Water Budgets

The foundation for determining sustainability

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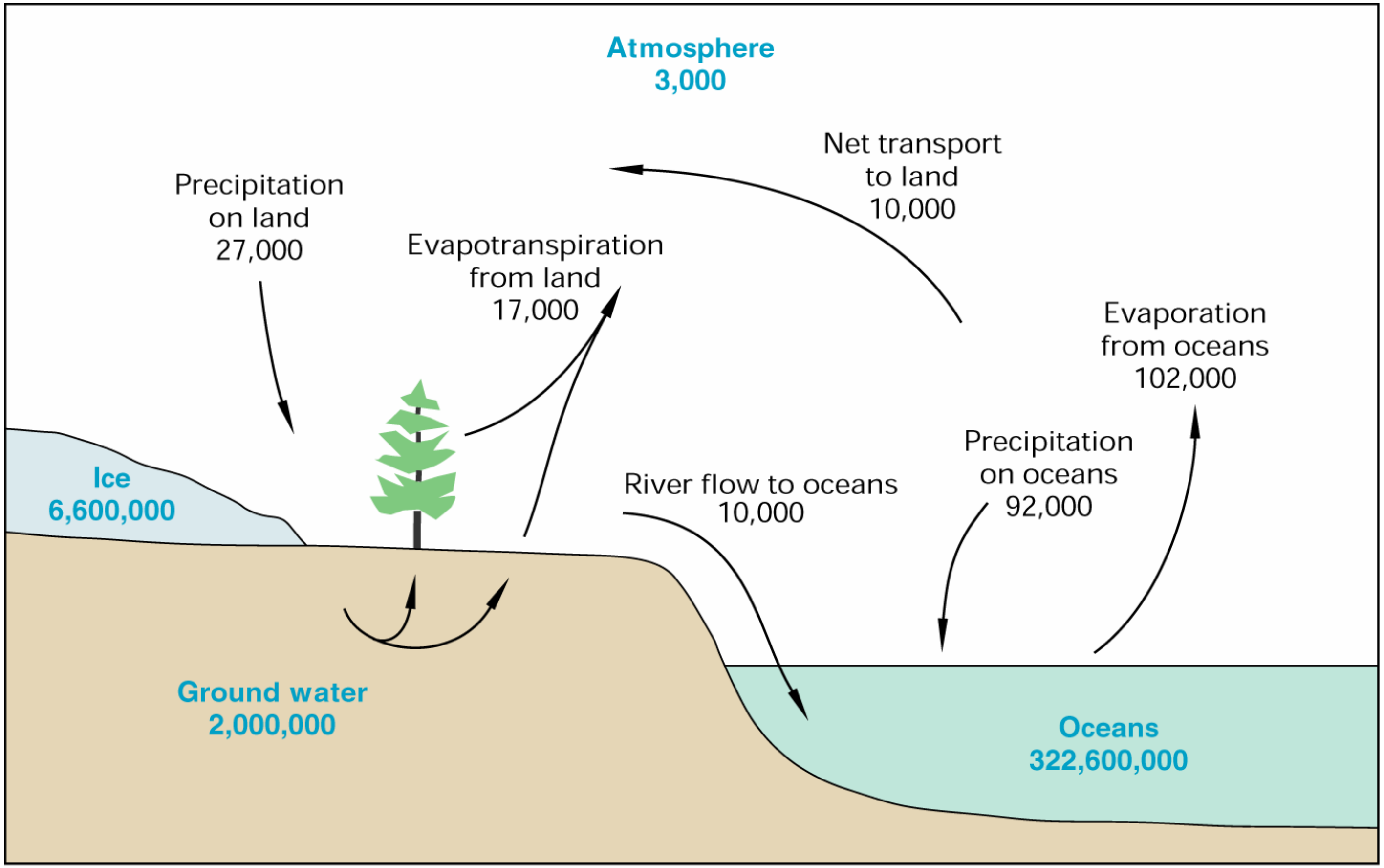
- **To determine sustainability of a resource it is essential to know how much is present in a given area or volume and how that amount is replenished and depleted.**

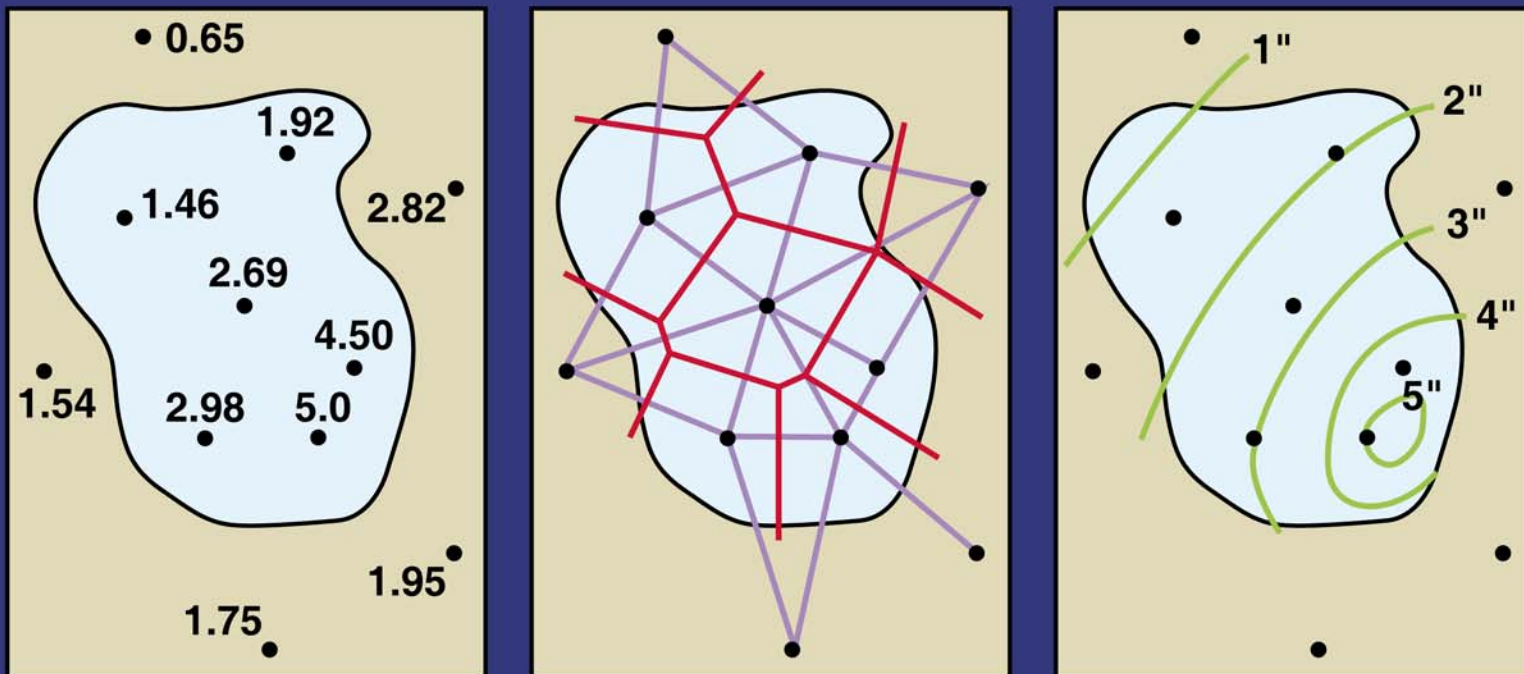
- **Water budgets are conceptually simple, but difficult and expensive to determine accurately.**
- **The problem relates to limitations in our ability to measure storage, and changes in storage, in an accounting unit, as well as the fluxes to and from it.**



Pools are in cubic miles

Fluxes are in cubic miles per year


Stream
Stream
Lake
Stream



Arithmetic mean: 3.09 inches

Thiessen method: 2.84 inches

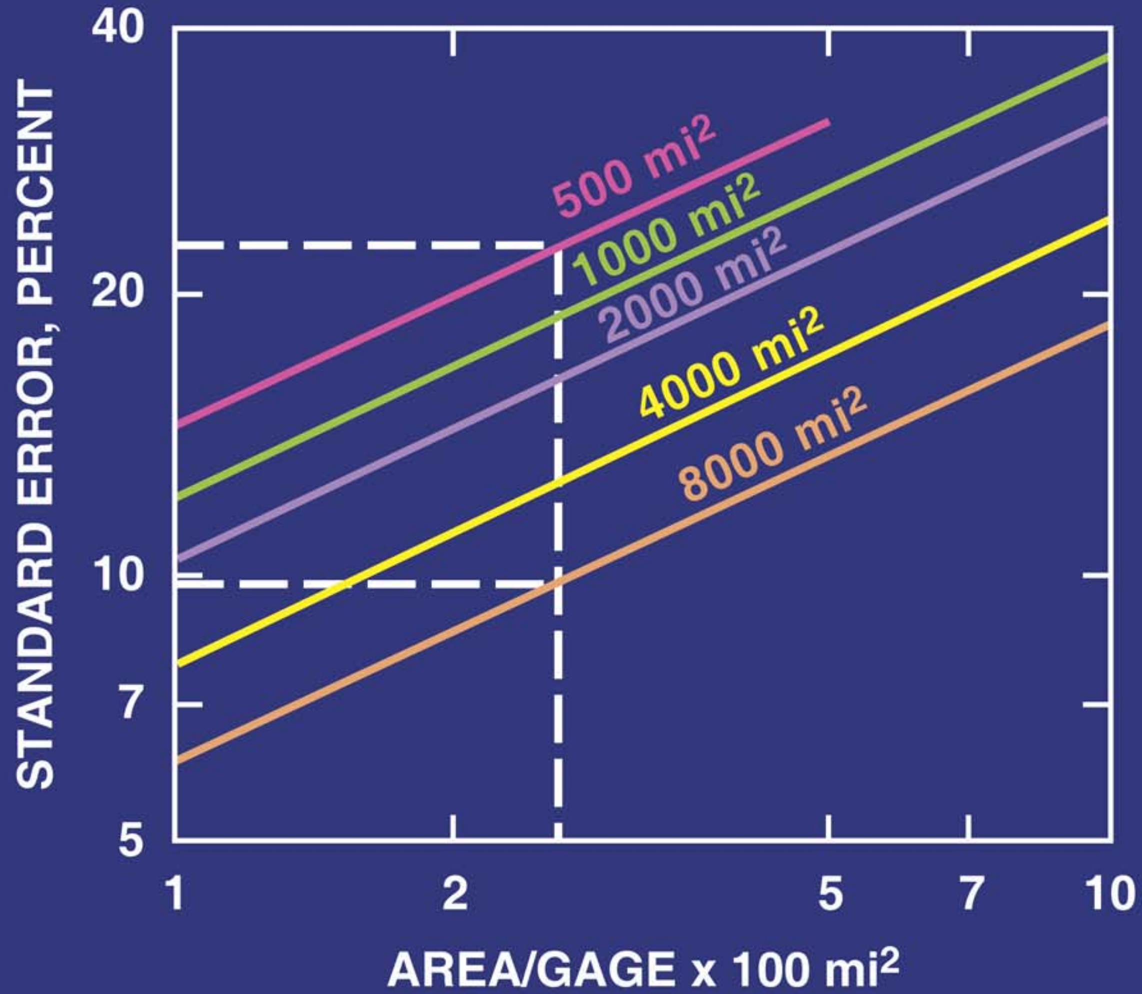
Isohyetal method: 2.61 inches

Gauge density *(mi2/gauge)*	Sampling error *(Percent)*			
	3-hour storm (in)			
	0.1	0.5	1.0	2.0
25	**10**	**6**	**4**	**3**
50	**17**	**10**	**8**	**6**

	Monthly			
	1	2	4	8
25	**4**	**3**	**3**	**2**
50	**6**	**5**	**5**	**4**

	Seasonal			
	10	15	20	30
25	**2**	**1**	**1**	**<1**
50	**3**	**2**	**2**	**1**

(Illinois) *Huff and Schickedanz, 1972*

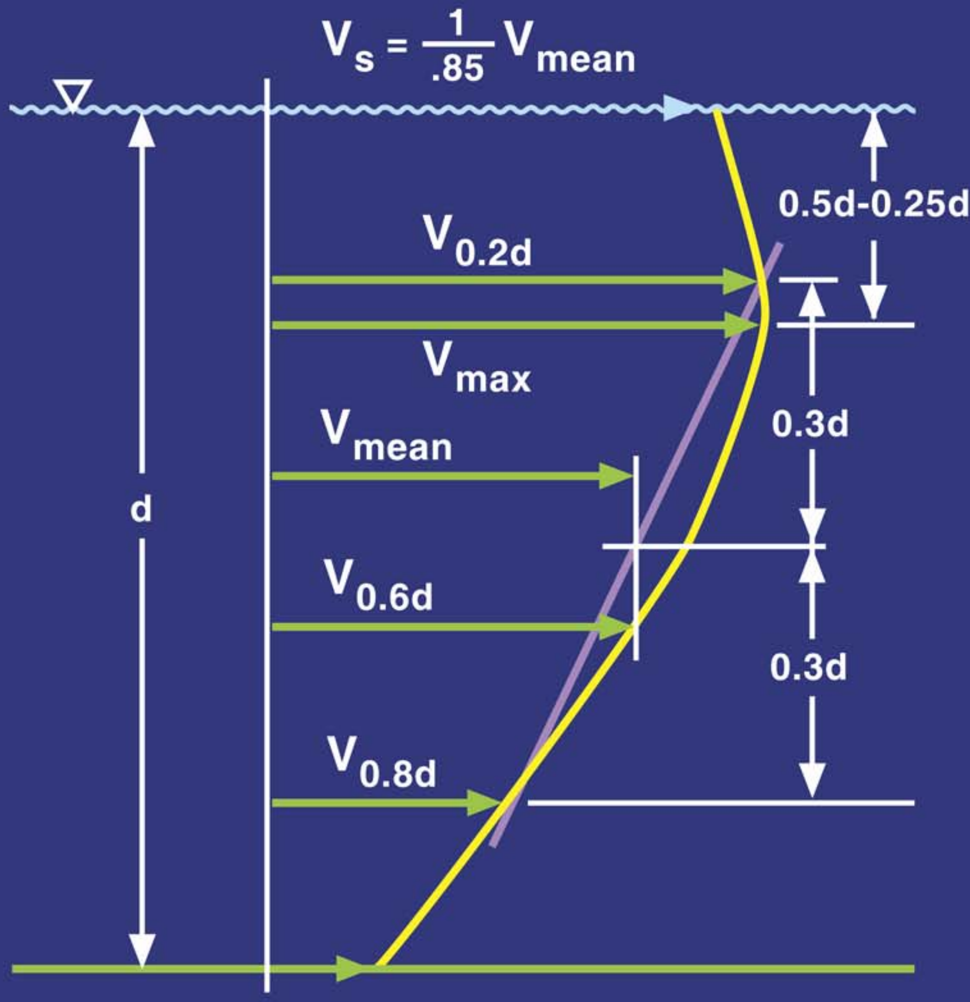


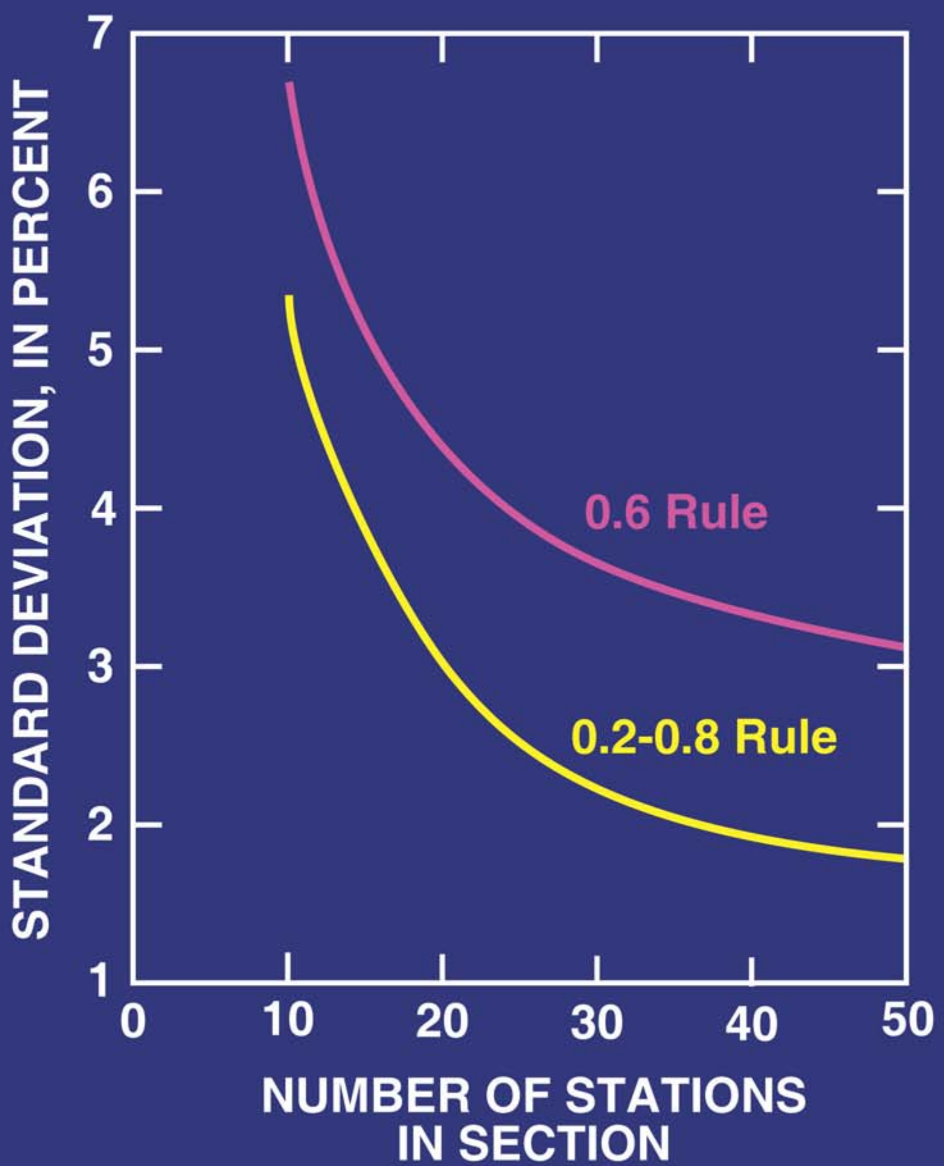
STANDARD ERROR, PERCENT
40
20
10
7
5
500 mi2
1000 mi2
2000 mi2
4000 mi2
8000 mi2
1
2
5
7
10
AREA/GAGE x 100 mi2

ET compared to Energy Budget - Williams Lake

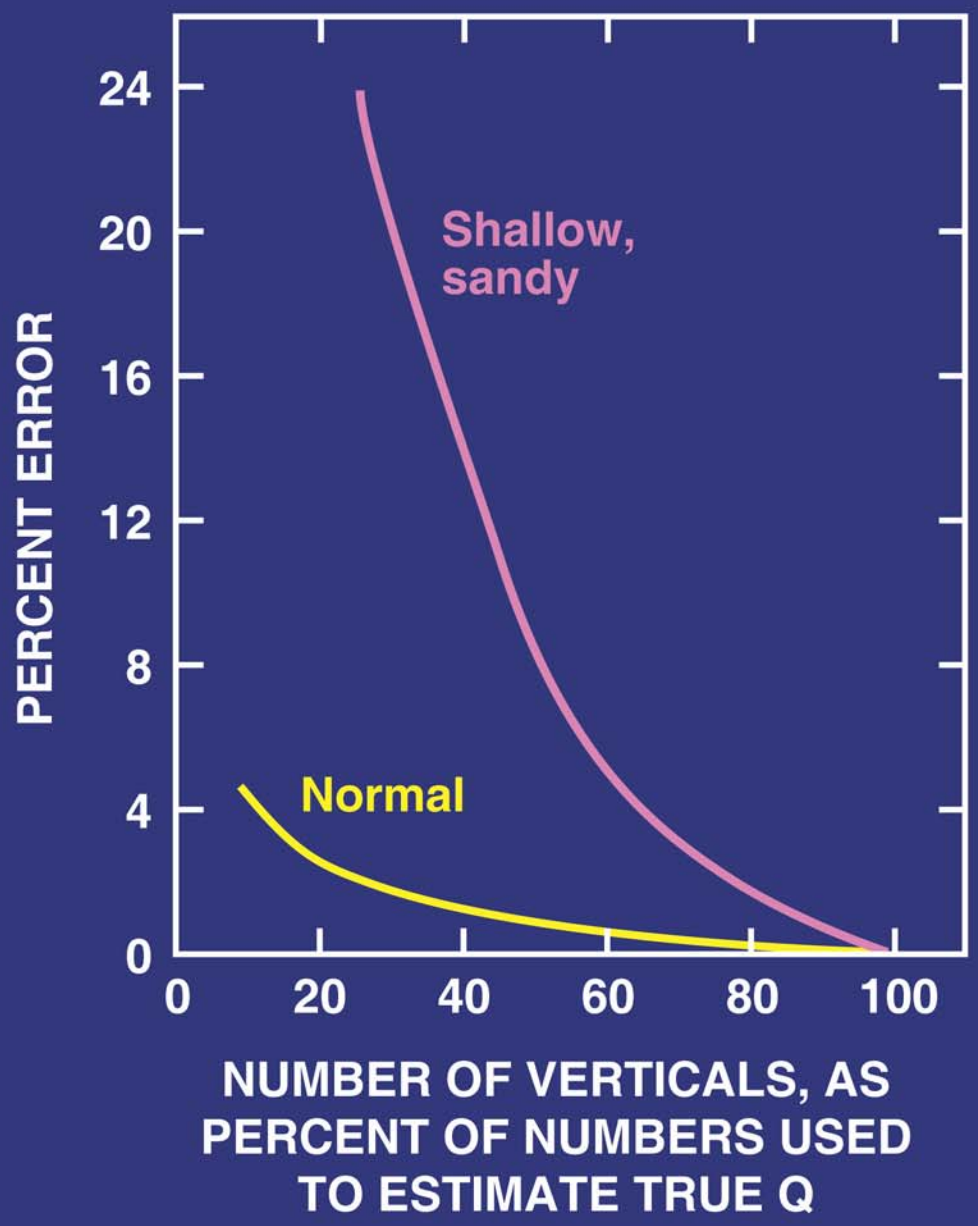
Method	Mean (cm/mo)	Std. Dev.
Penman	**-0.03**	**0.80**
DeBruin-Keijman	**0.16**	**0.90**
Priestley-Taylor	**0.42**	**0.96**
Jensen-Haise	**0.00**	**1.80**
Mass transfer	**-0.10**	**1.27**
Makkink	**-0.35**	**1.58**
Papadakis	**-0.43**	**1.21**
Hamon	**0.77**	**1.65**
DeBruin	**0.86**	**1.78**
Stephens-Stewart	**-1.30**	**1.32**
Brutsaert-Stricker	**2.17**	**1.27**


1.0
1.0


$V_s = \frac{1}{.85} V_{mean}$
0.5d-0.25d
$V_{0.2d}$
V_{max}
0.3d
V_{mean}
d
$V_{0.6d}$
0.3d
$V_{0.8d}$



7
6
5
4
3
2
1
0
10
20
30
40
50
STANDARD DEVIATION, IN PERCENT
0.6 Rule
0.2-0.8 Rule
NUMBER OF STATIONS
IN SECTION


PERCENT ERROR
24
20
16
12
8
4
0
Shallow, sandy
Normal
0
20
40
60
80
100
NUMBER OF VERTICALS, AS PERCENT OF NUMBERS USED TO ESTIMATE TRUE Q

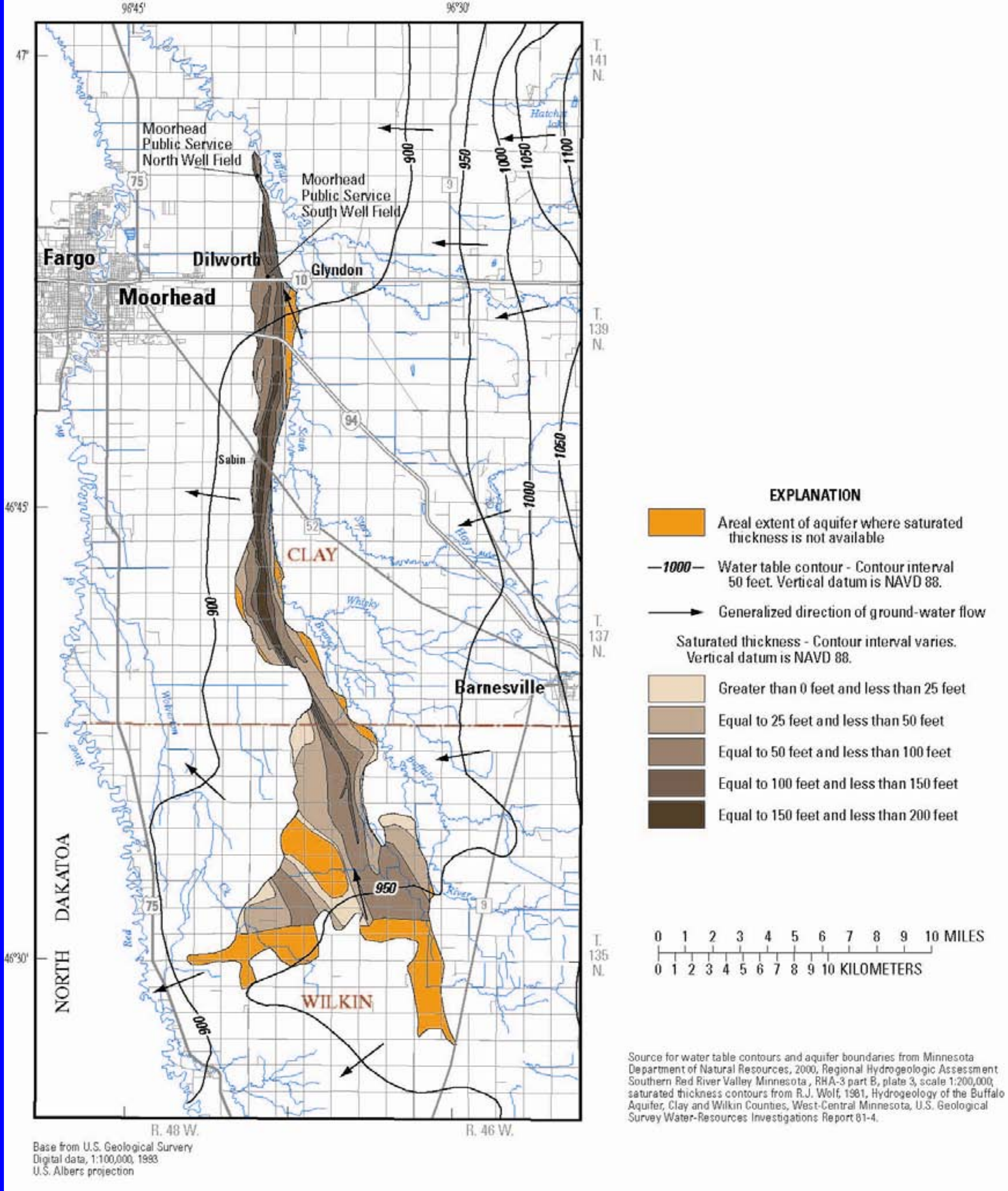


Figure 7. Generalized extent, elevation of regional potentiometric surface, generalized direction of ground-water flow, and saturated thickness of the Buffalo Aquifer.

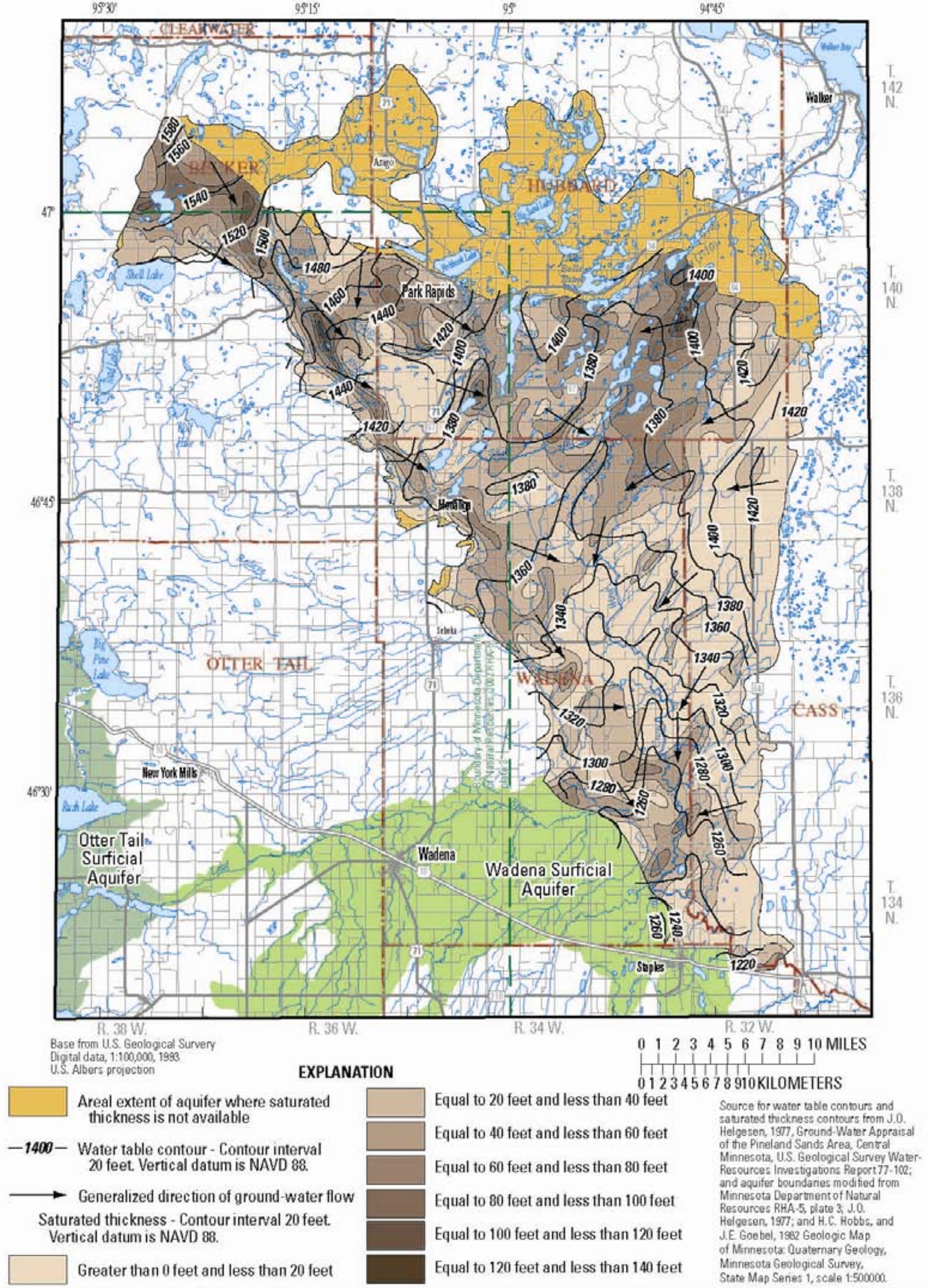
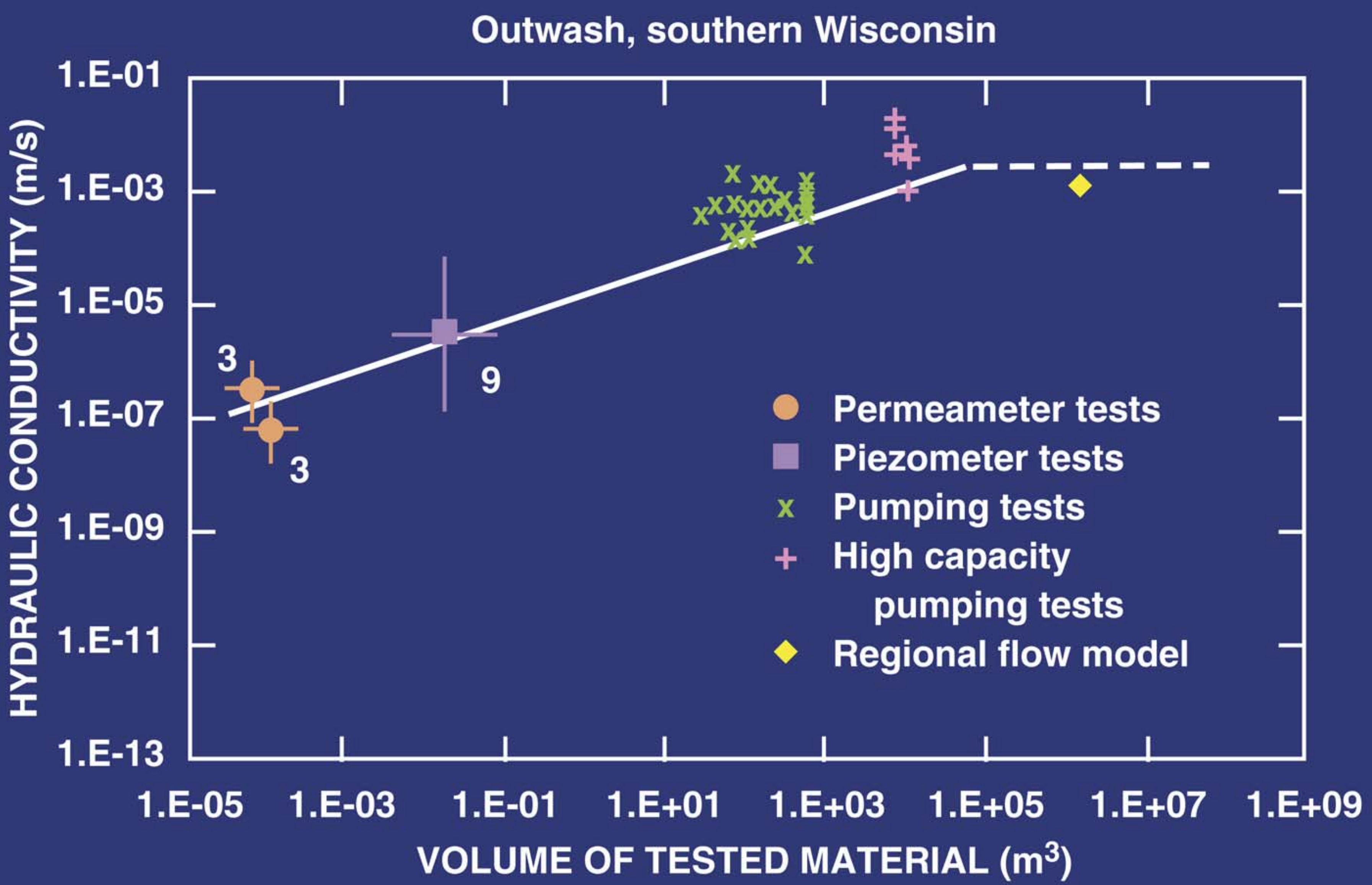
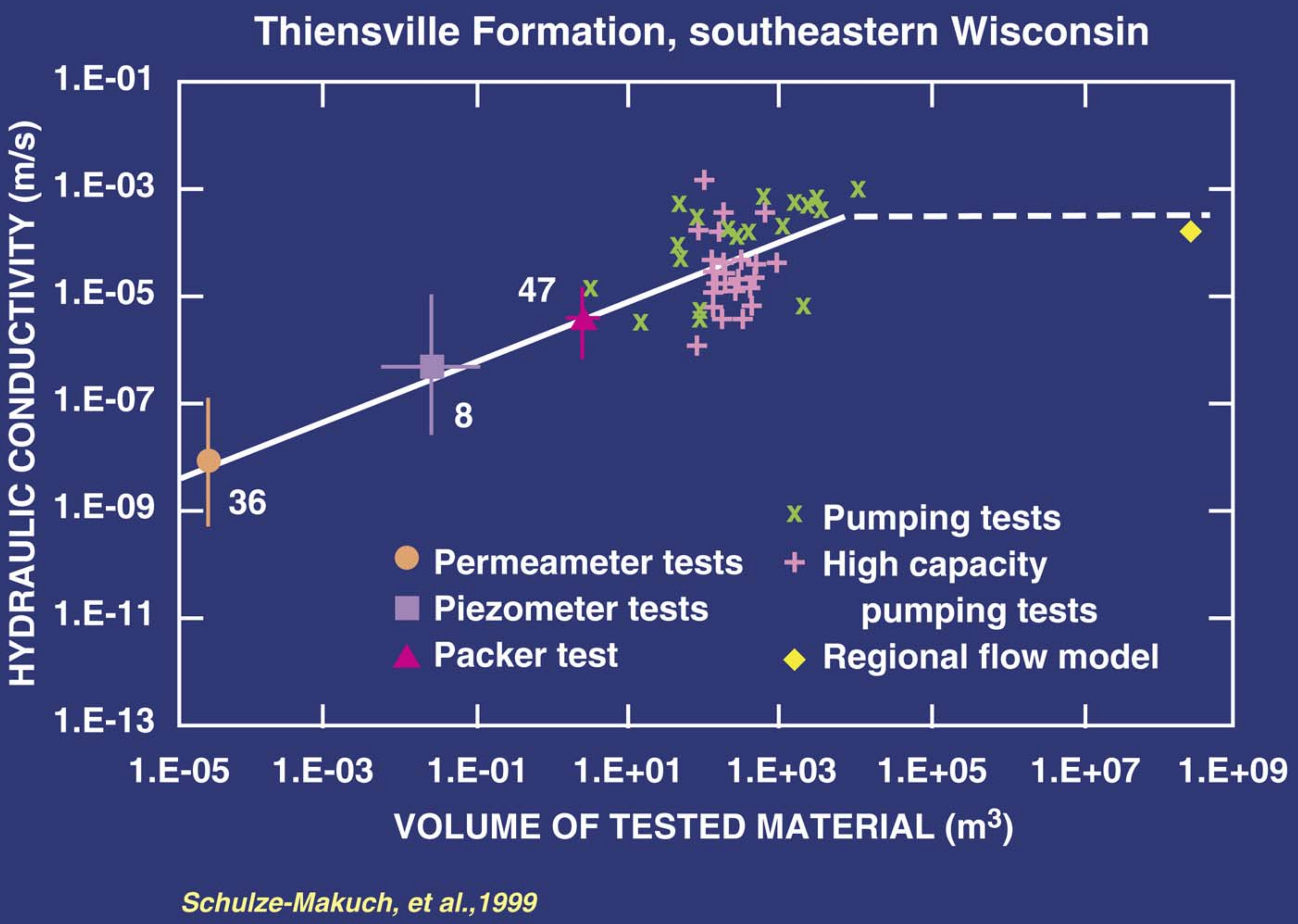
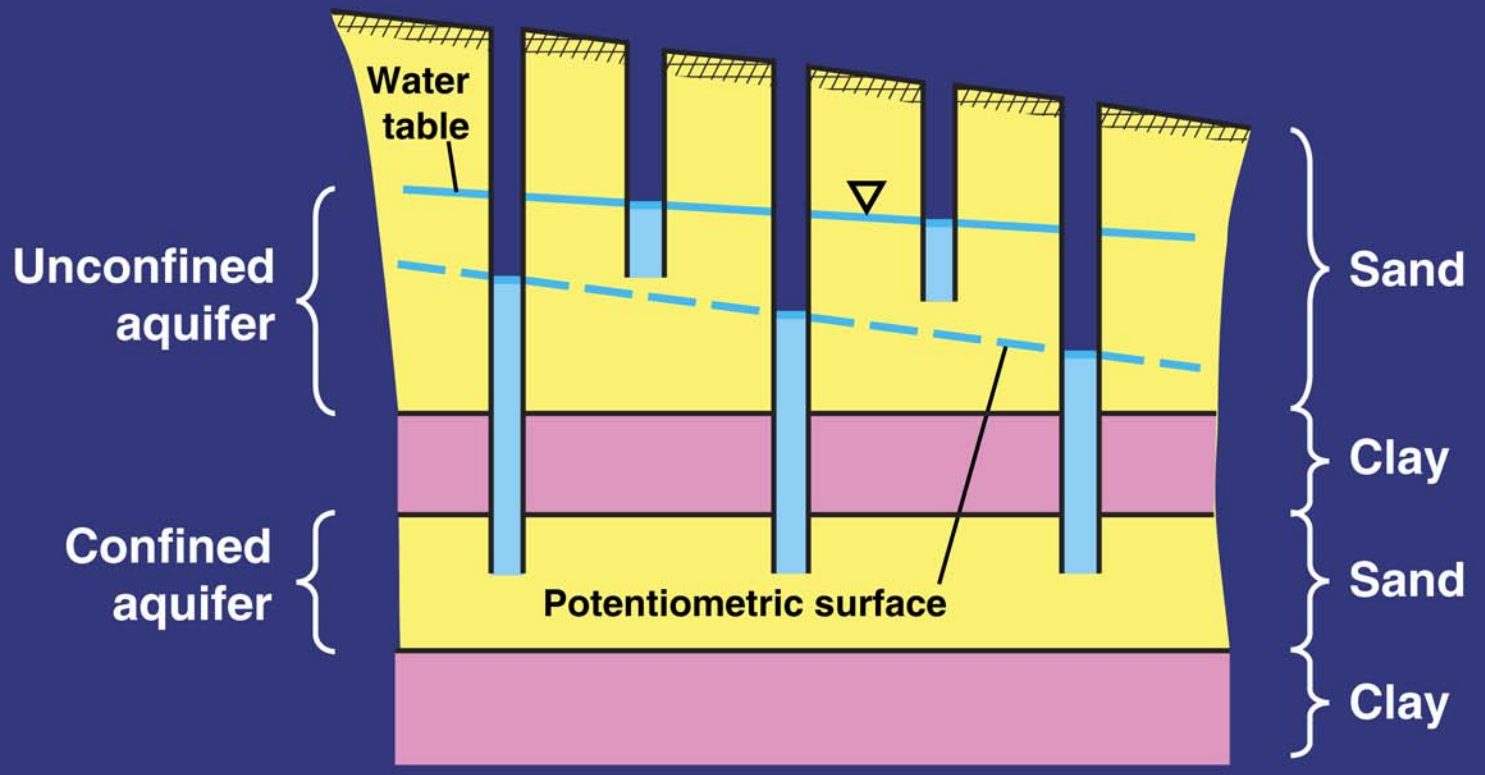


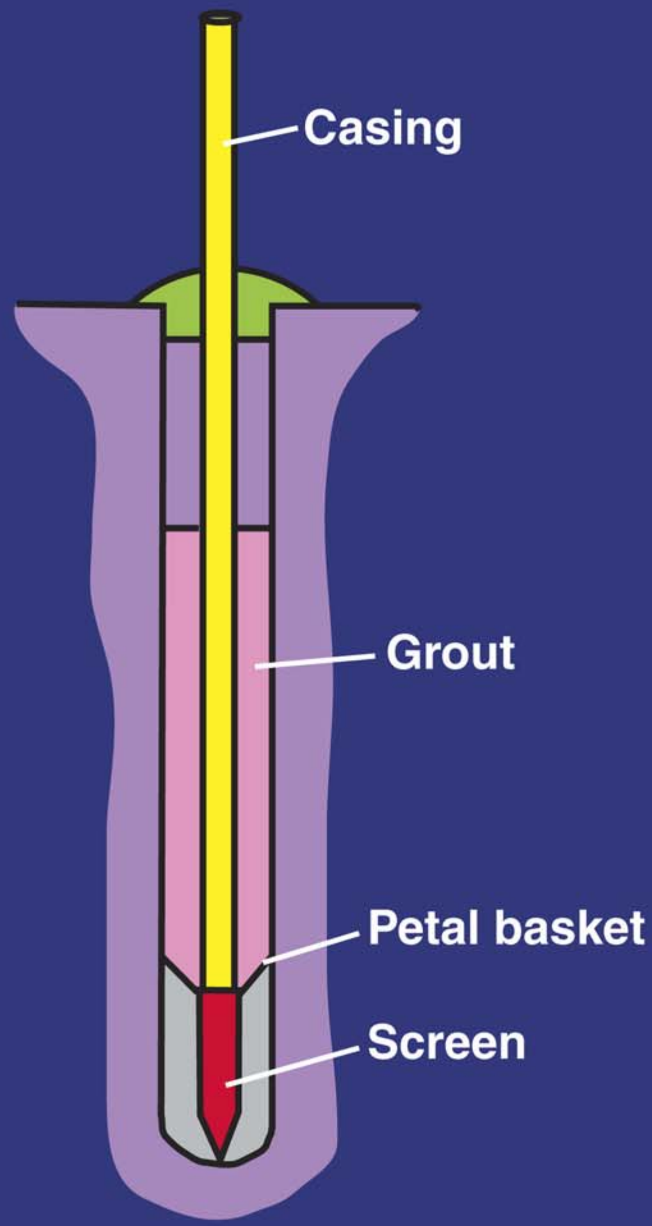
Figure 4. Generalized extent, elevation of regional potentiometric surface, generalized direction of ground-water flow, and saturated thickness of the Pineland Sands Surficial Aquifer.



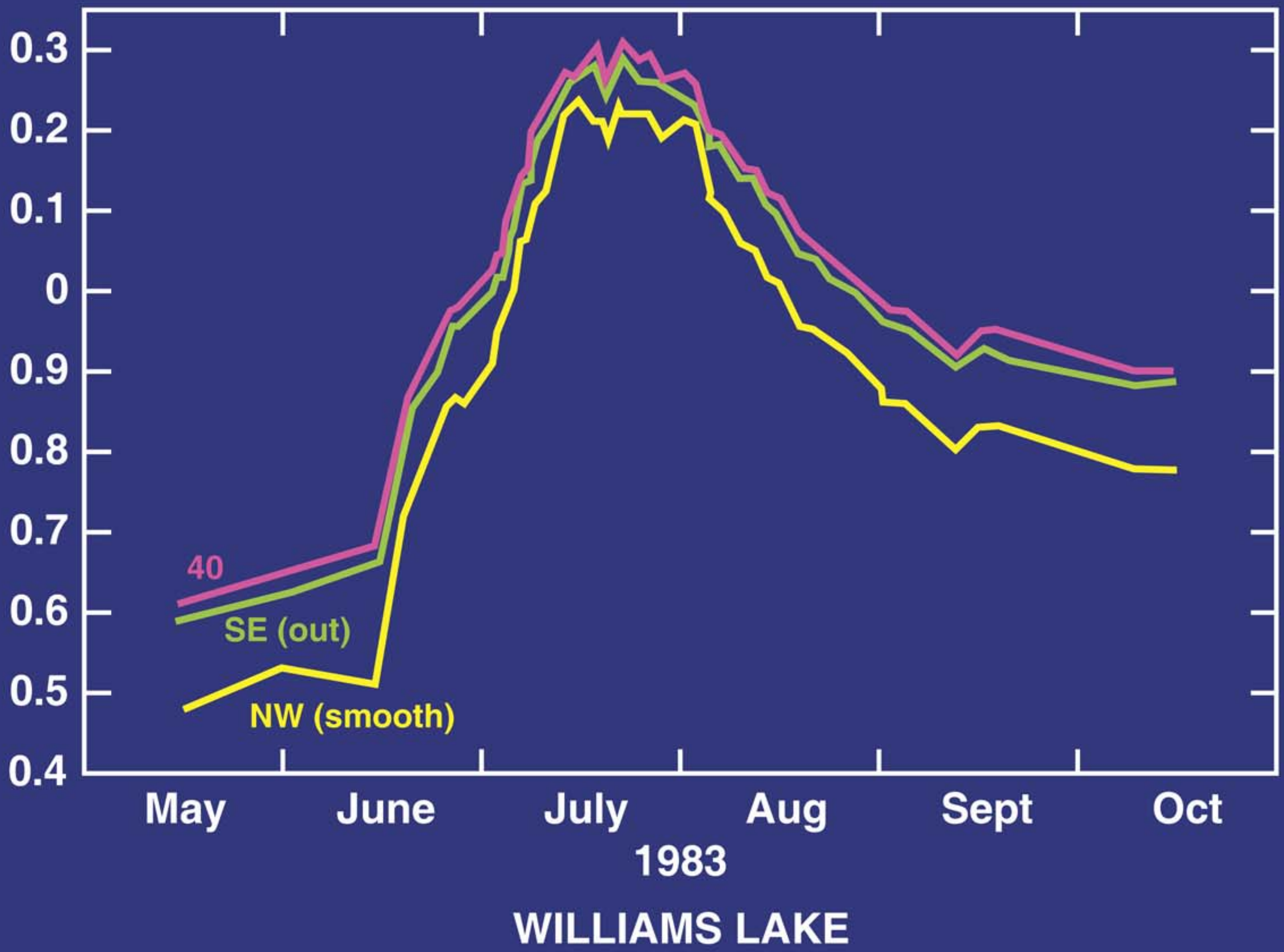
Schulze-Makuch, et al.,1999

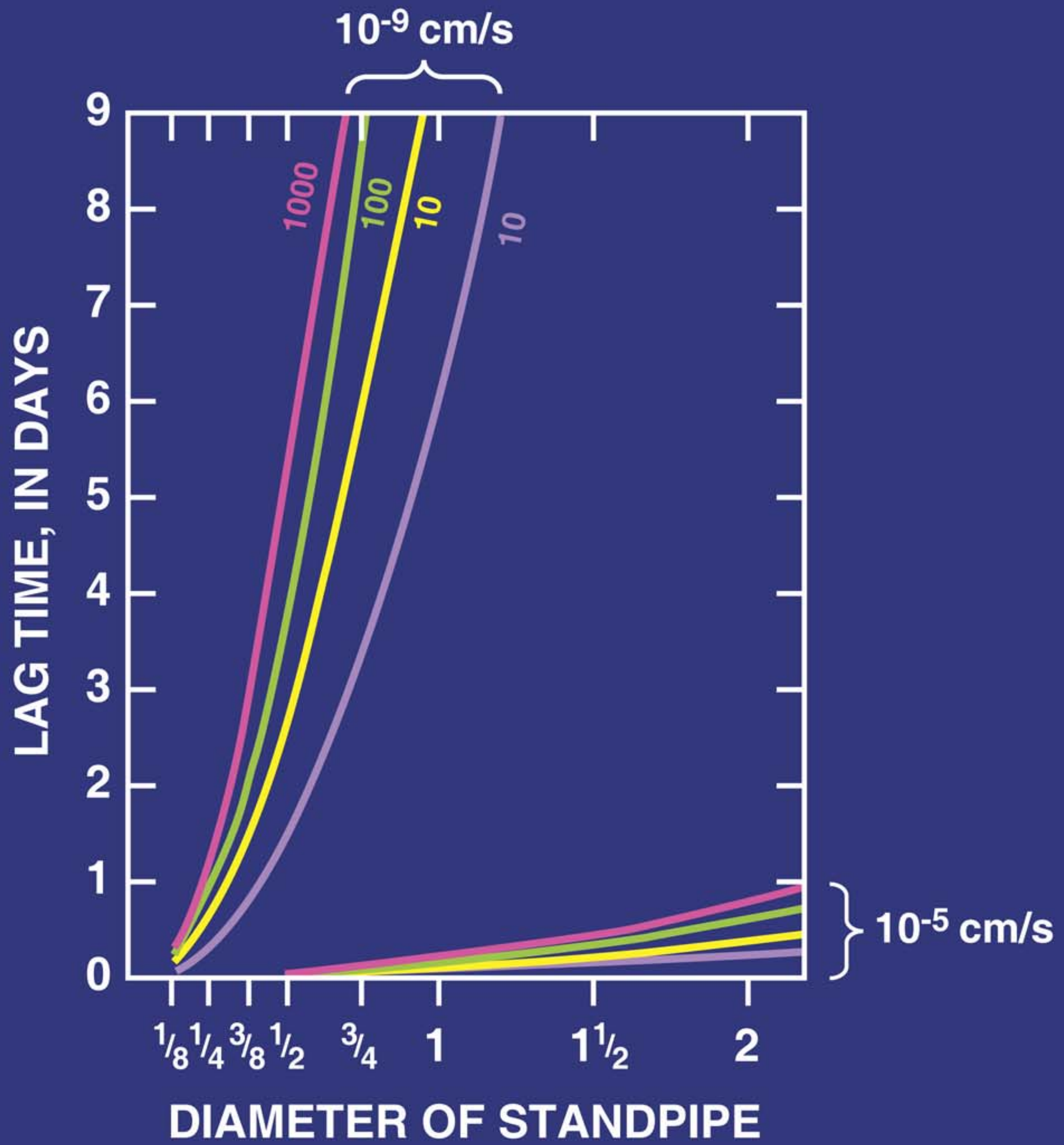

Thiensville Formation, southeastern Wisconsin
HYDRAULIC CONDUCTIVITY (m/s)
1.E-01
1.E-03
1.E-05
1.E-07
1.E-09
1.E-11
1.E-13
47
8
36
Pumping tests
High capacity pumping tests
Regional flow model
Permeameter tests
Piezometer tests
Packer test
1.E-05
1.E-03
1.E-01
1.E+01
1.E+03
1.E+05
1.E+07
1.E+09
VOLUME OF TESTED MATERIAL (m3)
Schulze-Makuch, et al.,1999


Water table
Unconfined aquifer
Confined aquifer
Potentiometric surface
Sand
Clay
Sand
Clay


Casing
Grout
Petal basket
Screen


FITTINGS


0.3
0.2
0.1
0
0.9
0.8
0.7
0.6
0.5
0.4
40
SE (out)
NW (smooth)
May
June
July
Aug
Sept
Oct
1983
WILLIAMS LAKE

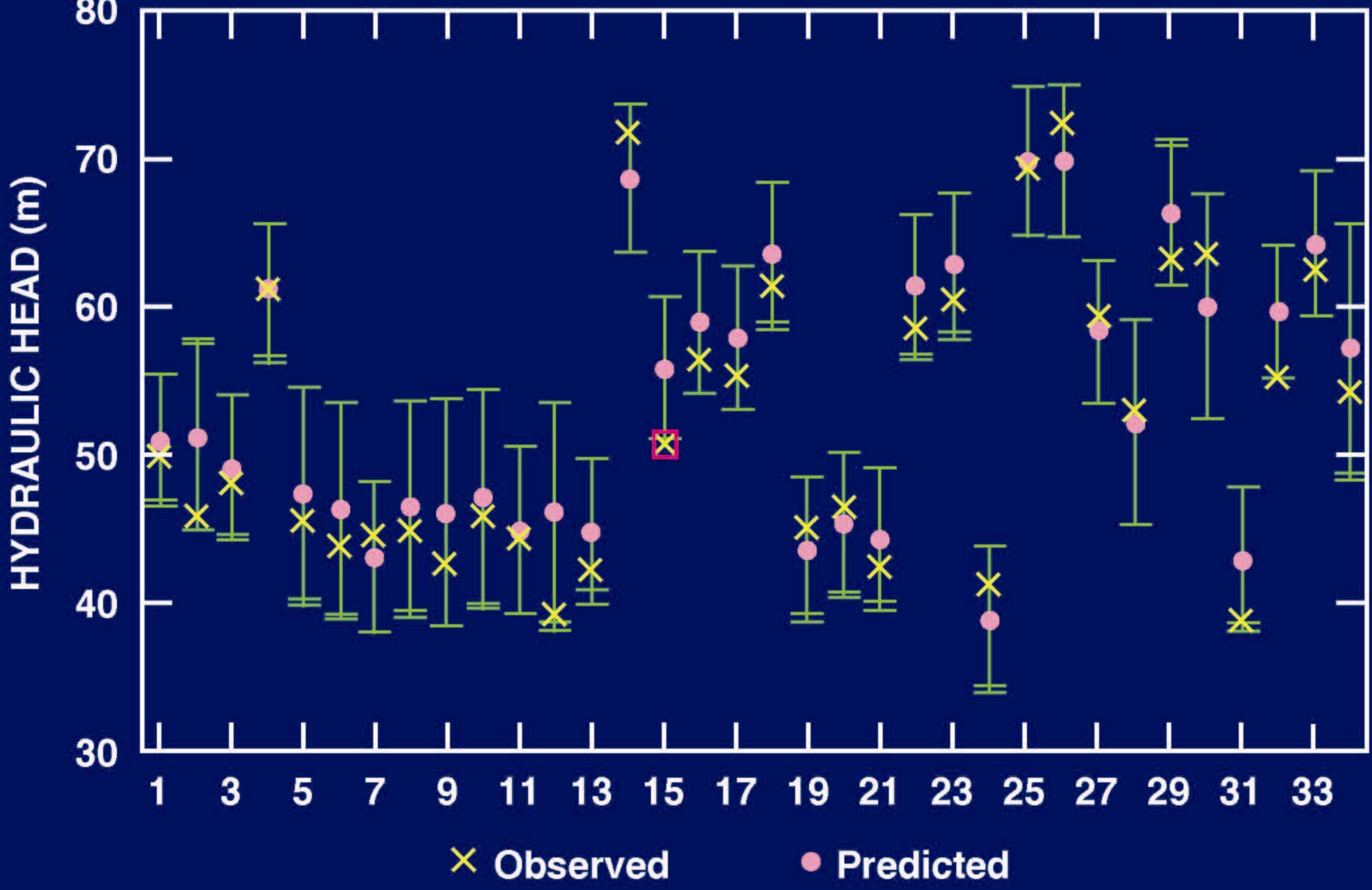


10-9 cm/s
10-5 cm/s
LAG TIME, IN DAYS
DIAMETER OF STANDPIPE
0
1
2
3
4
5
6
7
8
9
1/8
1/4
3/8
1/2
3/4
1
1 1/2
2
1000
100
10
10

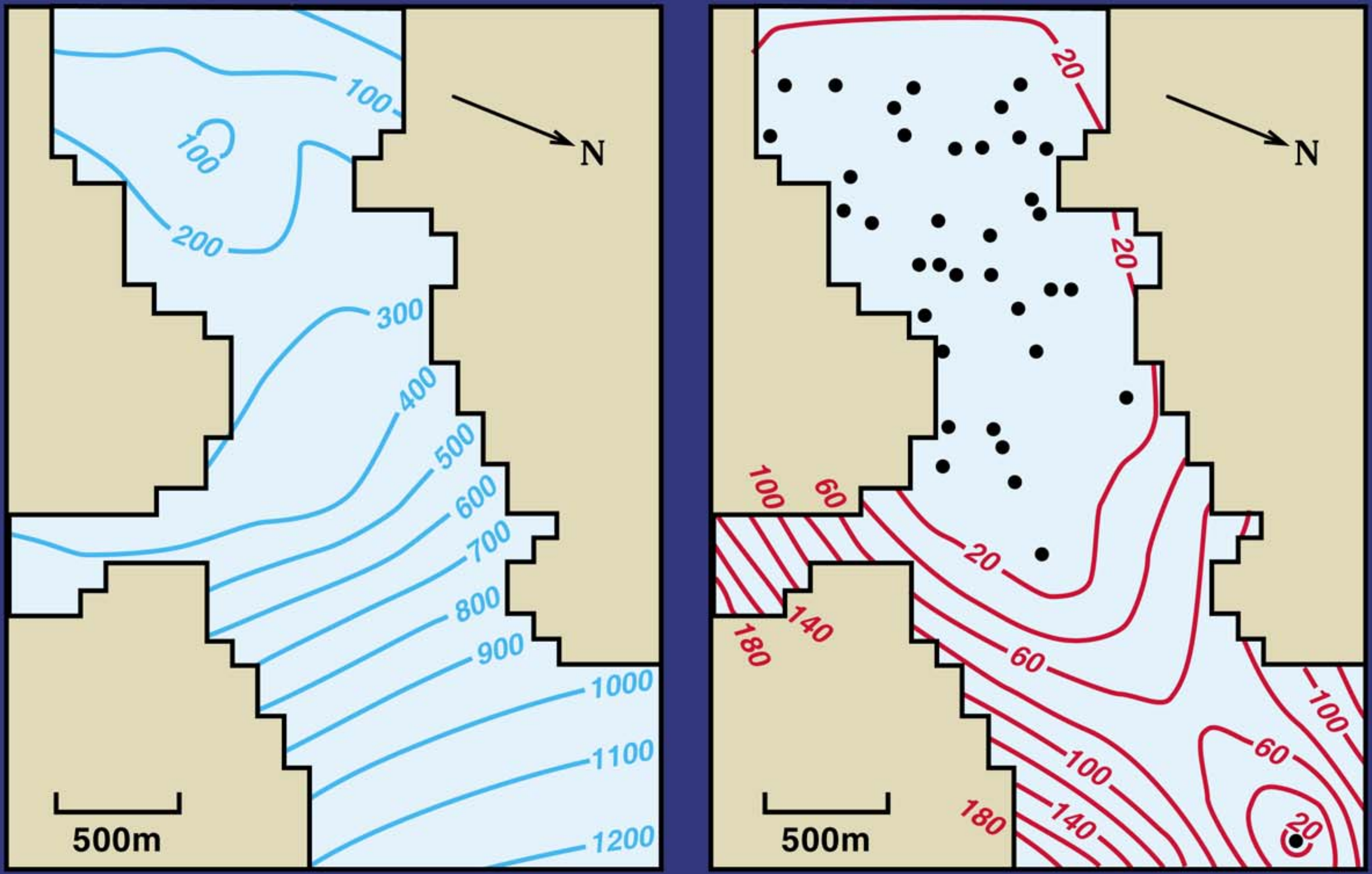
Errors in head map
related to density of control points *(Hanson, 1972)*

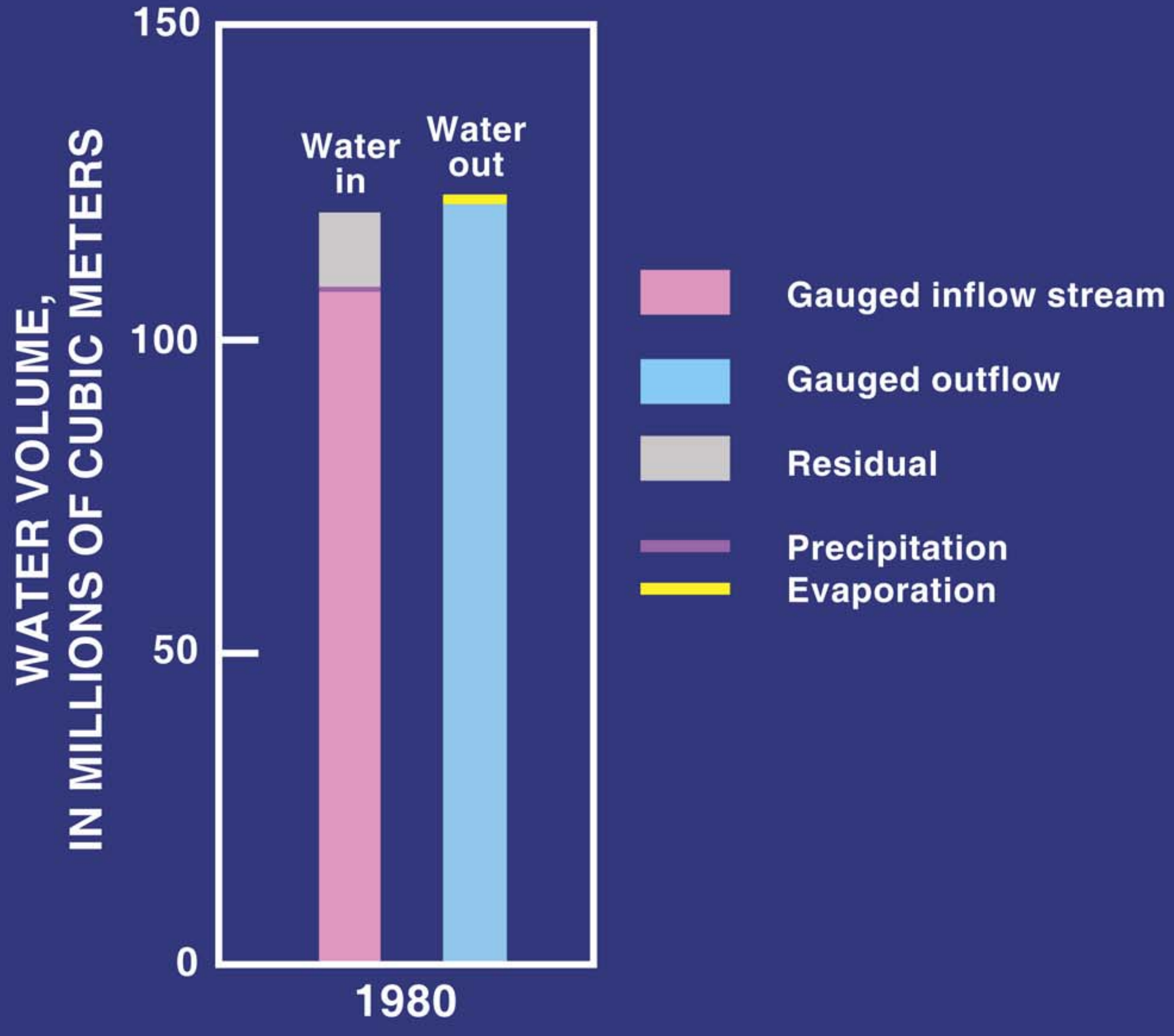
432 sq. mi.

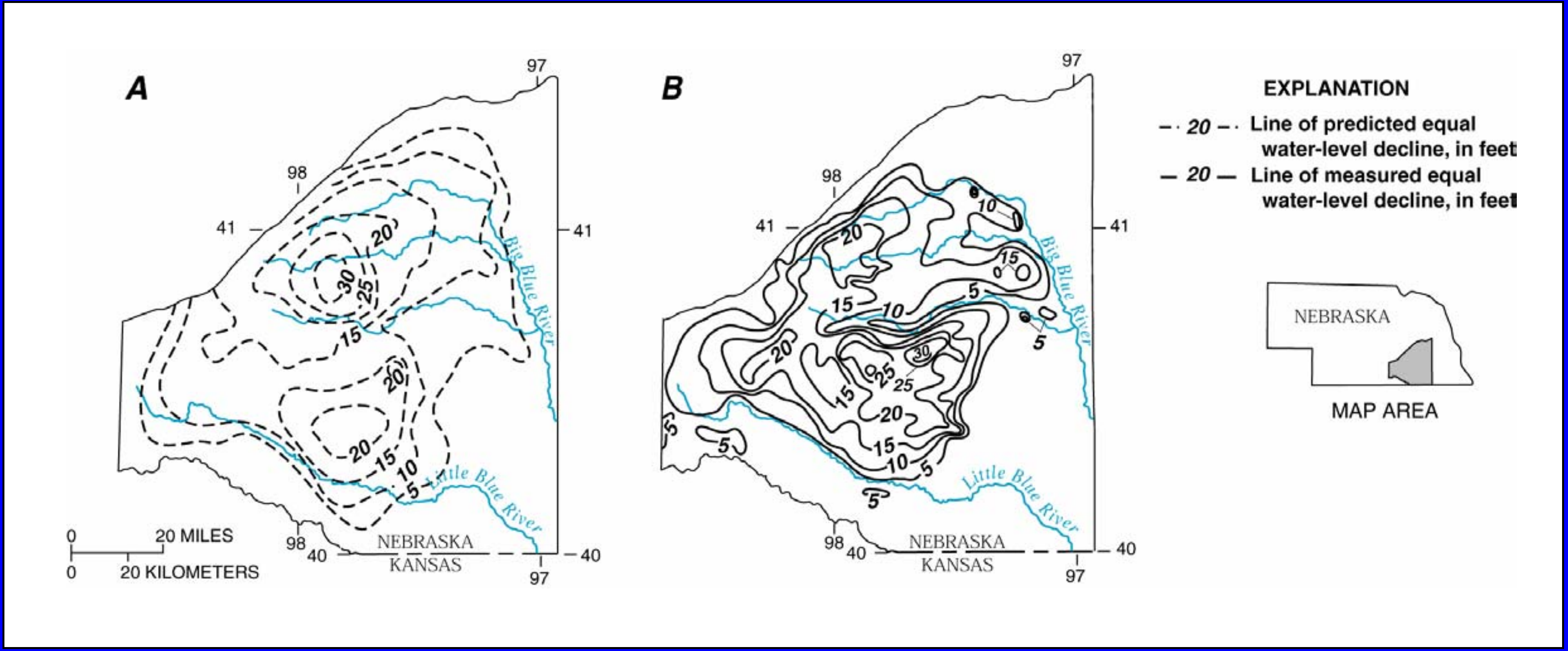
Well	Difference from standard		
spacing	Average	Range	
miles	feet	feet	feet
1	**0.09**	**6.7**	**-5.5**
4	**1.15**	**27.2**	**-24.1**
6	**1.33**	**29.2**	**-29.2**

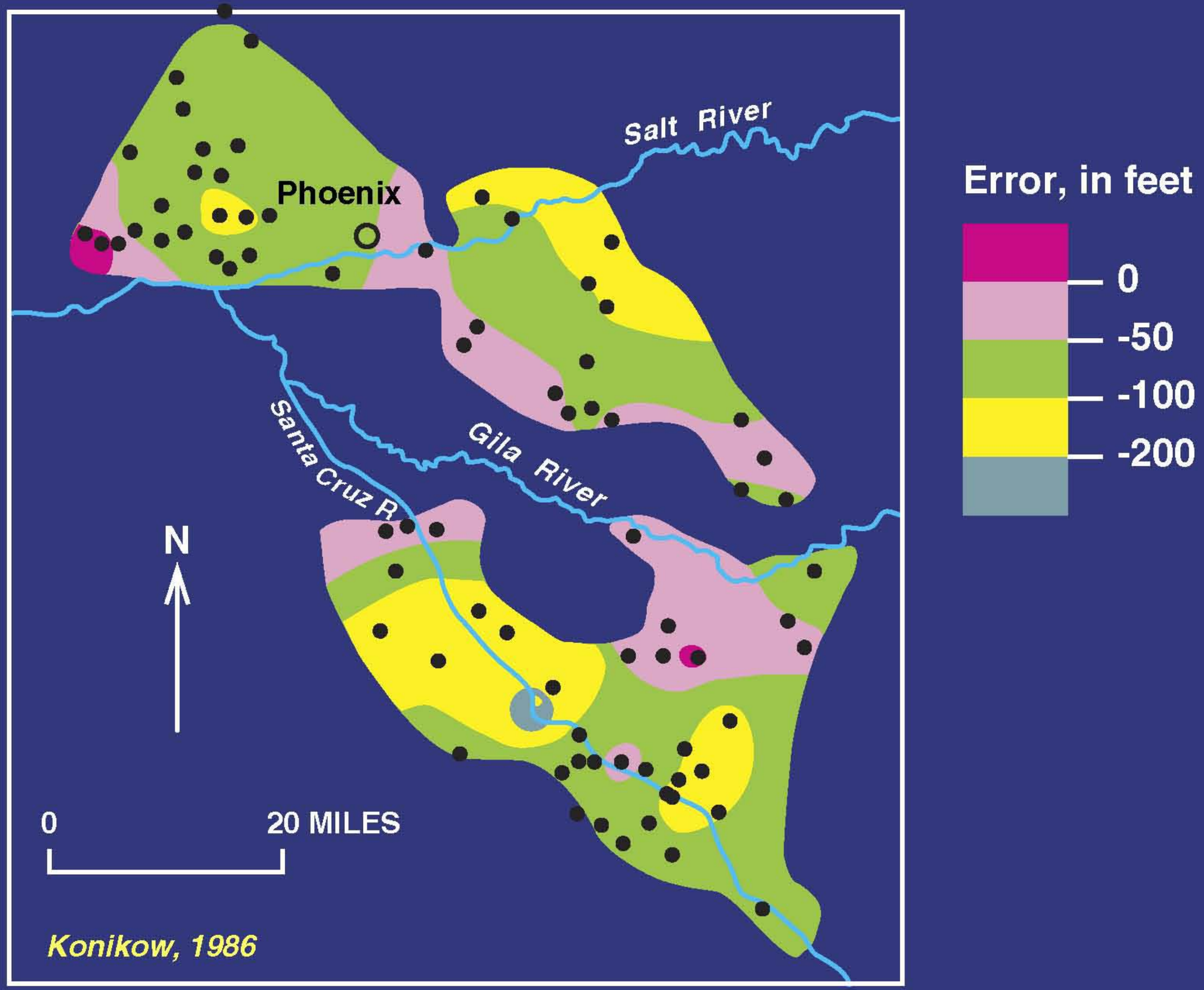


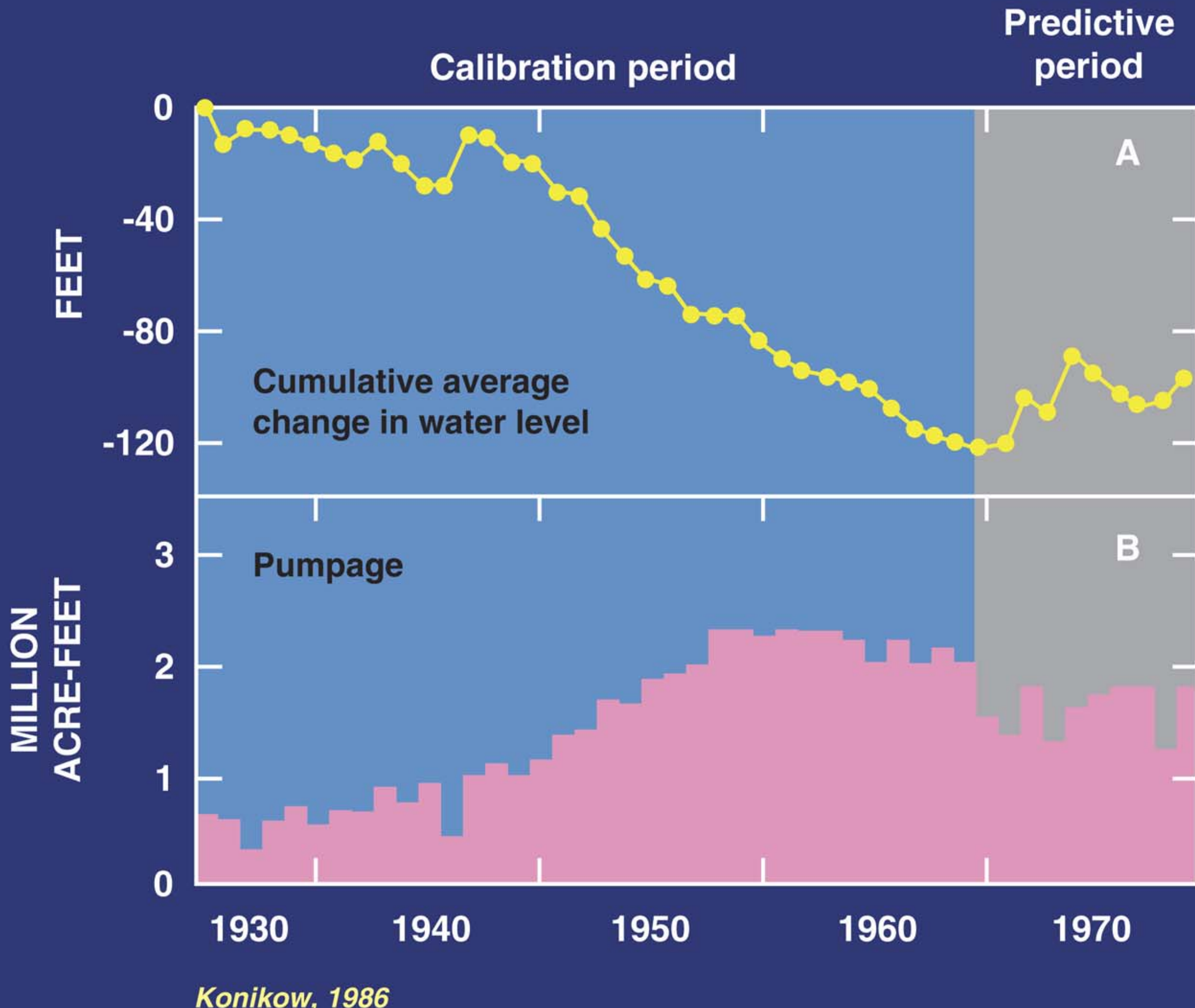
Christensen and Cooley, 1999


100
100
200
300
400
500
600
700
800
900
1000
1100
1200
N
500m
20
20
20
100
60
140
180
60
100
60
100
140
180
20
N
500m


WATER VOLUME,
IN MILLIONS OF CUBIC METERS
150
100
50
0
Water in
Water out
1980
Gauged inflow stream
Gauged outflow
Residual
Precipitation
Evaporation

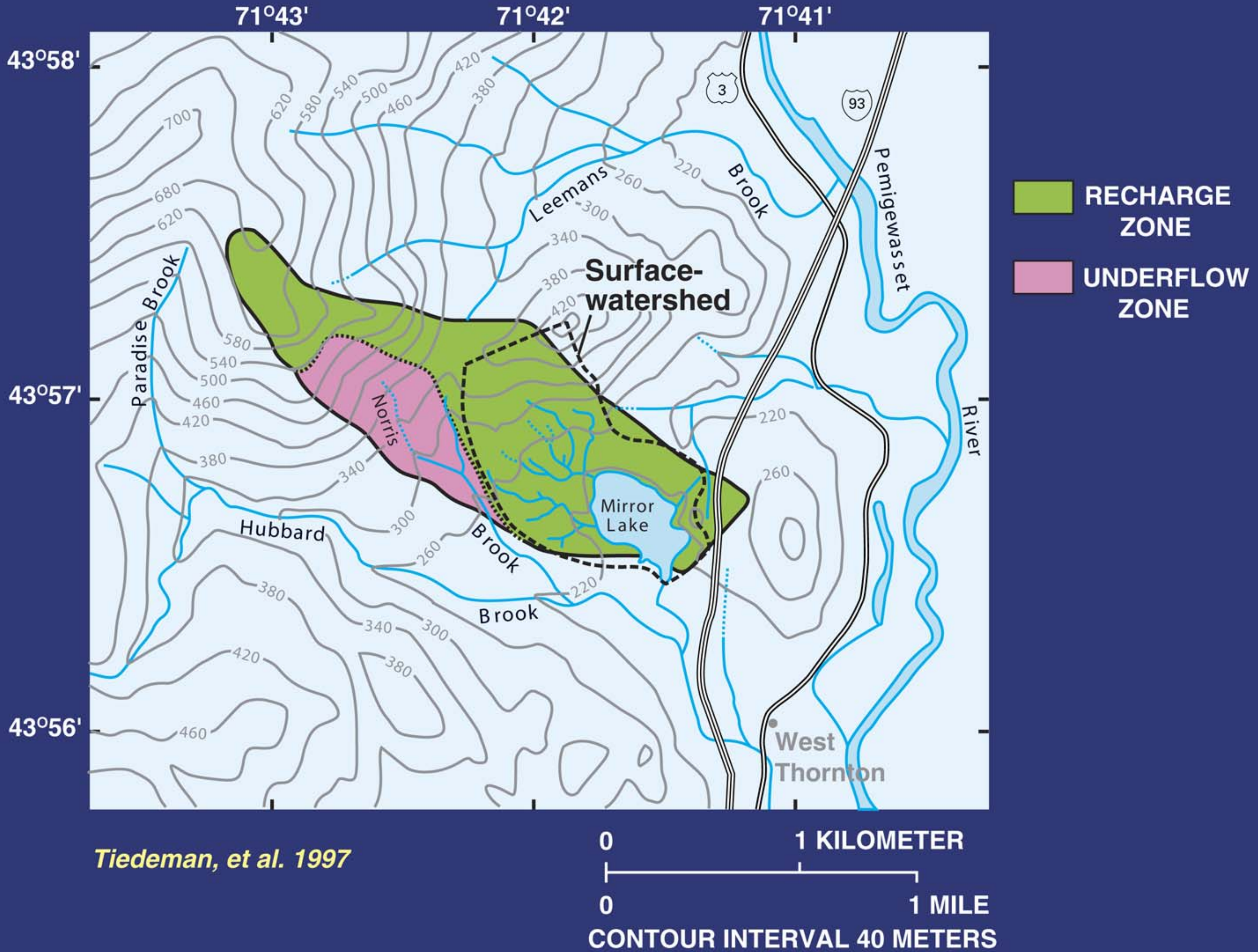

A
B
EXPLANATION
20 Line of predicted equal water-level decline, in feet
20 Line of measured equal water-level decline, in feet
NEBRASKA
MAP AREA
Big Blue River
Little Blue River
NEBRASKA
KANSAS
0 20 MILES
0 20 KILOMETERS
97
98
41
40


Salt River
Phoenix
Error, in feet
0
-50
-100
-200
Santa Cruz R.
Gila River
N
0
20 MILES
Konikow, 1986



Predictive period
Calibration period
0
-40
-80
-120
FEET
A
Cumulative average change in water level
3
2
1
0
MILLION ACRE-FEET
B
Pumpage
1930
1940
1950
1960
1970
Konikow, 1986


Stream
Stream
Lake
Stream



Tiedeman, et al. 1997

Water Budget of Mirror Lake Ground-Water Basin

(Tiedeman, Goode, and Hsieh, 1997)

Budget component	Simulation A (1000 m3/yr)	95 % CI
	Recharge	
Precip. To bedrock	**172**	**161-183**
Precip. To glacial deposits	**129**	**120-138**
Streams to glacial deposits	**6**	**5-7**
	Discharge	
Glacial deposits to streams	**171**	**161-181**
Glacial deposits to Mirror L.	**133**	**126-140**
Lake sediments to Mirror L.	**1**	
Bedrock to Mirror L.	**2**	
	Flow between hydrogeologic units	
Glacial deposits to bedrock	**18**	**13-23**
Bedrock to glacial deposits	**187**	**174-200**
Bedrock to lake sediments	**1**	

Mirror Lake Water Budget

1000 m3/yr

	Original	Model	Isotopes	Mg
Precip.	182			
SW in	417			
GW in	47	133	103	?
Evap.	77			
SW out	251			
GW out	281	366	337	?
In-Out	37			
Del.V	44			

A water budget is a progress report.

They need to be revised and updated as new information on water budgets of contiguous water bodies, and water development, become available.

In addition, in the case of ground-water budgets, new information on aquifer geometry and hydraulic heads accompany each new test hole and observation well, which affects the storage term.

Water budgets need to be corroborated by chemistry.

The real value of a water budget is determined by how well the user understands,

and takes into account,

its uncertainty.