Lamprey River Protected Instream Flow Study and Water Management Plan

Technical Review Committee Meeting 13 February 2006

Normandeau Associates, Inc.
University of New Hampshire
University of Massachusetts

Assessment of Well Withdrawal Impacts on Surface Water

Do groundwater withdrawals reduce streamflow?

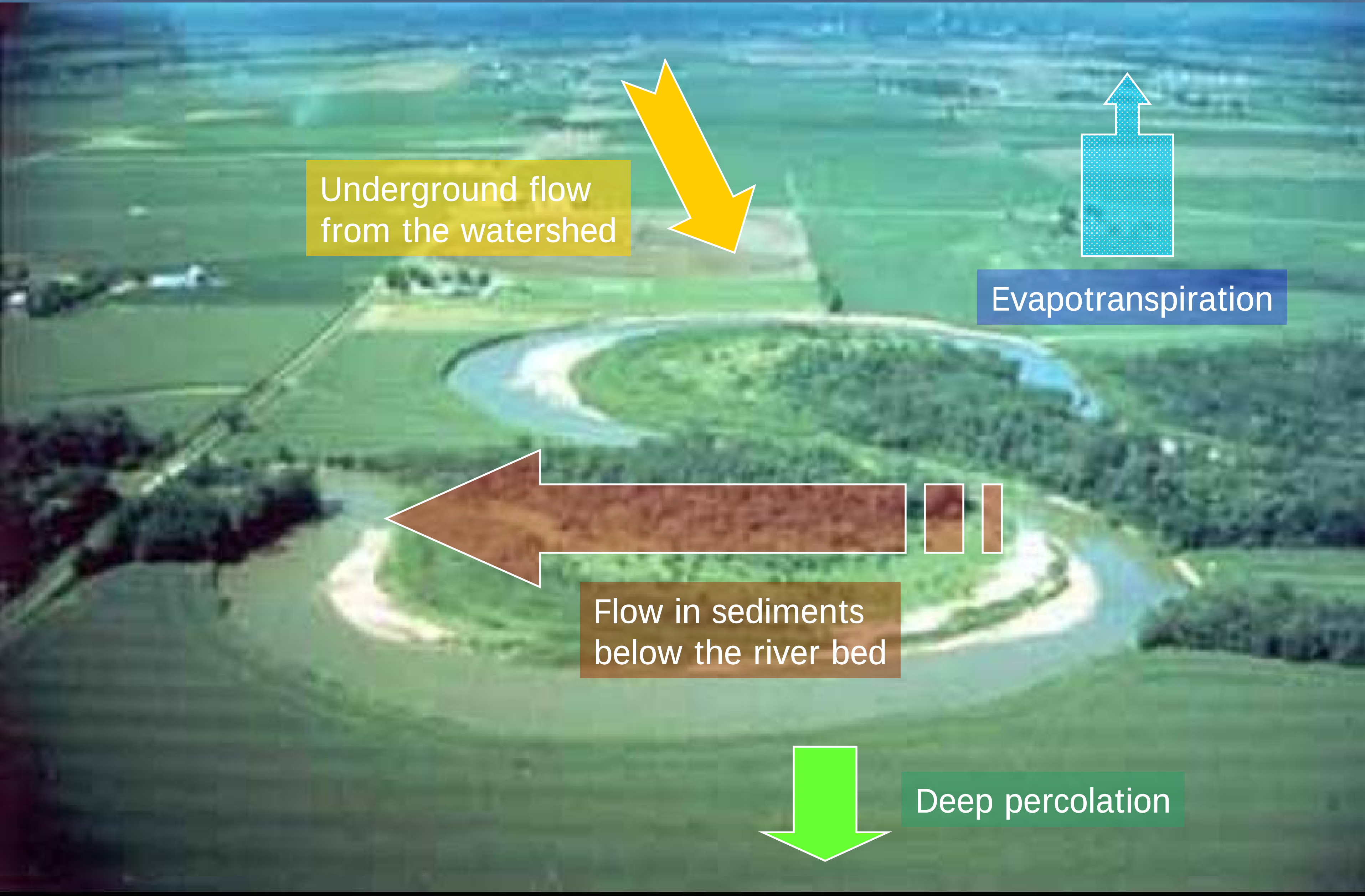
If so, can reductions to groundwater pumping be used at low flow times as one type of management strategy to meet instream flow needs?

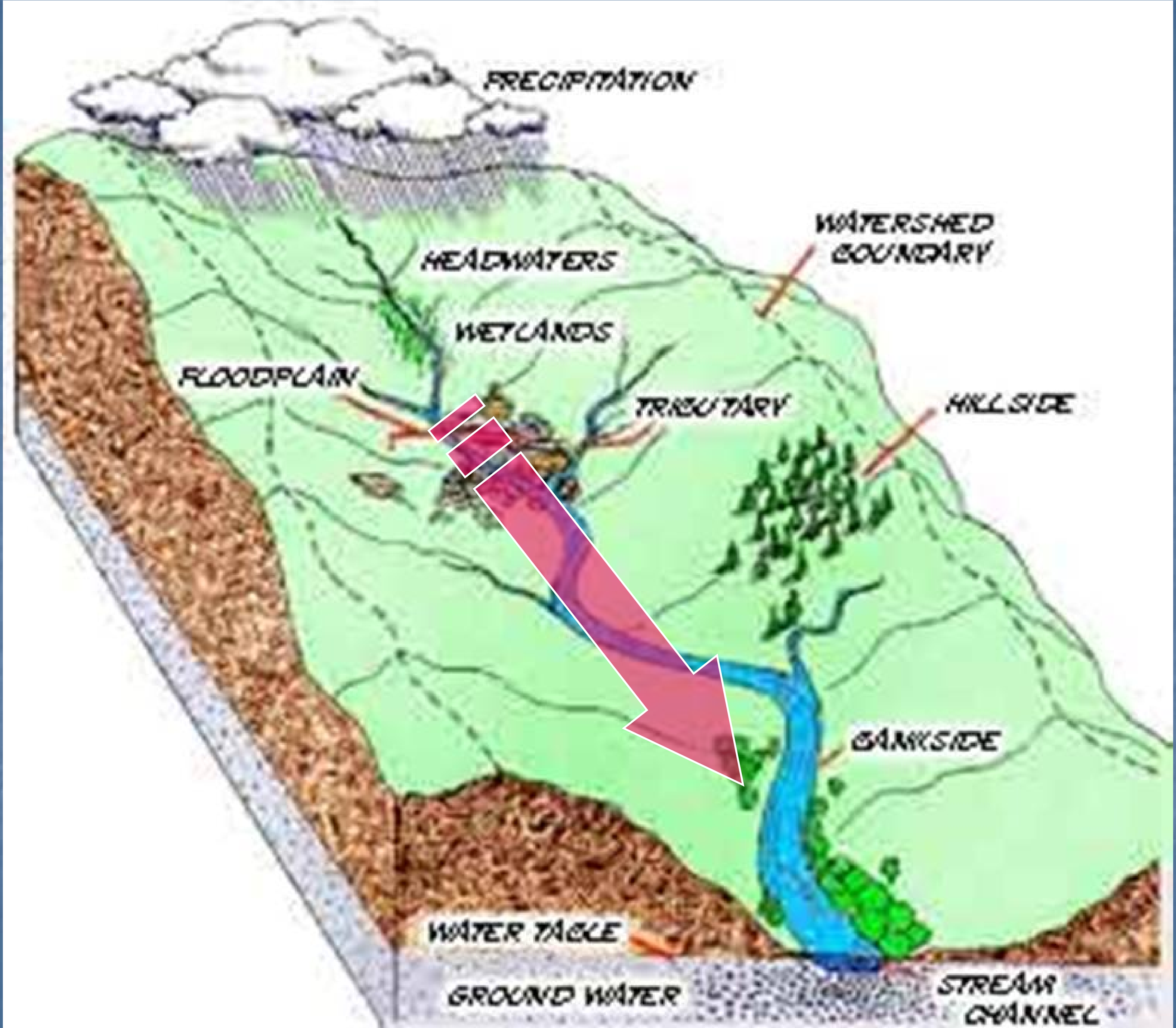
How effective are such strategies in comparison to other withdrawal reduction strategies?

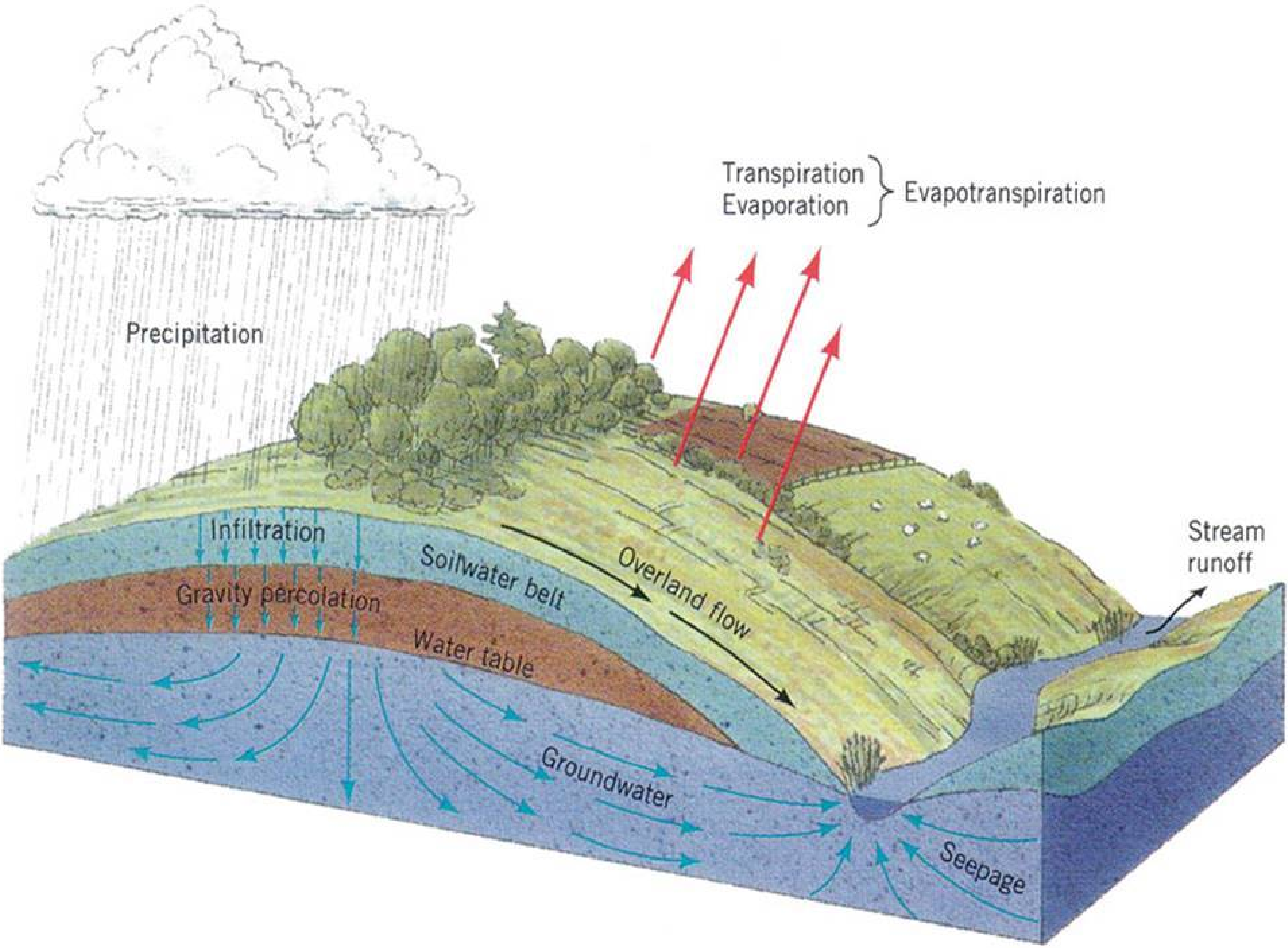
Do groundwater withdrawals reduce streamflow?

If the groundwater had not been pumped, where was it going?

- Discharge to river, tributaries, or other surface waters
- Continued groundwater movement
- Deeper groundwater circulation


Underground flow
from the watershed
Evapotranspiration
Flow in sediments
below the river bed
Deep percolation

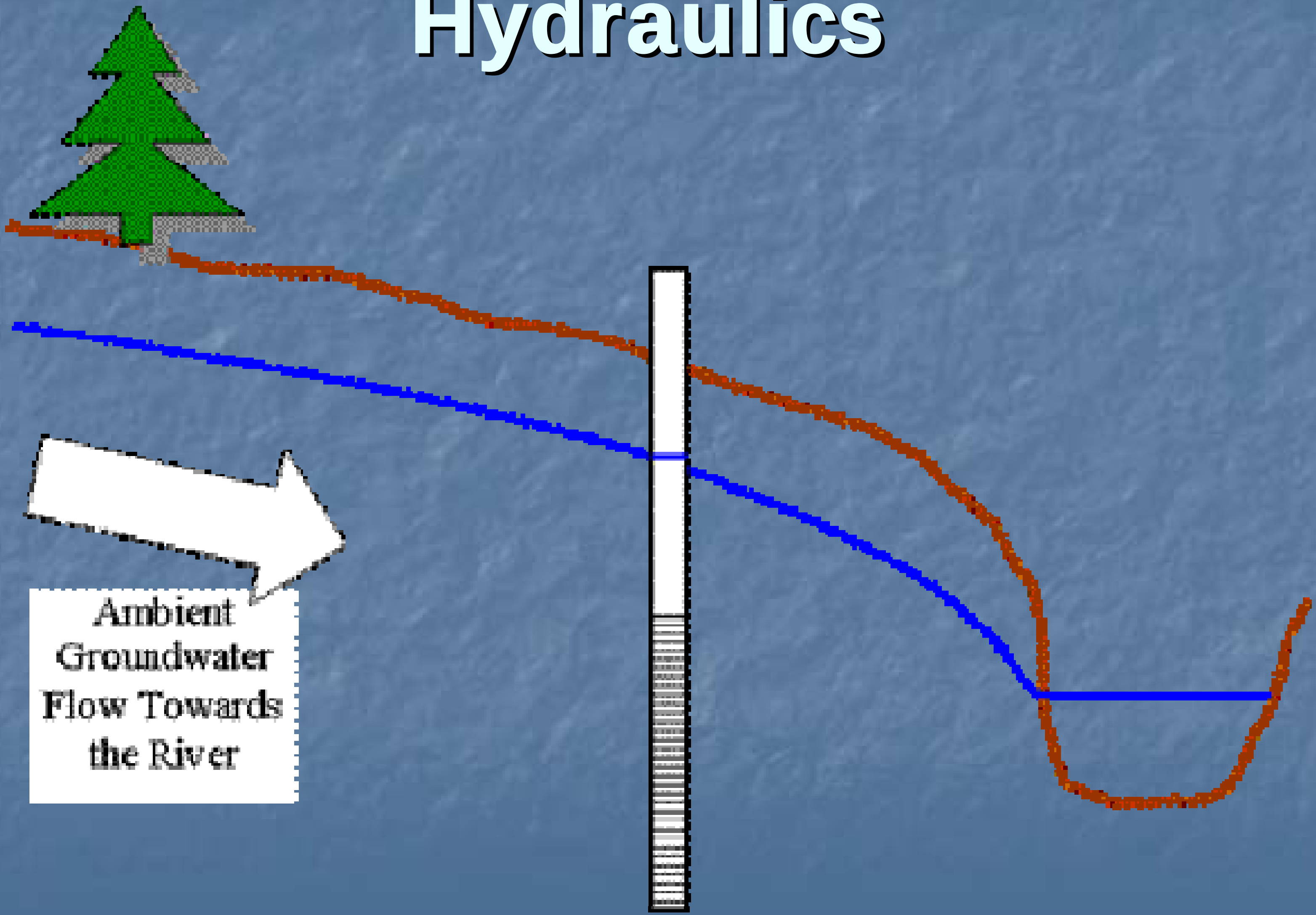

PRECIPITATION
WATERSHED BOUNDARY
HEADWATERS
WETLANDS
FLOODPLAIN
TRIBUTARY
HILLSIDE
BANKSIDE
WATER TABLE
GROUND WATER
STREAM CHANNEL


Transpiration
Evaporation
Evapotranspiration
Precipitation
Infiltration
Gravity percolation
Soilwater belt
Overland flow
Water table
Groundwater
Stream runoff
Seepage

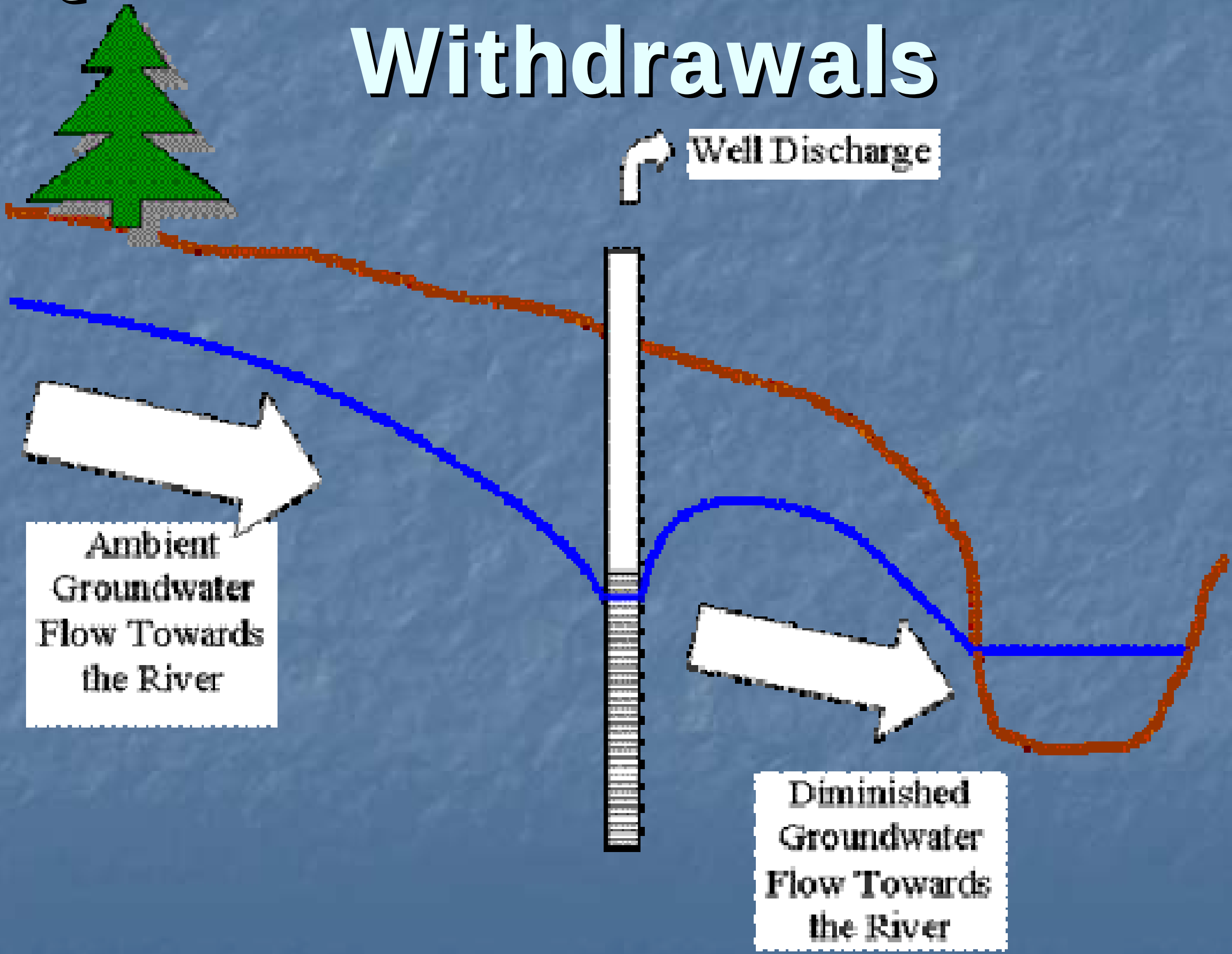
Can reductions to groundwater pumping be used at low flow times as one type of management strategy to meet instream flow needs?

- Are individual wells inducing river water recharge?

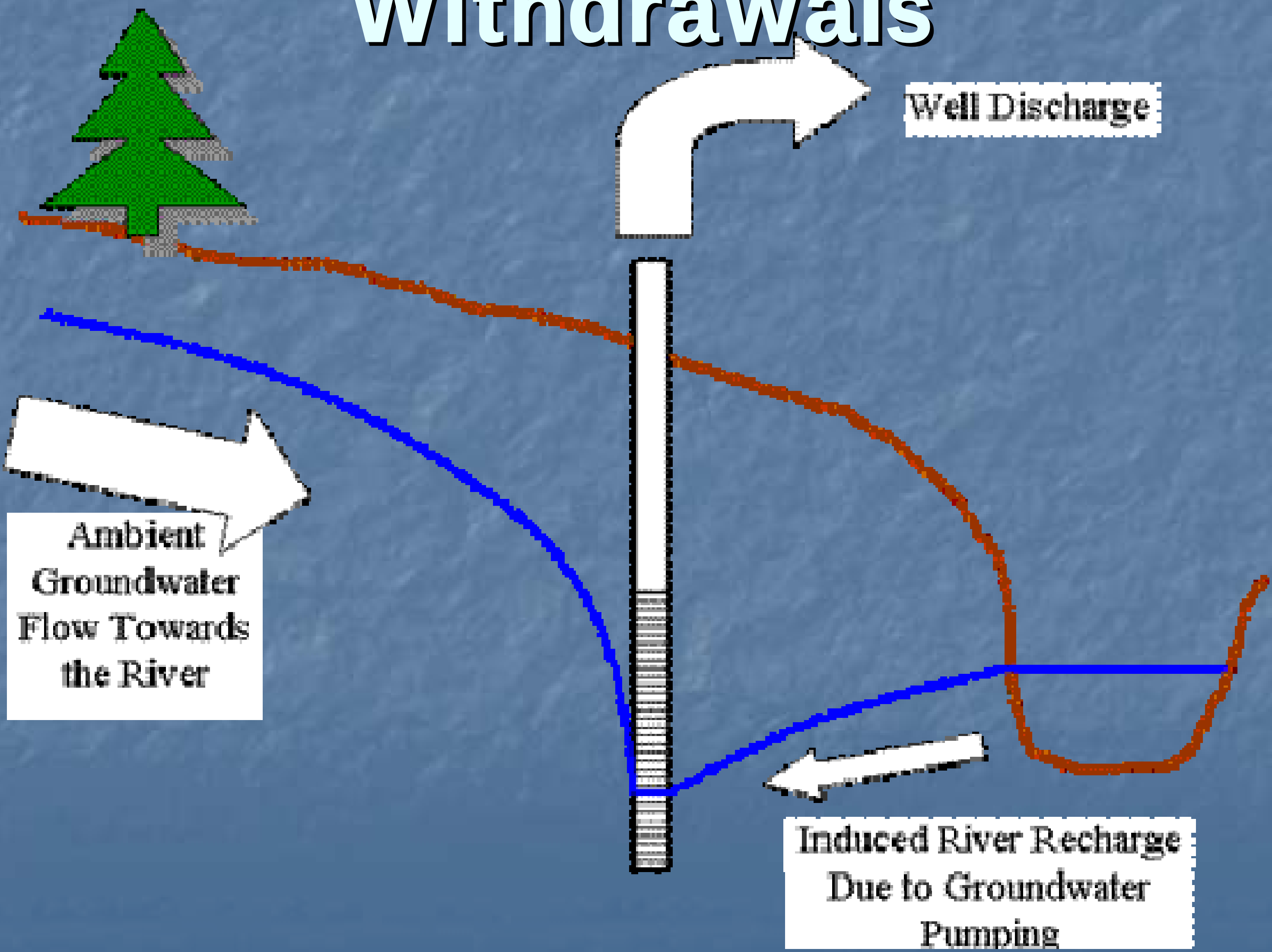
Ambient Groundwater Hydraulics



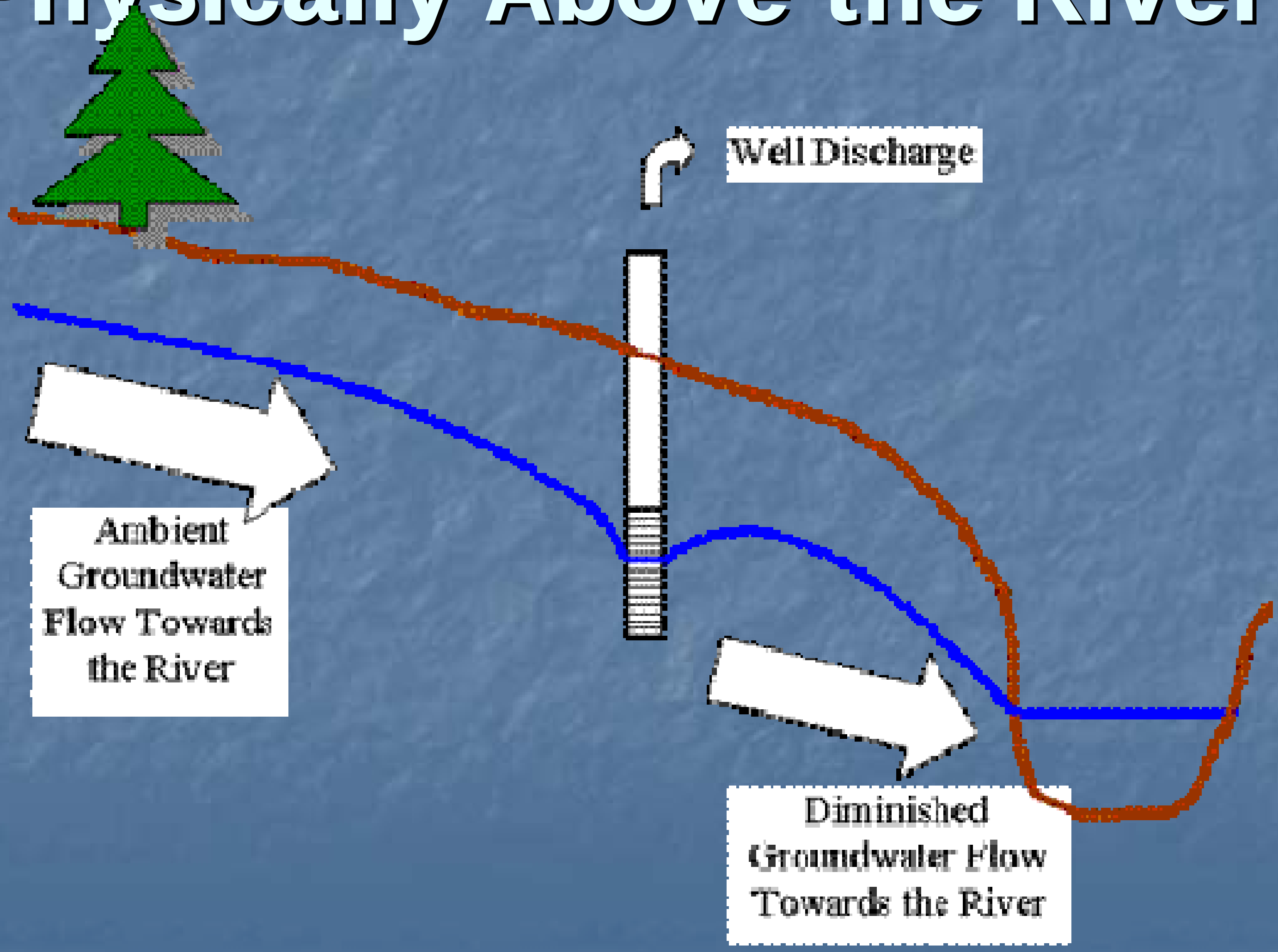
Effect of Relatively Small Quantities of Groundwater Withdrawals



Effect of Increasing the Quantity of Groundwater Withdrawals



Effect of Groundwater Pumping Even When Well is Physically Above the River



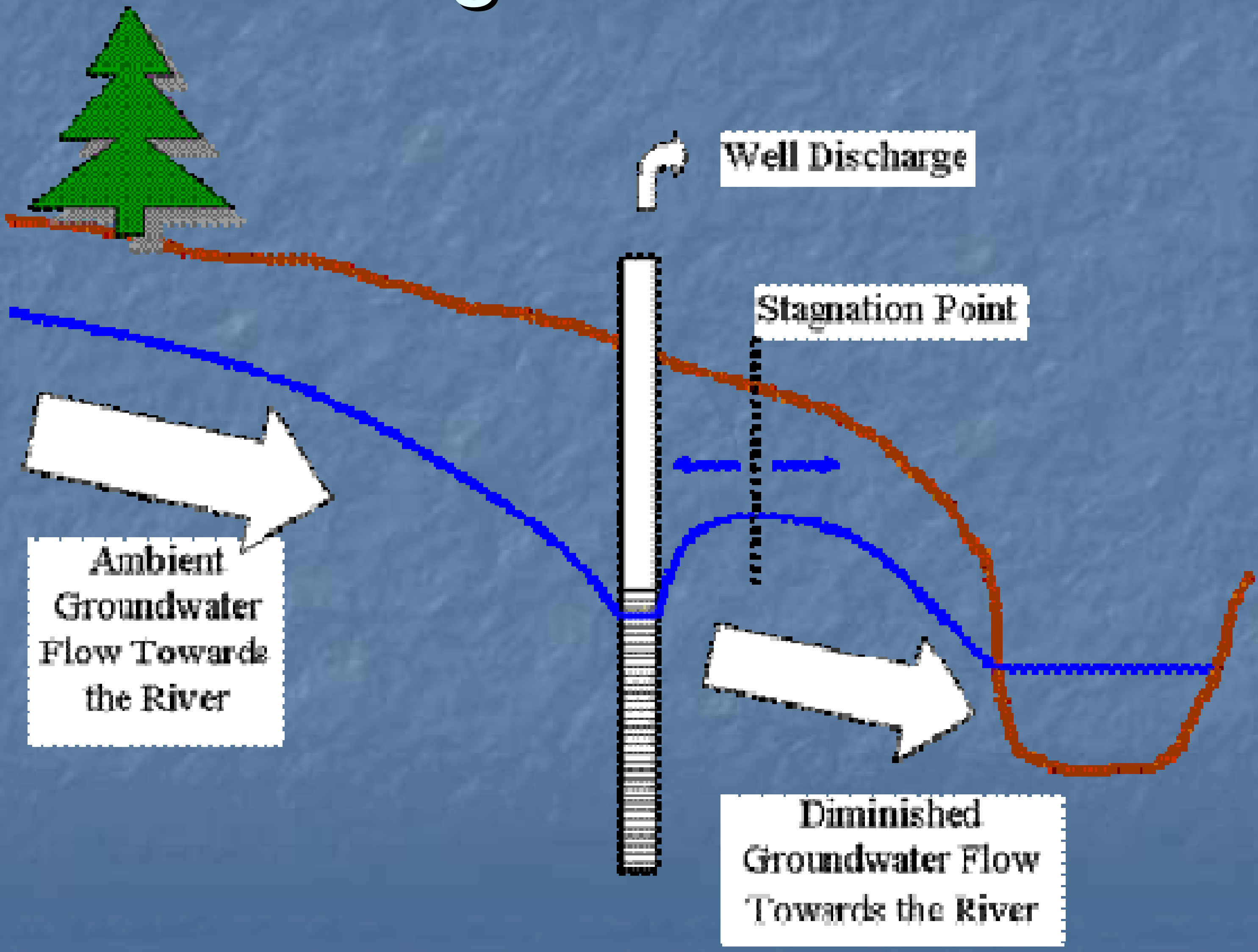
Induced Recharge

Since water resources operate on the watershed scale, in general, if the slope of the groundwater table is towards the river, then groundwater pumping has the likelihood of removing water that ultimately would have flowed in the river.

Induced recharge is surface water directly captured by groundwater pumping.

If the river discharge falls below the recommended ISF values, the most immediate flow control management strategy for groundwater is to address induced recharge.

Stagnation Point



Short Term Groundwater Management

When the stagnation point reaches the river, the well induces recharge from the river. Therefore a short term management strategy to improve (increase) river flow is to halt induced recharge. This would be accomplished by reducing the well pumping rate.

Methods for Evaluating Induced Recharge

1. **Existing Study**

2. **Analytical Estimation**

3. **Field Measurements - Office**

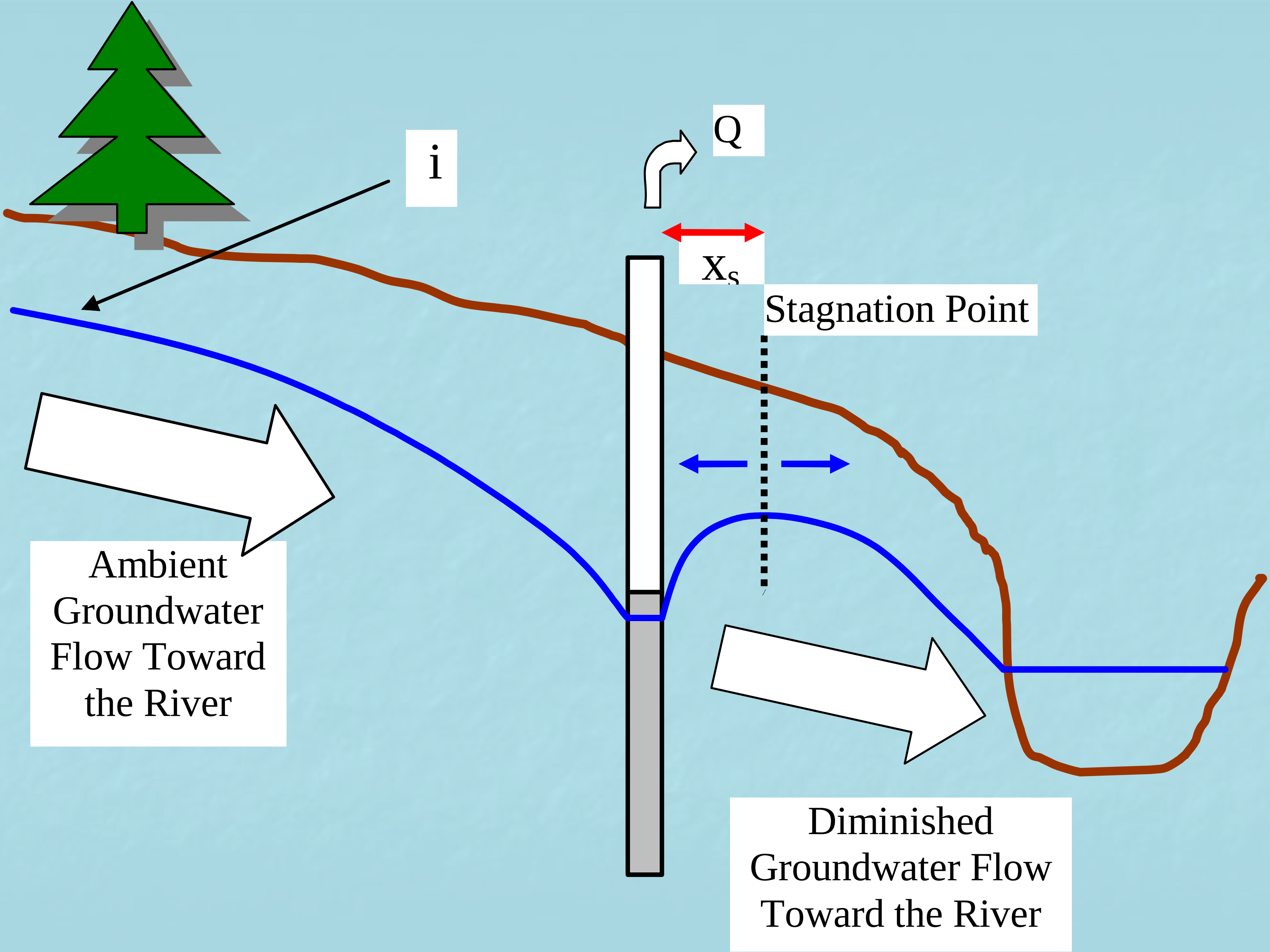
4. **Field Measurements**
   - **Miniature Piezometers or Wells**
   - **Seepage Meters**
   - **Tracers**
   - **Pumping Tests**

Existing Study

Reports submitted for large groundwater permit

Analytical Estimates

Use map or other existing aquifer information along with pumping information to estimate x_s and Q_s


i
Q
X_s
Stagnation Point
Ambient Groundwater Flow Toward the River
Diminished Groundwater Flow Toward the River

Methodology for Well Pumping

Distance from well to stagnation point = x_s (feet)

$$x_s = \frac{Q}{2\pi T i}$$

Q = well pumping rate (cubic feet per day)
T = aquifer transmissivity (feet per day)
i = the slope to the groundwater table (dimensionless)

Groundwater ISF Strategy

Compute well pumping rate to achieve x_s (this is Q_s)

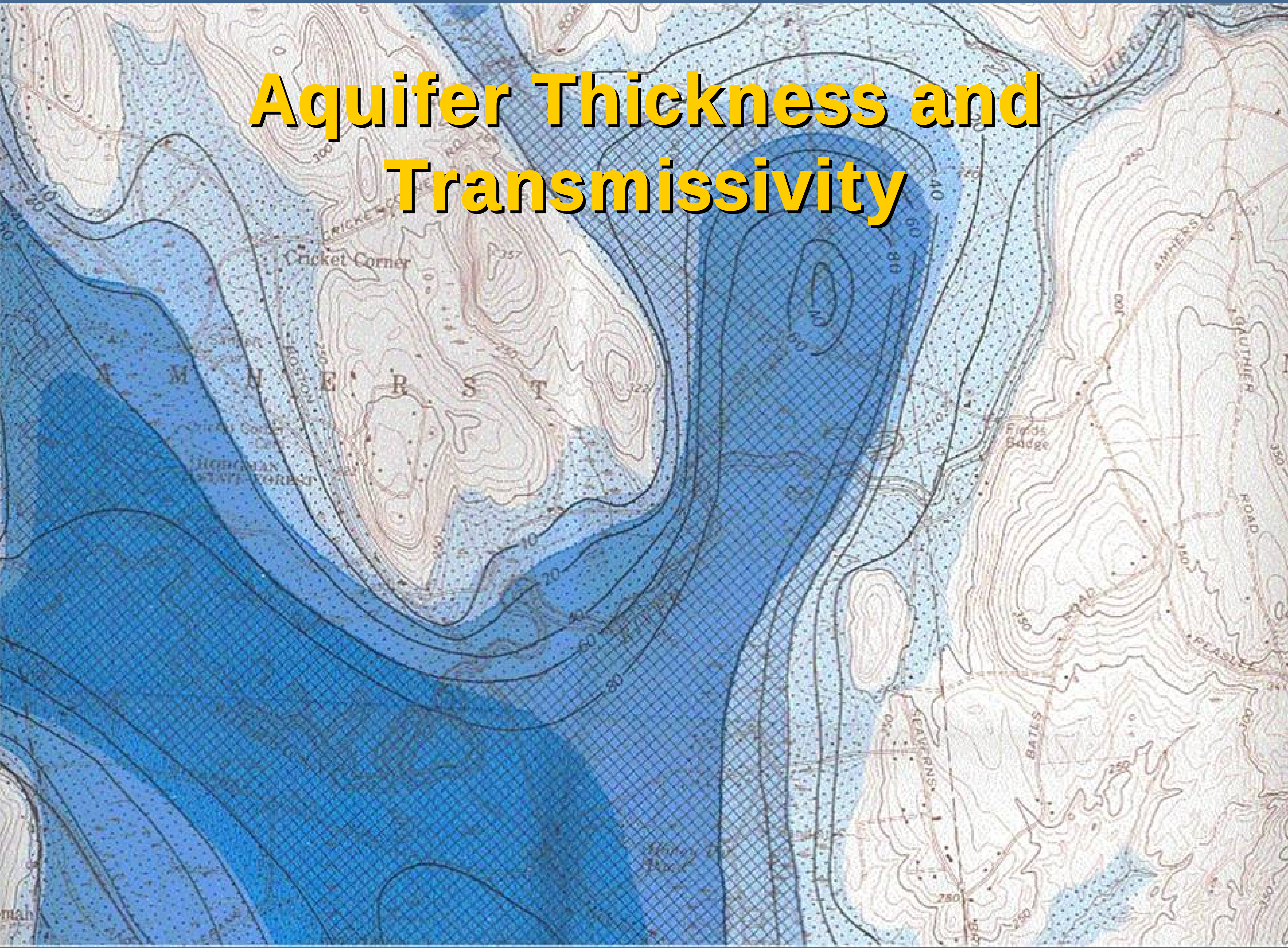
Compare Q_s to actual well pumping (Q_p)

If :

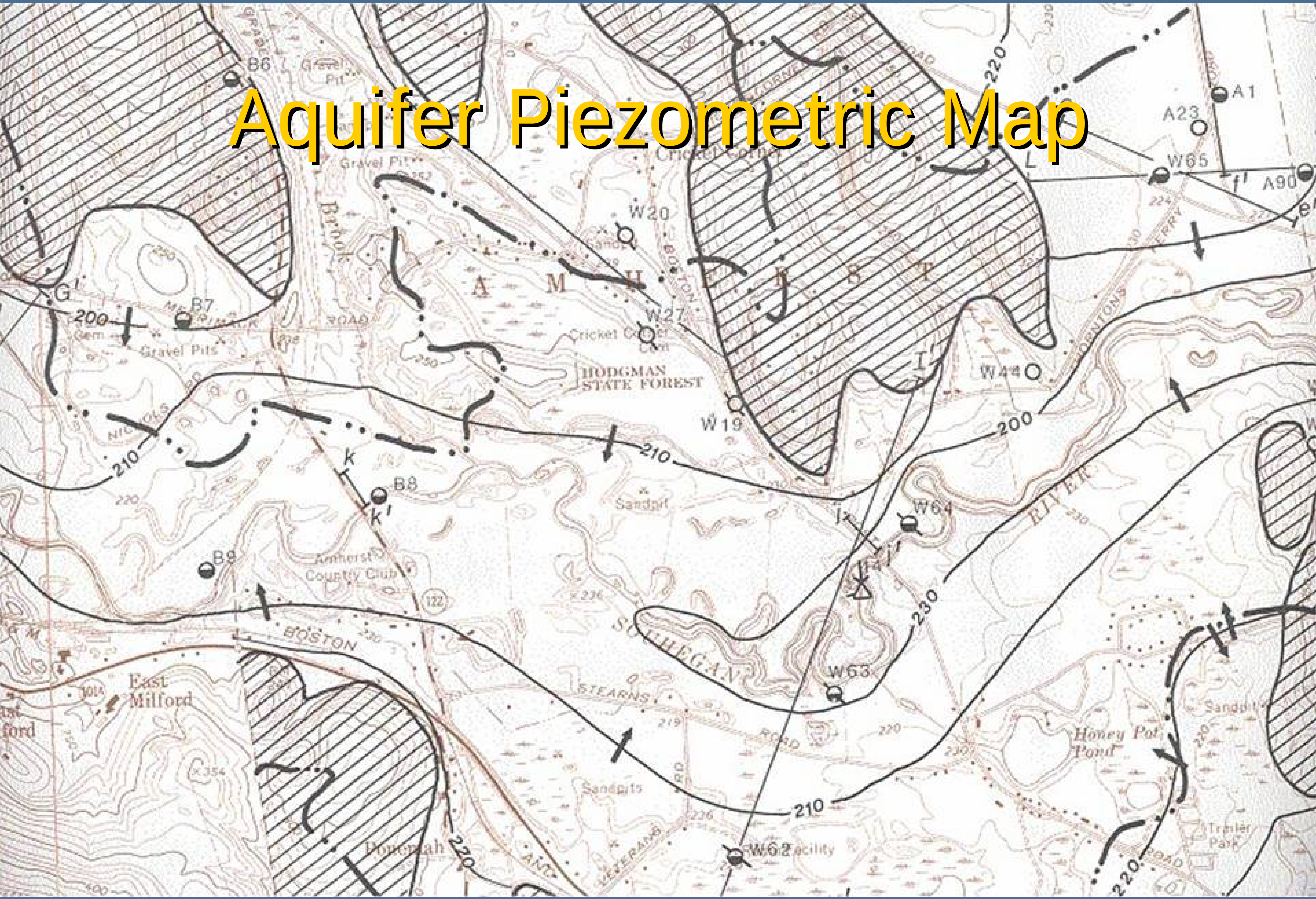
$Q_p \leq Q_s$ continue pumping

$Q_p > Q_s$ reduce pumping to Q_s

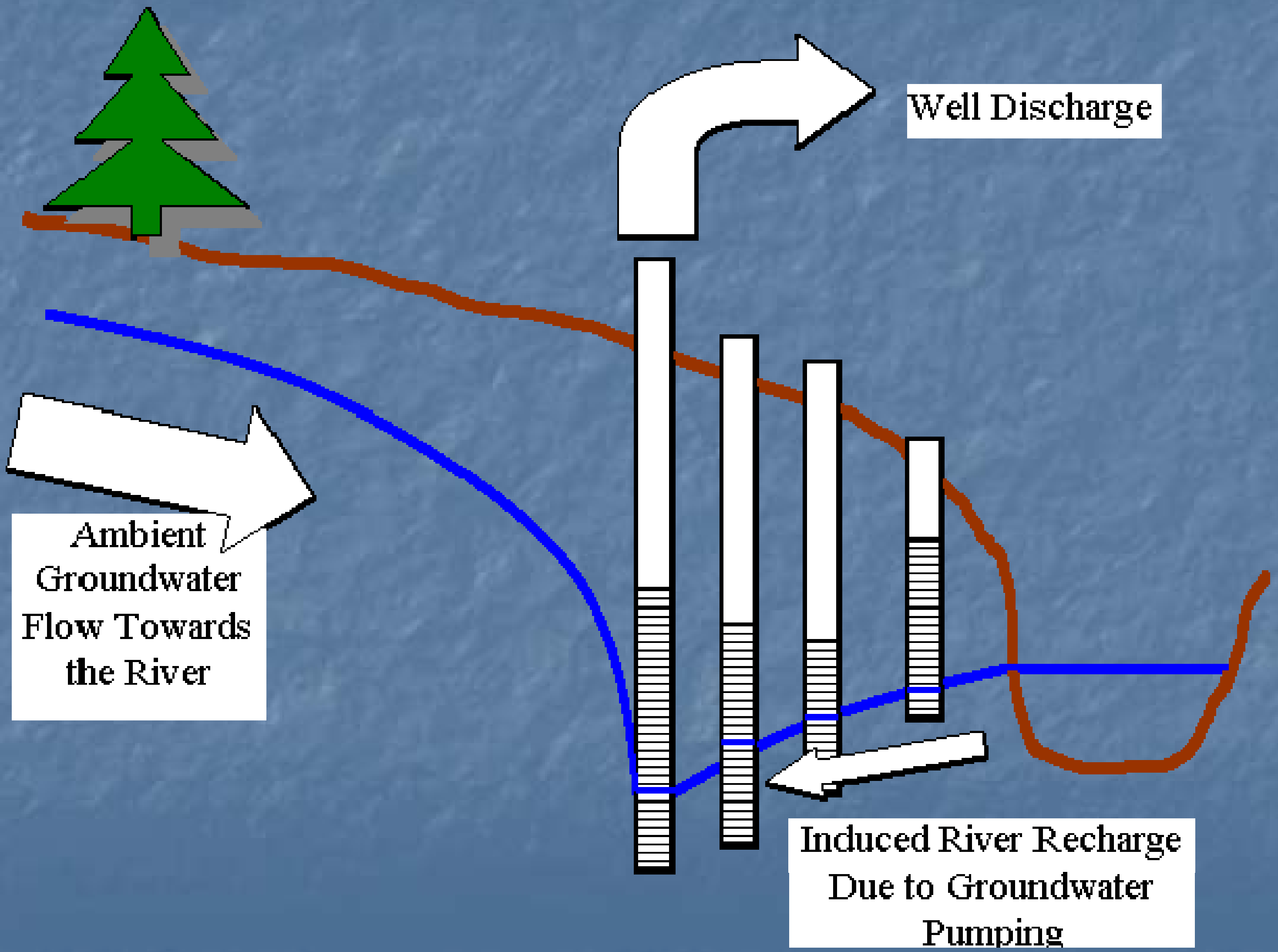
Aquifer Thickness and Transmissivity



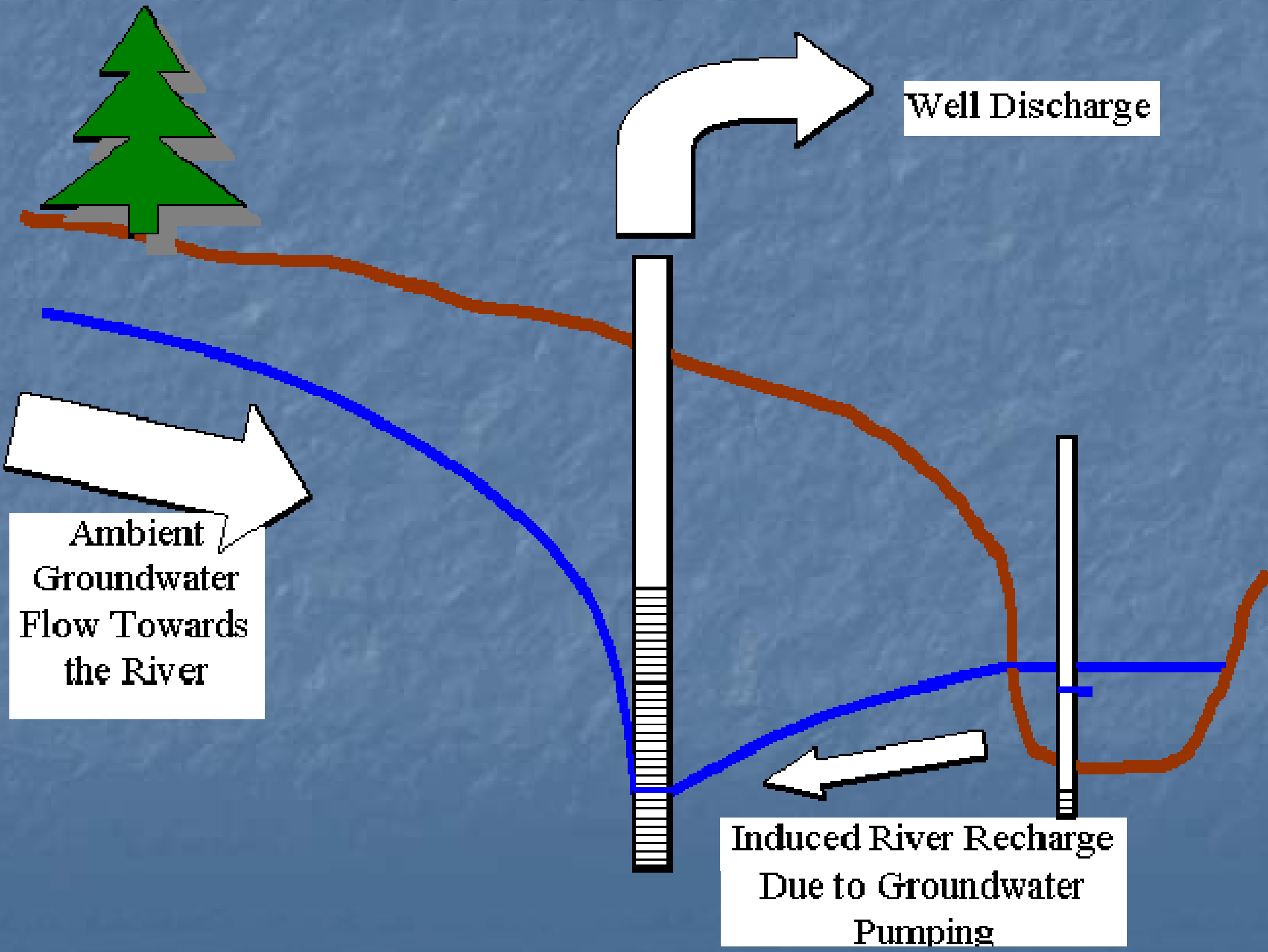
Aquifer Piezometric Map

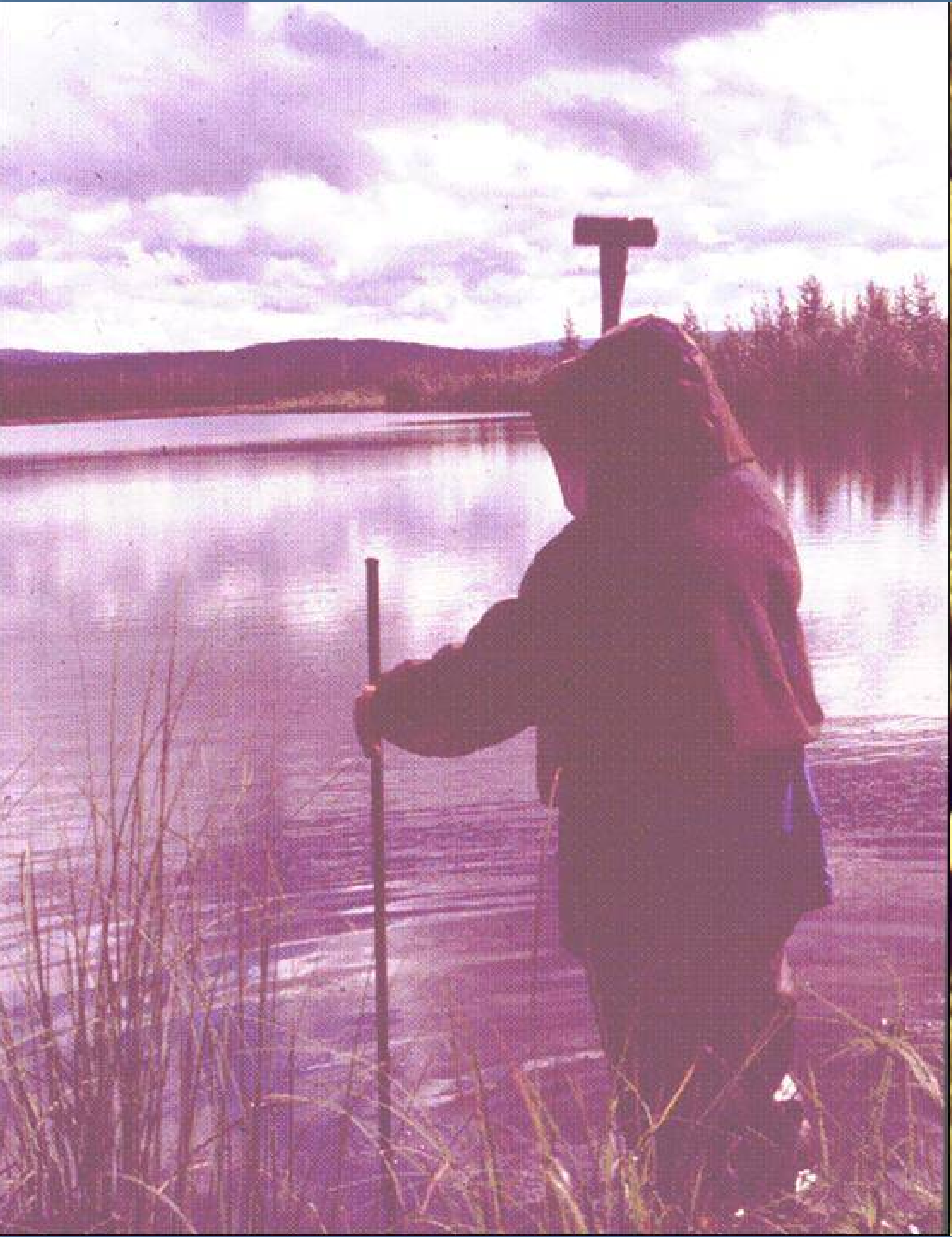


Field Measurements - Office



Field Measurements – Miniature Piezometers or Wells





Case Study

Water supply well (Town of Pembroke, NH) along the Soucook River

Site Data

- Well construction – summer 1993
- Pumping Test – November, 1993
  - 650 gpm
  - $T = 3800\ ft^2/day$
  - $S = 0.1$
  - $i = 0.03$
- Permitted Yield – 505 gpm

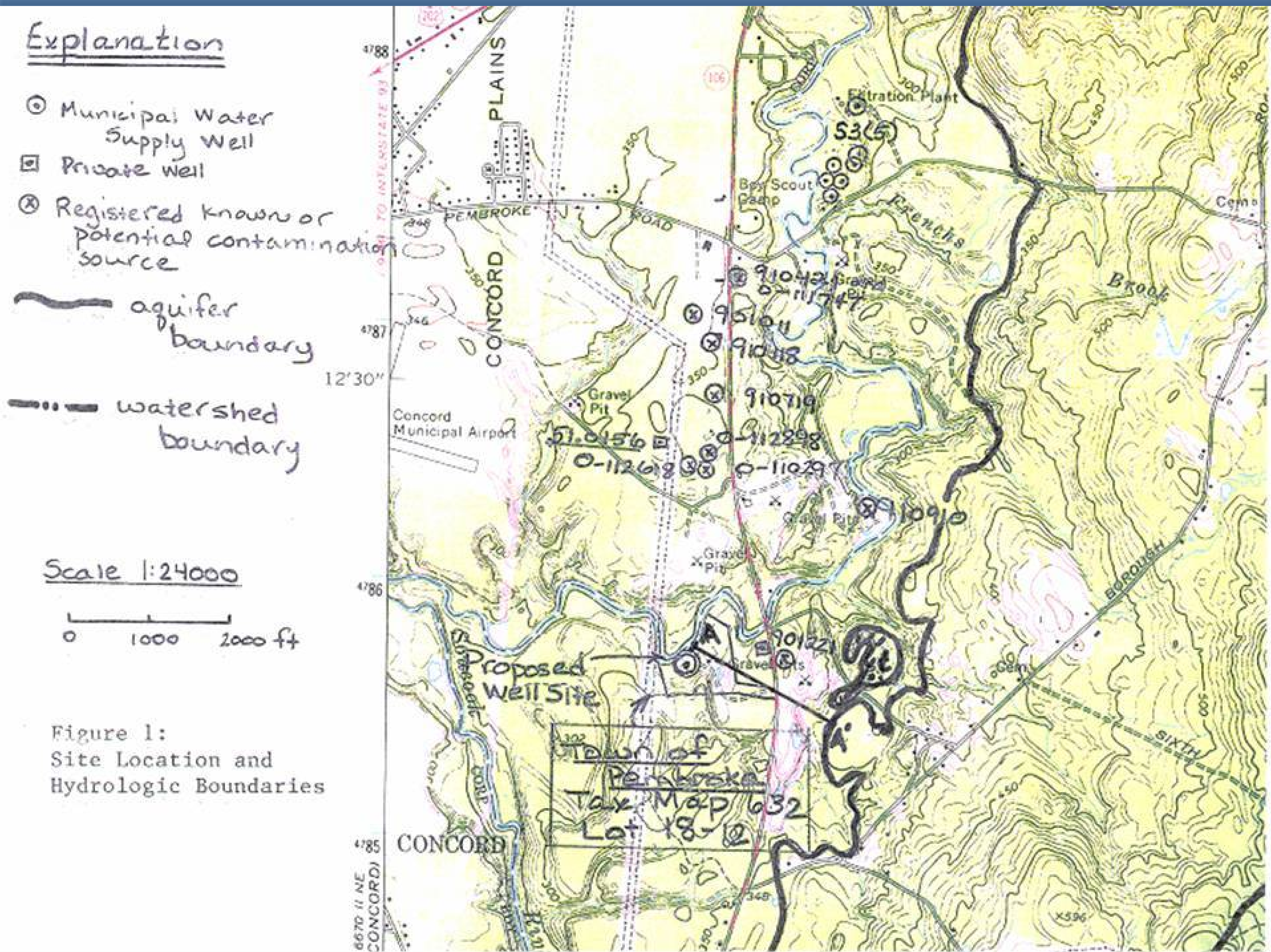


Figure 1:
Site Location and
Hydrologic Boundaries

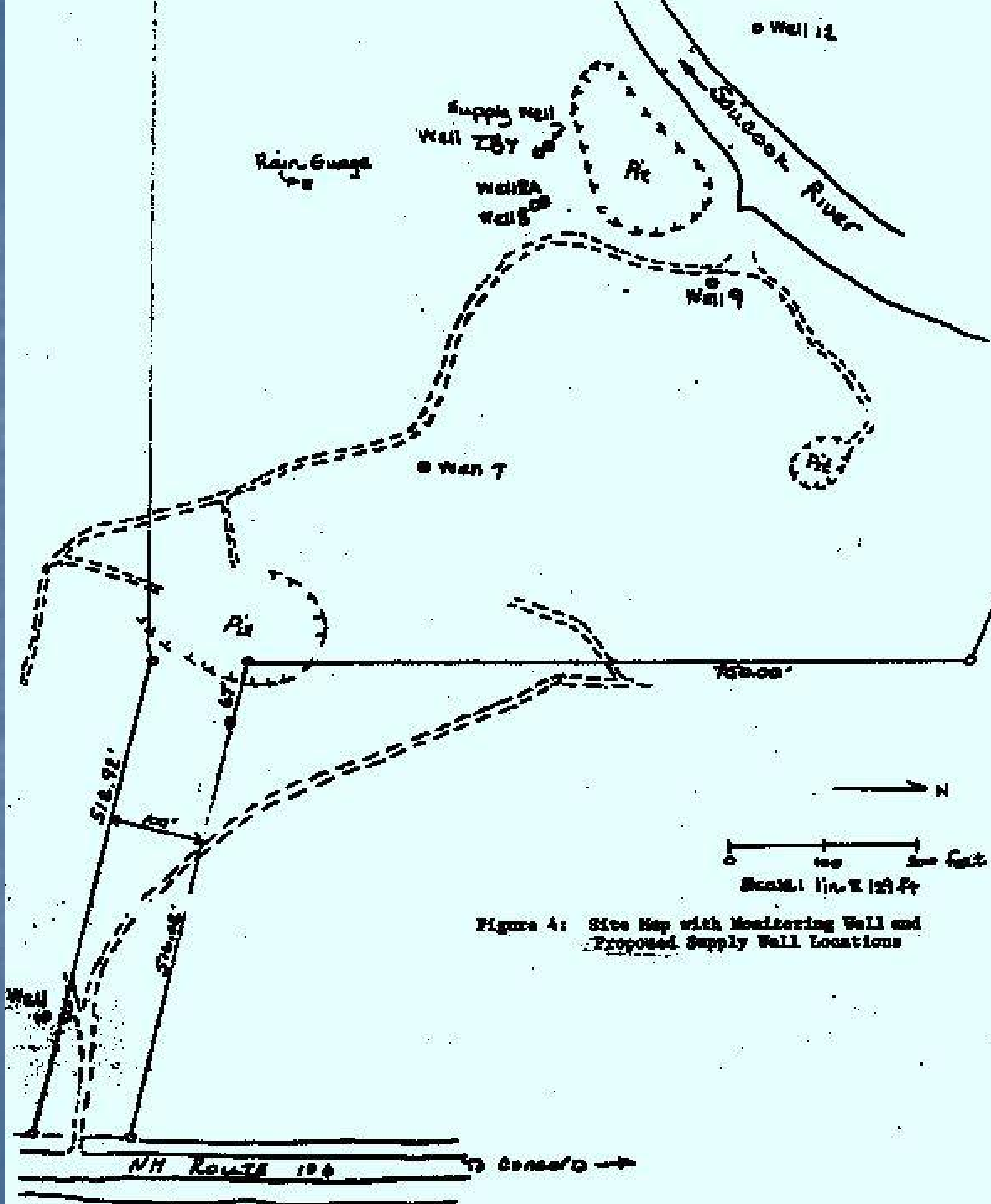
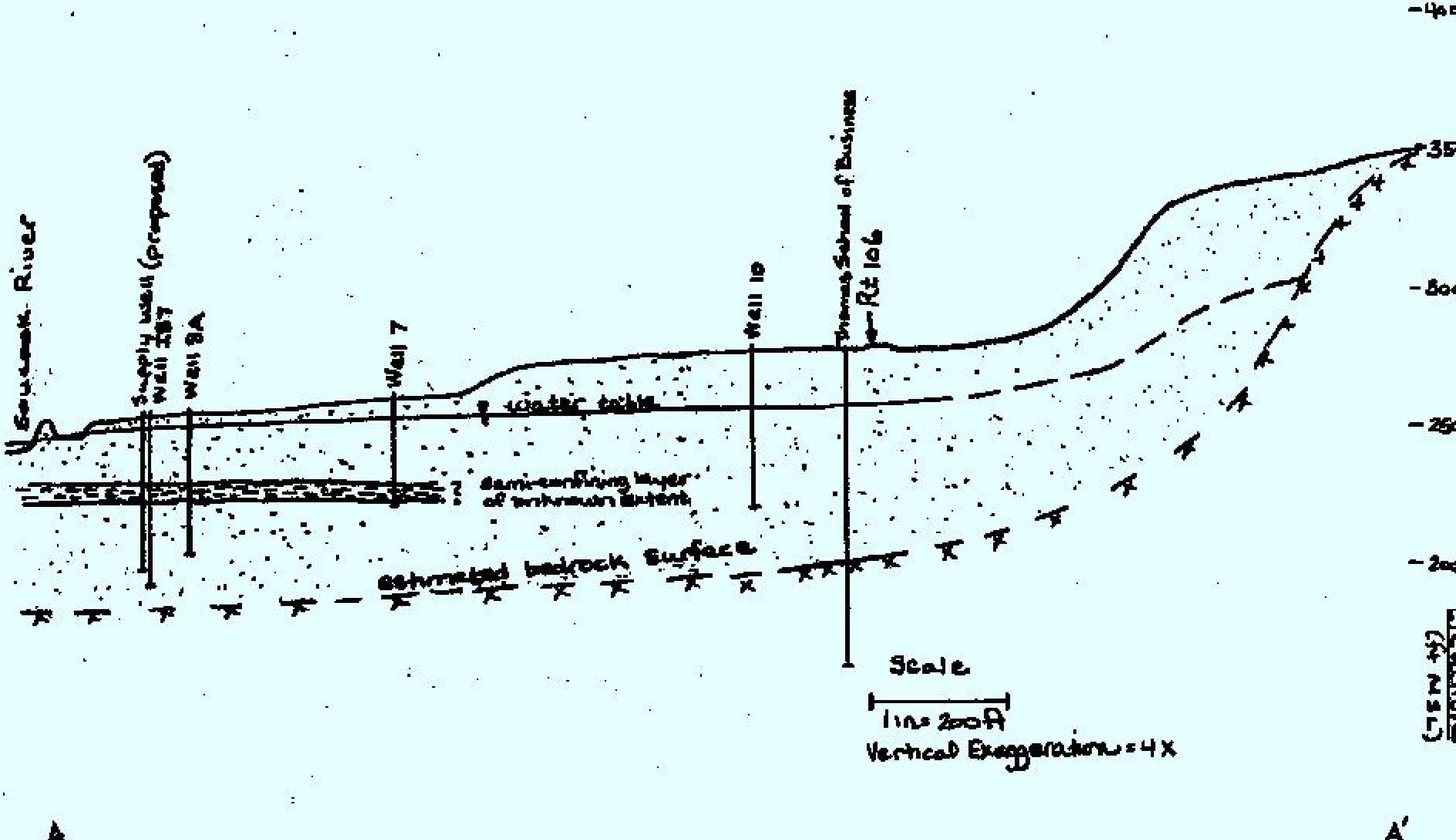


Figure 4: Site Map with Monitoring Well and Proposed Supply Well Locations

Figure 3: Estimated Geologic Cross-Section of the Stratified Drift Aquifer in the Vicinity of the Proposed Well Site, Pembroke, NH



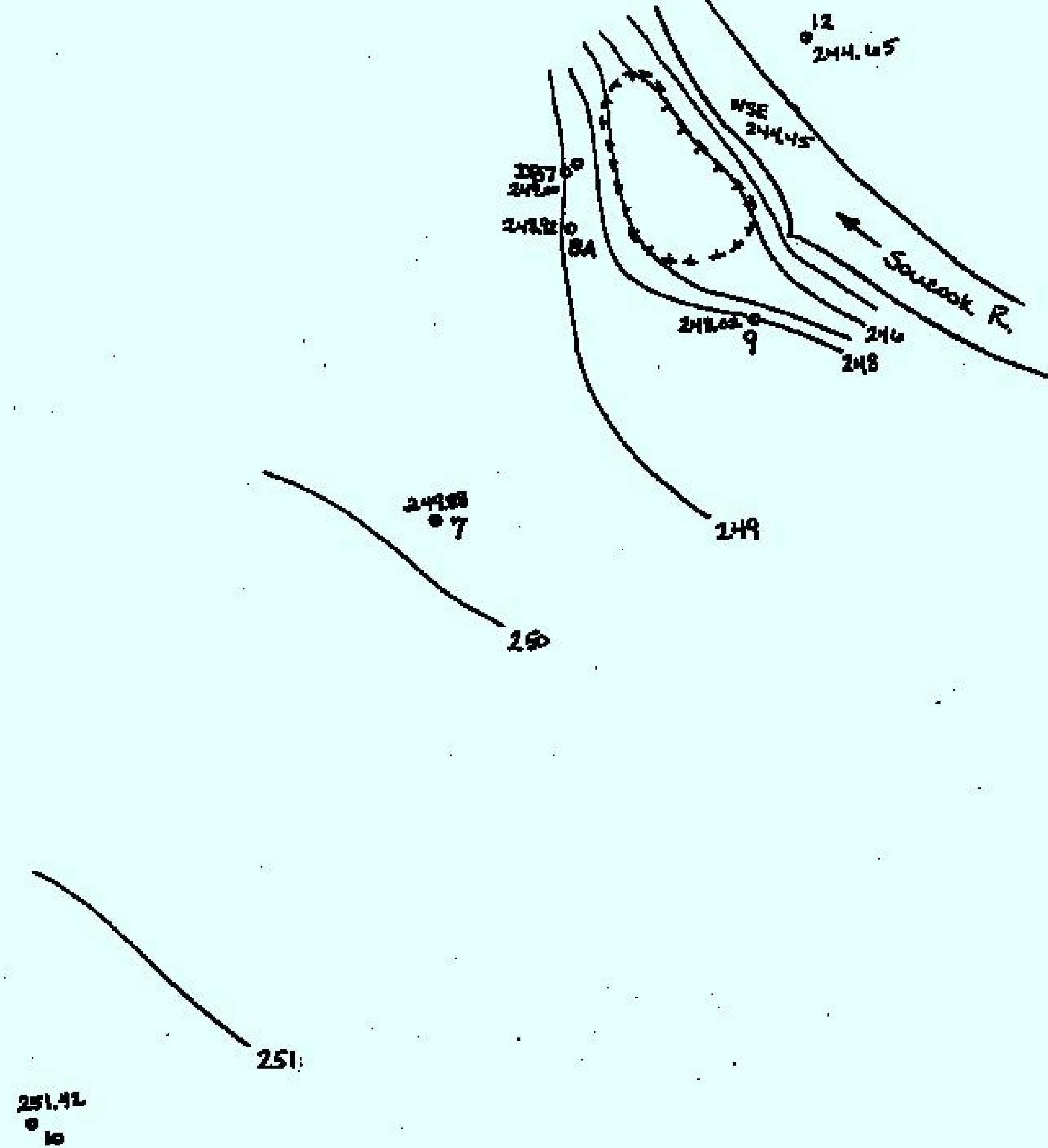


Figure 9a: Piezometric Contours prior to

Analytical Method

- **Q = 650 gpm**
- **T = 3800 ft^2/day**
- **S = 0.1**
- **i = 0.03**
- **Distance from well to river = 140 ft.**

- **x_s = 175 ft**
- **Q_s = 520 gpm**

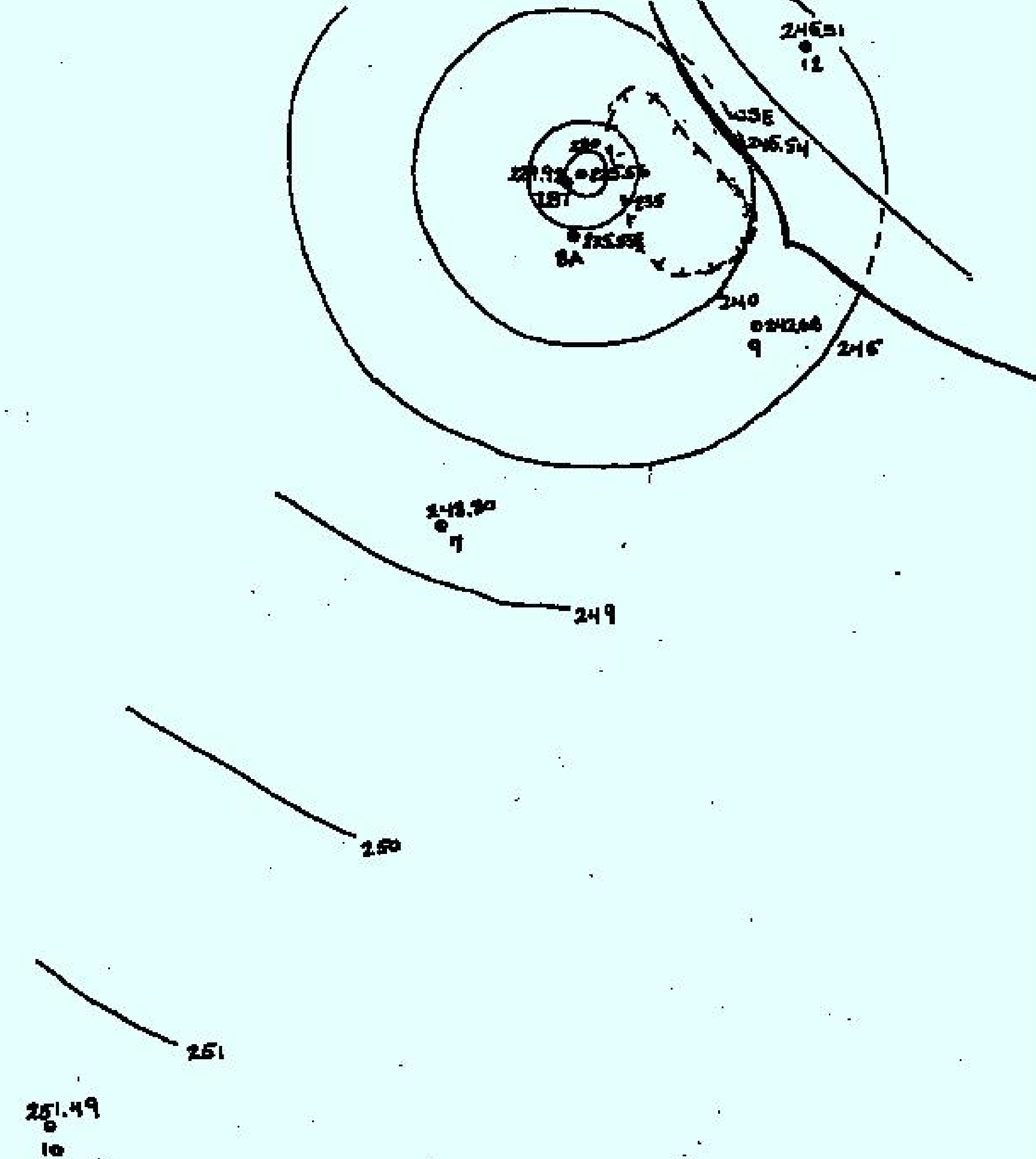


Figure 9b: Piezometric Contours after 100.5 hours of pumping (11/20/93 12:30 pm)

If ISF can be aided by reductions in groundwater pumping,

"How long does it take for the induced recharge to cease?

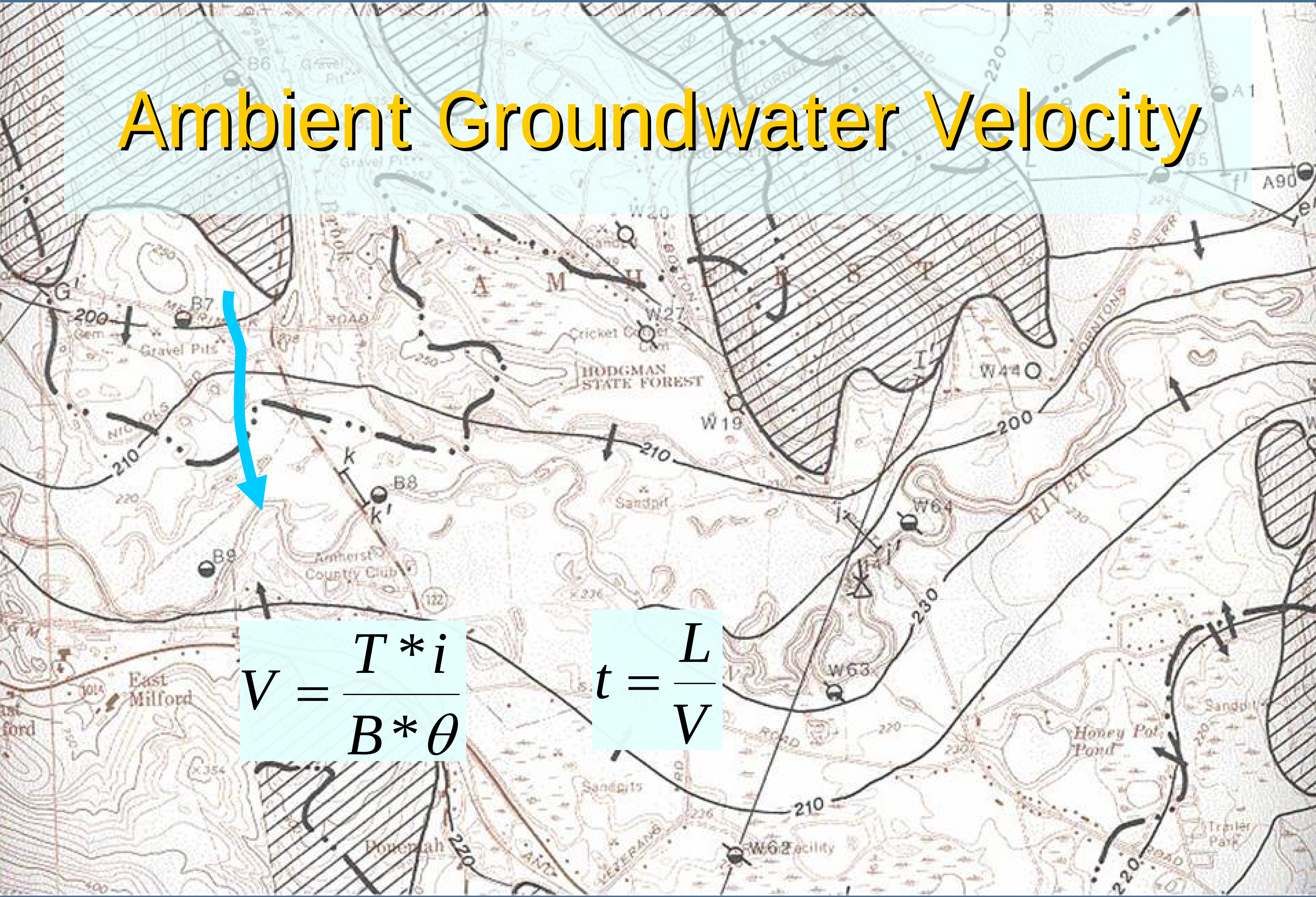
Ambient groundwater velocities

SLOW

Velocities in the cone of depression near to the pumping well

FAST

Ambient Groundwater Velocity



$$V = \frac{T * i}{B * \theta}$$

$$t = \frac{L}{V}$$

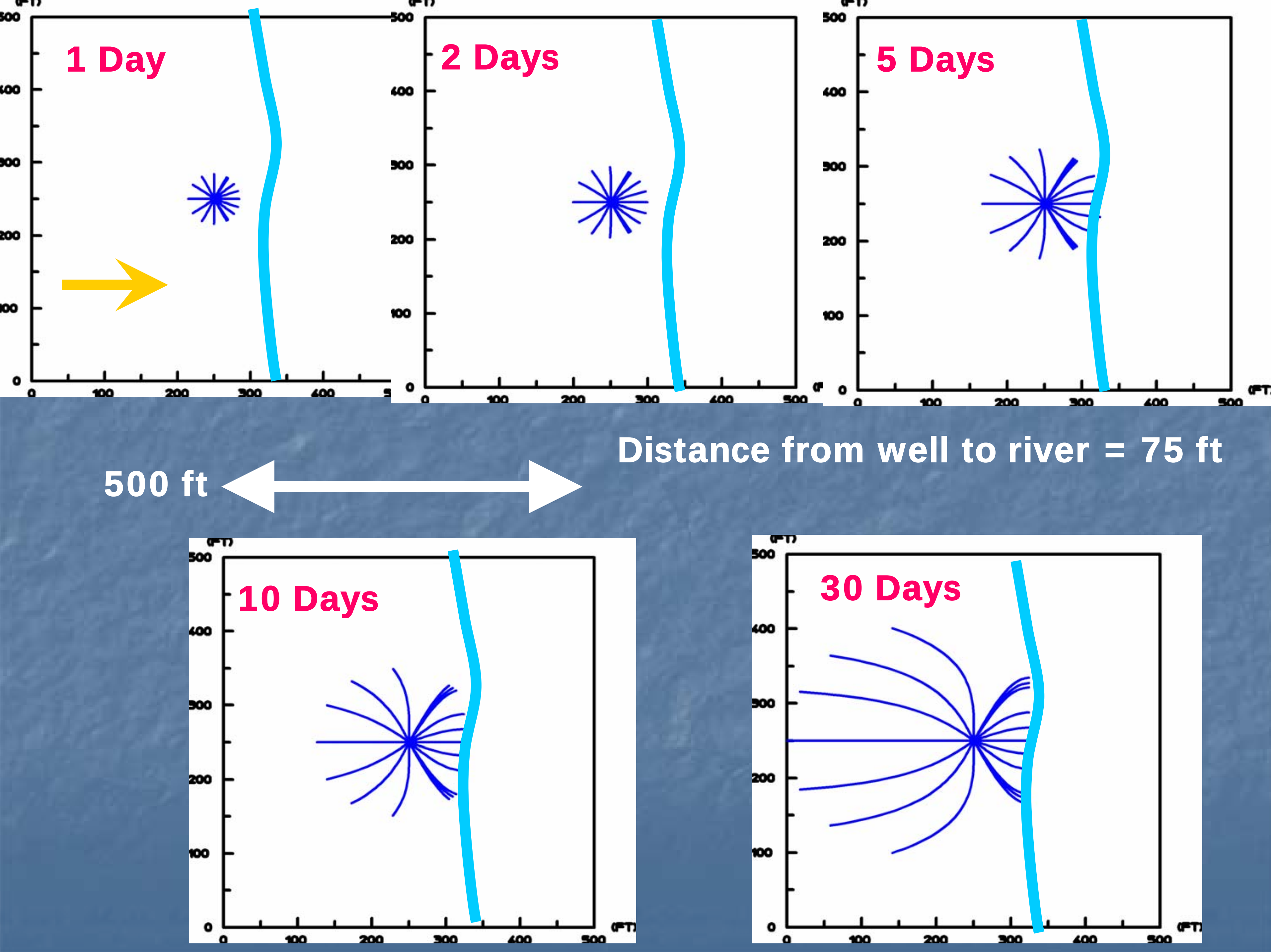
Example

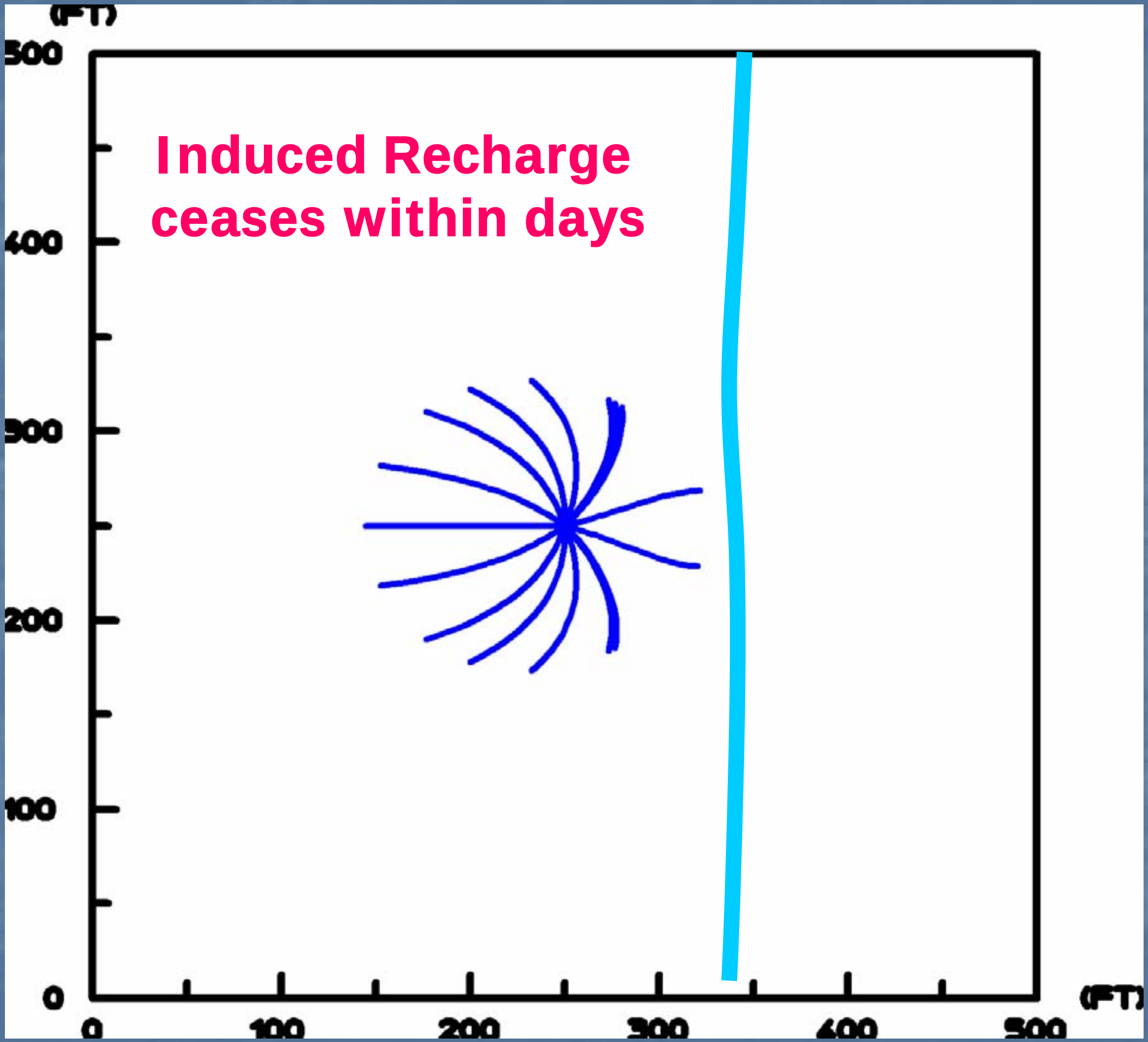
Transmissivity = 8,000 ft^2/d
Groundwater gradient = 0.01
Saturated thickness = 60 ft.
Effective porosity = 0.28
Distance to river = 100 ft.

V = 4.8 ft/d   t = 21 days

Induced recharge groundwater velocities in the cone of depression and near to the pumping well can be extremely fast since the gradient increases dramatically and the saturated thickness is smaller

$$V = \frac{T * i}{B * \theta}$$


1 Day
2 Days
5 Days
Distance from well to river = 75 ft
500 ft
10 Days
30 Days



(FT)
500
400
300
200
100
0
Induced Recharge
ceases within days
0
100
200
300
400
500
(FT)

Souhegan River Results

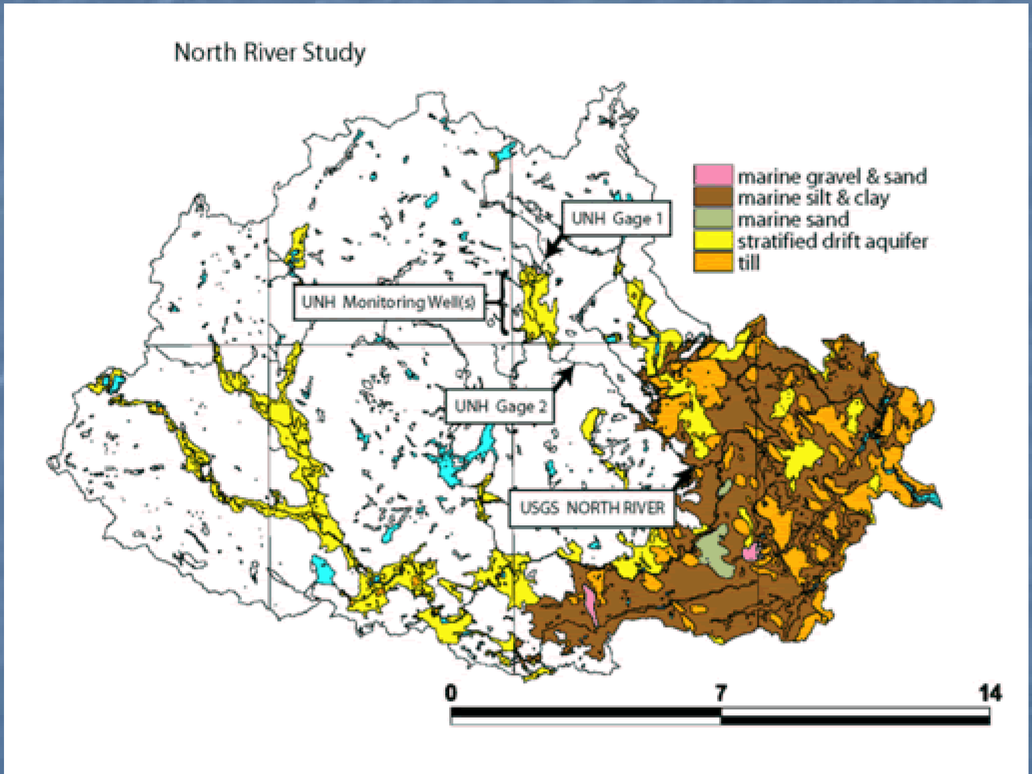
Well ID	Distance to River (ft)	Land Slope	Groundwater Slope	Transmissivity (sq. ft./day)
A	-	0.037	0.05	6,000
B	84	0.031	0.016	3,000
C	529	0.036	0.02	2,000
D	110	0.01	0.01	8,000
E	99	0.019	0.0133	2,000
F	75	0.055	0.009	1,000
G	994	-	-	-
H	306	-	-	-
I	273	0.006	0.0114	8,000
J	140	0.006	0.011	1,000
K	100	-	-	-
L	89	0.031	0.016	3,000
M	92	0.0005	0.032	6,000
N	849	0.013	0.02	6,000
O	97	0.015	0.01	8,000
P	213	0.015	0.02	8,000
Q	74	0.015	0.01	8,000
R	110	0.01	0.01	8,000
S	316	-	-	-
T	668	0.0129	0.0017	8,000

Well ID	Maximum Reported Average Well Discharge (1,000 gal/day)	Max Flow Stagnation Distance (ft)	2000-2004 Reported Average Well Discharge (1,000 gal/day)	Avg Flow Stagnation Distance (ft)	Actual Distance (ft)
A	0	0.0	0	0.0	-
B	31.0	13.7	20.0	8.9	84
C	62.0	33.0	39.8	21.2	529
D	0	0.0	0	0.0	110
E	111	88.8	41.5	33.2	99
F	20.8	49.2	10.6	25.1	75
G	0	0.0	0	0.0	994
H	0	0.0	0	0.0	306
I	**2139**	**499.0**	**1701**	**396.9**	**273**
J	0	0.0	0	0.0	140
K	0	-	0	-	100
L	31.0	13.7	20.0	8.9	89
M	156	17.3	37.5	4.2	92
N	312	55.3	96.0	17.0	849
O	215	57.2	96.5	25.7	97
P	700	93.1	470	62.5	213
Q	**700**	**186.2**	**470**	**125.0**	**74**
R	0	0.0	0	0.0	110
S	0	0.0	0	0.0	316
T	**1656**	**2590.8**	**851**	**1331.4**	**668**

Public Water Supply

- Durham withdraws water from above Wiswall Dam
- Newmarket has a surface water withdrawal
- Potential well sites for Lee and Newmarket along designated reach

Groundwater Resources



M. Davis, UNH

- **Stratified drift aquifers (sand & gravel)**
- **Drinking water sources (Raymond, potentially Epping, Durham, and Newmarket)**

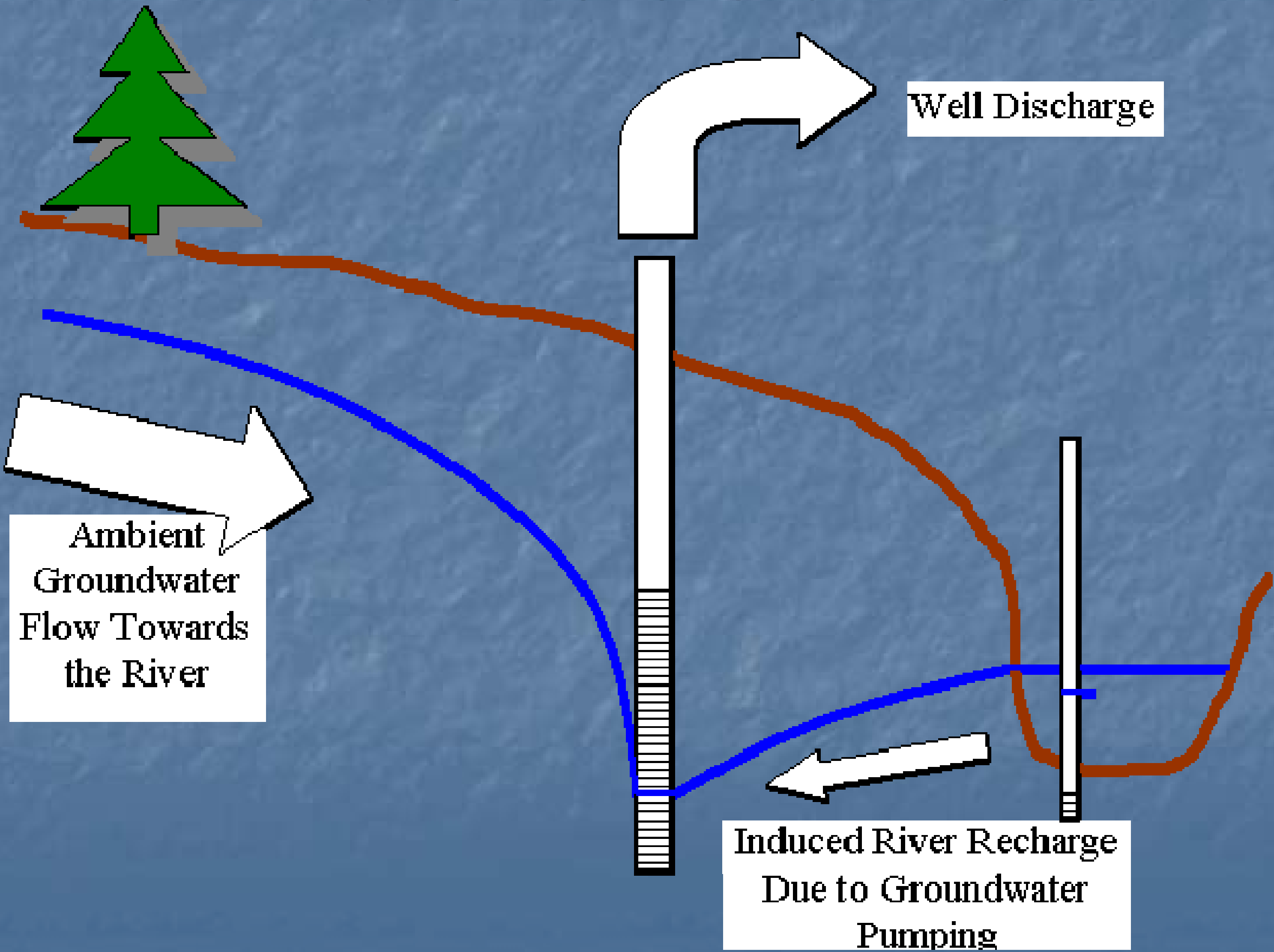
Well ID	2000-2004 Reported Average Well Discharge (1,000 gal/day	Flow to Achieve Stagnation at River (1,000 gal/day)	Possible Average Flow Reduction (1,000 gal/day)
I	1,701	1,170	531
Q	470	278	192
T	851	427	424

The preceding were the results of numerical estimates (office techniques)

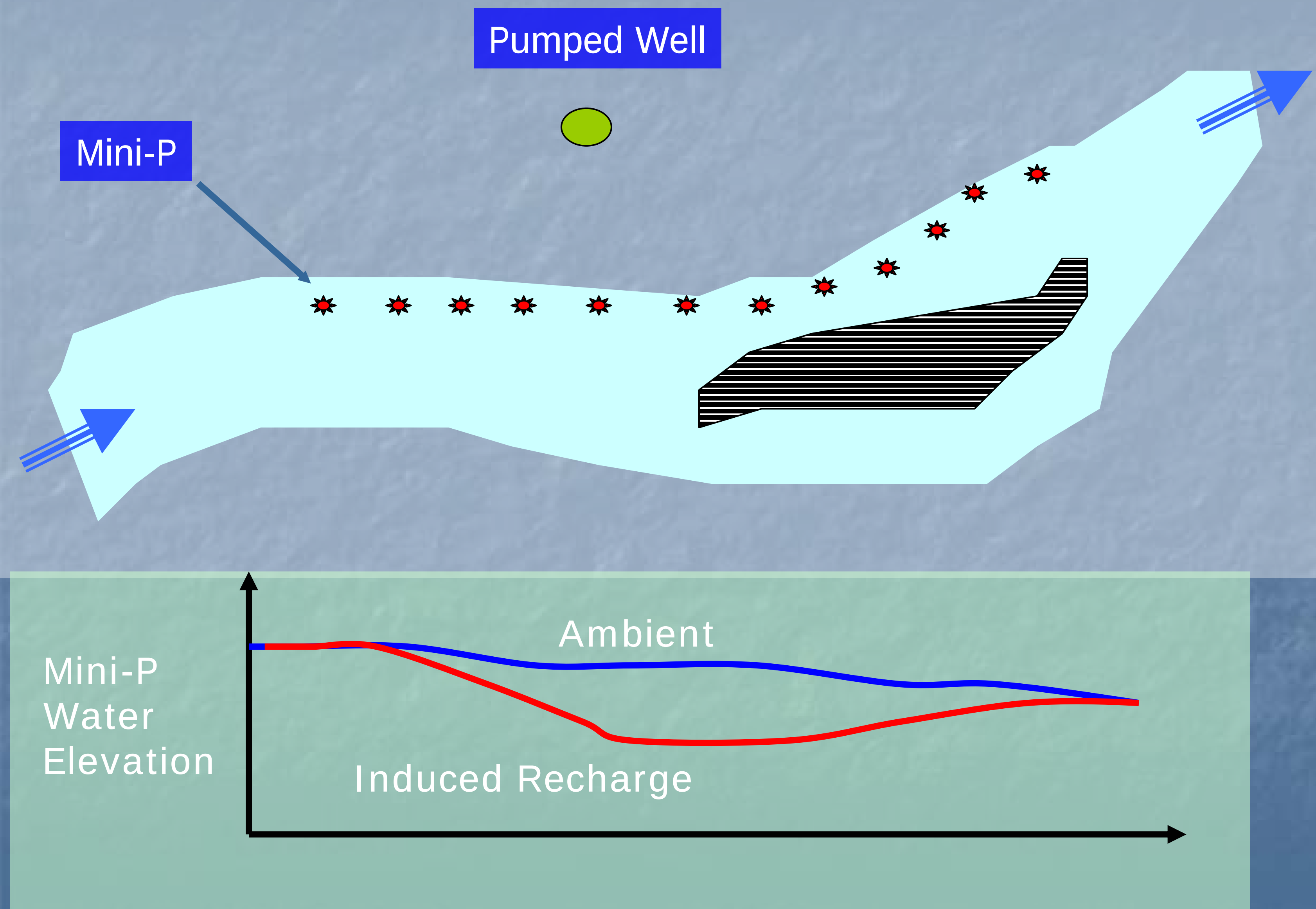
Field Techniques

- Pumping Tests
- Monitoring
- Miniature Piezometers
- Seepage Flux Meters
- Tracer Tests

Field Measurements – Miniature Piezometers or Wells




Poorly-groomed
field tech
07.16.2005


Pumped Well
Mini-P
Ambient
Mini-P
Water
Elevation
Induced Recharge

Field-Measured Vertical Gradients
(negative indicates downward flow)

Well ID	Horizontal Groundwater Slope (USGS Maps)	Max. Vertical Groundwater Slope (Field)	Upstream Distance to Ambient Slope (ft)	Upstream Distance to Ambient Slope (ft)
B	0.016	0.067	0	0
I	0.0114	-1.74	400	800
L	0.016	0.067	0	0
P	0.02	-1.00	300	900
Q	0.01	-1.00	300	900
T	0.0017	-1.74	400	800

Wells I, Q, and T were predicted to exhibit induced recharge. Well P is very close to well Q. The field data verified the numerical predictions.