BASIC GROUNDWATER HYDROLOGY AND EVALUATION PROCEDURES

TRAINING MANUAL

Prepared by

Tom Morrison, P.E.

Prepared for

New Mexico Office of the State Engineer

May 31, 2006

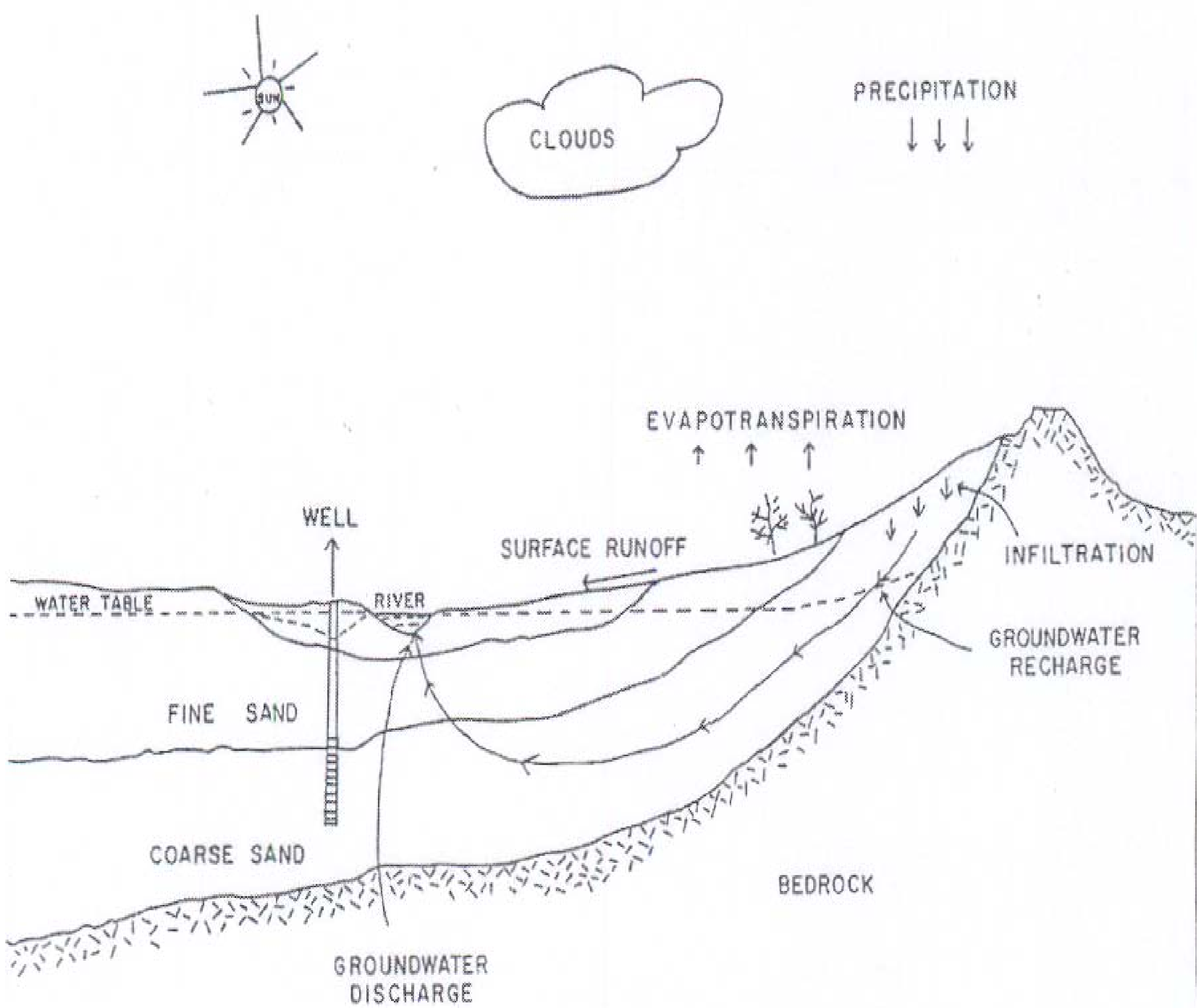
CONTENTS

SECTION I
DEFINITIONS AND CONCEPTS

TABLE OF CONTENTS

SECTION I
DEFINITIONS AND CONCEPTS

1. Hydrologic Cycle



2. Groundwater Budgets

Pre-development Budget (before water level declines started)

Inflows	Outflows
Mountain front recharge	Evapotranspiration
River leakage	Evaporation
Basin subsurface inflow	Seepage to river
	Basin subsurface outflow

Pre-development Groundwater Equation: Inflows = Outflows

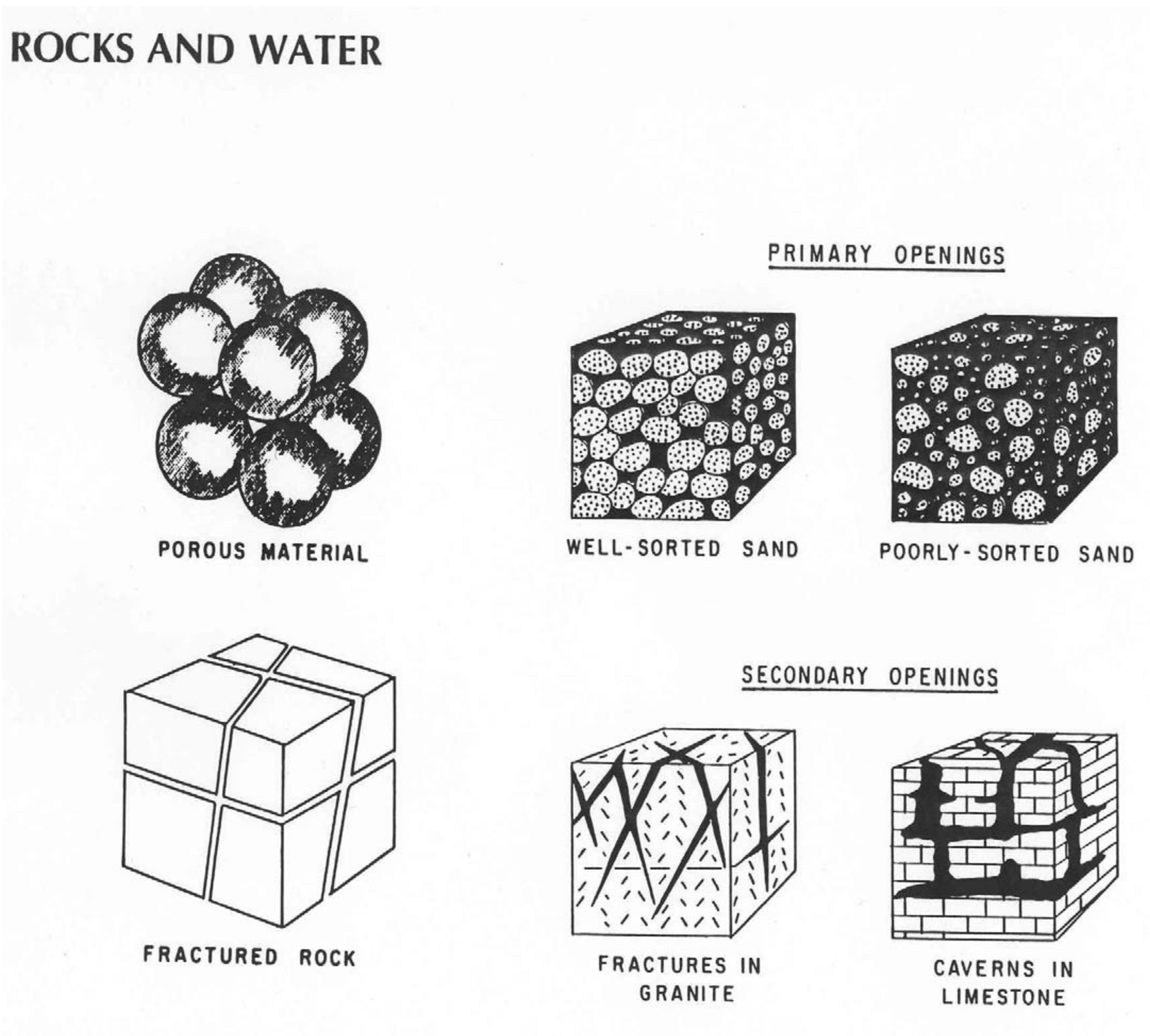
Post-development Budget (after water level declines started)

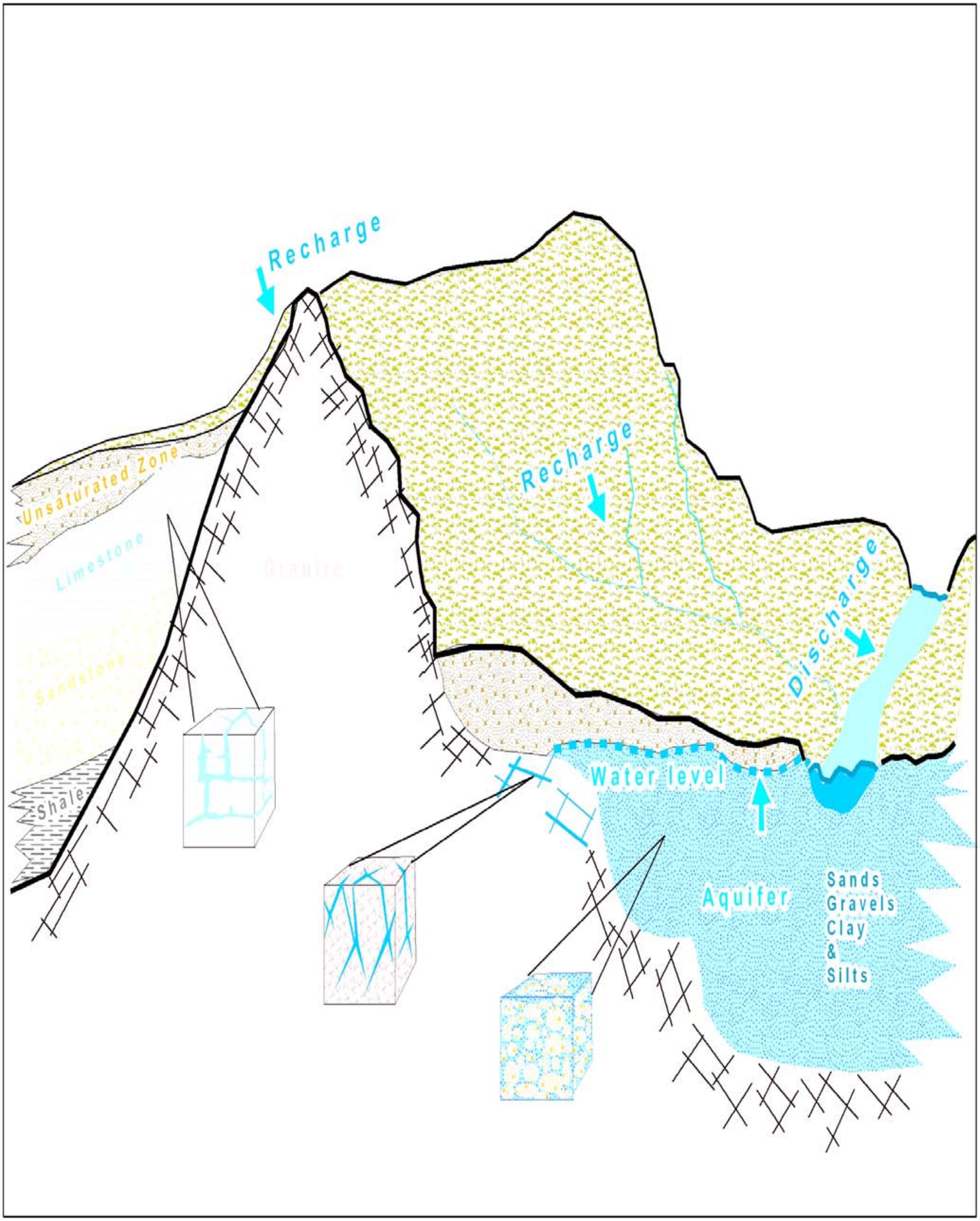
Inflows	Outflows
Mountain front recharge	Evapotranspiration
River leakage (natural)	Basin subsurface outflow
Stream Depletion (wells)	Evaporation
Seepage from irrigation	Seepage to river
Basin subsurface inflow	Depletion from aquifer
	Well pumpage

Post-development GW Equation: Change in aquifer storage = Inflows - Outflows

3. Geologic Influences

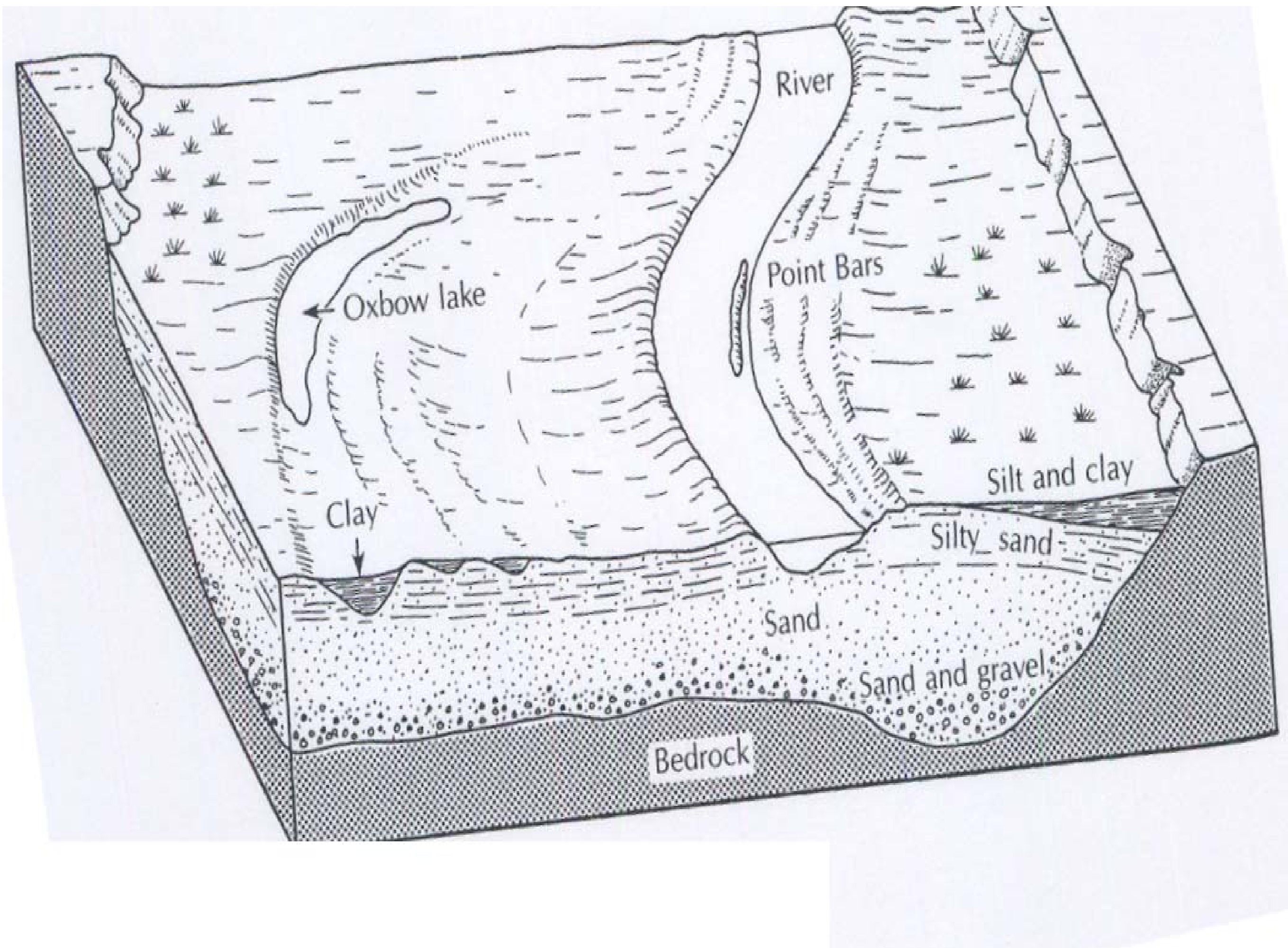
- Understanding the geology is essential for groundwater investigations.
- Rocks are composed of solids and voids.
- Without the voids there would be no room for groundwater.
- Voids also need to be connected for groundwater to move.




Recharge
Unsaturated Zone
Limestone
Granite
Sandstone
Shale
Recharge
Discharge
Water level
Aquifer
Sands
Gravels
Clay
&
Silts

Alluvial Aquifers

Alluvial aquifers are composed of unconsolidated (loosely arranged) zones of sand, gravel, clay, and silt which were deposited by surface water runoff.



From Fetter, 1988

Bedrock Aquifers

- Rock formations that are highly fractured, or have solution cavities, may be highly productive if the zones are extensive and saturated.
- Rocks with few voids, or have voids which are not connected, act as barriers to groundwater flow.

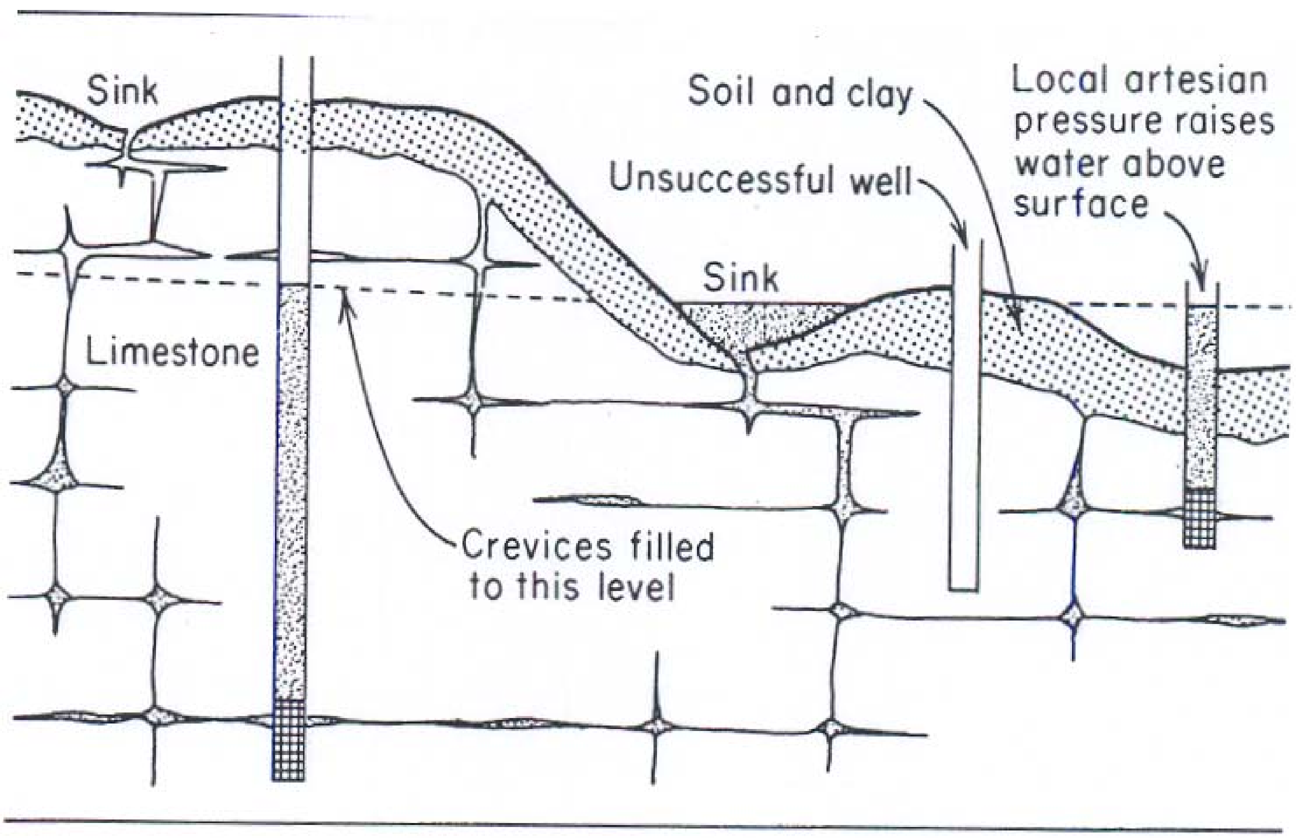
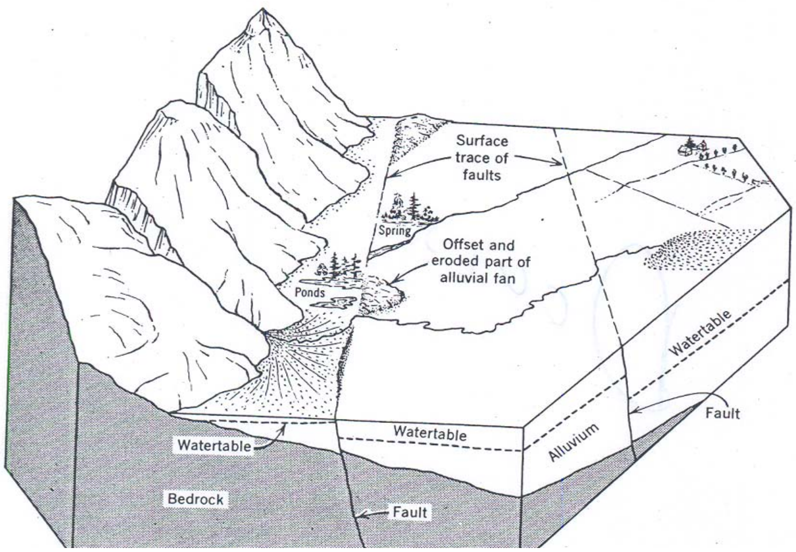


Figure 4.7 Schematic illustration of the occurrence of groundwater in carbonate rock in which secondary permeability occurs along enlarged fractures and bedding plane openings (after Walker, 1956; Davis and De Wiest, 1966).

From US Dept of the Interior, 1981

Influence of Faults

- Geologic faults may act as barriers to flow or as conduits.
- Water level data are useful for determining the influence of faults on groundwater flow.
- Alluvial faults often inhibit groundwater flow.
- Bedrocks faults often inhibit flow across the fault but facilitate flow along the fault.



From Davis and De Wiest, 1966

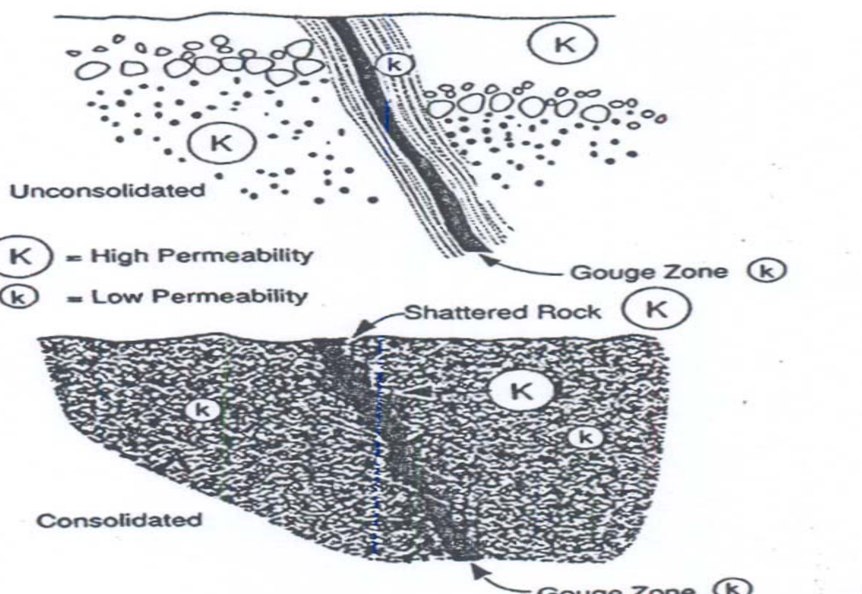
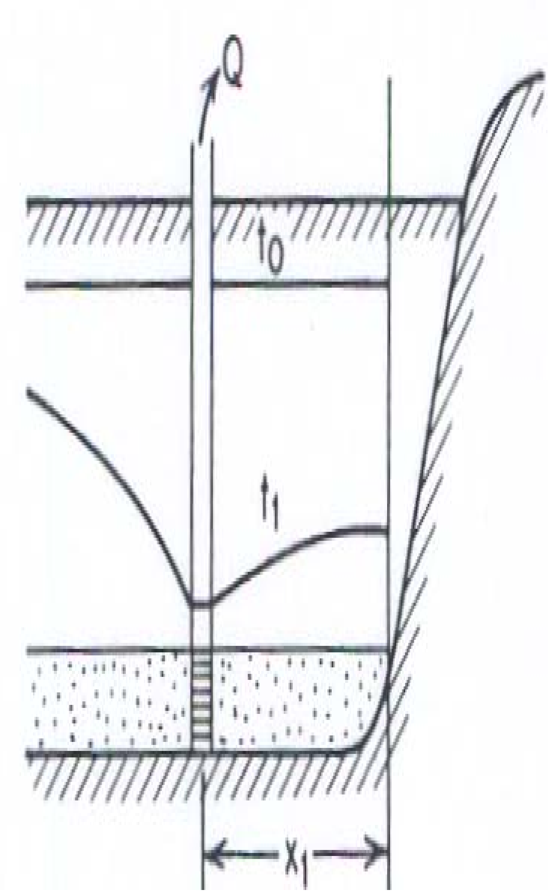


Figure 1.6. Effects of faulting in unconsolidated and consolidated formations.

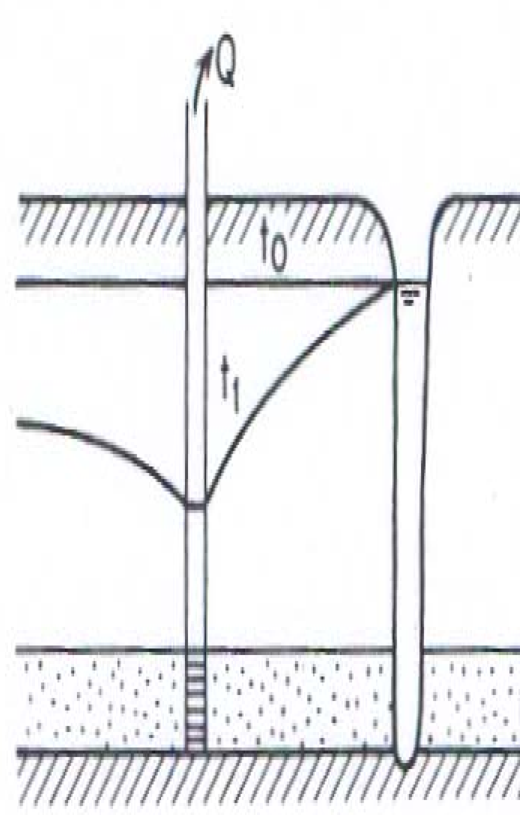
From Roscoe Moss Company, 1990

BOUNDED AQUIFERS

No-flow Boundary



River Boundary



From Freeze and Cherry, 1979

Geology controls groundwater conditions.

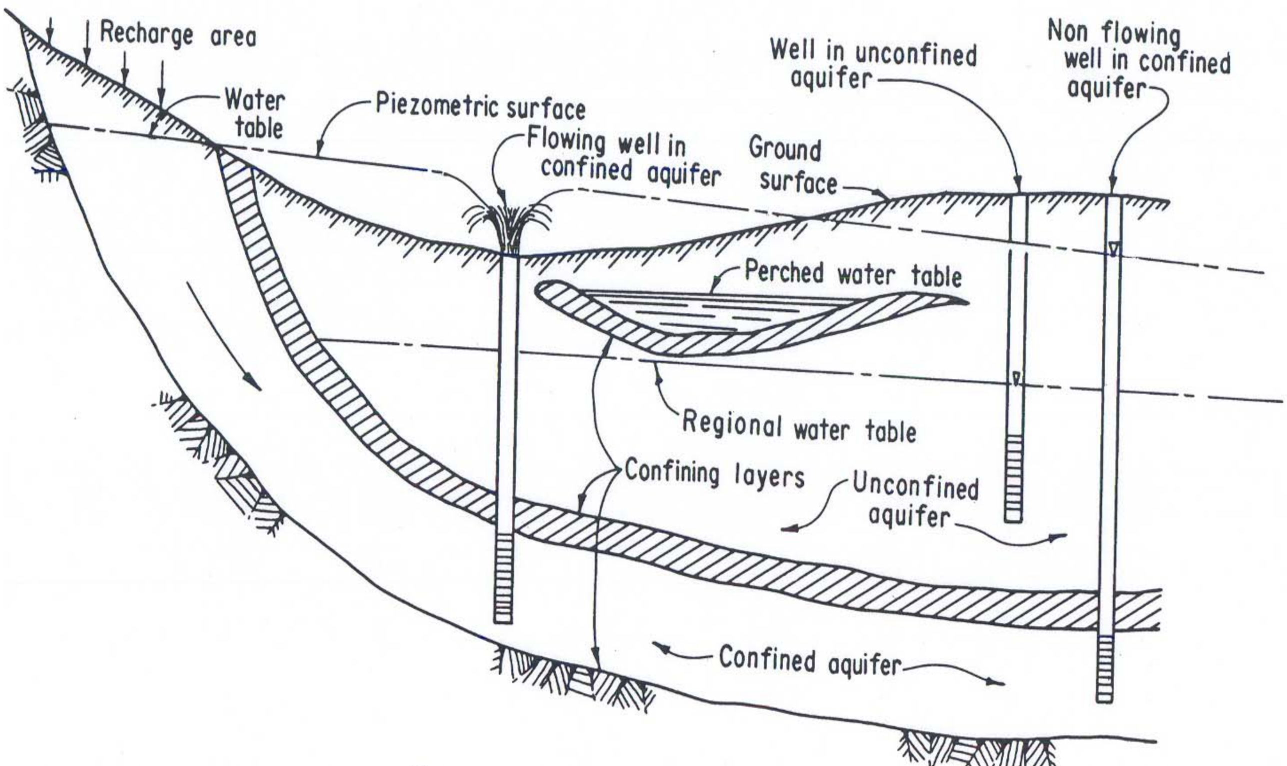


FIGURE 1-2.—Types of aquifers. 103-D-1401.

Definitions

Aquifer – A water-bearing rock that will yield water in a useable quantity

Confined Aquifer - an aquifer with a confining bed, also referred to as an artesian aquifer

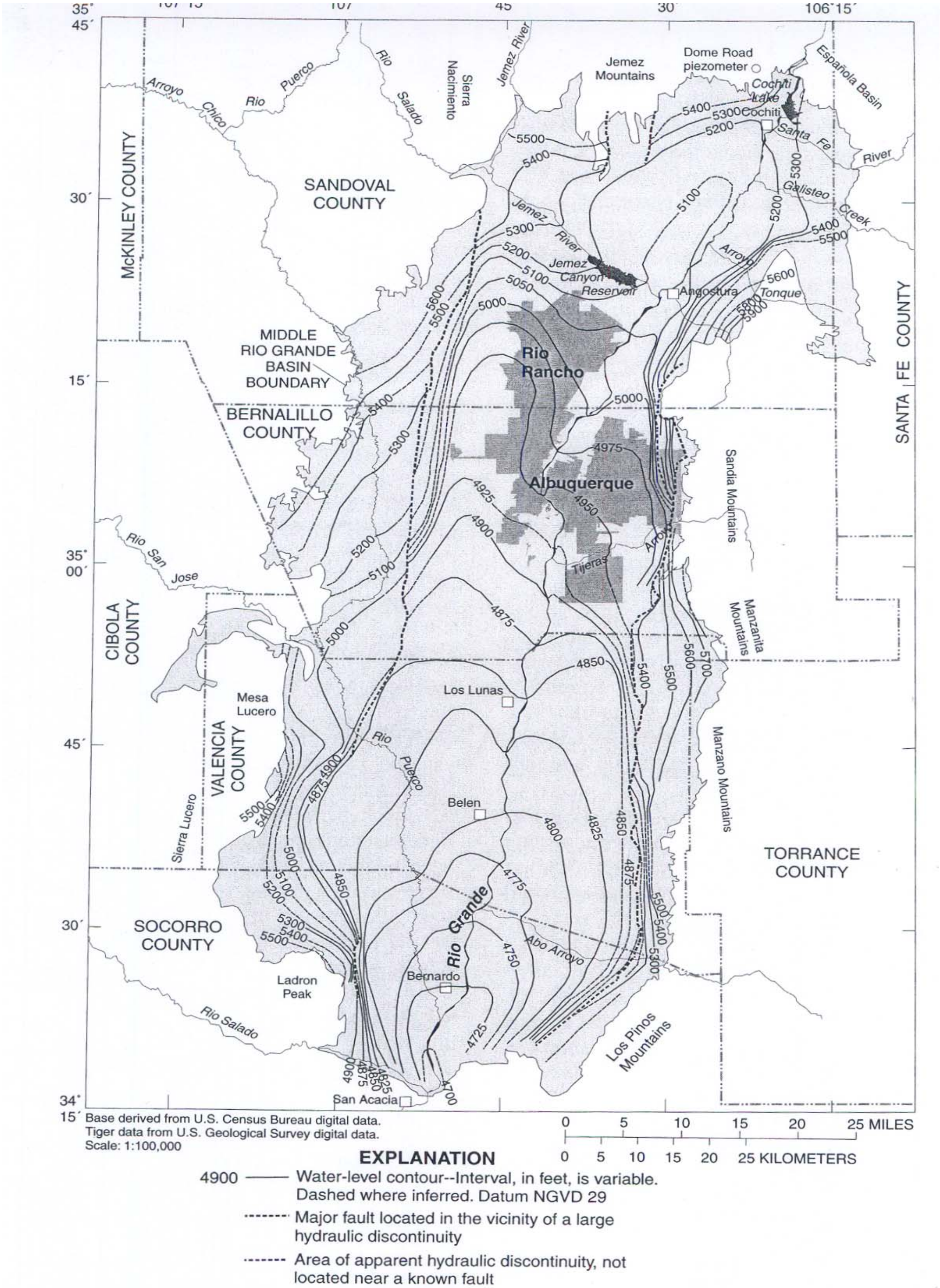
Confining Bed – A layer of rock having very low hydraulic conductivity that hampers the movement of water into and out of an aquifer

Potentiometric Surface – the depth to water in well penetrating a confined aquifer

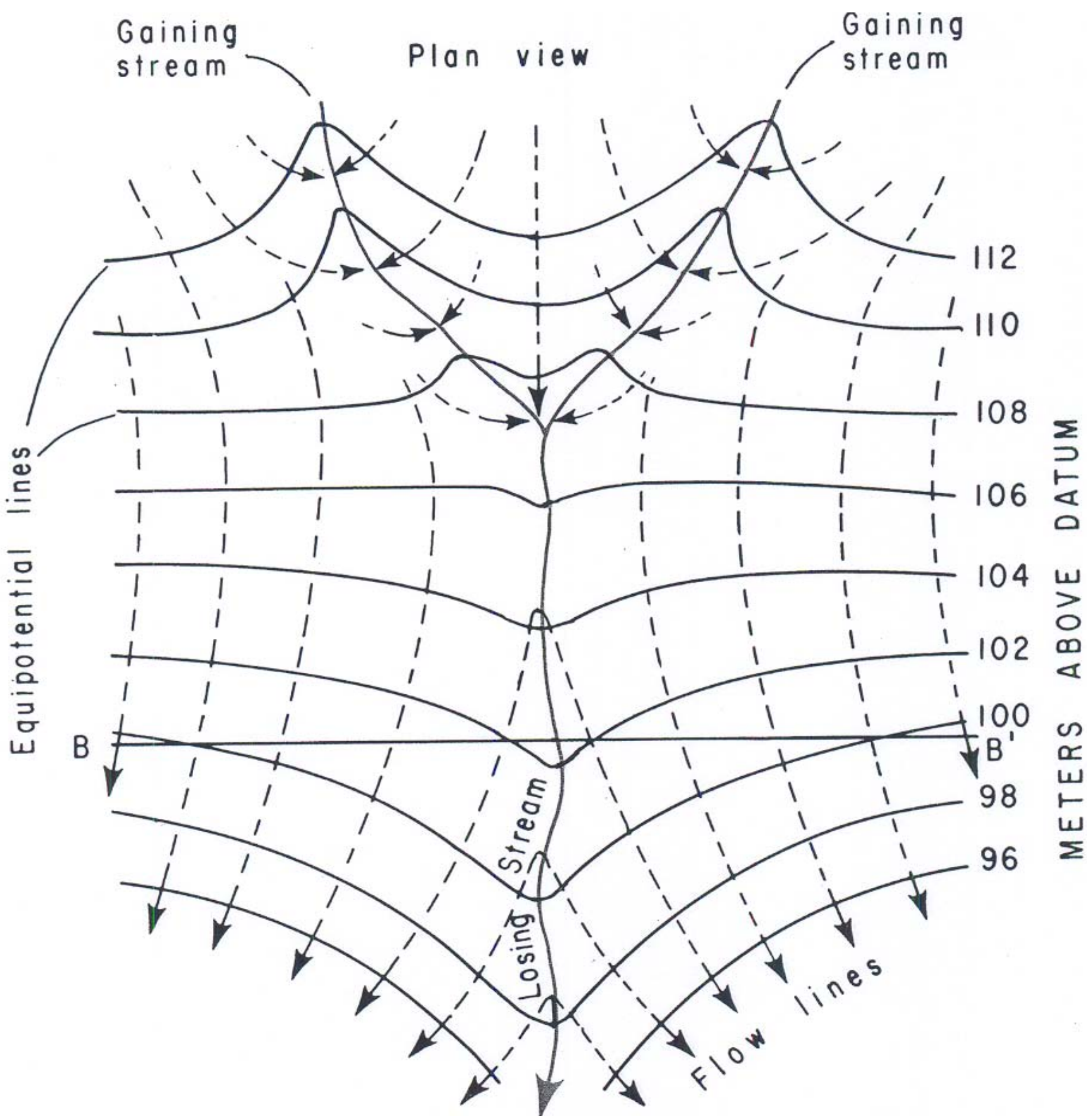
Perched Aquifer – an isolated body of water above the regional water table

Unconfined Aquifer – an aquifer with no upper confining bed, also referred to as a water table aquifer

4. Groundwater Level Maps



From McAda and Barroll, 2002

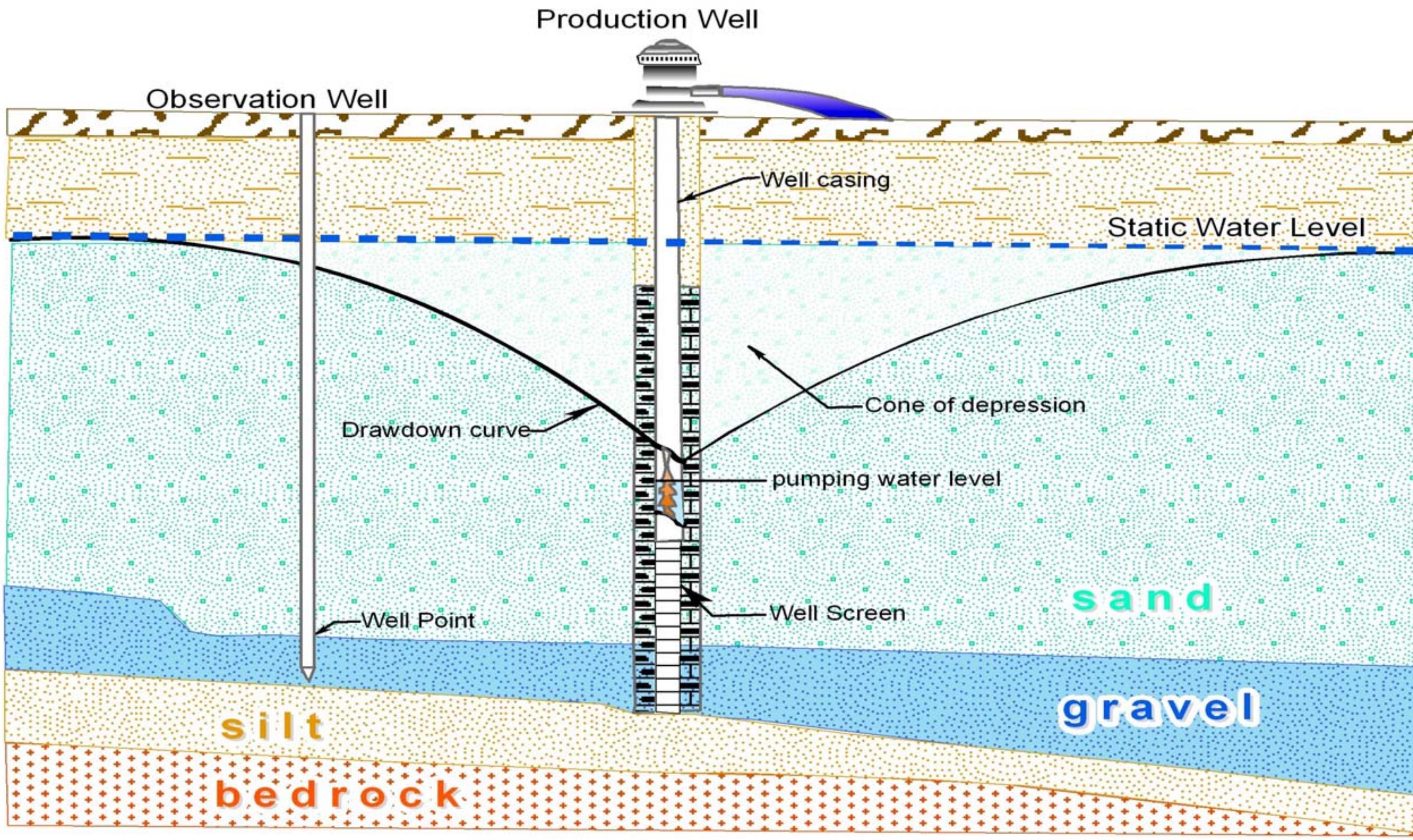


From Heath, 1983

<u>Information obtained from water level map:</u>

- Depth to water (difference between land surface and water table elevation)
- Direction of flow
- Areas of recharge
- Areas of discharge
- Aquifer – stream connections
- Gaining or losing stream
- Areas affected by wells
- Faults
- General water availability
  - Water level contours are close – relatively low water availability
  - Water level contours are wide apart – relatively greater water availability

5. Drawdown



Definitions

Static Water Level – The stable level at which water stands in a non-pumping well. It also represents the level to which water eventually return after pumping has stopped.

Pumping Water Level – Level of water in a well during pumping. Also called the dynamic water level.

Drawdown – Difference between the static and pumping water level.

Residual drawdown – Drawdown after pumping has stopped before full recovery.

Cone of Depression – Depression caused by a pumping well.

DRAWDOWN IN UNCONFINED AND CONFINED AQUIFERS

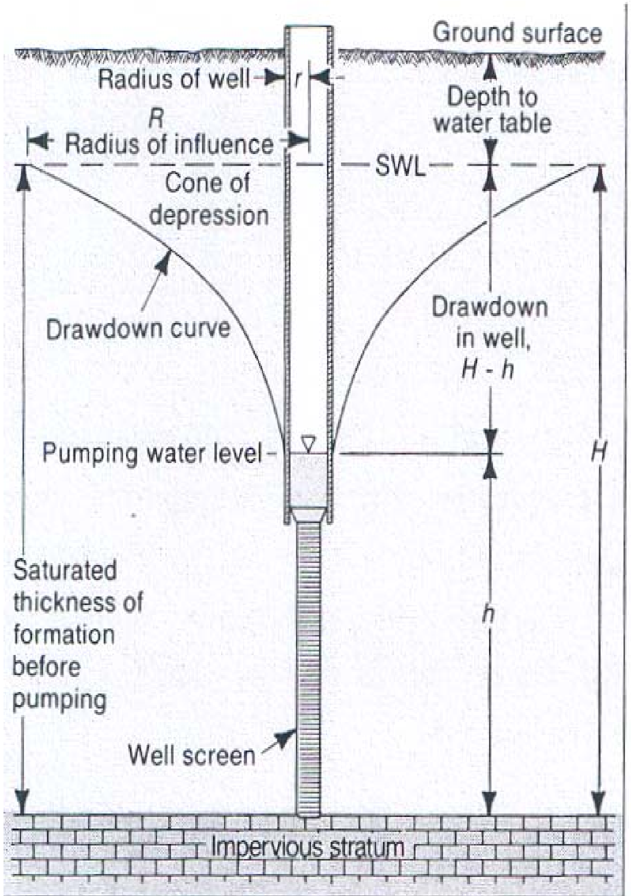


Figure 9.8. Well in an unconfined aquifer showing the meaning of the various terms used in the equilibrium equation.

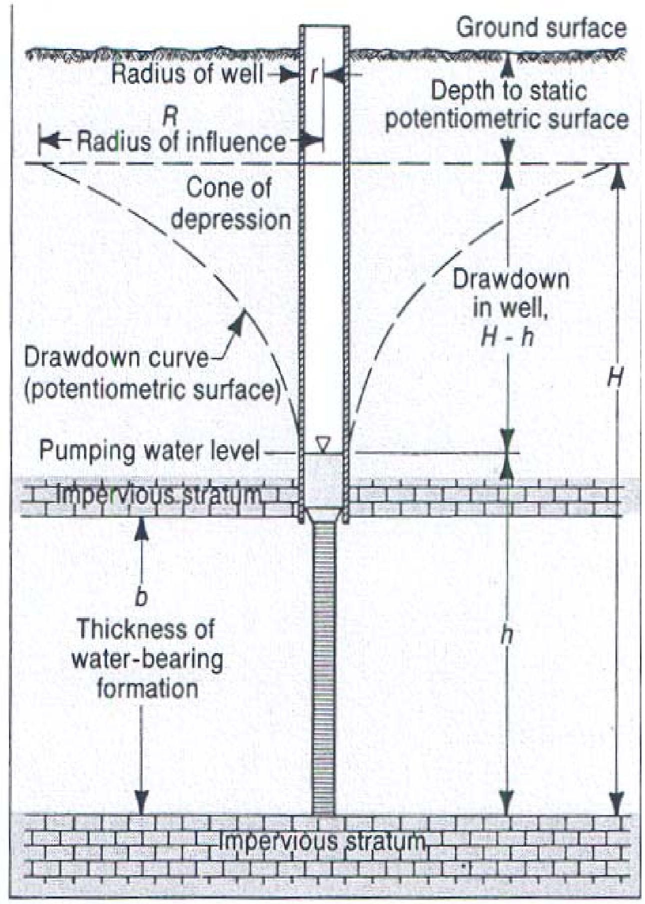


Figure 9.9. Well in a confined aquifer showing the meaning of various terms used in the equilibrium equation.

From Driscoll, 1986

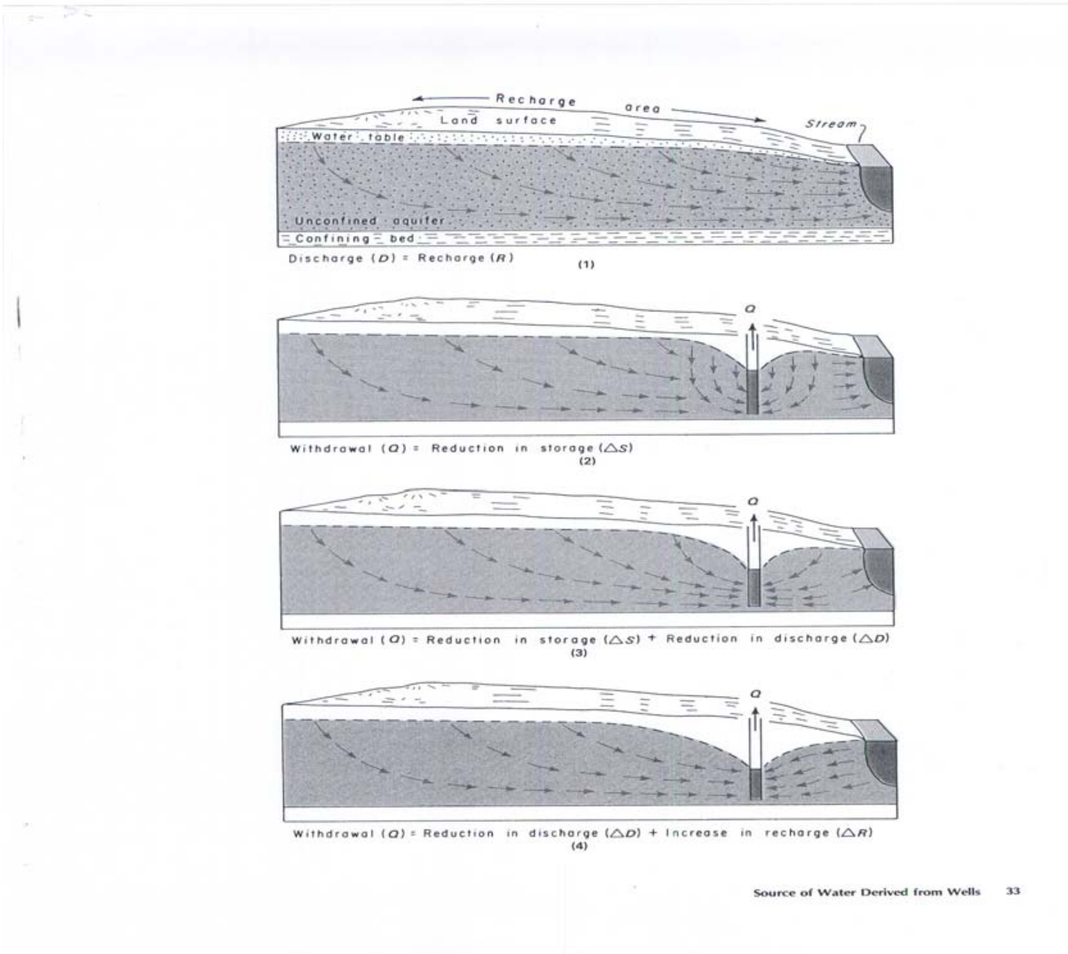
Cone of Depression

- Unconfined aquifer – represents dewatering aquifer storage
- Confined aquifer – represents reduction of head (pressure)

Drawdown Curve

- Unconfined Aquifer - represents depth to water
- Confined Aquifer – represents the potentiometric surface or total head

DEVELOPMENT OF CONE OF DEPRESSION



From Heath, 1983

<u>Development of Cone</u>

- Pump is turned on.
- Water is removed from well casing and forced upward.
- Water level in casing falls below static level and water begins to flow from the aquifer to the well.
- Water level decline begins next to well. Water is removed from storage and the cone of depression begins to form.
- More water is removed from storage and cone of depression expands outward and downward.
- Cone continues to expand until it hits an area where water is recharging the aquifer.
- Recharge will start supplying the well with water and less water is removed from aquifer storage.
- The rate at which the cone of depression expands is reduced

WELL INTERFERENCE

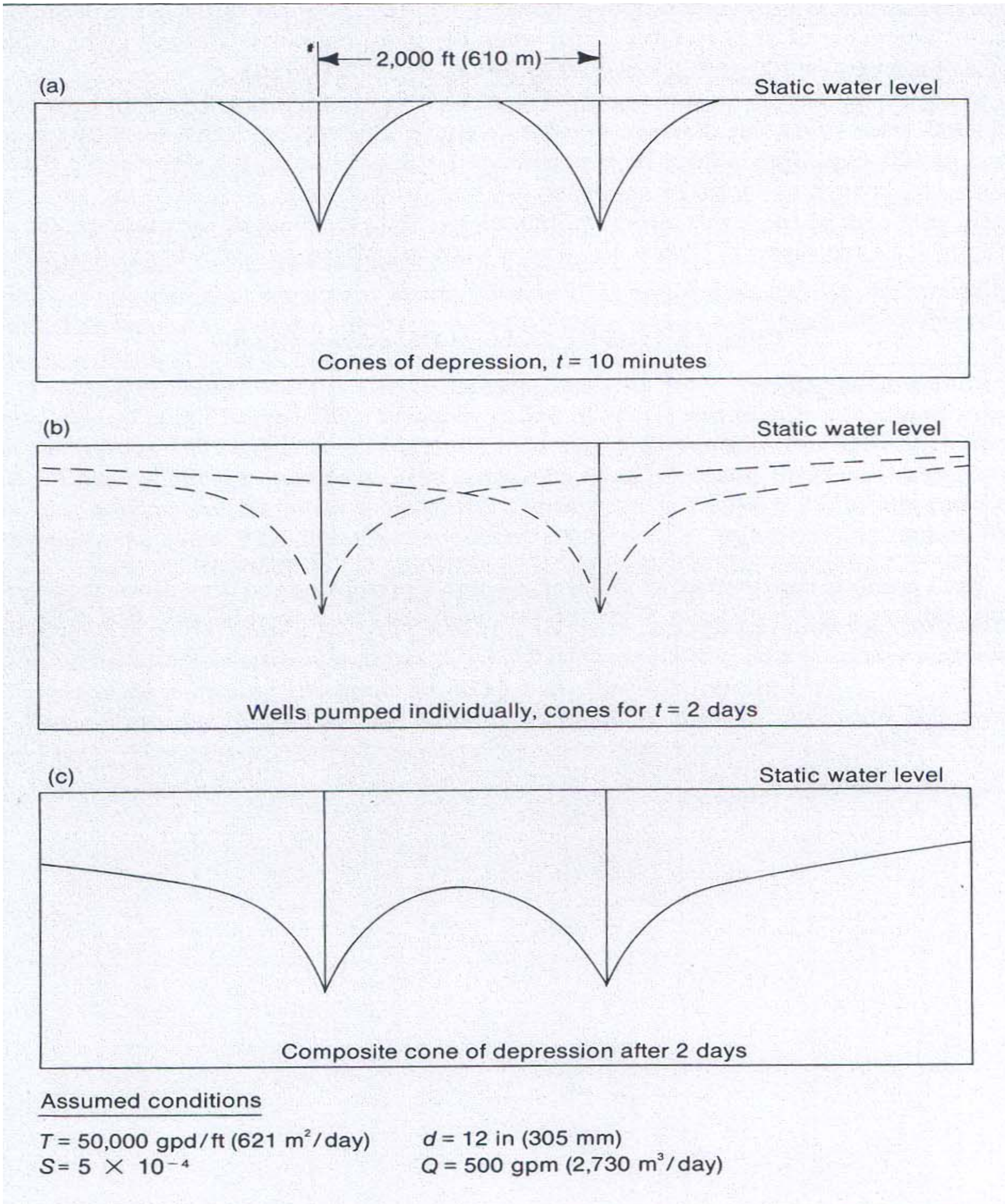
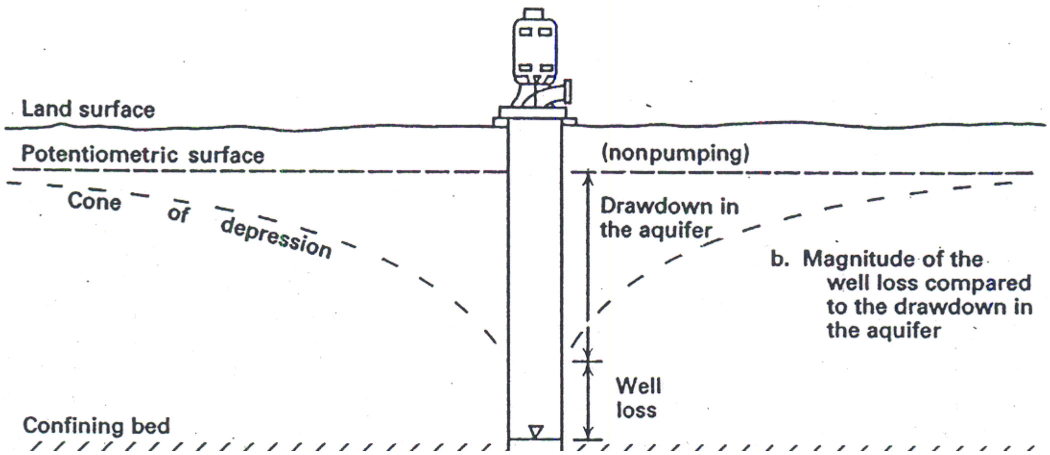


Figure 9.29. Interference between adjacent wells tapping the same confined aquifer. Composite cone is for both wells pumping simultaneously under the assumed conditions.

From Heath, 1983

WELL EFFICIENCY
DRAWDOWN INSIDE A WELL



From Heath

<u>Well Efficiency</u>

- Used to estimate the drawdown inside of a pumping well.
- Almost always a head difference between the aquifer adjacent to the borehole and inside of the well due to head losses.
- Theis or numerical model provides drawdown in the aquifer, not inside of the well casing.
- Drawdown inside of the casing is required to assess the degree of impact a drawdown may have on well production.
- A well efficiency of 70 % is often assumed in OSE evaluations.

Well Efficiency (E) = $s_a / s_t \times 100$ as a percentage

where:

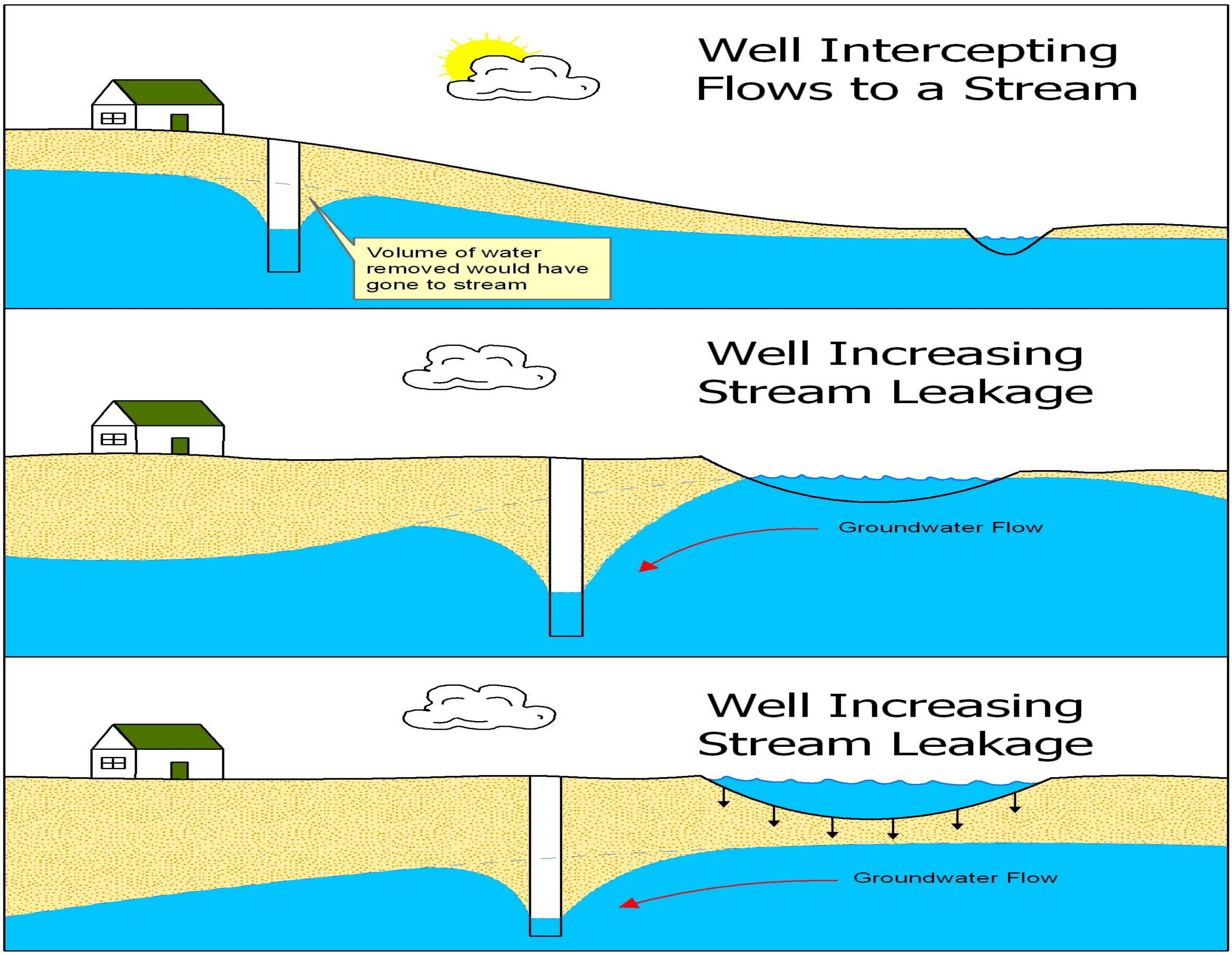
s_a = drawdown in aquifer

s_t = drawdown inside of well

Example
Use of the Theis equation predicts a drawdown of 50 feet 1 foot from a pumping well. What is the drawdown inside of the well assuming 70 % efficiency?

$E / 100 = s_a / s_t \qquad s_t = s_a / (E / 100) = 50 \text{ ft}/0.70 = 71.4 \text{ ft}$

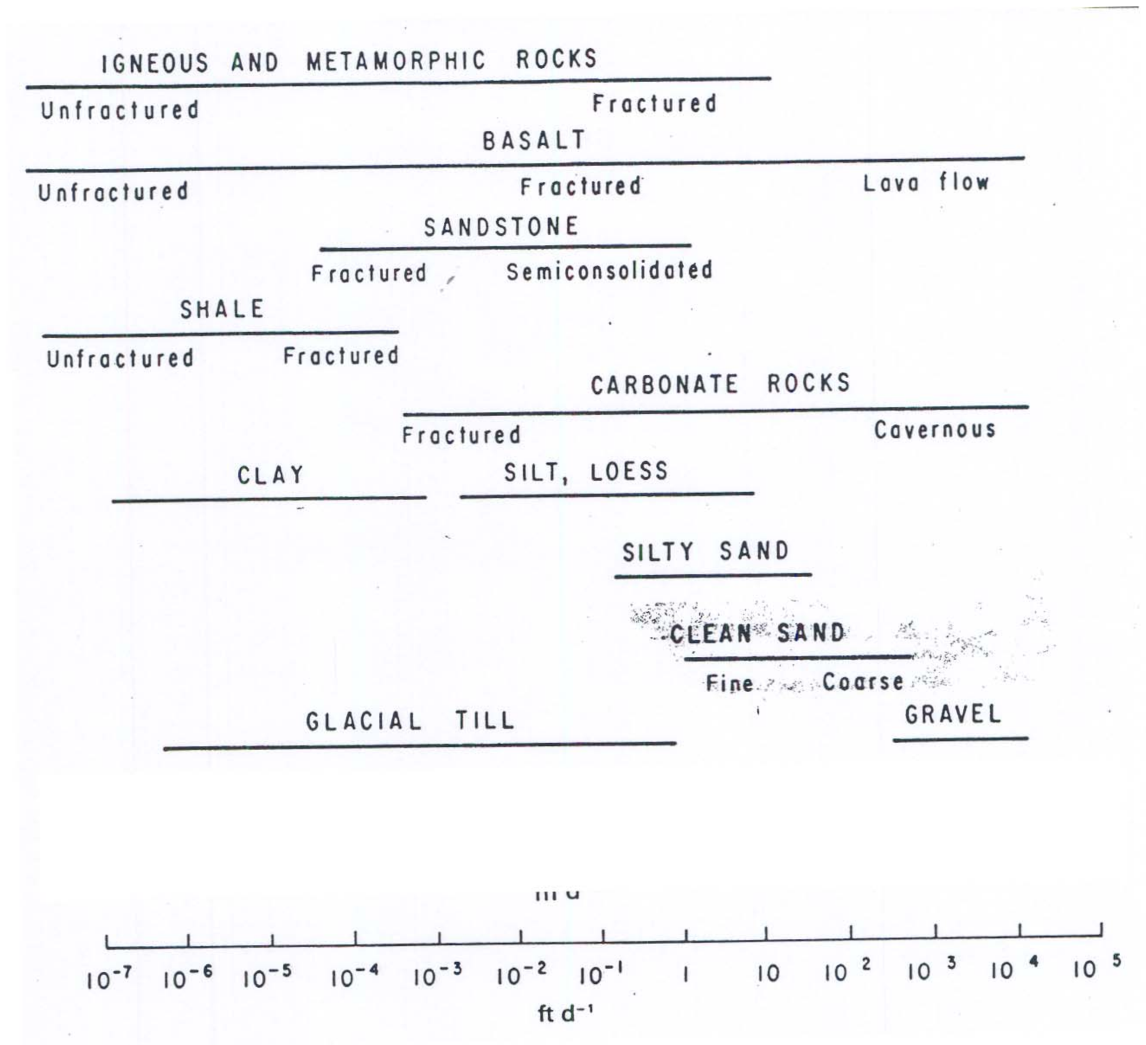
6. Stream Depletion



7. Hydraulic Conductivity & Transmissivity
Aquifer Parameters – Transmission of Water

HYDRAULIC CONDUCTIVITY

<u>Hydraulic Conductivity (K)</u> – The capacity of a rock to transmit water through a unit area. Units – ft/day



From Heath, 1983

Table 4--Hydrologic characteristics of rock materials found in Grant County[1/]

	Rock type composing the aquifer	Total porosity (percent of volume)	Specific yield[2/] (percent of volume)	Hydraulic conductivity (K)[3/] (feet per day)	Water yielding characteristic[4/]
CONSOLIDATED ROCKS	Granite, gneiss, schist, greenstone, quartzite[5/]	0.02- 0.6	0.0- 0.05	0.00013	Very small
	Basalt, andesite, rhyolite, minimal vesicularity & jointing[5/]	.1 - .5	.0- 1	.01 - .5	Very small to small
	Basalt, vesicular, brecciated, jointed	5 -10	4 - 9	5 - 500	Moderate to large
	Tuff, compacted or welded[5/]	5 -10	1 - 2	.01 - .7	Very small
	Tuff, sandy tuff, agglomerate[5/]	15 -25	5 -10	.7 - 10	Small to moderate
	Limestone, dolomite, marble[5/]	.2 - 5	.1- 4	.07 - 3	Very small to moderate
	Shale and sandy shale, siltstone	20 -40	.5-10	.0013- .13	Very small
	Sandstone, fine to medium, weakly to firmly cemented	15 -30	5 -15	.13 - 1.3	Small
	Conglomerate or sandstone, well cemented (lower Gila)	5 -10	.1- 2	.0013- .7	Very small
	Conglomerate, poorly cemented (upper Gila)	15 -30	10 -25	1 - 10	Small to large
UNCONSOLIDATED ROCKS — Bolson, channel, flood plain, and lake deposits	Clay and silty clay, dense, massive to bedded; no coarser material	50 -60	0 - 2	0 $-10x1^{-6}$	Very small
	Clay and silt, 65-70%; very fine to fine sand, 25-30%; medium to very coarse sand, 5%	50 -60	2 - 5	0 $-10x1^{-5}$	Very small
	Silt and clay, 90-95%; very fine to medium sand, 5-10%	50 -60	10 -20	.03 - .3	Small
	Silt and medium to very fine sand, 70-90%; clay, 10-30%	45 -55	25 -35	1 - 3	Small
	Sand, assorted, 75-80%; fine gravel, 5-20%; silt, less than 5%	35 -40	20 -30	3 - 5	Small
	Sand, very fine to medium, 45-50%; sand, coarse to very coarse, 40-50%; silt, less than 5%	35 -45	25 -40	5 - 15	Small to moderate
	Sand, fine to very fine, 60-70%; silt, 20-25%; clay, less than 10%	50 -55	40 -45	10 - 20	Small to moderate
	Sand, assorted, 65-75%; gravel, 15-30%; silt and clay, 1-5%	25 -40	20 -35	20 - 100	Moderate to large
	Sand, medium to very coarse, 60-80%; gravel, 10-30%; silt and fine to very fine sand, 1-5%; no clay	35 -60	32 -53	100 - 300	Large
	Gravel, 25-45%; medium to very coarse sand, 45-70%; silt and fine to very fine sand, 1-5%; no clay	25 -45	23 -42	300 - 500	Large
	Gravel, 25-75%; medium to very coarse sand, 25-65%; silt and fine to very fine sand, 5-10%; no clay	25 -35	22 -32	500 - 1,000	Large to very large
	Gravel, 70-90%; medium to very coarse sand, 20-30%; silt and fine to very fine sand, less than 10%; no clay	25 -40	24 -38	1,000 -10,000	Very large

1/ Values are based on pumping tests and observations of rock characteristics in Grant County, and on data for rock types and aquifers of similar character in other areas as reported by the following: Conover and Akin, 1942 (p. 258); Johnson, (1966); Meinzer, 1923a (p.10-11); Stearns, 1927 (p. 164-168); Wenzel, 1942 (p. 13); Wilson, 1965 (p. 1-361).

2/ Specific yield and storage coefficient (see section on "hydrologic terms") are nearly equivalent for water-table conditions. Under artesian conditions the storage coefficient commonly ranges between .001 and .00001 (10^{-3} to 10^{-5}), for most rocks, and is about 10^{-6} per foot of thickness of the aquifer. Thus the storage coefficient of a confined aquifer 200 feet thick would be approximately 2×10^{-4}.

3/ The term "hydraulic conductivity", represented by the letter "K", and expressed as feet per day, replaces the term "field coefficient of permeability" (P_f) expressed commonly as gpd per sq. ft. P_f is equal to K x 7.48 gal/cubic ft. The hydraulic conductivity x the thickness in feet of the aquifer gives the "transmissivity" of the entire aquifer thus an aquifer 200 feet thick having an average hydraulic conductivity of 130 would have a transmissivity of 26,000 ft^2 per day. The term "transmissivity", (T) expressed as "ft^2/day" (feet squared per day) replaces the term "coefficient of transmissibility", commonly expressed as gpd per foot (gallons per day per foot); gpd per foot is equal to ft^2/day x 7.48 gal/cubic ft. It is a function of the total thickness of the aquifer, and therefore partial penetration of the aquifer gives an apparent transmissivity that may differ appreciably from the true transmissivity, especially if penetration is less than one-half the saturated thickness of the aquifer.

4/ Very small, less than 2 gpm; small, 2-20 gpm; moderate, 20-100 gpm; large, 100-1,000 gpm; very large, more than 1,000 gpm. In general, the smaller the yield, the greater the drawdown in feet per gallon per minute of water pumped. Water levels in wells tapping the granites, clays, and well-cemented conglomerates and sandstones may draw down as much as 50-100 feet at pumping rates of 1-2 gpm.

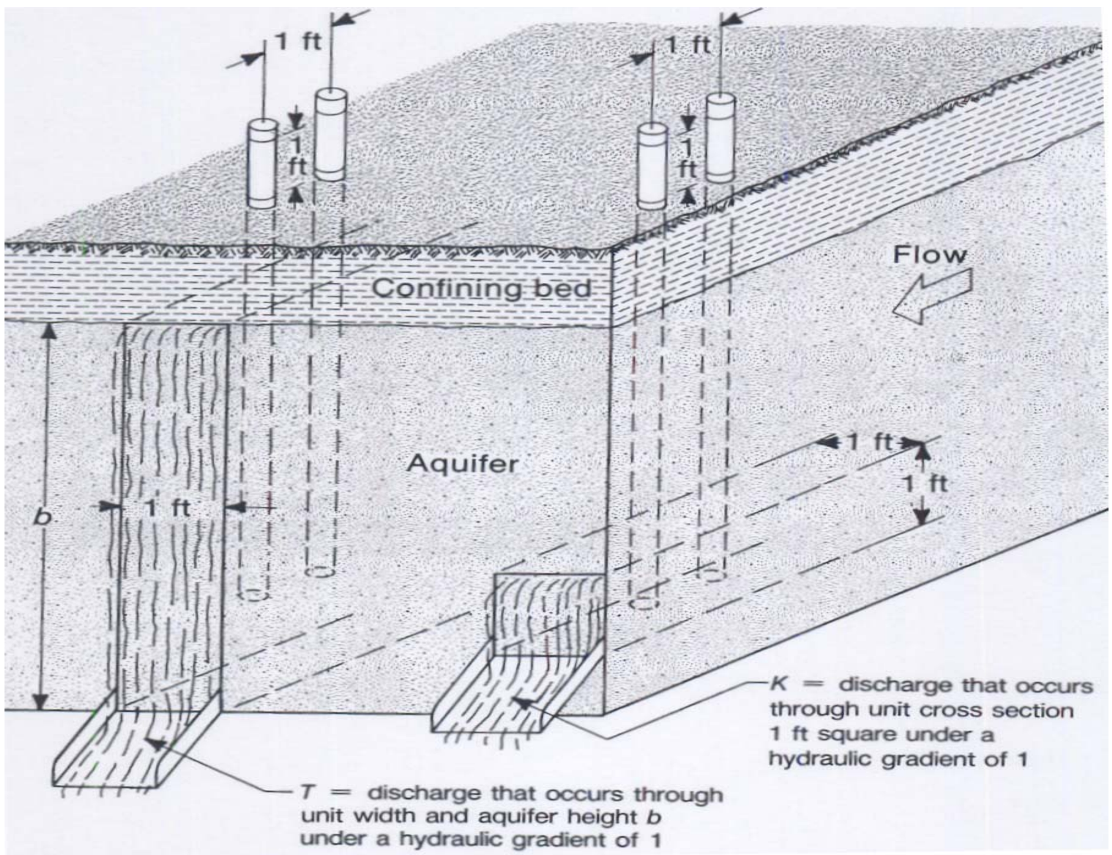
5/ Values for deeply weathered rock and rocks well-jointed, or fractured by faulting, may be an order of magnitude greater.

From Trauger

TRANSMISSIVITY

Transmissivity (T) – The rate at which water is transmitted through a unit width of the aquifer. The capacity of an aquifer to transmit water. Units – square feet per day, or gallons per day per foot.

T (gallons per day per foot) = (7.481 gallons per cubic ft) x T square feet per day

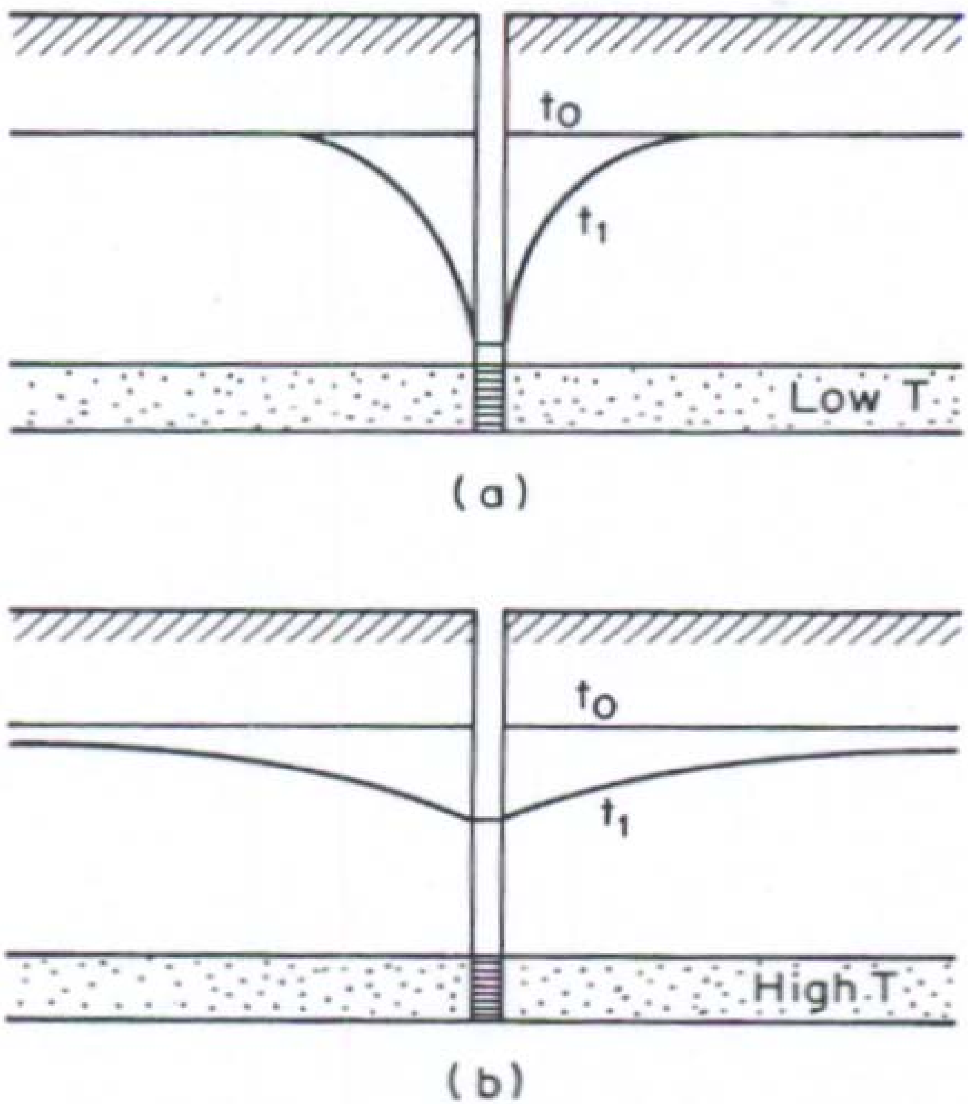


From Heath, 1983

T = Kb Where b = aquifer thickness

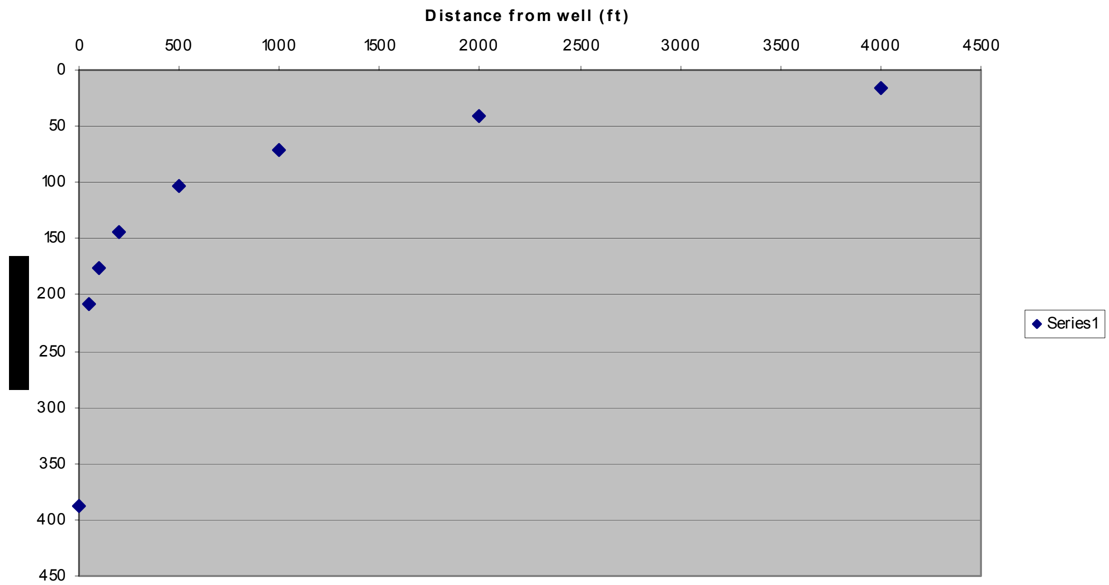
INFLUENCE OF TRANSMISSIVITY

The higher the T, the further away well affects will be observed for a given time and flow rate.



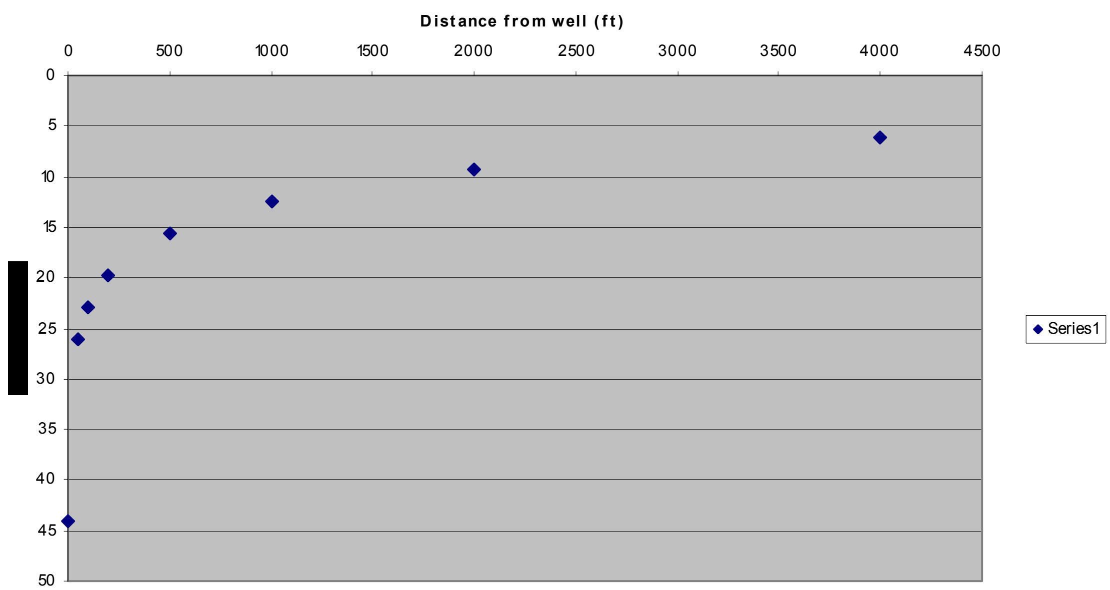
From Freeze and Cherry, 1979

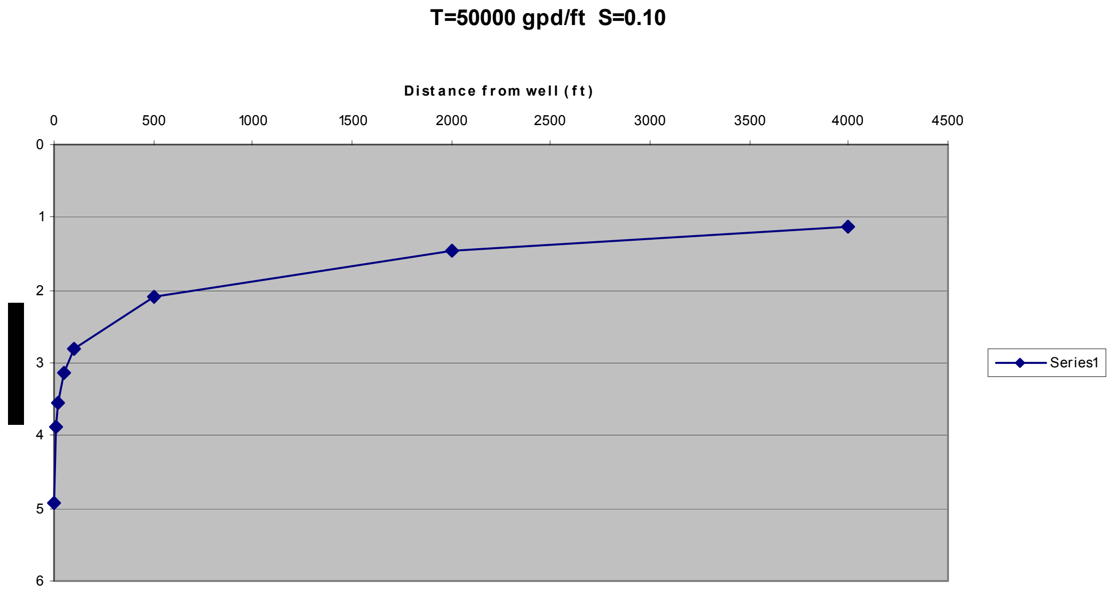
T=500 gpd/ft S=0.1



Q = 100 gpm   Time = 40 yrs   Note difference in vertical scales.

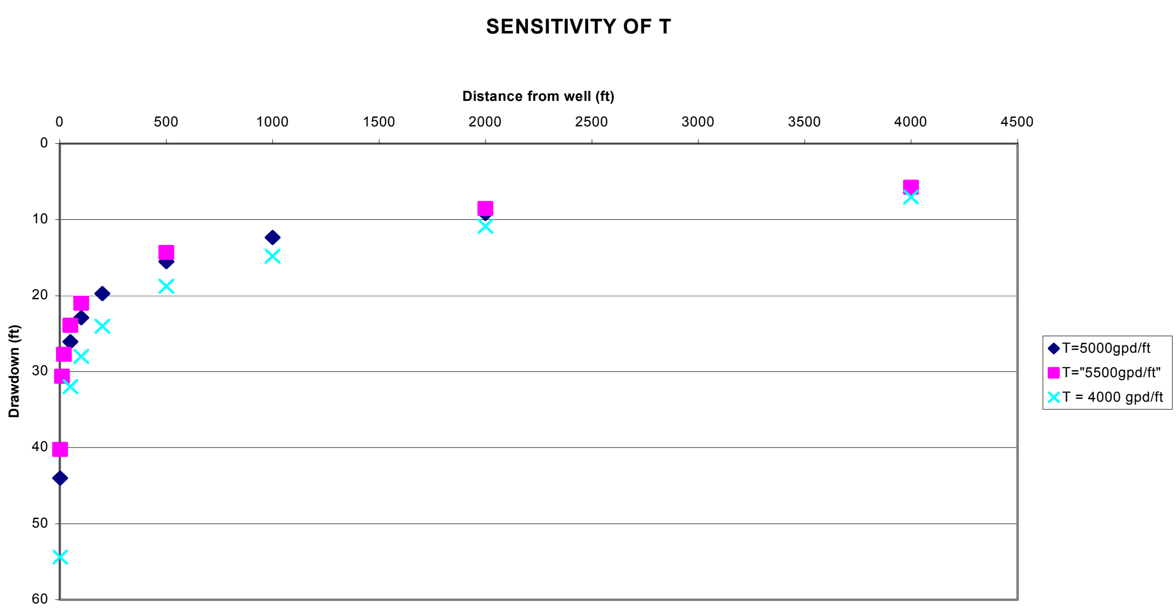
T=5000 gpd/ft S=0.10





Example
A well is proposed in an area where the T may range from 4000 gpd/ft to 5500 gpd/ft. If the nearest well were 1000 feet from the proposed well, which T would be more conservative with respect to drawdown?

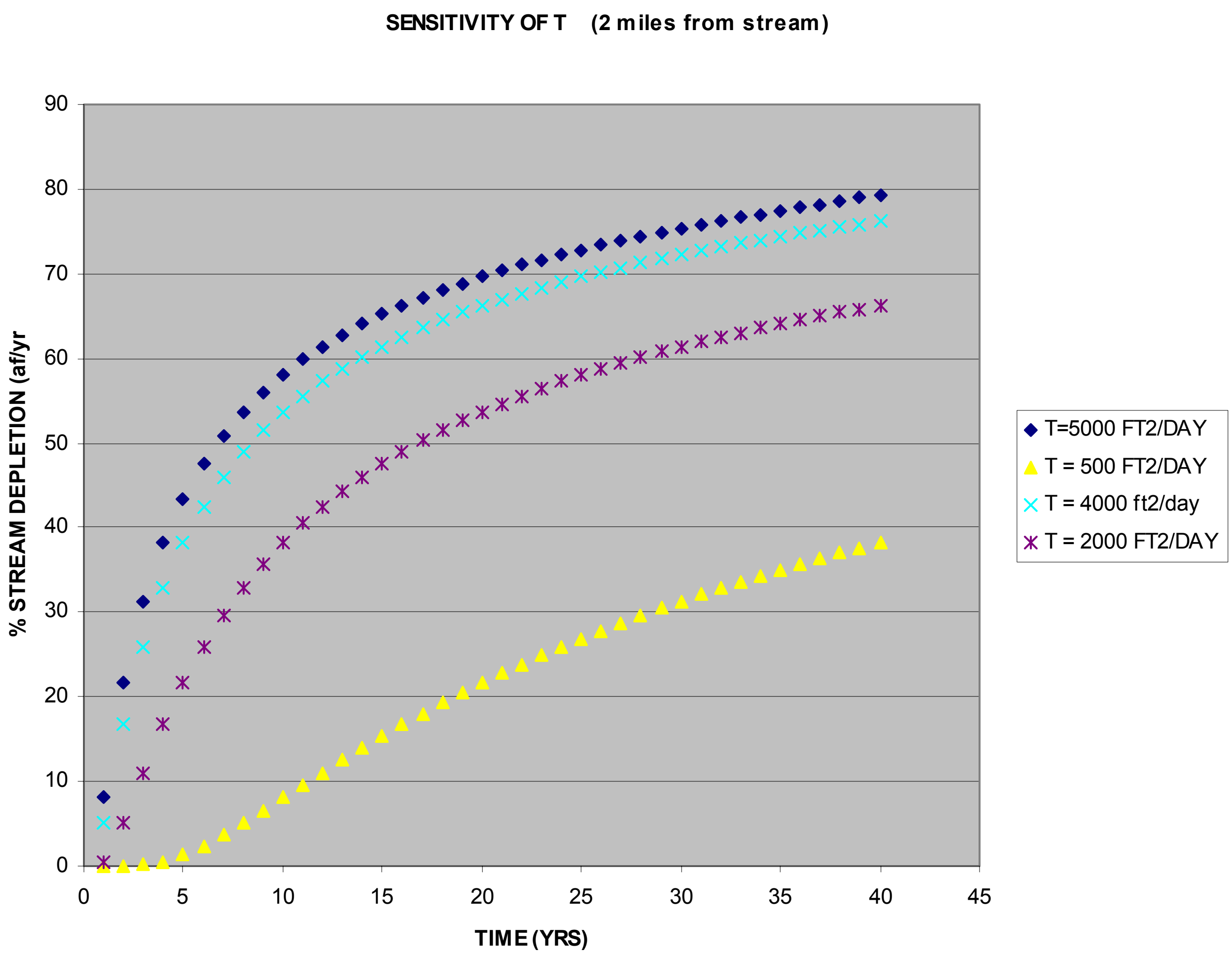
The T of 4000 gpd/ft would result in the greatest drawdown (most conservative). But the difference in drawdowns between the different T's is small and becomes smaller with distance from well.



Example

A well is proposed in an area where the T may range from 500 ft^2/day to 5000 ft^2/day. If a stream were 2 miles away, which T would be more conservative with respect to stream depletion? Q = 100 gpm

The T of 5000 ft^2/day would result in the greatest stream depletion (most conservative).



METHODS TO OBTAIN TRANSMISSIVITY

T is obtained in any of the following ways:

- Obtain K based on the geologic nature of the aquifer to compute T (T=Kb).
- Perform an aquifer test on the well or use results of a test from region.
- Specific capacity.
- Model calibration
- Obtaining values from available literature.

U.S. Geological Survey reports
NM Bureau of Geology and Mineral Resources reports
OSE Technical Reports, files & memos
Consultant reports
Models

EXAMPLE
A municipal well is proposed in an aquifer composed primarily of sands, gravels, and clays. The proposed well will likely penetrate 500 feet of the aquifer. An aquifer test is available for a nearby shallow well. T = 1,000 ft^2/day. Based on the well log for the shallow well, the well penetrates 50 feet of the aquifer and is fully screened. What T should be selected?

First step – compute K for the shallow well. T=Kb so K = T/b

K = 1,000 square feet per day/50 ft = 20 ft/day

Second step – compute T for the municipal well

T = Kb = 20 ft/d x 500 ft = 10,000 square feet/day

PARTIALLY PENETRATING WELLS

For partially penetrating wells, b represents the thickness of the aquifer providing water to the well. For unconfined aquifers with a test less than 1 day – typically use screen interval as b. Must evaluate well log, well construction, and length of test to select b.

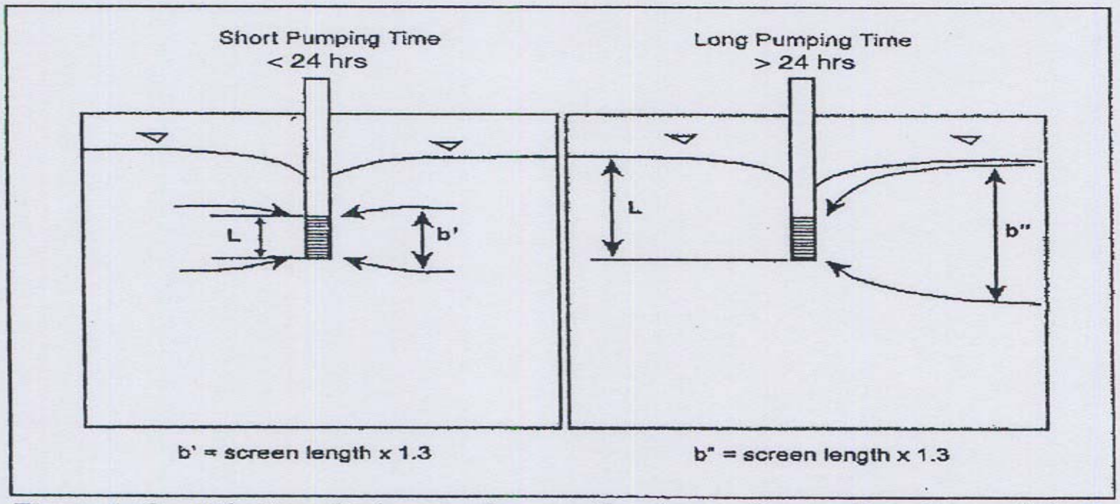


Figure 1. Contributing thickness of an aquifer depending on time for a relatively homogeneous hydrogeologic setting. (Weight and Sonderegger, 2001).

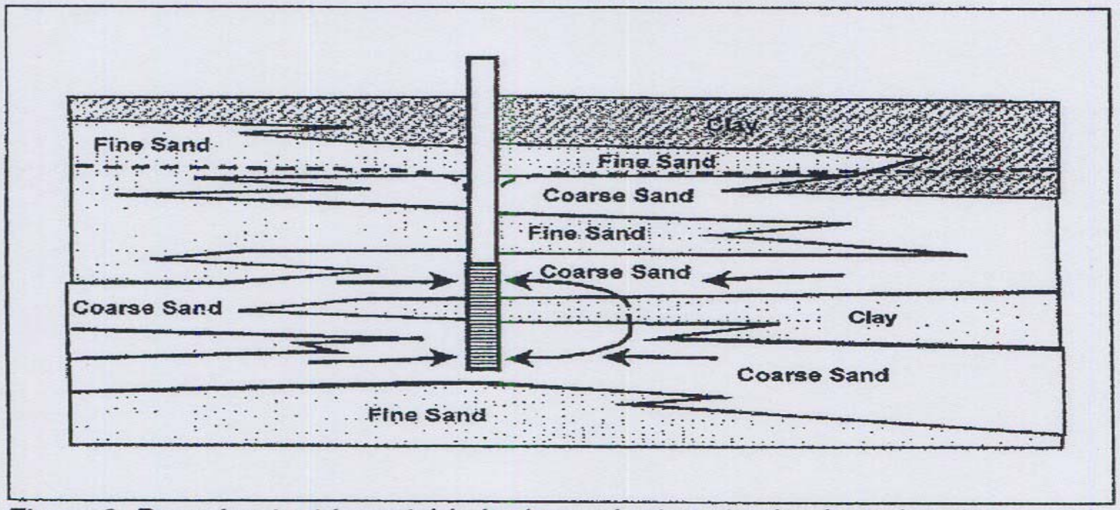


Figure 2. Pumping test in variable hydrogeologic units. In short duration tests, the actual contributing thickness may be less than the screen lenght. (Weight and Sonderegger, 2001).

8. Specific Yield and Storage Coefficient
Aquifer Parameters – Amount of Water Available for Release

SPECIFIC YIELD

Specific yield – This is the storage term for unconfined aquifers. It is measured (in terms of a ratio) of the amount of water that can be drained from a cubic foot of an unconfined aquifer when the water table falls one foot.

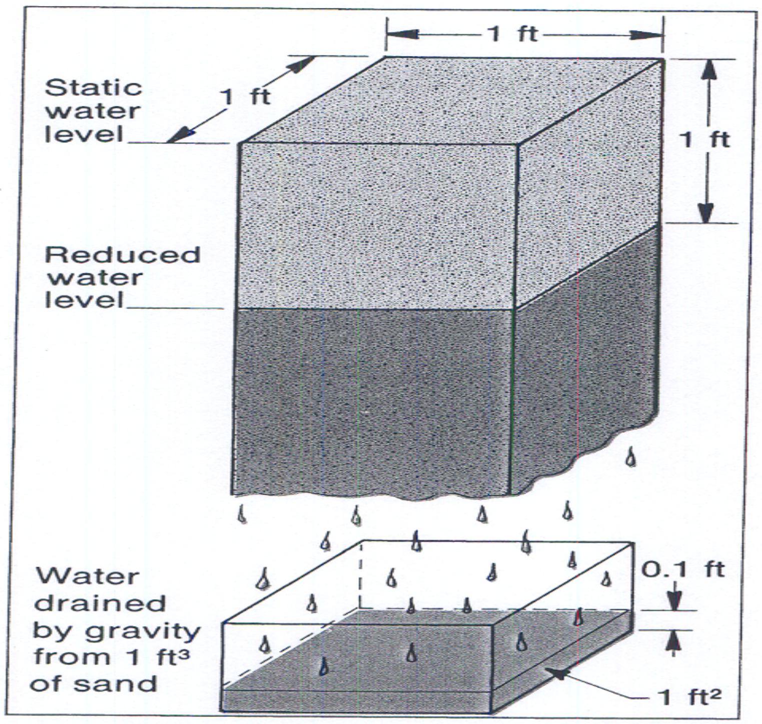


Figure 5.5. Specific yield of sand can be visualized from this diagram. Its value here is 0.1 ft^3 per ft^3 of aquifer material.

VALUES IN PERCENT

Material	Porosity	Specific yield	Specific retention
Soil ----------------------	55	40	15
Clay ----------------------	50	2	48
Sand ----------------------	25	22	3
Gravel --------------------	20	19	1
Limestone -----------------	20	18	2
Sandstone (semiconsolidated)	11	6	5
Granite -------------------	.1	.09	.01
Basalt (young) ------------	11	8	3

From Heath, 1983

STORAGE COEFICIENT

Storage Coefficient or Storativity – This is the storage term for confined aquifers. It is the volume of water released from storage per unit surface area per unit change in head.

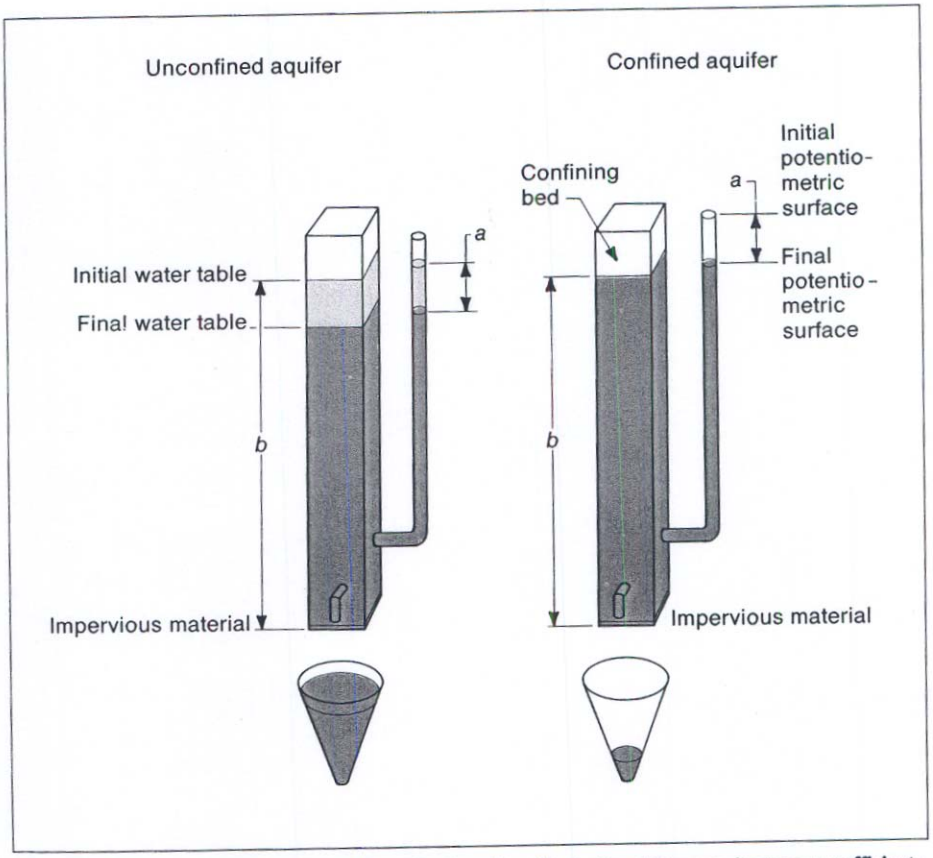


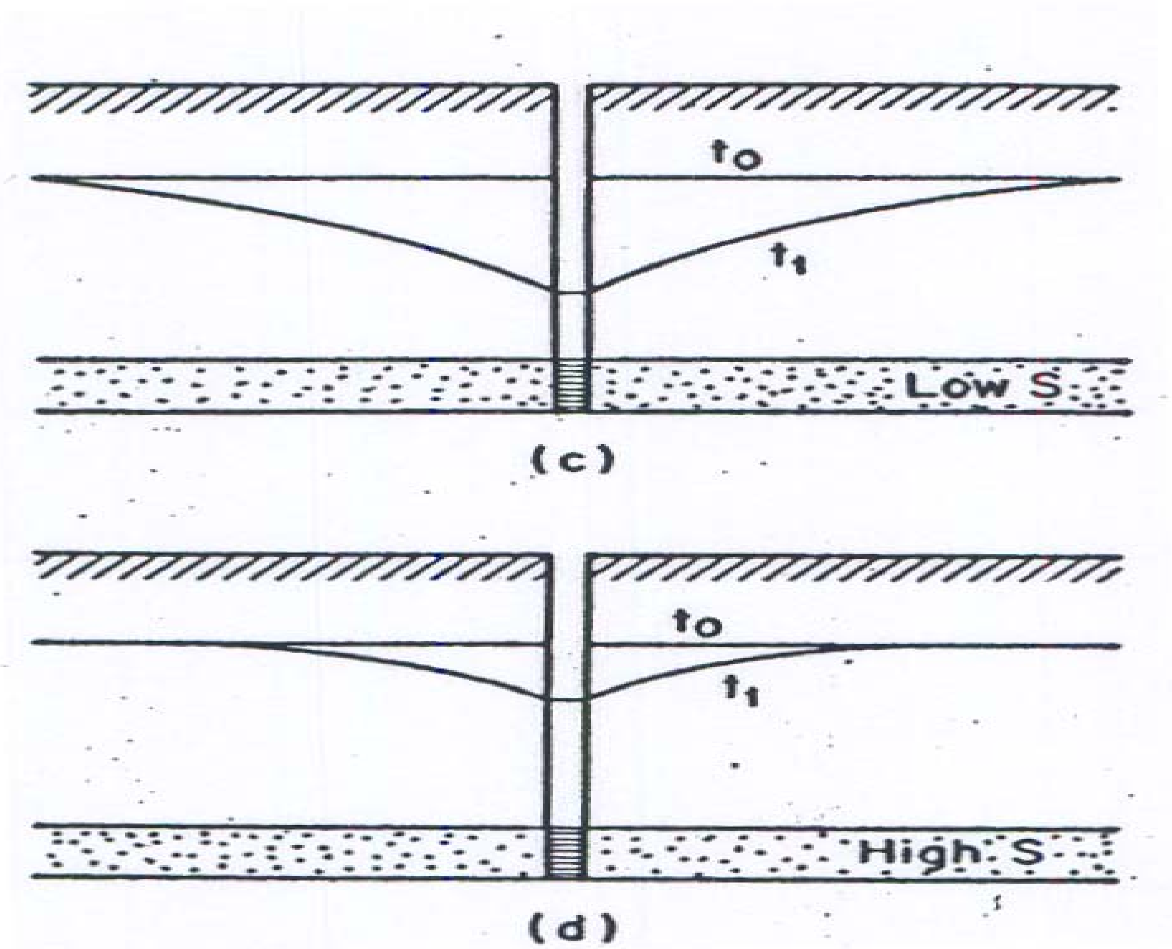
Figure 5.6. Unit prisms of unconfined and confined aquifers illustrating differences in storage coefficients. For equal declines in head, the yield from an unconfined aquifer is much greater than that from a confined aquifer. *(After Heath and Trainer, 1968)*

The specific yield and storage coefficient are both referred to as S. S is used in well impact calculations and has no units.

Specific yield may range from 0.01 – 0.30 for unconfined aquifers. Values typically range between 0.08 – 0.20.

Storage coefficients are less than 0.01 for confined aquifers and typically range from 0.00001 to 0.001.

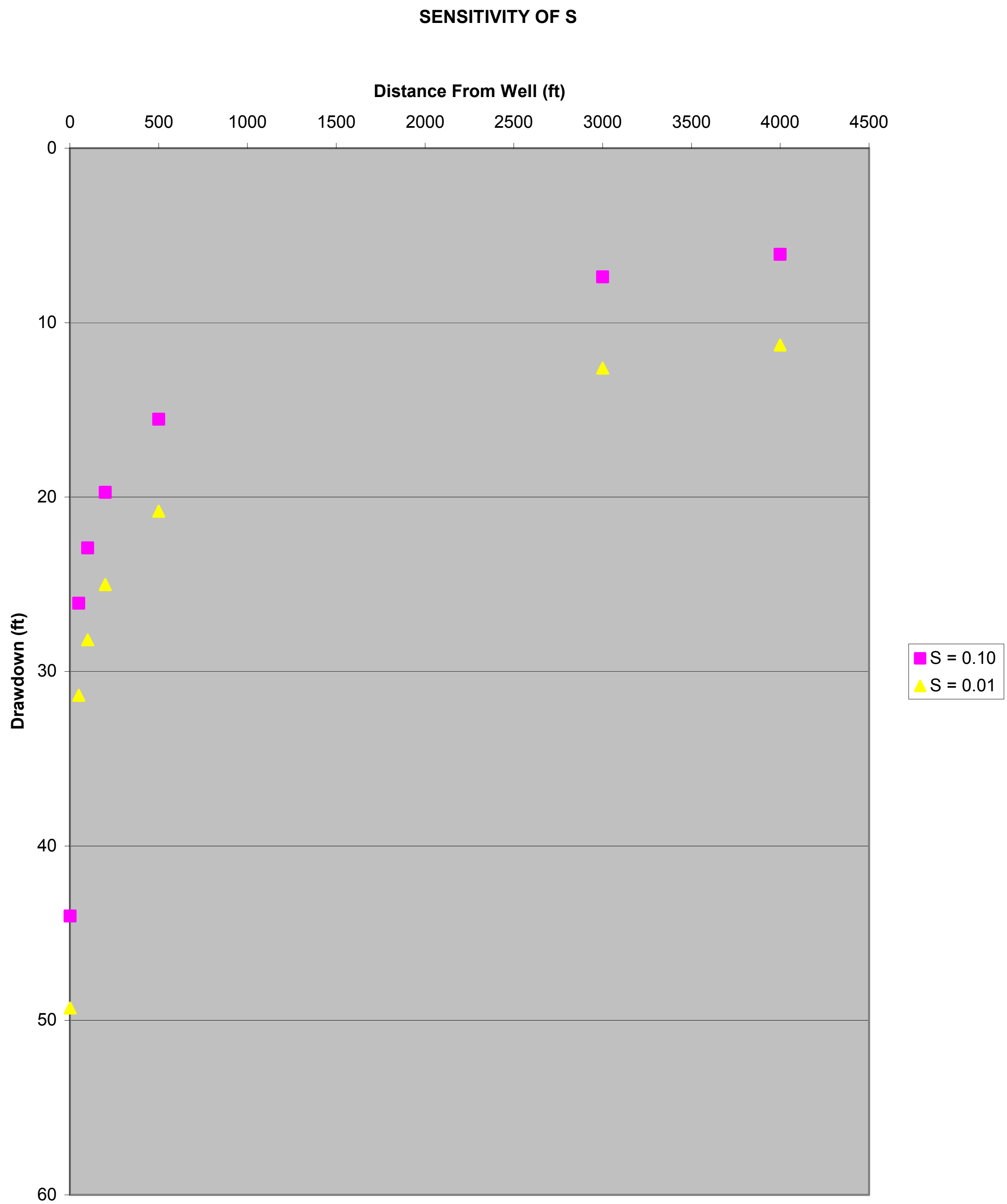
INFLUENCE OF S



From Freeze and Cheery, 1979 t_0 = steady-state t_1 = pumping state

METHODS TO ESTIMATE S

- Use geologic, well completion, and water level data to determine whether the aquifer is unconfined or confined.
- For unconfined aquifers S is typically selected based on geologic nature (see aquifer parameter table).
- For confined aquifers, S may be obtained by multiplying the aquifer thickness by 10^{-6}
- Perform an aquifer test with at least one observation well in addition to the pumped well.
- Obtaining values from available literature.
- Model calibration.



For T = 500 gpd/ft Q = 100 gpm t = 40 yrs

9. Well Yield

Potential to Produce Proposed Yield

Table 13.1. Recommended Well Diameters for Various Pumping Rates*

Anticipated Well Yield		Nominal Size of Pump Bowls		Optimum Size of Well Casing†		Smallest Size of Well Casing†	
gpm	m³/day	in	mm	in	mm	in	mm
Less than 100	Less than 545	4	102	6 ID	152 ID	5 ID	127 ID
75 to 175	409 to 954	5	127	8 ID	203 ID	6 ID	152 ID
150 to 350	818 to 1,910	6	152	10 ID	254 ID	8 ID	203 ID
300 to 700	1,640 to 3,820	8	203	12 ID	305 ID	10 ID	254 ID
500 to 1,000	2,730 to 5,450	10	254	14 OD	356 OD	12 ID	305 ID
800 to 1,800	4,360 to 9,810	12	305	16 OD	406 OD	14 OD	356 OD
1,200 to 3,000	6,540 to 16,400	14	356	20 OD	508 OD	16 OD	406 OD
2,000 to 3,800	10,900 to 20,700	16	406	24 OD	610 OD	20 OD	508 OD
3,000 to 6,000	16,400 to 32,700	20	508	30 OD	762 OD	24 OD	610 OD

*For specific pump information, the well-design engineer should contact a pump supplier, providing the anticipated yield, the head conditions, and the required pump efficiency.
†The size of the well casing is based on the outer diameter of the bowls for vertical turbine pumps, and on the diameter of either the pump bowls or the motor for submersible pumps.

From Driscoll

1 acre-foot per year = 0.62 gallons per minute at 100 % pumping time

1 acre-foot per year = 1.03 gallons per minute at 60 % pumping time

Example – A well penetrated 150 feet of limestone and encountered a water-bearing zone at 120 feet extending to 130 feet. The depth to water upon completion was 40 feet. The driller performed a short test and reported a drawdown of 50 feet while pumping 10 gpm. The well owner filed an application to appropriate 30 afy. Can the well produce this quantity?

For this artesian well assume the available drawdown to be the difference between the static water level and the top of the aquifer (120 – 40 = 80 ft)

$$\text{Specific capacity (SC)} = \frac{10 \text{ gpm}}{50 \text{ ft}} = 0.20 \text{ gpm/ft}$$

We know the following: SC, available drawdown, and flow rate requested. Lets use the flow rate requested and SC to determine the resulting drawdown. Then compare with available drawdown.

Find flow rate in gpm:

30 afy x 0.62 gpm/afy = 18.6 gpm at 100 % production time

But well will need more than 18.6 gpm because it will not be pumping 100 % of the time.

Assume well will produce 60 % of the time.

- Flow rate = 18.6 gpm/0.60 = 31 gpm.
- So 30 afy = 31 gpm at 60 % production time

Find Drawdown if 31gpm is pumped:

Specific capacity (SC) = $\frac{\text{flow rate}}{\text{drawdown}}$ Rearranging: Drawdown = $\frac{\text{Flow rate}}{\text{SC}}$

Drawdown = 31 gpm/0.20 = 155 ft which is more than the available drawdown

Other Considerations

- The well was tested at 10 gpm but 31 gpm was sought.
- The specific capacity decreases with increased drawdown so the use of the SC at 10 gpm leads to an under-prediction of drawdown.

10. Selected Sources of Information

By Basin

Animas Basin

Johnson, M. S., 2002, Simulation of non-irrigation ground-water withdrawals in the preliminary OSE Lower Animas ground-water flow model, OSE memorandum dated 5/24/02

NM Water Resources Research Institute, 2000, Trans-International Boundary Aquifers in Southwestern NM

Reeder, 1957, Groundwater in Animas valley, OSE Tec. Rep 11

Bluewater Basin

Baldwin and Anderholm, 1992, Hydrogeology …of the San Andres-Glorieta Aquifer, Acoma area, USGS WRIR 91-4033

Cooper and John, 1968, Ground water occurrence in Southeastern McKinley Co. OSE Tec Rep 35

Canadian Basin

Griggs, 1948, groundwater resources of eastern Colfax Co., NM Bureau of Geology GW-1

Griggs and Hendrickson, 1952, Ground-water resources of San Miguel County. NMBG GW-2

Mercer, J.W, Faust, E.G., Ground-water Resources of the Mora River Drainage Basin, OSE Technical Report 37

Rao, B.,1994. Hydrogeologic Analysis of the Water Rights Application Numbered 0379 into CR-2448 Through CR-2448-S-2, Moreno Valley, Colfax County, New Mexico, Special Projects Division Hydrology Report, SPDH-94-2.

Capitan Basin

Richey and Wells, 1984, Geohydrology of the Delaware basin…., USGS WRIR 84-4077

Carlsbad Basin

Barroll, P., 2000, Carlsbad Groundwater Flow Model, OSE memorandum dated 5/11/00

Bjorklund, 1959, Geology and Water Resources of the Carlsbad area, USGS Open file report

Hendrickson and Jones, 1952, Groundwater resources of Eddie County, NMBG GW-3

Richey and Wells, 1984, Geohydrology of the Delaware basin…., USGS WRIR 84-4077

Curry County Basin

Howard, 1954, Ground-water conditions in Curry County, OSE Tec. Rep 1

Chudnoff, M. and Logan,L.,1995. Groundwater Relationship Between New Mexico and Texas Along the State Line in the Southern High Plains, SPDH-95-01.

Musharrafieh, G., and Logan, L., 1999, Numerical Simulation of Groundwater Flow for Water Rights Administration in the Curry and Portales Valley Underground Water Basins, NM, TDH-99-2

Estancia Basin

Keyes, E., 2001. The Estancia Basin Groundwater Flow Model, OSE Model Design and Future Scenarios. TDH-01-03.

Meinzer, 1911, Geology and water resources of Estancia Valley, USGS Water Supply Paper 260

Smith, 1957, Ground-water resources of Torrance County, NMBG GW-5

White, 1993, Hydrology of the Estancia Basin, USGS WRIR 93-4163

Ft. Sumner Basin

Mourant and Shomaker, 1970, Water resources of De Baca County, NMBG GW-10

Gallup Basin

Cooper and John, 1968, Ground water occurrence in Southeastern Mckinley Co. OSE Tec Rep 35

Stone, and others, 1983, Hydrogeology …San Juan Basin, NMBG HR-6

Gila San Francisco Basin

Basabivazo, 1996, Ground-Water Resources of Catron County…, USGS WRIR 96-4258

NM Water Resources Research Institute, 2000, Trans-International Boundary Aquifers in Southwestern NM

Trauger, F.D., 1960, Availability of Ground Water at Proposed Well Sites in the Gila National Forest, Sierra and Catron Counties, OSE technical report 18

Hondo Basin

Hoines, S., 1994, Evaluation of Applications Submitted by the Village of Ruidoso, OSE memoranda dated 11/5/04

Mourant, 1963, Water Resources Rio Hondo drainage basin, OSE Tec. Rep 28

Rappuhn, D., 1994, Evaluation of Applications Submitted by the Village of Ruidoso, OSE memoranda dated 11/5/04

Hot Springs Basin

Murray, 1959, Ground-water conditions in non-thermal Artesian Basin, OSE Tec. Rep 10

Hueco Basin

Knowles and Kennedy, 1956, Ground-water Resources of the Hueco bolson, USGS Water Supply Paper 1426

Orr and Risser, Geohydrology and Potential Effects … ,USGS WRIR 91-4082

Papadopulos & Associates, 1988, Hueco Bolson Ground Water Flow Model, report for the OSE

Jal Basin

Hoines, S., 2004, Evaluation of Application J-11…., Jay Anthony, OSE memorandum dated 5/21/04

Reed, E. L., 1961, Proposed New Ground Water Basin, Southwest Jal Area, Consult. Rpt

Las Animas Creek Basin

Davie, W., and Spiegel, Z. 1967, Geology and Water Resources of Las Animas Creek, Sierra County, NM OSE hydrographic survey report

Myers, R.G., Everheart, J.T., Wilson, C.A. Geohydrology of the San Augustin Basin, Alamosa Creek Basin Upstream from Monticello Box, and Upper Gila Basin, USGS WRRI 94-4125

Lea County Basin

Musharrafieh, G., Chudnoff, M., 1999, Numerical Simulation of Groundwater Flow for Water Rights Administration in the lea County Underground Water Basin, NM, Hydrology Bureau Report 99-1

Nicholson, 1961, Ground-water resources of Lea Co., NMBG GW-6

Yates, J.C., 1953, Water Supply of lea County Underground Water Basin, OSE Report

Lordsburg Basin

Morgan, A. M., 1962 Groundwater conditions near Lordsburg OSE 16th and 17th Bienn. Repts.

NM Water Resources Research Institute, 2000, Trans-International Boundary Aquifers in Southwestern NM

West, F.G., 1961, Technical Basis for the Administration of the Lordsburg Valley Underground Water Basin, OSE memorandum dated 3/16/61

Lower Rio Grande Basin

Conover, 1954, Ground-water conditions in the Rincon and Mesilla Valleys, USGS Water Supply Paper 1230

Cox, E.R., Reeder, H.O., 1962, Ground-water conditions in the Rio Grande valley between Truth or Consequences and Las Palomas, Sierra Co. NM, OSE Technical report 25

Johnson, M.S., 2001a, Comparison of two ground-water flow models for administration of water rights. In the Southern Jornada basin…., OSE Hydrology Report 01-6, July 2001

Johnson, M.S., 2001b, Hydrologic evaluation of ..City of Las Cruces applications, OSE memorandum dated July 23, 2001

King and others, 1971, Ground-water resources ….Dona Ana County, NMBG HR-1

Murray, R.C., 1959, Ground-Water Conditions in the Nonthermal Artesian-Water Basin South of Hot Springs, Sierra County, OSE Technical Report 10

Nickerson and Myers, 1992, Geohydrology of the Mesilla Ground-Water Basin, USGS WRIR 92-4156

Wilson and others 1981, Water resources of the Rincon and Mesilla Valleys, OSE Tec Rep 43

Mimbres Basin

Hanson, R.T., McLean, J, S., Miller, R.S., 1994, Hydrogeologic Framework and Preliminary Simulation of Ground-Water Flow in the Mimbres Basin, USGS WRRI 94-4011

Hathaway, D.L., Use of a Regional Ground-Water Flow Model for Water Rights Administration, OSE report

Trauger, 1972, Water resources…Grant County, NMBG HR-2

Nutt Hocket Basin

Borton, R. L., Geology and Ground-Water Resources of the Nutt-Hockett Basin, OSE study

Penasco Basin

Subdivision reports

Playas Basin

Doty, 1960, Ground water in Playas Valley, Hidalgo Co. OSE Tec. Rep. 15

NM Water Resources Research Institute, 2000, Trans-International Boundary Aquifers in Southwestern NM

Portales Basin

Meinzer, 1909, Underground water resources in Portales valley, USGS Press Bulletin 406

Musharrafieh, G., and Logan, L., 1999, Numerical Simulation of Groundwater Flow for Water Rights Administration in the Curry and Portales Valley Underground Water Basins, NM, TDH-99-2

Rio Grande Basin – Middle

Albuquerque Area

Barroll, P., 2001. Documentation of the Administrative Groundwater Model for the Middle Rio Grande Basin. TDH-99-3.

Bjorklund, 1961, Ground-water resources in Albuquerque area, OSE Tec. Rep 20

McAda, D.P., and Barroll, P, 2002, Simulation of Ground-water flow in the Middle Rio Grande Basin: USGS Water-Resources Investigations Report 02-4200

Reeder and others, Water resources of Albq. Area, OSE Tec. Rep 33

Thorn and others, 1993, Geohydrologic Framework and Hydrologic Conditions…, USGS Water-Resource Investigation Reports (WRIR) 93-4149

Jemez River
Craig, 1989, Water Resources on Jemez, Zia, and Santa Ana Pueblos…, WRIR 89-4091

Musharrafieh, G., and Logan L., 2005, Projected Stream depletions …on Jemez River due to city of Rio Rancho, OSE memorandum dated 5/18/05

Musharrafieh, G., and Logan L., 2005, Historical Supply on Jemez River, OSE memorandum dated 5/2/05

Rio Puerco
Core, A., 2005, San Juan – Rio Grande Underground Water Basin Boundary Issue, OSE memorandum dated 11/28/05

Levings and others, 1989 – 1990, USGS Hydrologic Investigations Atlas HA-720 A-J

Stone, and others, 1983, Hydrogeology …San Juan Basin, NMBG HR-6

San Agustin Plains
Everheart, J.T., 1978, Pending applications in San Agustin Plains Area, OSE memorandum 10/26/78

Myers and others, 1994, Geohydrology of the San Agustin Basin, USGS WRIR 94-4125

Santa Fe Area
Core, A. 1996. Española Basin Santa Fe Region Modified McAda-Wasiolek Model User Manual, TDH-96-2.

McAda and Wasiolek, 1987, Simulation of the regional Geohydrology of the Tesuque Aquifer System, USGS WRIR 87-4056

Mourant, 1980, Hydrologic Maps and Data for Santa Fe County, USGS Basic Data Report

Spiegel and others, 1963, Geology and water resources of the Santa Fe area, USGS Water Supply Paper 1525

Rio Grande Basin – Upper
Barroll, P., Logan, L. Evaluation of Hydrologic Effects due to Ground Water Diversion from Proposed Supplemental Wells….City of Espanola, NM, Hydrology Bureau Report 98-3

Barroll, P. and Burck, P. 2006, Groundwater Flow Model Taos Area, OSE internal draft report

Garrabrant, 1993, Water Resources if Taos County, USGS WRIR 93-4107

Turney, Speigel, West, and others, Ground Water Investigations for Mutual Domestic Water Consumer Associations, Groundwater notes section of OSE library

Winograd, 1959, Ground-water conditions and Geology of Taos County, OSE Tec. Rep. 12

Roswell Basin

Hood, J.W and others, 1960, Occurrence of saline Ground Water near Roswell, OSE Technical Report 17

Fiedler and Nye, 1933, Geology and Ground-water resources of the Roswell Artesian basin, USGS Professional Paper 639

Papadopulos & Associates, 2003, Update and Recalibration of Roswell Basin Model, report for the OSE

Welder, 1983, Geohydrologic framework, Roswell Basin, OSE Tec. Rep 42

Salt Basin

Bjorklund, 1957, Ground-water conditions in the Crow Flats Area, OSE Tec. Rep. 8

Shomaker & Associates, 2002, Hydrogeologic Framework of the Salt Basin and Development of Three-Dimensional Ground-Water Flow Model, Report for the ISC.

Sandia Basin

Core, A. 1997. Evaluation of Hydrologic Issues Related to Application S-11-A, (D. W. Falls) for Permit to Change Location of Well and Place and Purpose of Use and Points of Diversion of Underground Waters of the State of New Mexico, OSE Hydrology Report dated 10/22/91.

Kues, 1989, Ground-Water Availability and Quality in Eastern Bernalillo County.., USGS WRIR 89-4127

Spinks, M.P., 1985, Application S-41 and S-41-S by Harwood Rice, OSE memorandum dated 5/3/85

Titus, 1980, Ground water in Sandia and northern Manzano Mountains, NMBG HR-5

San Simon Basin

NM Water Resources Research Institute, 2000, Trans-International Boundary Aquifers in Southwestern NM

San Juan Basin

Levings and others, 1989 – 1990, USGS Hydrologic Investigations Atlas HA-720 A-J

Stone, and others, 1983, Hydrogeology …San Juan Basin, NMBG HR-6

Tucumcari Basin

Berkstresser and Mourant, 1966, Ground-water resources of Quay County, NMBG GW-9

Trauger, 1964, Ground water in the vicinity of Tucumcari, OSE Tec. Rep 30

Tularosa Basin

Garza and Mclean, 1977, Freshwater resources of the Southeastern part of the Tularosa basin, OSE Tec. Rep 40

Keyes, E., 2005. Revised Model of the Tularosa Basin. TDH-05-01

McLean, 1970, Saline Ground Water Resources, USGS Research and Development Report 561

Morrison, T., 1989. A Regional Model of the Basin Fill Aquifer near Tularosa and Alamogordo, New Mexico, TDH-89-3.

Orr and Myers, 1985, Water Resources in Basin Fill Deposits…,USGS WRIR 85-4219

Upper Pecos Basin

Griggs and Hendrickson, 1952, Ground-water resources of San Miguel County. NMBG GW-2

Rao, B., 1989, Hydrologic Impacts of Pumping Ground Water from the City of Santa Rosa Municipal Well Field Near Colonias, New Mexico, TDH-89-7.

Virden Valley Basin

NM Water Resources Research Institute, 2000, Trans-International Boundary Aquifers in Southwestern NM

Selected Sources of Information
By County

Bernalillo County

Bjorklund, 1961, Ground-water resources in Albuquerque area, OSE Tec. Rep 20

McAda, D.P., and Barroll, P, 2002, Simulation of Ground-water flow in the Middle Rio Grande Basin: USGS Water-Resources Investigations Report 02-4200

Reeder and others, Water resources of Albq. Area, OSE Tec. Rep 33

Titus, 1980, Ground water in Sandia and northern Manzano Mountains, NMBG HR-5

Catron County

Basabilvazo, G. T., 1997, Ground-Water resources of Catron County, NM, USGS WRRI 96-4258

Myers, R.G., Everheart, J.T., Wilson, C.A. Geohydrology of the San Augustin Basin, Alamosa Creek Basin Upstream from Monticello Box, and Upper Gila Basin, USGS WRRI 94-4125

Trauger, F.D., 1960, Availability of Ground Water at Proposed Well Sites in the Gila National Forest, Sierra and Catron Counties, OSE technical report 18

Chavez County

Hood, J.W and others, 1960, Occurrence of saline Ground Water near Roswell, OSE Technical Report 17

Welder, 1983, Geohydrologic framework, Roswell Basin, OSE Tec. Rep 42

Cibola County

Baldwin and Rankin, 1994, Hydrogeology of Cibola County, USGS WRIR 94-4178

Colfax County

Griggs, 1948, groundwater resources of eastern Colfax Co., NM Bureau of Geology GW-1

Curry County

Howard, 1954, Ground-water conditions in Curry County, OSE Tec. Rep 1

Musharrafieh, G., and Logan, L., 1999, Numerical Simulation of Groundwater Flow for Water Rights Administration in the Curry and Portales Valley Underground Water Basins, NM, TDH-99-2

De Baca County

Mourant and Shomaker, 1970, Water resources of De Baca County, NMBG GW-10

Dona Ana County

King and others, 1971, Ground-water resources ….Dona Ana County, NMBG HR-1

Wilson and others 1981, Water resources of the Rincon and Mesilla Valleys, OSE Tec Rep 43

Eddy County

Hendrickson and Jones, 1952, Groundwater resources of Eddy County, NMBG GW-3

Richey and Wells, 1984, Geohydrology of the Delaware basin…., USGS WRIR 84-4077

Grant County

Trauger, 1972, Water resources…Grant County, NMBG HR-2

NM Water Resources Research Institute, 2000, Trans-International Boundary Aquifers in Southwestern NM

Guadalupe County

Dinwinddie and others, 1973, Water Resources of Guadalupe County, NMBG HR-3

Harding County

Trauger, F.D., Ground water resources and geology of Harding County, NM, USGS in progress study

Hildago County

NM Water Resources Research Institute, 2000, Trans-International Boundary Aquifers in Southwestern NM

Reeder, 1957, Groundwater in Animas valley, OSE Tec. Rep 11

Lea County

Musharrafieh, G., Chudnoff, M., 1999, Numerical Simulation of Groundwater Flow ….Lea County Underground Water Basin, NM, Hydrology Bureau Report 99-1

Nicholson, 1961, Ground-water resources of Lea Co., NMBG GW-6

Richey and Wells, 1984, Geohydrology of the Delaware basin…., USGS WRIR 84-4077

Lincoln County

Hoines, S., 1994, Evaluation of Applications Submitted by the Village of Ruidoso, OSE memoranda dated 11/5/04

Mourant, 1963, Water Resources Rio Hondo drainage basin, OSE Tec. Rep 28

Rappuhn, D., 1994, Evaluation of Applications Submitted by the Village of Ruidoso, OSE memoranda dated 11/5/04

Los Alamos County

Frenzel, P.F., 1995, Geohydrology and Simulation of Ground-Water Flow near Los Alamos, NM, USGS WRIR 95-4091

Luna County

Hanson, R.T., McLean, J, S., Miller, R.S., 1994, Hydrogeologic Framework and Preliminary Simulation of Ground-Water Flow in the Mimbres Basin, USGS WRRI 94-4011

NM Water Resources Research Institute, 2000, Trans-International Boundary Aquifers in Southwestern NM

McKinley County

Cooper and John, 1968, Ground water occurrence in Southeastern McKinley Co. OSE Tec Rep 35

Mora County

Mercer, J.W, Faust, E.G., Ground-water Resources of the Mora River Drainage Basin, OSE Technical Report 37

Otero County

Garza and Mclean, 1977, Freshwater resources of the Southeastern part of the Tularosa basin, OSE

McLean, 1970, Saline Ground Water Resources, USGS Research and Development Report 561

Orr and Myers, 1985, Water Resources in Basin Fill Deposits…,USGS WRIR 85-4219

Quay County

Berkstresser and Mourant, 1966, Ground-water resources of Quay County, NMBG GW-9

Trauger, 1964, Ground water in the vicinity of Tucumcari, OSE Tec. Rep 30

Rio Arriba County

Barroll, P., Logan, L. Evaluation of Hydrologic Effects due to Ground Water Diversion from Proposed Supplemental Wells….City of Espanola, NM, Hydrology Bureau Report 98-3

Turney, Speigel, West, and others, Ground Water Investigations for Mutual Domestic Water Consumer Associations, Groundwater notes section of OSE library

Roosevelt County

Cooper, 1960, Ground Water in the Causey-Lingo Area, OSE Tec. Rep. 14

Musharrafieh, G., and Logan, L., 1999, Numerical Simulation of Groundwater Flow for Water Rights Administration in the Curry and Portales Valley Underground Water Basins, NM, TDH-99-2

Sandoval County

Craig, 1989, Water Resources on Jemez, Zia, and Santa Ana Pueblos…, WRIR 89-4091

Johnson, P.S., 2000 Hydrogeologic and water Resource Assessment for the Placitas Development Area, Sandoval County, NM, Nm Bureau of geology and Mineral Resources Report

Trainer, F.W., Rogers, R.J., Michael, S.L., 2000,n Geothermal Hydrology of the Valles Caldera and the Southwestern Jemez Mountains, NM, USGS WRRI 00-4067

San Juan County

Levings and others, 1989 – 1990, USGS Hydrologic Investigations Atlas HA-720 A-J

Stone, and others, 1983, Hydrogeology …San Juan Basin, NMBG HR-6

San Miguel County

Griggs and Hendrickson, 1952, Ground-water resources of San Miguel County. NMBG GW-2

Turney, Speigel, West, and others, Ground Water Investigations for Mutual Domestic Water Consumer Associations, Groundwater notes section of OSE library

Santa Fe County

McAda and Wasiolek, 1987, Simulation of the regional Geohydrology of the Tesuque Aquifer System, USGS WRIR 87-4056

Mourant, 1980, Hydrologic Maps and Data for Santa Fe County, USGS Basic Data Report

Spiegel and others, 1963, Geology and water resources of the Santa Fe area, USGS Water Supply Paper 1525

White, 1993, Hydrology of the Estancia Basin, USGS WRIR 93-4163

Sierra County

Cox, E.R., Reeder, H.O., 1962, Ground-water conditions in the Rio Grande valley between Truth or Consequences and Las Palomas, Sierra Co. NM, OSE Technical report 25

Murray, R.C., 1959, Ground-Water Conditions in the Nonthermal Artesian-Water Basin South of Hot Springs, Sierra County, OSE Technical Report 10

Myers, R.G., Everheart, J.T., Wilson, C.A. Geohydrology of the San Augustin Basin, Alamosa Creek Basin Upstream from Monticello Box, and Upper Gila Basin, USGS WRRI 94-4125

Trauger, F.D., 1960, Availability of Ground Water at Proposed Well Sites in the Gila National Forest, Sierra and Catron Counties, OSE technical report 18

Socorro County

Roybal, 1989, Ground-Water resources of Socorro County, USGS WRIR 89-4083

Speigel, 1955, Ground-water resources of northeastern Socorro Co, NMBM GW-4

Taos County

Garrabrant, 1993, Water Resources if Taos County, USGS WRIR 93-4107

Turney, Speigel, West, and others, Ground Water Investigations for Mutual Domestic Water Consumer Associations, Groundwater notes section of OSE library

Winograd, 1959, Ground-water conditions and Geology of Taos County, OSE Tec. Rep. 12

Torrance County

Smith, 1957, Ground-water resources of Torrance County, NMBG GW-5

Union County

Cooper and Davis, 1967, General occurrence ...ground water in Union Co. NMBG GW-8

Valencia County

Titus, 1963, Ground-water conditions in eastern Valencia County, NMBG GW-7

Selected Sources of Information By Subject

Alluvial Basins

Kernodle, M. J., 1992, Summary of USGS Ground-water Flow Models of Basin-fill Aquifers, USGS Open-File Report 90-361

Wilkins, D. W., 1986, Geohydrology of the Southwest Alluvial Basins…., USGS WRIR 84-4224

Aquifer Tests - General

Driscoll, F.G., 1987, Groundwater and Wells

Walton, W.C., 1970, Groundwater Resource Evaluation

Aquifer Tests – Site Specific

Hydrology Bureau Data Base

OSE Subdivision Consultant Reports

Turney, Speigel, West, and others, Ground Water Investigations for Mutual Domestic Water Consumer Associations, Northern NM, Groundwater notes section of OSE library

Water Rights Files

Bibliographies

Borton OSE Bibliography

Hydrology Bureau Reports listing

New Mexico Bureau of Geology and Mineral Resources Publications report

OSE Library databases

Assessment of Drawdown

Morrison, T., 2006. Guidelines for the Assessment of Drawdown Estimates For Water Right Application Processing

Geologic Maps

NM Bureau of Geology and Mineral Resources geologic quadrangle maps

NM Bureau of Geology and Mineral Resources/USGS Geologic Map of NM

Ground Water Hydrology

Driscoll, F.G., 1987, Groundwater and Wells

Fetter, C. W. Jr., 1988, Applied Hydrogeolgogy

Freeze, R. A. and Cherry, J. A., 1979, Groundwater

Heath, R.W, 1983, Basic Ground-Water Hydrology: USGS Water Supply Paper 2220

U.S. Department of the Interior, 1981, Ground Water Manual

Historical Supply and Seepage Runs

OSE compilation report

Models

Kernodle, M. J., 1992, Summary of USGS Ground-water Flow Models of Basin-fill Aquifers, USGS Open-File Report 90-361

Morrison, T., 1989, A Summary of Regional Groundwater Models, OSE Hydrology Report 89-8

Morrison, T., 2003, Model Selection Objectives for the Administration of Water Rights, OSE memorandum dated June 26, 2003

Springs

White, W.E., Kues, G.E., 1992, Inventory of Springs in the State of New Mexico, USGS Open-File Report 92-118

Stream Flow

USGS annual data reports/USGS web site

Water Levels

USGS annual data reports

USGS GWSI data base

USGS web site

WATERS

Well Drilling

Driscoll, F.G., 1987, Groundwater and Wells

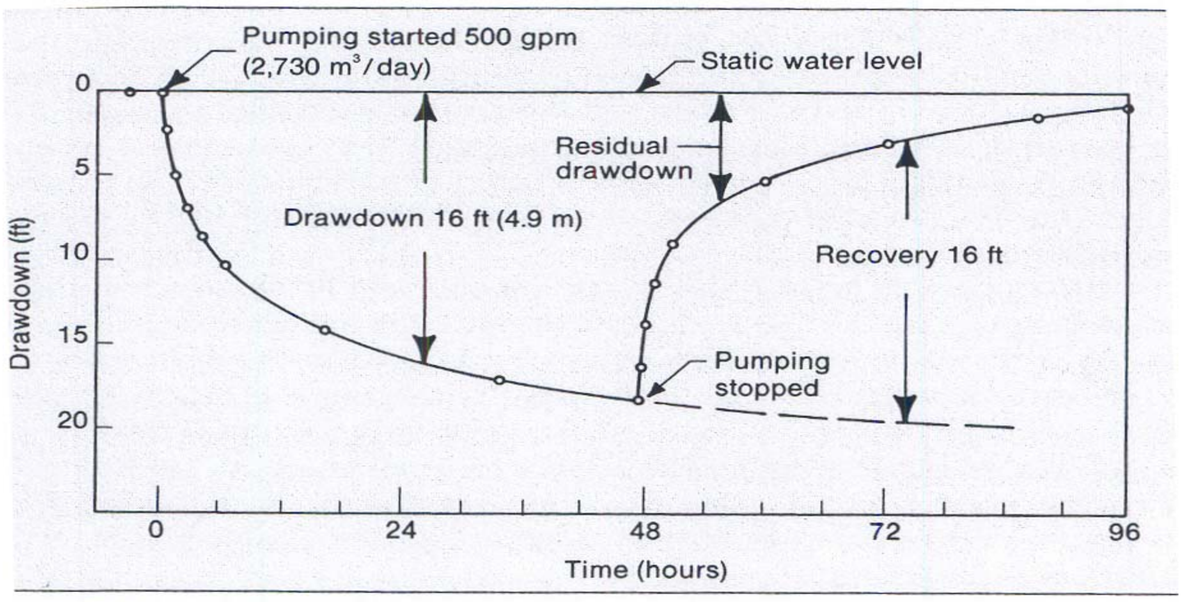
Roscoe Moss Company, 1990, Handbook of Groundwater Development

SECTION II
ESTIMATION OF AQUIFER PARAMETERS

TABLE OF CONTENTS

SECTION II
ESTIMATION OF AQUIFER PARAMETERS

1. Overview of Aquifer Tests

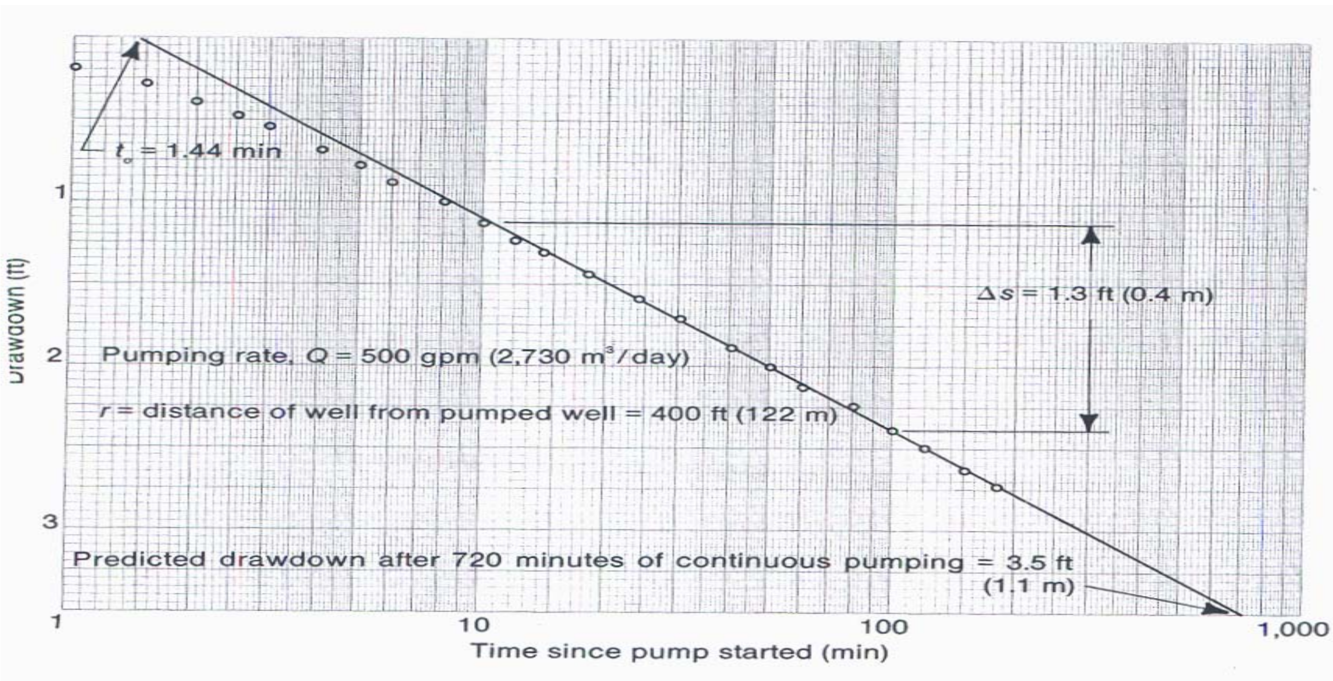


From Driscoll

Data to Collect

- Steady state water levels,
- Depth to water and corresponding time since pumping began,
- Flow rate during duration of test,
- Time the pump was turned off and corresponding water level,
- Depth to water and corresponding time after pumping stopped,
- Other information relating to factors that may influence the test (storms, pump problems…).

Time since pump started, in min	Drawdown, s ft	m	Time since pump started, in min	Drawdown, s ft	m
1	0.16	0.05	24	1.58	0.48
1.5	0.27	0.08	30	1.70	0.52
2	0.38	0.12	40	1.88	0.57
2.5	0.46	0.14	50	2.00	0.61
3	0.53	0.16	60	2.11	0.64
4	0.67	0.20	80	2.24	0.68
5	0.77	0.23	100	2.38	0.73
6	0.87	0.27	120	2.49	0.76
8	0.99	0.30	150	2.62	0.80
10	1.12	0.34	180	2.72	0.83
12	1.21	0.37	210	2.81	0.86
14	1.30	0.40	240	2.88	0.88
18	1.43	0.44			



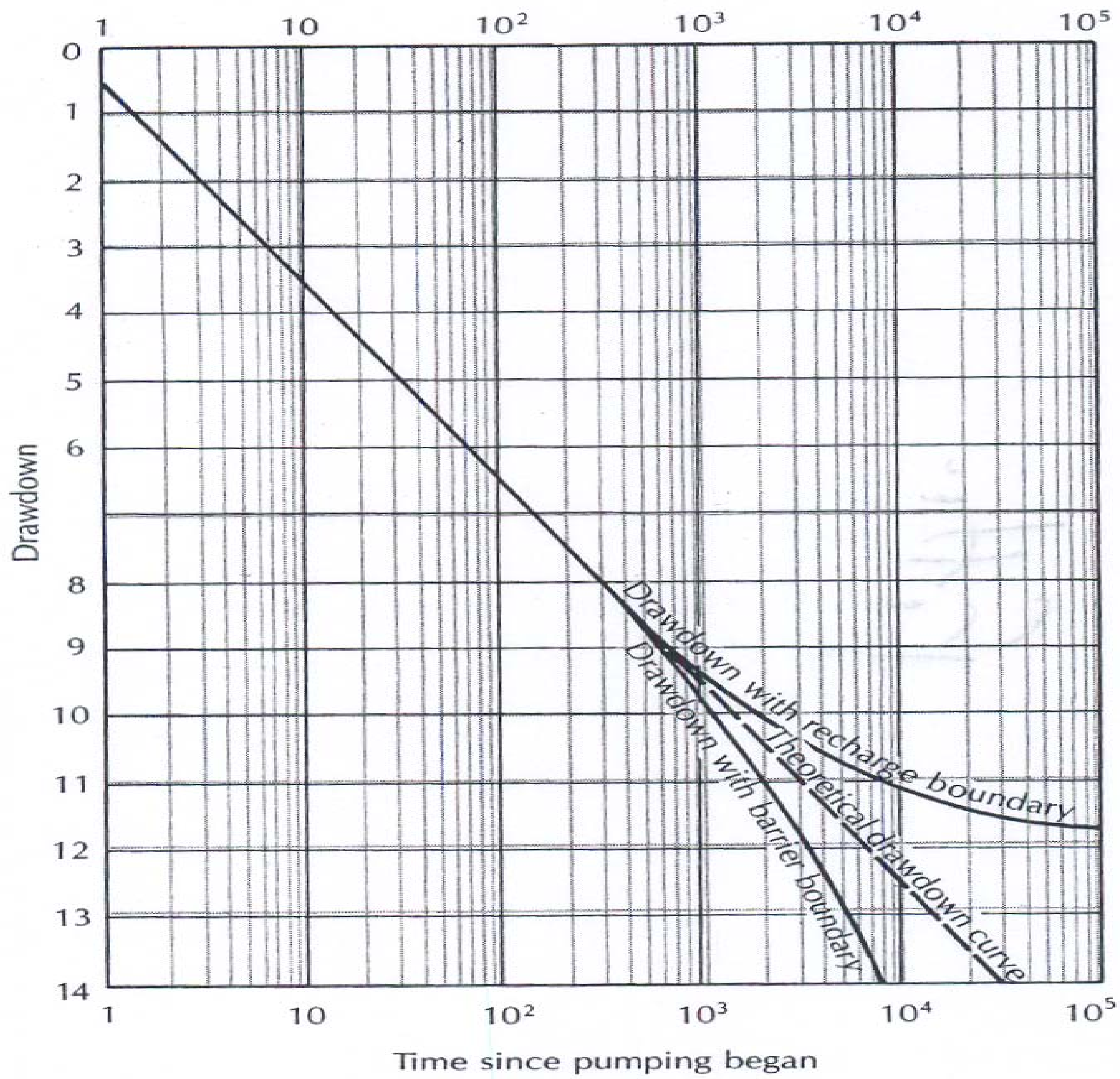
Common Problems

- Well was not adequately developed.
- Water level before pumping began does not represent static conditions.
- Flow rate did not remain constant.
- Flow rate was inadequate to stress the aquifer.
- Test duration was insufficient.
- More than one physical reason may exist for response observed.
- Inability to fully visualize physical character of aquifer.
- Selection of wrong slope to compute T.

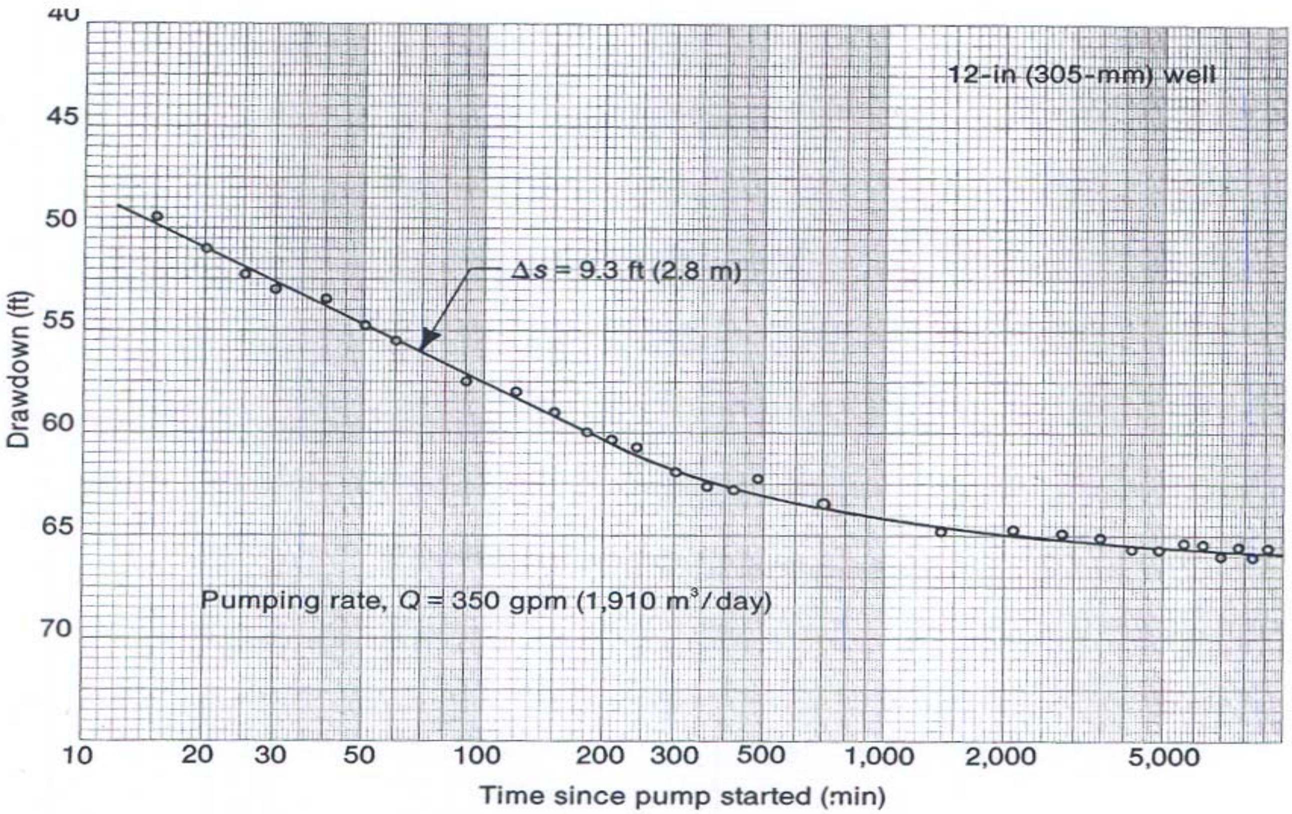
Test Results May Provide

- K & T
- S if an observation well was also measured
- How aquifer properties are changing with distance from the well
- Existence of no-flow boundaries
- Existence of recharge sources

Aquifer Test Response



Example 1



Types of Situations/Possible Reasons for Response:

Well near stream

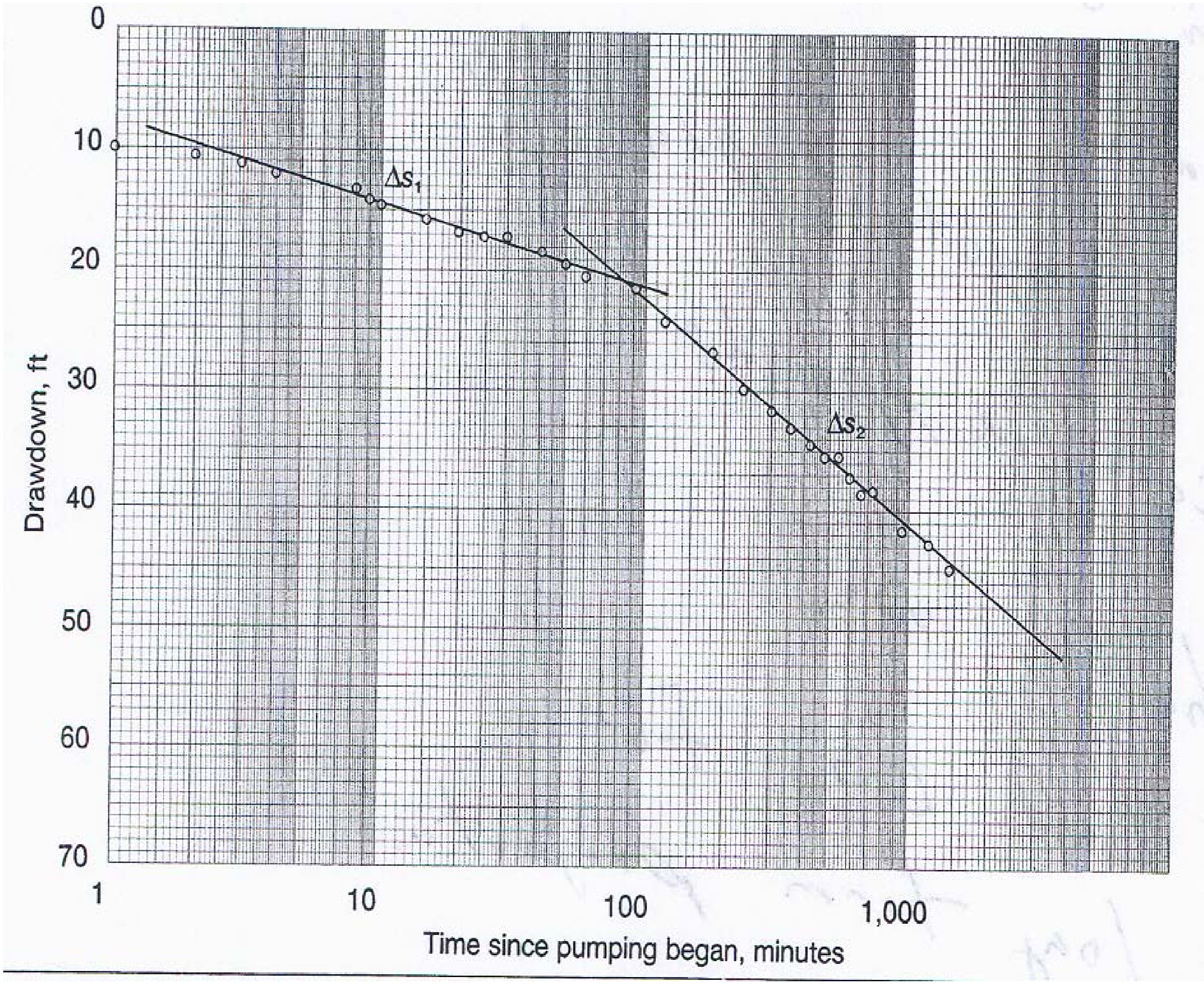
- recharge is causing leveling in 2nd leg
- use 1st leg slope to compute T

Well with no stream

- cone of depression reached a high T zone at 2nd leg, use 2nd leg slope to compute T
- 2nd slope caused by reduction in pumping, value of test is questionable
- return flow from test pumpage, value of test is questionable

<u>MUST UNDERSTAND GEOLOGY TO OBTAIN CORRECT INTERPRETION</u>

Example 2



Types of Situations/Possible Reasons:

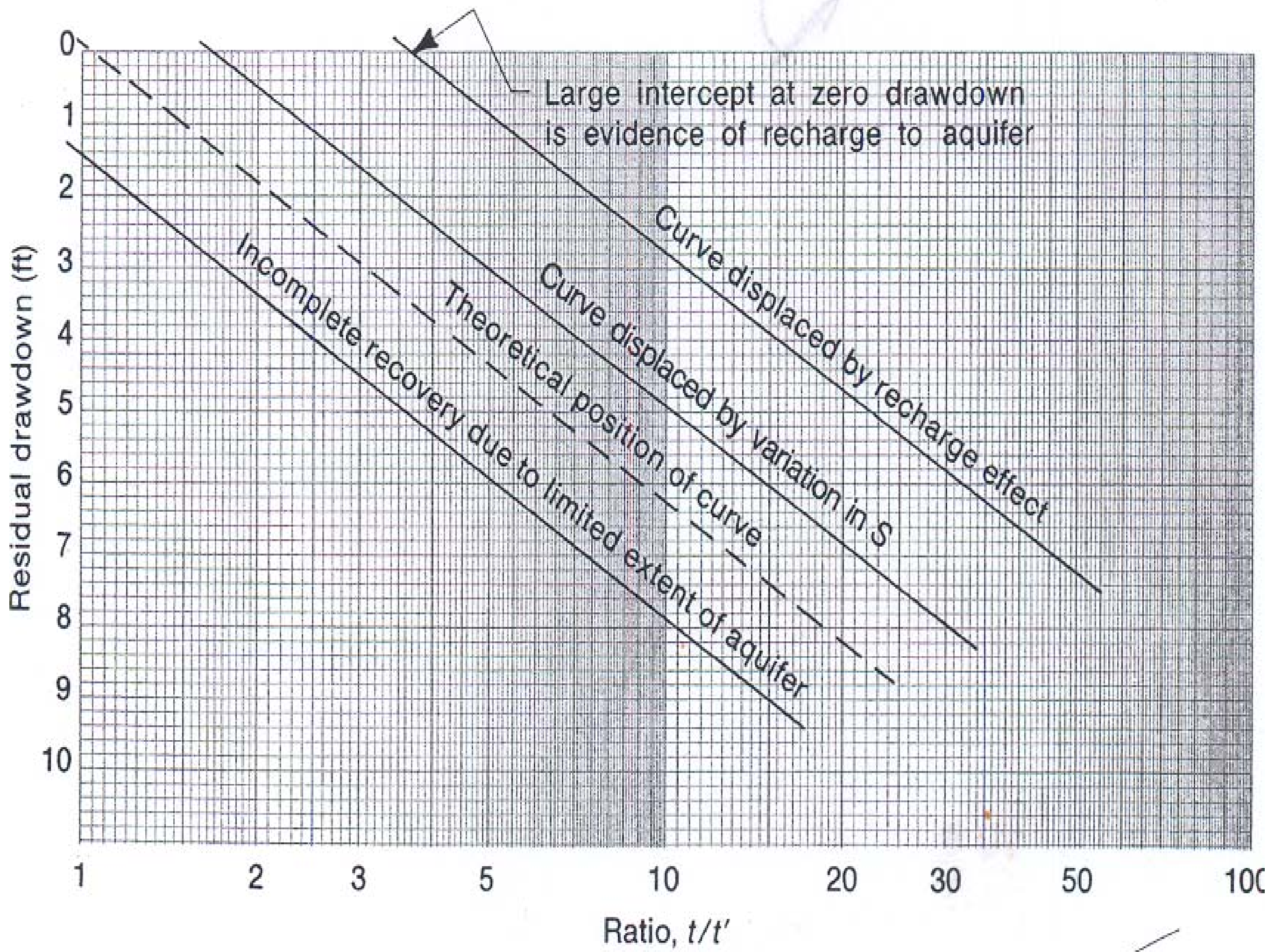
Well with no apparent boundaries

- lower T zone caused 2nd leg slope change, use 2nd leg slope to compute T
- Increase in flow rate caused change in slope, value of test is questionable

Well with possible no-flow boundary

- cone of depression reached boundary, use 1st leg slope to compute T
- Increase in flow rate caused change in slope, value of test is questionable

Use of Recovery Data to Assess Aquifer Conditions



When curve fails to pass through origin – aquifer conditions do not conform to assumed idealized conditions.

Graph indicates zero drawdown at a ratio of 2 or more - cone reached recharge source.

Graph indicates zero drawdown at a ratio between 0 and 1 – variation of S.

Graph indicates drawdown – aquifer of a limited extent

2. Computation of Aquifer Parameters
Time –Drawdown Graphs

TRANSMISSIVITY

Cooper – Jacob Method

- Uses semi-log paper: x axis – time since pumping started (min), y axis drawdown (ft).
- A straight line on the plot is selected to compute the slope Δs.
- More than one straight line is often obtained from a plot.
- Selecting the appropriate straight line to compute parameters is the most important part of applying the procedure correctly.
- The method may be applied to the drawdown and recovery portions of the test.

T = 264 Q/Δs

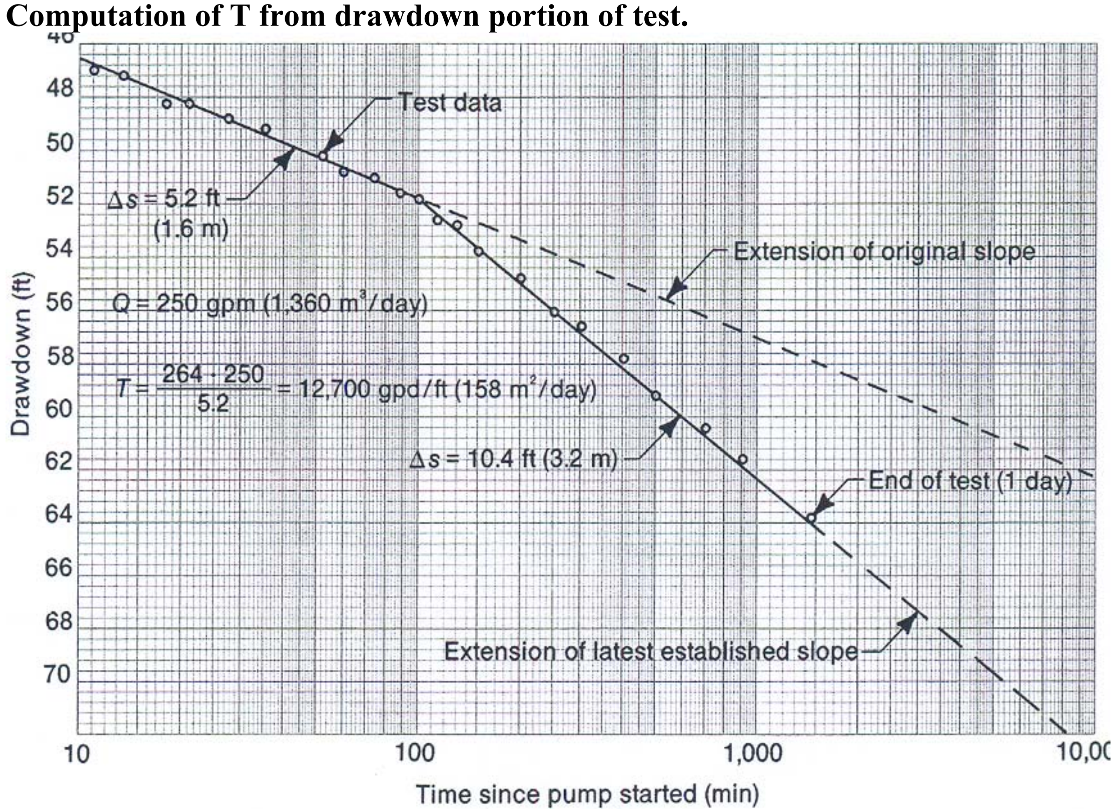
Where:

Q = pumping rate in gpm

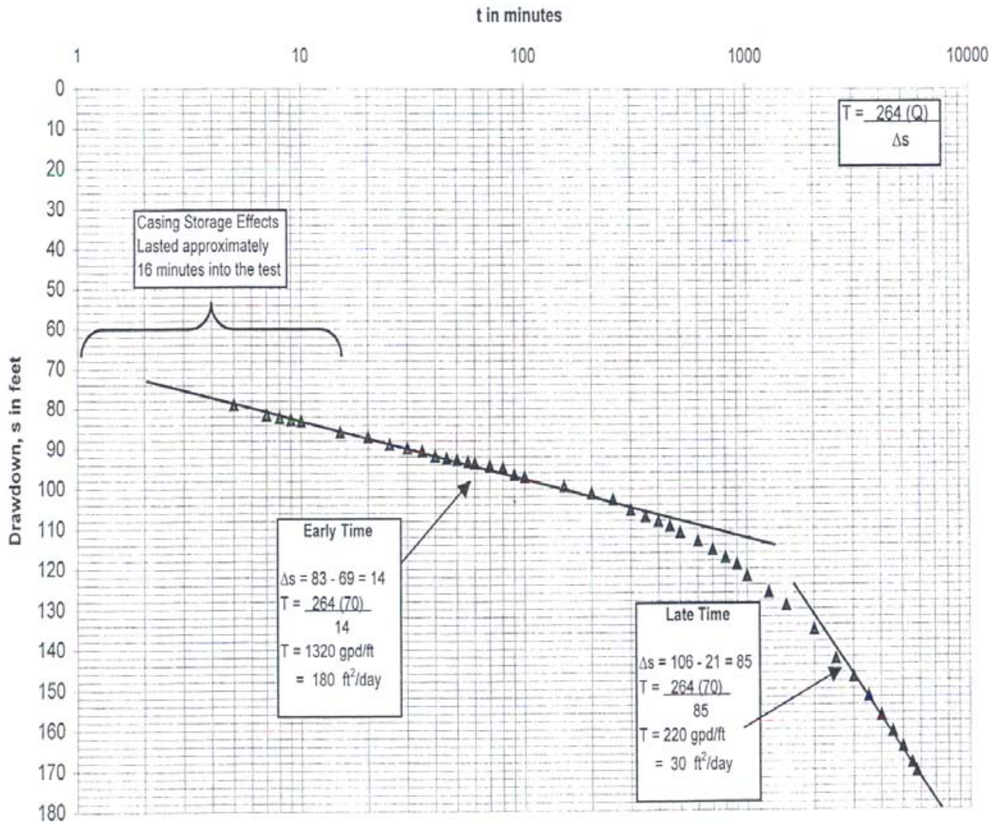
Δs = (delta s) = change in water level over one log cycle, in feet on a semi-log plot

T = transmissivity (gpd/ft)

Computation of T from drawdown portion of test.



Drawdown Graph for 96-Hour Pumping Test, RG-72559,
Rancho San Lucas Well No. 2, Q = 70 GPM



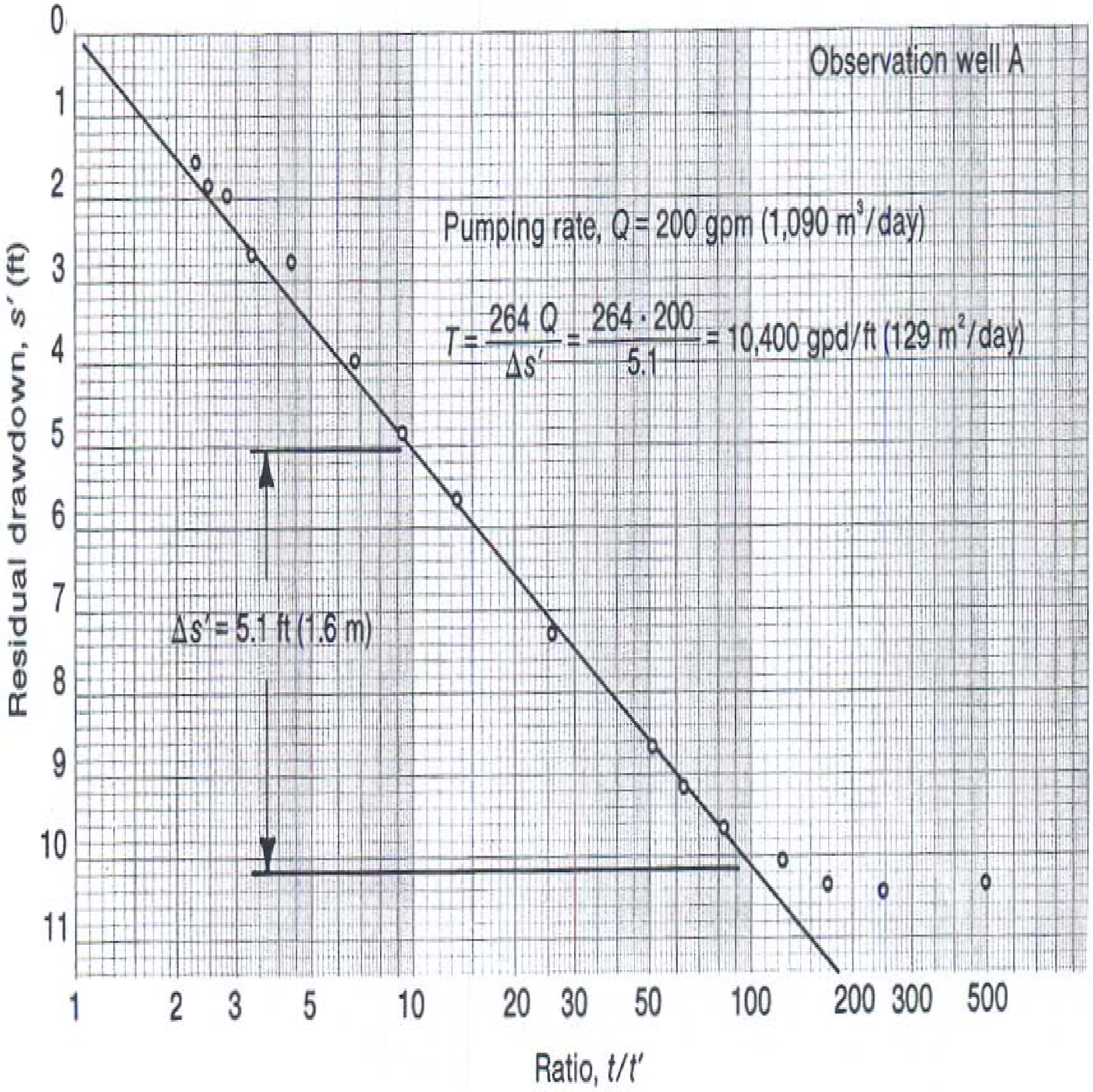
GLORIETA GEOSCIENCE, INC.

Computation of T from recovery test

Time during recovery period increases to the left. Flow rate must be constant to calculate T from recovery data.

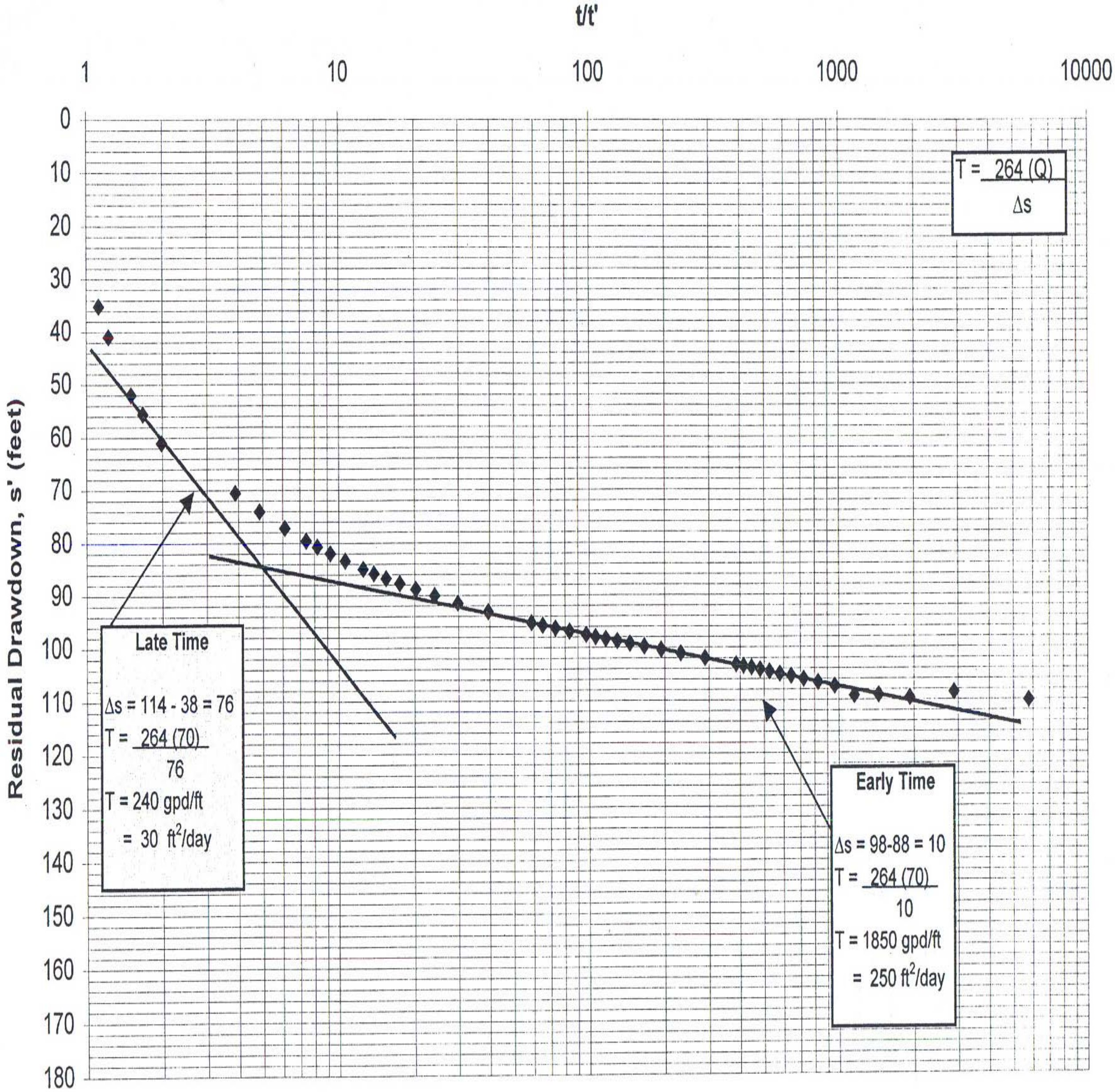
Where;

s'= residual drawdown (depth to water below static level after pumping has stopped in ft)
t = time since pumping started (min)
t'= time since pumping stopped (min)



From Driscoll

Recovery Graph for 96-Hour Pumping Test, RG-72559, Rancho San Lucas Well No. 2, Q = 70 GPM



GLORIETA GEOSCIENCE, INC

STORATIVITY
Time –Drawdown Graph

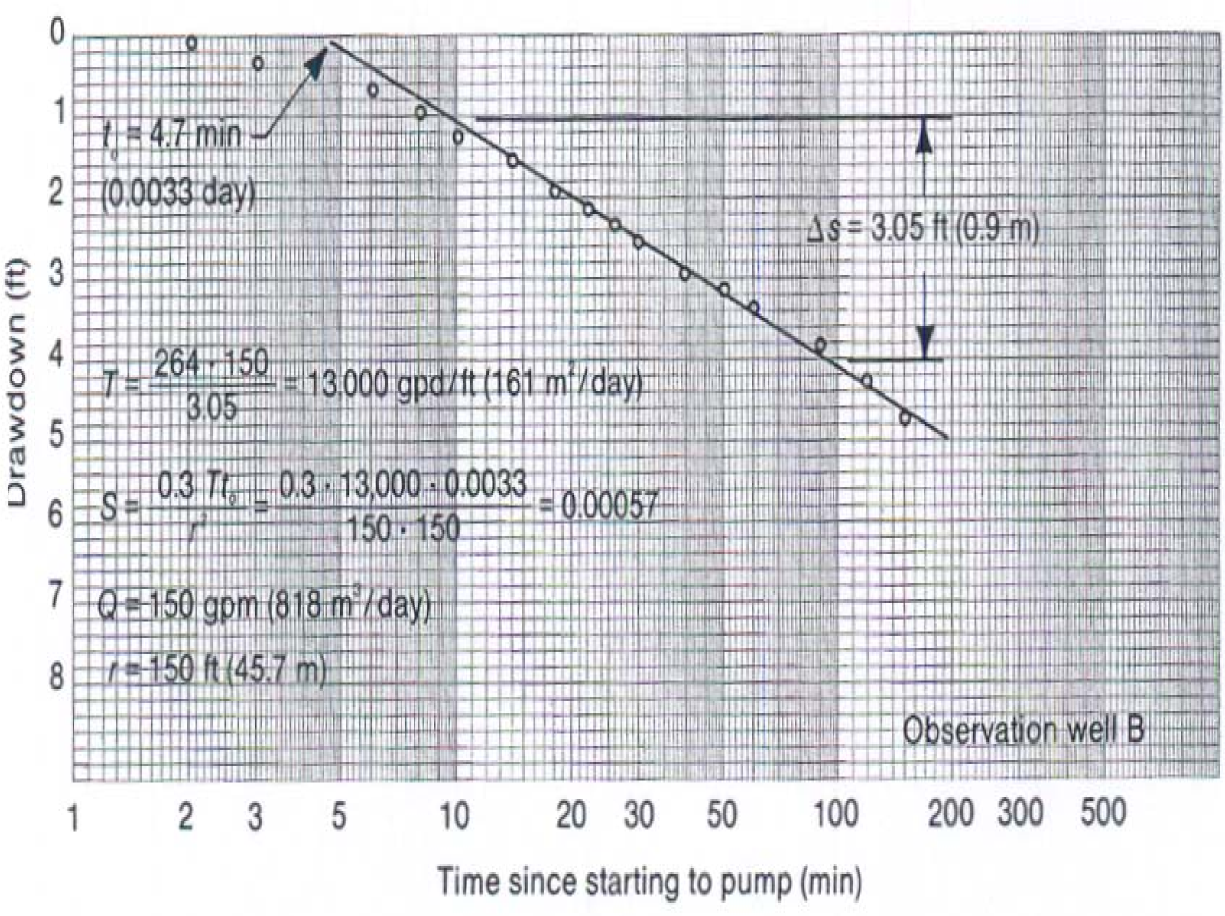
Drawdown data for an observation well is required to compute S.

$S = 0.3\ Tt_0/r^2$

Where

T = transmissivity (gpd/ft)
$t_0 =$ intercept of the straight line at zero drawdown in <u>days</u>
r = distance in ft. from the pumped well to the observation well

Or $S = 2.25\ Tt_0/r^2$ for t_0 in minutes and T in ft^2/day



From Driscoll

3. Computation of Aquifer Parameters Using Specific Capacity

<u>Specific Capacity (SC)</u>

- SC = flow rate (Q) of a well divided by the observed drawdown (s) after a given time has elapsed.
- Units – gallons per minute per foot of drawdown (gpm/ft).
- Used to provide a rough estimate of T when data are lacking
- SC is affected by the length of the test and decreases with time.

For a rough approximation the following equations may be used to estimate T.

T = Q/s x 300

SC = Q/s

Where

T = transmissivity (ft2/day)

s = drawdown (ft)

Q = flow rate (gpm)

SC = specific capacity (gpm/ft)

<u>Example</u> - A well driller pumped an alluvial well at 10 gpm and observed a drawdown of 2 feet. Find T.

T = Q/s x 300 = 10 gpm/2 ft x 300 = 1,500 ft2/day

GRAPHS TO ESTIMATE T FROM SPECIFIC CAPACITY

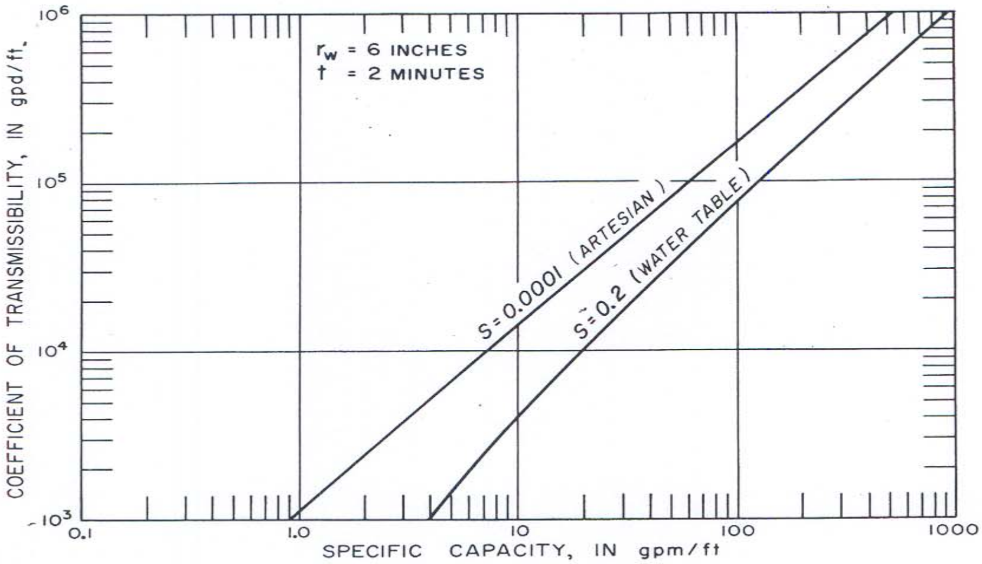


Fig. 5.4 Graphs of specific capacity versus coefficient of transmissibility for a pumping period of 2 minutes. (*From Walton, 1962.*)

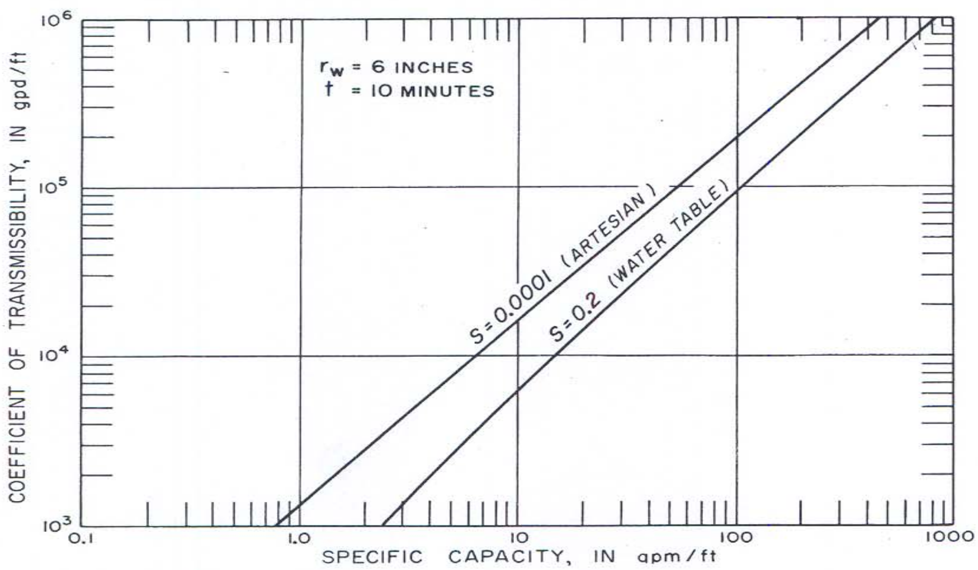


Fig. 5.5 Graphs of specific capacity versus coefficient of transmissibility for a pumping period of 10 minutes. (*From Walton, 1962.*)

GRAPHS TO ESTIMATE T FROM SPECIFIC CAPACITY

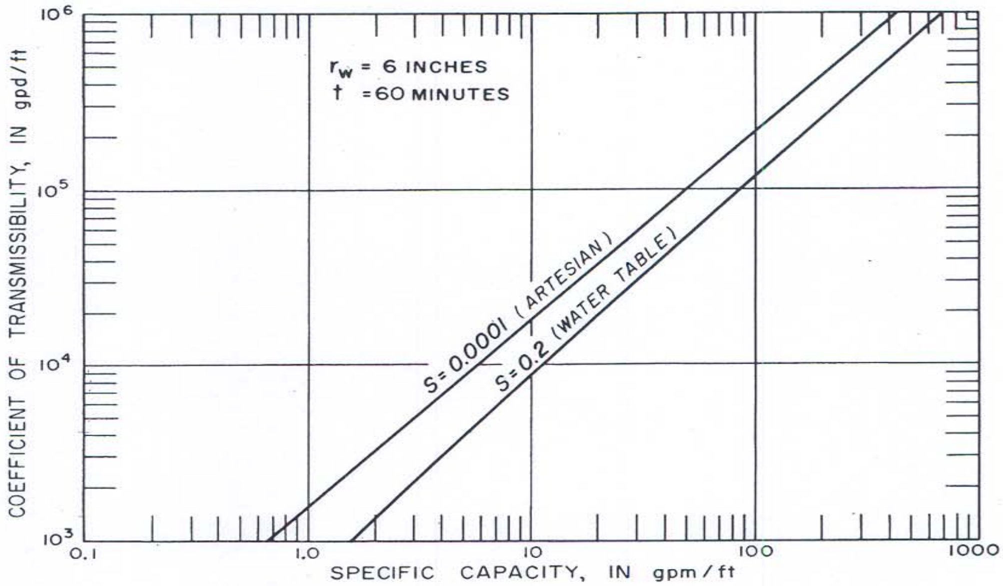


Fig. 5.6 Graphs of specific capacity versus coefficient of transmissibility for a pumping period of 60 minutes. (*From Walton, 1962.*)

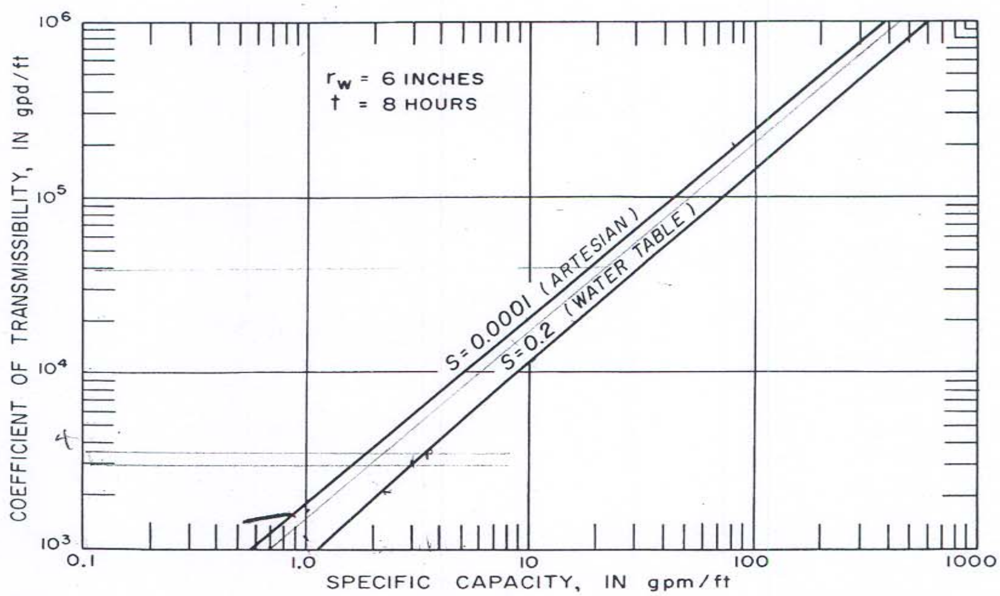


Fig. 5.7 Graphs of specific capacity versus coefficient of transmissibility for a pumping period of 8 hours. (*From Walton, 1962.*)

GRAPHS TO ESTIMATE T FROM SPECIFIC CAPACITY

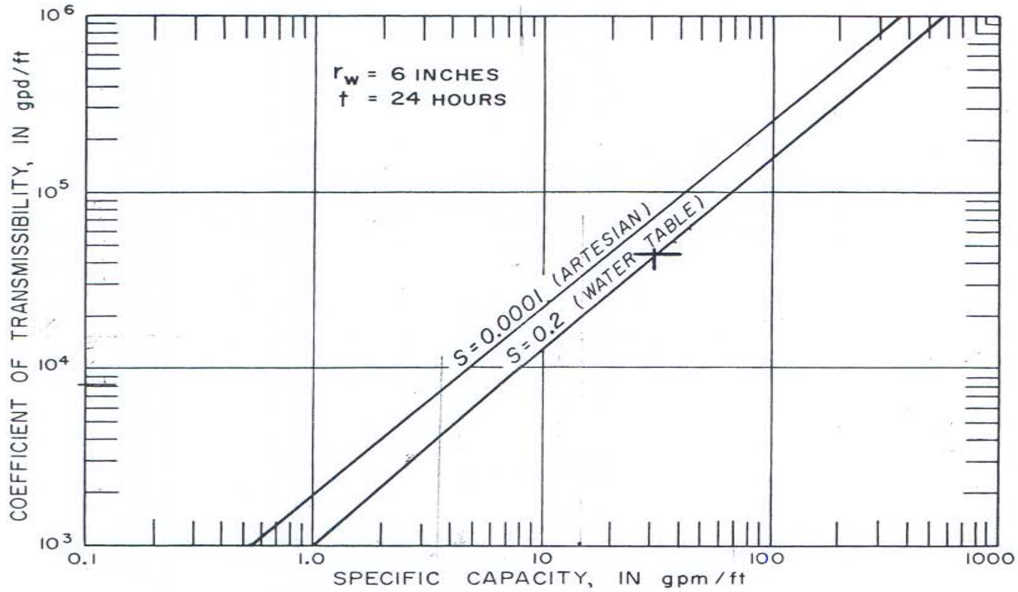


Fig. 5.8 Graphs of specific capacity versus coefficient of transmissibility for a pumping period of 24 hours. (*From Walton, 1962.*)

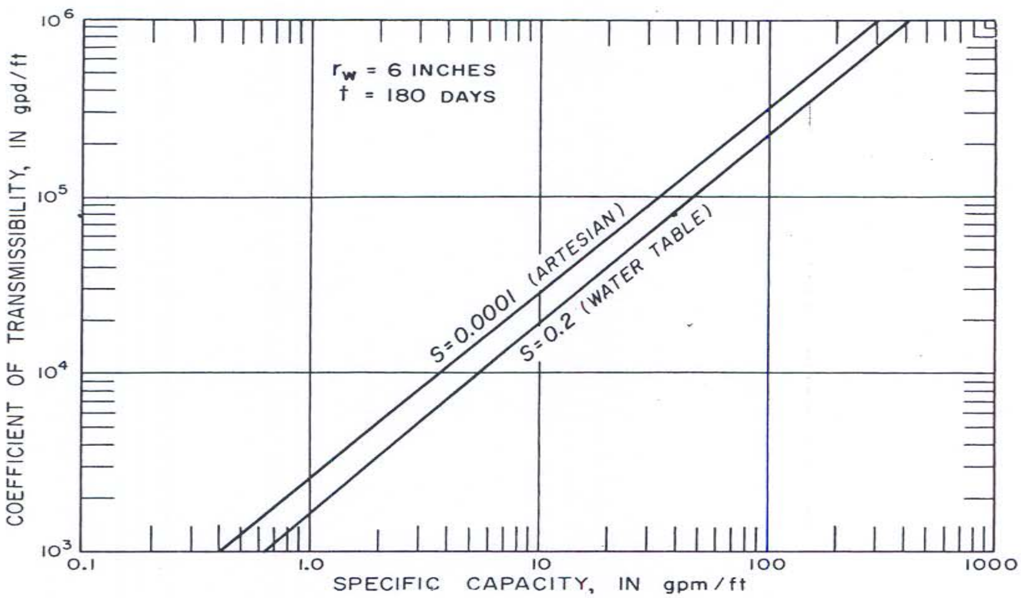
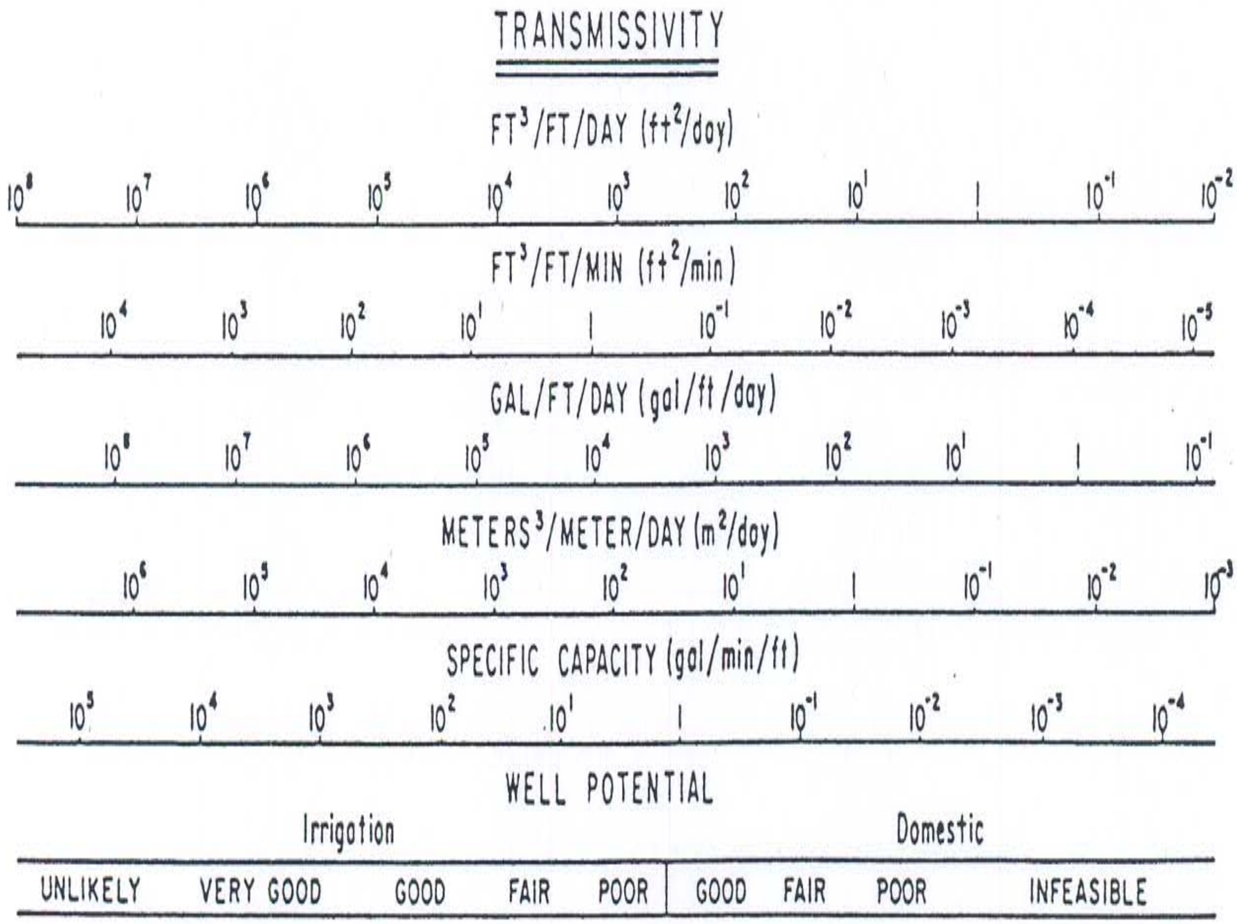


Fig. 5.9 Graphs of specific capacity versus coefficient of transmissibility for a pumping period of 180 days. (*From Walton, 1962.*)



NOTES: Transmissivity (T)=KM where
K=Permeability
M=Saturated thickness of the aquifer
Specific capacity values based on pumping period of approximately 8-hours but are otherwise generalized.

(Ground Water Manual, 1977)

From US Dept. of the Interior, 1981

SECTION III
MODELS

TABLE OF CONTENTS

SECTION III
MODELS

1. Types of Models

Definition of Model

- A tool designed to represent a simplified version of reality.

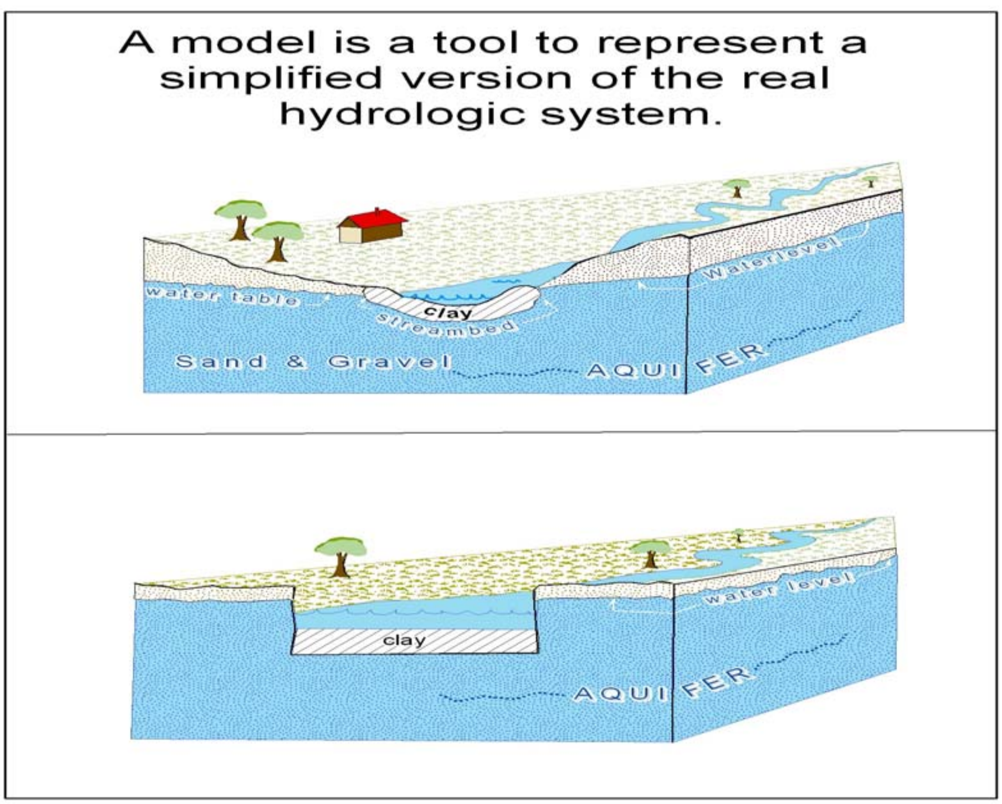
- The reliability depends on how well the model approximates field conditions.

Conceptual Model

- A cartoon showing the most important physical features that affect the problem you are trying to solve.

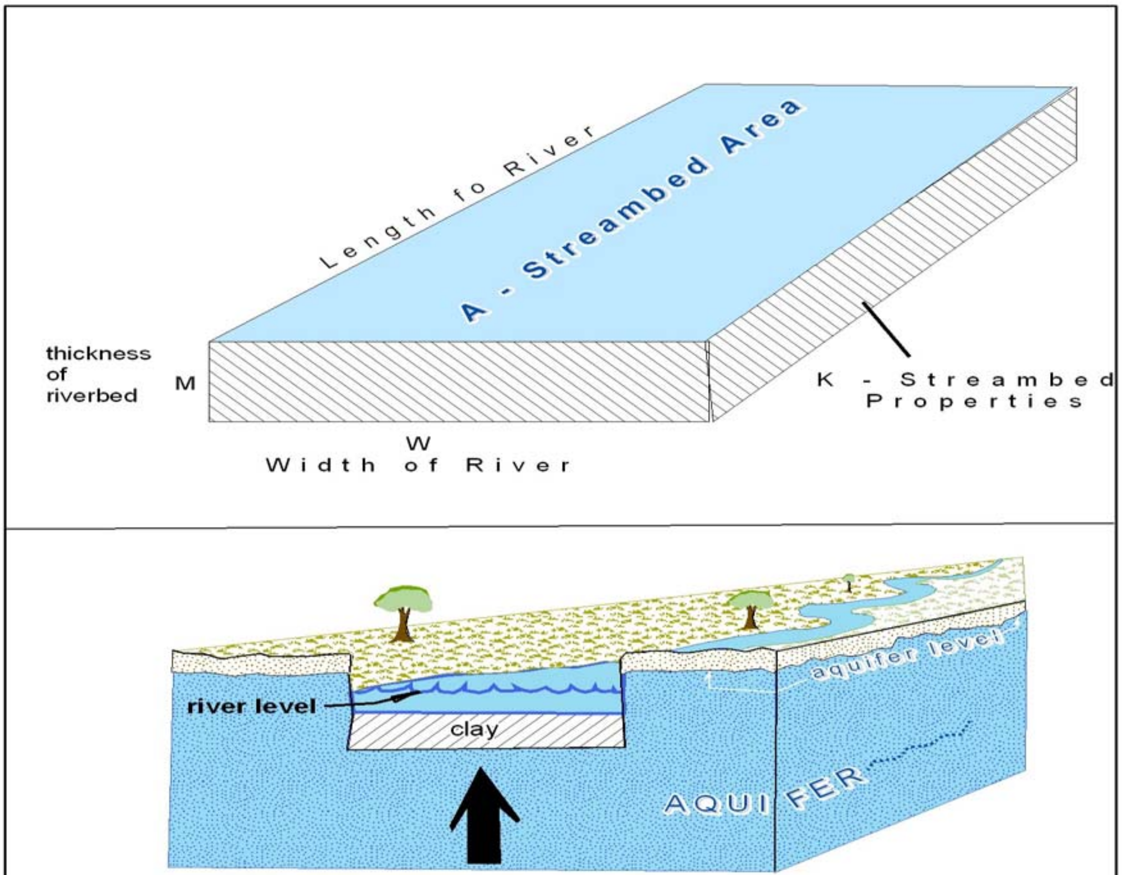
- Conceptual model is typically represented with a sketch, which may show extent of aquifers, boundaries, movement of groundwater, estimates of the aquifer parameters and other terms.

- Development of a conceptual model is the first step in preparing a model to compute well impacts (analytical or numerical).



Mathematical Model

- All aquifers are complex, and not every detail can be simulated explicitly.
- The key is to simulate the features and boundaries that have an important effect on groundwater (the conceptual model).
- To describe the aquifer mathematically, simplifying assumptions are required.



Flow From Aquifer to River =

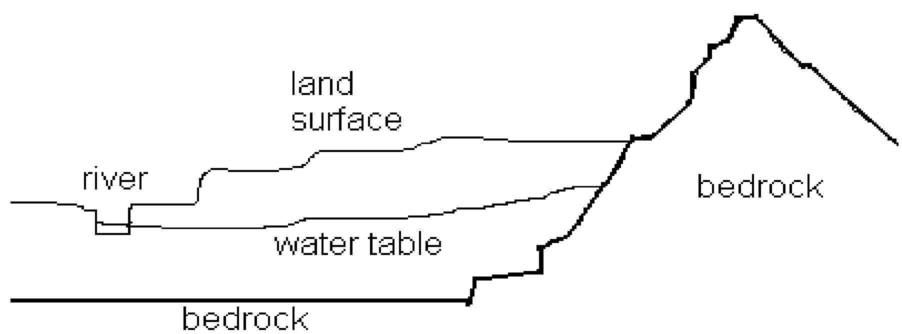
$$\left(\frac{A \times K}{M}\right)(\text{River Level} - \text{Aquifer Level})$$

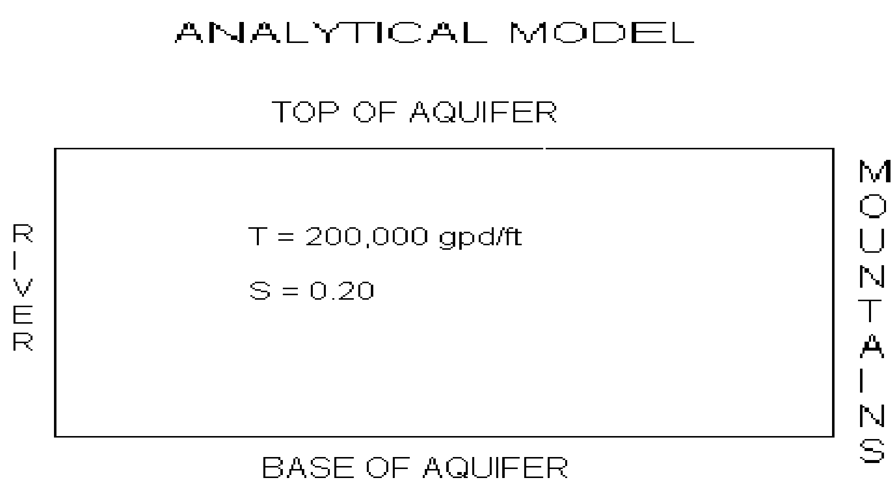
Mathematical Representation of an Aquifer.

Analytical Models

Theis and Glover/Balmer methods are analytical models. For these methods, the hydrologic system has been simplified to a single equation or set of equations that may be solved by hand.

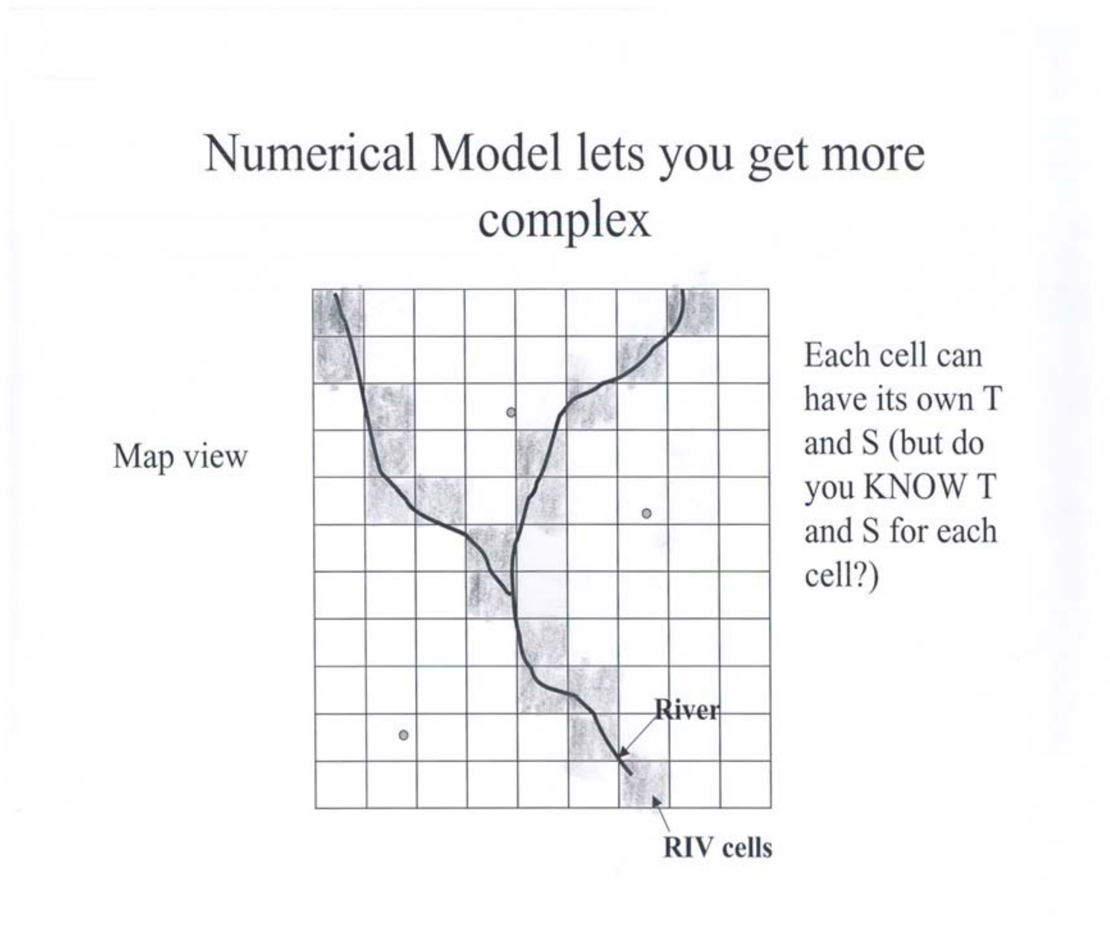
SIDE VIEW



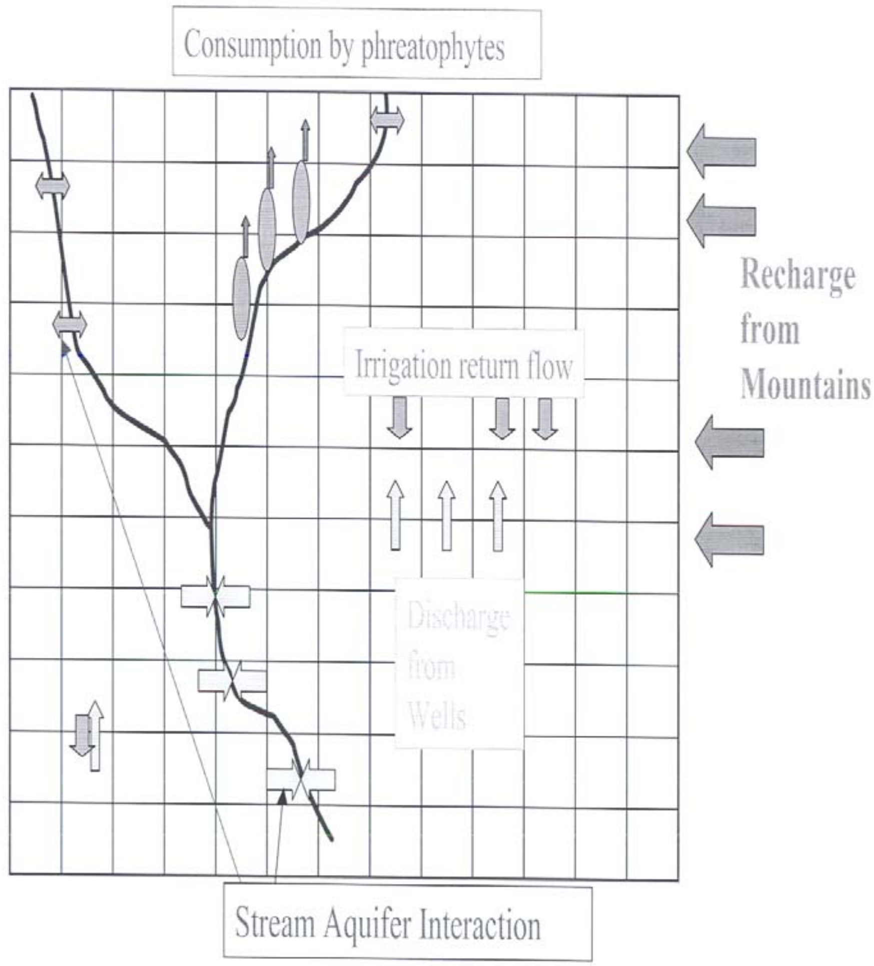


Numerical Model

- For a numerical model, the aquifer is subdivided into blocks (model cells) and a set of hydrologic properties may be assigned to each cell.
- Numerical models allow aquifers and boundaries to be simulated more realistically.
- A computer must be used to solve the equations.
- MODFLOW is the computer program typically used.



Numerical Models can simulate the entire groundwater cycle



SIDE VIEW

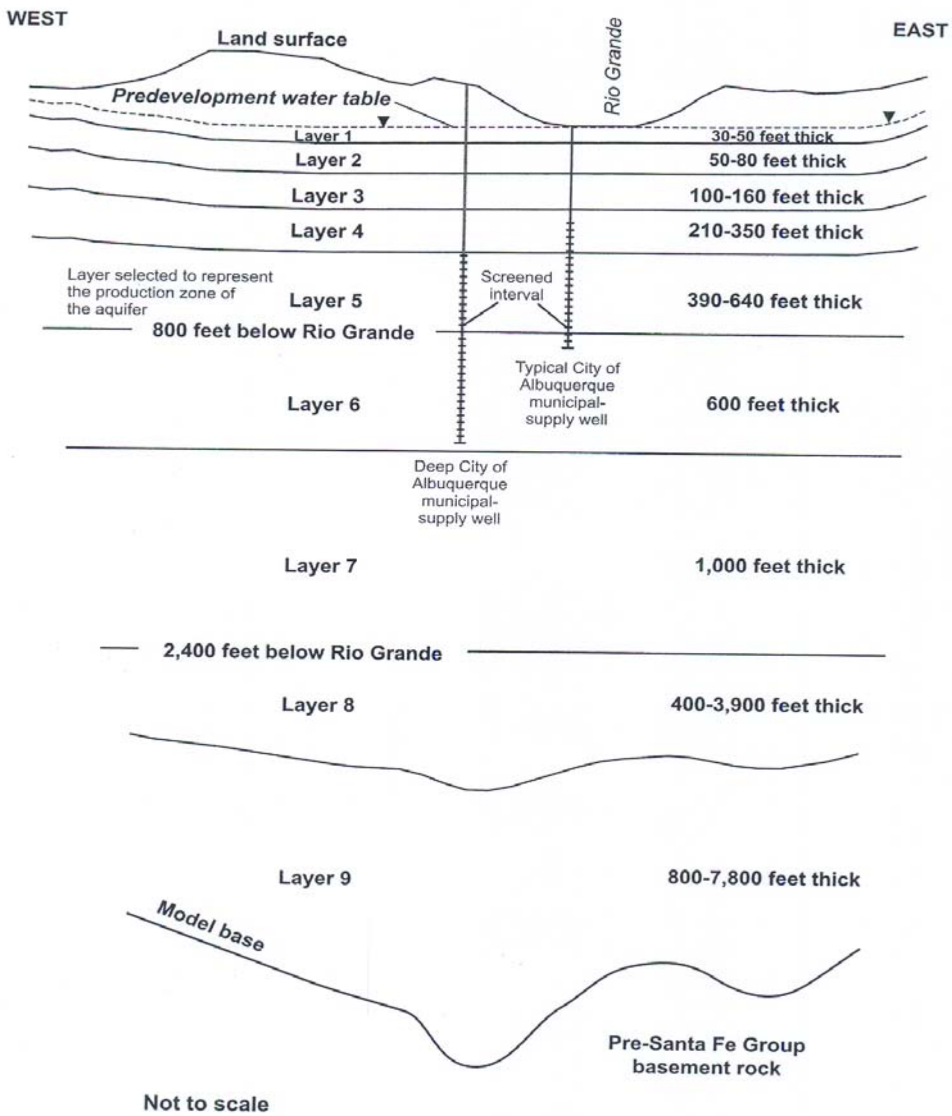


Figure 7. Configuration of layers in the McAda and Barroll (2002) model (modified from McAda and Barroll, 2002, fig. 8).

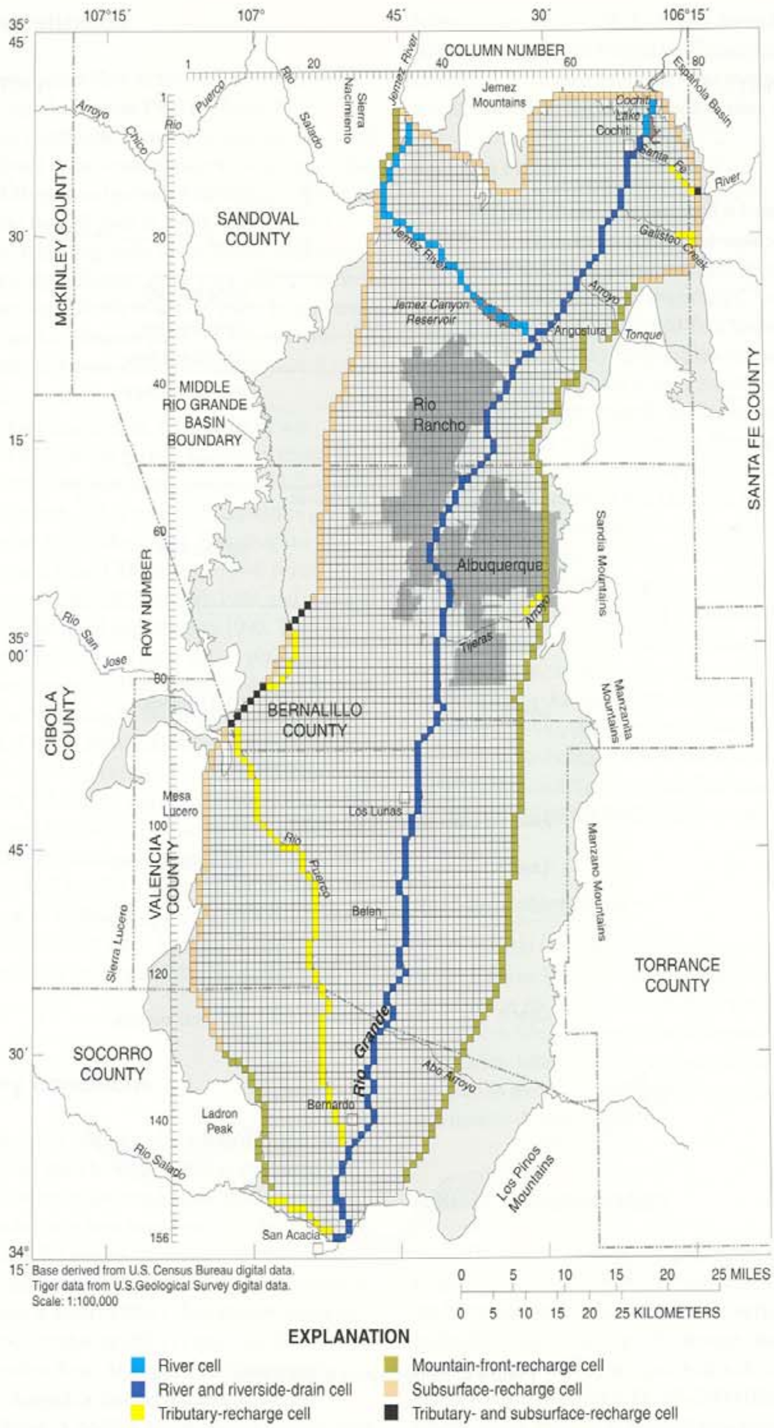


Figure 7. Model grid and active model cells in layer 1.

From McAda and Barroll

Model Calibration

- Model calibration is the process of adjusting the aquifer parameters to duplicate observed heads and other information such as base flows and aquifer test data.
- Not unreasonable to adjust these parameters within their plausible range because they are not precisely known
- If the model is able to duplicate the field observations it will hopefully be able to accurately estimate well impacts into the future.
- Model calibration provides a non-unique solution: more than one set of input values may result in recreating observed conditions.
- Although a model is said to be calibrated, this does not necessarily mean that the model is appropriate to process water rights applications.
- Un-calibrated models are appropriate to use in some situations, especially in cases with little data.
- Two types of calibration: steady-state and transient

Steady – State Calibration

Uses pre- development conditions, such as water levels, as calibration target

T, K, natural recharge/discharge, and boundary conditions may be modified within plausible range to obtain acceptable stead-state calibration

S values are not a variable in steady-state calibration

Calibration does not rely on well diversion data, which are often poorly documented

Lack of water level data, or data of good quality, may be a problem

Steady – state parameters must also provide acceptable results in transient calibration

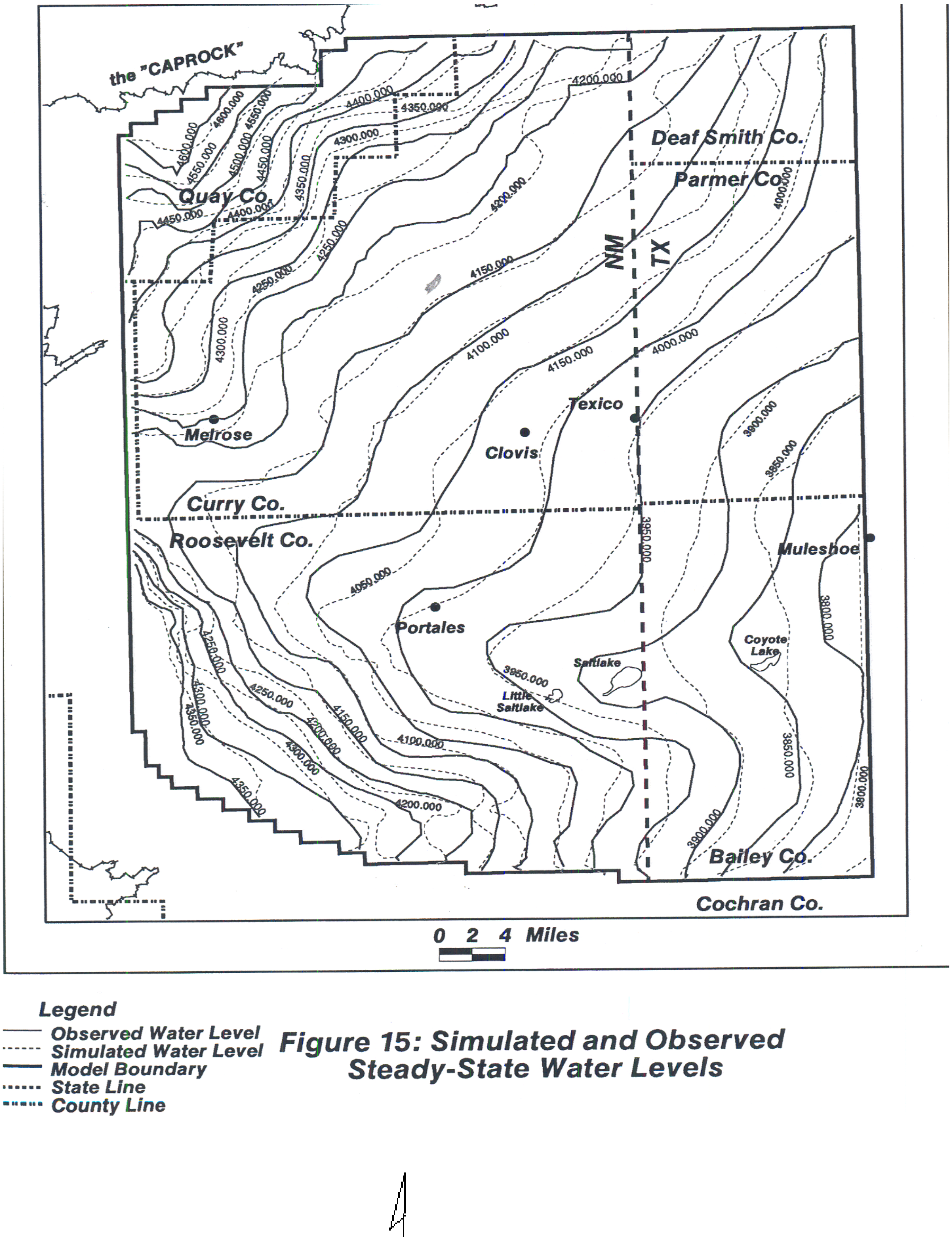


Figure 15: Simulated and Observed Steady-State Water Levels

From Musharrafieh and Logan, 1999

Transient Calibration

- Relies upon changing conditions over time, such as drawdown, as a calibration target
- T, K, S, recharge, discharge, and boundary conditions may be modified within plausible range to obtain acceptable calibration
- Calibration relies on well diversion and water level decline data
- Calibration is limited by data availability
- Lack of well diversion information is often a problem
- Parameters obtained from transient calibration must provide acceptable steady – state calibration

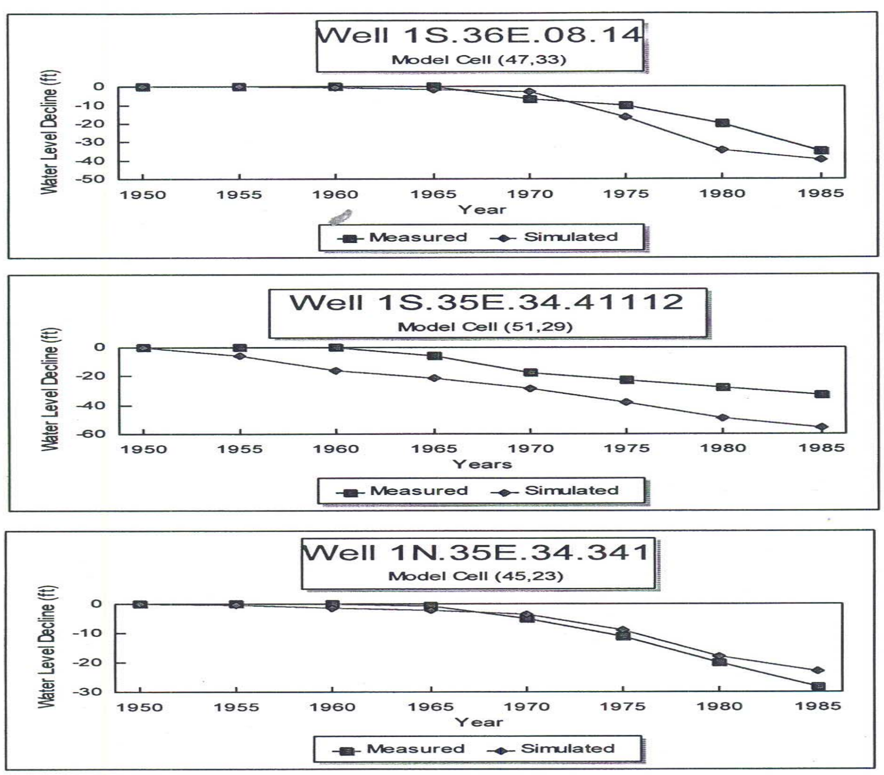


Figure 18. Simulated versus Observed drawdowns in Selected Wells (Cont.).

March 5, 1999
CPB7.WPD

40

From Musharrafieh and Logan, 1999

Example Problem – Calibrated aquifer parameters vs. aquifer test data.
A numerical model was developed and calibrated in the late 1980s. Very little data was available along the northern 1/3 of the model. Model calibration provided estimates of T and S. In 2006 a firm proposes to drill 15 wells in this area for an appropriation of 10,000 afy. The nearest wells are 5 miles away. The firm drills an exploratory well and performs an aquifer test. The test was of high quality and provided a T that was much larger than the calibrated value. Should the 1980s version of the numerical model be used to compute impacts?

Due to the relatively large quantity of water requested and the lack of data available in the 1980s, it may be appropriate to try to re-calibrate the numerical model with the new aquifer test results. In this case, using the larger T will increase drawdown estimates at the nearest wells of other ownership.

Example Problem – Steady State vs. Transient Calibration
A consultant develops a model using transient calibration. Observed declines are well produced by the model. Most of the pumpage is for irrigation which is poorly documented. Should the consultant perform a steady-state calibration?

Yes. The transient calibration is questionable given the lack of pumpage data. The calibration can only be as good as the data it is based upon. A steady-state calibration would not require historical pumpage data and would not be influenced by this data limitation. The same set of aquifer parameters should provide reasonable results for both the steady state and transient calibrations.

Principal of Superposition

Drawdown or stream depletion from a well can be calculated even if the recharge rate, the actual heads, the gradients, or even the pumping stresses from other wells is unknown.

Superposition applies to linear systems

- T does not change (no greater than 20 % change in saturated thickness)
- Natural recharge remains unchanged
- Natural discharge remains unchanged
- Lakes, streams and drains that are well connected to the groundwater system will remain well connected to the groundwater system.

For linear systems, drawdown is proportional to flow rate (double the flow rate you double the drawdown).

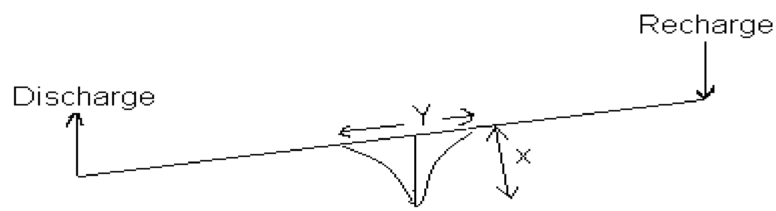
Principal of Superposition

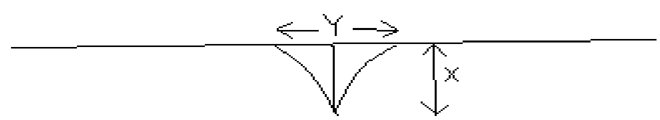
Top diagram below represents actual system.

The bottom diagram represents simpler problem using the principle of superposition.

The drawdown from each model will be the same.

SIDE VIEW OF WATER TABLE





OSE Regional Basin Scale Models

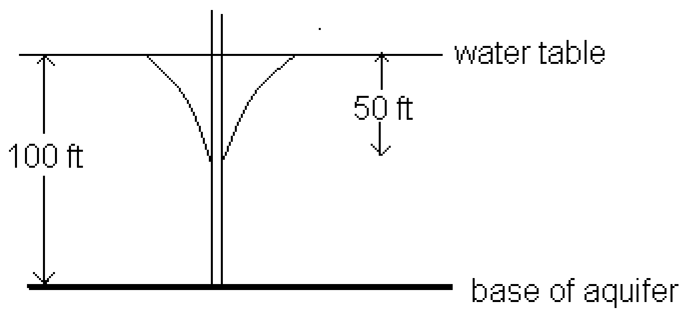
- We typically develop a numerical non-superposition model.
- After model calibration, a superposition numerical model may be prepared to process well applications if the system is linear.
- Superposition models are typically easier to apply compared to non-superposition models.
- Although a numerical model is available, it may be necessary to use an analytical model to estimate impacts to nearby wells.
- Analytical models are typically used in superposition mode.

OSE Local Scale Models

- We typically use a superposition analytical model

Example 1.
A well is proposed in Curry County. The aquifer is 100 feet thick and has a uniform K. A T was obtained by multiplying the saturated thickness (100) by K. Using Theis, 50 feet of drawdown is computed at the proposed well. What conclusions can be reached?

Example 1 SIDE VIEW



<u>Conclusions</u>

- Since drawdown exceeds 20 % of the aquifer thickness, T is not linear
- T will decline significantly (by ½ in this case) as the saturated thickness declines
- Actual drawdown will be greater than 50 feet
- Superposition principal does not apply, to obtain the best estimate a numerical model using K and saturated thickness would be necessary

Example 2
A well is proposed adjacent to a well of other ownership that has an allowable drawdown of 30 feet. The application is for 100 afy. The estimated drawdown on the nearest well is 60 feet. What amount may the proposed well pump so drawdowns are not excessive?

Drawdown is proportional to flow rate.

$$\frac{\text{Allowable flow rate}}{\text{Allowable drawdown}} = \frac{\text{Proposed flow rate}}{\text{Drawdown for proposed rate}}$$

$$\text{Allowable flow rate} = \frac{\text{Proposed flow rate}}{\text{Drawdown for proposed rate}} \times \text{Allowable drawdown}$$

Allowable flow rate = 100 afy/60 ft x 30 ft = 50 afy

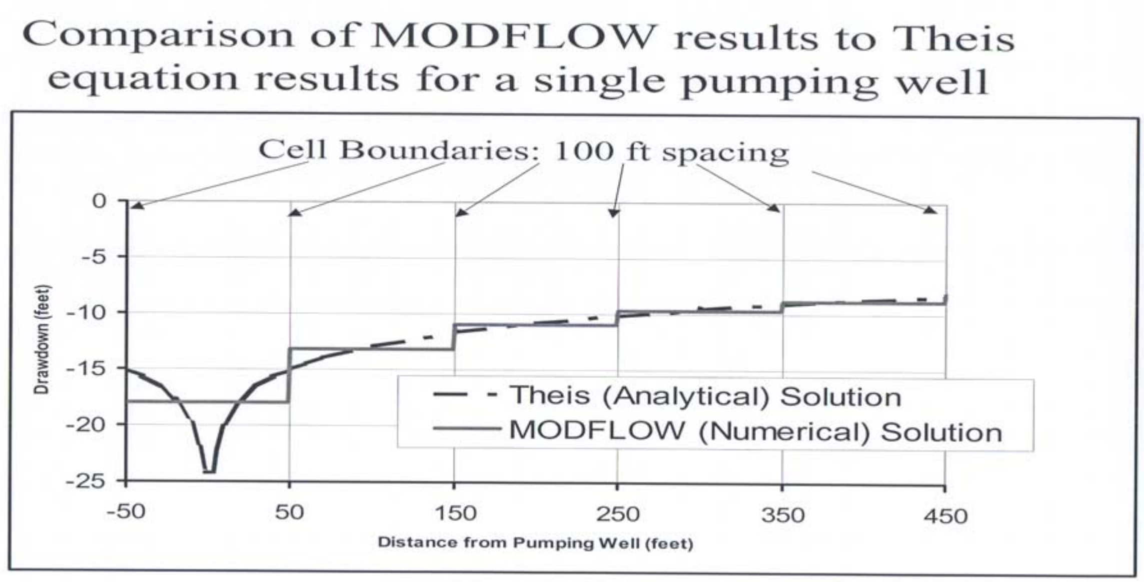
2. Comparison Between Analytical and Numerical Models

Analytical Models

- Well suited to evaluate local impairment
- Well suited for situations with little data
- Well suited for situations with uniform conditions
- Well suited if impairment is unlikely
- Analytical models are often the first type of model used to assess the need to develop a numerical model
- Easy and quick to develop
- Provides accurate estimates when conditions are right

Numerical Models

- Well suited when numerous details are important
- Allows a greater degree of complexity
- Well suited for situations with abundant data
- Capable of providing more accurate estimates than analytical methods when conditions are right
- Requires more expertise and time to develop



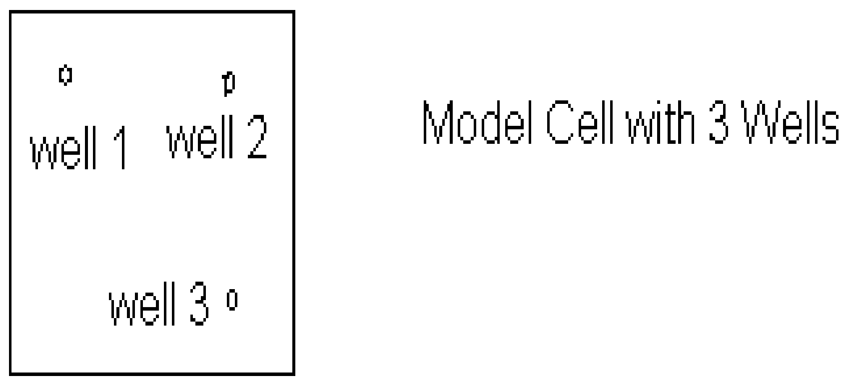
SIDE VIEW

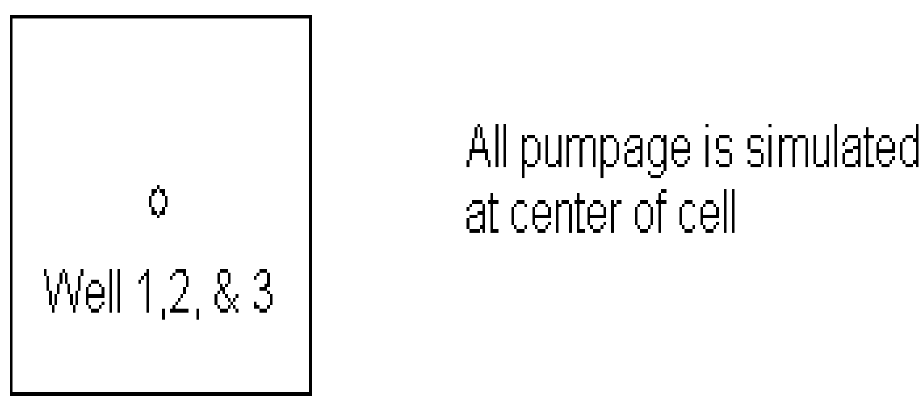
3. Numerical Models

Pumping Simulation

All pumpage from wells is simulated by a single well at the center of the model cell.

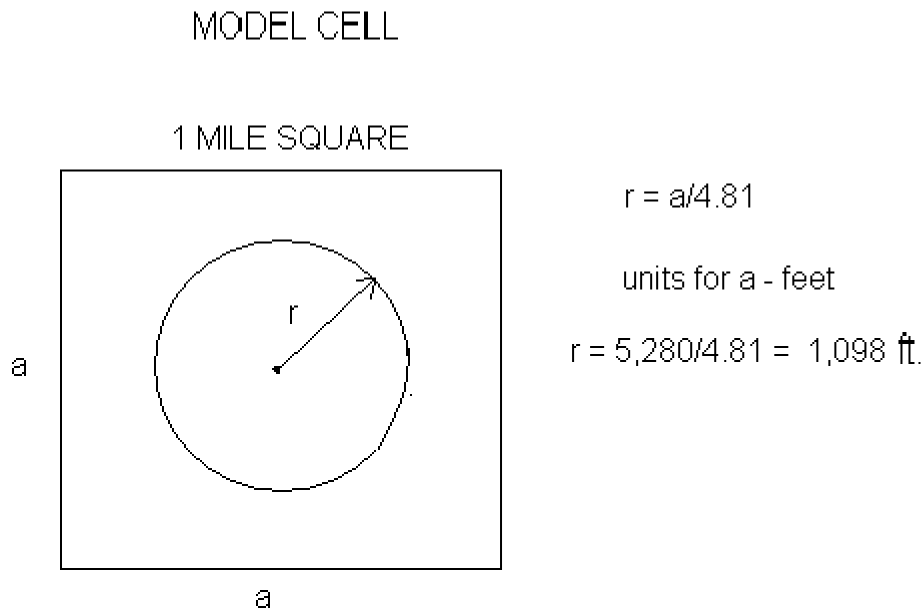
MAP VIEW





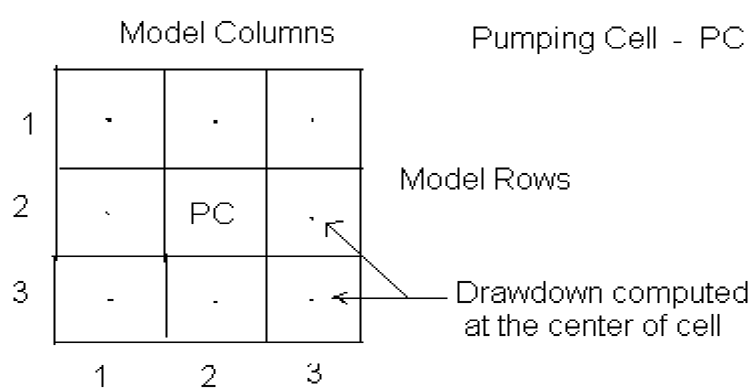
Drawdown Simulation

Case 1 - Drawdown in a pumping cell represents drawdown at radius r.

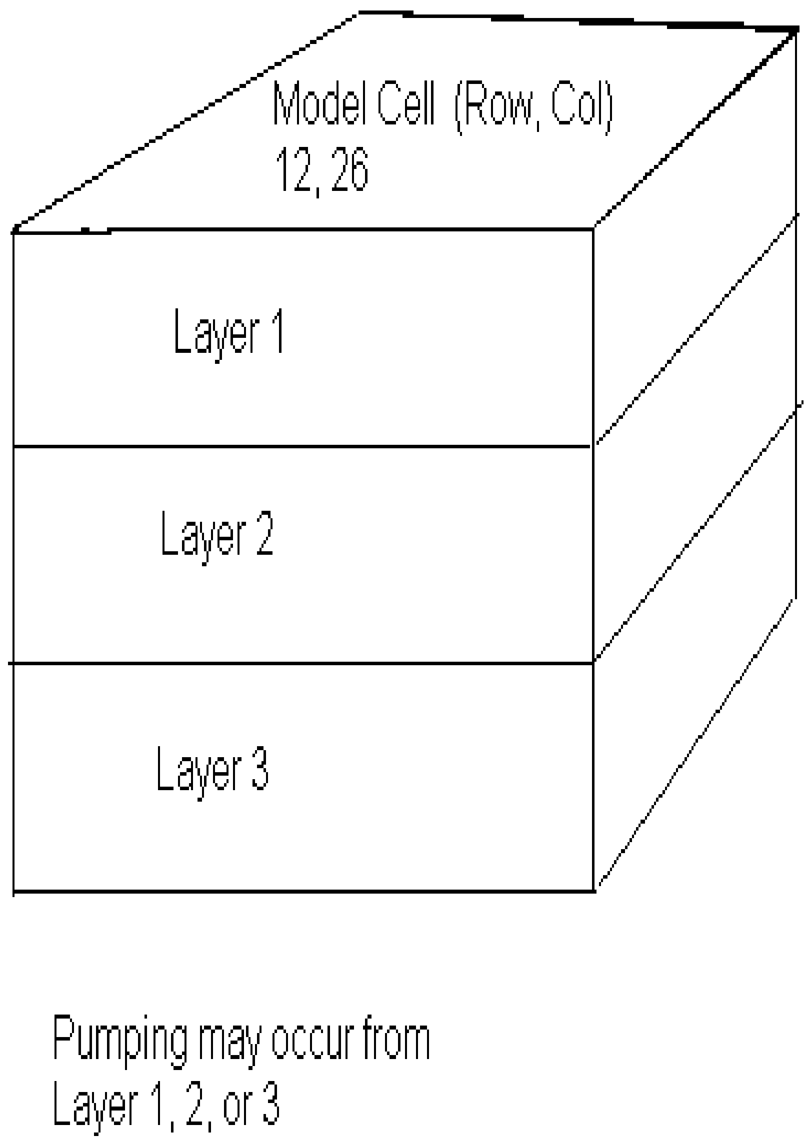


Case 2 – Drawdown at other cells represents drawdown at center of cell.

MAP VIEWS



Model Layers for Cell 12, 26



Example 1 - Calculating Drawdown at Nearby Well
A proposed well is located in the same model cell as the protestant's well.
The model estimates a nodal drawdown at radius r (1,098 ft). Since Well B is located 500 feet from the proposed well, the nodal drawdown may underestimate the drawdown.

The equation for estimating drawdown at any point within the cell follows:

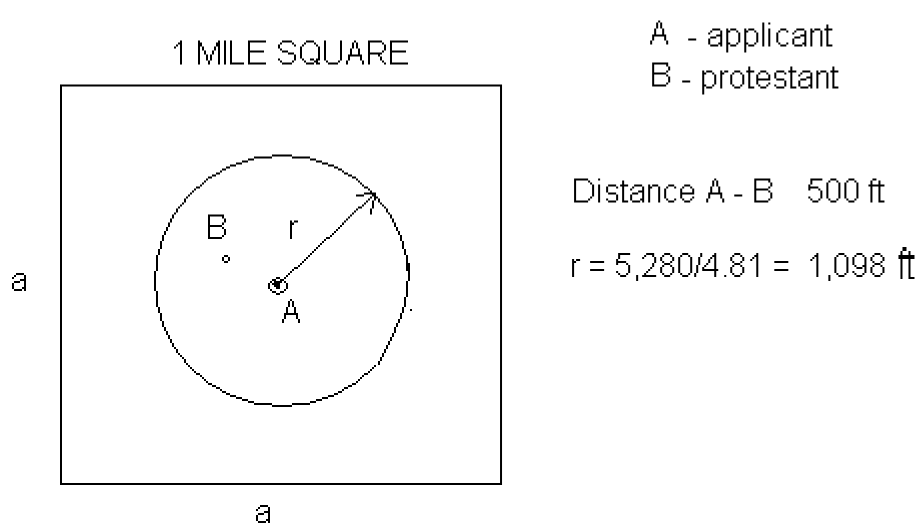
$$s = 0.3665(Q/T)\log(a/4.81r))$$

where

s= additional drawdown to be added to calculated nodal value from model in ft.

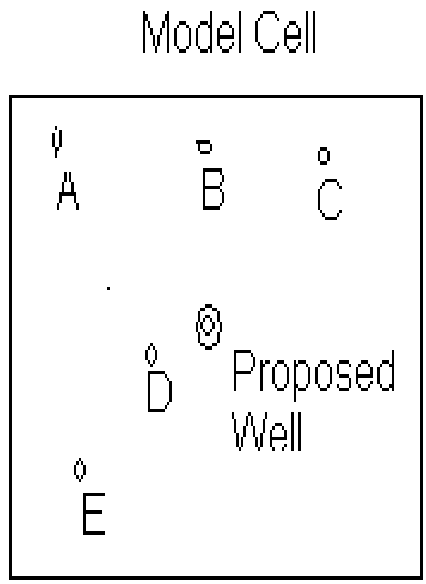
T=transmissity in gpd/ft

Q= pumping rate in gpd



MAP VIEW

Example 2 – Although a numerical model is available, you may still need to use the Theis equation depending upon the scale of the problem.



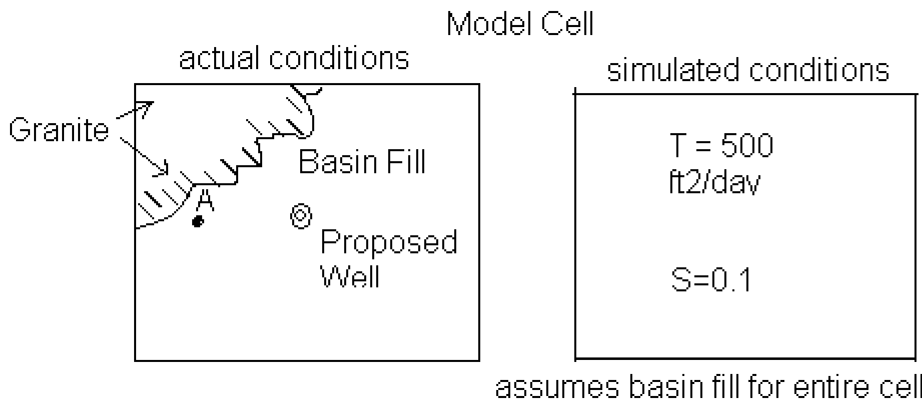
Well A, B,C, D, & E are nearby wells of other ownership

Since all the wells are located in a single model cell, it may be appropriate to use the Theis Method to compute drawdown at each well

MAP VIEW

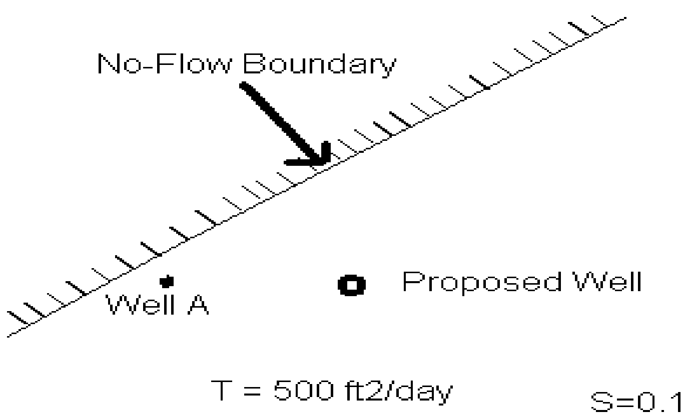
Example 3 – Although a numerical model is available, you may still need to use the Theis equation depending upon assumptions made in the numerical model.

MAP VIEWS



A well will produce from a basin fill aquifer. A basin numerical model provides a T and S for the cell representing the basin fill. These values apply throughout the cell although a part of the cell is granite which probably has a much lower T and S. Well A represents the nearest well of other ownership. To calculate impacts, the Theis equation should be used so the influence of the granite may be included

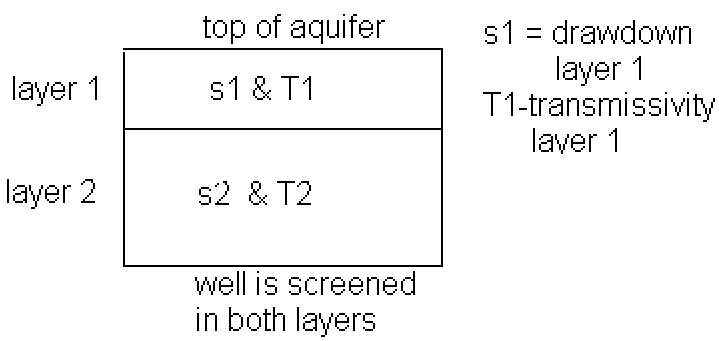
T = 0 S= 0 Theis model to estimate impacts on Well A.



Example 4

A numerical model estimates the drawdown on a well that produces from layers 1 and 2. Layer 1 and 2 each have a different T. What is the total drawdown on the well?

SIDE VIEW

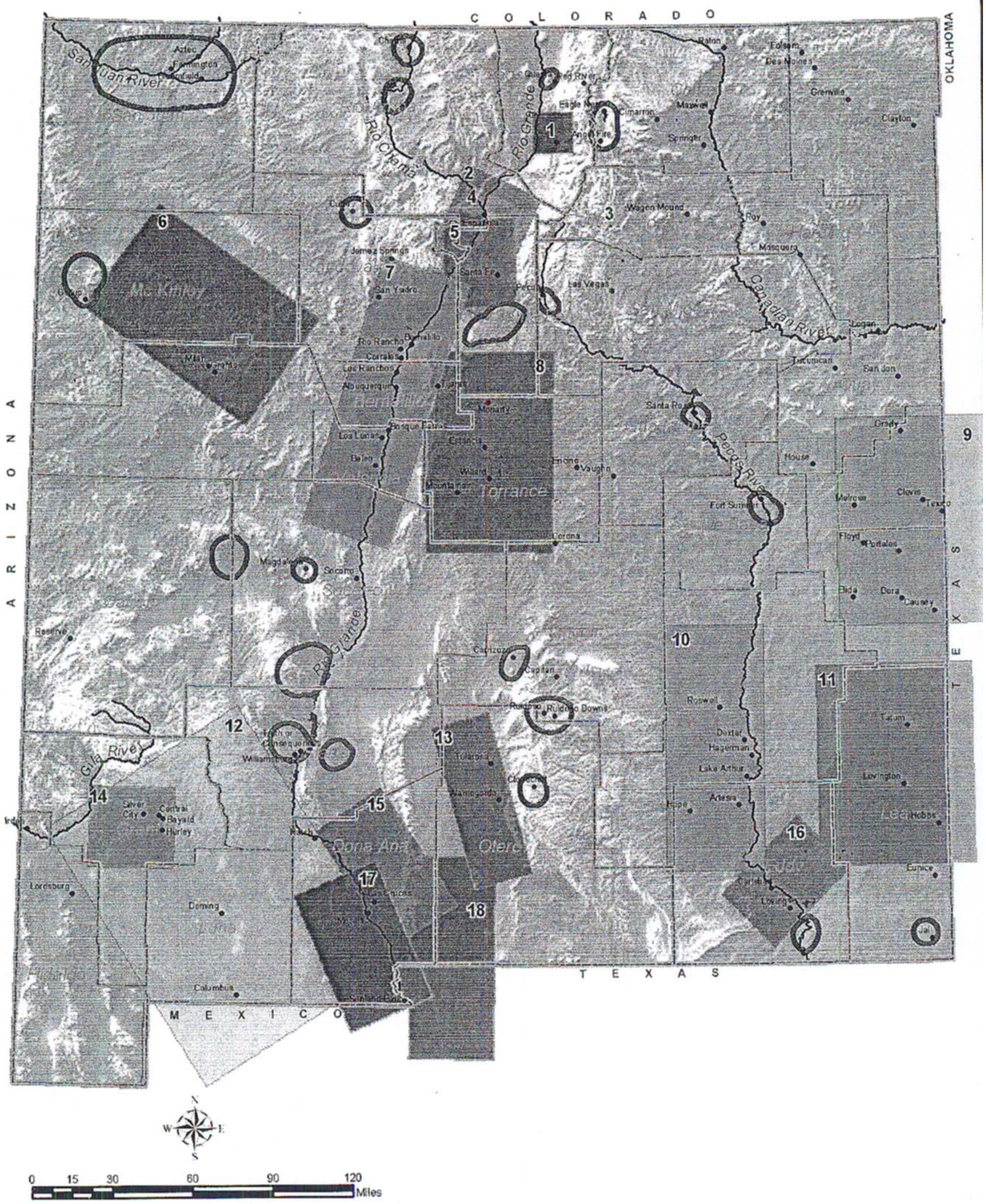


The drawdowns cannot be added together to obtain the total drawdown. The total drawdown is a weighted average.

Drawdown in layer 1 - s_1
Drawdown in layer 2 - s_2
T of layer 1 - T_1
T of layer 1 - T_2

$$\text{Total Drawdown} = \frac{s_1 T_1 + s_2 T_2}{T_1 + T_2}$$

OSE Models



COLORADO
OKLAHOMA
ARIZONA
TEXAS
MEXICO
San Juan River
Rio Chama
Rio Grande
Canadian River
Pecos River
Gila River
McKinley
Torrance
Dona Ana
Otero
Lea
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Raton
Clayton
Santa Fe
Las Vegas
Albuquerque
Rio Rancho
Los Lunas
Belen
Socorro
Roswell
Artesia
Carlsbad
Hobbs
Lovington
Tatum
Clovis
Portales
Fort Sumner
Deming
Lordsburg
Columbus
Silver City
Alamogordo
Tularosa
Tucumcari
Santa Rosa
Reserve
Eunice
0
15
30
60
90
120
Miles

Map References

Note – The models listed may or may not be appropriate to use to evaluate water rights applications. They are presented merely to show the distribution of models that may be available.

Explanation:

Model Name (Principal Author, Date)

1 Taos (Burke, Draft)
2 Espanola (Logan, Barroll, 1998)
3 Mora (Shomaker, 1990)
4 Modified Hearne (BGW, 1997)
5 Modified McAda-Wasiolek (Core, 1996)
6 Bluewater (Spinks, 1978)
7 OSE Middle Rio Grande (Barroll, 2001)
8 Estancia (Shafike, 2000)
9 Curry (Musharrafieh, 1999)
10 Roswell (Keyes, 1999)
11 Lea (Musharrafieh, 1999)
12 Mimbres (Hanson, etal, 1994)
13 Tularosa (Morrison, 1989)
14 Silver City (Johnson, 2000)
15 Jornada (Shomaker, 2000)
16 Carlsbad (Barroll, 2002)
17 OSE Lower Rio Grande (Barroll, 2000)
18 Hueco (SSP&A, 1988)

Local Area Models

4. THEIS EQUATION – DRAWDOWN ANALYSIS

The Theis equation follows:

$$s = \frac{114.6\ Q\ W(u)}{T}$$

s = drawdown (feet)
Q = pumping rate (gpm)
T = transmissivity (gpd/ft)

W(u) = is read "well function of u" and represents an exponential integral

$$u = \frac{1.87\ r^2 S}{Tt}$$

r = radius (ft) from center of pumped well to point where drawdown is computed

S = storage coefficient (dimensionless)

t = time since pumping started (days)

SELECTED THEIS EQUATION ASSUMPTIONS

- Homogeneous aquifer (T and S are constant throughout aquifer)
- No change in T with change in saturated thickness
- No recharge
- Fully penetrating well
- All water removed comes from the aquifer
- 100 % well efficiency
- Potentiometric surface has no slope

OSE THEIS COMPUTER PROGRAM

The Theis program may be obtained from snap server L under analytical programs.

DOCUMENTATION FOR THEIS EQUATION PROGRAM, 1994

A set of THEIS programs were originally written by Mike Spinks (of the NM SEO) in the 1980's. The programs were combined and rewritten, and problems with two-boundary systems were corrected (involving image wells) in 1992 by P. Barroll, of the NM SEO. Another correction was made by P. Barroll in 1994, which only affects systems that have more than one pumping well, and then only if the wells have differing pumping histories.

GENERAL INFORMATION

Pumping wells are placed at locations specified by user. Each well may have an independent pumping schedule.

A number of observation (calculation) points may be defined. The locations of these points may be entered one-by-one, or the specifications for a grid of observation points may be entered.

The program checks whether any observation point is located at a pumping well. If so, the program relocates the observation point by +.5 feet in the x direction from its original location, and prints a notice to that effect.

When two boundaries are set, the program must calculate an infinite series of images for each well and pumping rate at each time step. When three images in a row have no terms greater than the image control factor, then the solution is assumed to have converged, and no more images are calculated.

Units: all distances: feet
all times: days
pumping rate: gpm
T: gpd/ft

Constraints: 200 timesteps
101 observation points
50 pumping wells
13 pumping rates per pumping well
(these can be changed fairly easily by altering the source code)

The user must name the general-purpose output file and graphics output file (if desired). If filename is already in use, user is prompted to enter another filename.

BOUNDARY CONDITIONS

Boundaries (if required) are planes that are parallel to the x-axis placed at y=0 and/or at a specified y.
User is given a choice of boundary conditions:

at y=0
- no boundary at all
- no-flow boundary
- constant head (river) boundary

at y=dscalr (feet), dscalr specified by user
- no boundary at all
- no-flow boundary
- constant head (river) boundary

If there are no boundaries at all, wells and observation points may be placed anywhere.

If a boundary is placed at y=0, all wells and observation points must be placed at y>0.
If a boundary is placed at y=dscalr, all wells and observation points must be placed at y<dscalr.

If two boundaries are specified, then the wells and observation points MUST be between the boundaries.

Beyond the boundaries, drawdowns are theoretically zero, because the no-flow or constant head boundary 'protects' these areas. If the program tried to come up with values in these areas (y<0 or y>dscalr), the results would be meaningless because the program places image wells in these areas.

```
example system:                         MAP VIEW
                         outside system
                       / / / / / / / / / / / / / / / /
        y=dscalr---------------------------------------------------no-flow or  river
                                  +
                                  ↑
                                  |
                          + <- observation points

                   pumping well -> *

                                * <- pumping well

  y|                    +
   └───-      y=0 ---------------------------------------- no-flow or
      x                 / / / / / / / / / / / / / / / / /       river
                          outside system
```

IMAGE CONTROL/ACCURACY

The degree of accuracy of the calculations is, in part, determined by the **image control** parameter: **g**. When a problem has more than one boundary, the analytical solution (for the drawdown at each time and each observation point) contains an infinite series of 'image terms'. The terms in this series tend to get successively smaller (with some fluctuation depending on the exact order in which they are calculated). The program will cut off the series when three terms in a row are smaller than **g**. The value of **g** should be much less than the level of accuracy that you are interested in; we suggest **g** < 0.001, see EXAMPLE 1 below.

INPUT OPTIONS

Input may be entered interactively or by way of an input file.

Interactive input:

The user answers the questions at the keyboard as they are asked by the program.

Input from file:

The user creates an input data file, following the instructions in this documentation, using an editor such as Wordpad (save as text) or notepad (**not** WORD).

The user provides the name of the file to the program when asked.

If file named does not exist, user is prompted to try again.

OUTPUT OPTIONS

This program always produces an output file, which the user must name, which contains all of the input information and the resulting drawdowns at the observation points. The program does not allow the user to overwrite (and thus destroy) an existing program, so the user must give a new name for every output file he or she creates.

In addition, there is an option to create a graphics output file (named by user). This file provides the drawdowns at all x,y observation point locations for timesteps designated by the user (the user designates the first and last time step of interest). This output is designed to be used by contouring software (such as SURFER™). When producing output for contouring purposes, it is best to designate observation points on a grid. You will probably need to adjust some dimensions in TH96S.FOR upward in order to get a fine enough grid to be useful for this purpose.

FORMAT OF OPTIONAL INPUT FILE/ DESCRIPTION OF VARIABLES

All input is free format, just separate data by "," or by spaces.
(Variable names listed below are not necessarily those in code)

DATA TO BE ENTERED:

BOUNDARY INFORMATION

nb1,nb2 nb1 = 0 , no boundary at y=0
nb1 = 1 , no-flow boundary at y=0
nb1 = 2 , constant head (river) at y=0
nb2 = 0 , no boundary at y=dscalr
nb2 = 1 , no-flow boundary at y=dscalr
nb2 = 2 , constant head (river) at y=dscalr

HYDROLOGIC PARAMETER, BOUNDARY AND WELL INFO

T,S,dscalr,nwells T : transmissivity gpd/ft
S : storage (unit less)
dscalr : y location (feet) of 2nd boundary
(enter 0 if no boundary wanted)
nwells : number of pumping wells

OUTLINE OF PUMPING HISTORY

(do i=1,nwells) Enter one line for each well
x(i),y(i),nrates(i) x(i) : x location (feet) of pumping well i
(end do) y(i) : y location (feet) of pumping well i
nrates(i) : number of different pumping

rates in the schedule of well i

PUMPING HISTORY FOR EACH WELL

(do i=1,nwells) Enter one set for each well
(do j=1,nrates(i)) Each set contains nrates line, one for each pumping rate.
q(i,j),t(i,j) q(i,j) : pumping rate j (in gpm) of well i
(end do) t(i,j) : time well i pumps at rate q(i,j)
(end do)

OBSERVATION POINTS

ncp = 0; Enter observation points one by one
ncp ncp = 1; Enter observation point grid

OBSERVATION GRID

(if(ncp=1) Enter this set if ncp=1
xmin,xmax,deltax Minimum, maximum and increment values
ymin,ymax,deltay needed to set up observation point grid.
If deltax (or deltay) = 0 then only xmin
(or ymin) will be used. (units: feet)

OBSERVATION POINTS

(else if(ncp=0)) Enter this set if ncp=0: one-by-one
nscalr nscalr : Number of observation points
(do i=1,nscalr) enter one line for each obs. point
x(i),y(i) x(i) : x coordinate of obs point i (ft)
(end do) y(i) : y coordinate of obs point i (ft)
(end if)

TIME STEPS

tmin,tmax,deltat tmin : Minimum time of observation (days)
tmax : Maximum time of observation (days)
deltat : Observation time increment (days)
(if deltat =0 only tmin is used)

IMAGE CONTROL

g When all image terms are less than g, for three
images in a row, program stops calculating images.
(g should be much less than 1, but not equal to 0). (units: feet)

Documentation was prepared by P. Barroll.

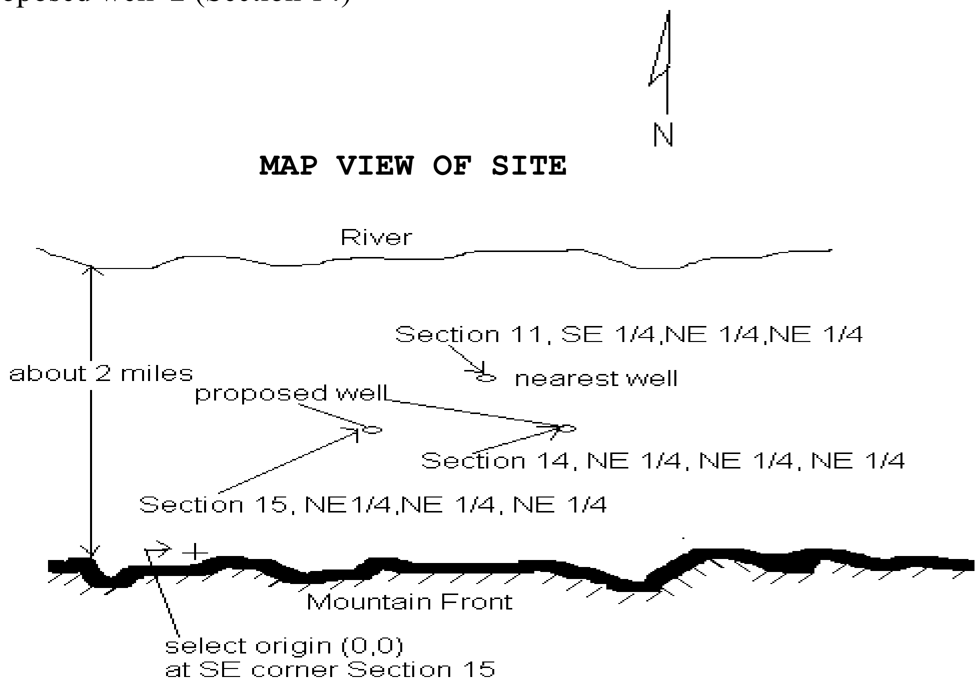
Examples

EXAMPLE 1 Obtain the coordinates for the three wells and river

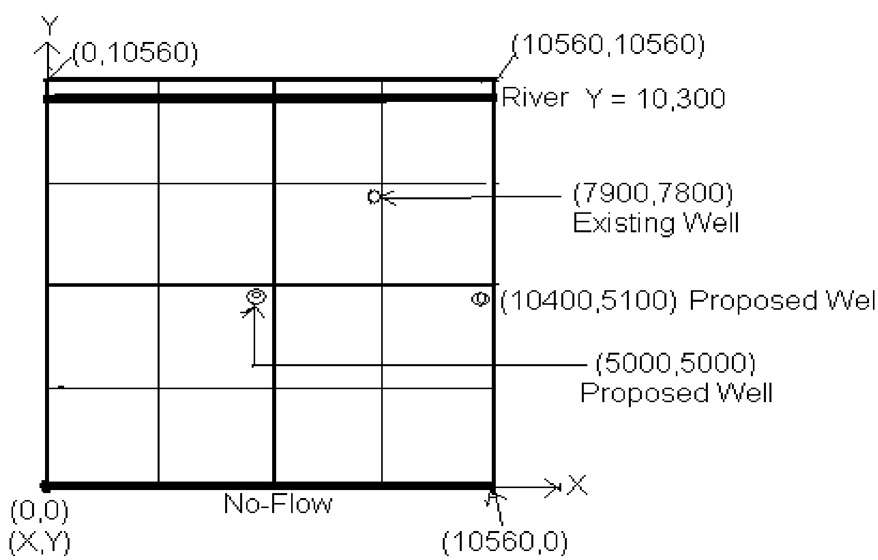
Proposed well 1 (Section 15)

Proposed well 2 (Section 14)

MAP VIEW OF SITE

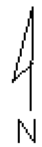


MODEL

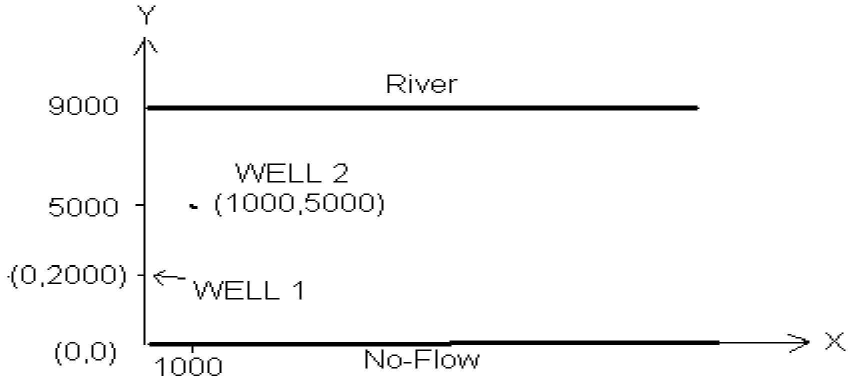


Each square represents a quarter section

EXAMPLE 2 Input file for river and No-Flow Boundary, 2 Wells multiple flow rates & use of grid to compute drawdowns



Map view



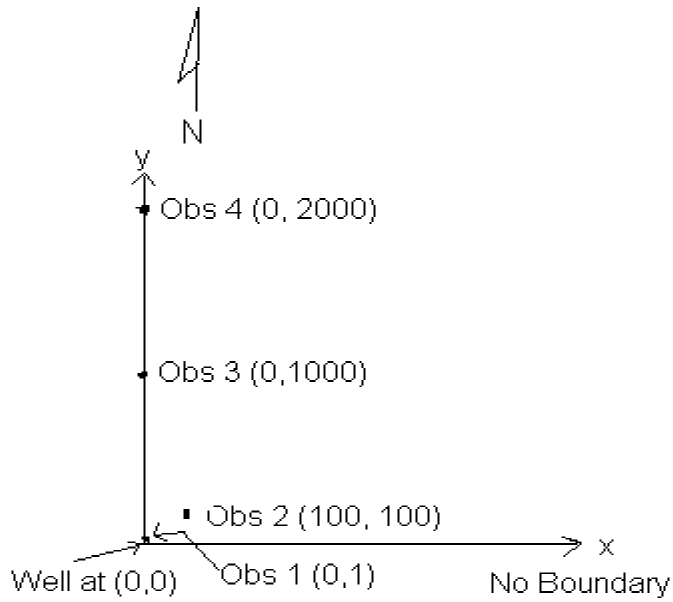
T=10,000 gpd/ft S=0.1 Q1 = 100 gpm for 365 days then well1 pumps at 200 gpm for 36500 days; Q2 = well2 pumps at 200 gpm for 37230 days

Input File:
The Theis program will request the name of the input file. The name entry is case sensitive and requires the extension following the name (i.e. .txt). Microsoft Notepad may be used for data entry.
--

NOTE: start file with 3 blank lines

```
1,2                 no-flow at y=0, river at y=dscalr(9000)
10000,.1,9000,2       T=10000, S=0.1, dscalr=9000, 2 pump wells
0,2000,3             x(well1)=0, y(well1)=2000,  3 pumping rates
1000,5000,1            x(well2)=1000, y(well2)=5000, 1 pumping rate
200,365              well1 pumps at 200 gpm for 365 days
100,365              then well1 pumps at 100 gpm for 365 days
200,36500              then well1 pumps at 200 gpm for 36500 days
200,37230              well2 pumps at 200 gpm for 37230 days
1                      enter observation points by grid
0,0,0       x(obs)=0 for all y (except x=0.5,y=2000;which is near location of well 1)
1000,5000,1000        y(obs)=1000,2000,3000,4000,5000 ft.
365,37230,3650        observation times: 365,4015,7665,11315 etc.
.00001               stop calculating images when terms are < .00001
```

EXAMPLE 3 Prepare input file - No Boundaries, 1 Well at (0,0), 4 Observation Points



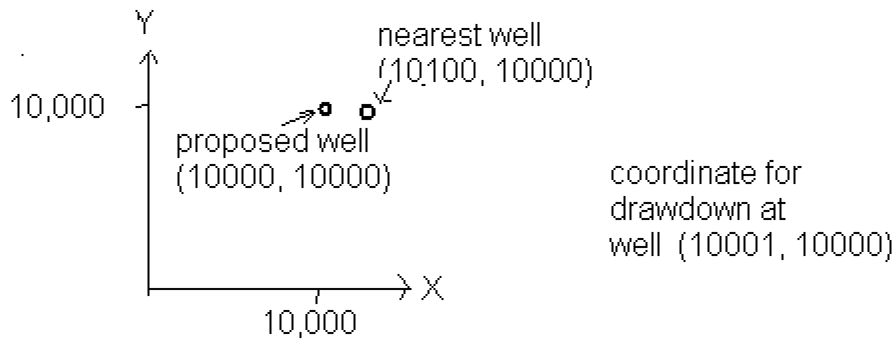
NOTE: start file with 3 blank lines

0,0 no boundaries
1000,.0001,0,1 T=1000 gpd/f, S=.0001, no 2nd boundary, 1 pumping well
0,0,1 pumping well is at x=0,y=0, and has one pumping rate
100,10000 well pumps at 100 gpm for 10000 days
0 enter observation points one-by-one
4 4 observation points
0,1 obs. point 1 is at x=0,y=1 ft
100,100 o.p. 2 is at x=100 ft,y=100 ft **
0,1000 o.p. 3 is at x=0,y=1000 ft
0,2000 o.p. 4 is at x=0,y=2000 ft
365,10000,365 observation times: 365,730,1095 etc
.1 no boundary, no images; g is not used, but some value must be input

** Because there are no boundaries in Example 3, there are no restrictions on the values of x and y, except that an observation point cannot be placed directly on top of the pumping well.

EXAMPLE 4 Output File Example

Calculate Drawdown at the proposed well and nearest well given:
T = 1000 ft2/day x 7.48 gal/ft3 = 7,480 gpd/ft
S = 0.10 Q = 100gpm
No boundaries
Distance to nearest well - 100 feet
Pumping time = 40 yrs x 365 day/yr = 14,600day
Drawdown at every 10 yrs or 3650 days




```
  DRAWDOWN AT RANDOM COORDINATES IN AN INFINITE
             STRIP, NON - LEAKY AQUIFER USER SPECIFIED BOUNDARIES
             AT Y = 0 AND A Y SPECIFIED BY USER
              PUMPING MULTIPLE WELLS LOCATED AT POINTS SPECIFIED
              BY USER. EACH WELL MAY HAVE A DIFFERENT
             PUMPING SCHEDULE. ALL COORDINATES IN THE X - Y PLANE.


                          (Theis equation)
               At y = 0, there is no boundary
                There is no other boundary to system
               T =   7480.  gpd/ft                   S = 0.100000
                           Number of pumping wells =  1
          Coordinates of pumping wells and the no. of pumping rates
        Well #        X Coordinate    Y Coordinate      No. of Pumping
Rates
           1             10000.0         10000.0              1
                      PUMPING SCHEDULES FOR THE WELLS
                 Well Schedule for Pumping Well Number  1
                  Pumping Rate               Pumping Time
              Q(  1) =  100.0 gpm      for    14600.000 days
                    Coordinates of Computation Points
                   (Number of computation points =   2)
         Point #        X Coordinates            Y Coordinates
                             feet                     feet
            1              10001.0                  10000.0
            2              10100.0                  10000.0
                      Image Control = .1000000E-05
                    time variable (t)
               t min =  3650.000 days;          t max = 14600.000 days;
```

```
                   delta t =  3650.000  days
             ************* RESULTS **************
         Drawdowns and Coordinates of computation points
                   Measured in feet

              X =   10001.0      X =   10100.0
              Y =   10000.0      Y =   10000.0
  Time in days
    3650.000       27.915           13.805
    7300.000       28.977           14.867
   10950.000       29.598           15.488
   14600.000       30.039           15.929
```

Example 5 Input and Output File For Plotting

Input

```
Blank line
Blank line
Blank line
0,0                     no boundaries
500,.1,0,1              T, S, dscalr = 0 feet, 1 pumped well
1000,1000,1             pumped well at X(1) = 1000 feet, Y(1) = 1000
feet,
100,14600               Q = 100 gpm t = 14600 days = 40 years
0                       code for enter observation points one at a time
10                      Number of OBS(n)
1000,1001               OBS(1)
1000,1050               OBS(2)
1000,1100               OBS(3)
1000,1200               OBS(4)
1000,1500               OBS(5)
1000,2000               OBS(6)
1000,3000               OBS(7)
1000,5000               OBS(8)
1000,7500               OBS(9)
1000,10000              OBS(10)
3650,14600,3650         t(1) = 3650 days,total t = 14,600 days(40 yrs),
.0001                   Stop calculating images when < 0.0001
```

Output for Plotting – 40 Years (Increment 4)

```
Header Record for Time Increment Number    4
    1000.000    1001.000    -387.382
    1000.000    1050.000    -208.070
    1000.000    1100.000    -176.303
    1000.000    1200.000    -144.549
    1000.000    1500.000    -102.672
    1000.000    2000.000     -71.338
    1000.000    3000.000     -41.272
    1000.000    5000.000     -15.724
```

5. GLOVER – BALMER METHOD
CALCULATION OF STREAM DEPLETIONS

Documentation

P. Barroll

Program: glov99.for

Originally written by Mike Spinks, NMOSE in the 1980's. Somewhat revised by Peggy Barroll in 1994. No formal documentation was ever written.

The Glover-Balmer equation is derived from the Theis equation, and allows you to calculate stream depletions, subject to a number of simplifying assumptions, such as

1) The aquifer is a single homogeneous, isotropic layer,
2) The stream is an infinite linear feature that is fully connected with the aquifer maintaining a constant head along its length.,
3) A no-flow boundary to the aquifer is linear and parallel to the stream,
4) The well or wells are located between the stream and the no-flow boundary.

The program asks for

1) Aquifer Transmissivity (in ft^2 per day)
2) Aquifer Storage coefficient (unit less)
3) The distance between the no-flow boundary and the stream (in miles).
4) Information on pumping wells
    a. Number of wells to be simulated
    b. Distances between each well and the stream (in miles), and
    c. Well pumping schedule: pumping rates (in acre-feet per year), and length of time pumped at that rate (in years).
5) "Image control" which tells the program when it can stop iterating its solutions (make this a small number, like .001)
6) Time interval at which output is needed

Runs can be automated if you create an input file that has exactly the same inputs that you would have typed in when running the program. Glove.in is an example of this type of file. Must use a file named glove.in for input file. To run the program with this set of inputs click on gbexe.bat.

Sample Input File

```
test5.OUT                          Output file name (will over-write)
N                                 Graphics output file (Y/N)
20000                             Transmissivity (ft2/d)
.1                                Storativity
1                                 Number of wells
10.                              Distance - stream to no-flow boundary
(miles)
5.                               Distance - well  to stream (miles)
1                               Number of pumping rates for well 1
100                              Q (1) (AF/yr) for well 4 - year 1960
100                                 T (1) (year) for Q (1) for well 1-
1960
.0000001                          Image Control
1                                 T-min  Minimum time (years)
100                               T-max  Length of time (years)
```

1 Delta T Time increment (years)

Sample Output File

```
                TIME and DATE
       month:  5       day: 16      year:  2006
       hour:  8  minute: 34   second:    25
      STREAM DEPLETION CAUSED BY PUMPING MULTIPLE WELLS AT
      VARIOUS RATES IN AN INFINITE - STRIP, NON - LEAKY AQUIFER.
      THE WELLS ARE BETWEEN THE STREAM AND A PLANE BOUNDARY.

                 (Glover and Balmer equation)
          T = 20000.  square ft/day               S =  .100000
                      Number of wells =   1
          Distance from stream to plane boundary = 10.00 miles
          Distances of the wells from the stream and the
                          number of pumping rates

      Well #          Distance (miles)      No. of rates
          1                  5.00                 1
                PUMPING SCHEDULES FOR THE WELLS

               Pumping schedule for well number  1

                   Pumping rate              Pumping time
         Q(  1) =  100.0  ac-ft/yr    for    100.000  years

                   Image Control = .10000000E-06

                     Time variable (t)  Only 500 timesteps allowed

          t min =   1.000 years;   t max = 100.000 years;
                    delta t =   1.000  years
```

Time (years)	Rate of Depletion (ac-ft/yr)	Accumulated Depletion Volume (acre-feet)	Depletion Volume in Time Period (acre-feet)
1.000	2.895259	.662143	.662143
2.000	12.249161	8.148782	7.486639
3.000	20.746055	24.794017	16.645235
4.000	27.585628	49.081474	24.287457
5.000	33.206646	79.560414	30.478939
10.000	52.747073	298.508939	51.157228
20.000	75.292632	951.017359	74.476342
40.000	93.219704	2673.741434	92.995718
100.000	99.859872	8571.039117	99.855243

Note: The rate of depletion (ac-ft)/yr is typically used for OSE evaluations. The other two columns are generally not considered.

COMPARISON OF UNITS

PARAMETER	THEIS	GLOVER-BALMER
Distance	feet	miles
Flowrate Q	gpm	af/yr
T	gpd/ft	Ft2/day
Time	days	years

SECTION IV
CALCULATION PROCEDURES

TABLE OF CONTENTS

SECTION IV
CALCULATION PROCEDURES

Introduction

- Several strategies are provided below for instructional purposes only.
- Every case has unique aspects that must be taken into account to select the appropriate method. The methods required might be different from those presented below.
- For each of the examples below, additional information beyond that presented below may require different methods than described in this SECTION.
- Some basins may have established policies that may be different from the approach presented in the examples.

1. General Guidelines For Problem Solving

Develop a work plan

- What is the problem to be solved?
- What is the degree of concern for excessive impacts?
- What are the important physical features that should be modeled?
- What is the calculation method?

Factors that influence method of calculation

- Type of application/information presented in application
- Perform conservative but reasonable calculations
- Keep the river whole
- Little data – keep it simple
- Less data = more conservative approach
- Hydrogeologic complexity/boundaries
- Availability of basin guidelines/agency model
- Magnitude of proposed pumping.
- Distance to nearest wells/ protestant wells.

Regional Assessments

- Regional or basin wide assessments are typically described in basin guidelines.
- Evaluates impact of all existing wells plus proposed well.
- Goal is to compute drawdown on administrative block rather than specific wells.
- Based on a 40-year planning period with a specified end date.
- May be used to determine availability of unappropriated water based on average well completions.
- Basin complexity, data inadequacy, low number of pending applications, or low regional declines may be reasons for the lack of a regional model.

Local Assessments

- Local assessments are performed to determine the drawdowns on the nearest wells of other ownership.
- The Theis equation is typically applied but numerical models may also be used under certain conditions.
- Assesses 40-year drawdown from date of application review.
- Site-specific conditions taken into account such as aquifer properties, well completions, and well hydraulics.

2. General Calculation Procedures
No existing model or existing models are inappropriate

General procedure

- Identify the problem to be solved.
- Select area of study.
- Research geology.
- Compile data/information on hydrogeology.
- Develop conceptual model
- Select model (analytical or numerical).
- Calculate impacts
- Assess need to revise model input
- Update or refine calculations
- Write documentation

Example 1
A proposed well (100 afy, 100 foot well depth) will be located near an intermittent stream near a small community in northern New Mexico. The site is located in a narrow alluvial valley bounded by mountains. Several domestic wells are within 1,000 feet of the proposed well and water levels have remained steady. All wells are located in the valley and produce from alluvial sediments. All wells are less than 80 feet deep and produce from sands and gravels. Clay zones are generally less than 5 feet thick. Little data is available on aquifer parameters. Water levels from well logs indicate shallow conditions. Outline a calculation plan.

One Approach

- Problem - Drawdown and stream depletion required.
- Little data is available and small study area so use analytical models to perform local assessment.
- High level of concern with respect to potential for excessive drawdown impacts to ensure water rights are not impaired. Use Theis with two no-flow boundaries to calculate drawdown. This is conservative, as it does not consider a river boundary.

- We are unsure of aquifer-stream connection so to protect surface water rights: assume a connection and apply Glover-Balmer with a no-flow boundary. This is conservative as it assumes an active fully penetrating stream. By using the elevation of the water table and stream, it may be possible to verify aquifer-stream connection.
- Select water table S of 0.10.
- Based on the well logs and Trauger, select 10 ft/day for K.
- Assume a saturated thickness of 80 feet to compute T.

Example 2
An application is filed for a small quantity of water in an area where existing wells have large allowable drawdowns. The nearest well is 1000 feet from the proposed well. Available information is limited but the alluvial aquifer is unconfined and probably has a relatively large T and S. Outline a calculation plan.

- Problem - Drawdown estimate required.
- Little data so lets keep calculations simple.
- Due to the magnitude of pumping, distance to nearest wells, and aquifer properties – a local area assessment is required and there is a low level of concern pertaining to the potential for excessive drawdown.
  - Use Theis.
  - Decision on application is not sensitive to aquifer parameter selection if parameters remain in plausible range.

Example 3
An application is filed to appropriate 20 afy from a sandstone aquifer in a remote area. The aquifer properties in the region are unknown. The nearest well (a domestic) is about 3000 feet away and is completed in the same formation. Unconfined conditions were encountered in the domestic well and 10 gpm was the reported well yield. The domestic well has 50 feet of water column. Outline a work plan and discuss general procedures to obtain aquifer parameters.

<u>Plan</u>

- Problem – Determine drawdown to protect existing water rights.
- Little data so lets keep calculations simple.
- Due to magnitude of pumping, distance to nearest wells, and aquifer properties – a local area assessment is required and there is a low level of concern pertaining to the potential for excessive drawdown.
- Use Theis equation.

To obtain T and potential boundaries, look at a geologic map (see publication by NM Bureau of Geology describing available maps). Try to identify the formation and look for any geologic structures like faults or formation changes that might act as a barrier. Determine whether there are any regional reports such as OSE Technical reports, Bureau of Geology Reports, or USGS reports (see Selected Sources of Information, SECTION I). If available, review information pertaining to the geologic formation. Look for information on aquifer properties S, T or K or other information that characterizes the aquifer. If no information is available, look at Table 4 by Trauger (1972) to obtain range of S and K. Calculations for unconfined aquifers are generally not too sensitive to the selection of S. Select a value of 0.10 based on Table 4. Select T or K based on values in reports. If K is selected assume a saturated thickness based on the proposed well depth and other information to obtain T.

Example 4
A well is proposed northwest of the Town of Cuchillo, near Truth or Consequences. Nearby wells of other ownership are located about 1,500 feet from the proposed well. The area is relatively undeveloped. One method to compute drawdown and stream impacts follows.

A geologic map was obtained for the area by using the geologic map key provided in a NM Bureau of Mines publication of available documents. The proposed well site was plotted indicating that the well site is on the Santa Fe Formation. The geologic map indicates that the Santa Fe Formation is composed of sands, gravels, silts and clays. An inspection of well logs for the nearby wells confirm the Santa Fe as the source of water supply.

The geologic map also shows the Cuchillo Mountains (volcanic rocks) are located west of the well site. These rocks are probably a poor source of water based on their geologic description. The Rio Grande is located east of the well site. Other drainages are typically dry. From this information a conceptual model is developed.

<u>Aquifer Parameters</u> - Logs indicate a number of clay layers and mixed layers containing sands, gravels and clay. Wells tap the upper portion of the aquifer. Although several wells indicate that water rose above the level at which water was first encountered, the aquifer should be considered as unconfined. The upper portions of basin fill aquifers are unconfined. Based on this information an S of 0.05 is assumed.

A geology report for the area indicates a specific capacity of 5.39 gpm/ft for a nearby well. Based on tables presented in Walton (1970), a T of 4,200 gpd/ft is derived. A report for the region provides a S of 0.10 and a T of 20,000 gpd/ft.

<u>Model Selection</u> - The no-flow and stream boundaries are a relatively long distance away from the proposed well so describing these boundaries in great detail with a numerical model seems unjustified. Relatively little information is available on the variation of the aquifer properties so analytical methods should be OK. The geologic map indicates that the Santa Fe formation is wide spread in the area so the evaluation will pertain to one aquifer rather than multiple aquifers. The application is for a relatively small quantity of water and local impairment is the primary issue with respect to drawdown. Use of analytical methods should also be more conservative with respect to stream depletion compared to numerical models. Theis and Glover-Balmer are selected.

Aquifer Parameter Selection - An S of 0.05 is supported by the well logs and would be a more conservative value compared to 0.10. A T of 4,200 gpd/ft is selected for the Theis equation based on the specific capacity obtained for a nearby well. With respect to drawdown, the area of concern is relatively small due to the short distance to the nearby wells. A smaller T would be more conservative for calculation of drawdown. For calculation of stream depletion, a T of 20,000 gpd/ft is selected for Glover-Balmer. This value may be more representative of the aquifer on a broad scale and would be more conservative with respect to stream depletion.

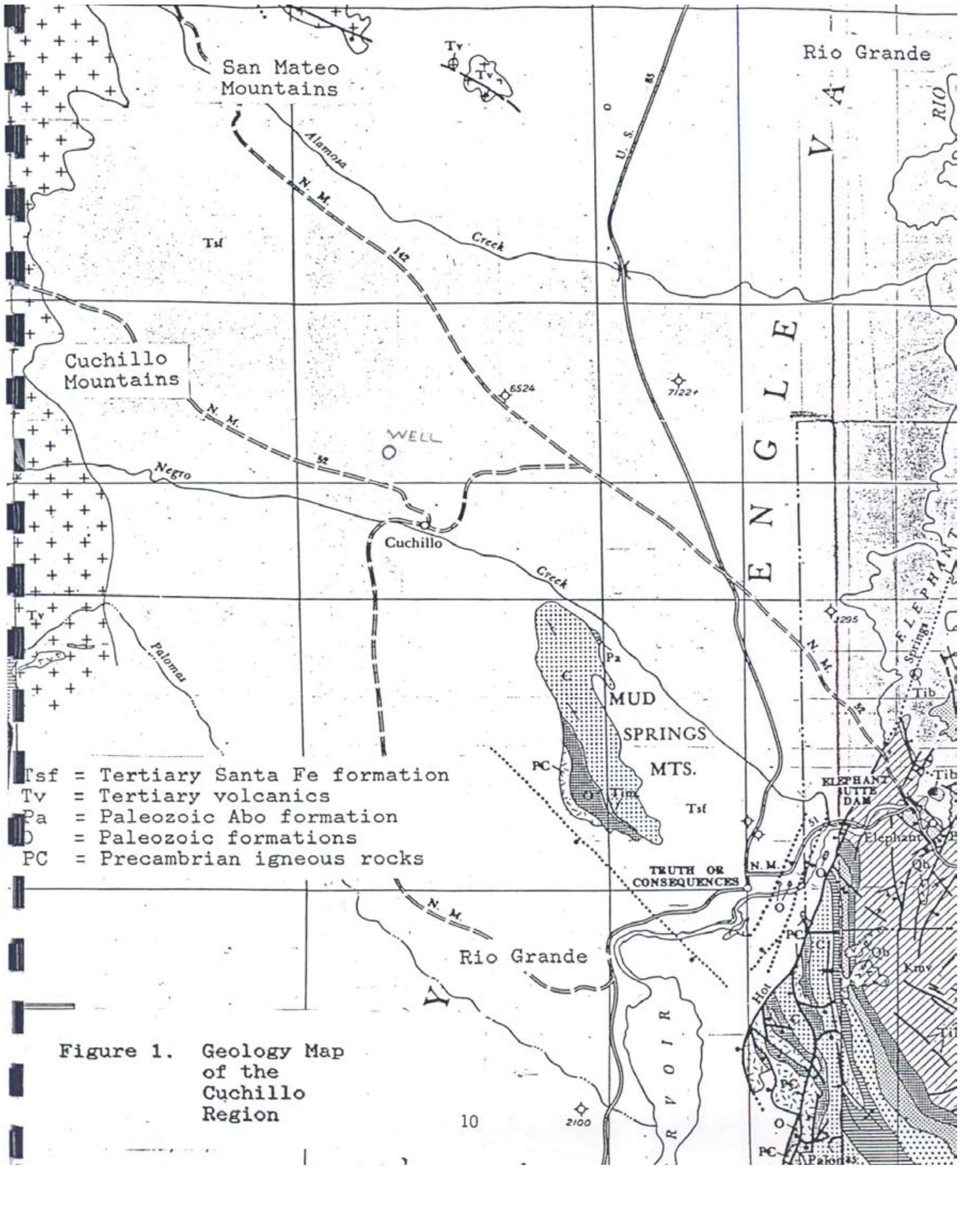


Figure 1. Geology Map of the Cuchillo Region

3. Calculation Procedure Options for Certain Types of Applications

Worst Case Strategy

- This strategy is useful in areas with little information, or where the requested appropriation is anticipated to have minimal impact, or for a first cut computation.
- If the greatest magnitude of impact is deemed acceptable in relation to available drawdown - no further work is necessary.
- If impacts are excessive the reviewer may assess available information in more detail to arrive at a model deemed more appropriate.
- This strategy is not applicable if firm modeling approach is apparent at the start of review.

Example 1

A well is proposed (5 afy) within 200 feet of an existing domestic well (allowable drawdown of 30 feet). Excessive drawdown is not anticipated given the low flow rate requested. The reviewer makes a brief review of available information and finds that estimates of T for the area vary over a wide range.

Approach

- The lowest T is selected as this will probably provide the greatest impact (not so for every situation, this depends on T and distance to well).
- A drawdown of less than 10 feet is computed at the nearest well so there should be no problem with excessive drawdown.
- There is no need to continue the drawdown evaluation.
- If there is uncertainty about the lowest T being the most conservative, another set of aquifer parameters (like mid-range parameters) may be selected for a test run.

Example 2

Same example as above but with a higher flow rate (17.5 afy) resulting in a 35 foot drawdown under worst case assumptions.

Approach

- There are typically various degrees of conservatism.
- Re-evaluate approach by examining the available data in more detail to select a reasonable set of parameters that are still on the conservative side.

Example 3

A well is proposed in an area with complex geology. The reviewer is uncertain whether to use Theis or to develop a numerical model.

Assessments should always begin as simple as possible and progress in complexity in stages as the available data allows. In this case the reviewer should start with Theis with worst-case assumptions (aquifer parameters and boundary conditions) to estimate the magnitude of impacts. If the worst-case estimates do not create excessive drawdown further modeling is not required. If the worst-case estimates cause excessive drawdown the reviewer should revisit the Theis run to determine if a more plausible run can be performed. If excessive drawdown is determined the reviewer will have to decide whether to continue to refine the modeling or to accept the results. Numerical modeling should not be pursued unless data is sufficient to justify the approach.

Strategy For Supplemental Wells

The point of a supplemental well evaluation is to determine the additional impacts from the addition of a new supplemental well. Supplemental well applications are sometimes difficult to process because of uncertainty pertaining to the existing and potential pumping distribution due to the new well. Reviewers should use available information to develop a reasonable pumping distribution. If information is lacking, assuming a worst-case distribution (all diversion from the proposed supplemental well) may be appropriate.

First step, calculate the drawdowns due to the existing pumping distribution. Second step, calculate the drawdowns due to the new pumping distribution with the proposed supplemental well. Third step, determine the difference in effects between the first and second steps. This difference, or net effect, is the impact of the new supplemental well. Keep in mind that the new pumping distribution for the second step may increase or decrease drawdowns at nearby wells depending upon the location of the supplemental well.

Example 1

A farmer has a primary well and files an application for a supplemental well due to decline in yield. The casing size of the new supplemental well is adequate to provide the entire diversion permitted.

First step, calculate the impacts to the nearest wells assuming the entire appropriation is derived from the primary well. Second step, calculate the drawdown assuming the entire appropriation is derived from the supplemental well. Third step, find the difference in effects between the first and second step. This approach represents a worse case scenario. The casing size is important to verify the ability of the supplemental well to produce the entire quantity. Refer to SECTION I (Table 13.1 from Driscoll) to assess well yield capability based on casing size.

Example 2

A farmer has three supplemental wells and files an application for a fourth well. The new supplemental well is required for more efficient irrigation. No information is available on the existing pumping distribution between the primary well and three supplemental wells. The fourth supplemental well will move the pumping center towards an existing well.

A worst-case scenario may be performed in which the entire diversion is derived from the fourth well. If the estimated drawdown does not exceed the allowable drawdown no further evaluation may be required.

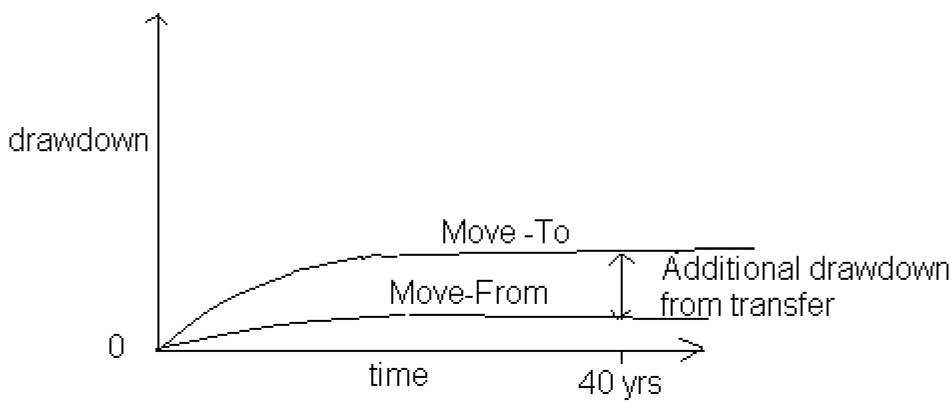
- First step, calculate the impacts to the nearest wells assuming the appropriation is derived in equal proportions from the three existing supplemental wells and primary well.
- Second step, assume the new supplemental well is pumping the entire diversion and estimate drawdown.
- Third step, find the difference in effects between the first and second step.

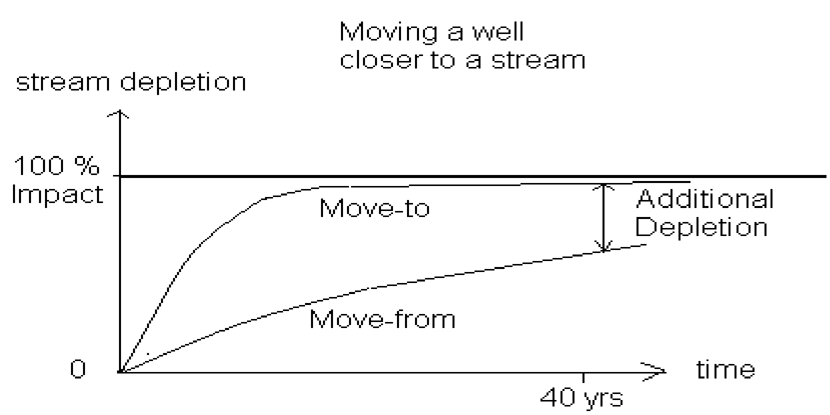
If the estimated drawdown exceeds the allowable drawdown - revise the second step by distributing the pumping equally to the five wells to estimate drawdown. If drawdown is excessive in relation to allowable drawdown a negative opinion may be appropriate.

If the drawdown is not excessive, the reviewer will need to select the most plausible scenario for decision-making.

Strategy For Change in Point of Diversion – well to well

The general approach is to estimate the impacts of the move-from well then estimate the impacts of the move-to well. The difference between these runs is the impact of the proposed transfer. Calculations are typically performed by assuming the full appropriation is diverted for a 40-year period from the move-from well. The amount available for transfer is assigned to the move-to well for the second step.





Strategy For Change in Point of Diversion – from surface to ground

Drawdown impacts from the new well are required. Keep in mind that only the consumptive use associated with irrigation is transferable. The transfer amount is also reduced by the same percentage as the historical supply. For transfers from irrigation to irrigation the farm delivery requirement may be diverted at the move-to well if hydrologic conditions (depth to water & geology) remain the same. For these cases the diversion amount should be used to compute drawdown. Stream impacts may be of concern in some cases if the move is leaping upstream over other surface water diversions that have a historical supply less than 100 %.

A number of problems may arise for these types of proposals due to inadequate information. This is especially the case for historical supply estimates. In some situations the OSE has assumed a 100 % historical supply while field observations indicate a shortage. A 100 % supply may have been assumed simply due to lack of surface water flow data to quantify the supply. Reviewers may wish to revisit the basis for a historical supply estimate to ensure proper actions are taken to protect water right owners. The examples below illustrate a possible approach that may not apply for some areas due to unique circumstances.

Example 1

A surface water right for irrigation has been placed to beneficial use and is sold to a village which would like to increase well diversions. The consumptive use associated with the surface water right is 100 afy. The OSE has computed an 80 % historical supply. Describe the calculation approach.

The diversion for transfer will be limited to 80 afy due to historical supply. Calculate the drawdown at the move-to location using 80 afy. Compare the drawdown with basin guidelines (if available) and estimates of allowable drawdown for nearby wells of other ownership.

Example 2

A surface water right for irrigation has been placed to beneficial use and is sold to a village to offset stream impacts (example 1 above was to increase well diversion). No increase in well diversion is proposed. Describe the calculation approach.

Transfers are made for different reasons, these reasons are important as they influence the work to be performed. No drawdown calculations are required because there will be no increase in well withdrawals. Only the valid consumptive use of the move-from right is available for transfer. For situations with historical supply estimates, the consumptive may also be reduced if the historical supply is less than 100 %. A different practice may be used for other watersheds.

Example 3
A permit for a town allows well diversions to increase based on the submittal of a return flow plan acceptable to the OSE. The town is allowed to divert and consume 100 afy. The town submits a return flow plan demonstrating a return flow of 60 afy when 100 afy is diverted. How much additional water may be pumped?

Diversion (D) = 100 afy
Consumptive Use (CU) = 100 afy
Return Flow (RF) = 60 afy
Return Flow Fraction = RF/D = 60 afy/100afy = 0.60
Depletion Fraction = 1 – RFF = 1 – 0.60 = 0.40

New Diversion = CU/DF = 100afy/.40 =250 afy

Local impairment caused by the increase in groundwater diversion must also be considered along with applicable basin guidelines.

Example 4
The Town files a permit to transfer 30 afy CU. What will be the permitted diversion?

CU = 100 + 30 = 130 afy

New Diversion = CU/DF = 130/0.40 = 325 afy

SECTION V
ASSESSMENT OF DRAWDOWN ESTIMATES

TABLE OF CONTENTS

SECTION V
ASSESSMENT OF DRAWDOWN ESTIMATES

1. Drawdown Tolerances
How much water level decline may a well tolerate?

- A lowering of the water level may result in uneconomical well operation (economic hardship).

- A lowering of the water level may result in loss of the required production (physical hardship).

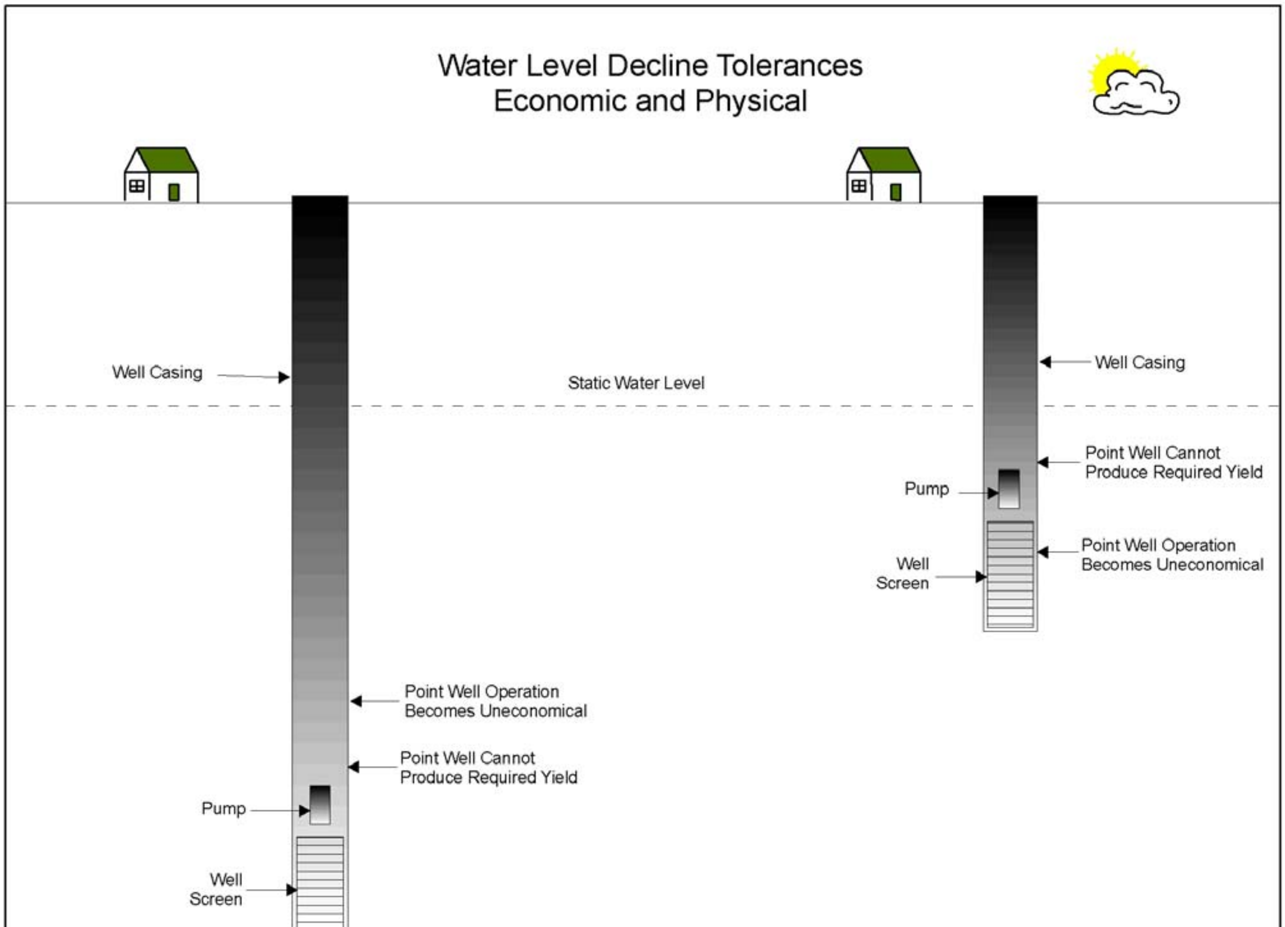
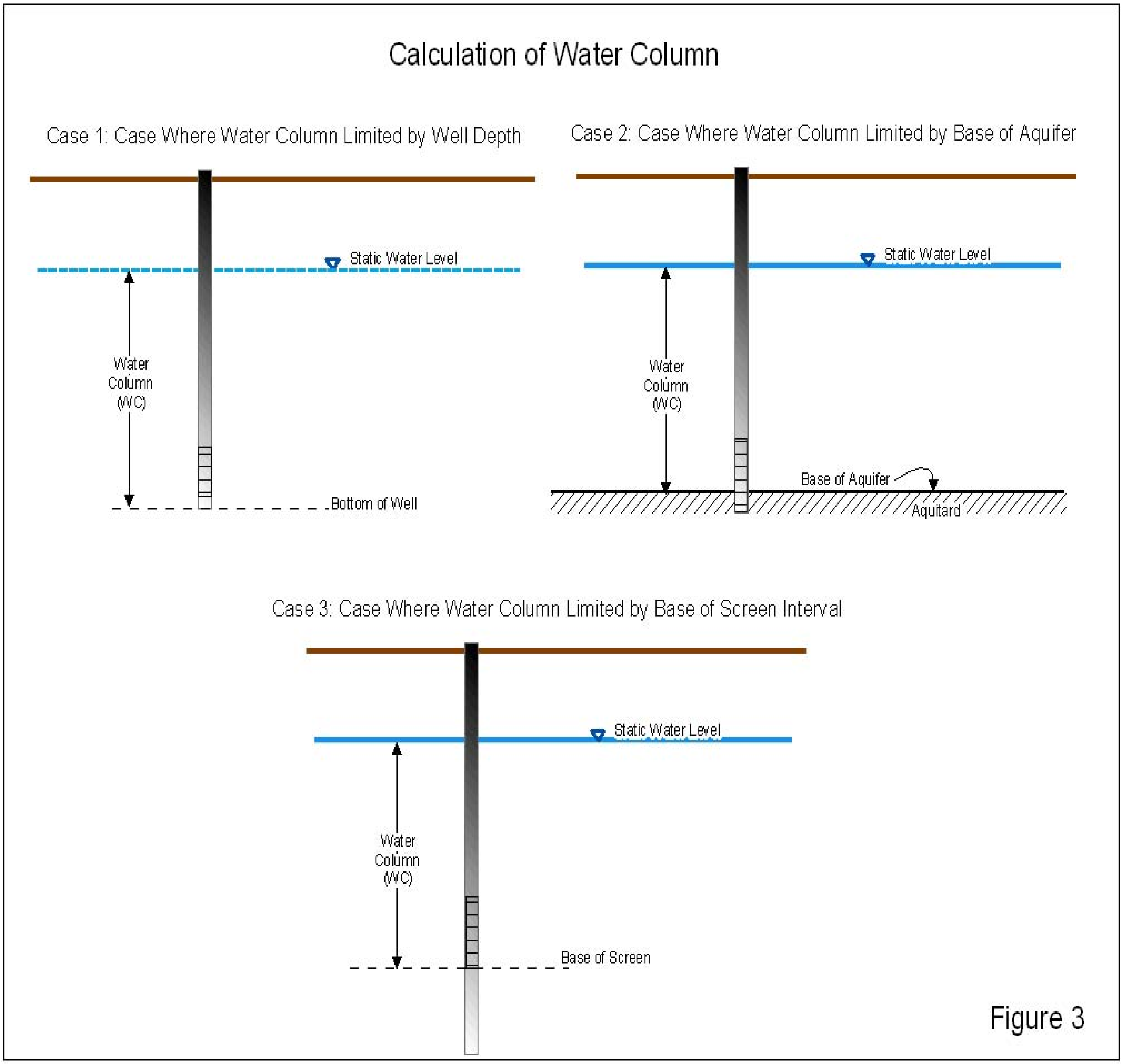


Figure 1

2. Water Column

Water column - length of the well casing containing water that is currently above the base of the production zone.



NOTE: The definition of water column in WATERS is the difference between the total well depth and the water level. This may not be the same as the definition above should be used.

WATERS does not provide all of the necessary information required for well impact evaluations. Use Well Records from water rights files.

Example 1 – Find the water column.

Base of production zone – 350 ft   Depth to water – 193 ft

Water column = 350 – 193 = 157 ft

Revised June 1972

STATE ENGINEER OFFICE

WELL RECORD

2005 JAN 31 AM 11:44

Section 1. GENERAL INFORMATION

(A) Owner of well Associated Asphalt & Materials CO. Owner's Well No. ____
Street or Post Office Address 3810 Oliver Rd,
City and State Santa Fe, NM 87507

Well was drilled under Permit No. RG-83663 and is located in the:

a. ____ ¼ SE ¼ SW ¼ SW ¼ of Section 2 Township 16N Range 8E N.M.P.M.

b. Tract No. ____ of Map No. ____ of the ____

c. Lot No. 2 of Block No. ____ of the ____
Subdivision, recorded in Santa Fe County.

d. X= ____ feet, Y= ____ feet, N.M. Coordinate System ____ Zone in the ____ Grant.

(B) Drilling Contractor Lujan Drilling License No. WD-547

Address 9A Caminito de Pinon Santa Fe, NM 87505

Drilling Began 1-12-05 Completed 1-24-05 Type tools Rotary Size of hole 8 3/4 in.

Elevation of land surface or ____ at well is ____ ft. Total depth of well 500 ft.

Completed well is ☒ shallow ☐ artesian. Depth to water upon completion of well 193 ft.

Section 2. PRINCIPAL WATER-BEARING STRATA

Depth in Feet From	Depth in Feet To	Thickness in Feet	Description of Water-Bearing Formation	Estimated Yield (gallons per minute)
193	194	1	Yellowish Tan Sand & Gravel	1-2
250	252	2	Pinkish Tan Sand	10
280	282	2	Pinkish Tan Sand	50
345	350	5	Pinkish Tan Sand	100+

Section 3. RECORD OF CASING

Diameter (inches)	Pounds per foot	Threads per in.	Depth in Feet Top	Depth in Feet Bottom	Length (feet)	Type of Shoe	Perforations From	Perforations To
5	SDR 17		0	500	500		420	480

2005 JAN 25 PM 3:19

STATE ENGINEER OFFICE ALBUQUERQUE, NEW MEXICO

Section 4. RECORD OF MUDDING AND CEMENTING

Depth in Feet From	Depth in Feet To	Hole Diameter	Sacks of Mud	Cubic Feet of Cement	Method of Placement
6	20		Bentonite Pellets 100#		

Section 5. PLUGGING RECORD

Plugging Contractor ____
Address ____
Plugging Method ____
Date Well Plugged ____
Plugging approved by: ____
State Engineer Representative

No.	Depth in Feet Top	Depth in Feet Bottom	Cubic Feet of Cement
1			
2			
3			
4			

FOR USE OF STATE ENGINEER ONLY

Date Received ____ Quad ____ FWL ____ FSL ____

File No. RG-83663 Use ____ Location No. ____

TRN - 314958

Example 2 - Find the water column from the well record and compare to the water column in WATERS.

Well record water column – 2 ft
WATERS water column (see copy bottom of page– 25 ft)
Use well record to compute water column.

Revised June 1972

STATE ENGINEER OFFICE
WELL RECORD

Section 1. GENERAL INFORMATION

(A) Owner of well Clayton Briggs Owner's Well No. ____
Street or Post Office Address Star Route Box 141 B '84 APR 5 PM 1 10
City and State Tijeras, NM 87059

Well was drilled under Permit No. E-3968 and is located in the: STATE ENGINEER OFFICE SANTA FE

a. nw ¼ nw ¼ ____ ¼ ____ ¼ of Section 3 Township 8N Range 6E N.M.P.M.

b. Tract No. ____ of Map No. ____ of the ____

c. Lot No. ____ of Block No. ____ of the ____
Subdivision, recorded in Bernalillo County.

d. X= ____ feet, Y= ____ feet, N.M. Coordinate System ____ Zone in the ____ Grant.

(B) Drilling Contractor Ron Lancaster License No. WD1063

Address P.O. Box 910, Edgewood, NM 87015

Drilling Began 2-18-84 Completed 2-20-84 Type tools ____ Size of hole 7-7/8 in.

Elevation of land surface or 6500' at well is ____ ft. Total depth of well 260 ft.

Completed well is ☒ shallow ☐ artesian. Depth to water upon completion of well 235 ft.

Section 2. PRINCIPAL WATER-BEARING STRATA

Depth in Feet From	Depth in Feet To	Thickness in Feet	Description of Water-Bearing Formation	Estimated Yield (gallons per minute)
235	237	2	Sand, gravel, rock	5

Section 3. RECORD OF CASING

Diameter (inches)	Pounds per foot	Threads per in.	Depth in Feet Top	Depth in Feet Bottom	Length (feet)	Type of Shoe	Perforations From	Perforations To
5	pvc 1120		0		20		220	260

Section 4. RECORD OF MUDDING AND CEMENTING

Depth in Feet From	Depth in Feet To	Hole Diameter	Sacks of Mud	Cubic Feet of Cement	Method of Placement

84 MAR 1 AM 7:55
STATE ENGINEER OFFICE DISTRICT I ALBUQUERQUE, N. MEX.

Section 5. PLUGGING RECORD

Plugging Contractor ____
Address ____
Plugging Method ____
Date Well Plugged ____
Plugging approved by: ____
State Engineer Representative

No.	Depth in Feet Top	Depth in Feet Bottom	Cubic Feet of Cement
1			
2			
3			
4			

FOR USE OF STATE ENGINEER ONLY

Date Received 3-1-84

Quad ____ FWL ____ FSL ____

File No. E-3968 Use dom Location No. 8N.6E.3 411 (Bern)

From WATERS

WATER COLUMN REPORT 05/23/2006

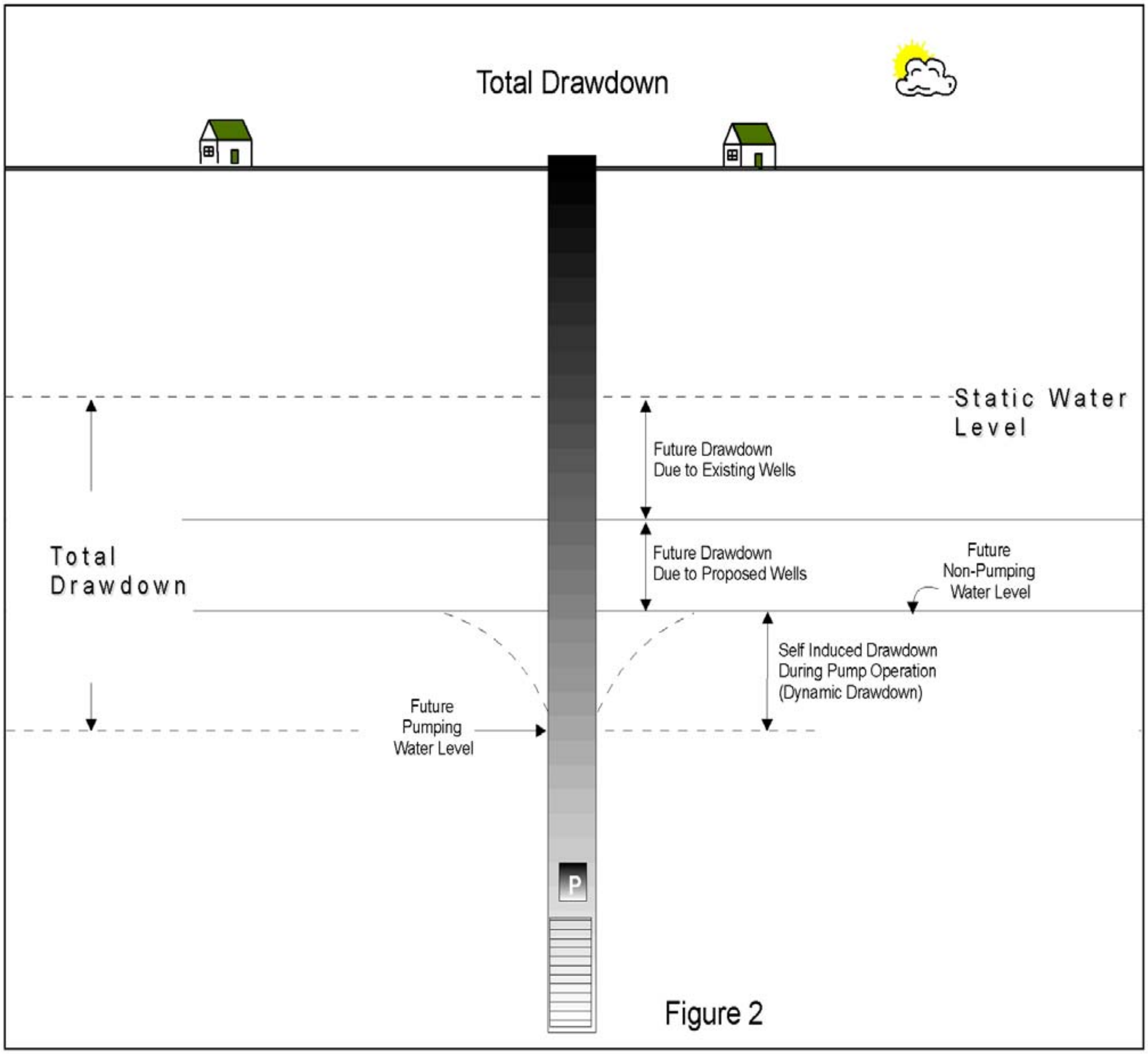
E 03968

X	Y	Depth Well	Depth Water	Water (in feet) Column
		260	235	25

3. Total Drawdown

Drawdown Components

- Drawdown due to existing wells
- Drawdown due to the proposed pumping
- Self-induced drawdown as pumps are cycled on and off



Self-Induced Drawdown (Dynamic Drawdown)

- Represents drawdown inside of casing
- Represents fluctuating drawdown as pumps are cycled on and off
- Use well efficiency to compute

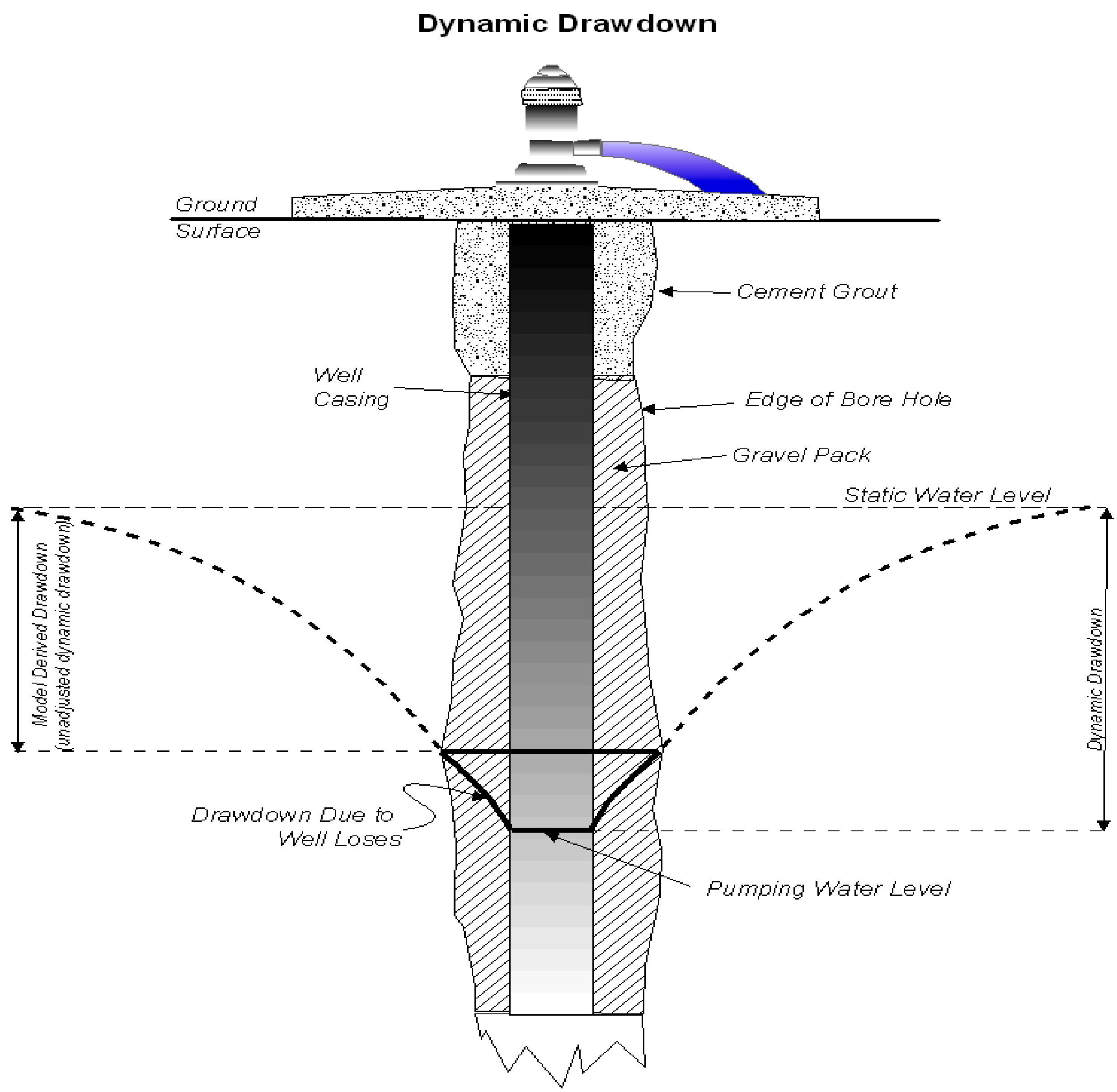
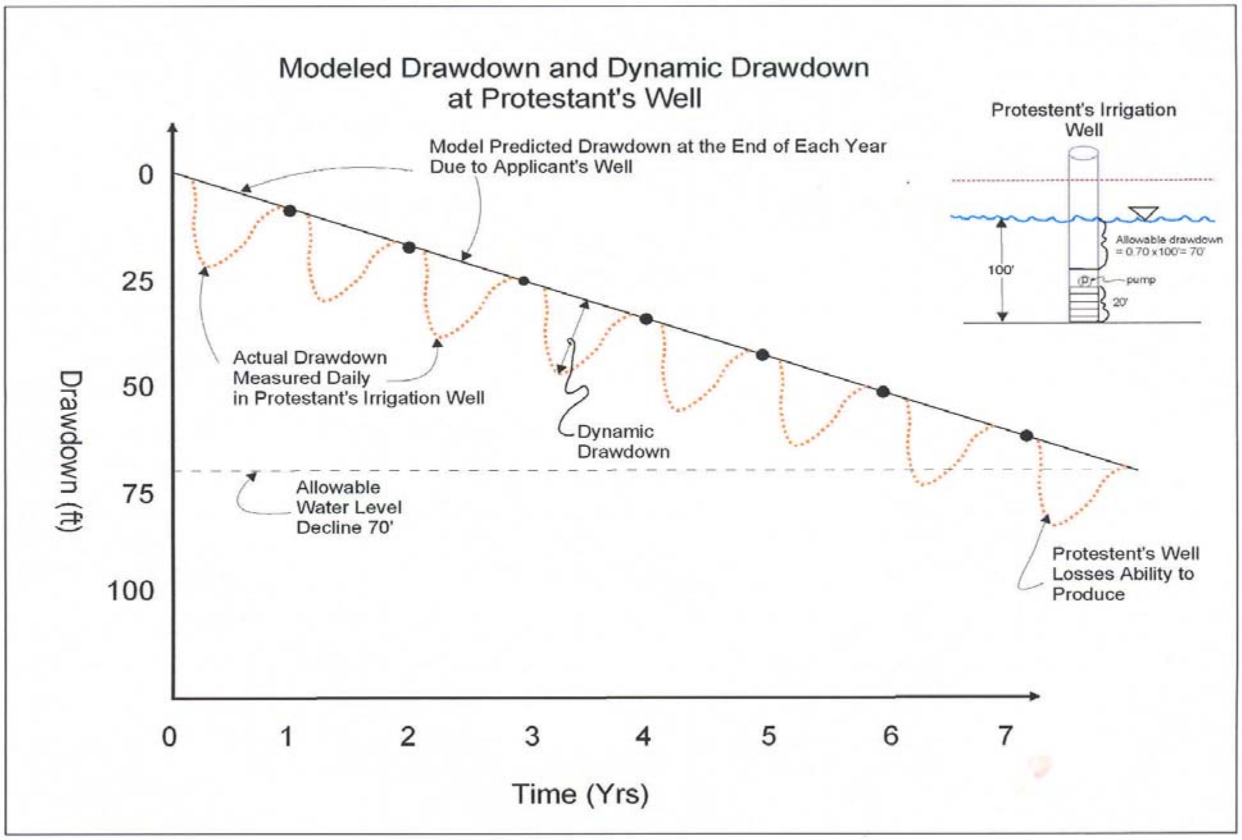


Figure 4



4. Allowable Economic Drawdown (70 Percent Rule)

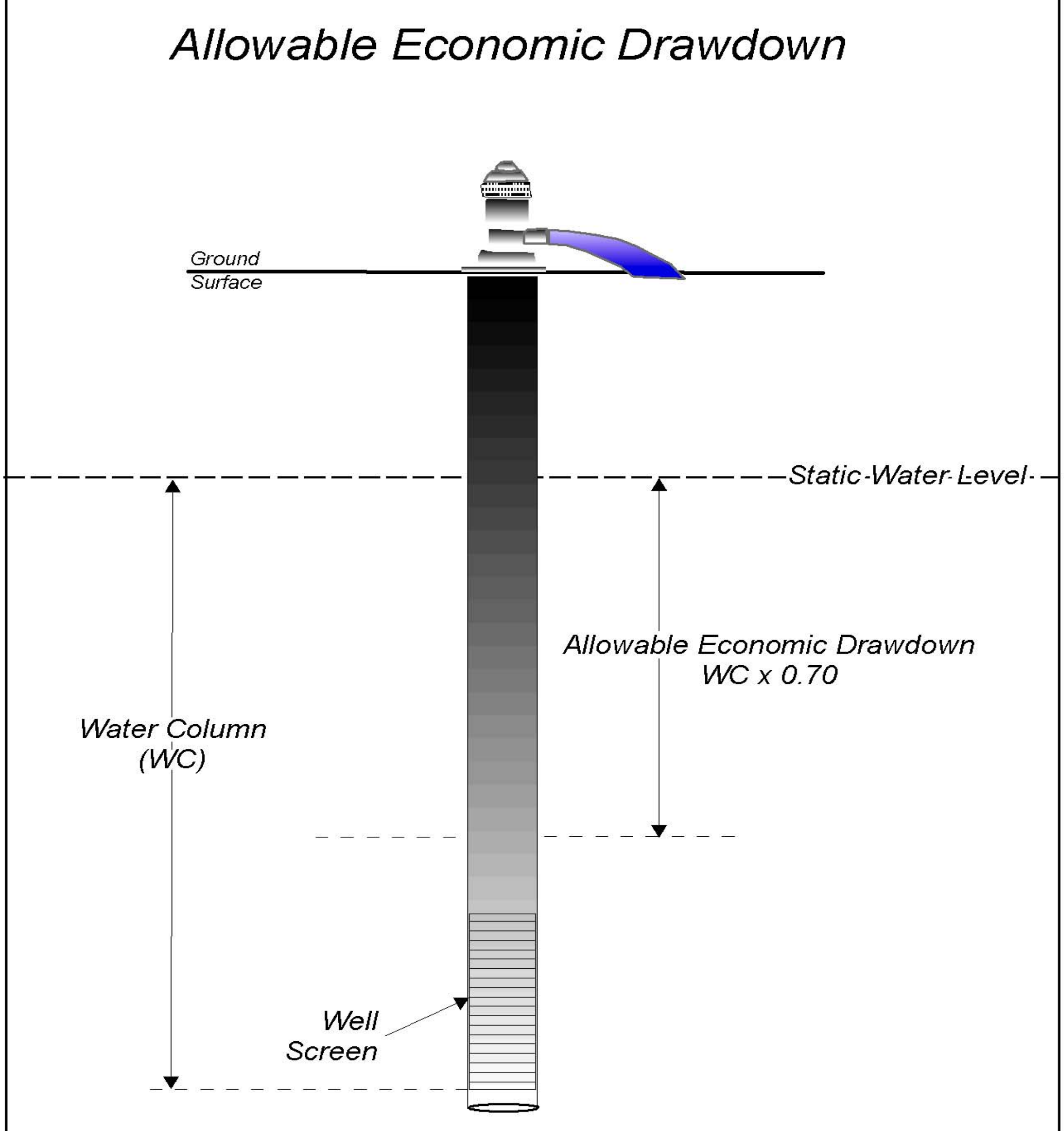
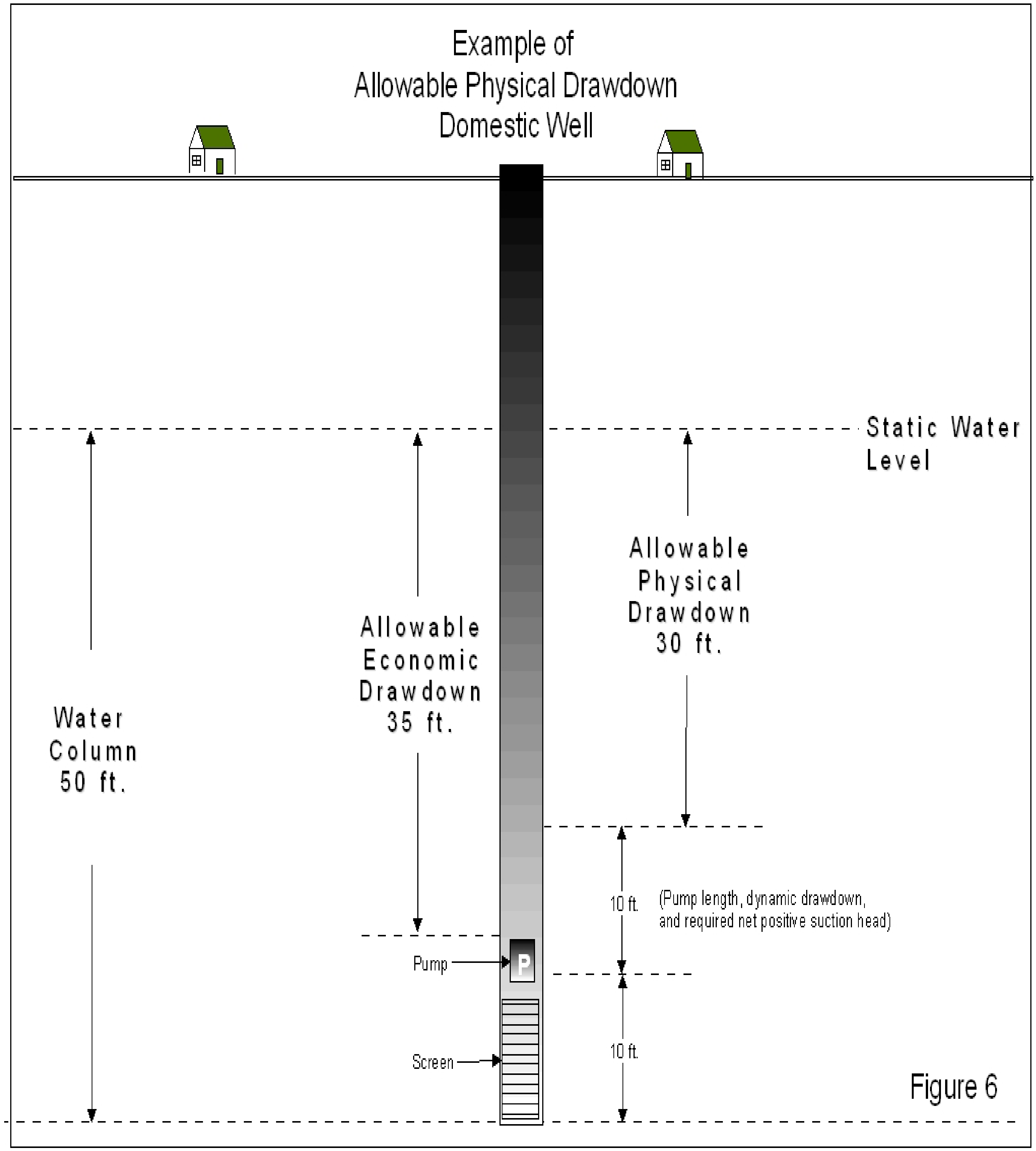


Figure 5

5. Allowable Physical Drawdown


Example of
Allowable Physical Drawdown
Domestic Well
Static Water Level
Allowable Physical Drawdown 30 ft.
Allowable Economic Drawdown 35 ft.
Water Column 50 ft.
10 ft.
(Pump length, dynamic drawdown, and required net positive suction head)
Pump
10 ft.
Screen
Figure 6

6. Lowest Practical Pumping Level (LPPL)

Allowable Physical Drawdown - Controlled by lowest practical pumping water level (LPPL)

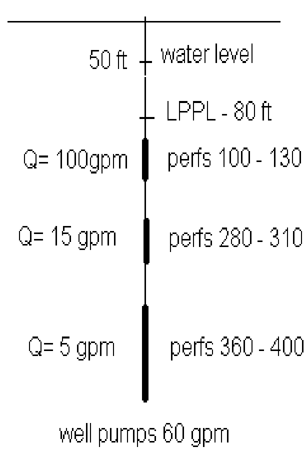
<u>LPPL Depends On</u>

- Depth to water
- Depth and thickness of water bearing zones
- Yield of water bearing zones
- Screen setting
- Depth at which the pump is set
- Pump characteristics
- Other factors

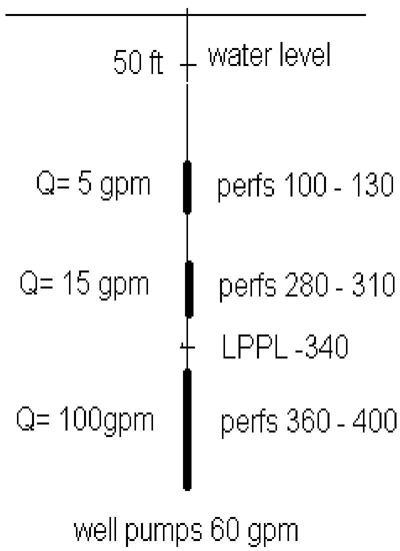
A. General Guidelines LPPL Selection Non-Domestic Wells

- Depends on unique characteristics of each well
- Where water levels are well above the screen - LPPL may be assumed at 20 to 30 feet or more above the top of the well screen unless there is information to the contrary.

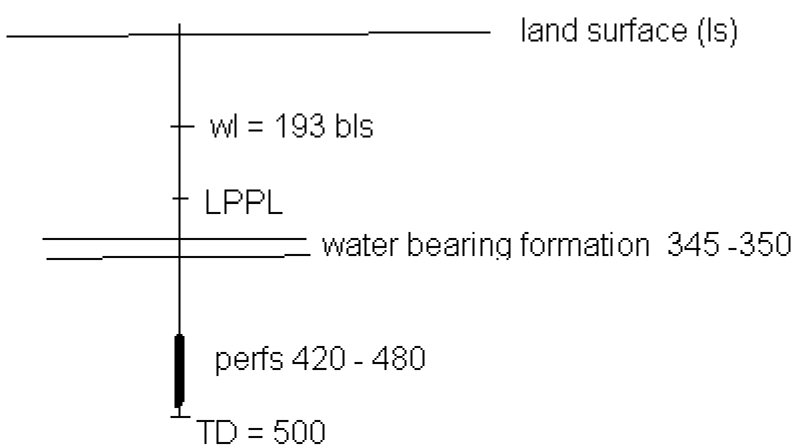
Example 1 LPPL must be above upper screen due to flow rate required



Example 2 LPPL may be above lower screen due to production capacity of lower zone

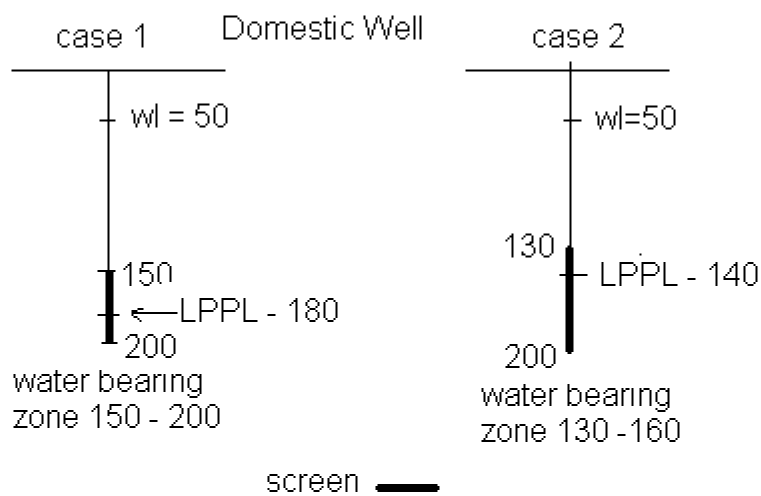


Example 3   For some cases the depth to the perforations does not influence selection of LPPL. The depth to the top of the water bearing formation controls LPPL.



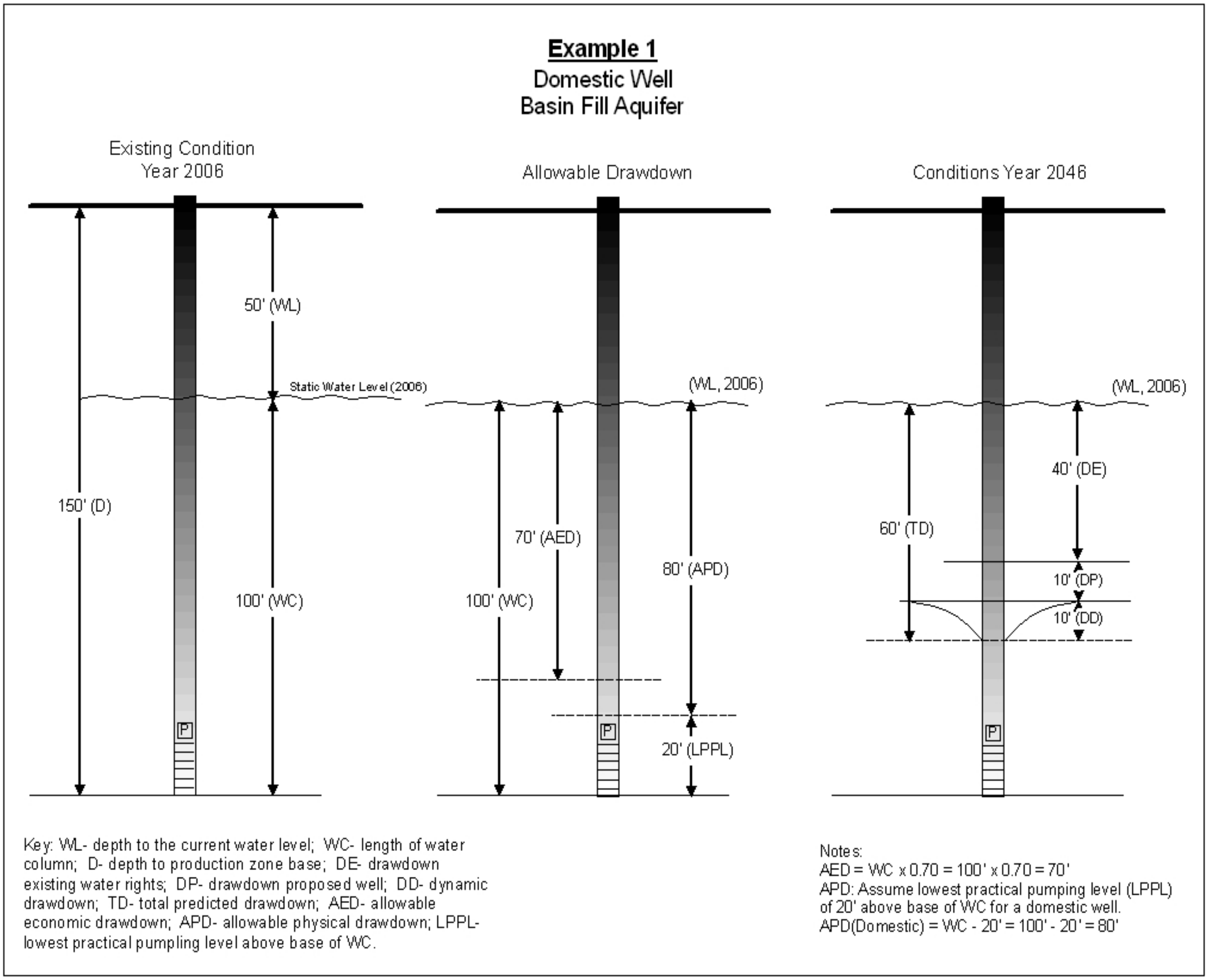
General Guidelines LPPL Selection - Domestic Wells

Where screen extends to bottom of well - LPPL is typically assumed to be 20 feet above the bottom of the well (case 1) unless a different value is supported such as case 2 where the water bearing zone controls LPPL. For poor aquifers, it may be appropriate to assume 30 feet.

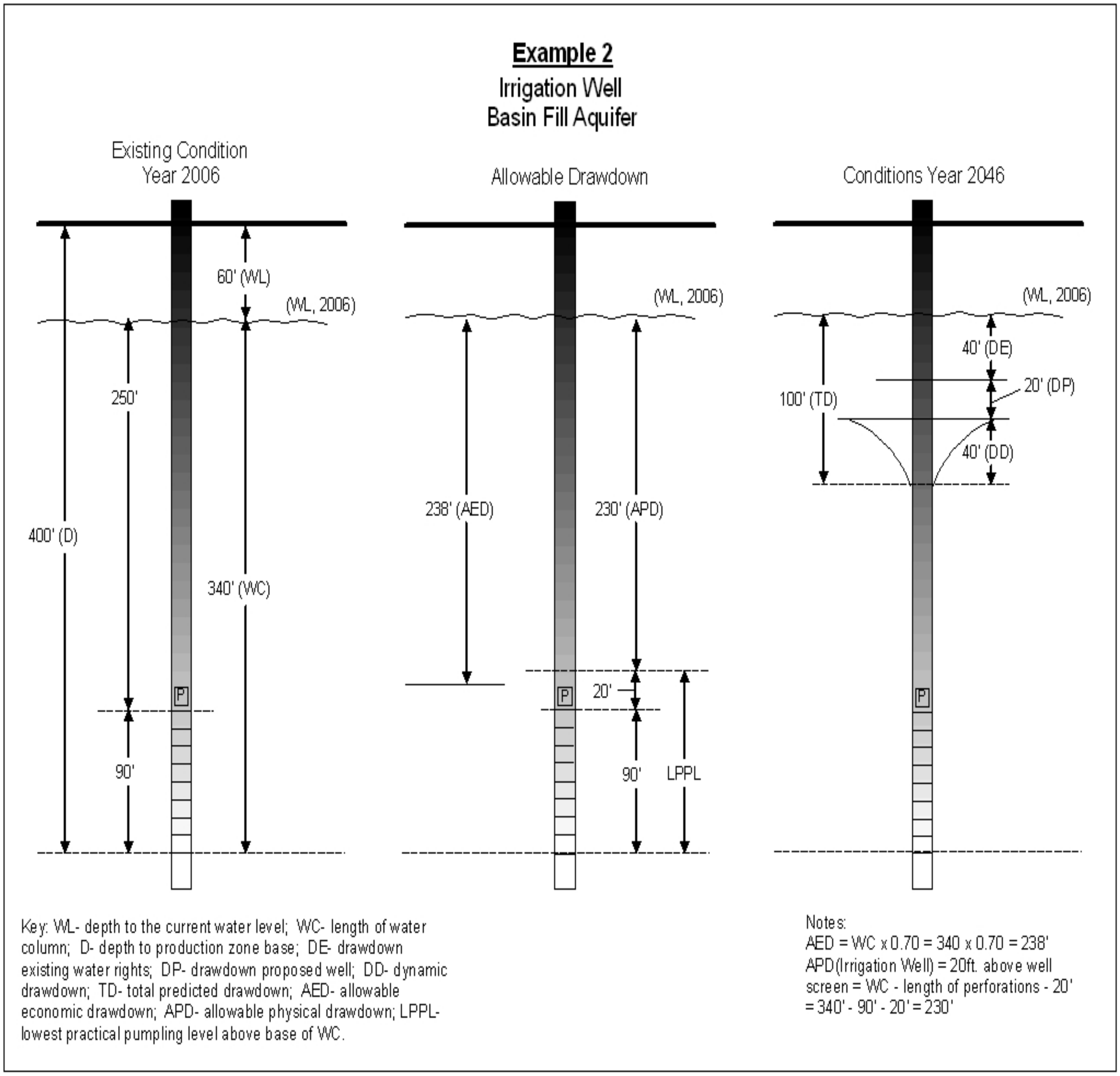


7. Procedures

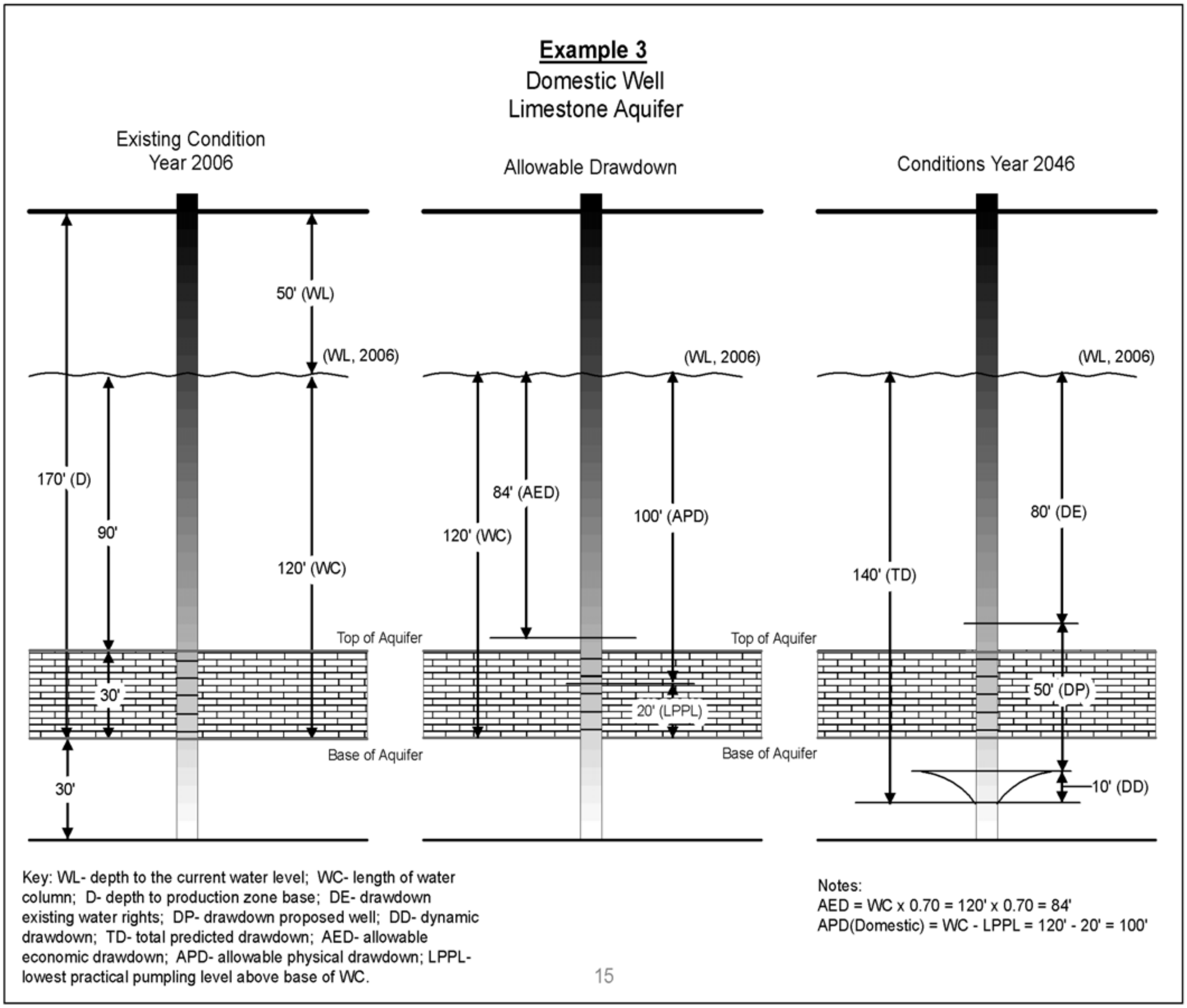
- Estimate the existing water column (WC).
- Multiply WC by 0.70 to obtain allowable economic drawdown (AED).
- Estimate drawdowns due to existing water rights (DE).
- Estimate drawdowns due to proposed use (DP).
- Estimate dynamic drawdown (DD).
- Add results from steps 3 through 5 to obtain the total drawdown (DT).
- Estimate LPPL in relation to base of water column
- Subtract LPPL from water column to obtain allowable physical drawdown (APD)
- Compare total drawdown (DT) with allowable economic drawdown (AED) and allowable physical drawdown (APD)



Well #	Use	Depth to Base of Water Column bls (D)	Water Level 2006 (WL)	Water Column 2006 (WC) (WC= D - WL)	40-Year Drawdown From Existing Wells (DE)	40-Year Drawdown From Proposed Well (DP)	Dynamic Drawdown (DD)	Total Drawdown (TD= DE + DP + DD)	Allowable Economic (AED)	Drawdown Physical (APD)
Ex. 1	Dom.	150	50	100	40	10	10	60	70	80



Well #	Use	Depth to Base of Water Column bls (D)	Water Level 2006 (WL)	Water Column 2006 (WC) (WC= D - WL)	40-Year Drawdown From Existing Wells (DE)	40-Year Drawdown From Proposed Well (DP)	Dynamic Drawdown (DD)	Total Drawdown (TD= DE + DP + DD)	Allowable Economic (AED)	Drawdown Physical (APD)
Ex. 2	Irr.	400	60	340	40	20	40	100	238	230



Well #	Use	Depth to Base of Water Column bls (D)	Water Level 2006 (WL)	Water Column 2006 (WC) (WC= D - WL)	40-Year Drawdown From Existing Wells (DE)	40-Year Drawdown From Proposed Well (DP)	Dynamic Drawdown (DD)	Total Drawdown (TD= DE + DP + DD)	Allowable Economic (AED)	Drawdown Physical (APD)
Ex. 3	Irr.	170	50	120	80	50	10	140	84	100

REFERENCES

Davis, S.N. and DeWiest, R .J., 1966, Hydrogeology

Driscoll, F.G., 1987, Groundwater and Wells

Fetter, C. W. Jr., 1988, Applied Hydrogeolgogy

Freeze, R. A. and Cherry, J. A., 1979, Groundwater

Glorieta Geoscience, Inc., Rancho San Lucas Well, Santa Fe County, NM

Heath, R.W, 1983, Basic Ground-Water Hydrology: USGS Water Supply Paper 2220

McAda, D.P., and Barroll, P, 2002, Simulation of Ground-water flow in the Middle Rio Grande Basin: USGS Water-Resources Investigations Report 02-4200

Musharrafieh, G., and Logan, L., 1999, Numerical Simulation of Groundwater Flow for Water Rights Administration in the Curry and Portales Valley Underground Water Basins, NM, TDH-99-2

Roscoe Moss Company, 1990, Handbook of Groundwater Development

Trauger, F.D., 1972, Water Resources and General Geology of grant County: NM, New Mexico State Bureau of mines and Mineral Resources, Hydrologic Report 2

U.S. Department of the Interior, 1981, Ground Water Manual

Walton, W.C., 1970, Groundwater Resource Evaluation

Weight, W. D. and Sonderegger, J.L., Manual of Applied Field Hydrogeology

Also see SECTION I for selected sources of information