Penn State's Living Filter System
A 52-Year Perspective

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IDAHO WATER REUSE CONFERENCE
BOISE, IDAHO
MAY 15-16, 2013

Penn State's 1950's Environmental Problem: A National Problem

- Discharge of secondary effluent to Thompson Run and tributaries of Spring Creek.
- World class trout stream, cold-water fishery.
- Stimulation of aquatic plants by nutrients.
- Eutrophication and diurnal depletion of O_2 resulting fish kills.
- Cyanide release from research lab-extensive fish kill.
- University growth: 1000 to 1500 new students/yr.

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President Eric Walker and Vice-president E.F. Osborn Campus-wide suggestions (Fall 1961)

- Up-grade sewage treatment plant.
- Bypass Spring Creek to confluence with N. Bald Eagle Creek.
- Discharge effluent into Scotia ore pits for N and P removal.
- Deep well injection into Gatesburg Formation.
- Restrict campus enrollment to 25,000 (presently >44,000).
- Students should help “harvest” aquatic plants.
- Land reclamation.

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Waste Water Reuse Committee Established 1961-62

- M.A. Farrell, College of Agriculture, Chairman
- H. Chisman/W.E. Sopper, Forestry/Forest Hydrology
- R. Cone, Microbiology
- E.E. Cooper, Fisheries
- R. Butler, Wildlife
- L.T. Krdos, Soil Physics
- R.A. Kuntz/J.B. Nesbitt, Sanitary Engineering
- E.A. Myers, Agricultural Engineering
- R.R. Parizek, Hydrogeology
- T.B. Keen/L.A. Nieman, Office of Physical Plant

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Development of Waste Water Renovation and Conservation Cycle Concept

- Feasibility of year-round disposal of sewage effluent on land.
- Degree of renovation of sewage effluent by biological, chemical and mechanical processes in soil.
- Extent of conservation of water returned to groundwater.
- Effect of applied effluent on soils, crops and wildlife.

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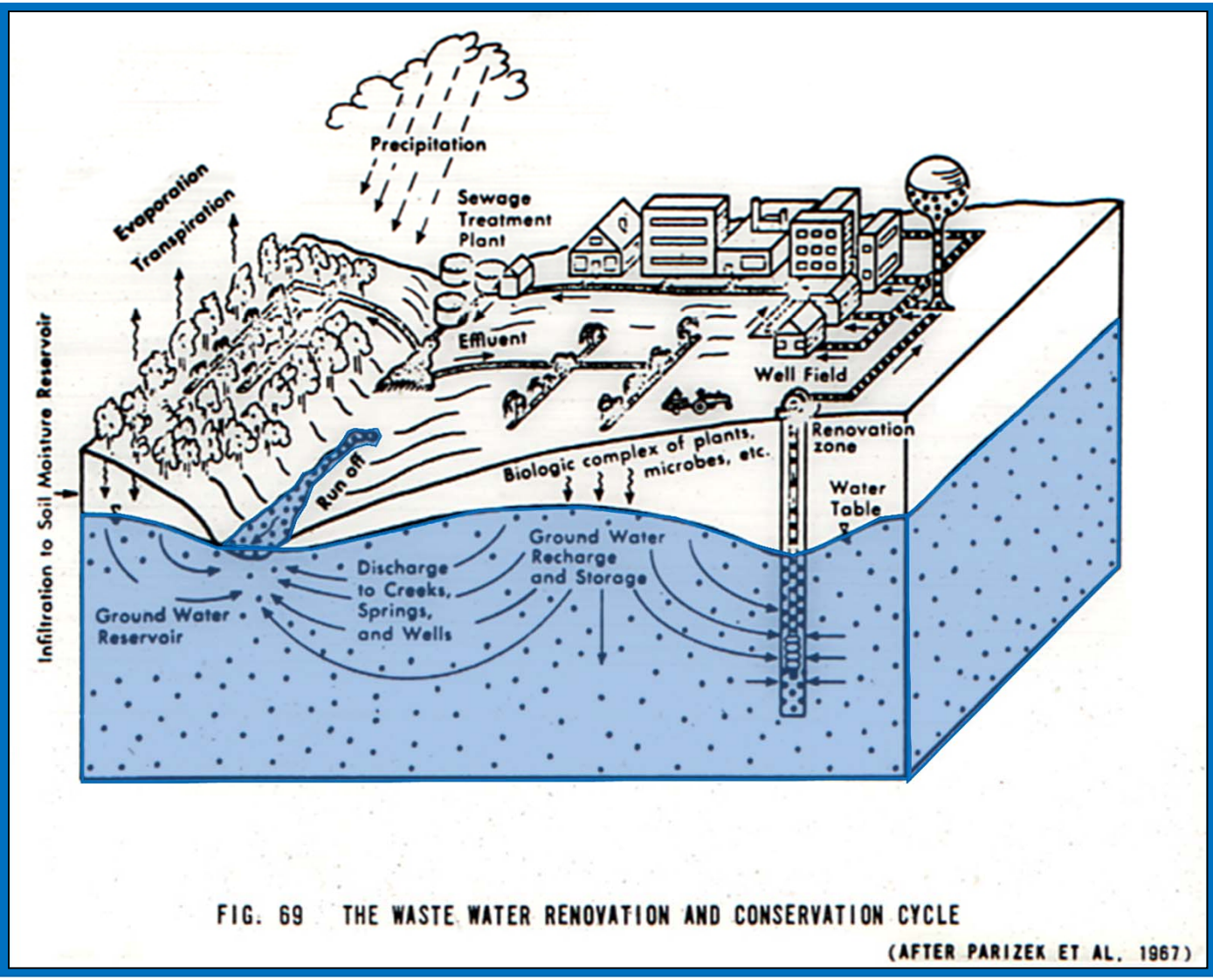

FIG. 69 THE WASTE WATER RENOVATION AND CONSERVATION CYCLE

(AFTER PARIZEK ET AL. 1967)

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Table 1.1 Typical composition of secondary treated sewage effluent at the Penn State Wastewater treatment plant (Shaw, 1999).

Substance	Concentration	Units
pH	7.69	Standard Units
Chloride	206	mg/l
Ammonia Nitrogen	<0.20	mg/l
Nitrate Nitrogen	3.15	mg/l
Nitrite Nitrogen	<0.10	mg/l
Phosphate - Ortho	4.27	mg/l
Sulfate	30.4	mg/l
Hardness	232	mg/l as CaCO3
Total Organic Carbon	19	mg/l
Fluoride	0.421	mg/l
Iron	0.151	mg/l
Copper	0.039	mg/l
Manganese	0.01	mg/l
Cadmium	<0.0003	mg/l
Lead	0.00373	mg/l
Total Solids	655	mg/l

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WASTEWATER TREATMENT PLANT EFFLUENT AVERAGE NITROGEN CONCENTRATIONS (mg/l as N)

YEAR	NITRATE N	AMMONIA N	NITRITE N	TOTAL N
1983	5.13	6.57	2.27	13.97
1984	4.18	16.14	5.32	25.62
1985	4.47	7.71	0.17	12.35
1986	1.85	24.45	7.13	33.43
1987	2.55	18.08	0.25	20.88
1988	1.40	16.58	0.51	18.48
1989	1.53	21.90	0.53	23.95
AVG. 83-89	3.01	15.91	2.31	21.24

Findings 1963 -1967 Routine Operation 1983 – Present

- Penn State's facility is the only one permitted in Pennsylvania that allows year-round irrigation without required storage
- 2 inches/week application rate is optimum
- Nutrients removed year-round during infiltration and overland flow
- Nutrients removed within wetlands

Findings 1963 -1967 Routine Operation 1983 – Present (Continued)

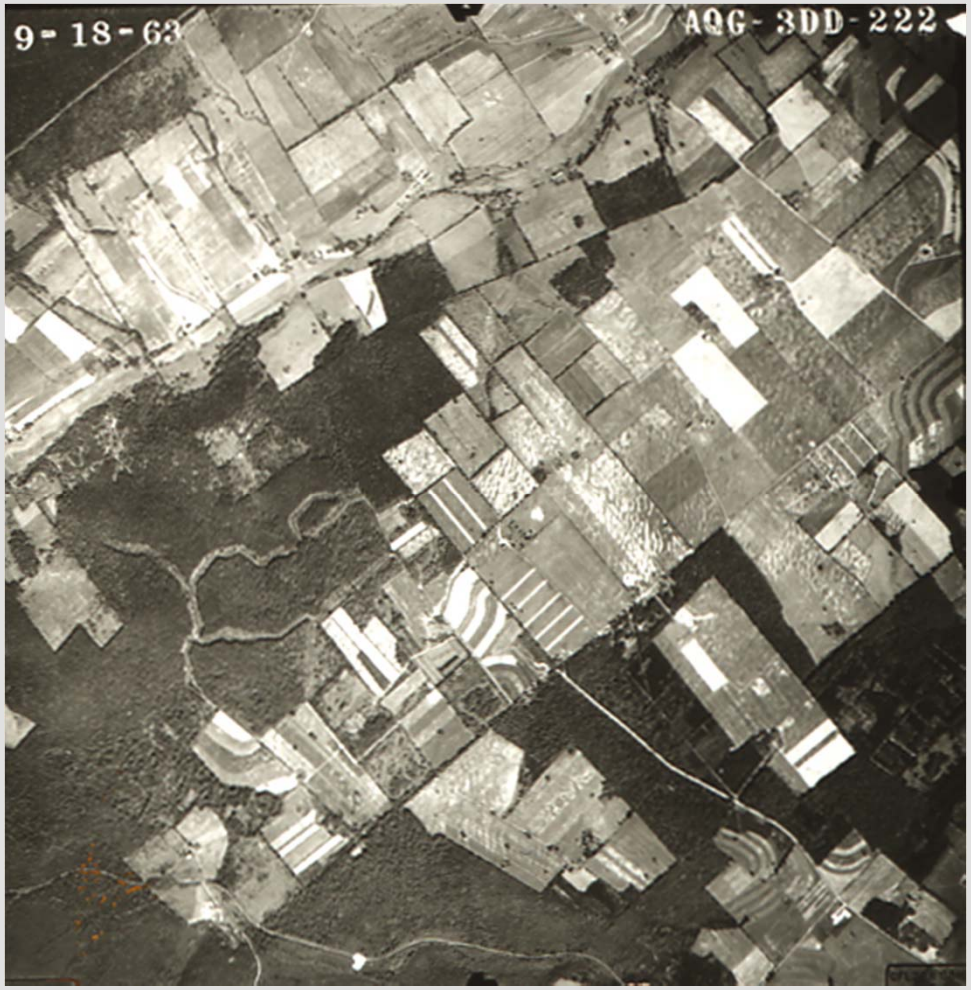
- Nearly one billion gallons of potable water is added to groundwater annually
- On-site groundwater nitrates are now maintained below 8 mg/l
- Hundreds of feet of precipitation and effluent have successfully passed through the soil profile since 1983
- Biomass removal is necessary to allow year-round irrigation
- Detention depressions are necessary to prevent winter runoff
- Forested borders are desirable

Findings 1963 -1967 Routine Operation 1983 – Present (Continued)

- Dedicated management group is needed for successive year-round operation
- The Living Filter presents education, outreach, and research opportunities
- Lands serve multiple uses (e.g., wastewater treatment and recharge, farming, forestry, wildlife, hiking, hunting)
- Some pharmaceuticals and healthcare products are present in trace concentrations

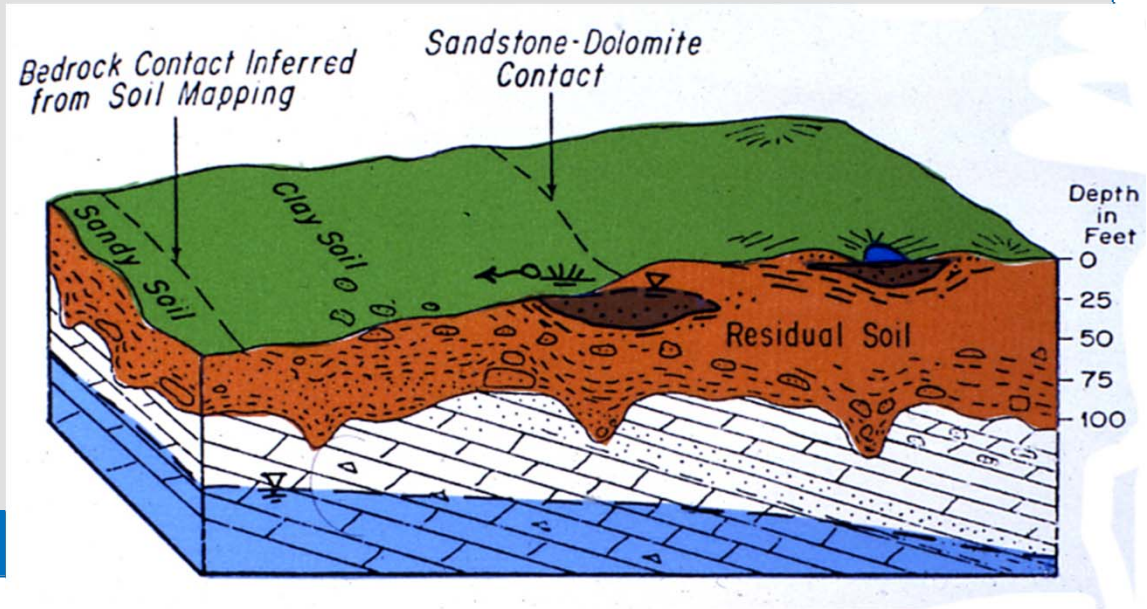
Research Design

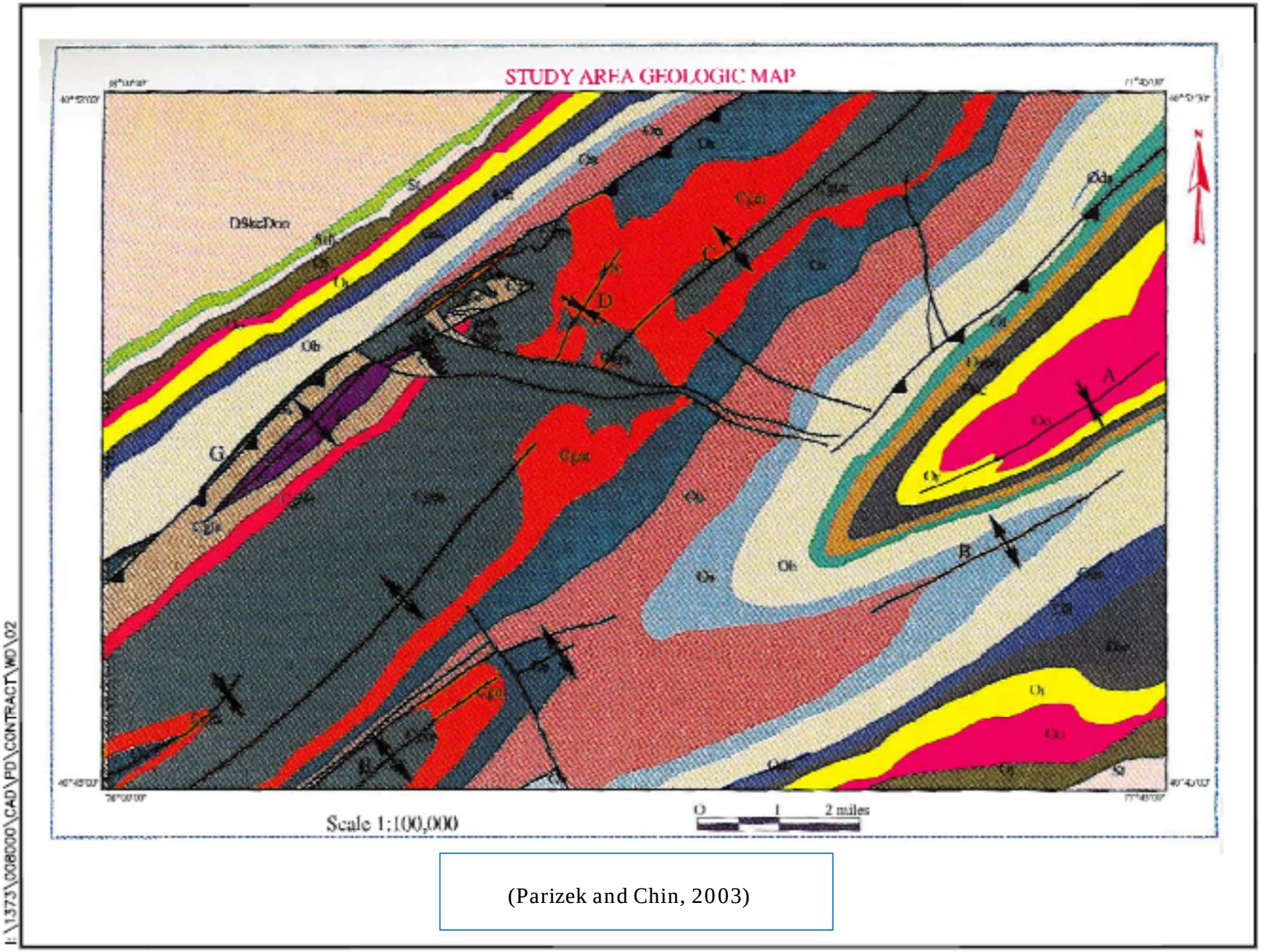
- Site selection
- Series of treatment ponds.
- Crop selection.
- Effluent application rates
  - 1-,2-,4- and 6 inches /week
  - Growing and non-growing season.
- Monitoring program
  - Agricultural
  - Unsaturated zone
  - Saturated zone
  - Wildlife
- Compliance monitoring
- Public information meetings



Site Selection

- Thick residual soils
- Favorable infiltration and drainage characteristics
- Upland setting underlain by limestone/dolomite
- Detention depressions reduces stormwater runoff
- Deep water table
- Forest borders
- Remote from wells, springs and homes





(Parizek and Chin, 2003)

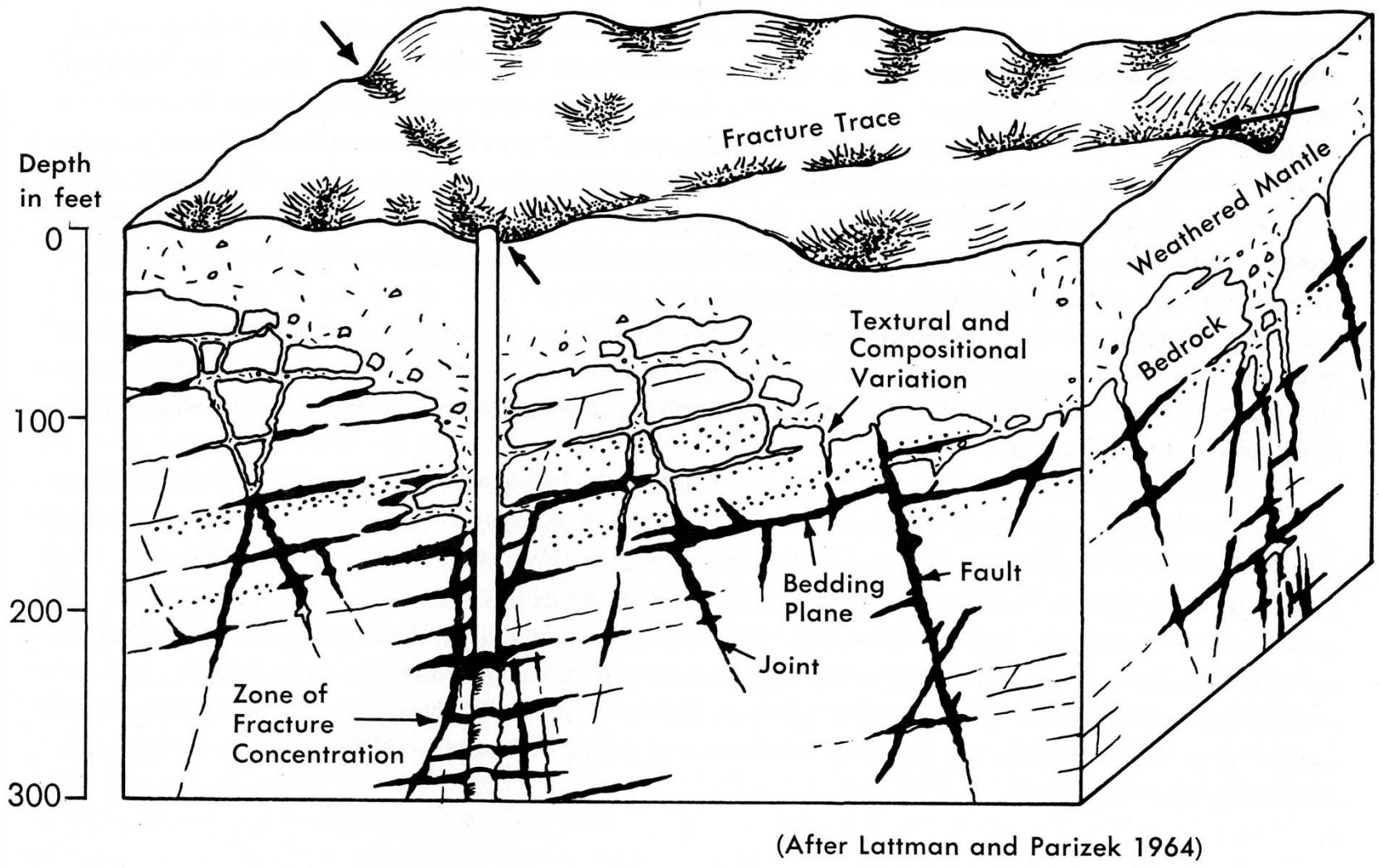


FIGURE 4. Block Diagram of Fracture Zones and Solution Cavities Associated with Surface Fracture Traces.

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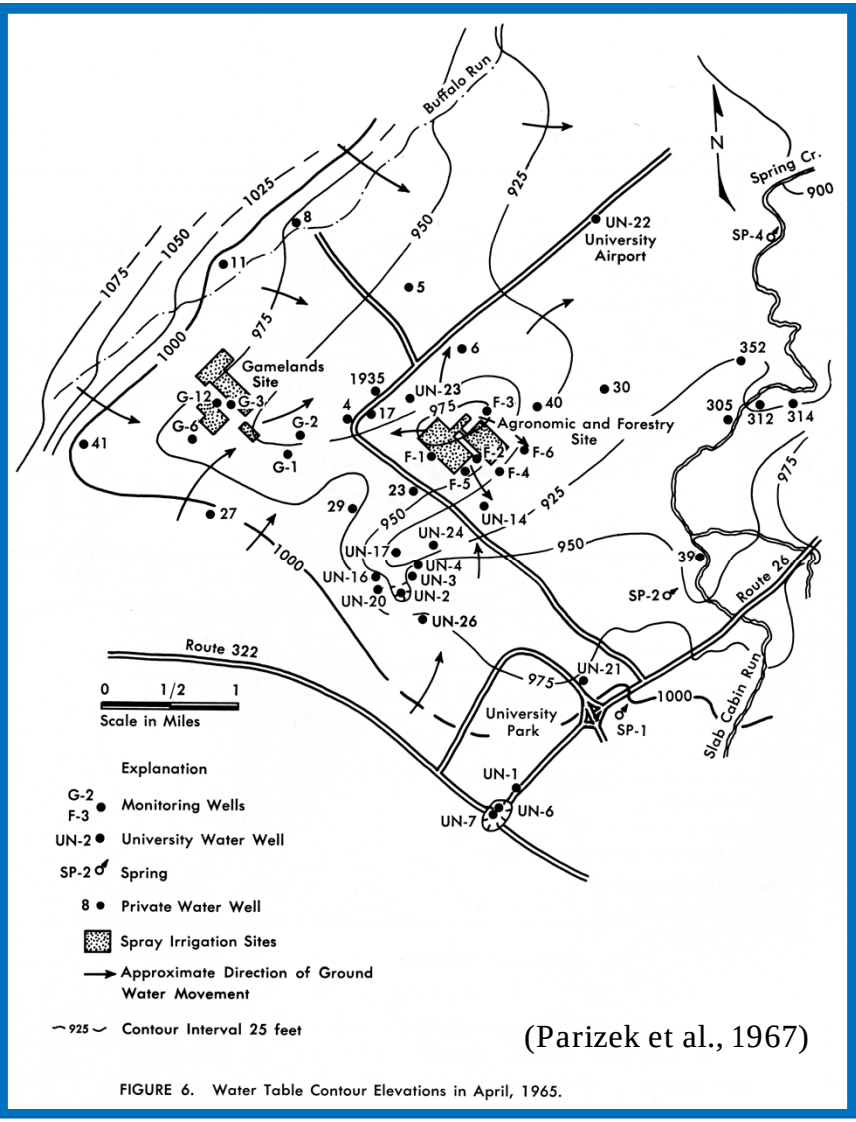
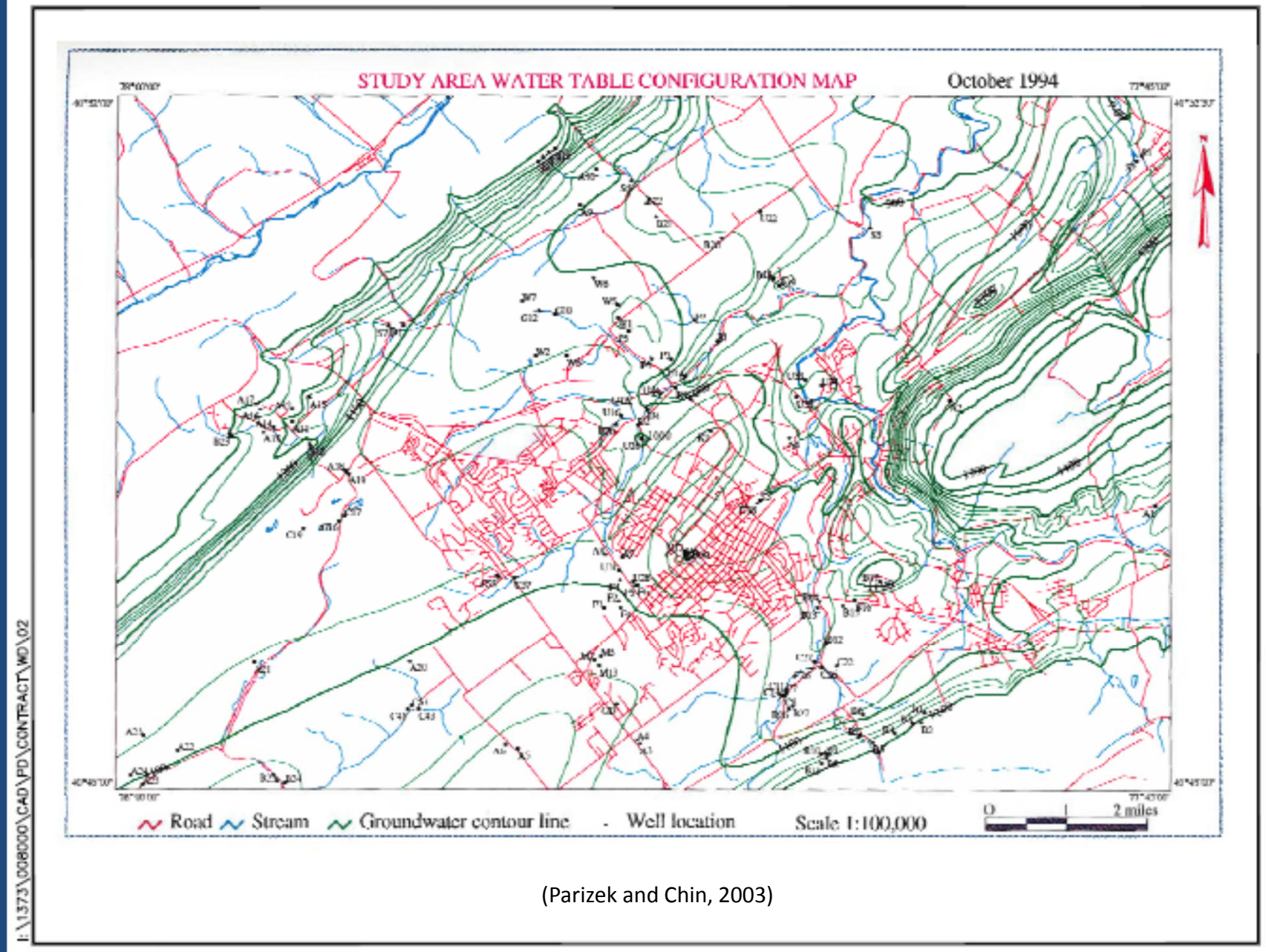
Site Characterization

- Soil map/ test pits
- Detailed geologic mapping (first up-grade since 1936)
- Split spoon soil sampling to bedrock
- Diamond cores bedrock to water table
- Seismic geophysical surveys
  - Regolith thickness
- Water table map (perched/regional) (first map Central Pennsylvania)
- First use of fracture traces and lineaments to define
  - Soil thickness
  - Bedrock permeability
  - Groundwater exploration
  - Location of monitoring wells
  - Risk of sinkholes and foundation stability



(Parizek et al., 1967)

FIGURE 6. Water Table Contour Elevations in April, 1965.



(Parizek and Chin, 2003)

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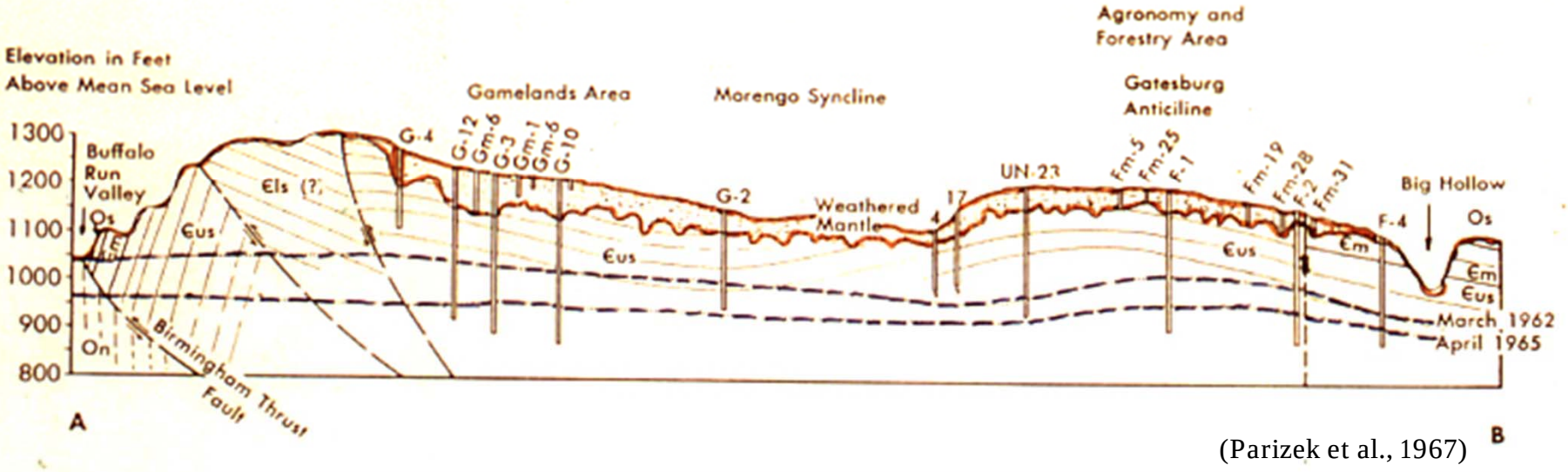
Stratigraphic Cross Section of Study Area



(Parizek et al., 1967)

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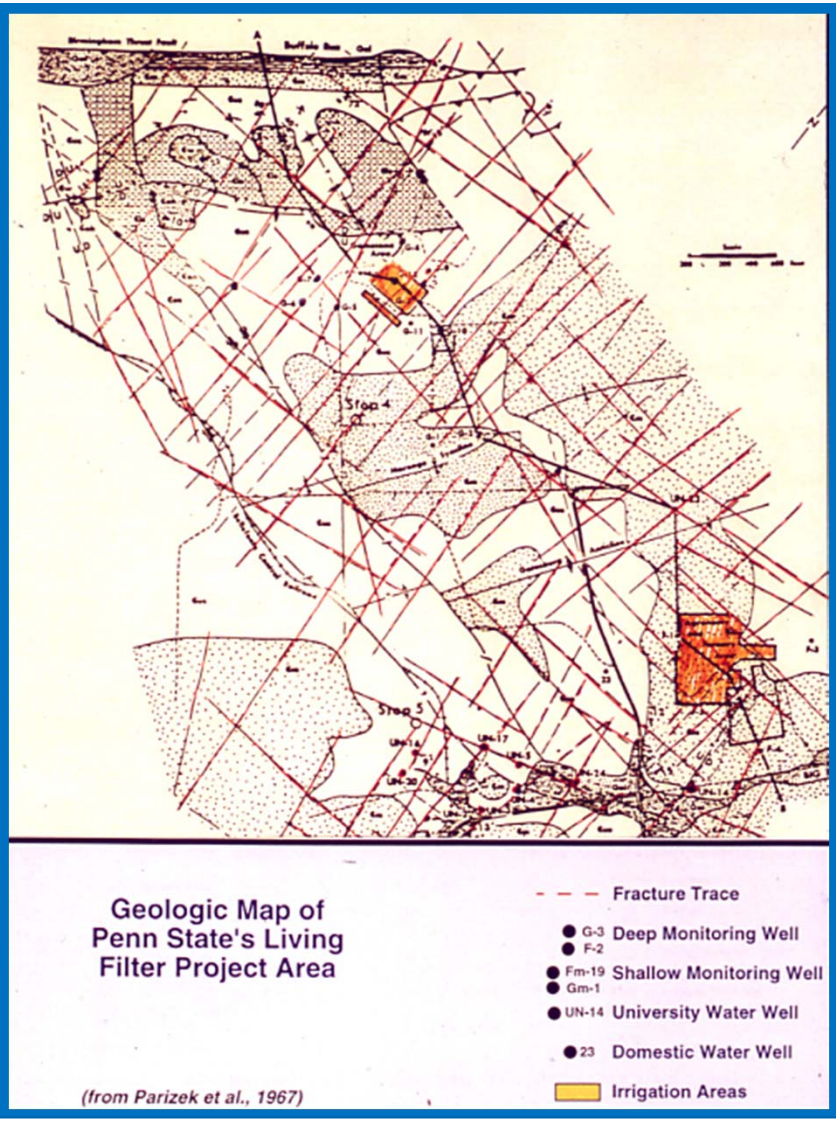
Stop 4
Stop 5
Geologic Map of
Penn State's Living
Filter Project Area
(from Parizek et al., 1967)
Fracture Trace
G-3 F-2 Deep Monitoring Well
Fm-19 Gm-1 Shallow Monitoring Well
UN-14 University Water Well
23 Domestic Water Well
Irrigation Areas

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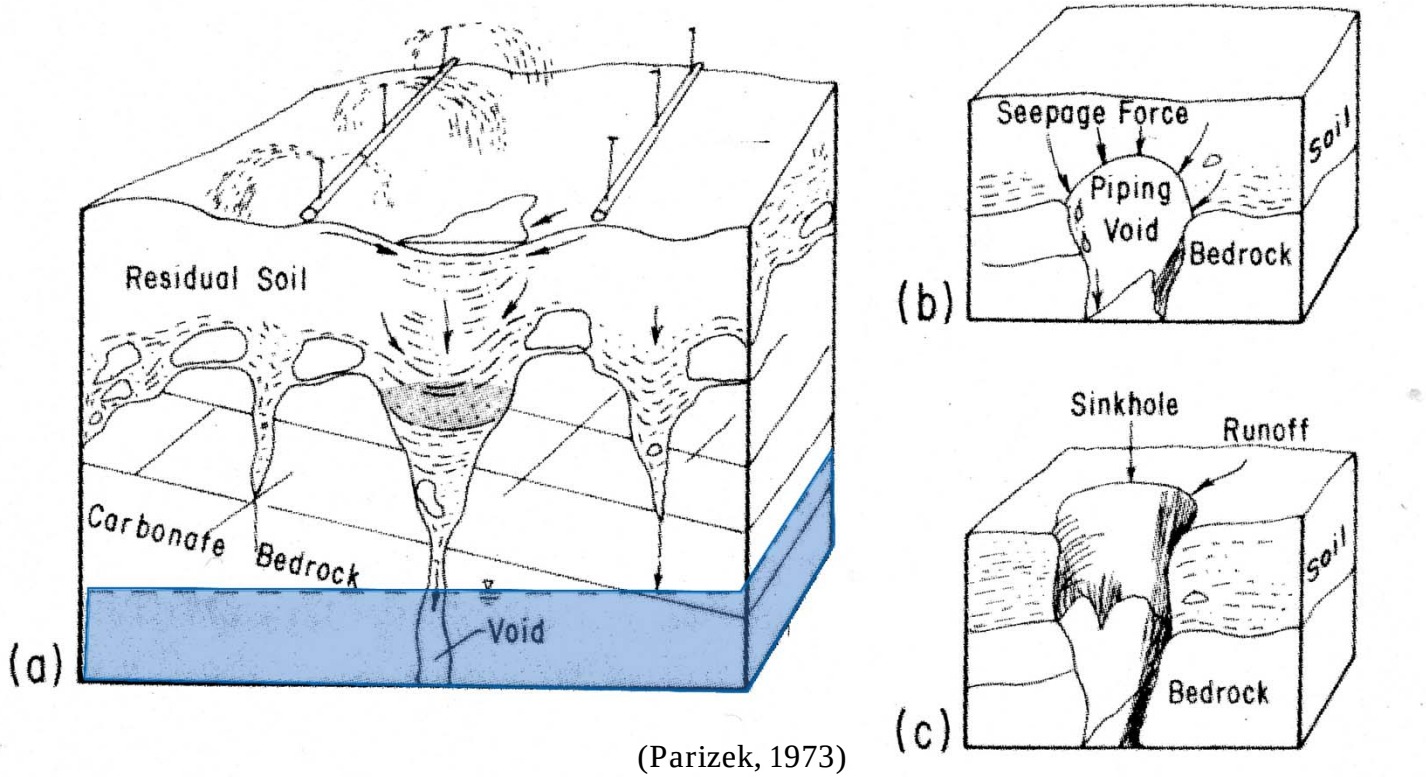
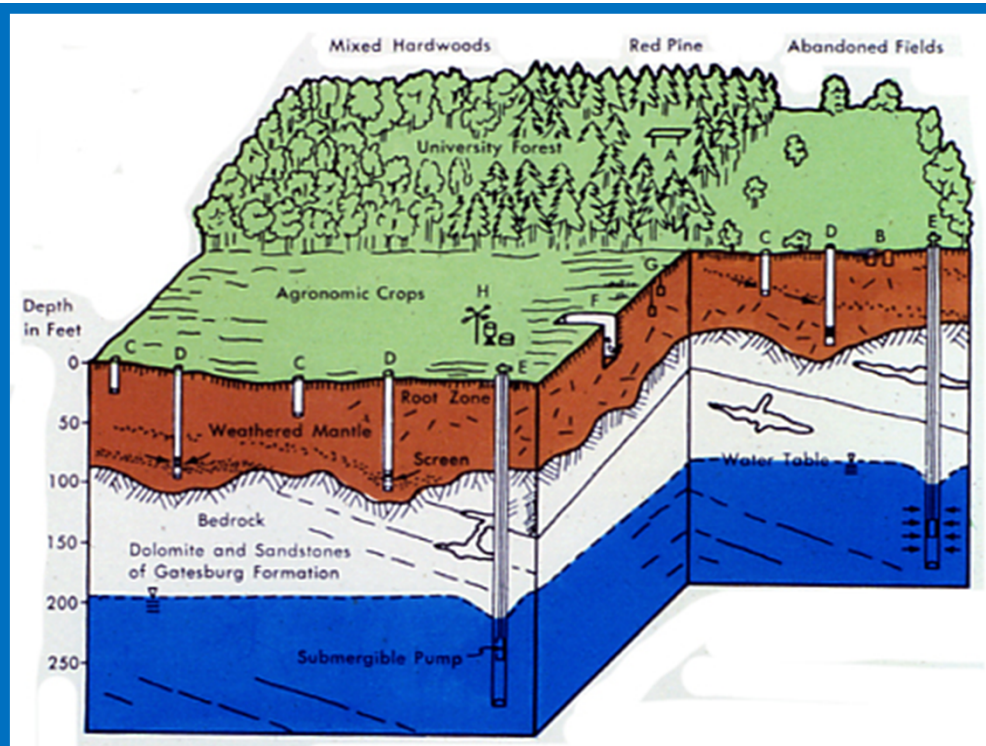


(Parizek, 1973)

Figure 6-6. Development of piping voids and sinkholes when irrigating residual soils in carbonate terranes. In (a), soil water is channeled to voids in bedrock. Seepage forces help to erode overlying soil into voids (b) and sinkholes may finally develop allowing for recharge of unrenovated effluent (c).

Water Monitoring Program

- On-site
  - Weather station
  - Uniformity coefficient, sprinkler heads
  - Pan lysimeters
  - Trench lysimeters
  - Throughfall rain gage
  - Soil moisture content (neutron logging)
  - Sandpoint wells (perched groundwater)
  - Pressure vacuum lysimeters (first modification to allow deep samples)



A. Throughfall gauge

B. Lysimeters (In root zone at depth of 1½ inches to 4 feet).

C. Soil Moisture Access Tubes (To measure changes in soil moisture— 8 to 20 feet deep).

D. Sand-point Wells (completed in the weathered mantle at depths from 6 to 52 feet).

E. Deep Water-table Wells (Contain submergible or piston pumps, 250 to 300 feet deep).

F. Trench with pan lysimeters at one foot intervals to depths 6 and 16 feet.

G. Suction lysimeters, 6 inches to 26 feet in depth

H. Weather Station

(Parizek et al., 1967)

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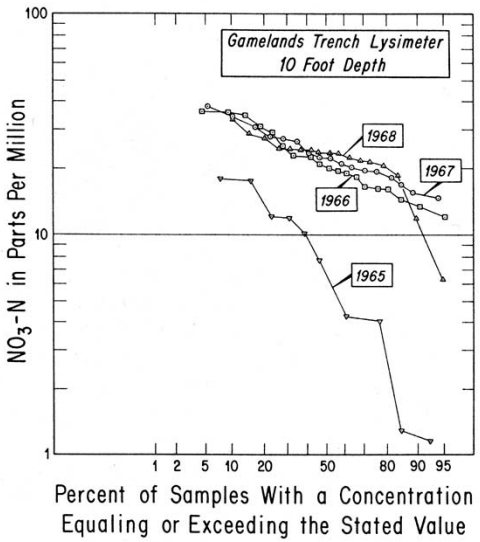

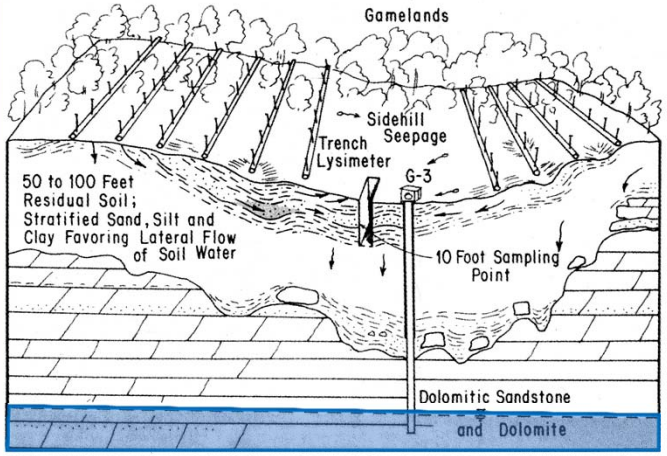

(Parizek, 1973)

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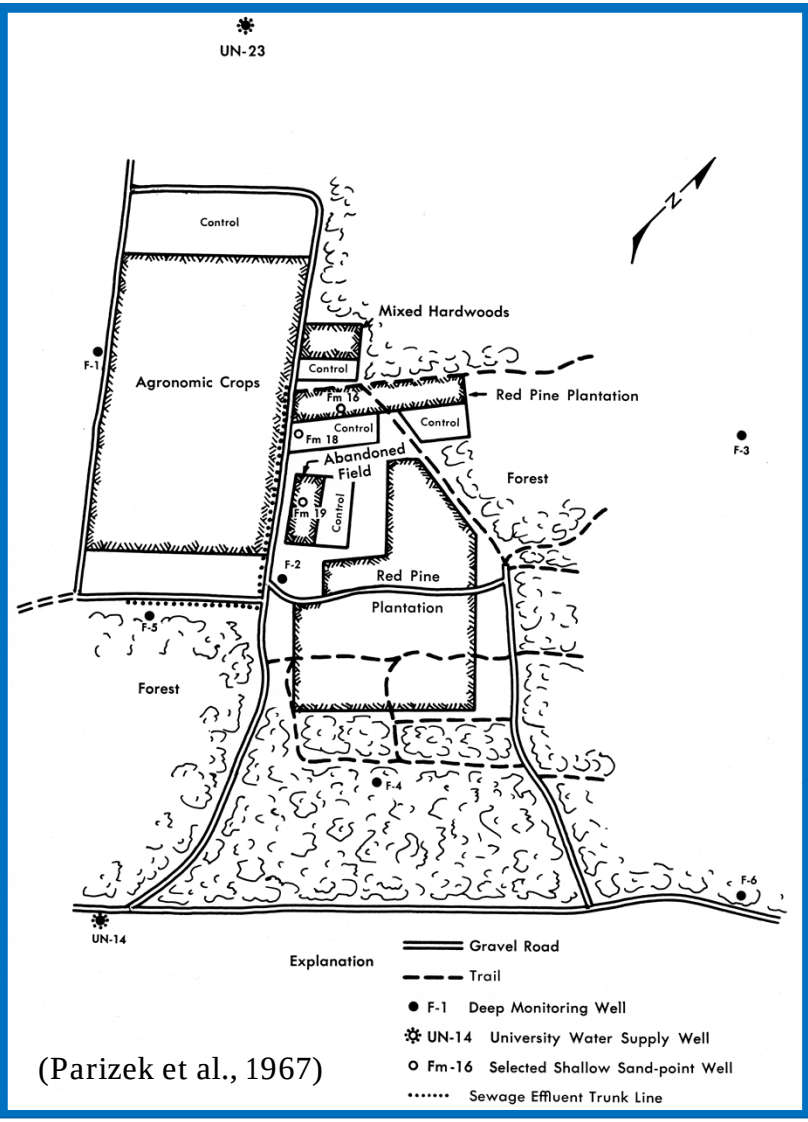

(Parizek et al., 1967)

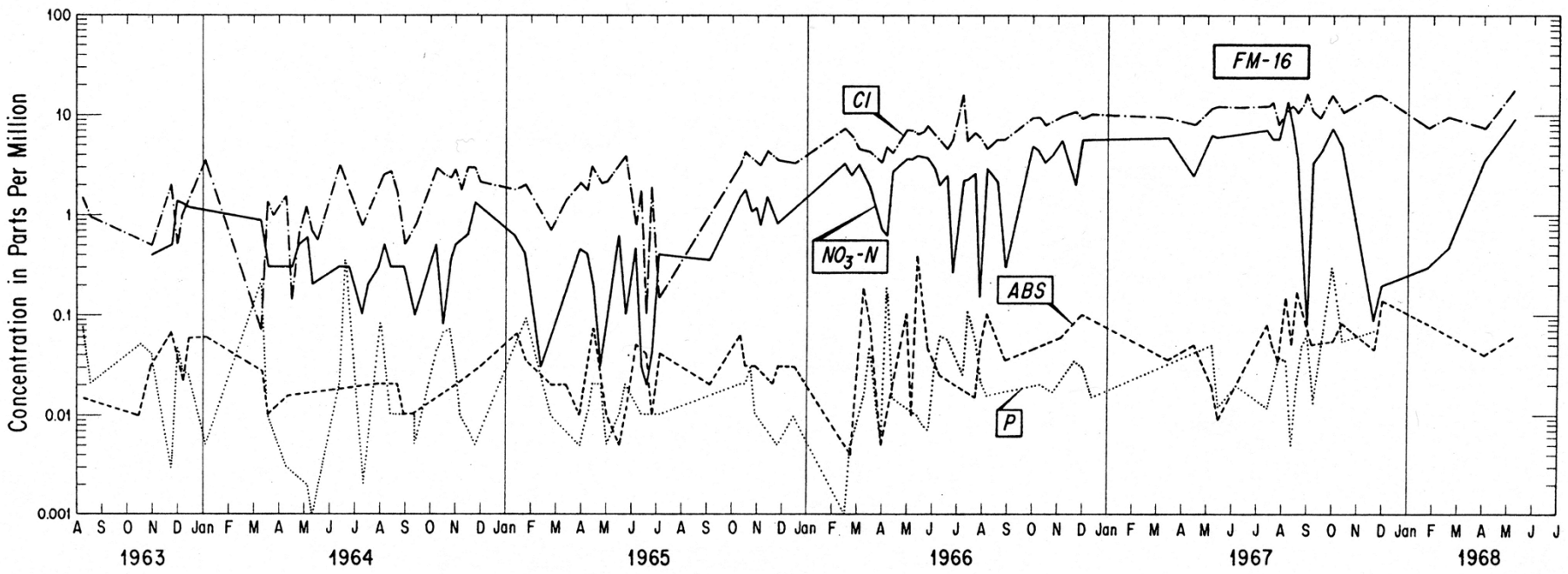

Figure 6-21. Concentration of chlorides, ABS, phosphorus and nitrate nitrogen in sand point well FM-16 at a site receiving 2 inches of effluent per week April through November since 1963. Note the erratic plots obtained. Significant quality changes can be difficult to establish in the short term.

(Parizek, 1973)

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Water Monitoring Program

- Off-site
  - Inventory of 71 domestic, farm and public water supplies
  - Monthly water quality monitoring of 56 wells and springs
  - Analysis provided by independent DEP approved laboratory
  - Data provided to property owners following each sampling
  - Data provided to Pennsylvania Department of Health, later Pennsylvania Department of Environmental Resources

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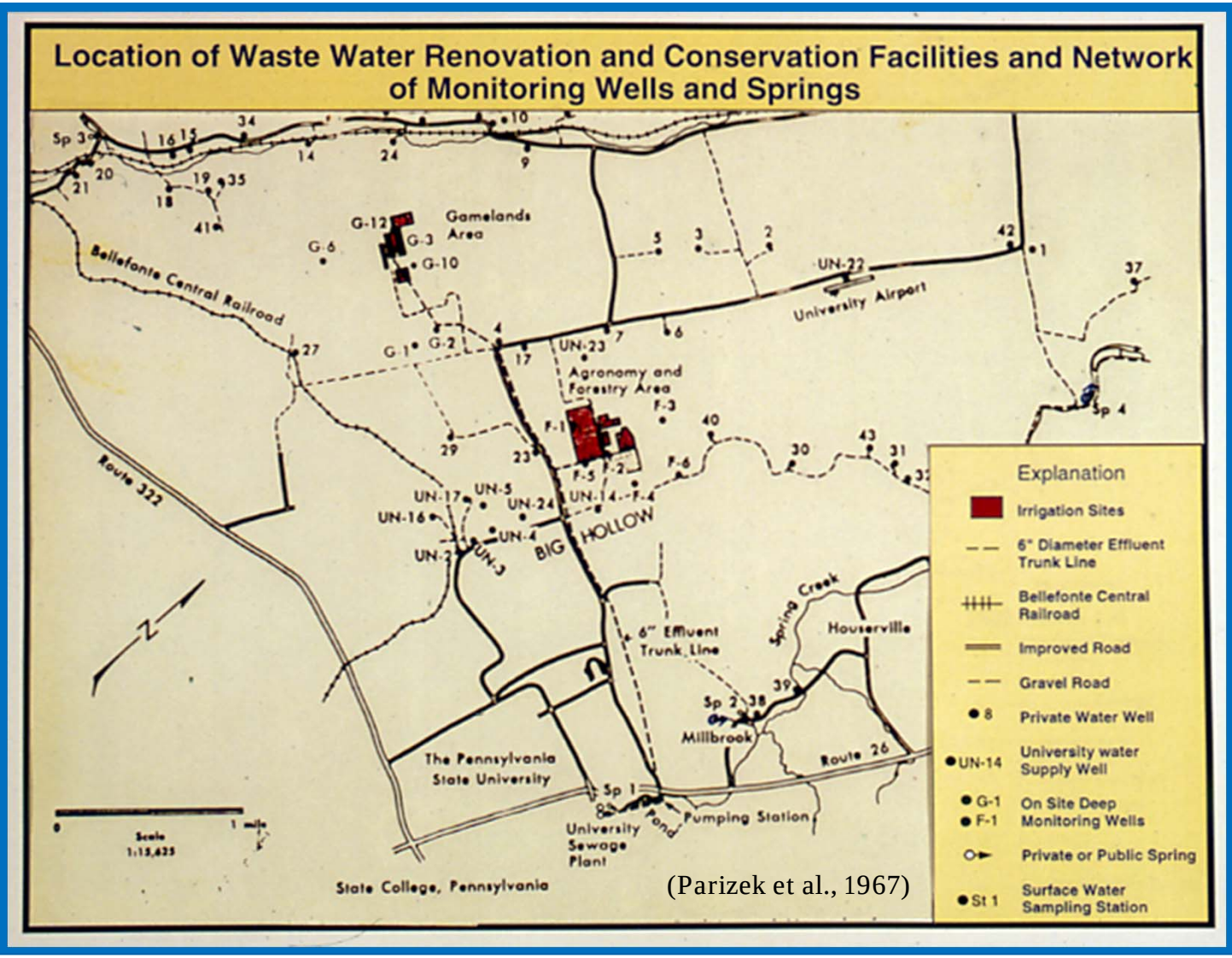

(Parizek et al., 1967)

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Mean Annual Concentration of Nitrate-N in a Deep Groundwater Monitoring Well Adjacent to the Wastewater Irrigation Areas

Year	Nitrate-N (mg/l)	Year	Nitrate-N (mg/l)
1963	1.9	1975	3.5
1964	2.3	1976	3.5
1965	1.4	1977	4.1
1966	1.8	1978	4.5
1967	2.9	1979	4.3
1968	3.1	1980	3.3
1969	4.0	1982	2.5

(from W. Sopper)

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Findings 1963-1967 Routine Operation 1983-Present

- Effluent can be applied in winter
  - Furrows
  - Perforated pipe
  - Sprinklers
  - Topography too uneven for overland flow
- Design rate 2 inches/week
- Agricultural crops showed favorable growth and nutrient up-take responses.
- No till and limited till beneficial
- Biomass must be removed to maintain <10 mg/l groundwater target
- Forest growth responses variable
  - Young water tolerant trees favorable
  - Red Pine and other dryland species decline
- NO_3 can be maintained at 10 mg/l at 120 cm given winter rest

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Net Nitrate Uptake of the Harvested Crops to Date in 1991

Treatment		Uptake N lbs/A	Uptake P lbs/A
1	Corn grain*	0	0
2	Rye* Soybeans	100	19
3	Rye* Corn silage	104	19
4	Rye* Sudangrass	146	28
5	Corn Grain* Sawdust*	0	0
Others			
	Reed Canarygrass	251	34

** Nitrogen fertilizer 50 lbs/A applied to all corn*

Reed canarygrass used as feed for University's dairy herds

monetarily valuable

environmentally advantageous

Other solutions
double cropping

(from Lanyon, Cauffman, and Loughran, 1991)

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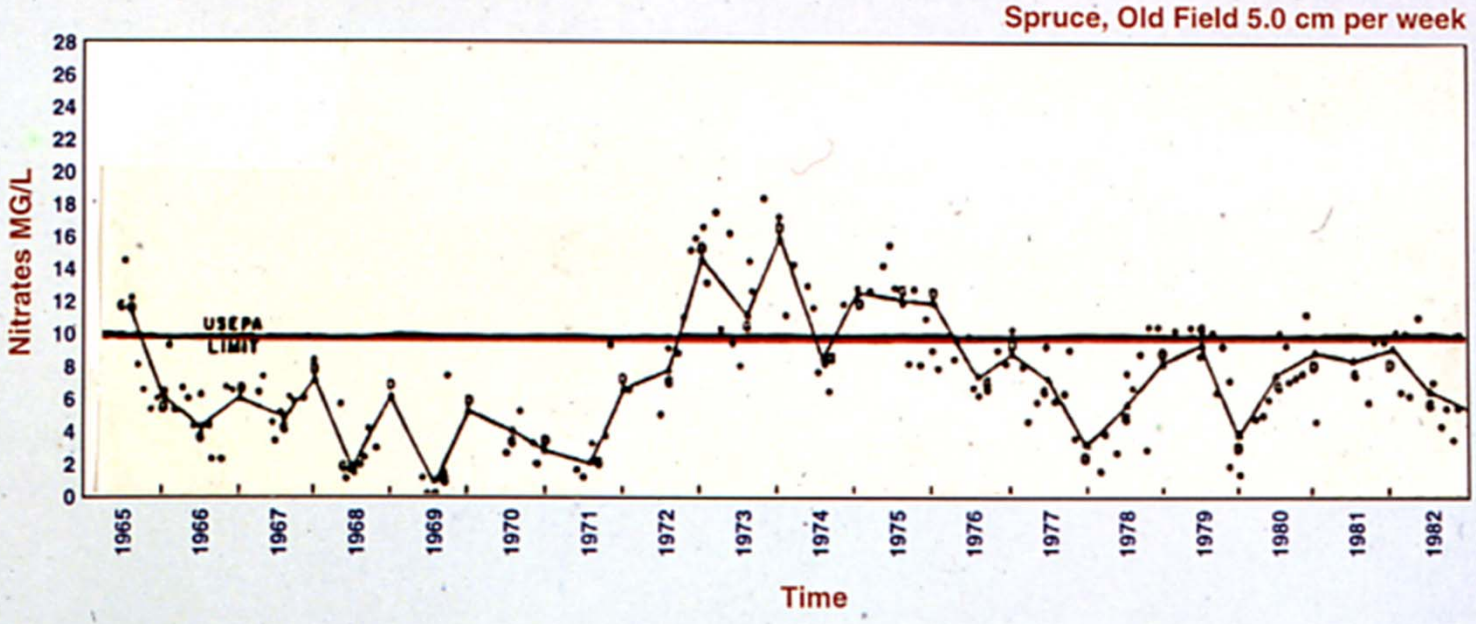
Average monthly and seasonal nitrate-N concentrations of soil water at the 120 cm soil depth in the white spruce, old field forest ecosystem irrigated with municipal wastewater at 5 cm/wk during the growing season, 1965-1982.



(W. Sopper)

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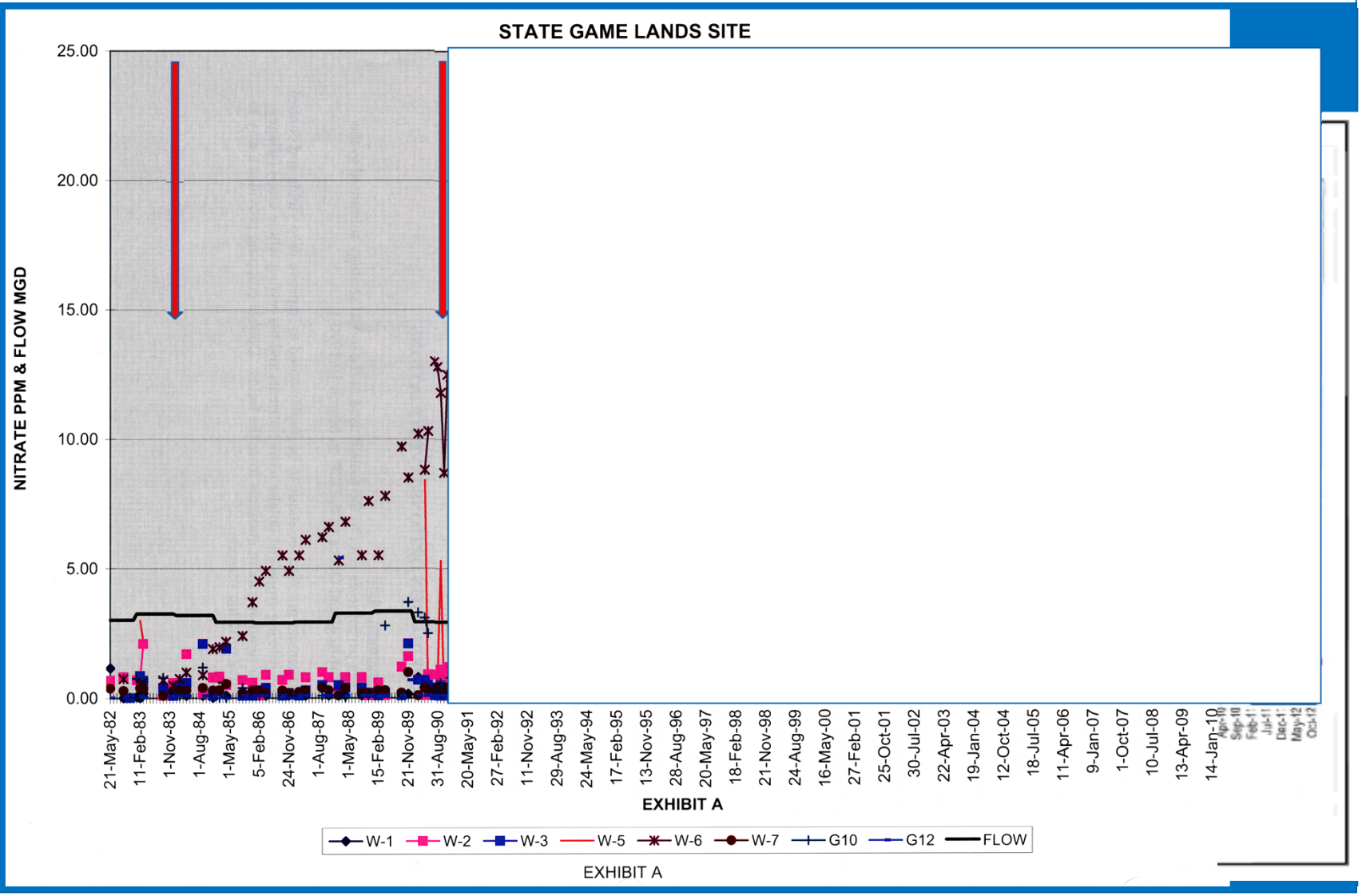

EXHIBIT A

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SGL MONITORING WELL W-6

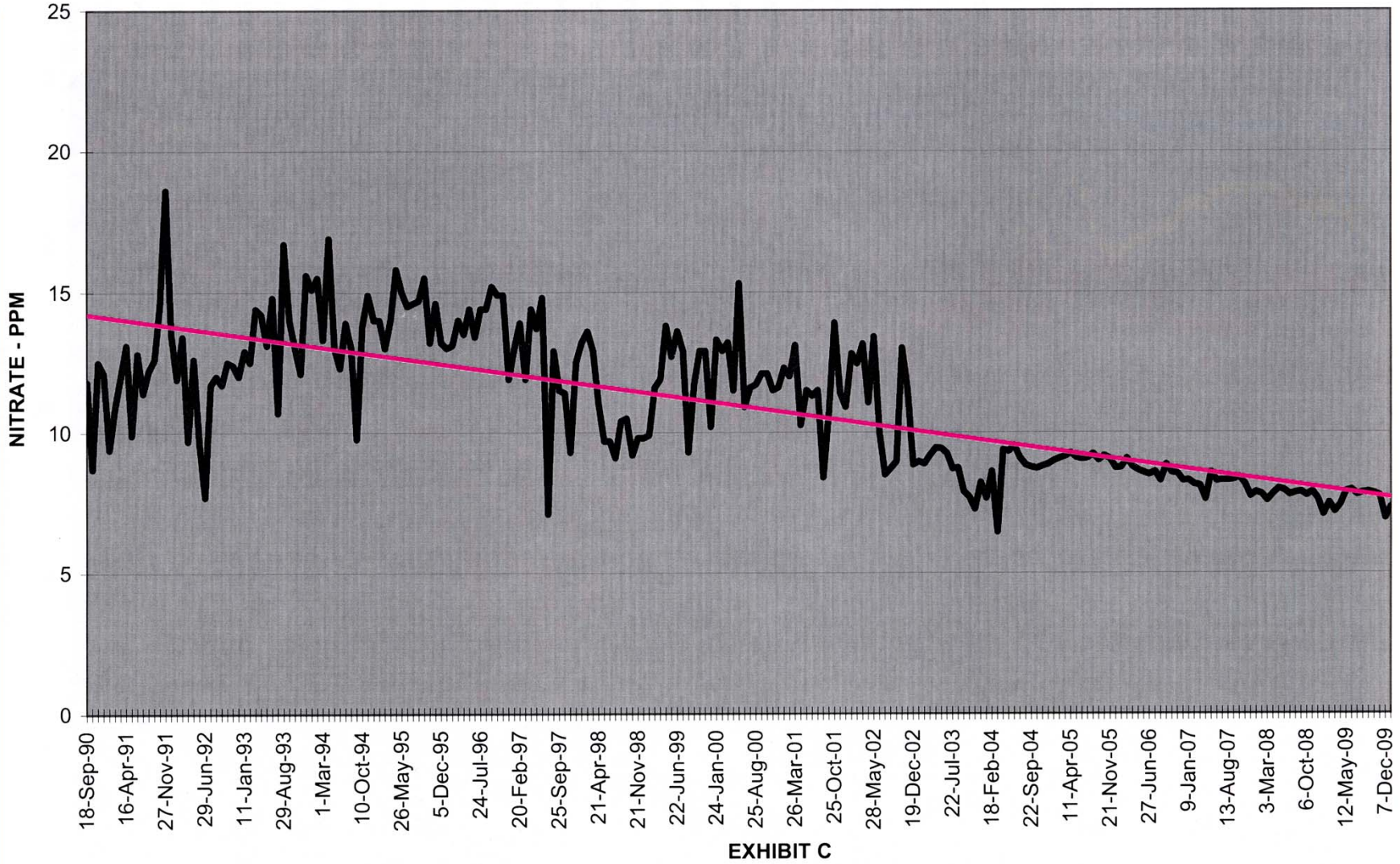

EXHIBIT C

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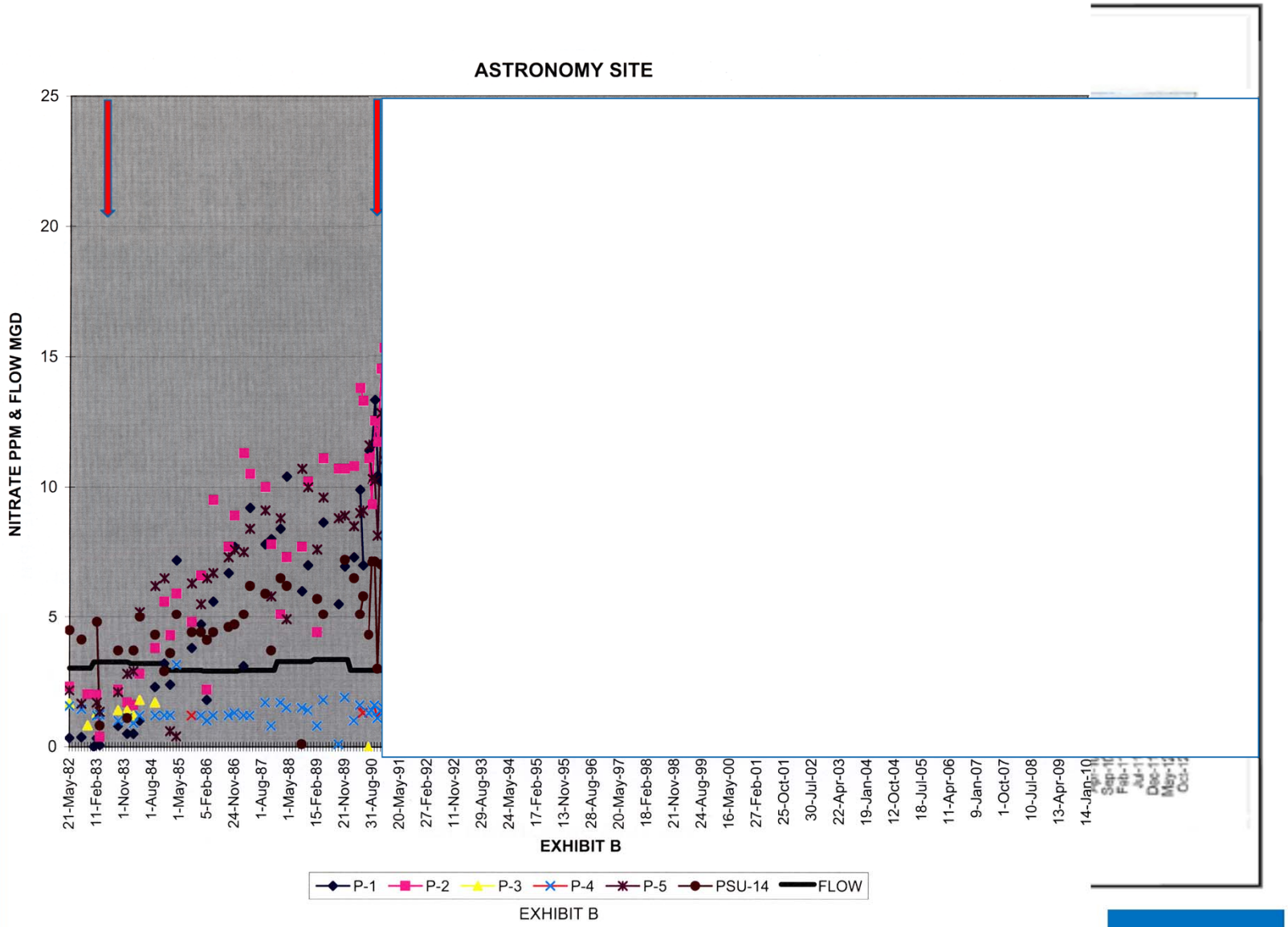

EXHIBIT B

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RECHARGE BY SEWAGE EFFLUENT FOR 1 AND 2-INCH (2.5 AND 5 CM) APPLICATION

RATES BY YEAR AT THE PENNSYLVANIA STATE UNIVERSITY PROJECT SITE*

Year	Application Rate Inches/Week (cm) April-November		% Potential Recovery		Recharge (gal/acre/yr)
1963	1	*(2.5)*	65.5		427,000
1963	2	*(5)*	82.7		1,078,000
1964	1	*(2.5)*	59.8		--
1964	2	*(5)*	79.9		--
1965	2	*(5)*	--		1,493,000
			Inches (cm) of Recharge		
1963	1	*(2.5)*	18	*(46)*	488,700
1963	2	*(5)*	41	*(104)*	1,113,000
1964	1	*(2.5)*	26	*(66)*	706,000
1964	2	*(5)*	59	*(150)*	1,602,000
1965	2	*(5)*	--		1,493,000
1967	2	*(5)*	--		1,959,000

Parizek et al. (1967); Kardos et al. (1974).

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Recharge rate from the Living Filter Project for the period 1968-1969

(From Kardos et al, 1974)

Irrigation Period	No. of Irrigations	Effluent Applied	Rainfall	PET	Groundwater Recharge	%Recharge
		gal/acre	gal/acre		gal/acre	
June 18-Dec 5, 1963	23	1,249,000	447,500	583,500	1,113,000	89
Apr 8-Nov 18,1964	33	1,792,000	460,800	650,800	1,602,000	89
Apr 20-Nov 16, 1965	31	1,684,000	444,800	635,800	1,493,000	89
Apr 5-Nov 15, 1966	32	1,738,000	553,900	637,900	1,654,000	95
Apr 18-Oct 31, 1967	28	1,521,000	745,600	407,600	1,859,000	100
Apr 9-Nov 12, 1968	32	1,738,000	700,000	591,000	1,847,000	100
Apr 15-Oct 29, 1969	21	1,140,000	589,500	396,000	1,333,500	100
Average					1,557,000	95

Potential evapotranspiration calculated by method of Thornthwaite and Mather (99,100)

Expressed on basis of effluent applied

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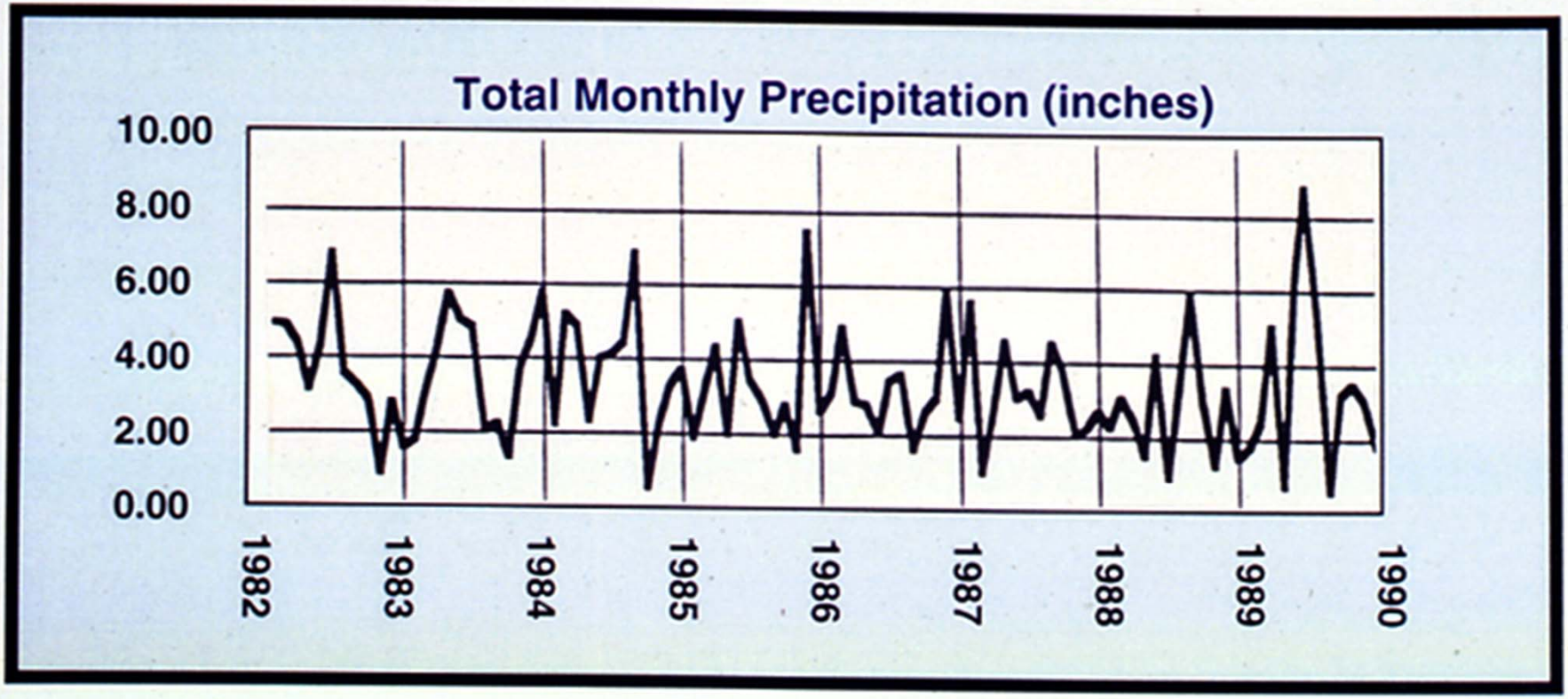
Climatological Summary of State College, Pennsylvania



(from Duffy 1991)

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Climatological Summary of State College, Pennsylvania

30 Years Record 1982 to 1989

	Precip. (inches	Mean Temp. F	Precip. (inches)	Mean Temp. F	Calc. PE (inches)	Recharge (inches)
January	2.83	28.2	2.95	26.4	0.10	9.85
February	2.59	29.3	3.45	28.3	0.01	10.44
March	3.40	36.7	3.84	36.0	0.34	10.50
April	3.47	48.3	2.85	47.4	1.56	8.28
May	4.07	59.6	4.22	58.6	3.34	7.88
June	4.04	67.8	4.45	66.6	4.60	6.85
July	3.79	71.9	3.49	71.8	5.51	4.98
August	3.55	70.0	3.37	69.4	4.76	5.61
September	2.88	63.1	2.50	61.6	3.18	6.32
October	2.89	52.5	2.29	50.9	1.73	7.57
November	2.73	40.9	4.05	40.6	0.59	10.47
December	2.66	30.2	2.77	31.4	0.13	9.64
Year	38.8	49.9	40.2	49.1	25.9	98.4

Total Monthly Precipitation in inches for State College, Pennsylvania from 1982 to 1989. Climatological summary for the period 1982 to 1989 compared with the 30 year record

98.4 inches temperate rain forest

10 inches average recharge rate for this area

(From Duffy, 1991)

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State Gamelands spray field showing wetlands mapped before the start of irrigation. Lines show the location of effluent mains and laterals.

Modified from Parizek, 1974).

State Gamelands spray field showing wetlands following eight years of irrigation.

(From Storm, Yahner, and Kristine, 1991).

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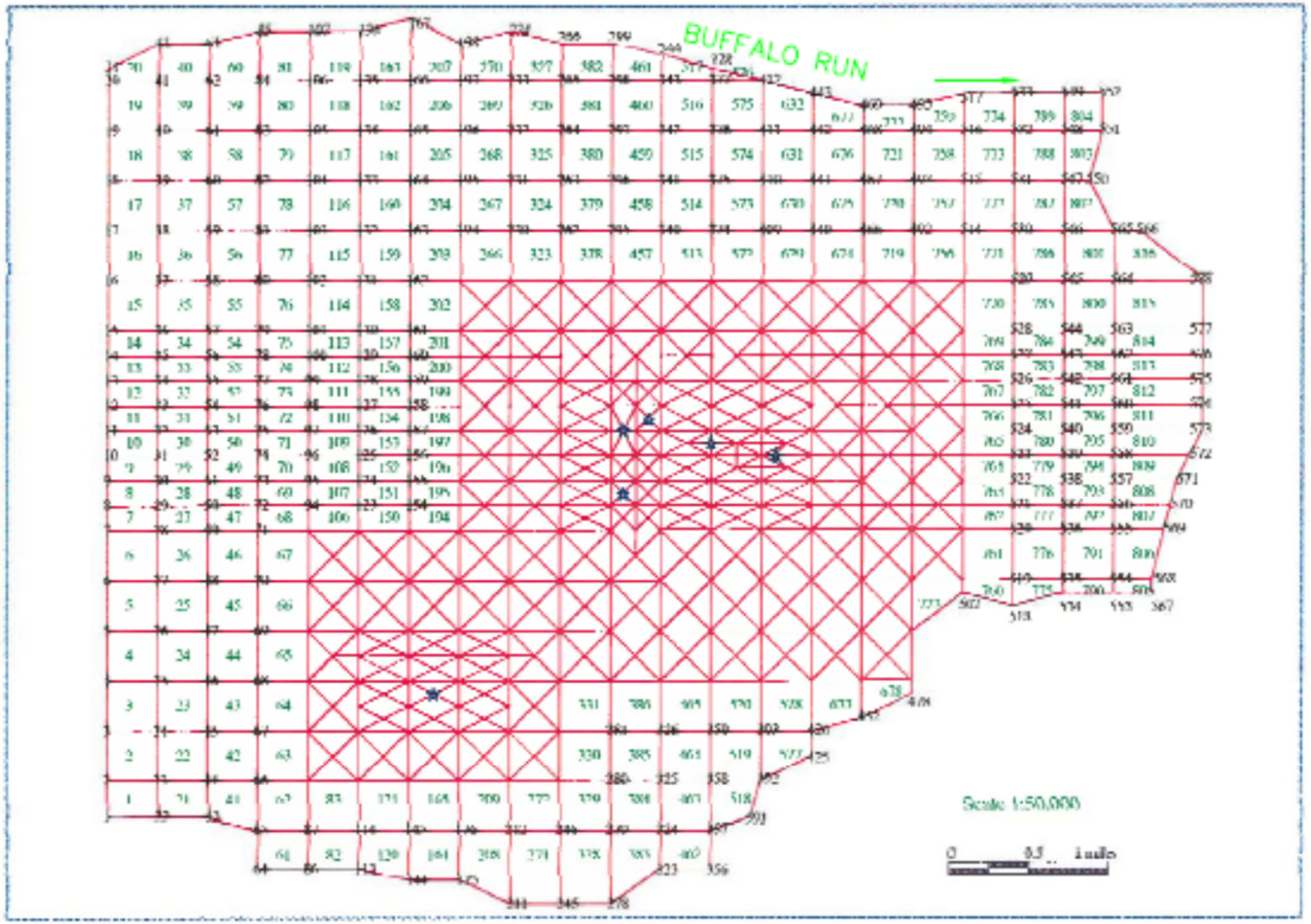

Grid design in the modeled area. Black color represents node number and green color represents element number.

(Parizek and Chin, 2003)

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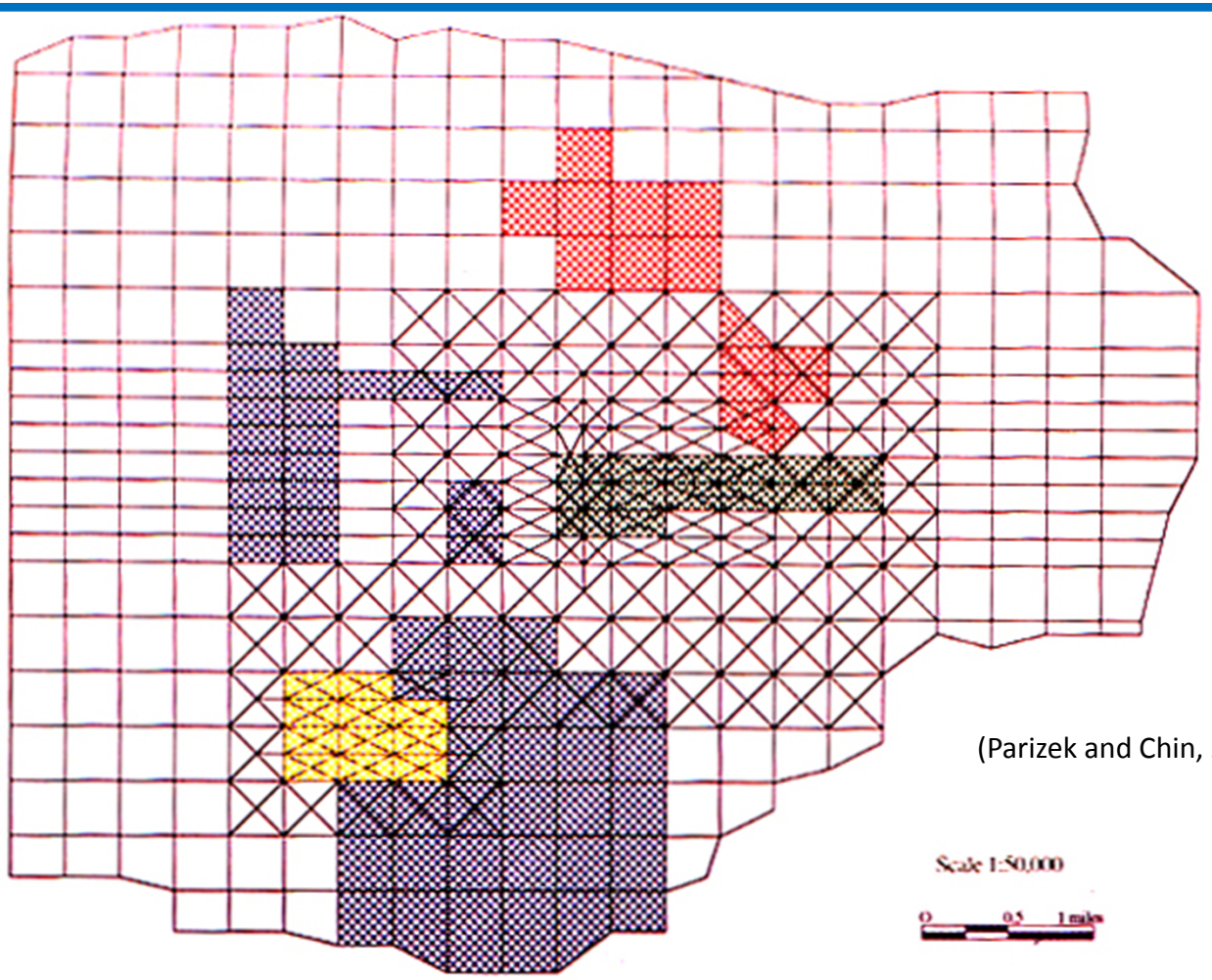
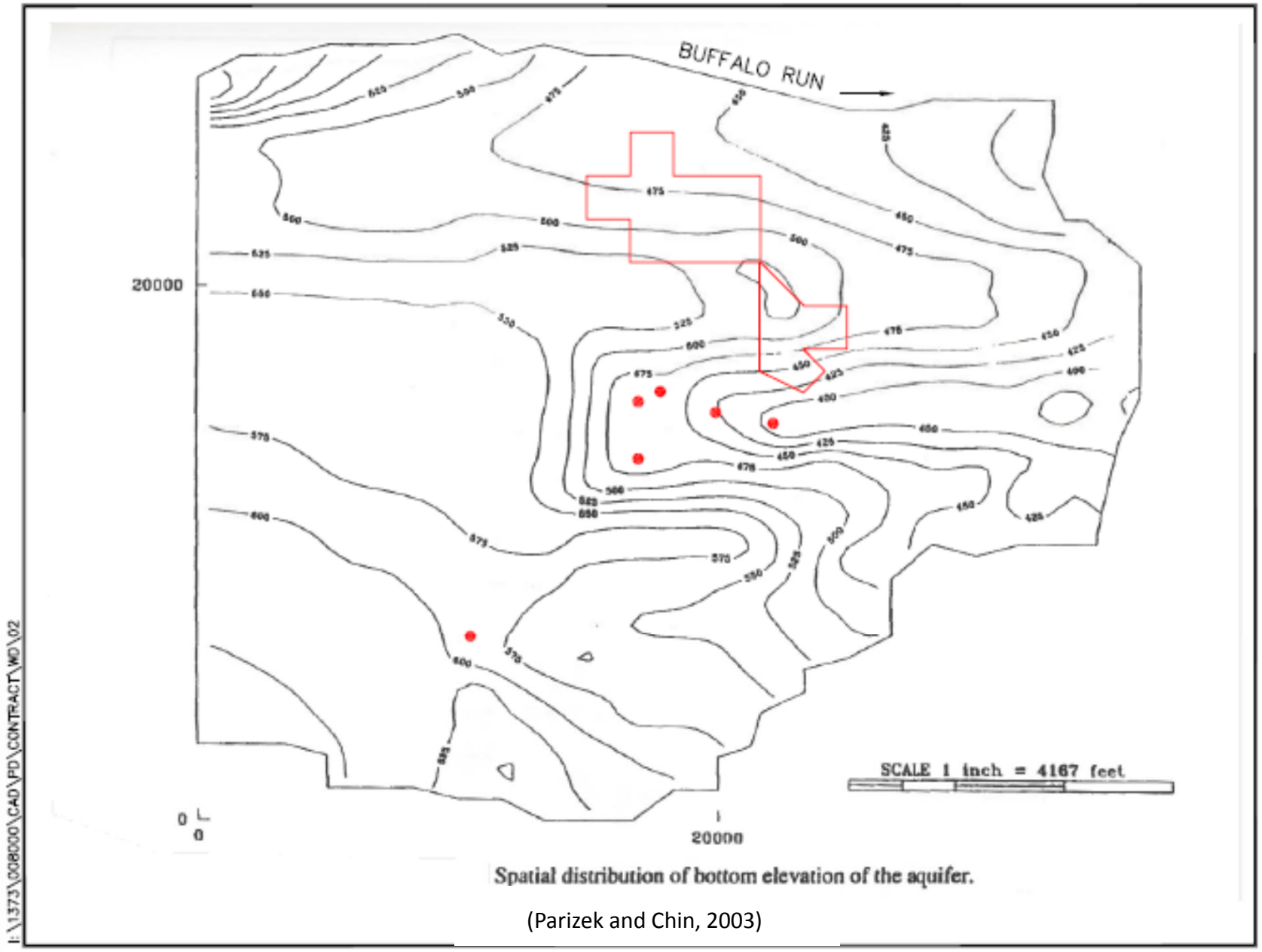


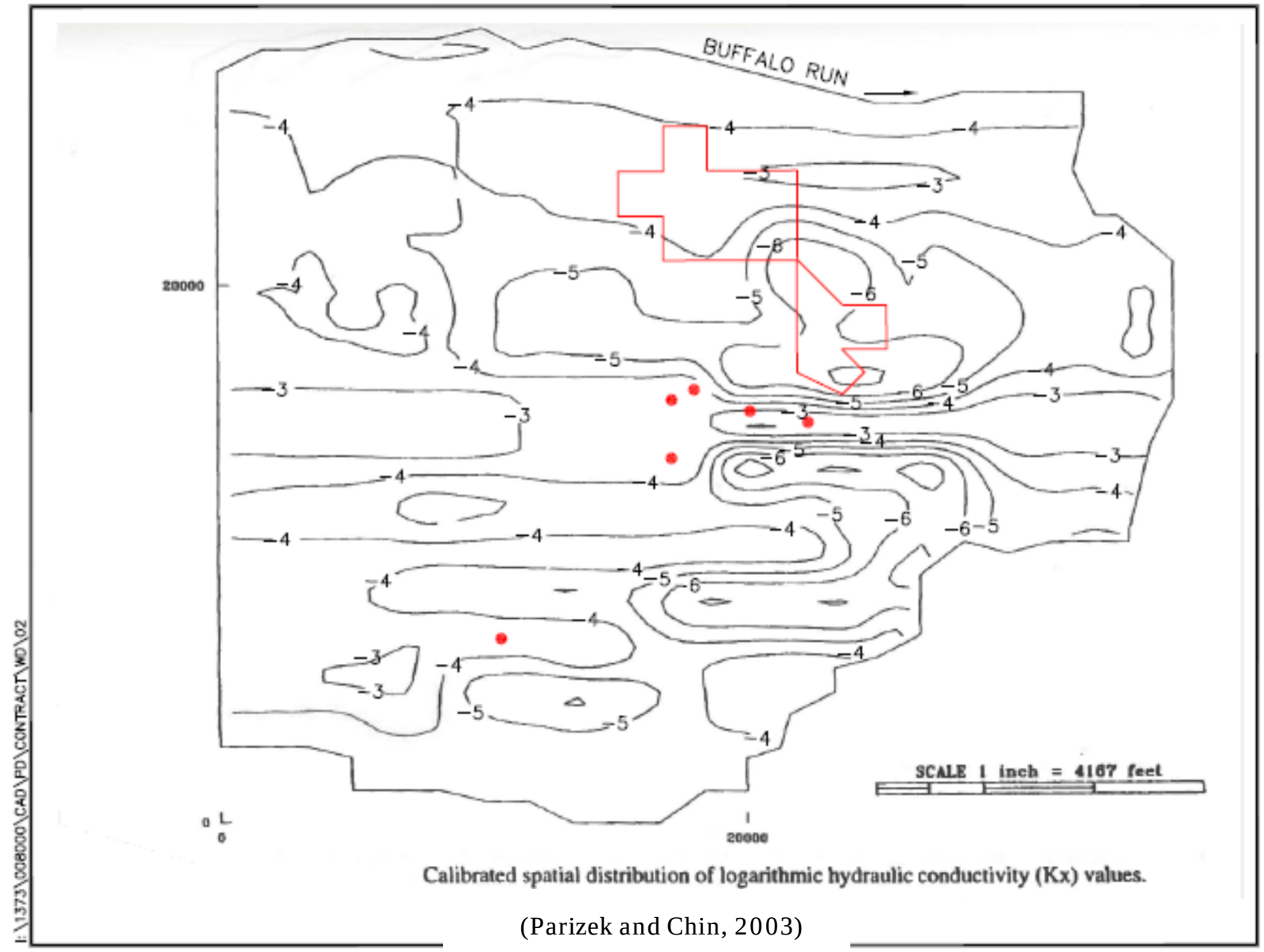
(Parizek and Chin, 2003)

Figure 4.12 Spatial distribution of recharge rate in the modeled area. Red color is spray field (78 in/yr), green color is Big Hollow (14.4 in/yr), blue color is residential area (8 in/yr), yellow color is PSU golf course (12 in/yr) and blank is 10 in/yr.



Spatial distribution of bottom elevation of the aquifer.

(Parizek and Chin, 2003)



Calibrated spatial distribution of logarithmic hydraulic conductivity (Kx) values.

(Parizek and Chin, 2003)

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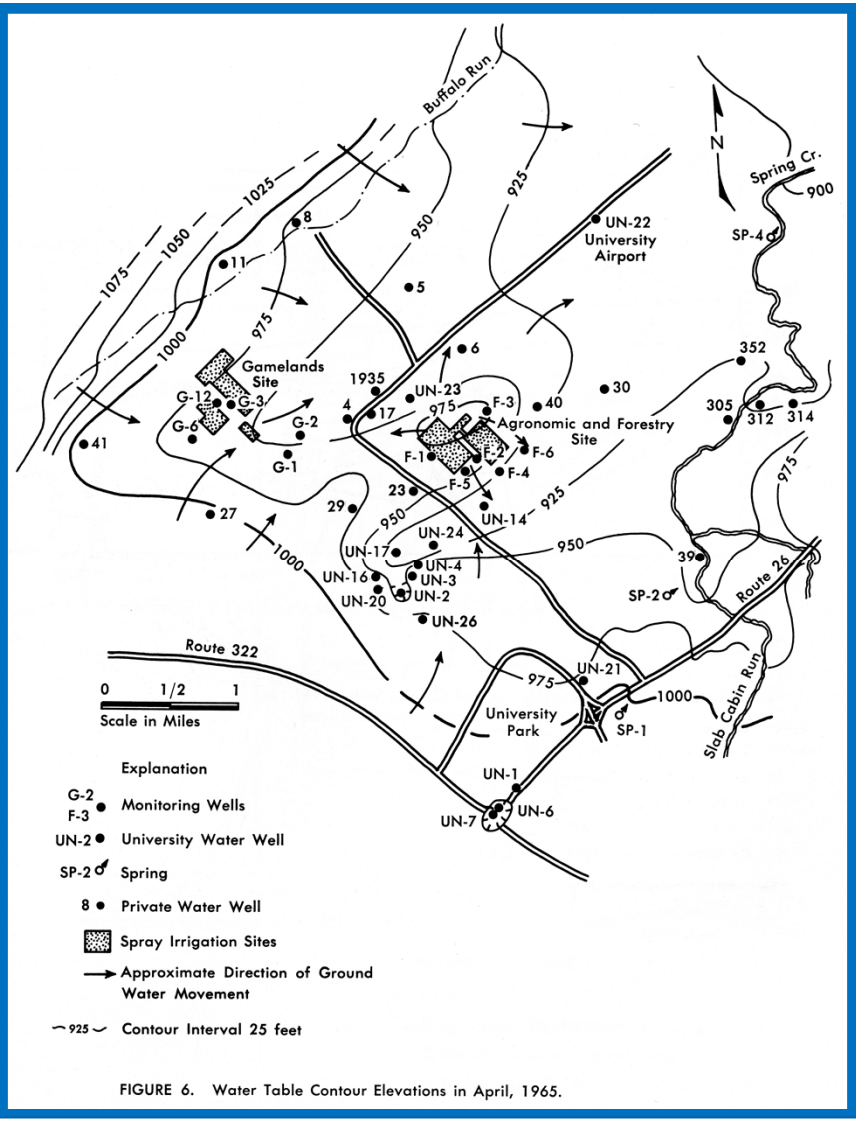
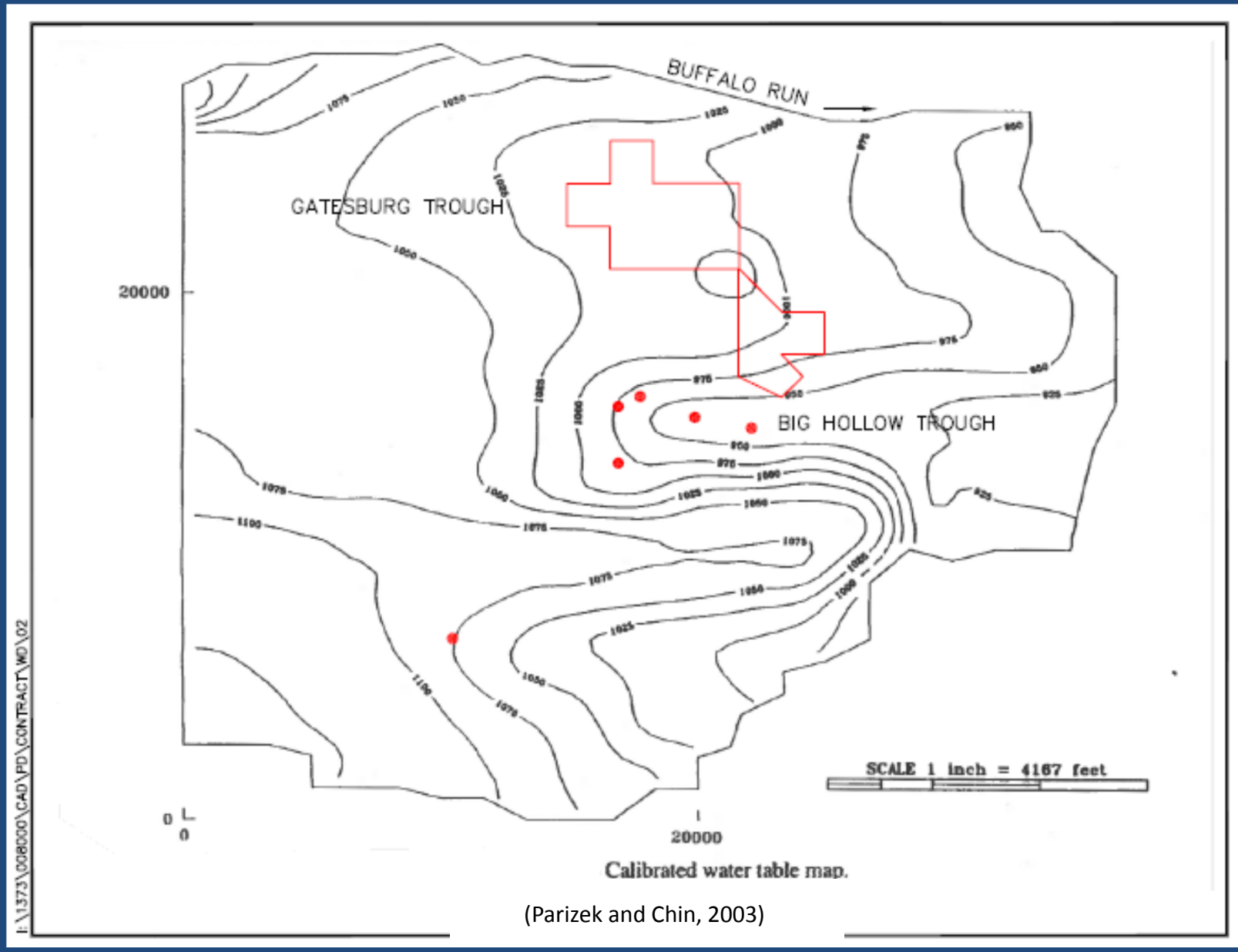
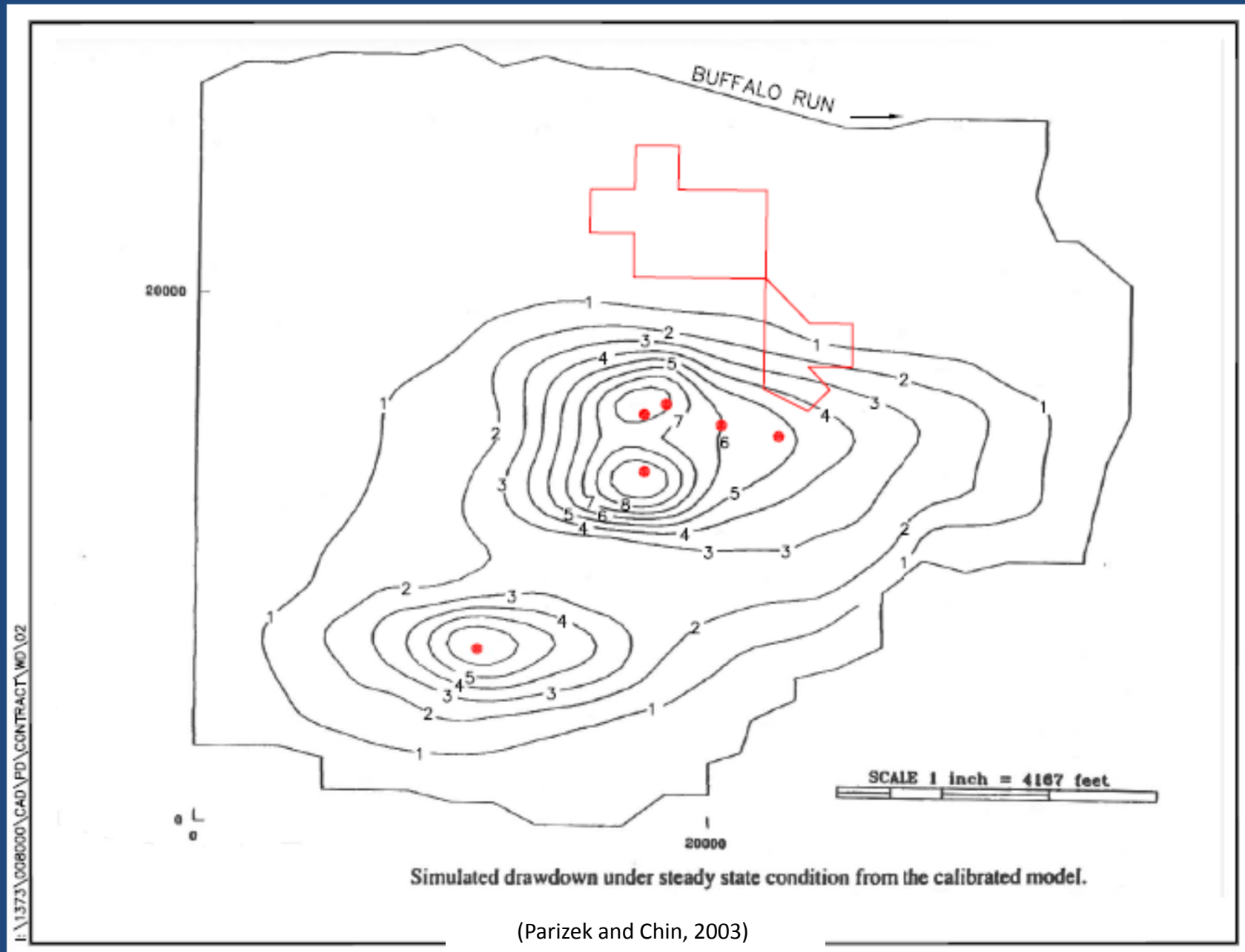


FIGURE 6. Water Table Contour Elevations in April, 1965.



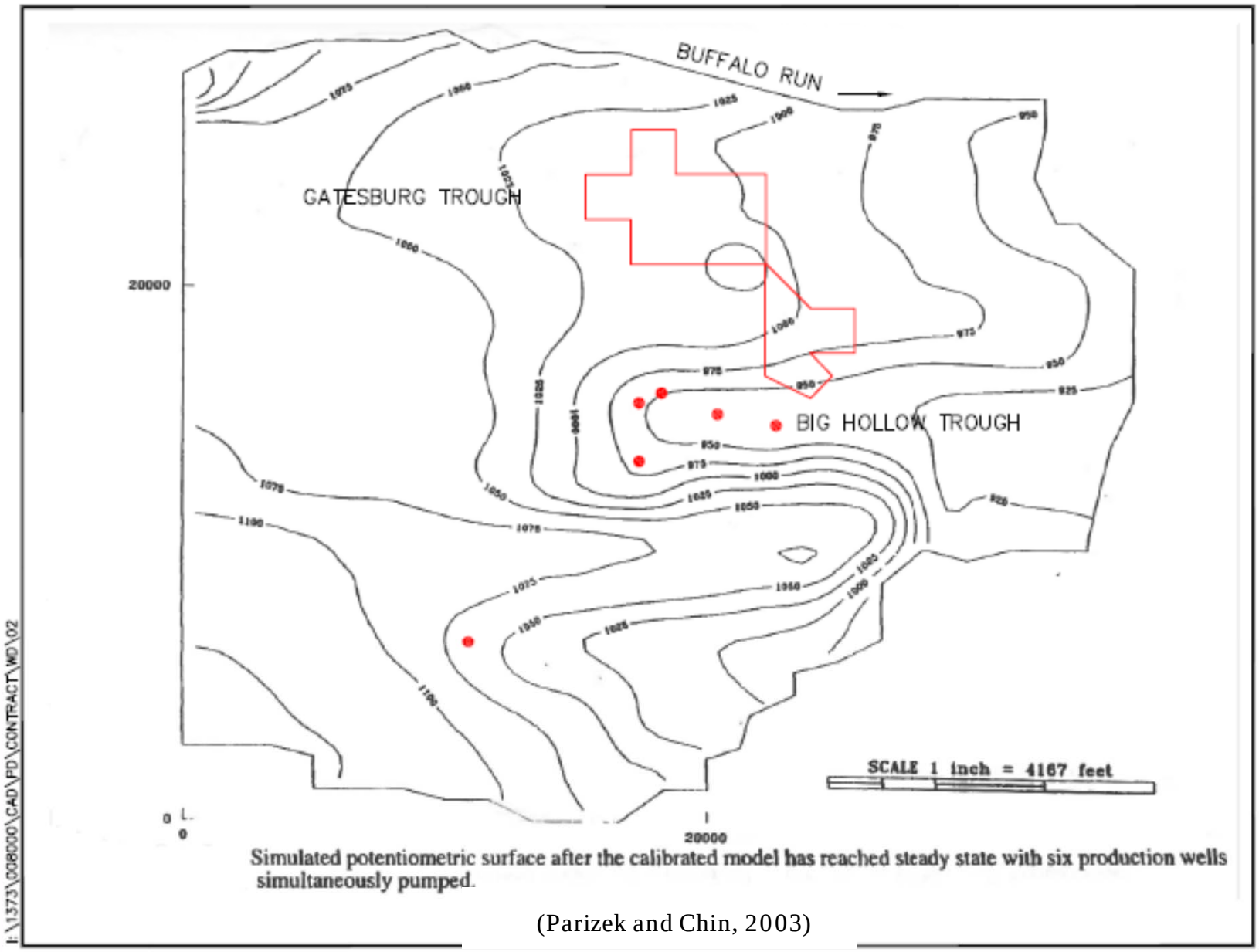
Calibrated water table map.

(Parizek and Chin, 2003)



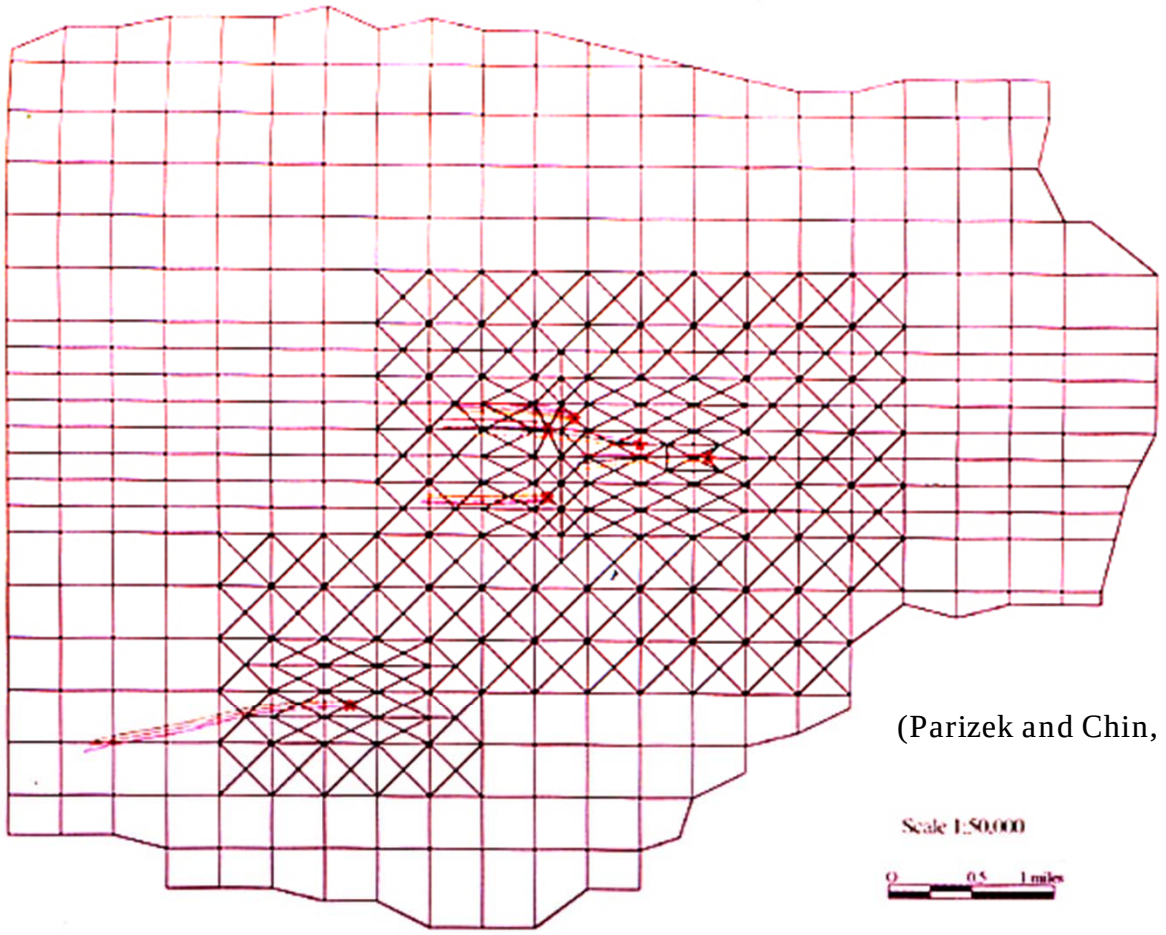
Simulated drawdown under steady state condition from the calibrated model.

(Parizek and Chin, 2003)



Simulated potentiometric surface after the calibrated model has reached steady state with six production wells simultaneously pumped.

(Parizek and Chin, 2003)



(Parizek and Chin, 2003)

Figure 4.20 Pathlines of particle tracking analysis –third case –in the modeled area. Red stars are pumping wells.

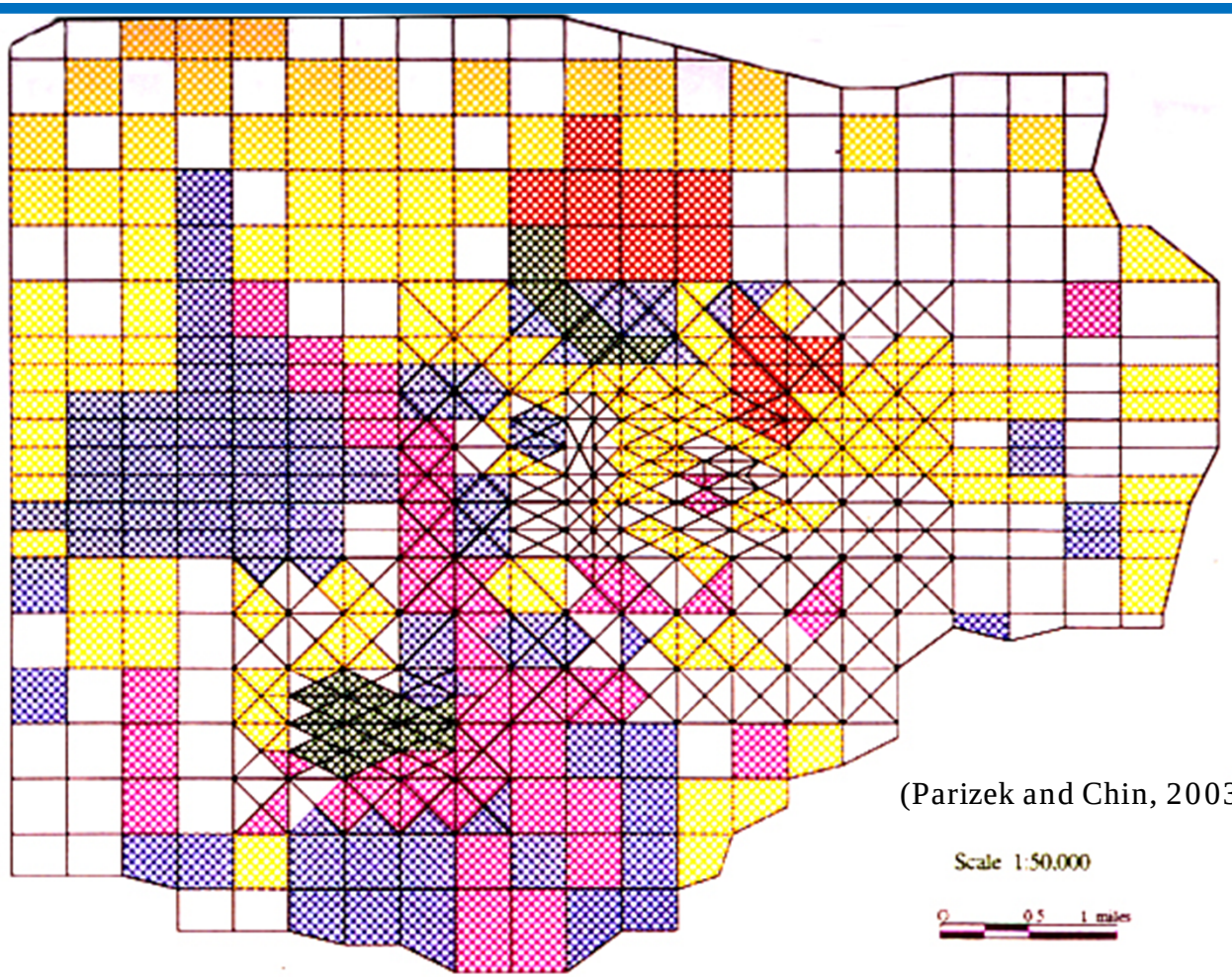


Figure 4.26 Spatial distribution of land use type in the modeled area. red color is spray field. green color is golf course , blue color is residential area. yellow color is forest . magenta color is commercial area and blank is agricultural area.

Summary of nitrate concentrations in different land uses and hydrogeologic settings

Agricultural Land	Lawn	Manure or Spray Field	Septic Tank	Forest	Undeveloped Land	Residential Land	Hydrogeologic Setting	Reference
3.25					1.05	3.35	Franklin Township, unconsolidated sediments consist of alternating layers of sand, silt, and clay of Cretaceous to Holocene age	Macleod et al.
7.2					2.9	5	Gloucester County, same as above	Macleod et al.
3.6				1.2		2	Unconsolidated to partly consolidated sediment of	McFarland (1973)
							Cretaceous, Tertiary, and Quaternary	
3.6				1.2		2.4	Same as above	McFarland (1985)
4.1				1.4		2.3	Same as above	McFarland (1990)
	17.89		33.9			1.5; 0.75	Yarmouth, Massachusetts	Nelson and Giggey
> 7					0.1		New Jersey Coastal Plain Aquifer Systems, unconsolidated sediments consisting of alternating layers of sand, silt, and clay of Cretaceous to Holocene age	Vowinkel
8.5; 9.8							Same as above	Vowinkel and Tapper
19; 16; 15							Hagerstown silt loam in central Pennsylvania	Toth
18.8		19.3					Same as above	Jemison and Fox
23; 10; 10							Same as above	Shuford
		9 to 43					Duffied silt loam developed in limestone residuum	Simmon
17.5 to 31.4							Peters Creek Schist and Wissahickon Formation in the Piedmont physiographic province	Doscher
7.3						6.3	Regolith-mantled carbonate-rock aquifer system	Hippe et al.
6					1	4	Karst carbonate in the central Pennsylvania	Kastrinos et al.
7.4				1.2			Fractured, folded interbedded of sequence of siltstone, shale, and sandstone	Pionke and Urban

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(Chin, 1996)

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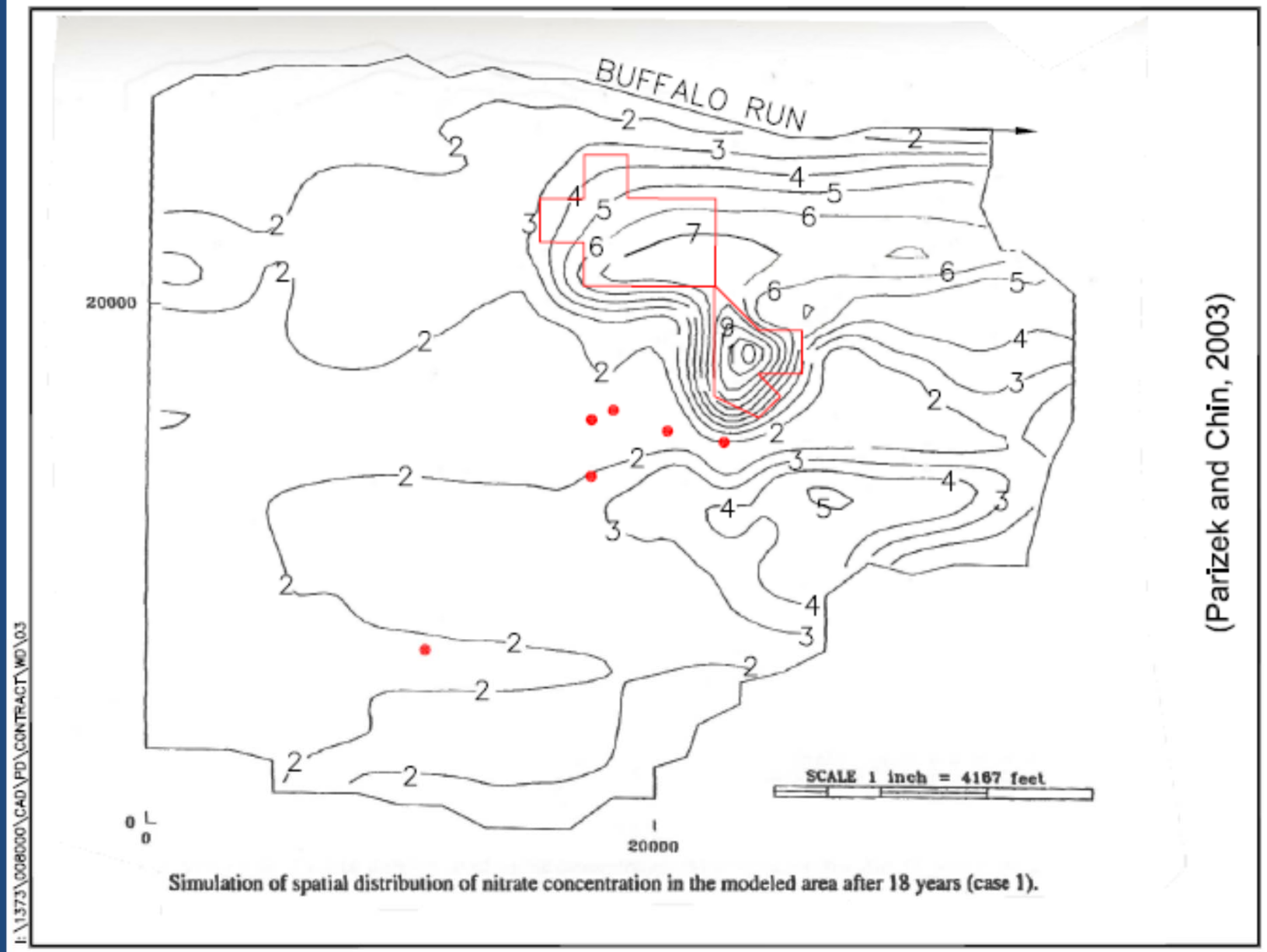
Table 4.11 Nitrate concentration loading data used in the transport model.

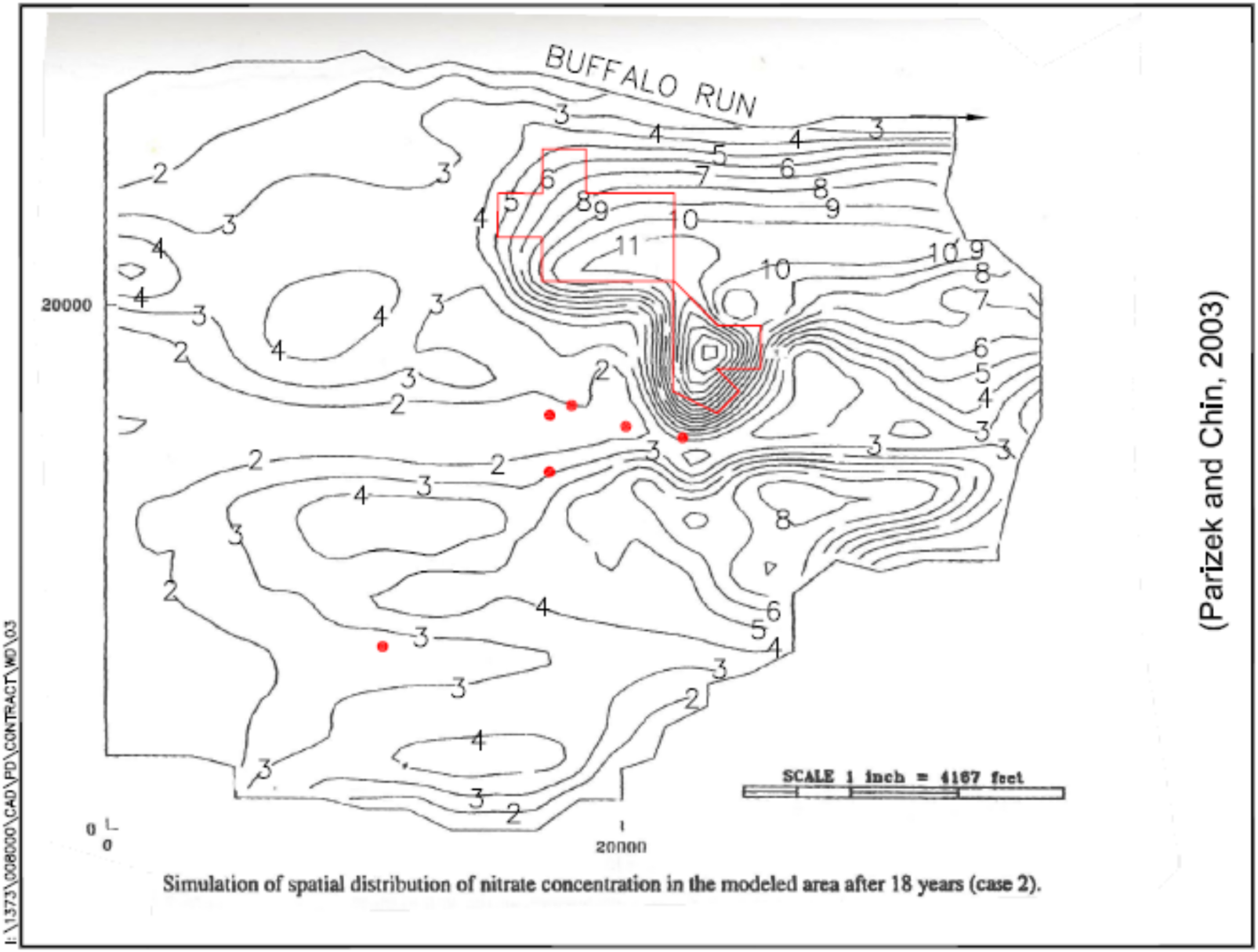
	Total Acreage	Case 1 (mg/l)	Case 2 (mg/l)	Case 3 (mg/l)	Case 4 (mg/l)
Sewage Effluent of Spray Fields	733	10	15	5	12.5
Agricultural	7270	6	10	6	8
Forest	5516	1.2	1.2	1.2	1.2
Residential	3428	3	6	3	4.5
Golf Course	407	4	5	4	4.5
Commerical	2088	2	4	2	3

Note: in the LEMA transport code, the nitrate loading term was input using concentration, i.e., M/L^3)



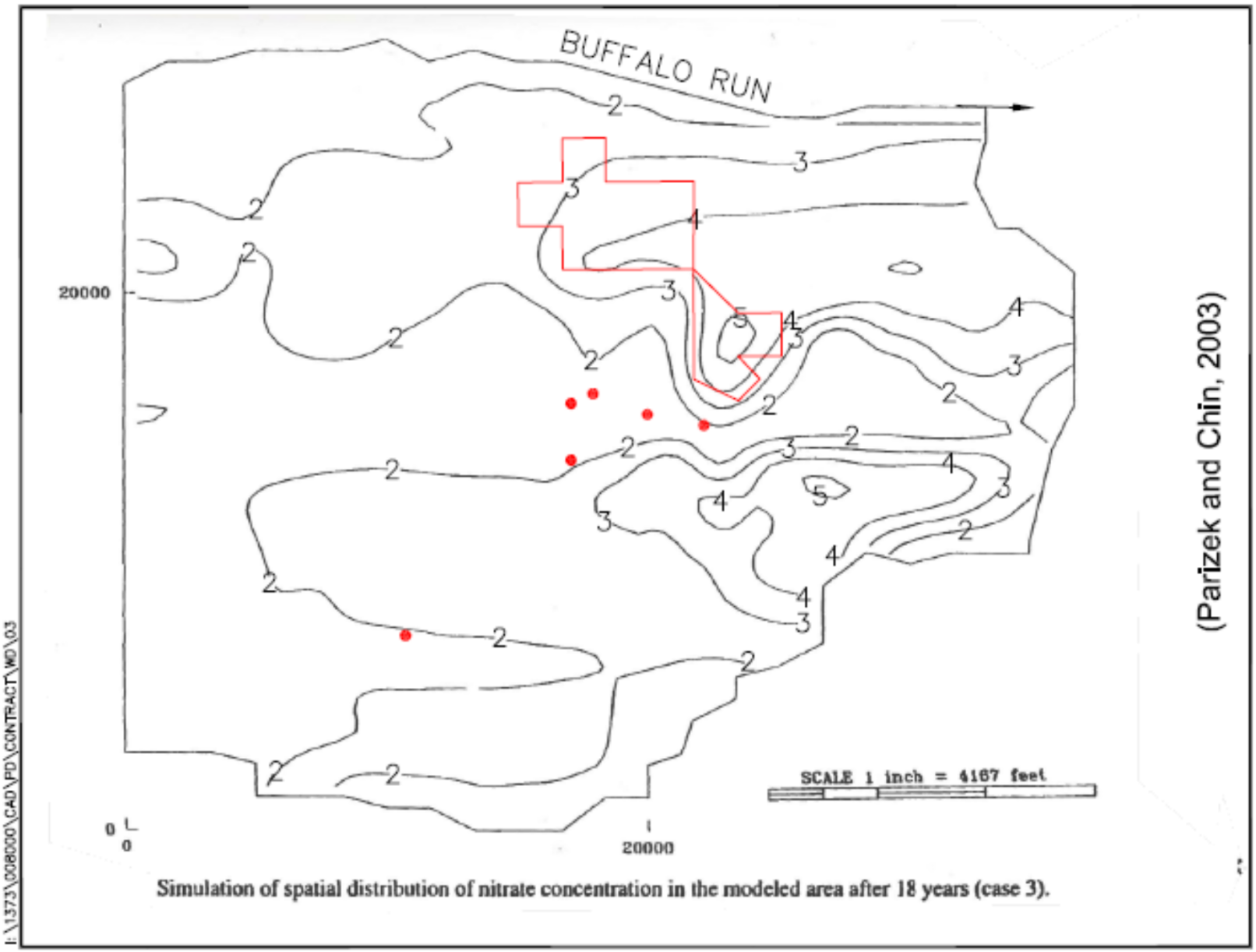
Simulation of spatial distribution of nitrate concentration in the modeled area after 18 years (case 1).

(Parizek and Chin, 2003)



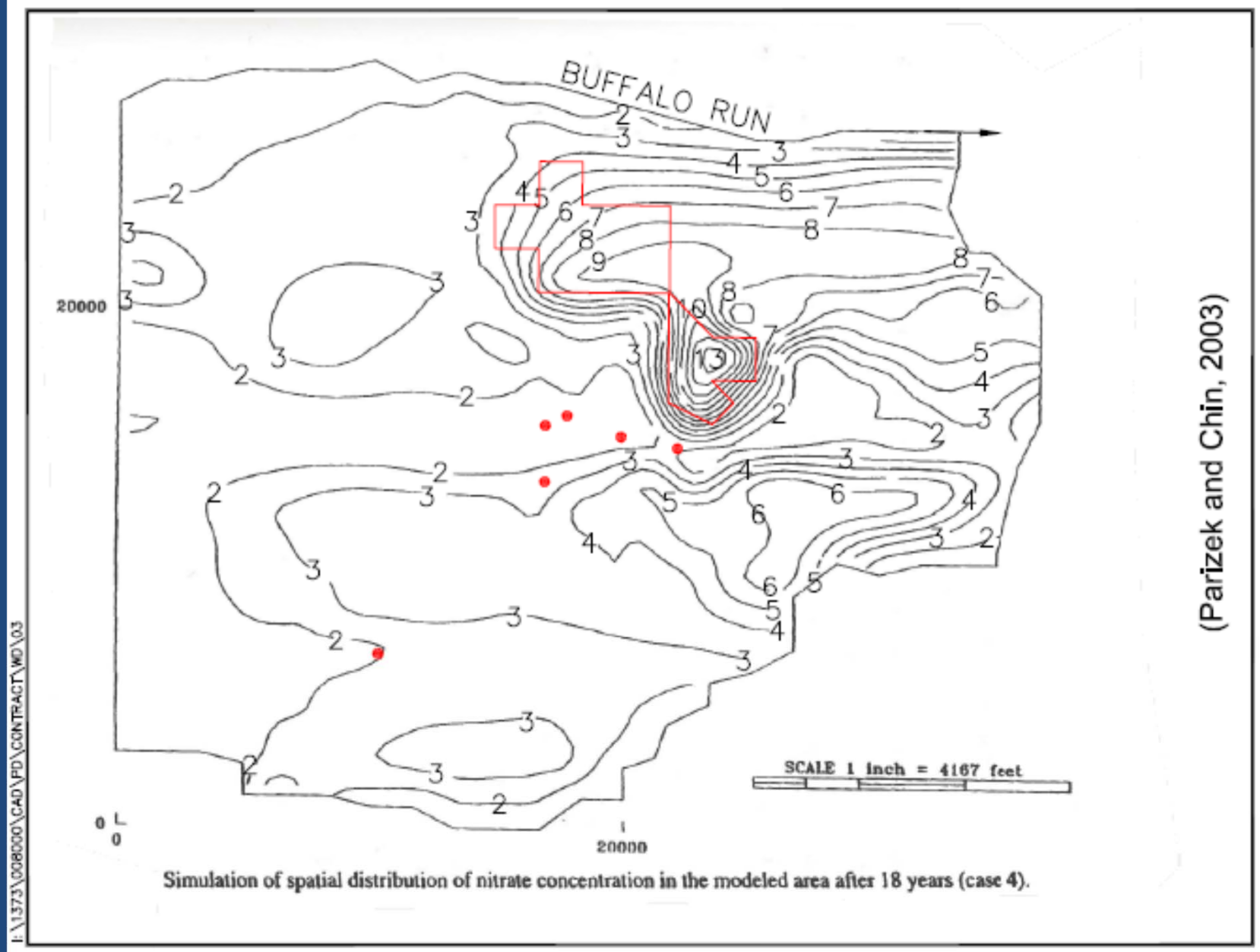
Simulation of spatial distribution of nitrate concentration in the modeled area after 18 years (case 2).

(Parizek and Chin, 2003)



Simulation of spatial distribution of nitrate concentration in the modeled area after 18 years (case 3).

(Parizek and Chin, 2003)



Simulation of spatial distribution of nitrate concentration in the modeled area after 18 years (case 4).

(Parizek and Chin, 2003)

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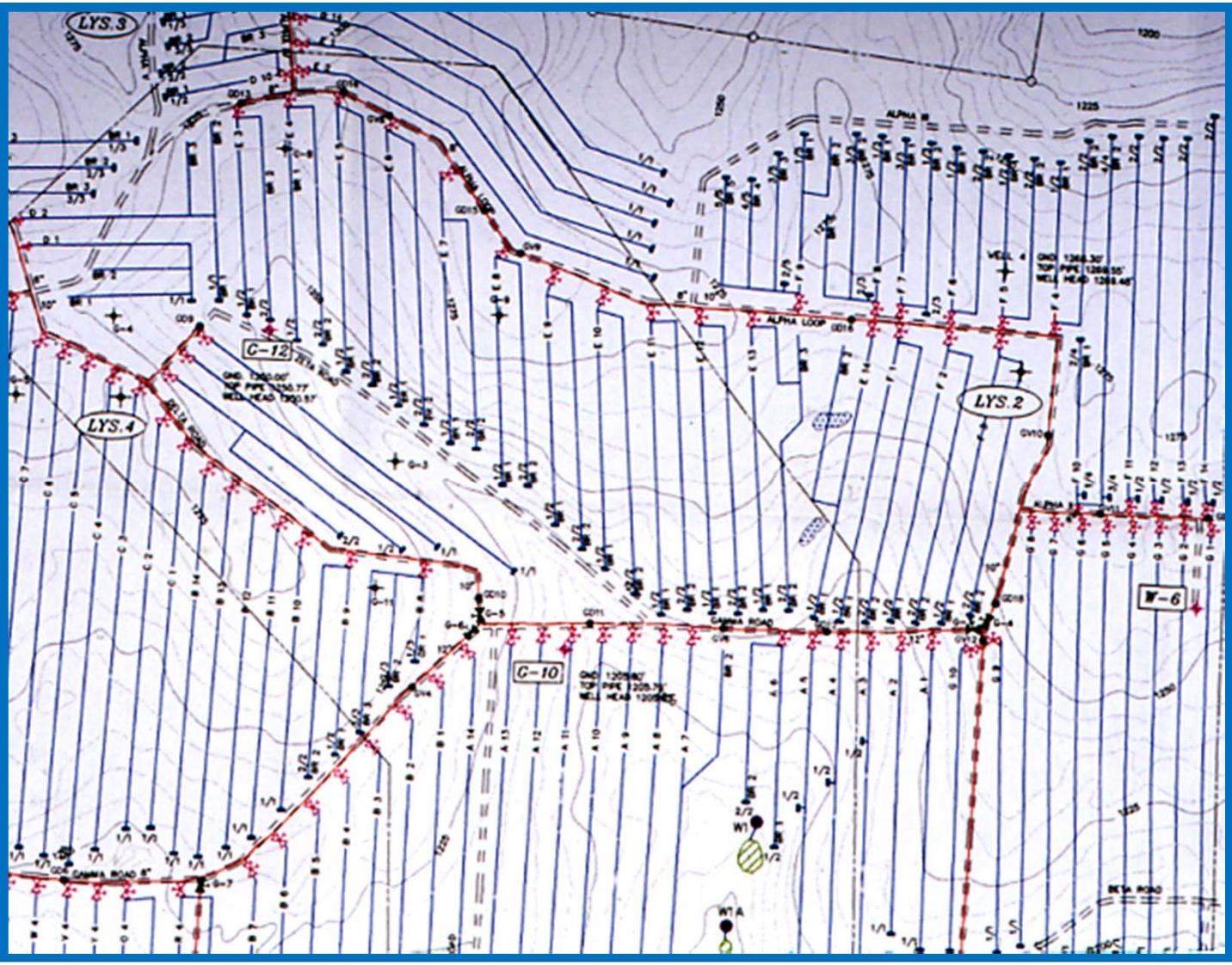
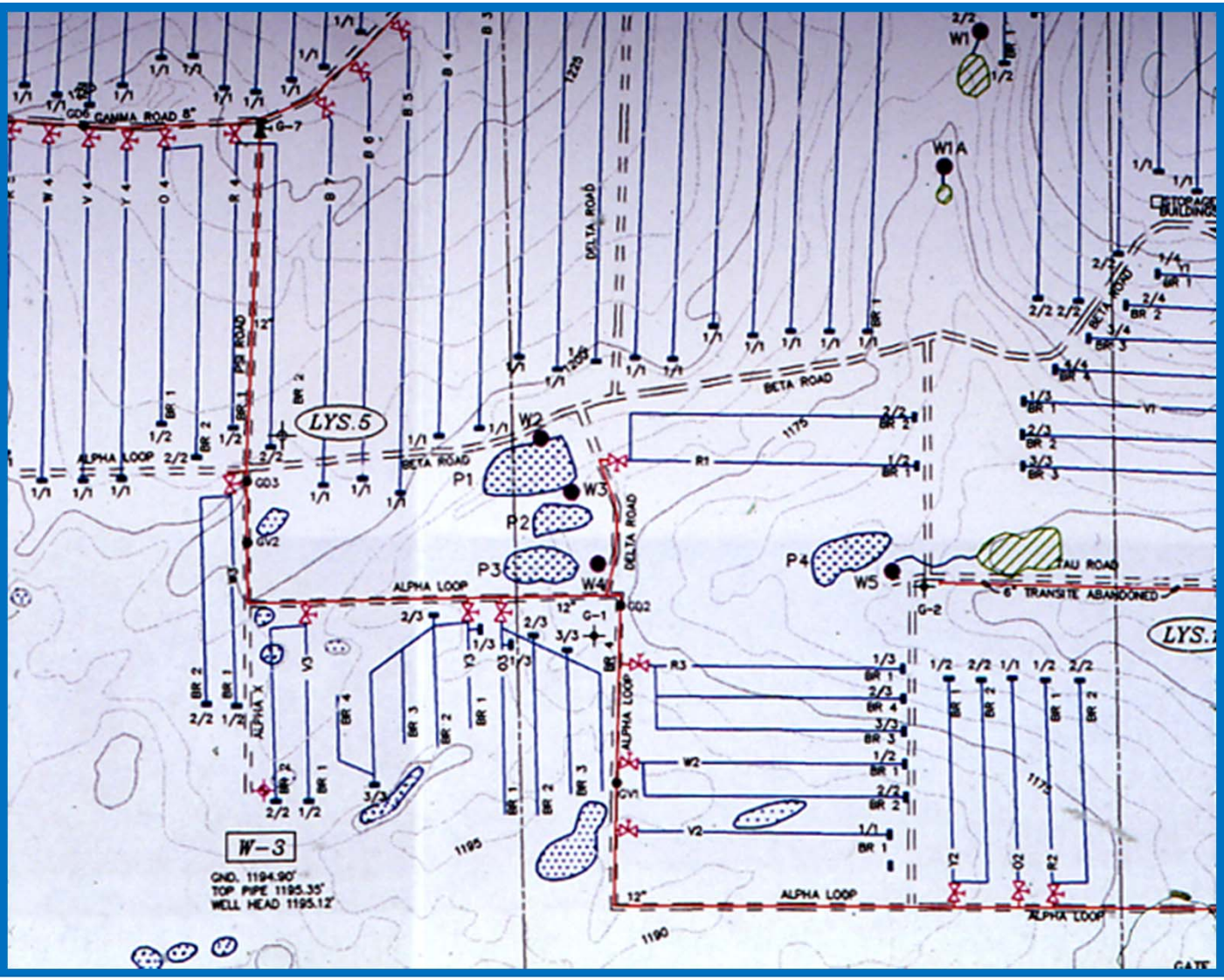

LYS.3
LYS.4
LYS.2
C-12
C-10
W-6
ALPHA LOOP
GAMMA ROAD
BETA ROAD
1200
1225
1250
1275

PENNSTATE



GAMMA ROAD 8"
G-7
LYS.5
ALPHA LOOP
BETA ROAD
DELTA ROAD
PSI ROAD
W1
W1A
W2
W3
W4
W5
P1
P2
P3
P4
TAU ROAD
6" TRANSITE ABANDONED
G-1
G-2
W-3
GND. 1194.90'
TOP PIPE 1195.35'
WELL HEAD 1195.12'

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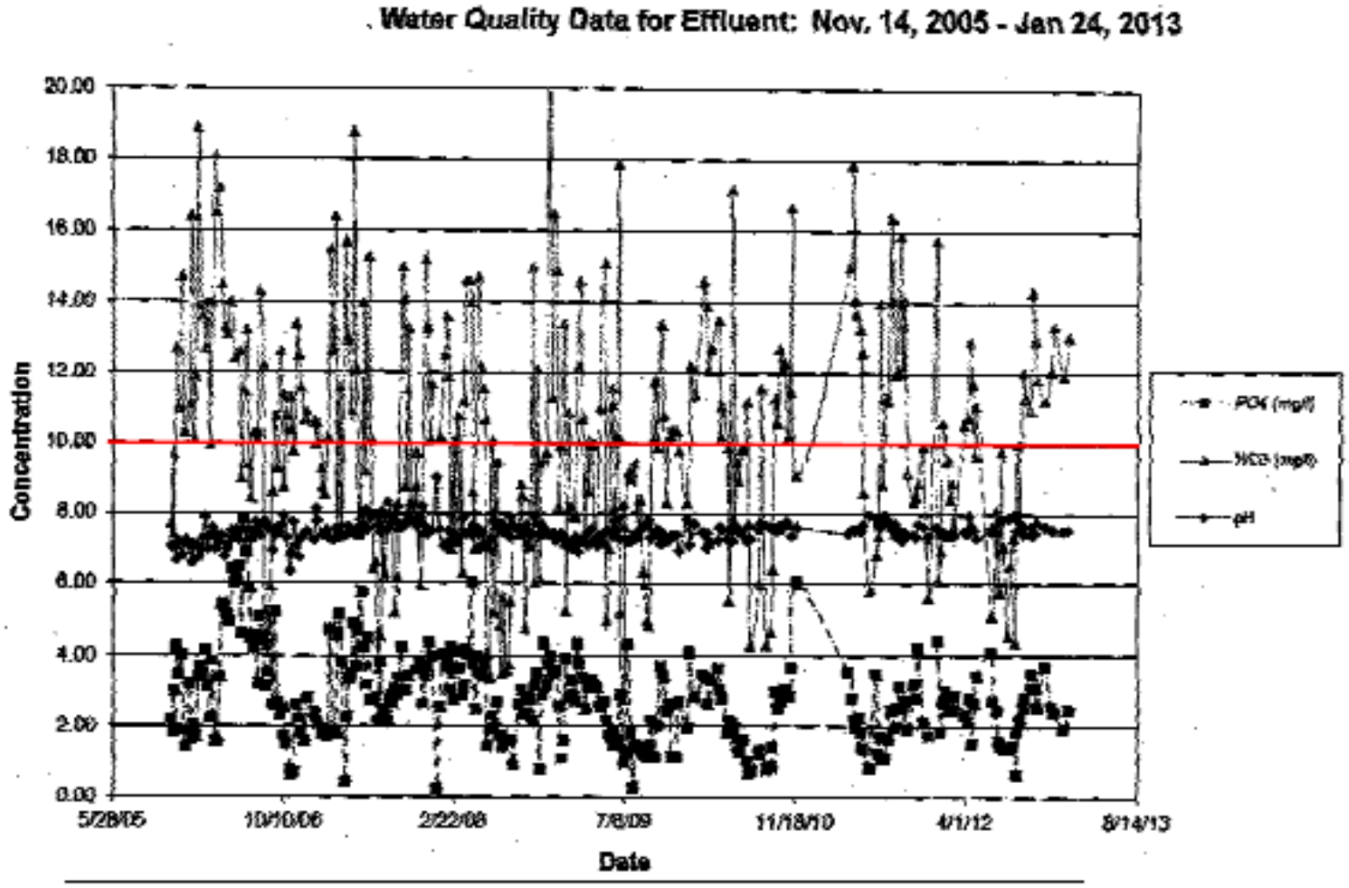

(Parizek and McCoy, 2013)

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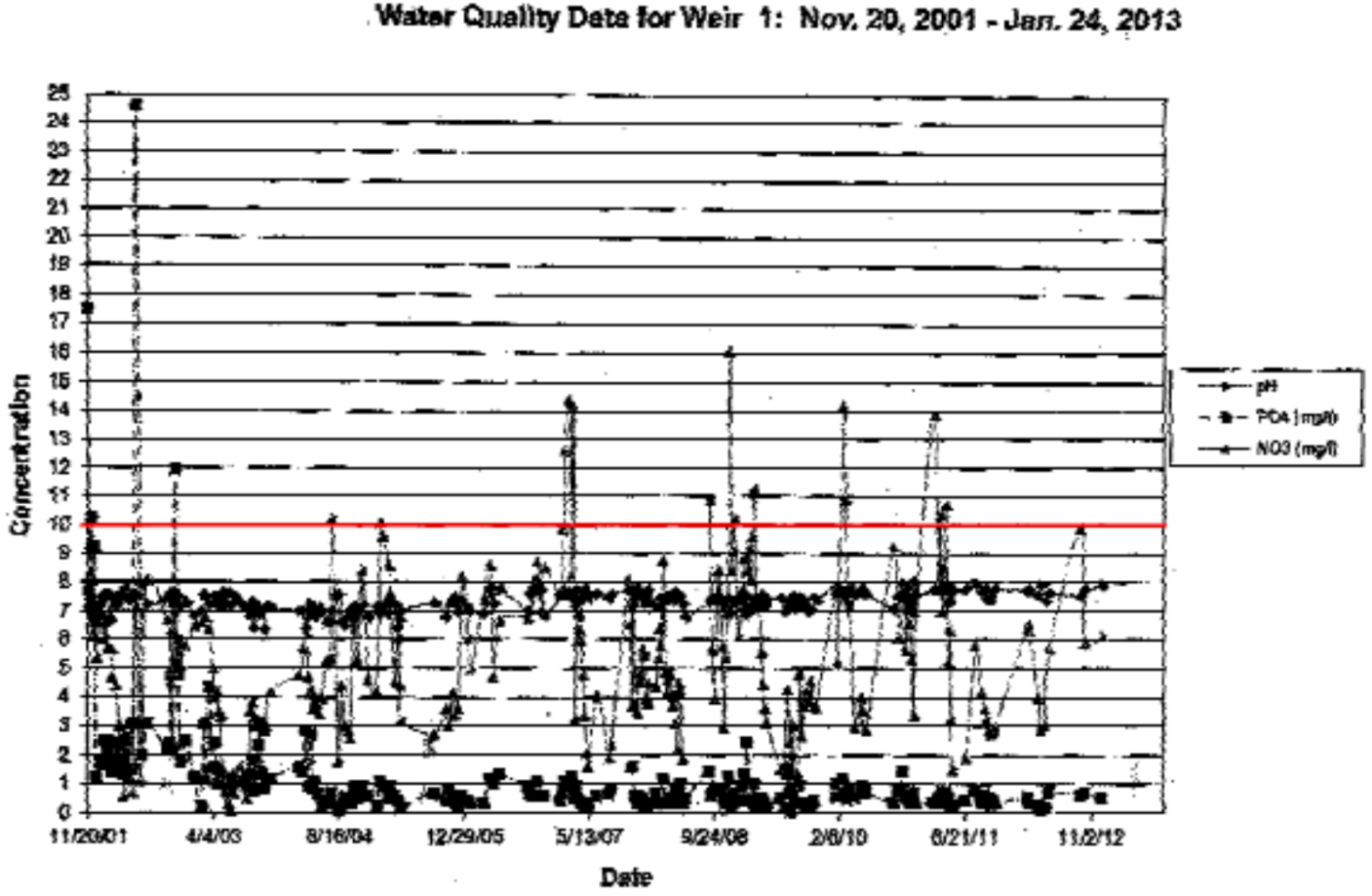

(Parizek and McCoy, 2013)

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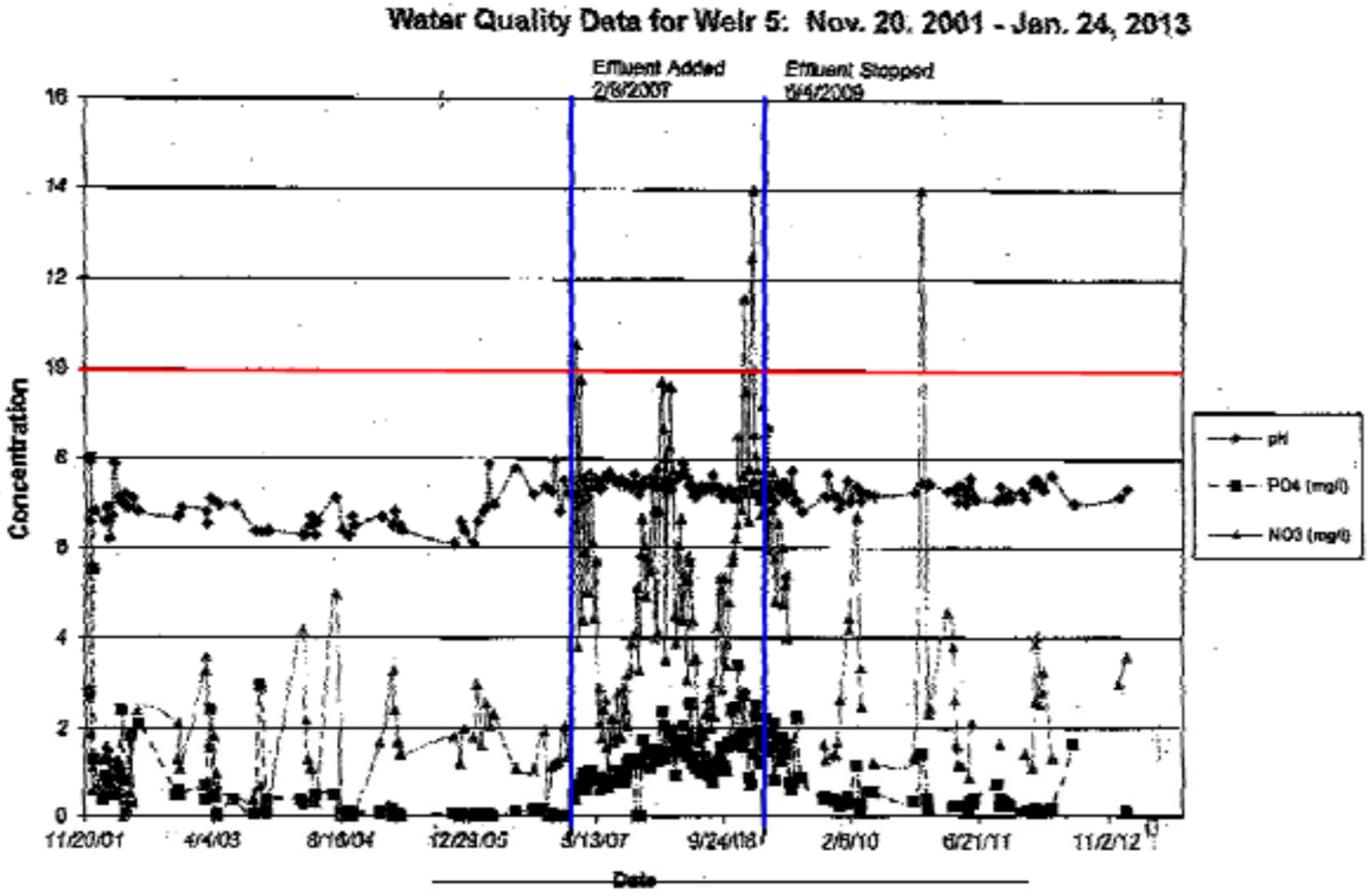

(Parizek and McCoy, 2013)

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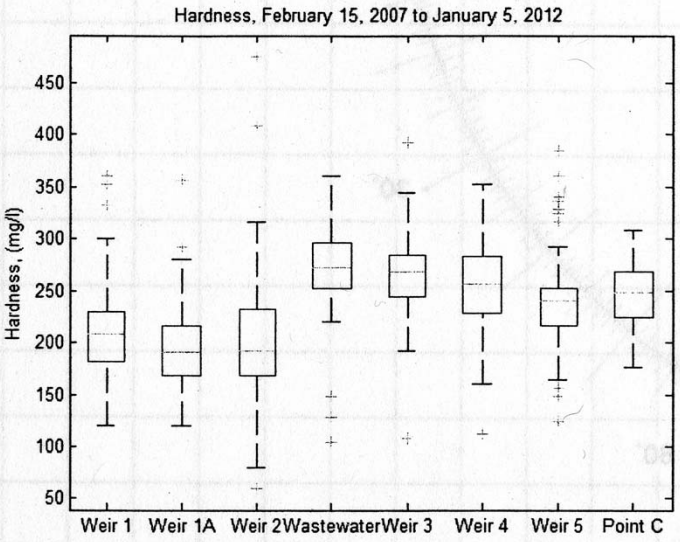


Figure 12c. Box plot of hardness for secondary effluent and water collected at Weirs 1, 1A, and 2 (Feb. 2007-January 2012), 3, 4, and 5 (February 2007 – May 2009) and Point C (December 2007- May 2009).

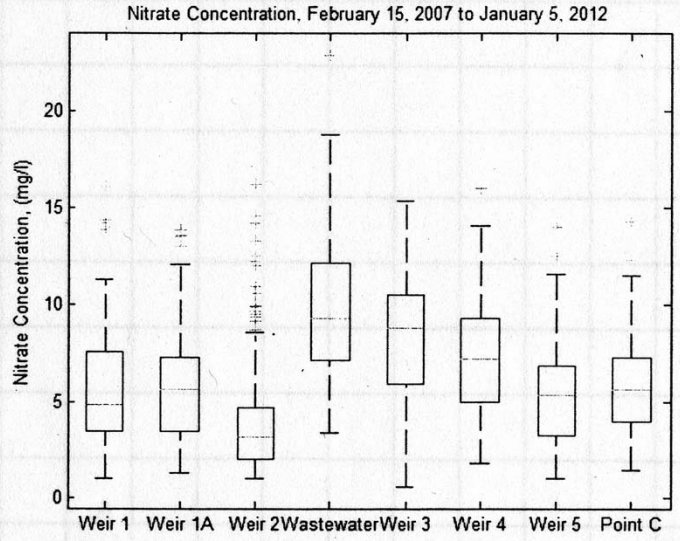


Figure 12d. Box plot of nitrate concentrations for secondary effluent and water collected at Weirs 1, 1A, and 2 (Feb. 2007-January 2012), 3, 4, and 5 (February 2007 – May 2009) and Point C (December 2007- May 2009).

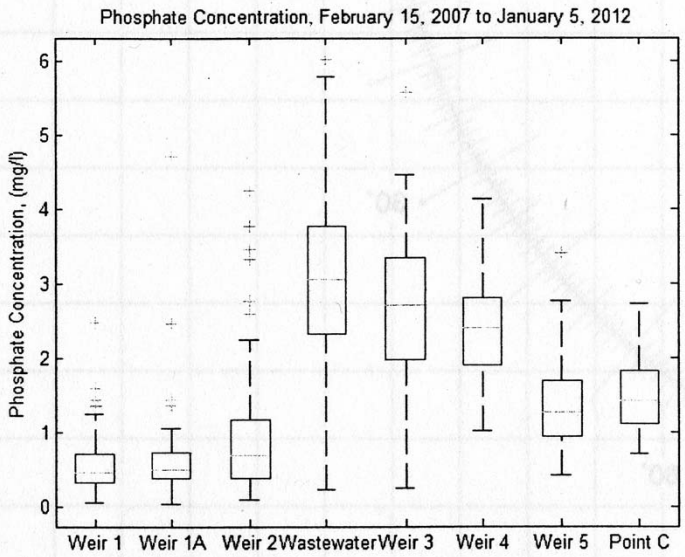


Figure 12e. Box plot of phosphate concentrations for secondary effluent and water collected at Weirs 1, 1A, and 2 (Feb. 2007-January 2012), 3, 4, and 5 (February 2007 – May 2009) and Point C (December 2007- May 2009).

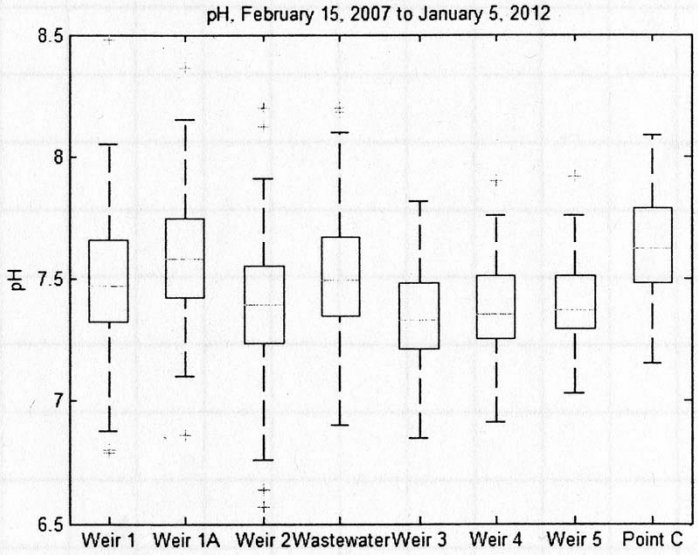
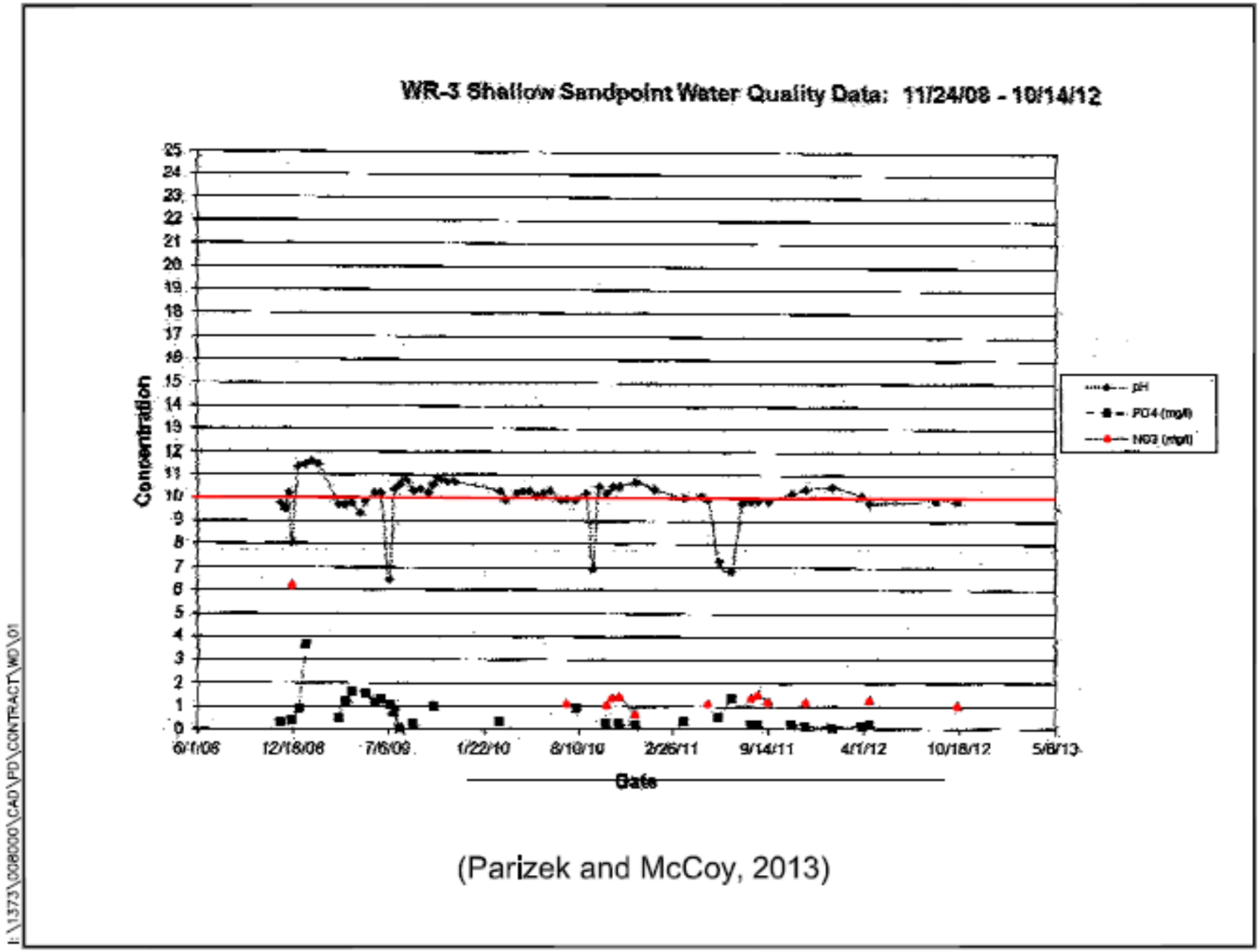


Figure 12f. Box plot of pH for secondary effluent and water collected at Weirs 1, 1A, and 2 (Feb. 2007-January 2012), 3, 4, and 5 (February 2007 – May 2009) and Point C (December 2007- May 2009).



(Parizek and McCoy, 2013)

Figure 7
Shallow Monitoring Wells
Gamelands Site

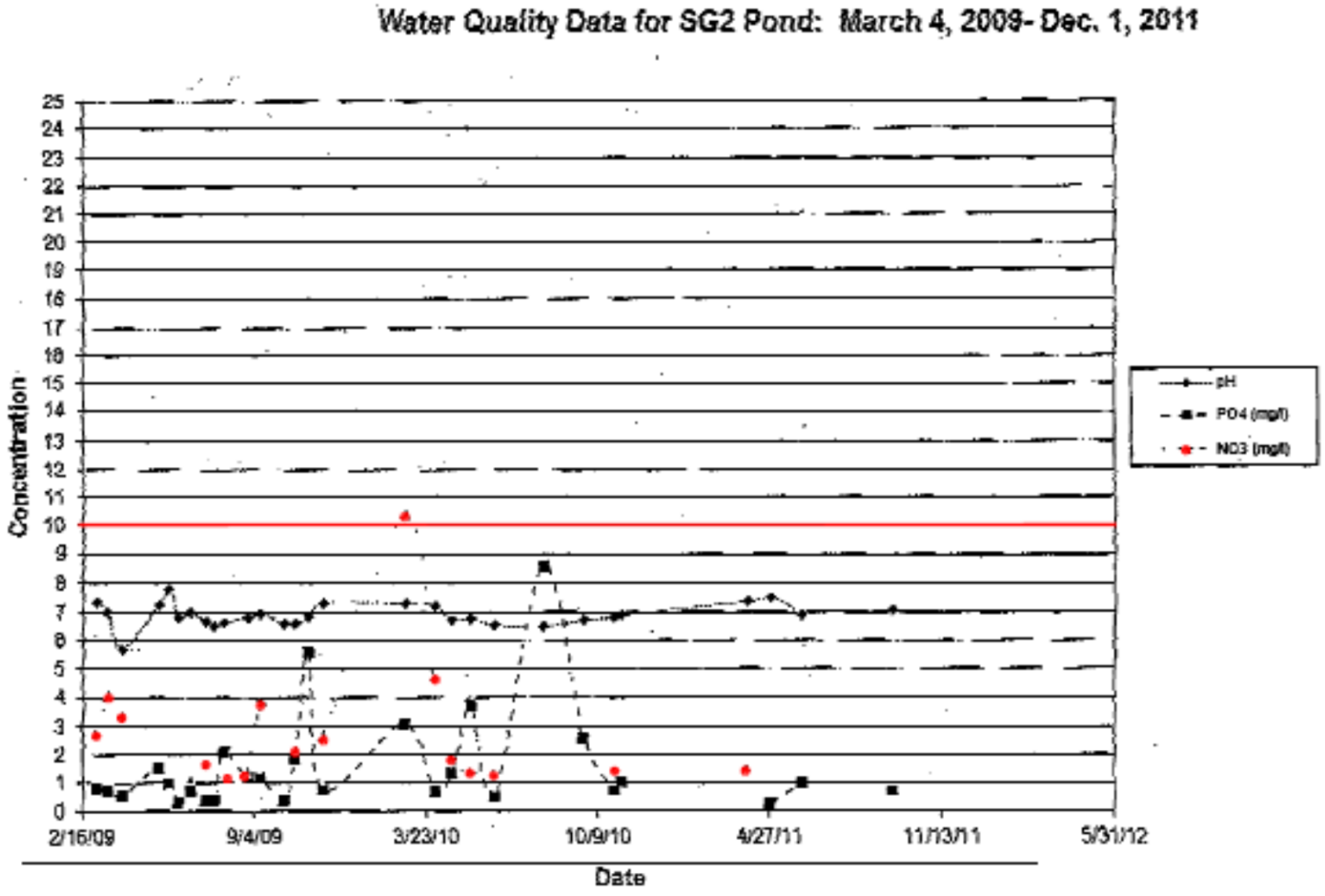
(SG-XX Monitoring Wells
Ponds and Swamps
) Drains
(Valve Boxes
Sprayheads
Lateral Pipes

0 50 100 200
Feet

Figure 9
Shallow Monitoring Wells
Gamelands Site

(SG-XX Monitoring Wells
Ponds and Swamps
) Drains
(Valve Boxes
Sprayheads
Lateral Pipes

0 50 100 200
Feet



(Parizek and McCoy, 2013)

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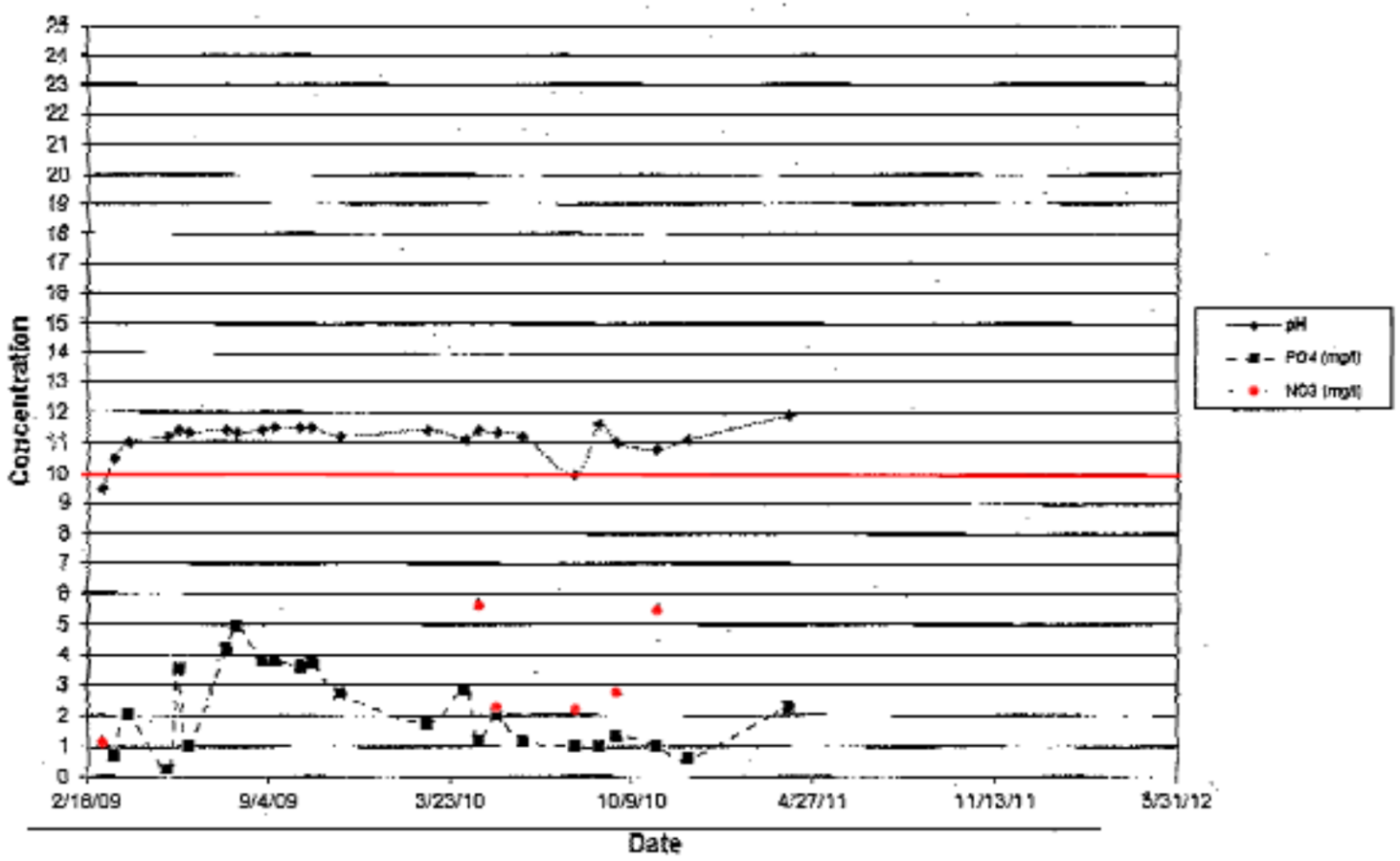

(Parizek and McCoy, 2013)

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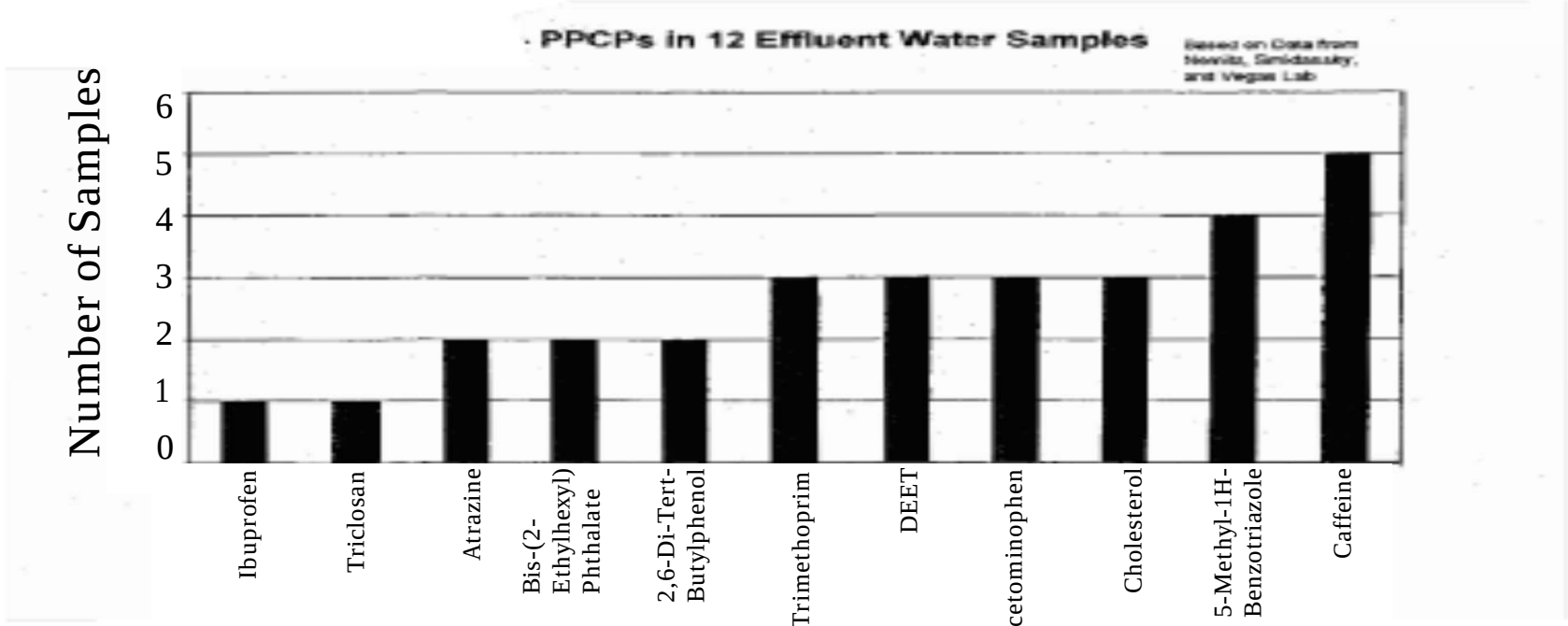
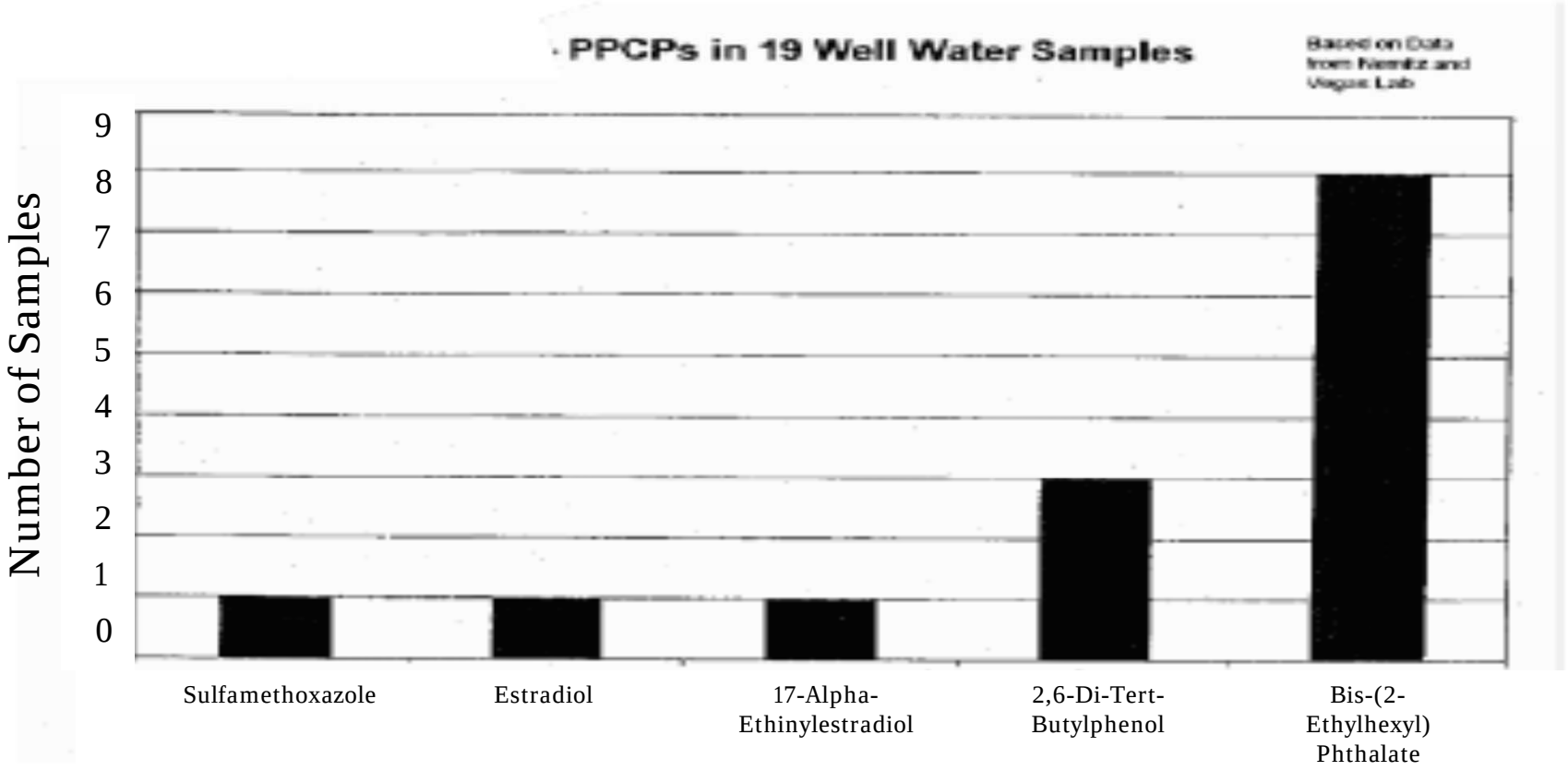
PPCP	Concentration
Triclosan	0.02 µg/L
Cholesterol	0.01-0.02 µg/L
Caffeine	<0.1-0.13 µg/L
Bis (2-ethylhexyl) Phthalate	<0.1-0.29 µg/L
Trimethoprim	0.11-0.13 µg/L
DEET	0.1-0.46 µg/L
Atrazine	0.02-0.1 µg/L
2,6 Di-Tert-Butylphenol	<0.1 µg/L
Acetaminophen	<0.1 µg/L
Ibuprofen	<0.1 µg/L
Others	<0.1 µg/L

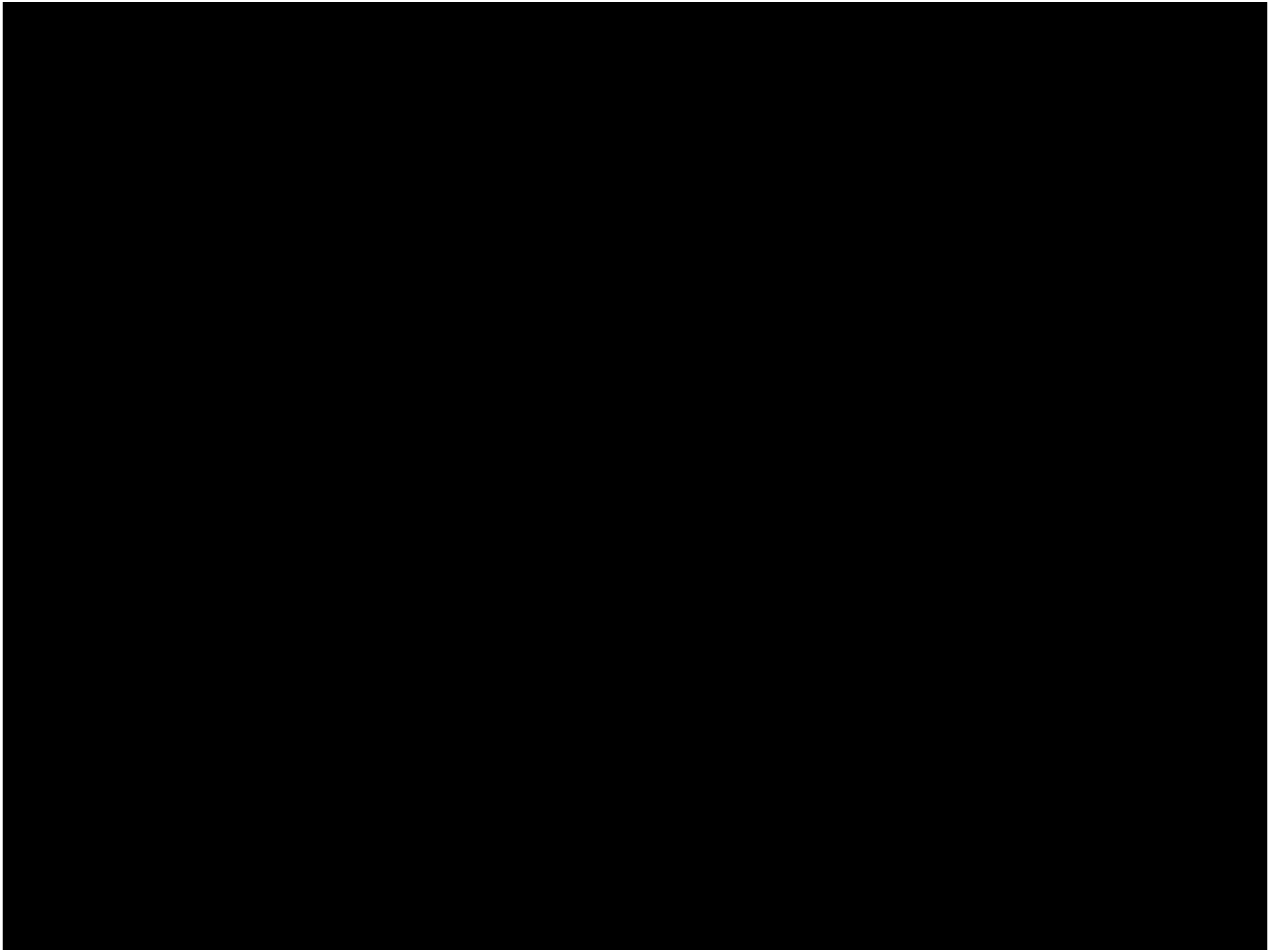
(Smldansky, 2004; Nemltz and Parlzek, 2005)



(Smldansky, 2004; Nemltz and Parlzek, 2004-08; Las Vegas Lab)



(Nemitz and Parizek, 2004–08)



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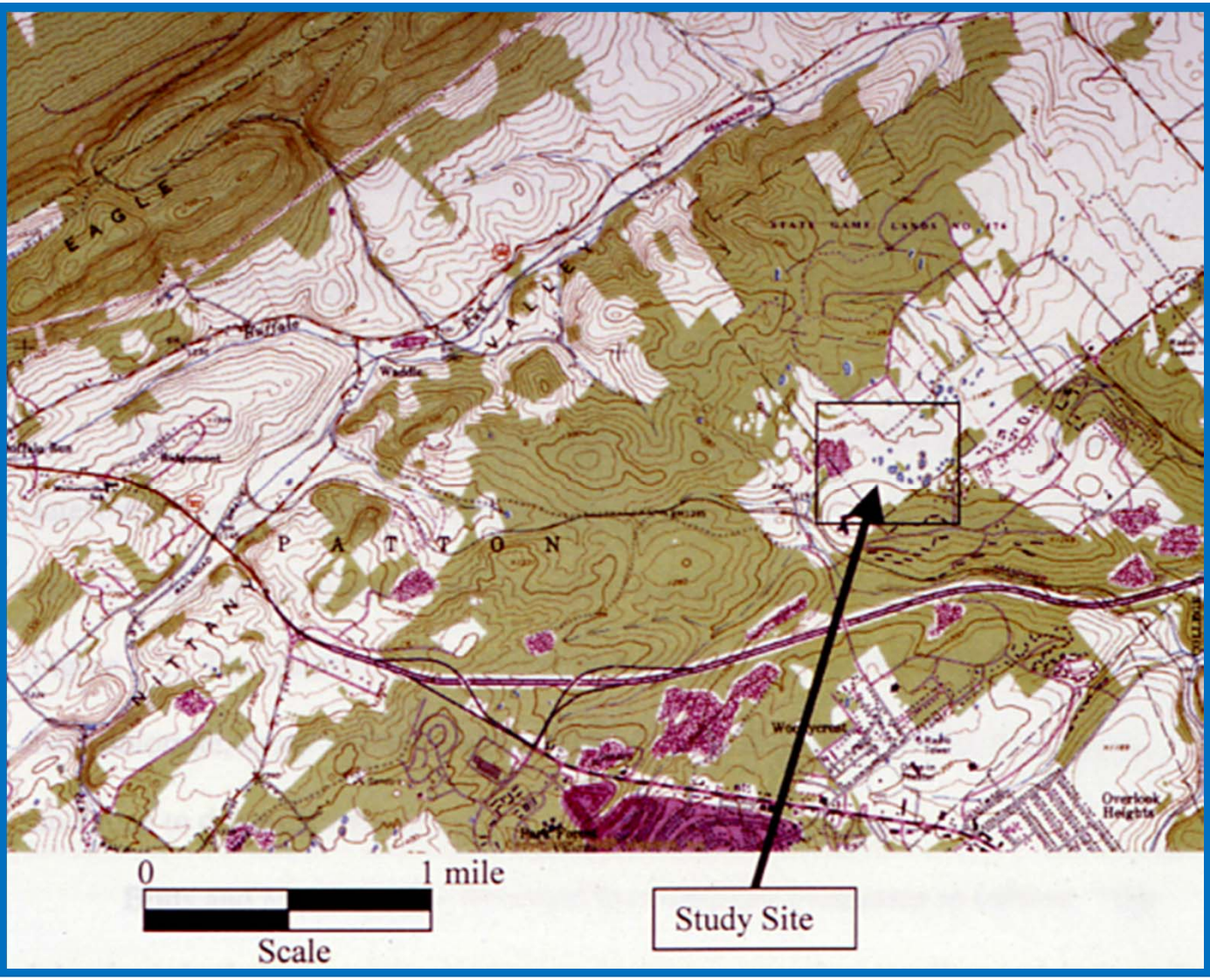
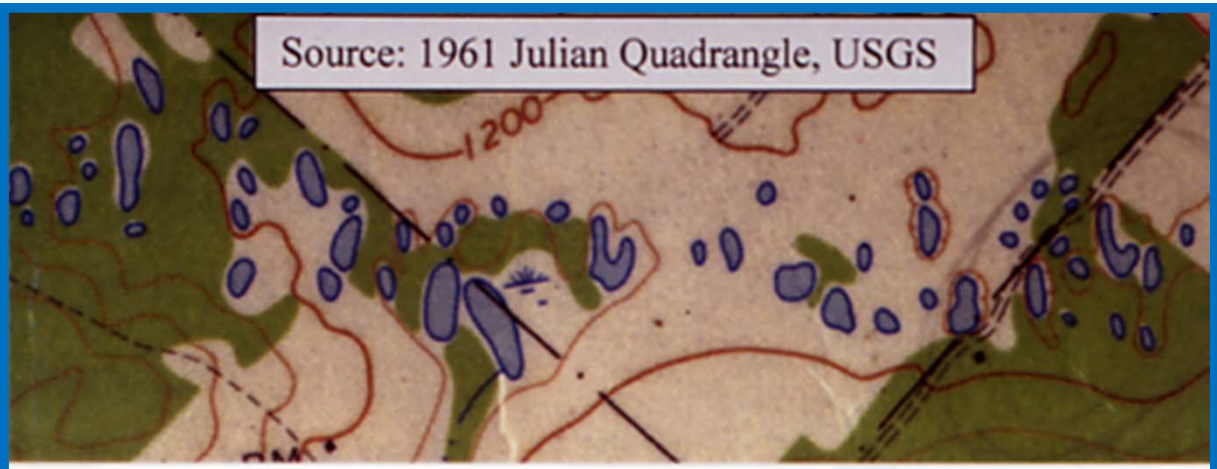
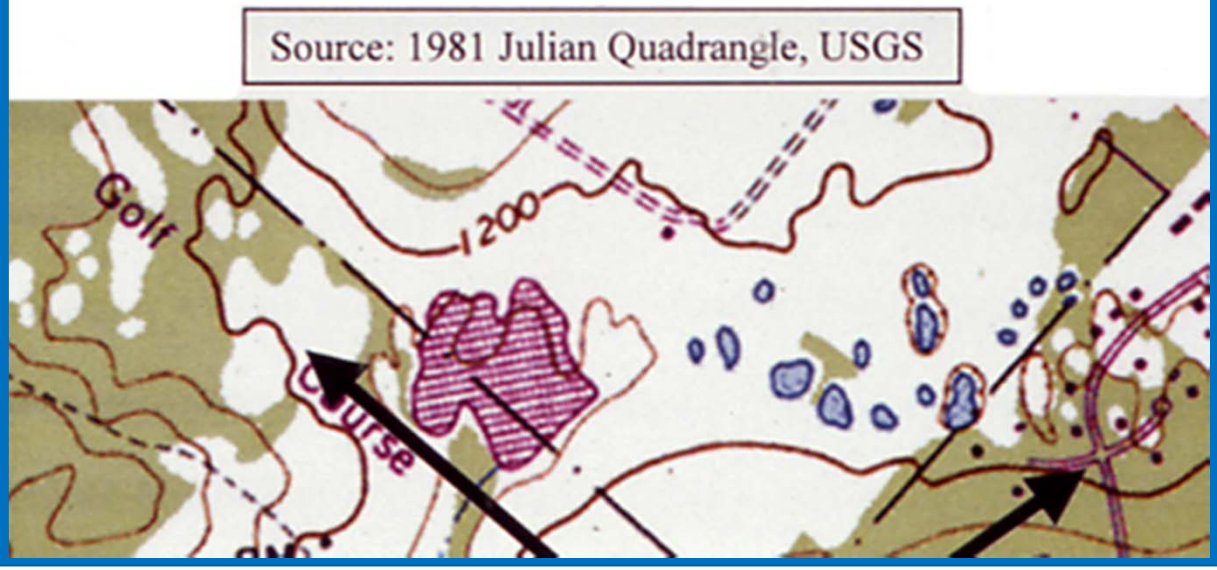
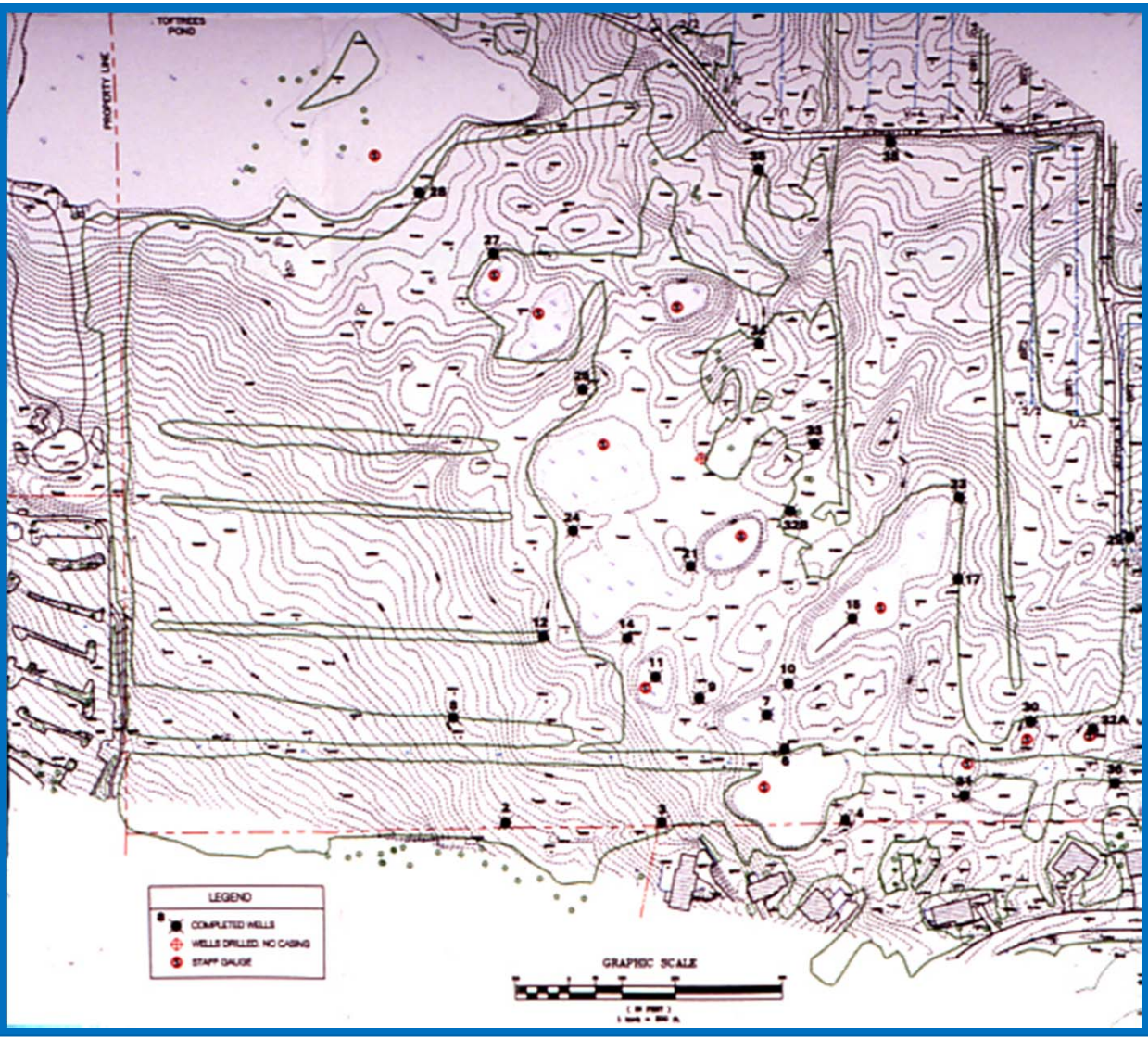

EAGLE
VALLEY
PATTON
Buffalo
Waddle
Overlook Heights
0
1 mile
Scale
Study Site

PENNSTATE


Source: 1961 Julian Quadrangle, USGS
1200


Source: 1981 Julian Quadrangle, USGS
Golf
1200
Course

PENNSTATE


TOFTREES POND
PROPERTY LINE
LEGEND
COMPLETED WELLS
WELLS DRILLED NO CASING
STAFF GAUGE
GRAPHIC SCALE

PENNSTATE

Figure 3.2 Locations of piezometer nests and staff gauges

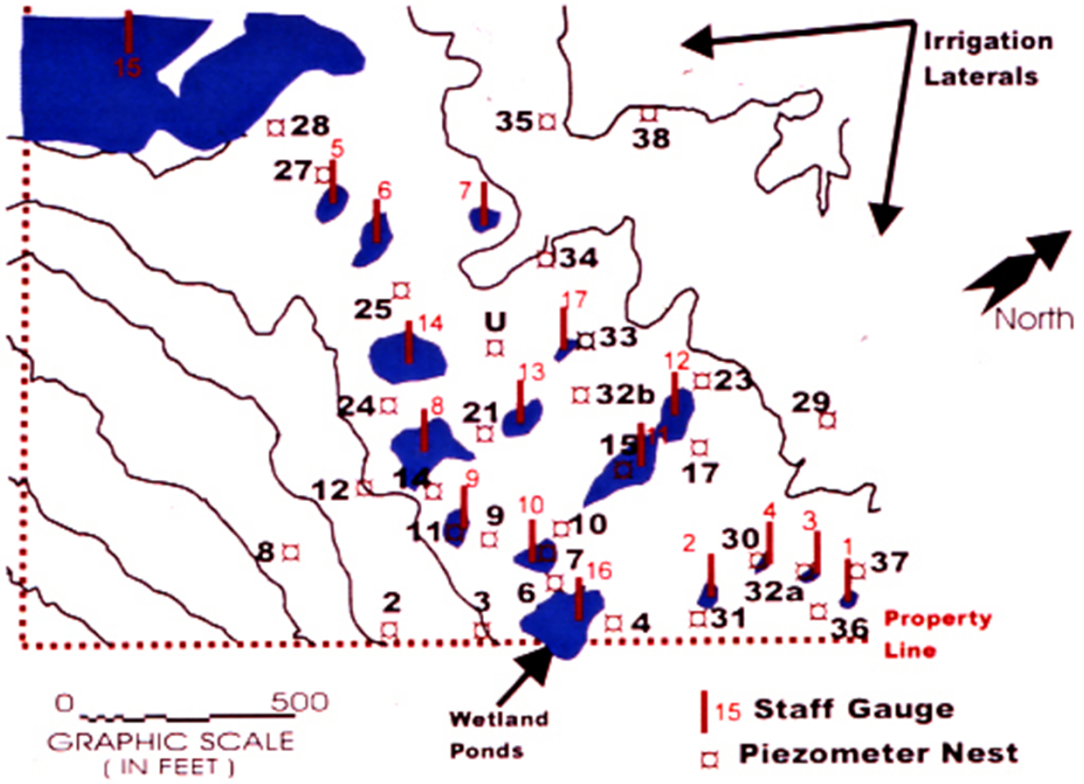


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Figure 4.2 Map-view of soil stratigraphic cross-sections

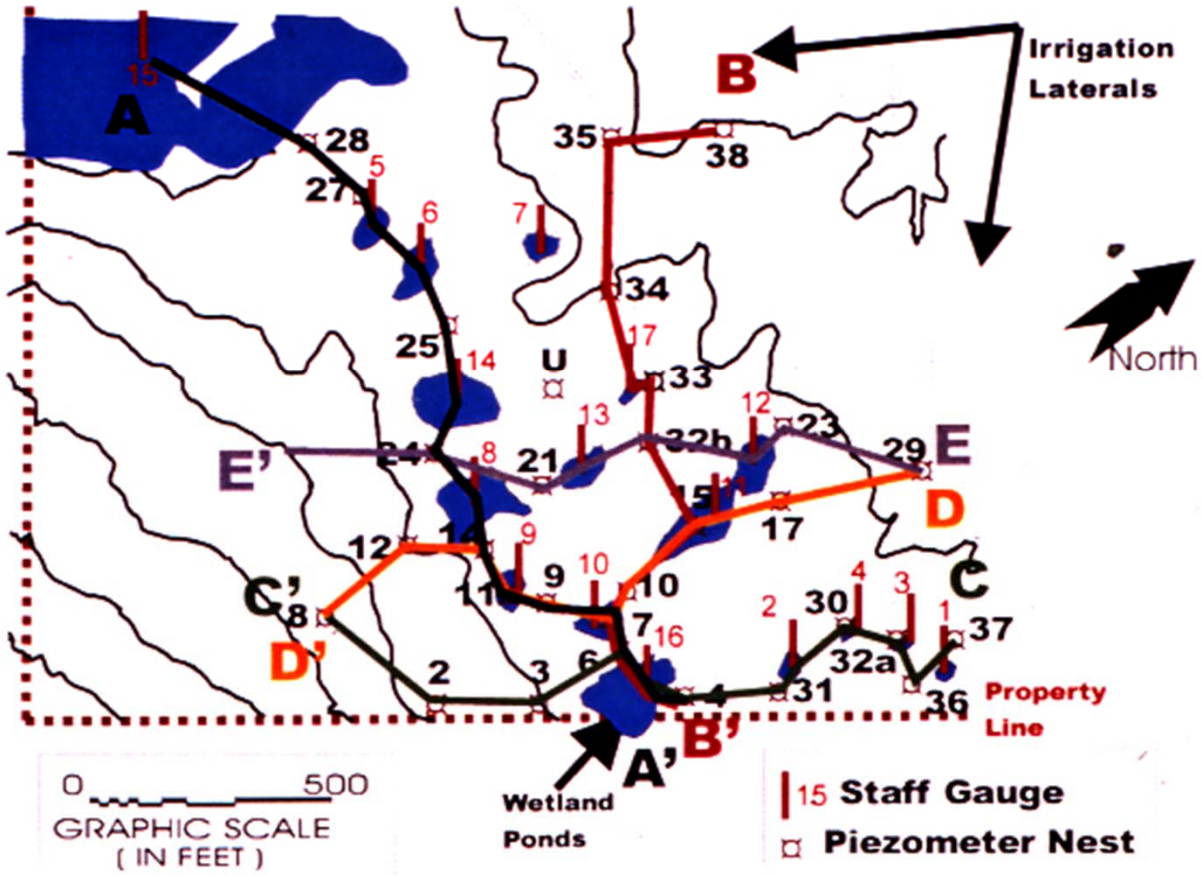

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Figure 4.3 Soil stratigraphic cross-section A-A'

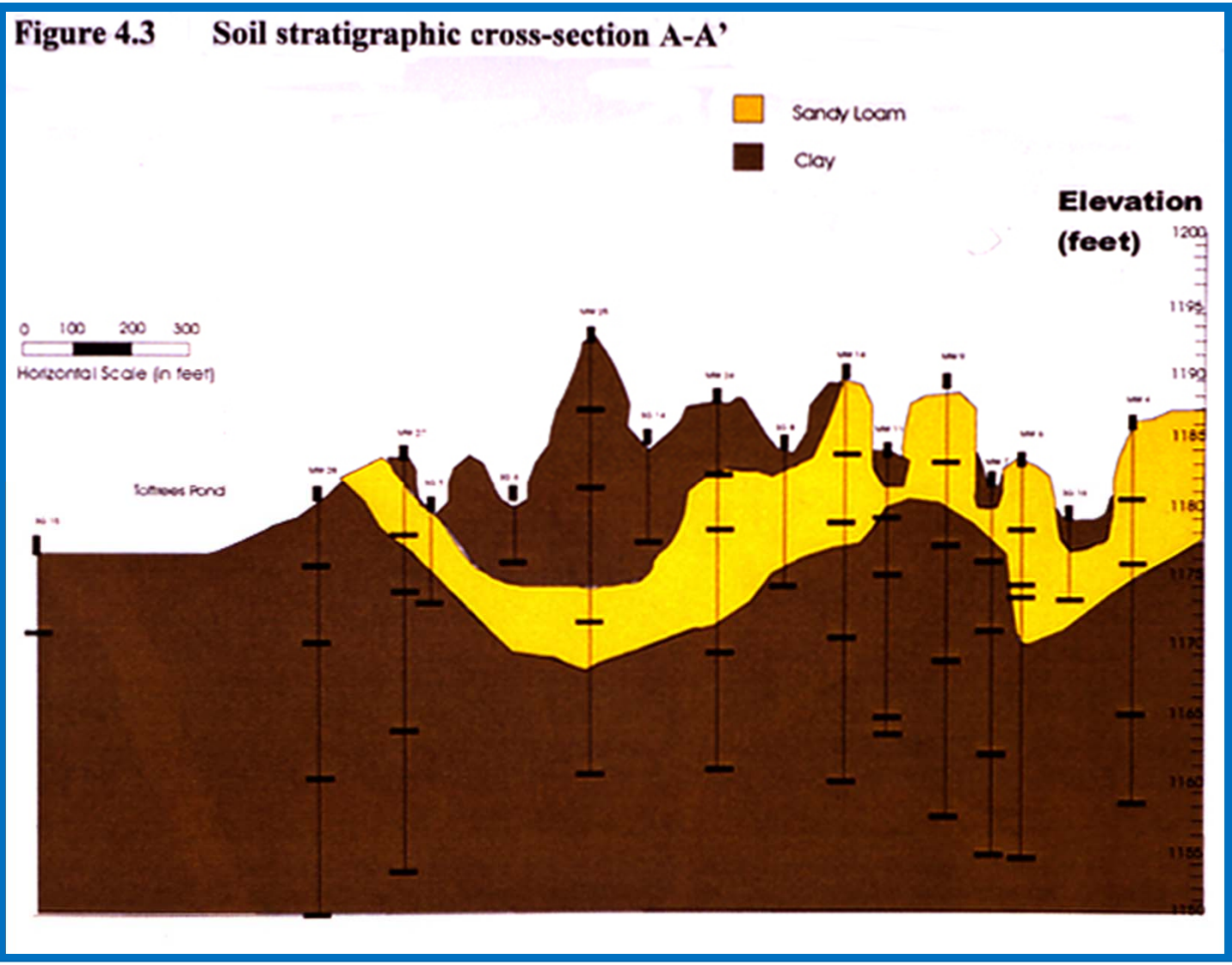

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Figure 4.4 Soil stratigraphic cross-section B-B'

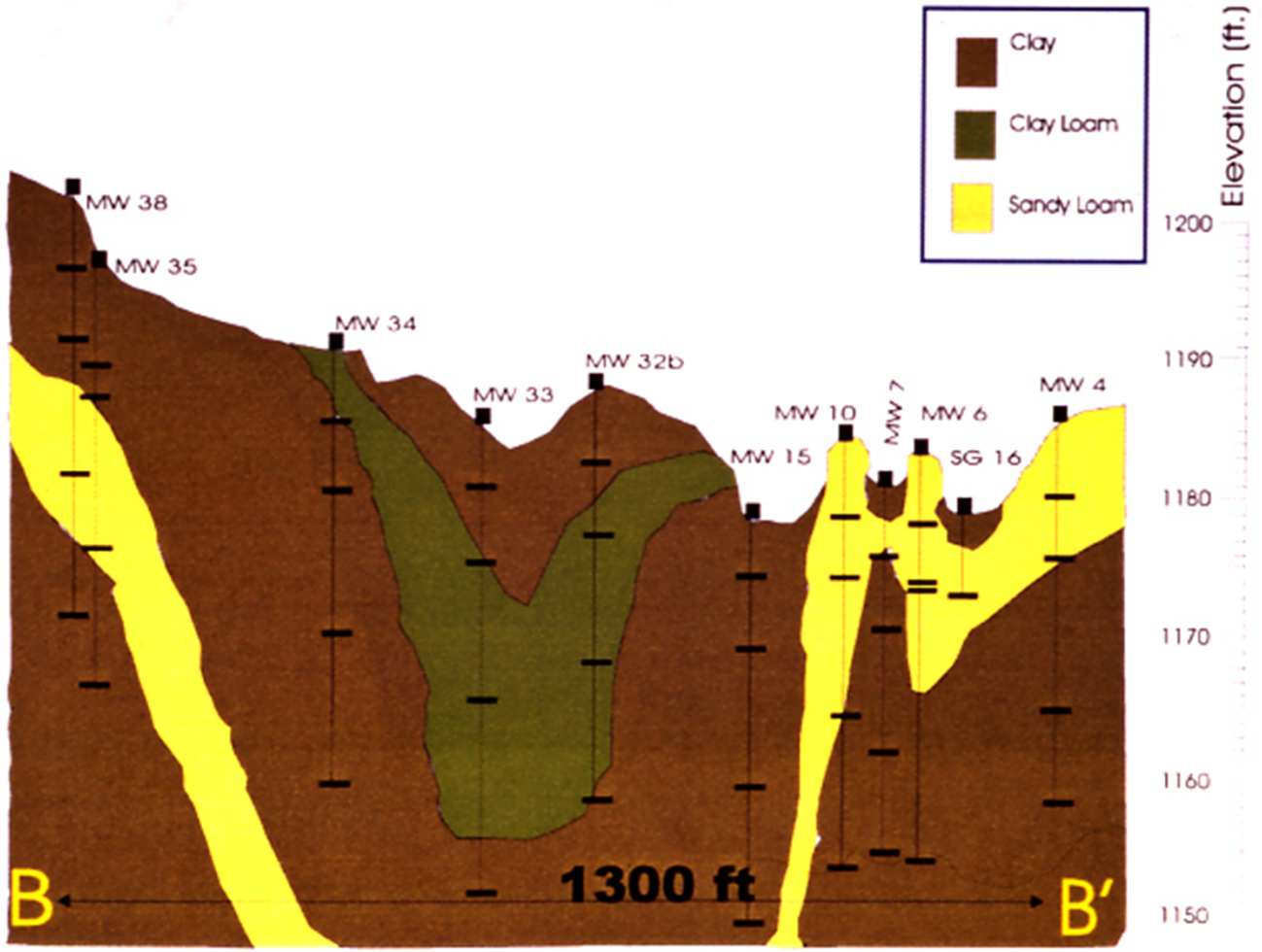

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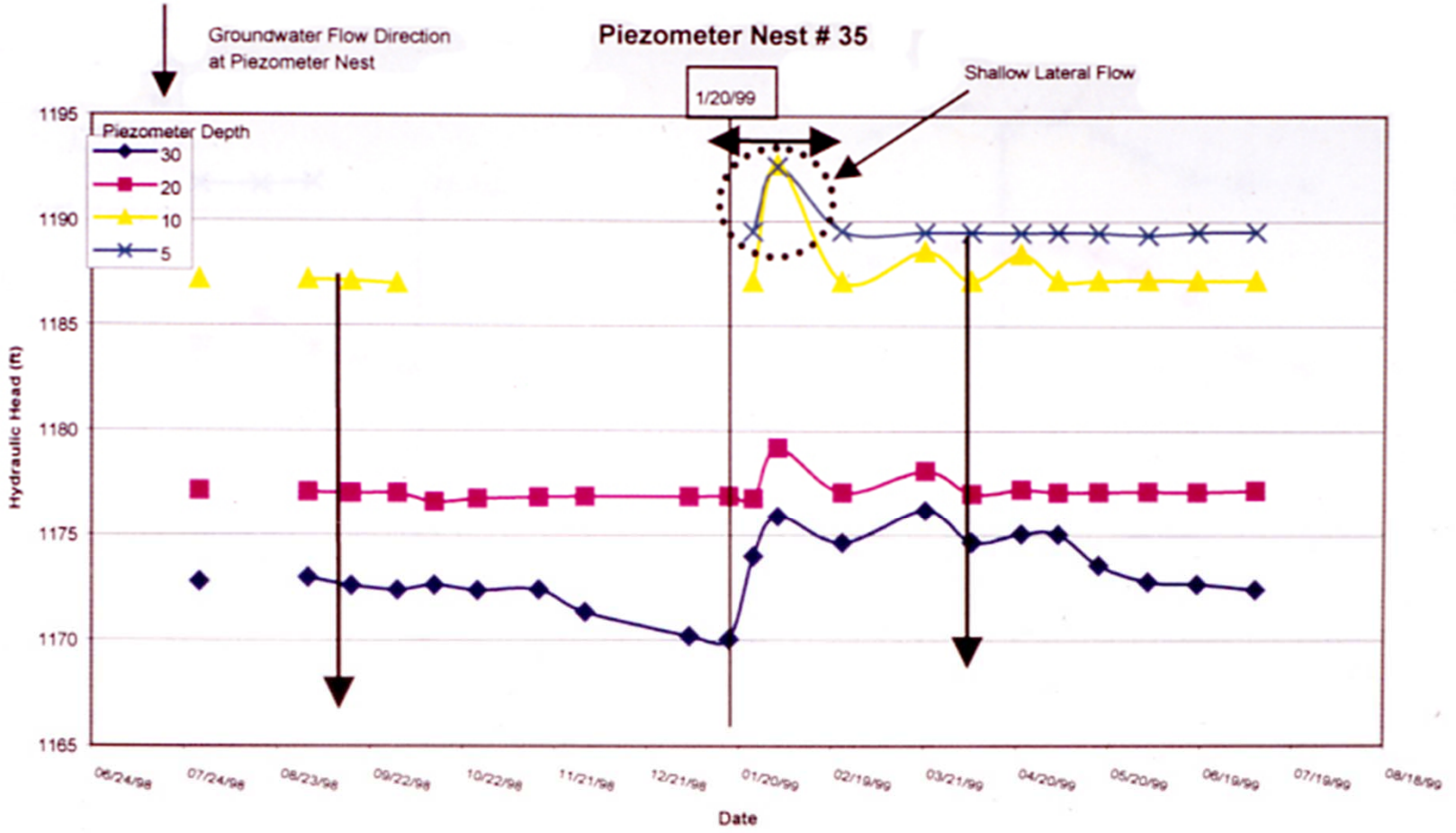
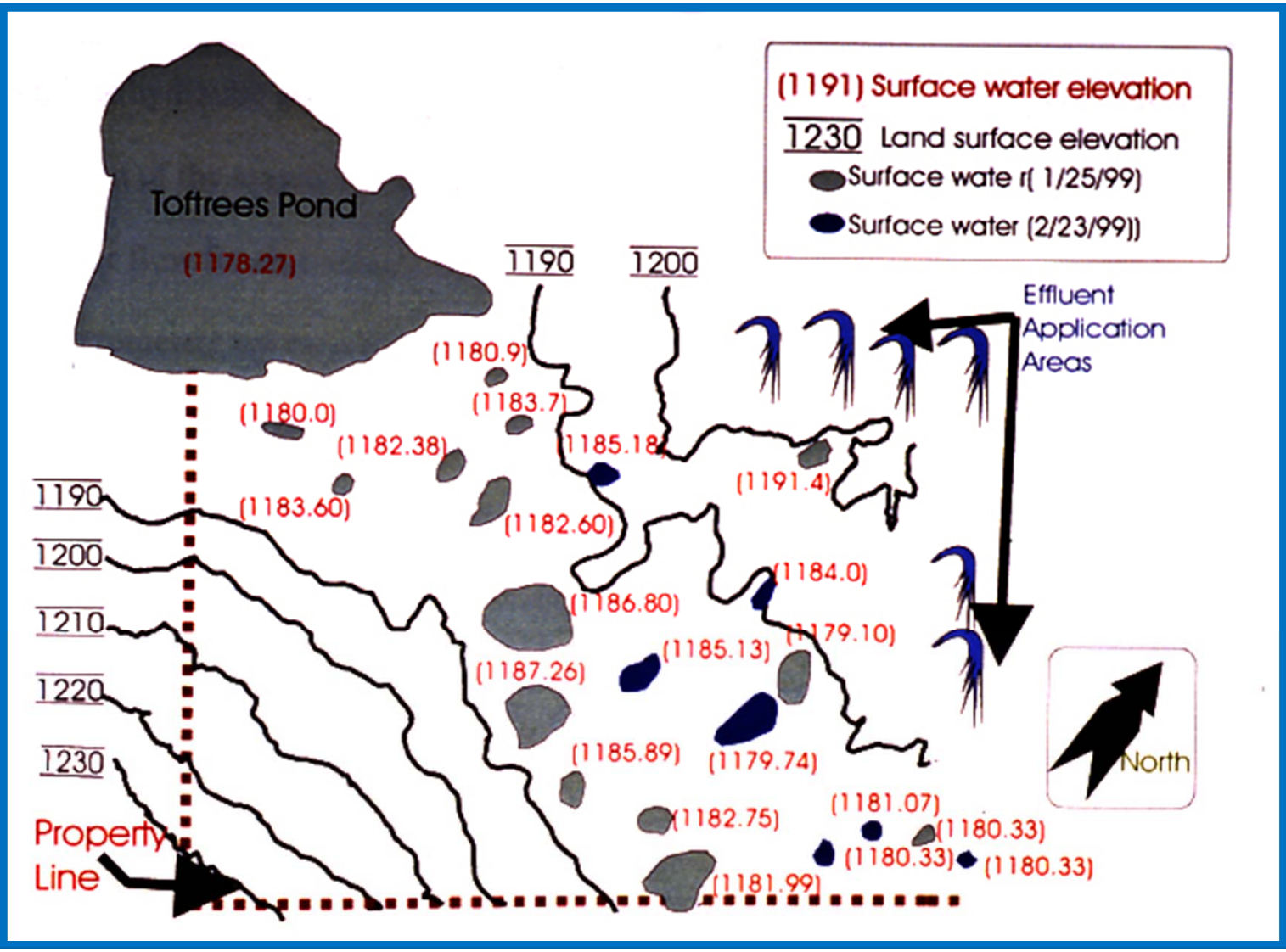
Figure 6.14 Seasonal hydraulic head levels in piezometer nest MW-35



PENNSTATE


(1191) Surface water elevation
1230 Land surface elevation
Surface wate r(1/25/99)
Surface water (2/23/99))
Toftrees Pond
(1178.27)
1190
1200
Effluent
Application
Areas
(1180.9)
(1183.7)
(1180.0)
(1182.38)
(1185.18)
(1191.4)
(1183.60)
(1182.60)
(1184.0)
(1186.80)
(1179.10)
(1185.13)
(1187.26)
(1185.89)
(1179.74)
(1181.07)
(1182.75)
(1180.33)
(1180.33)
(1180.33)
(1181.99)
1190
1200
1210
1220
1230
Property
Line
North

PENNSTATE

Figure 7.1 **Specific Conductance of surface water on May 11, 1999**

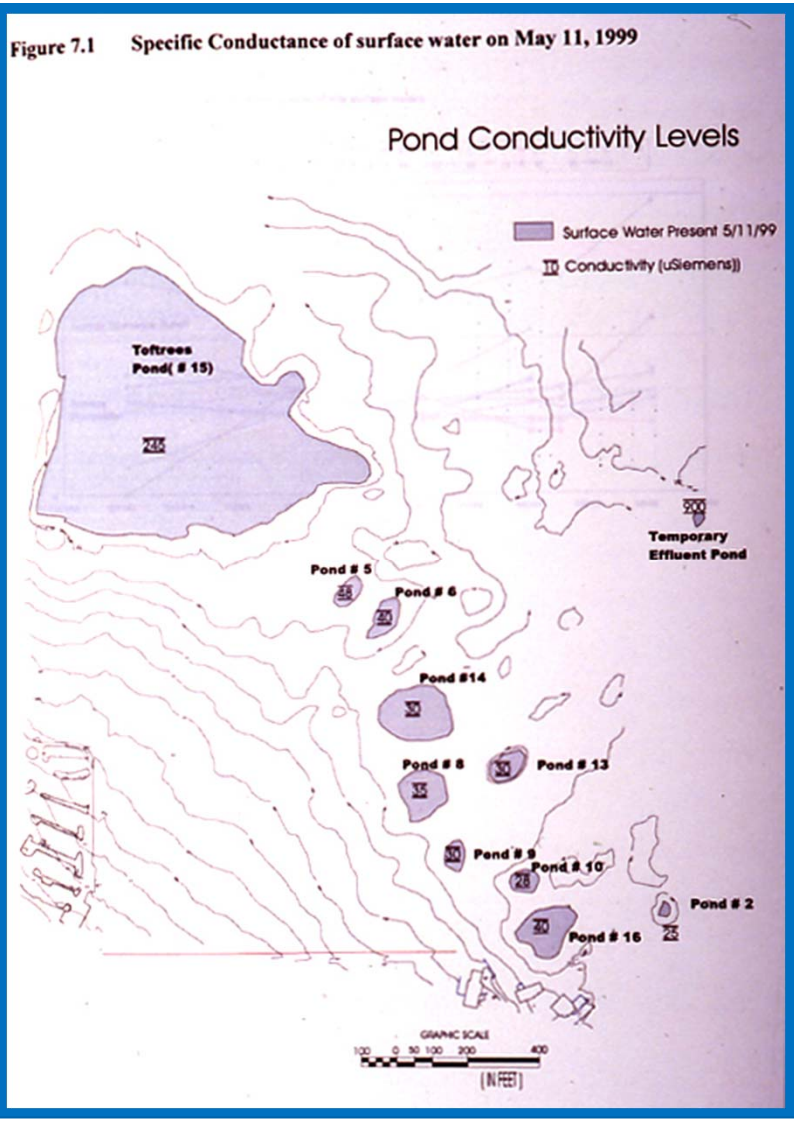


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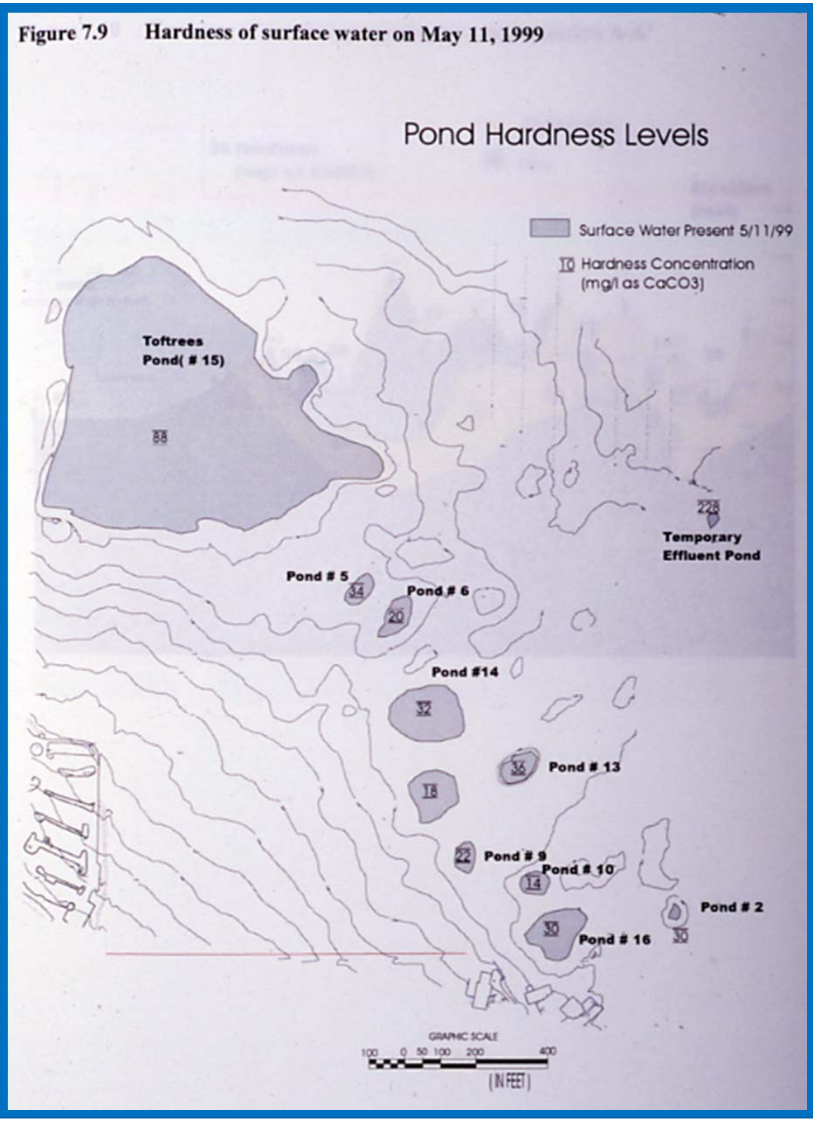
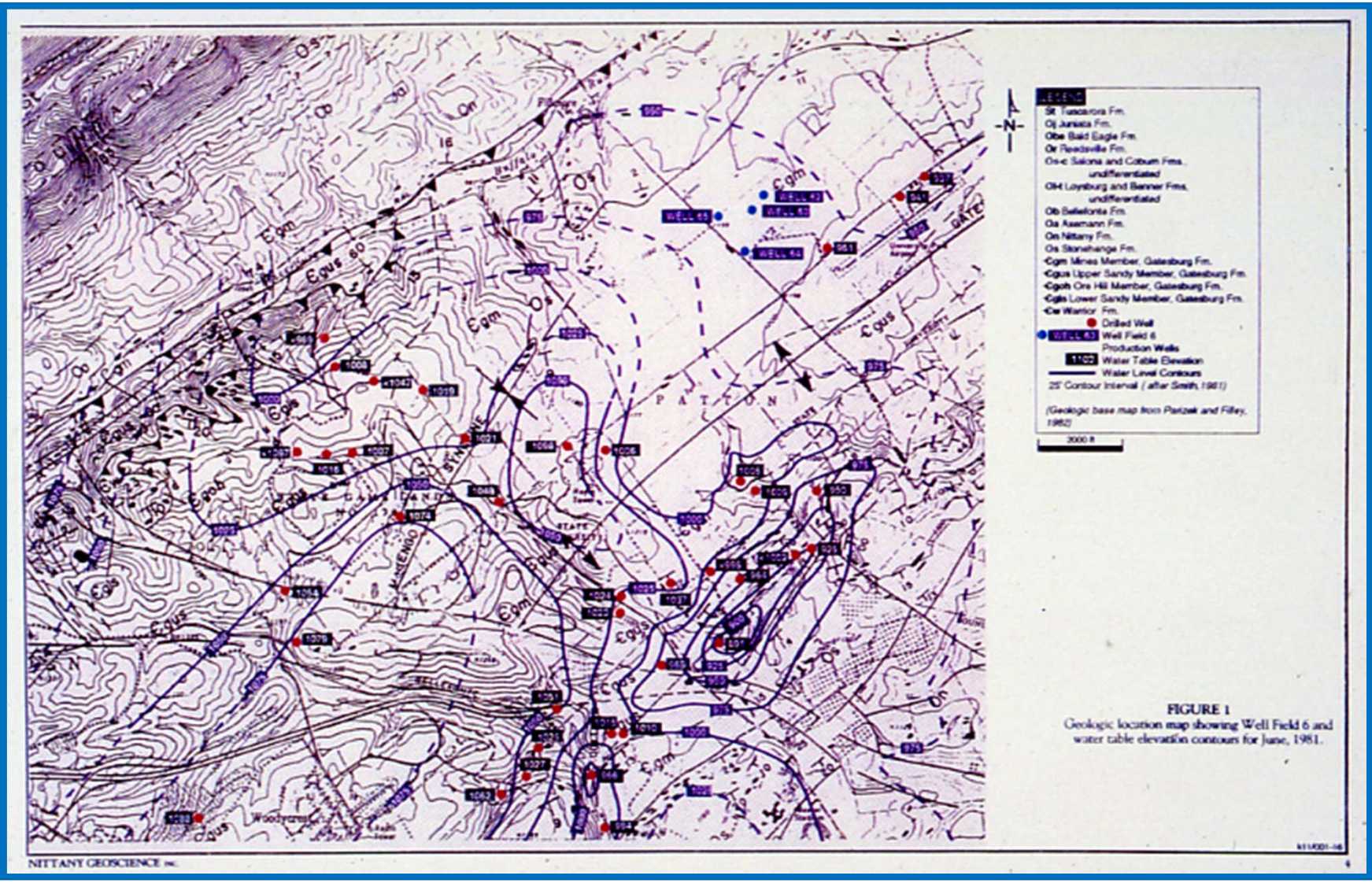
Figure 7.9 **Hardness of surface water on May 11, 1999**



PENNSTATE


LEGEND
St Tuscarora Fm.
Oj Juniata Fm.
Obe Bald Eagle Fm.
Or Reedsville Fm.
Oe-c Salona and Coburn Fms., undifferentiated
Olt Loysburg and Benner Fms., undifferentiated
Ob Bellefonte Fm.
Oa Axemann Fm.
On Nittany Fm.
Os Stonehenge Fm.
Cgm Mines Member, Gatesburg Fm.
Cgus Upper Sandy Member, Gatesburg Fm.
Cgoh Ore Hill Member, Gatesburg Fm.
Cgls Lower Sandy Member, Gatesburg Fm.
Cw Warrior Fm.
Drilled Well
Well Field 6
Production Wells
1102 Water Table Elevation
Water Level Contours
25' Contour Interval (after Smith, 1981)
(Geologic base map from Platzek and Filley, 1982)
3000 ft
N
FIGURE 1
Geologic location map showing Well Field 6 and water table elevation contours for June, 1981.
NITTANY GEOSCIENCE INC.

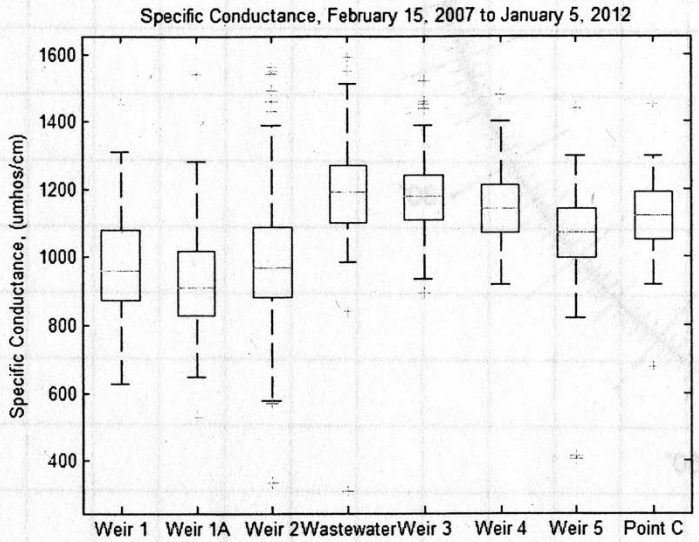


Figure 12a. Box plot of specific conductance for secondary effluent and water collected at Weirs 1, 1A, and 2 (Feb. 2007-January 2012), 3, 4, and 5 (February 2007 – May 2009) and Point C (December 2007- May 2009).

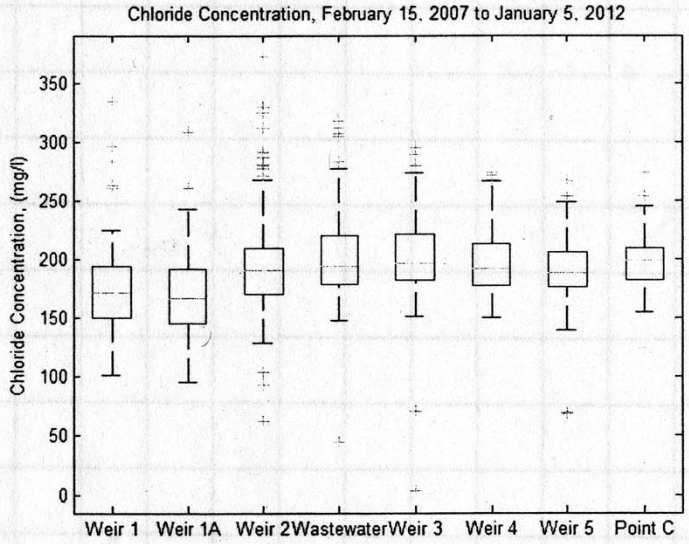


Figure 12b. Box plot of chloride concentrations for secondary effluent and water collected at Weirs 1, 1A, and 2 (Feb. 2007-January 2012), 3, 4, and 5 (February 2007 – May 2009) and Point C (December 2007- May 2009).

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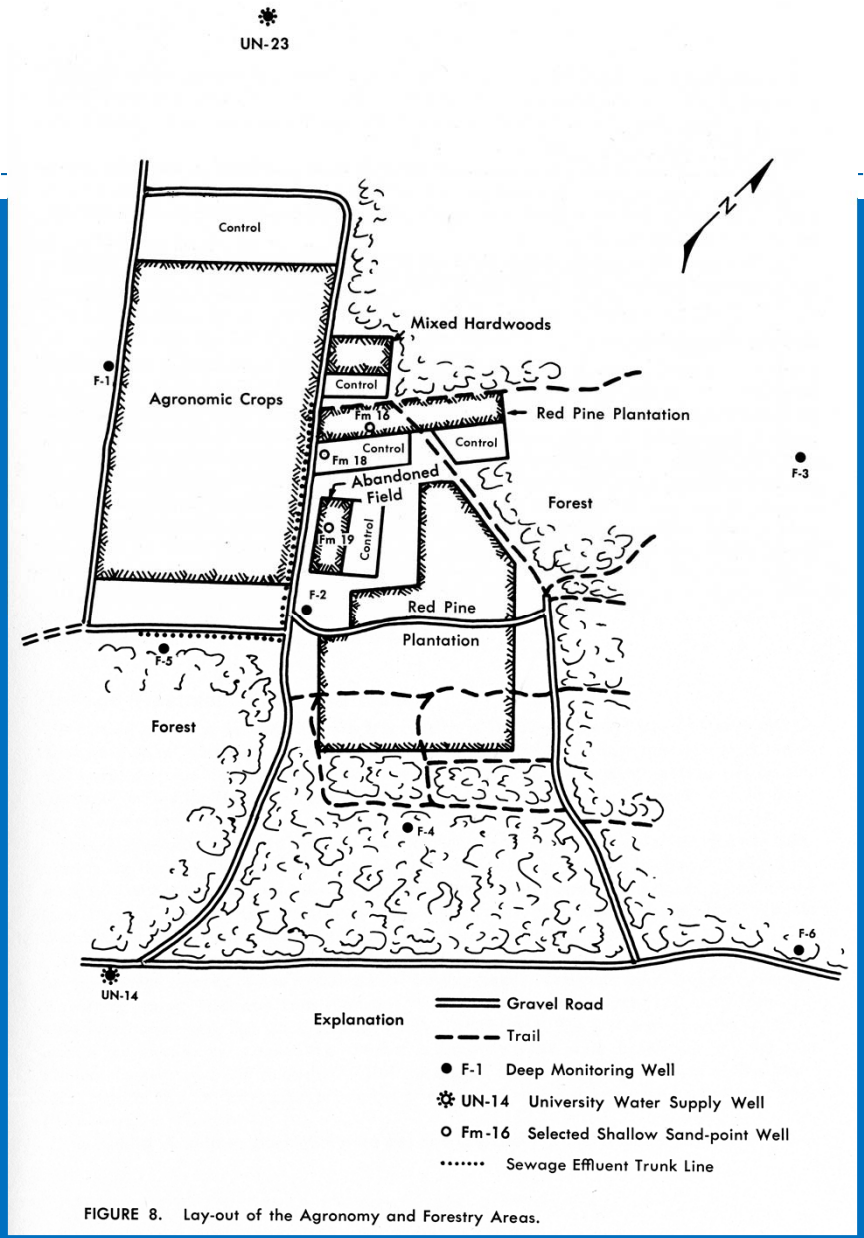
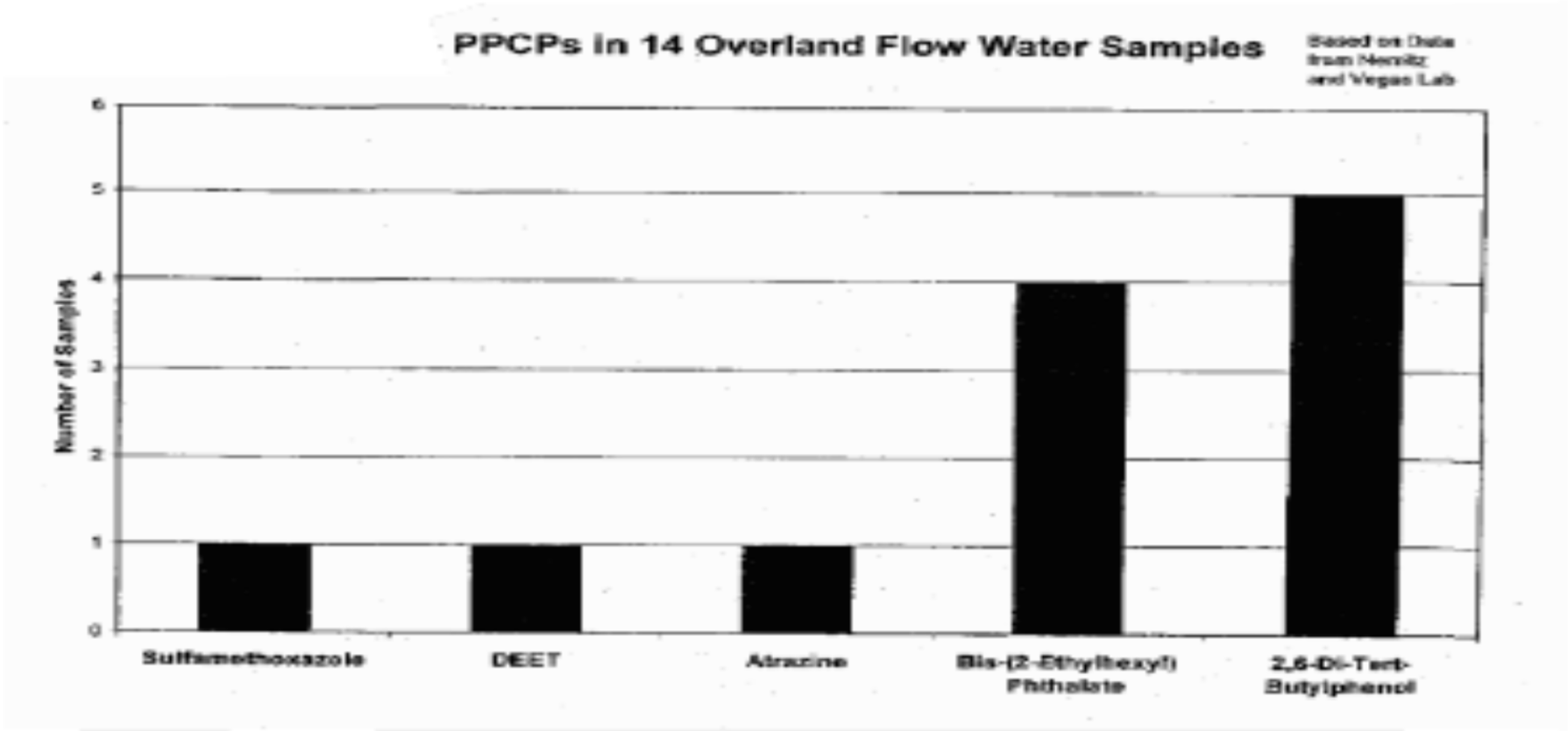
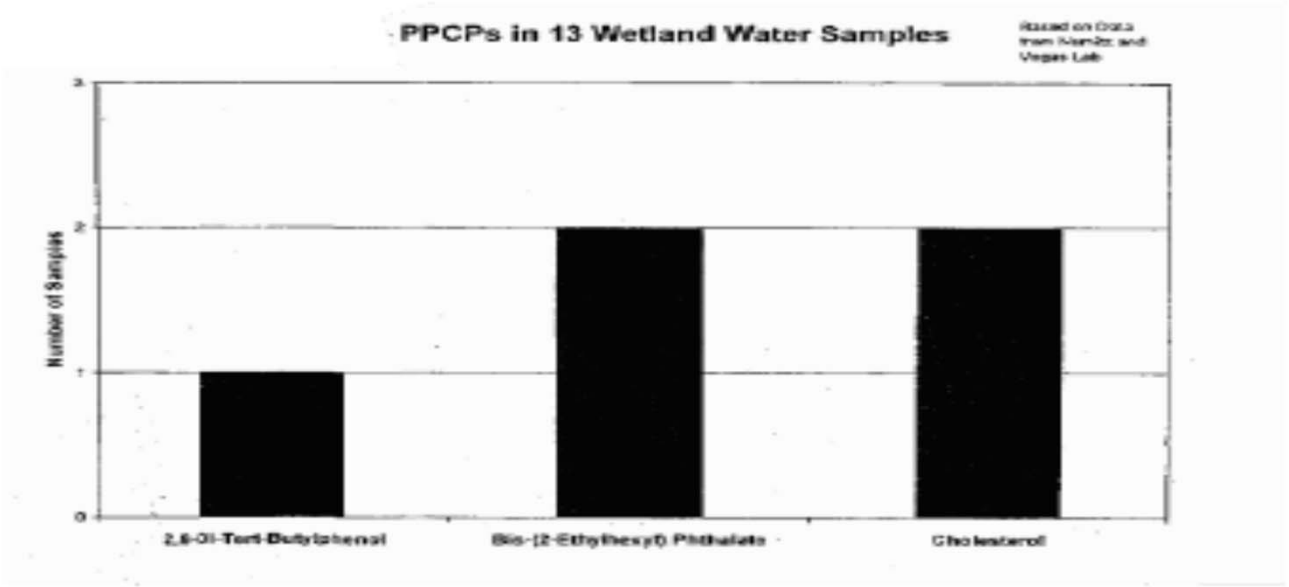


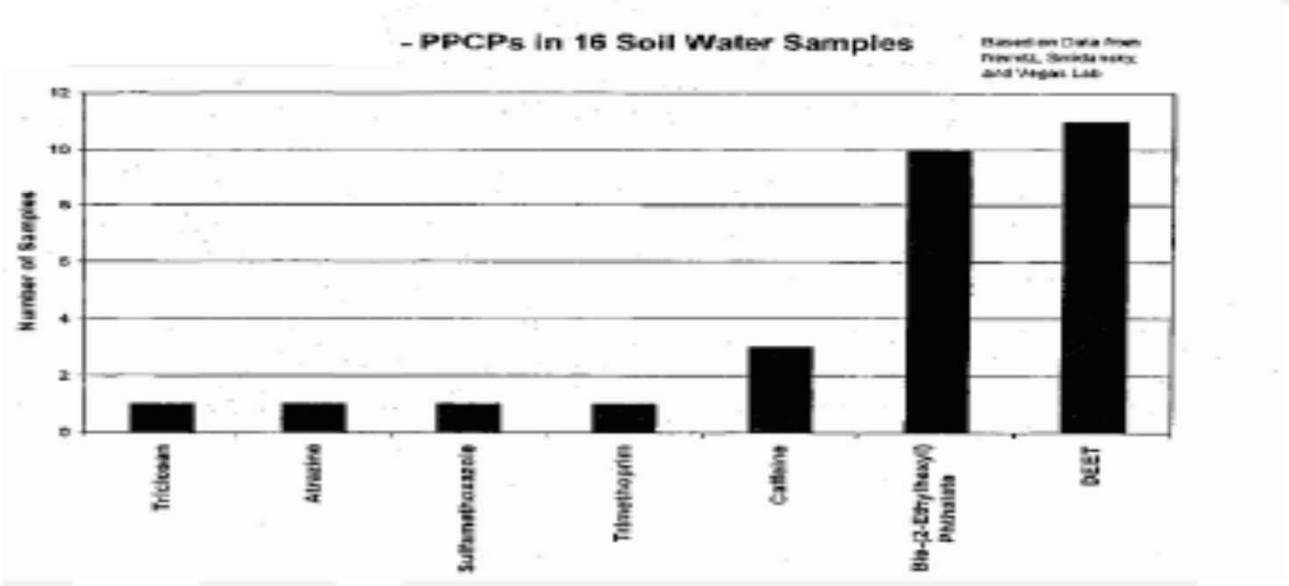
FIGURE 8. Lay-out of the Agronomy and Forestry Areas.



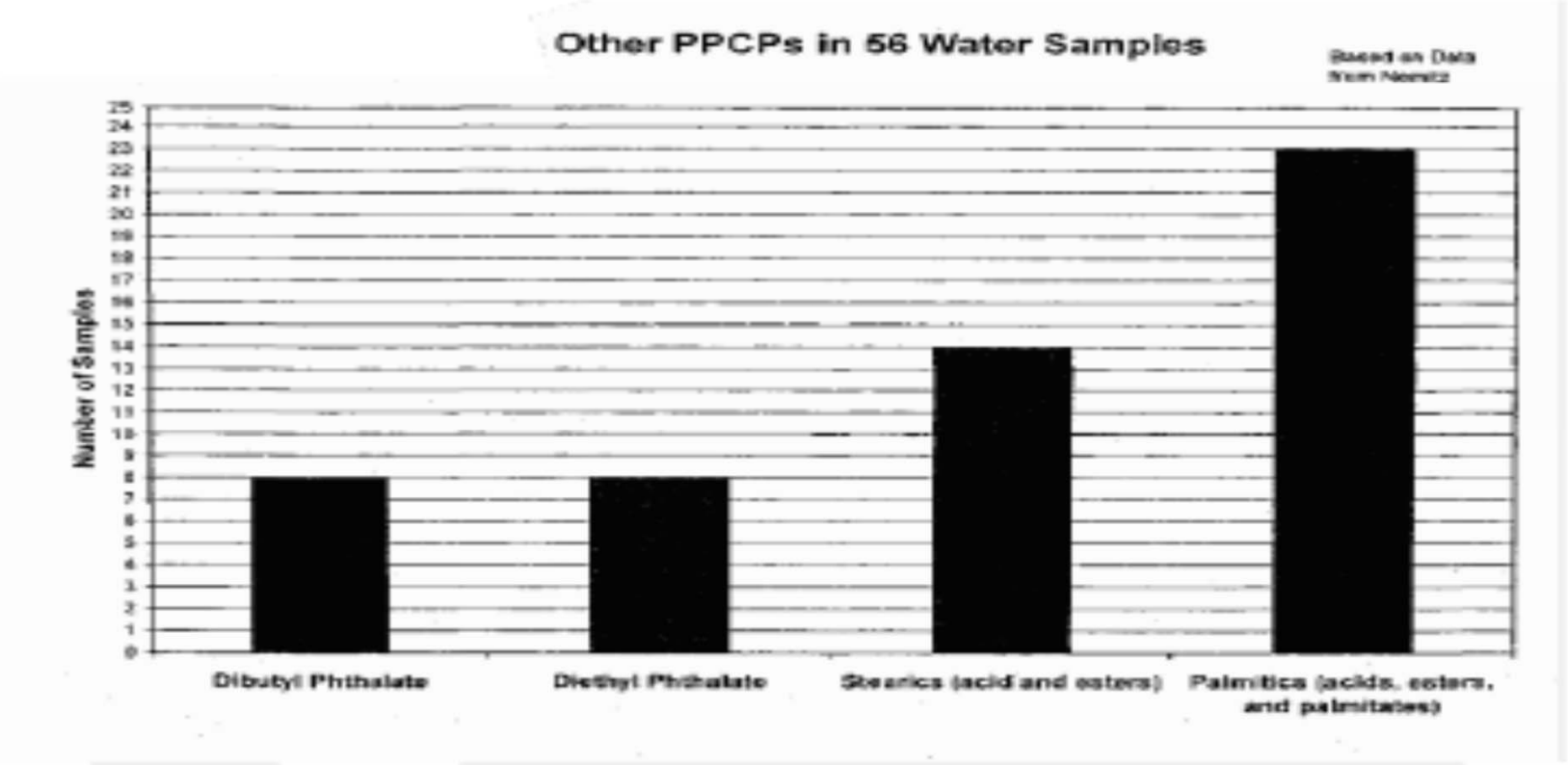
(Nemitz and Parizek, 2004-08; Las Vegas Lab)



(Nemltz and Parlzek, 2004–08)



(Smldansky, 2004; Nemltz and Parlzek, 2004–08; Las Vegas Lab)



(Nemitz and Parizek, 2004-08)

Findings 1963 -1967 Routine Operation 1983 – Present (Continued)

- Recharge rates vary with application rates, duration, and weather
- Growing Season
  - 1 – inch/ week
  - 2- inch/week
- Year round
  - 2 – inches/week