjacent sections could result in steeper water-table gradients between aggregated sections and the stream and, thereby, result in greater stream depletion than calculated with this method. Also, significant well pumpage more than a few miles from streams results in little or no stream depletion with this method. Well development along Yearian, Reese, Peterson, Little Eightmile, Big Eightmile, or Mill Creeks could deplete these intermittent streams and reduce flow in the Lemhi River during some parts of the year. However, the spreadsheet notebook method cannot represent intermittent streams without close attention to spreadsheet inputs and outputs. Sometimes extremely small negative results are calculated. This condition is associated with the previous condition and indicates a limitation of the analytical method. Finally, stream depletions are assumed to be additive. Stream depletion in subbasins reduces total streamflow that otherwise would have flowed into the Lemhi River and passed through the narrows to the northern part of the basin.

VII. CONCLUSIONS

The spreadsheet notebook provides an easy to use method to calculate stream depletion by pumping wells distributed throughout the Lemhi valley upstream from the Lemhi townsite. Values obtained from the method can be used to identify how location, pumping rate, and pumping duration affect streamflow in the Lemhi River and several of its tributaries. This approach also can be used in an inverse mode by specifying a negative pumping rate to evaluate effects of recharge on streamflow. In this case, negative stream depletions represent increased flow rates and volumes. Values obtained from this method can be used to adjust streamflow measured at the Lemhi gauging station to evaluate downstream effects.

The method is highly dependent on the depiction of the distribution of transmissivity throughout the aquifer. However, actual transmissivity data in the basin does not exist. Transmissivity was estimated from specific capacity data from wells that are not distributed over the entire extent of the aquifer and then was corrected in order of magnitude to transmissivity in a neighboring valley. Transmissivity estimates could be improved by conducting several aquifer tests.

The method works reasonably well for sections located within a few miles from major stream channels. Adding more subbasins to represent perennial streams in areas more than a few miles from a major stream may improve representation of stream depletions.

VIII. REFERENCES

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