Headquarters U.S. Air Force

Integrity - Service - Excellence

Section 5 – Case Study
Massachusetts Military Reservation – Landfill 1

U.S. AIR FORCE

Presented by

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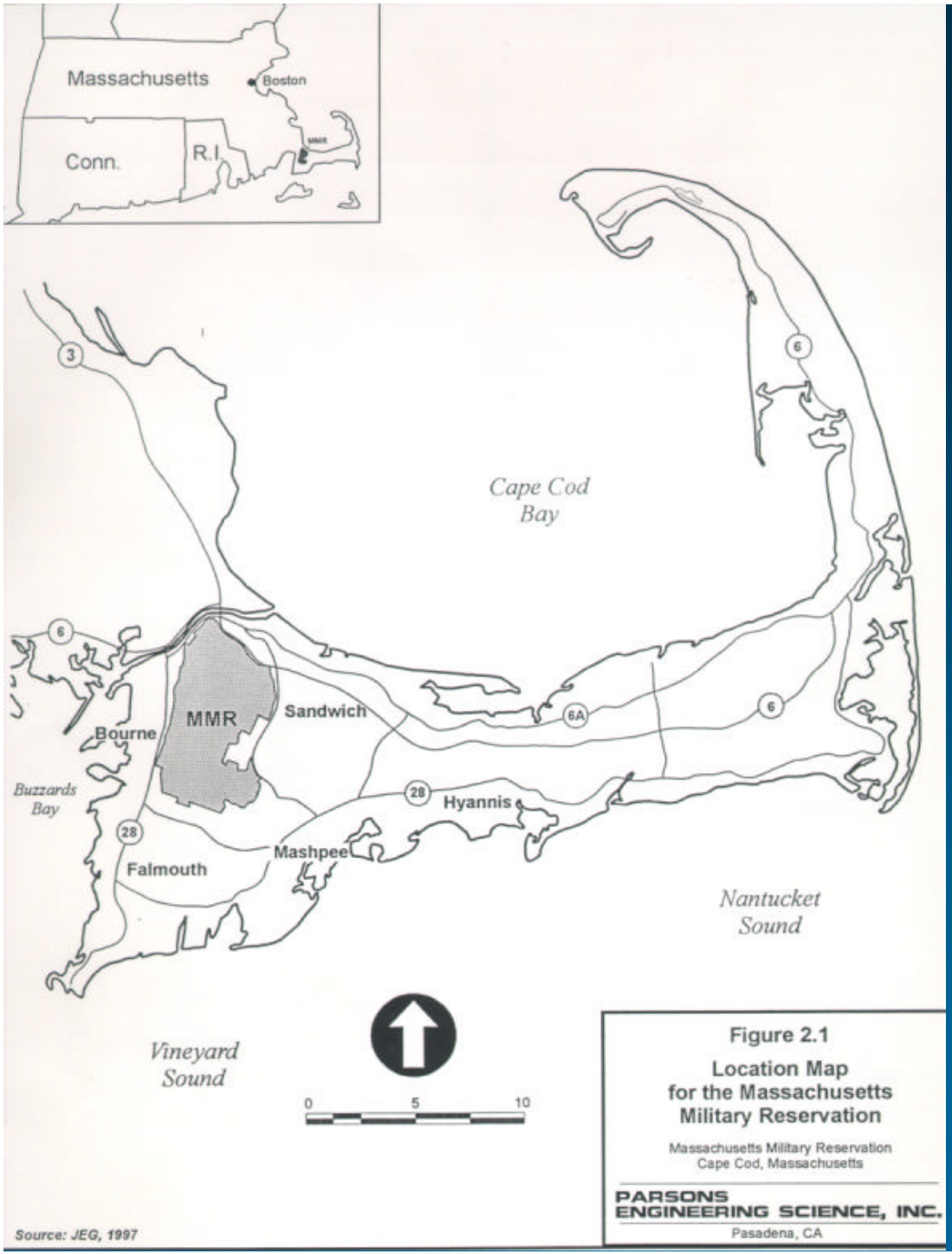
Project Start

- **Focused Feasibility Study**
  - **“May the best cleanup alternative win”**
- **Conducted in accordance with:**
  - **US EPA OSWER Directive 9200.4-17, “Use of MNA…”**
  - ***Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water*, EPA/600/R-98/128**
  - **Plus Additional “Innovative” Techniques**

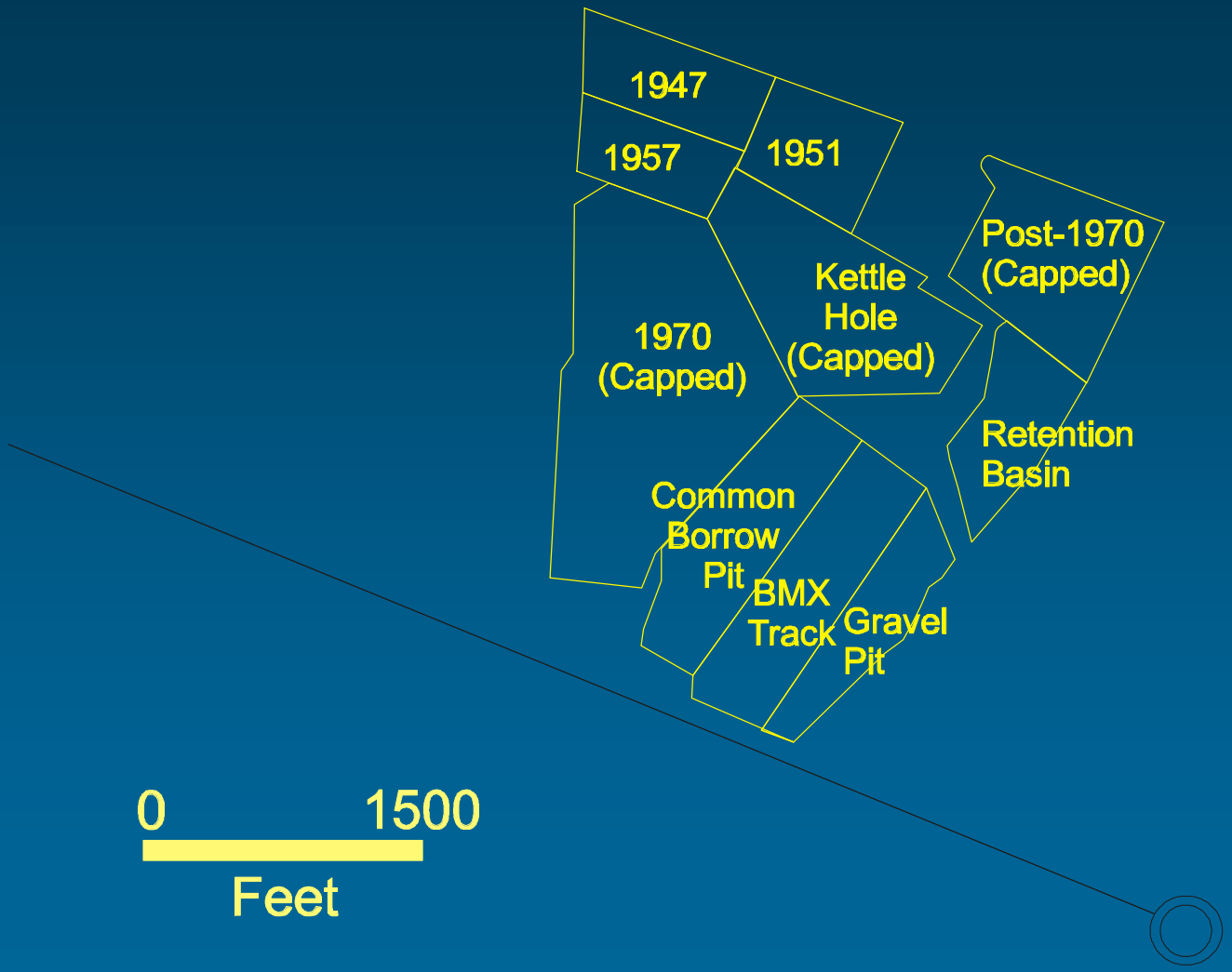


Location Map

Background

- Landfill in use from 1941 - 1989
- Capped in 1995 - 60% coverage
- Contaminants of concern: PCE; TCE, Carbon Tetrachloride.
- Contaminants: 90 - 160 feet bgs

LF-1


1947
1957
1951
Post-1970
(Capped)
Kettle
Hole
(Capped)
1970
(Capped)
Retention
Basin
Common
Borrow
Pit
BMX
Track
Gravel
Pit
0
1500
Feet

MMR Base Map


1947
1957
1951
Post-1970
(Capped)
Kettle
Hole
(Capped)
1970
(Capped)
Retention
Basin
Common
Borrow
Pit
BMX
Track
Gravel
Pit
Base Boundary
N
0
1500
3000
Feet

Current Conceptual Site Model

- Landfill Cap Effective in Reducing Contaminant Flux;
- However, Lower Level Contaminant Flux will Most Likely Persist for Decades
- Strong Trend Toward Decreasing Concentrations
- Dissolved Contaminant Mass Decreasing over Time
- Current plume configuration is most likely the result of multiple releases at different locations over time (e.g. A release in 1945, one in 1958, etc)

Site Risk Profile

- Contaminants:
  - Perchloroethylene (PCE)
  - Tricholoethylene (TCE)
  - Carbon Tetrachloride (CT)
- Human health - No/Low Risk
  - Contaminants - lower interval of aquifer
  - Water supply - upper interval of aquifer
    - No current or future MCL exceedances
  - Contaminants - typically < 10 x MCLs
- Environment - No Risk
  - No unacceptable discharges to ponds, bays, other

Sampling History

- Grand totals (Sampling on-going)
  - 656 well sampling events, 1989 - 1998
  - 85 duplicate samples analyzed, 1989 - 1998
    - To verify data quality/precision
- Plume data will be compiled to provide accurate "snapshots" over time
- Current data set sufficient to analyze plume trends
  - Is the plume shrinking, stable, or expanding?
  - Is the dissolved contaminant mass increasing or decreasing?
  - Are plume concentrations increasing or decreasing?

1998 Sampling

- 63 monitoring wells sampled
  - 26 wells sampled under FFS Project
  - 16 wells sampled by Jacobs
  - 21 wells sampled by Sudhakar
- 25 of 63 wells have at least 1 MCL exceedance
- 13 of 63 wells: Sum of contaminants exceeding MCLs > 20 ug/L (ppb)
- 4 of 63 wells: Sum of contaminants exceeding MCLs > 50 ug/L (ppb)
- 0 of 60 wells: Sum of contaminants exceeding MCLs > 200 ug/L (ppb)

Focus of Data Collection

- **Multiple lines of evidence**
  - **As per Air Force/US EPA Protocol**
- **Primary Lines of Evidence**
  - **Concentrations over time**
  - **Total mass of contaminant over time**
  - **Plume configuration over time**
- **Secondary Lines of Evidence**
  - **Known contaminant breakdown products**
  - **Biodegradation indicator compounds**

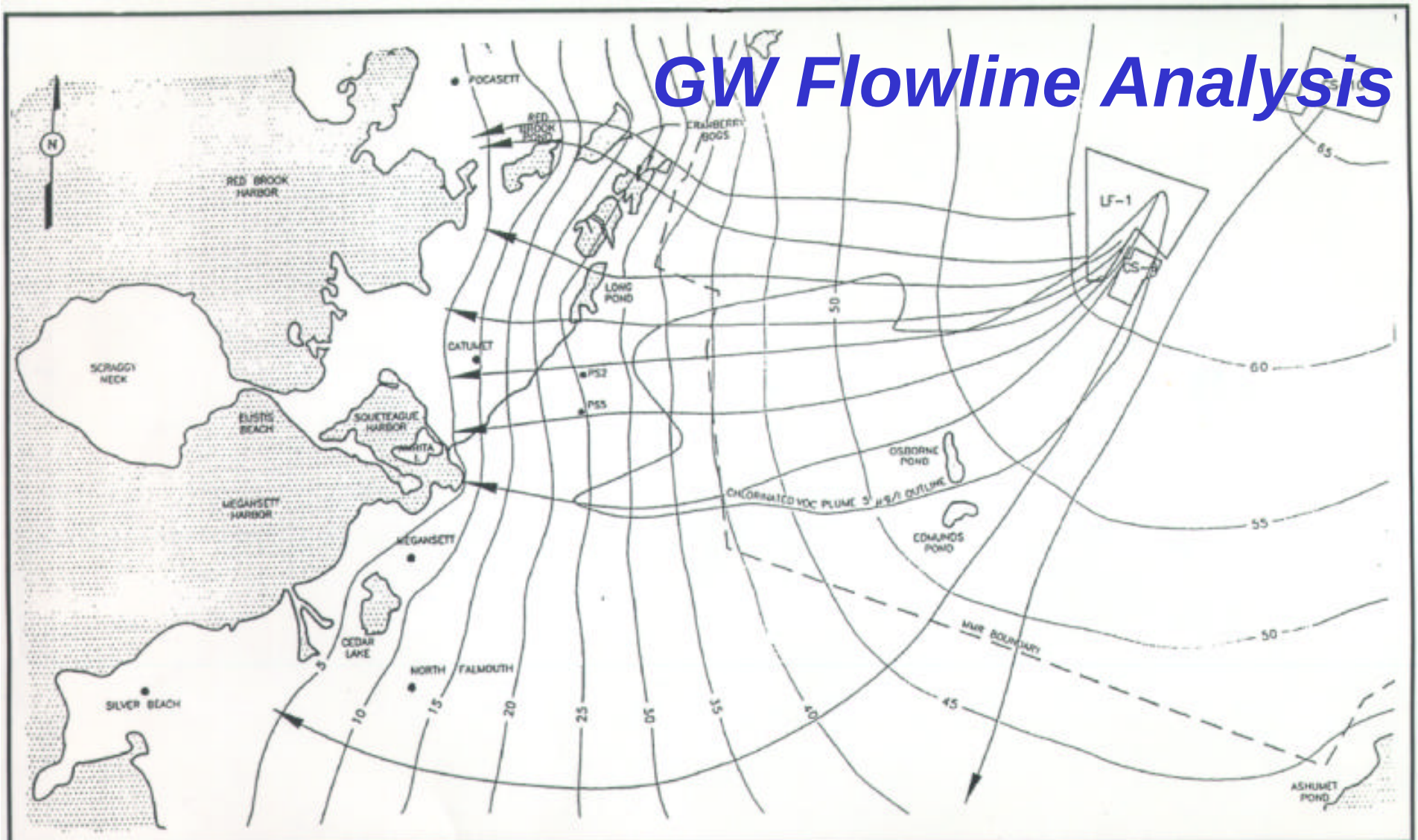
Site Characterization

- **Nature and extent**
- **Fate and transport**
  - **Nondestructive processes**
    - **Dilution**
    - **Sorption**
    - **Volatilization**
  - **Destructive processes**
    - ***Biotic degradation***
    - **Abiotic degradation**

Hydrogeology – Con't

- **Ground Water Table: 40 - 80 feet bgs**
- **Aquifer consists of Glacial Outwash Poorly sorted sand and gravel**
- **Ground water seepage velocity: 1 - 3 feet/day**

GW Flowline Analysis



Plume outline based on 1993 data.

0 3,000'

Approximate Scale

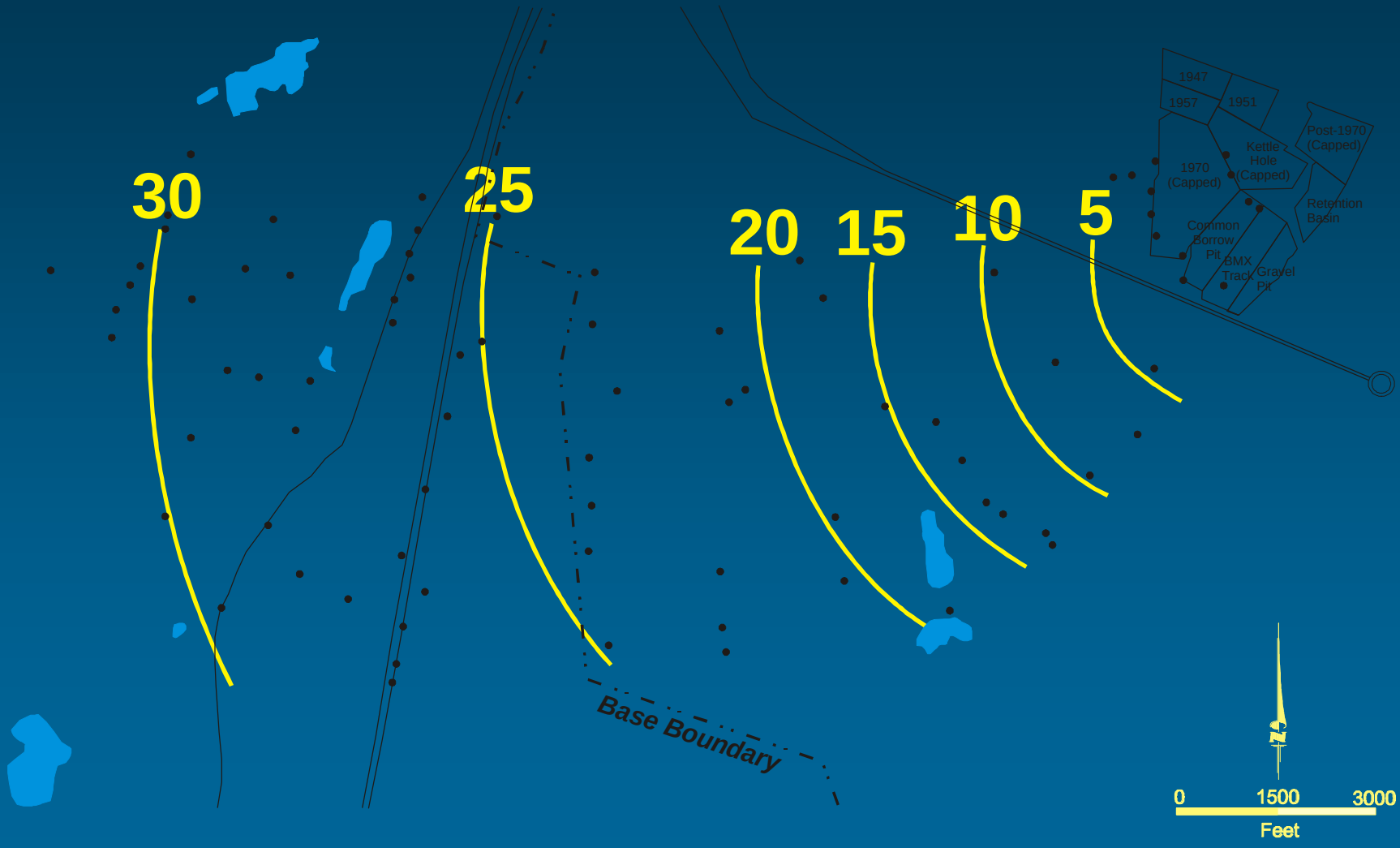
(Based Upon February 1994 Waterlevel Data)

Source: CDM, 1996.

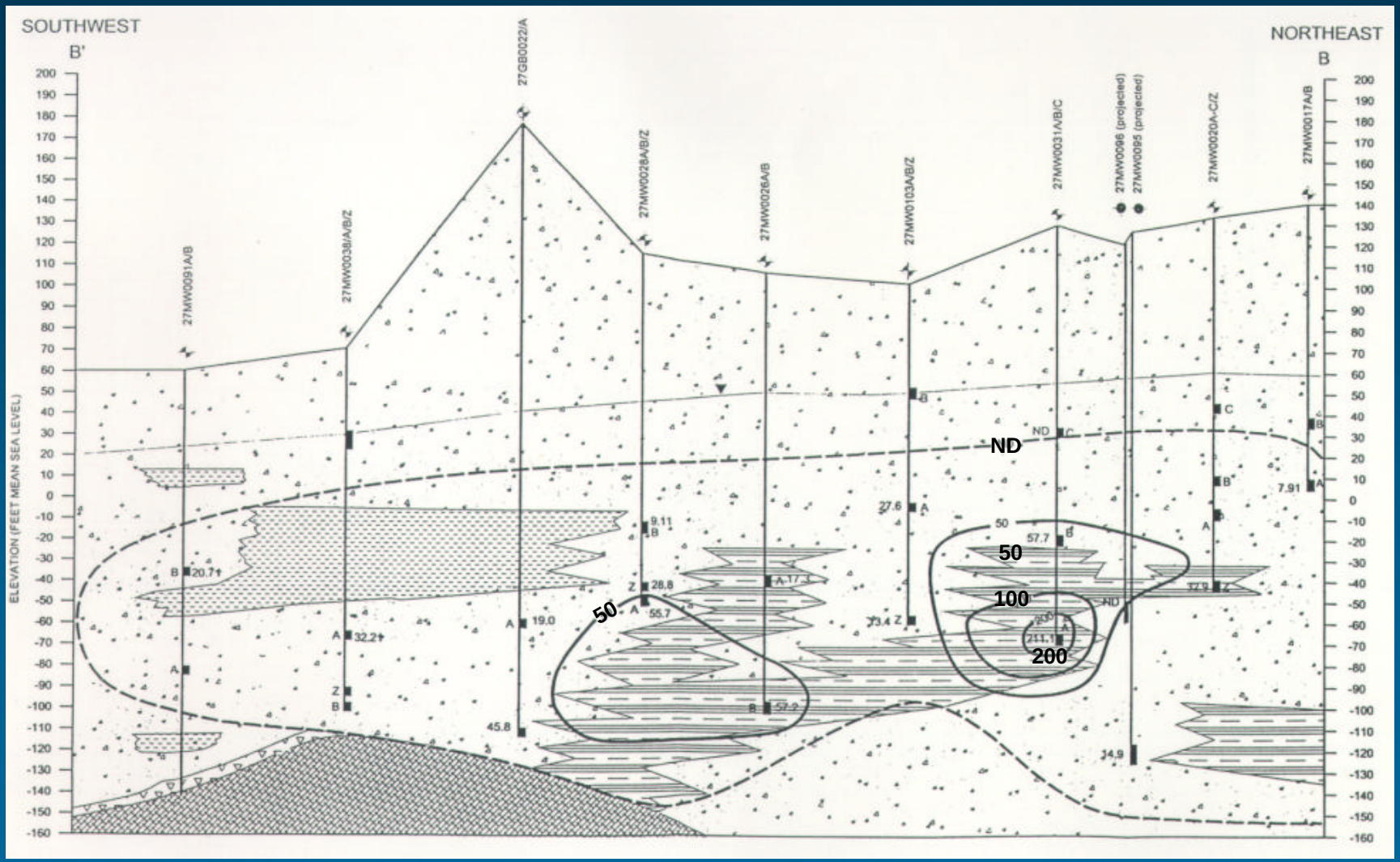
Figure 4.8
Groundwater Flowline Analysis
(Based Upon February 1994 Waterlevel Data)
Massachusetts Military Reservation
Cape Cod, Massachusetts

PARSONS ENGINEERING SCIENCE, INC.
Pasadena, CA

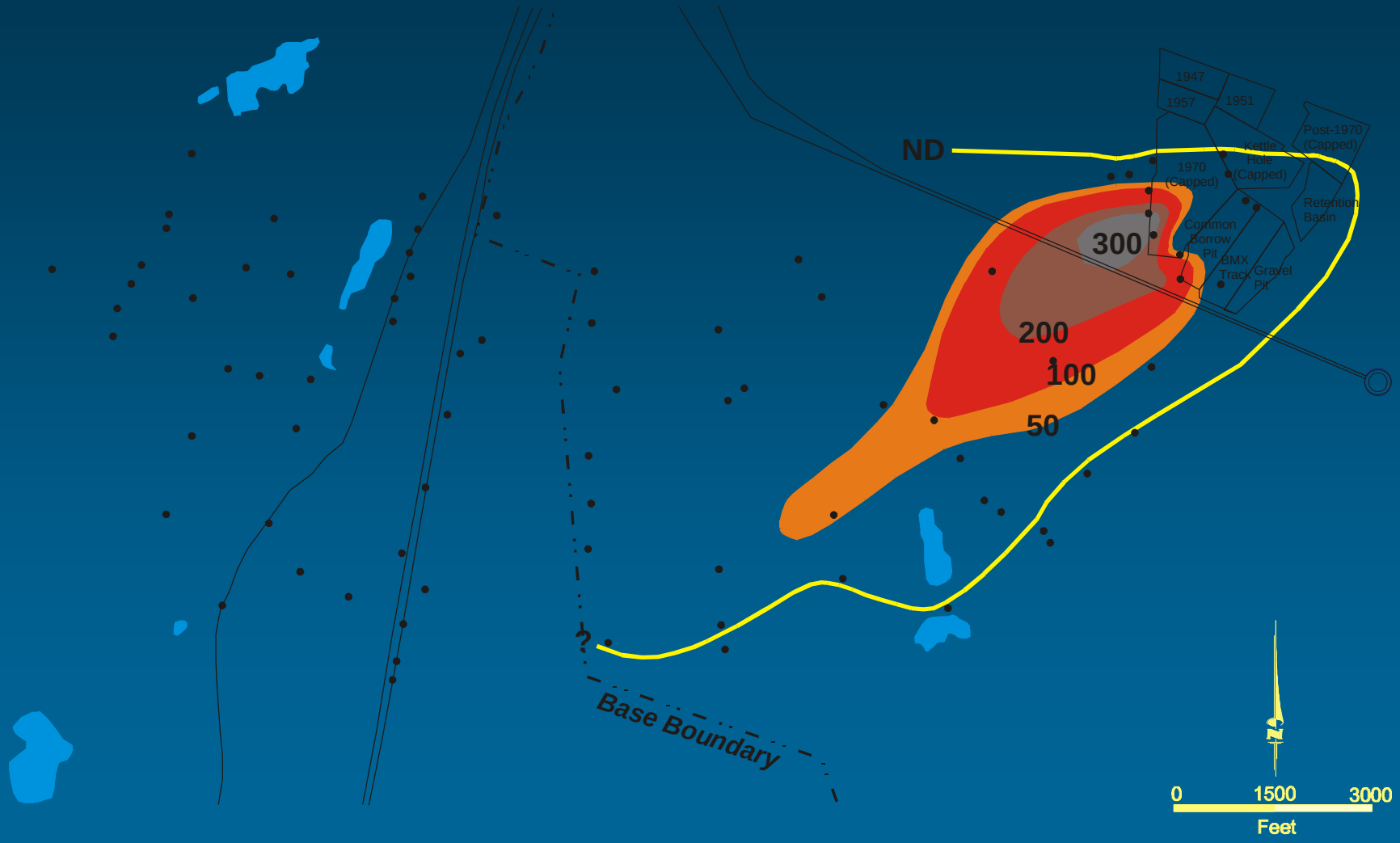
Groundwater Travel Time (years)



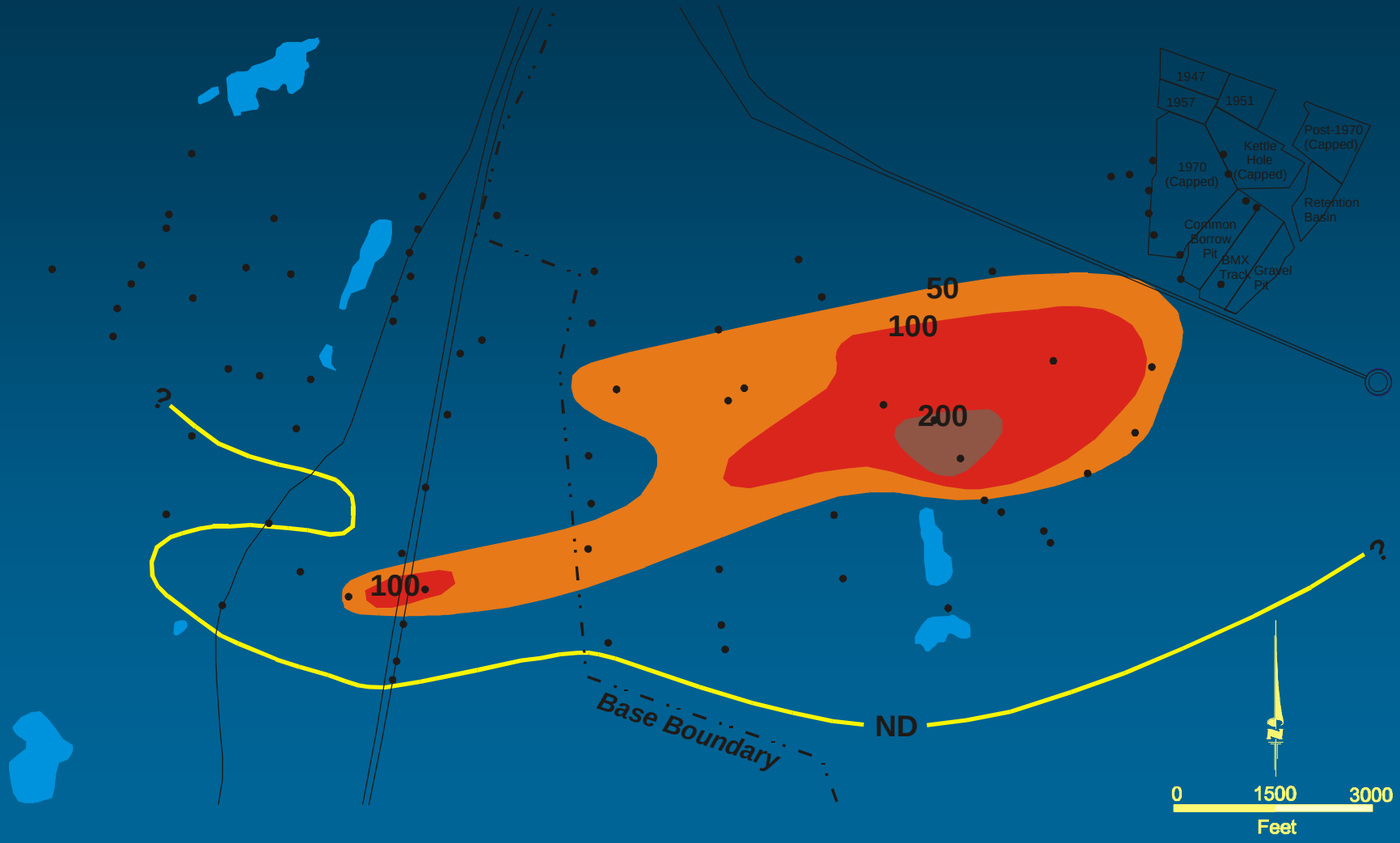
Geologic Cross Section



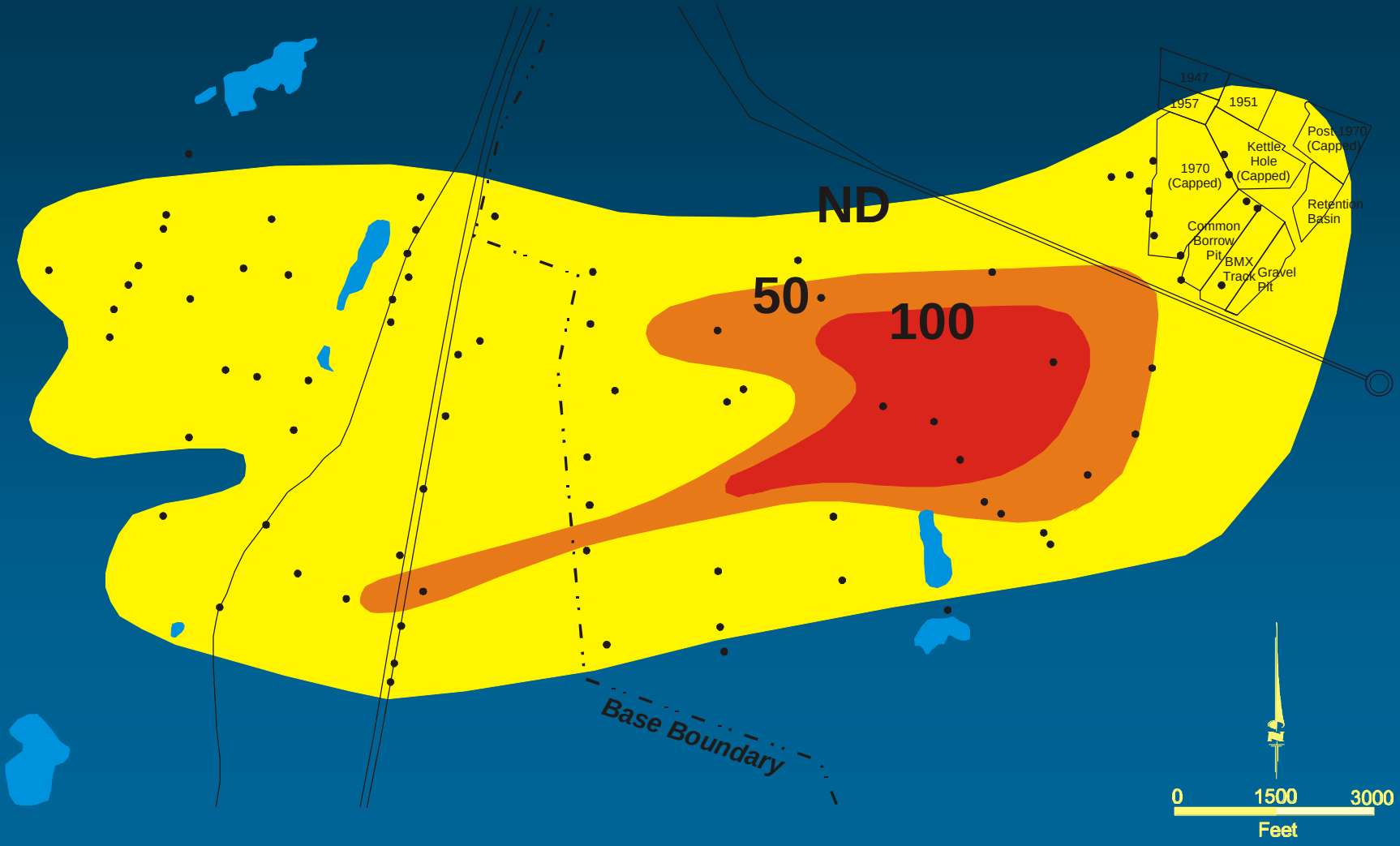
Total VOCs 10/89-4/90



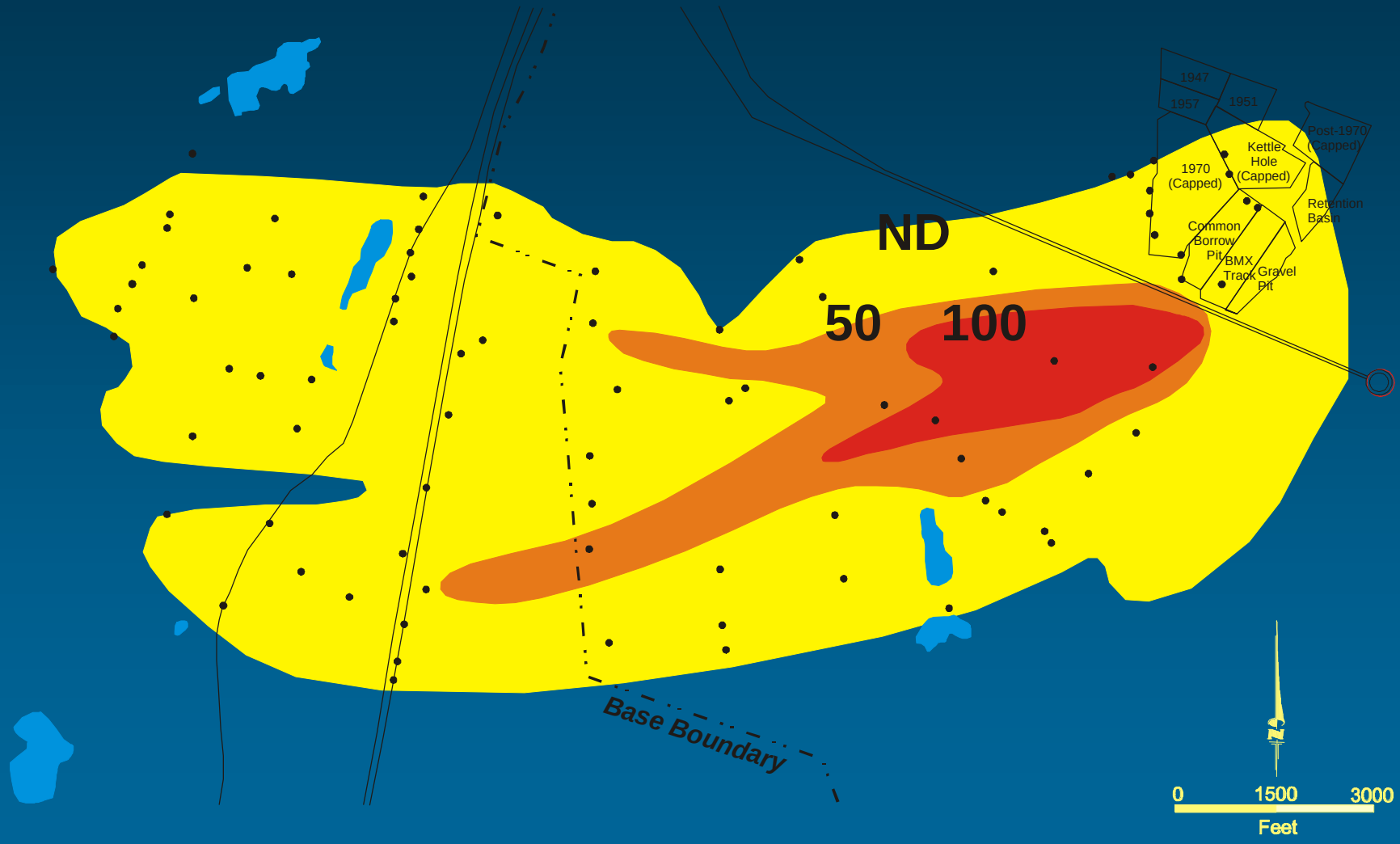
Total VOCs 2/93-12/94



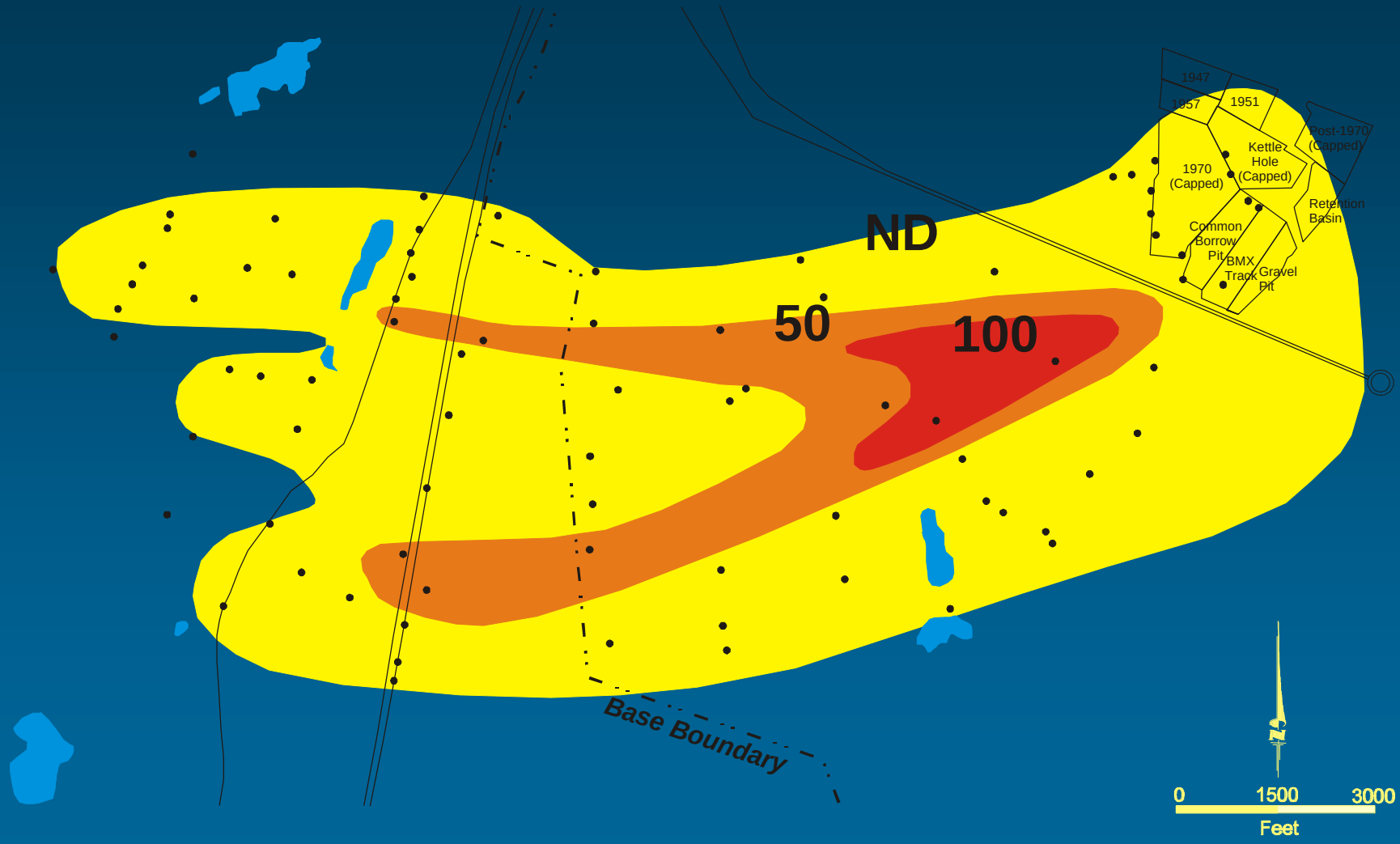
Total VOCs 3/95-12/95



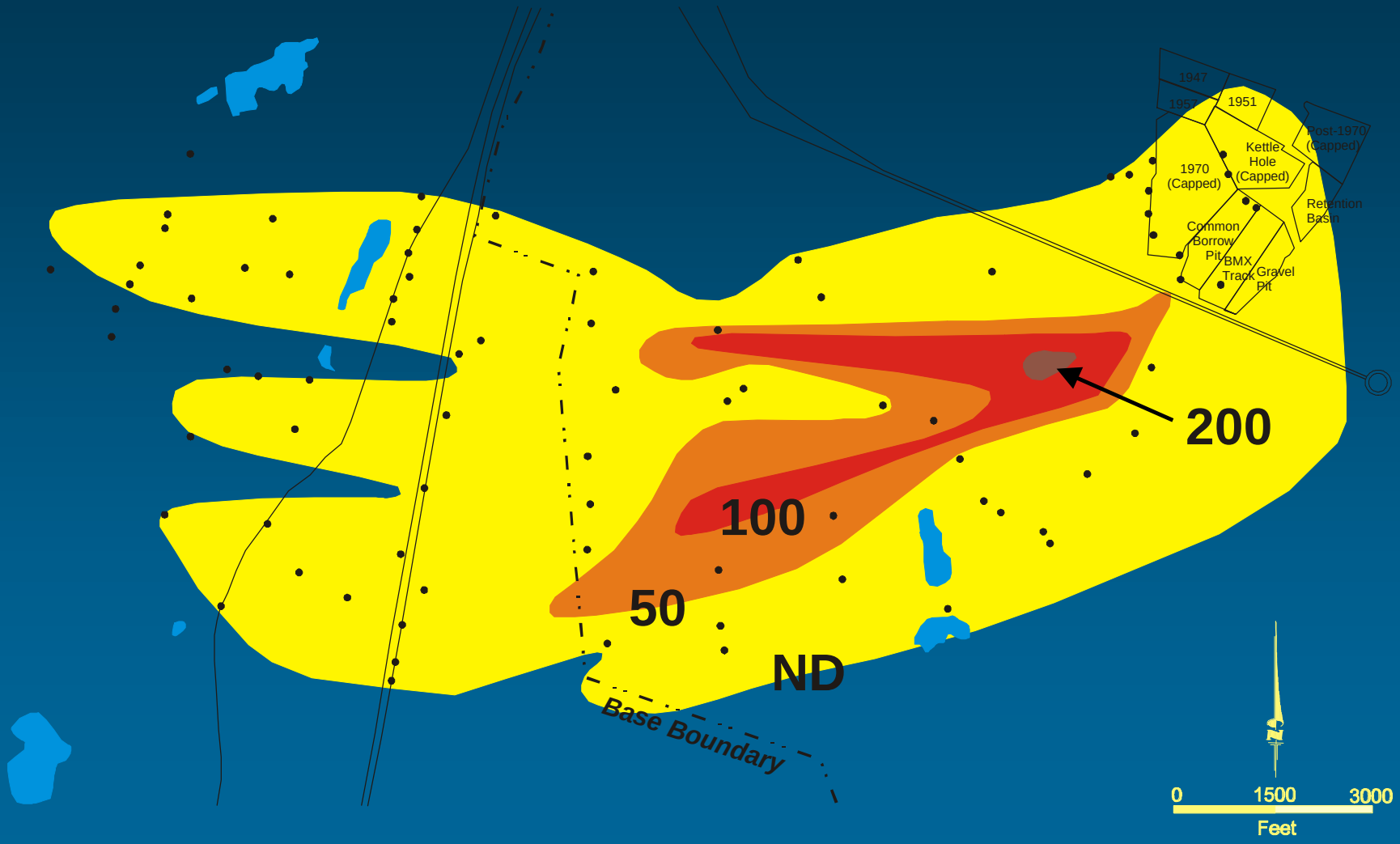
Total VOCs 1/96-12/96



Total VOCs 3/97-12/97

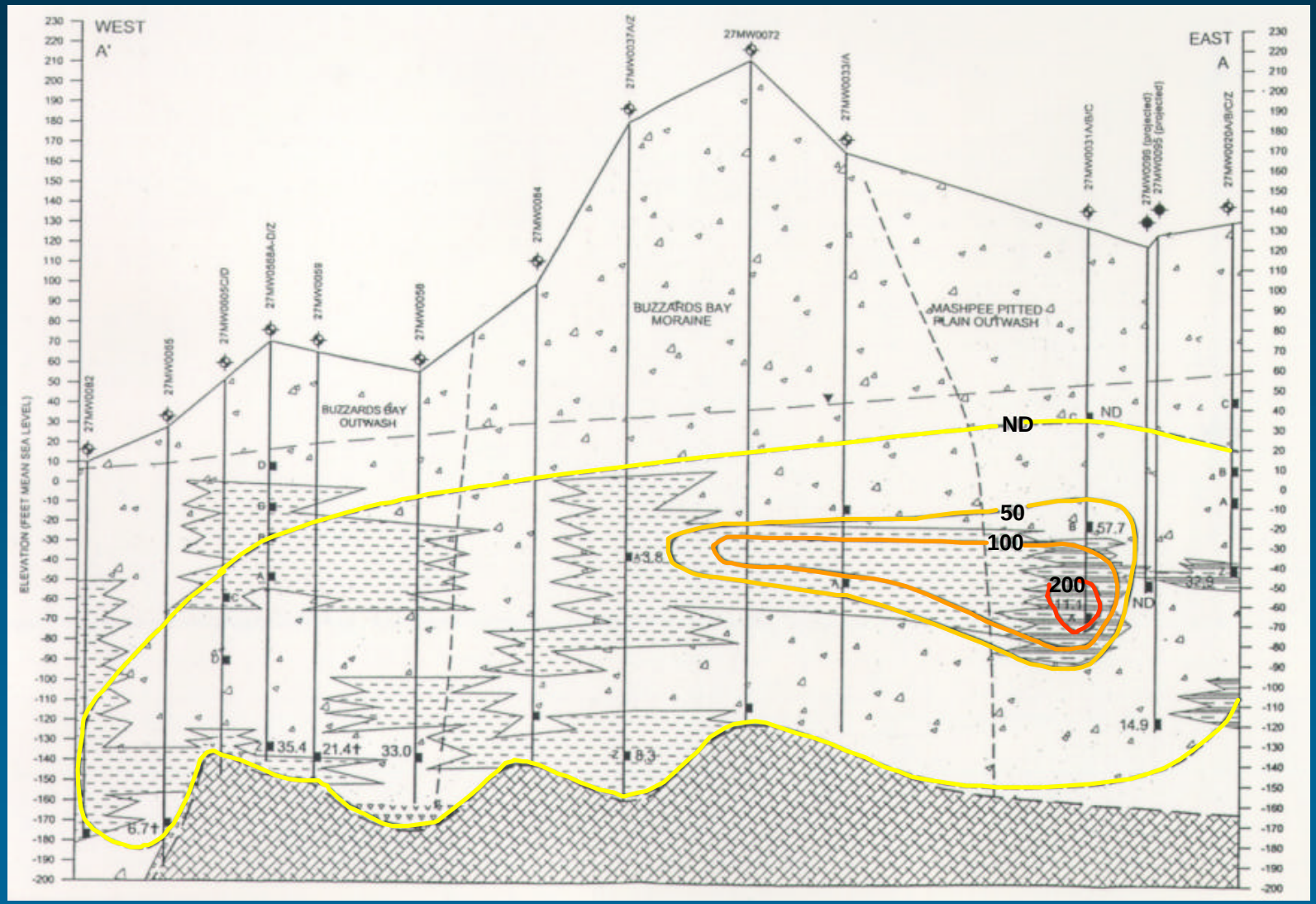


Total VOCs 1/98-8/98

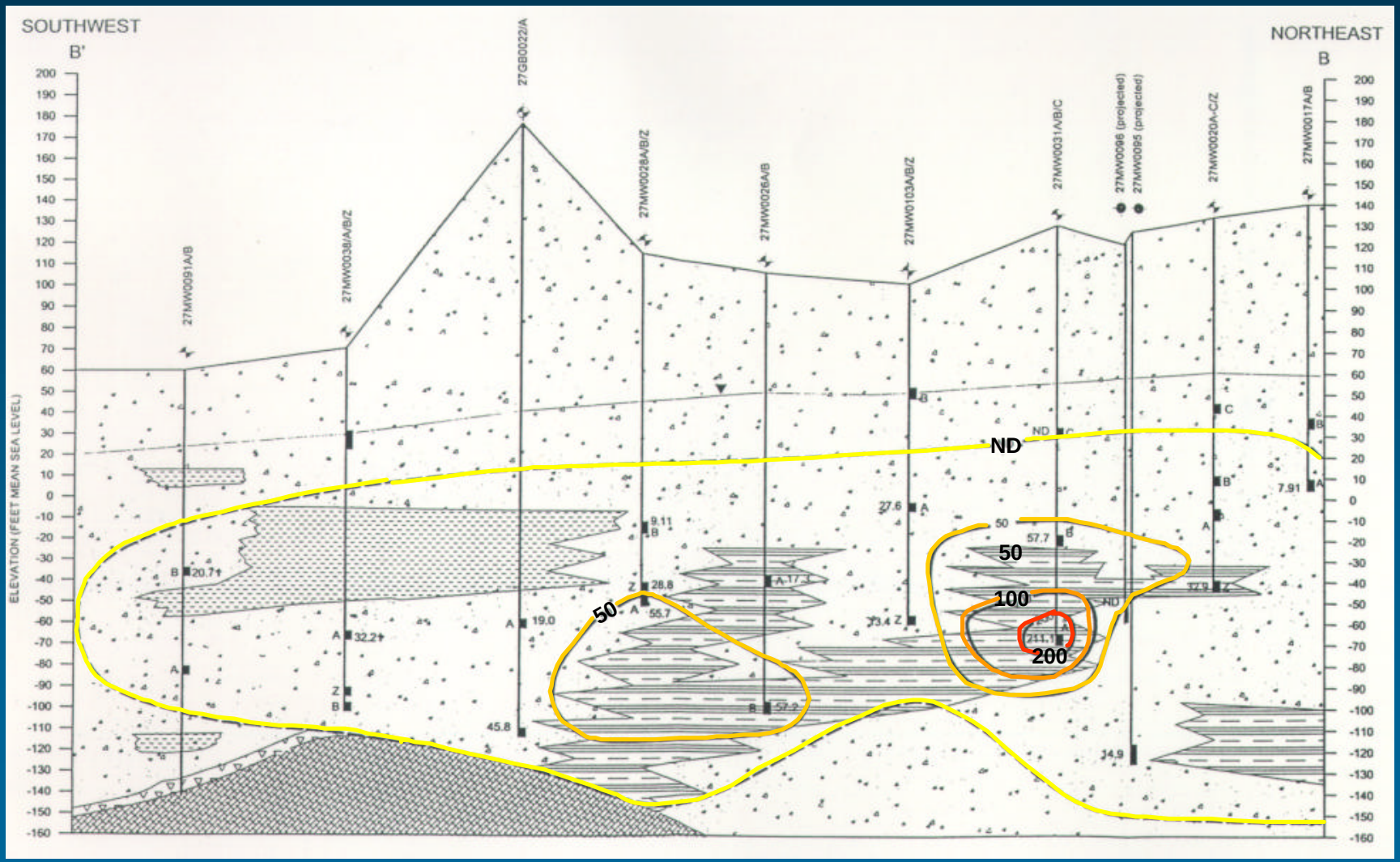


Cross-Section Location Map

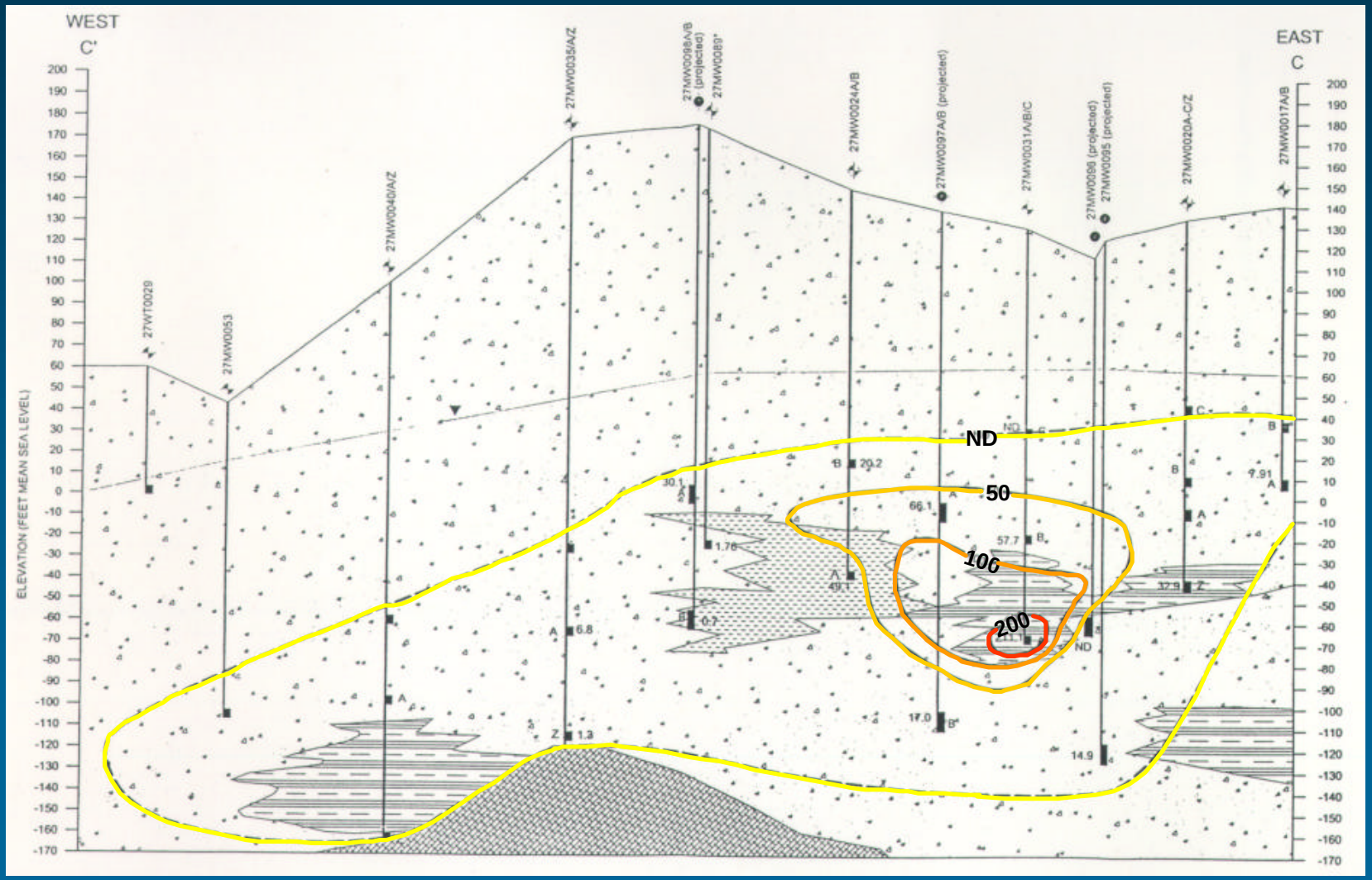
Distribution of Total VOCs Along Section A-A' at LF-1 (January 1998 - August 1998)



Distribution of Total VOCs Along Section B-B' at LF-1 (January 1998 - August 1998)



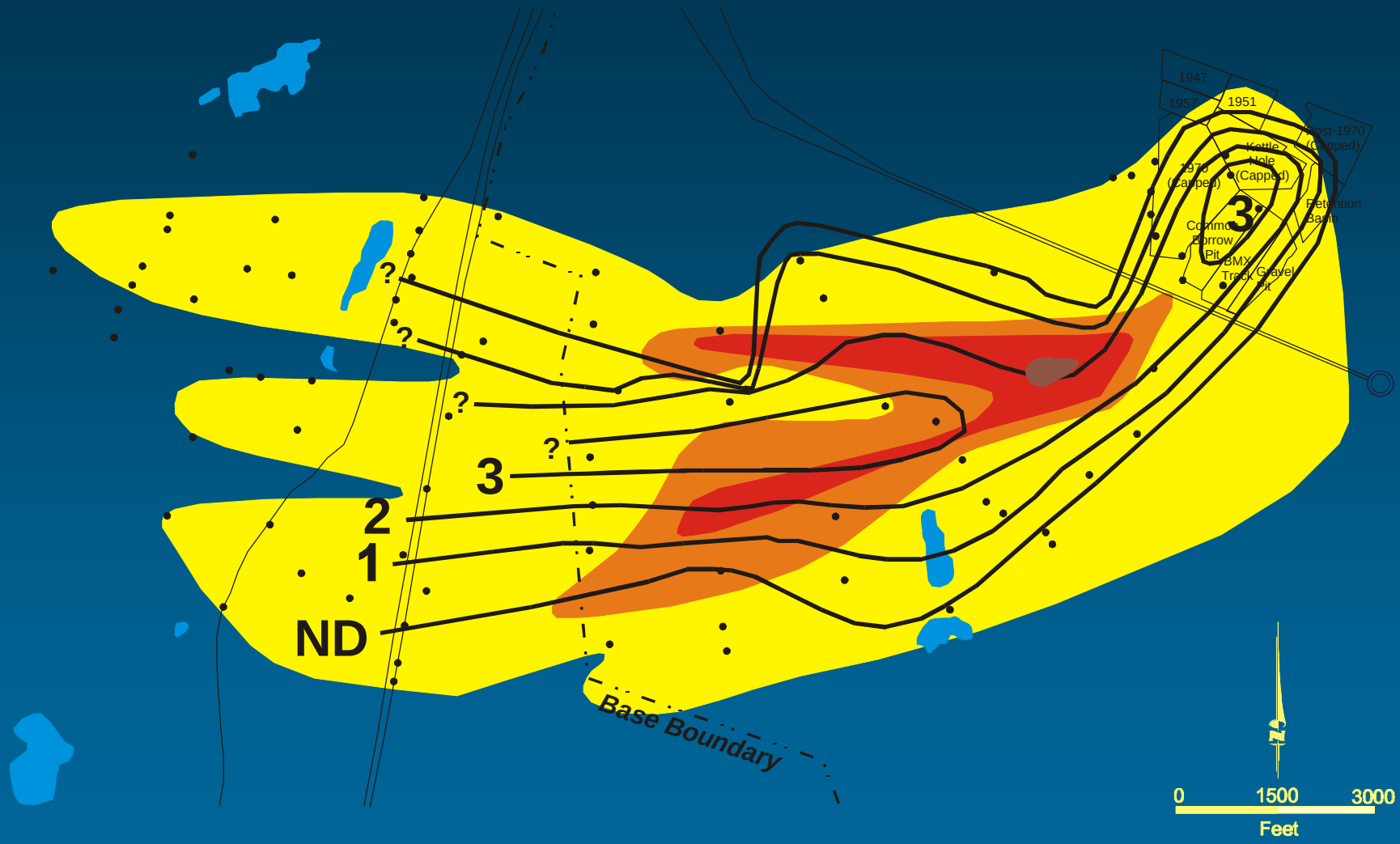
Distribution of Total VOCs Along Section C-C' at LF-1 (January 1998 - August 1998)



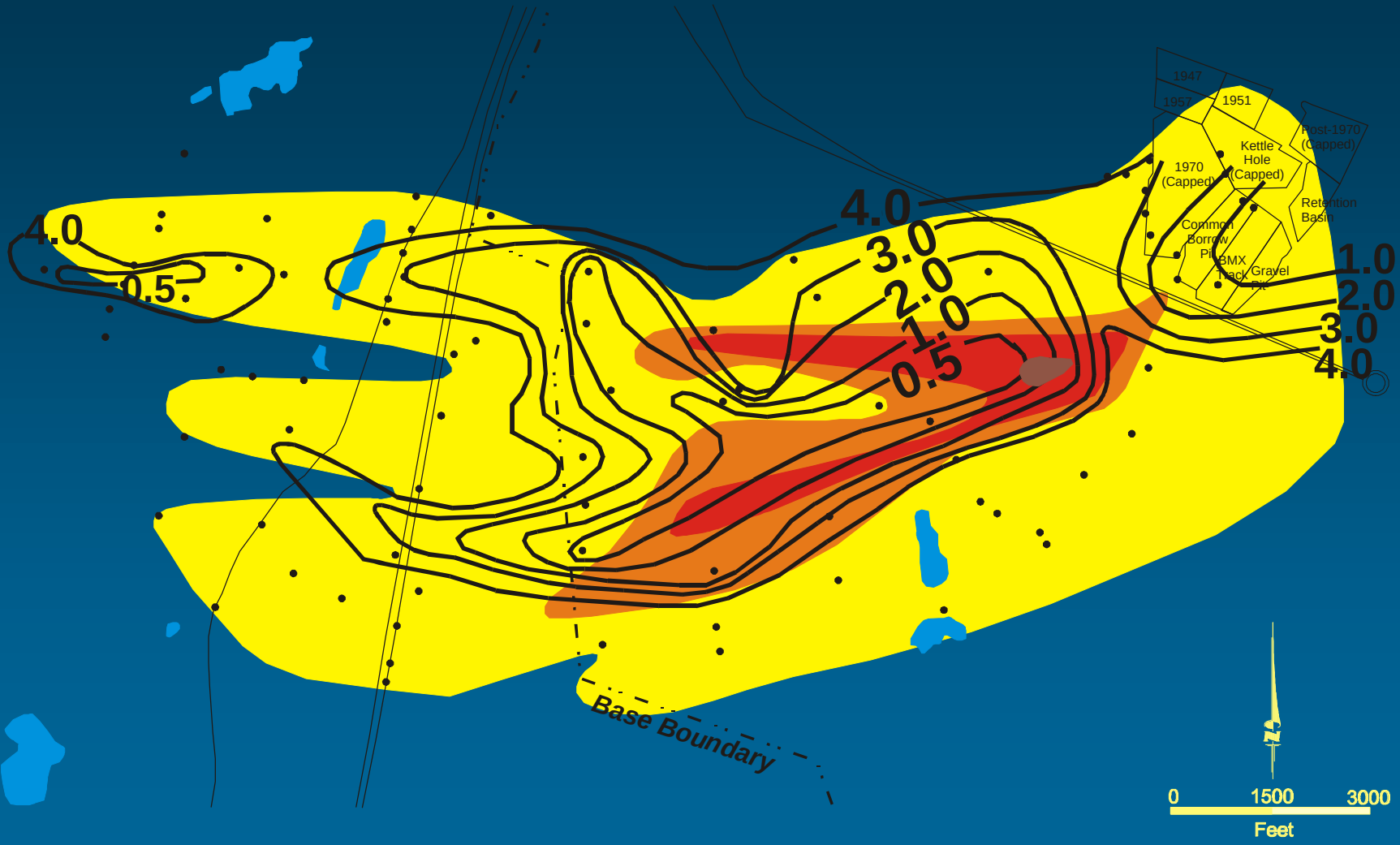
Natural Biodegradation: Second Line of Evidence

- **Positive indicators of contaminant biodegradation**
  - **Depleted Dissolved Oxygen and Sulfate Within the Plume**
  - **Elevated Fe(II), Methane, Alkalinity, Chloride, Carbon Dioxide, and Organic Carbon Concentrations Within the Plume**
  - **Lower oxidation reduction potential readings compared to background**

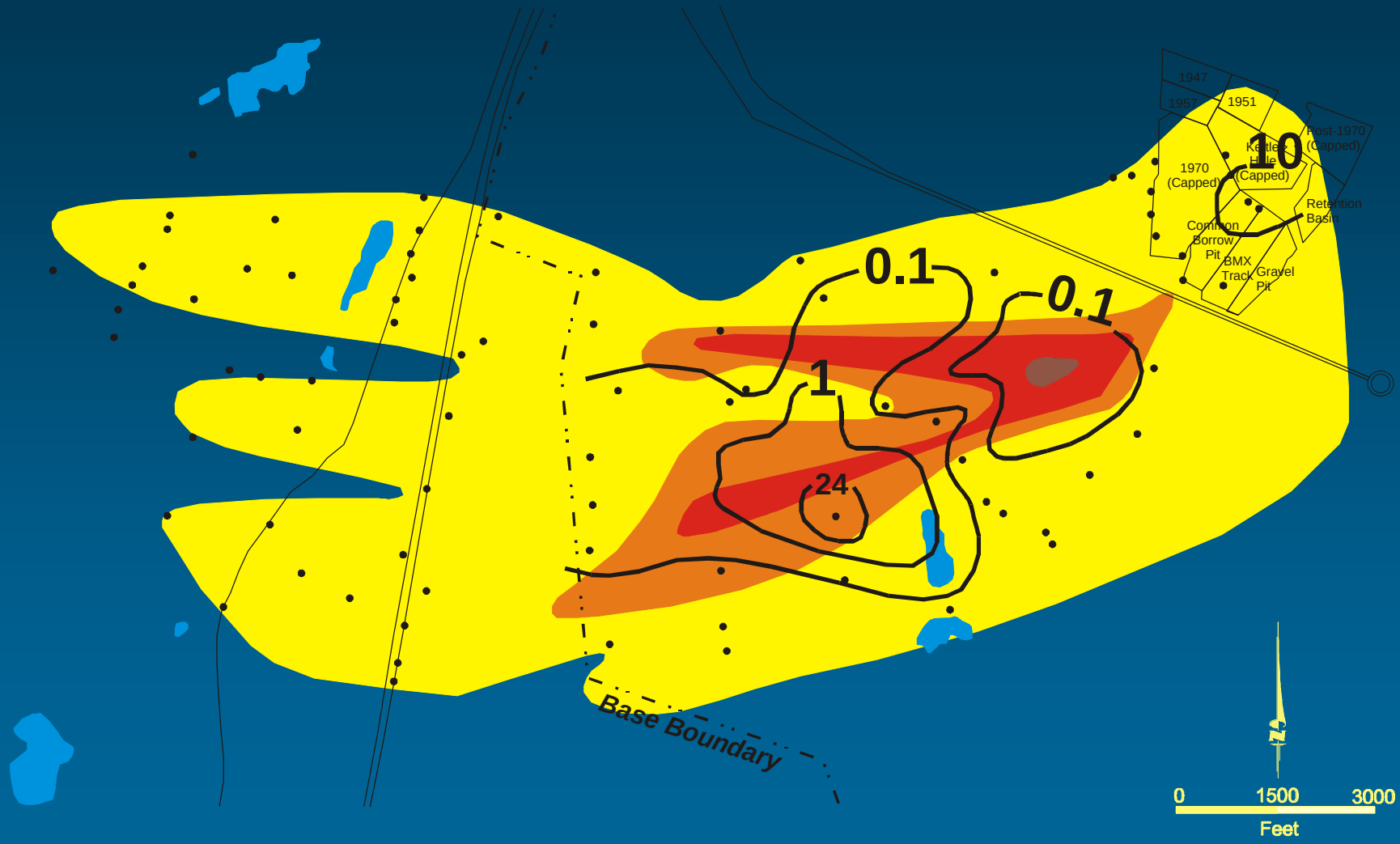
Total Organic Carbon (mg/L) 4/98



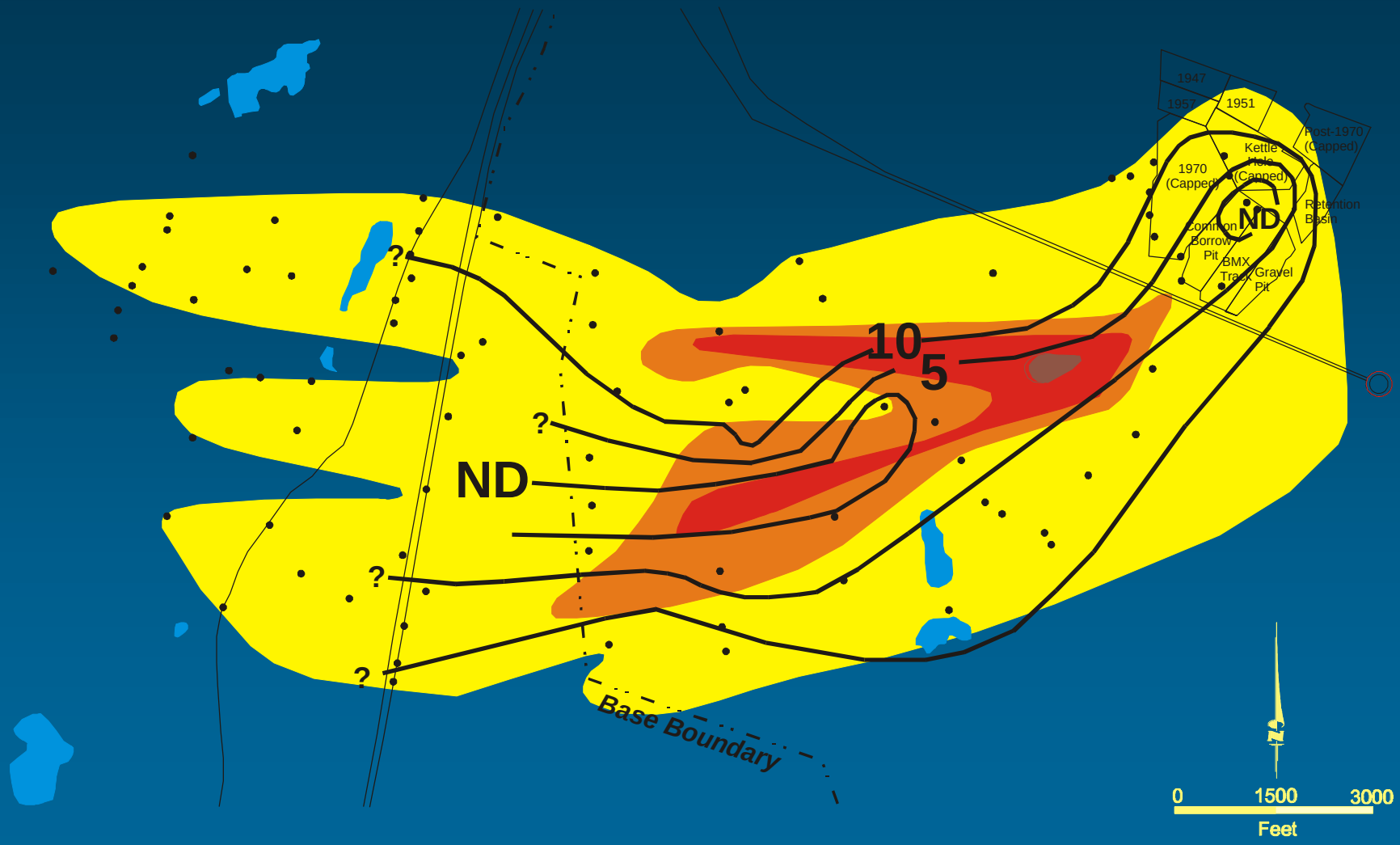
Dissolved Oxygen (mg/L) 4/98



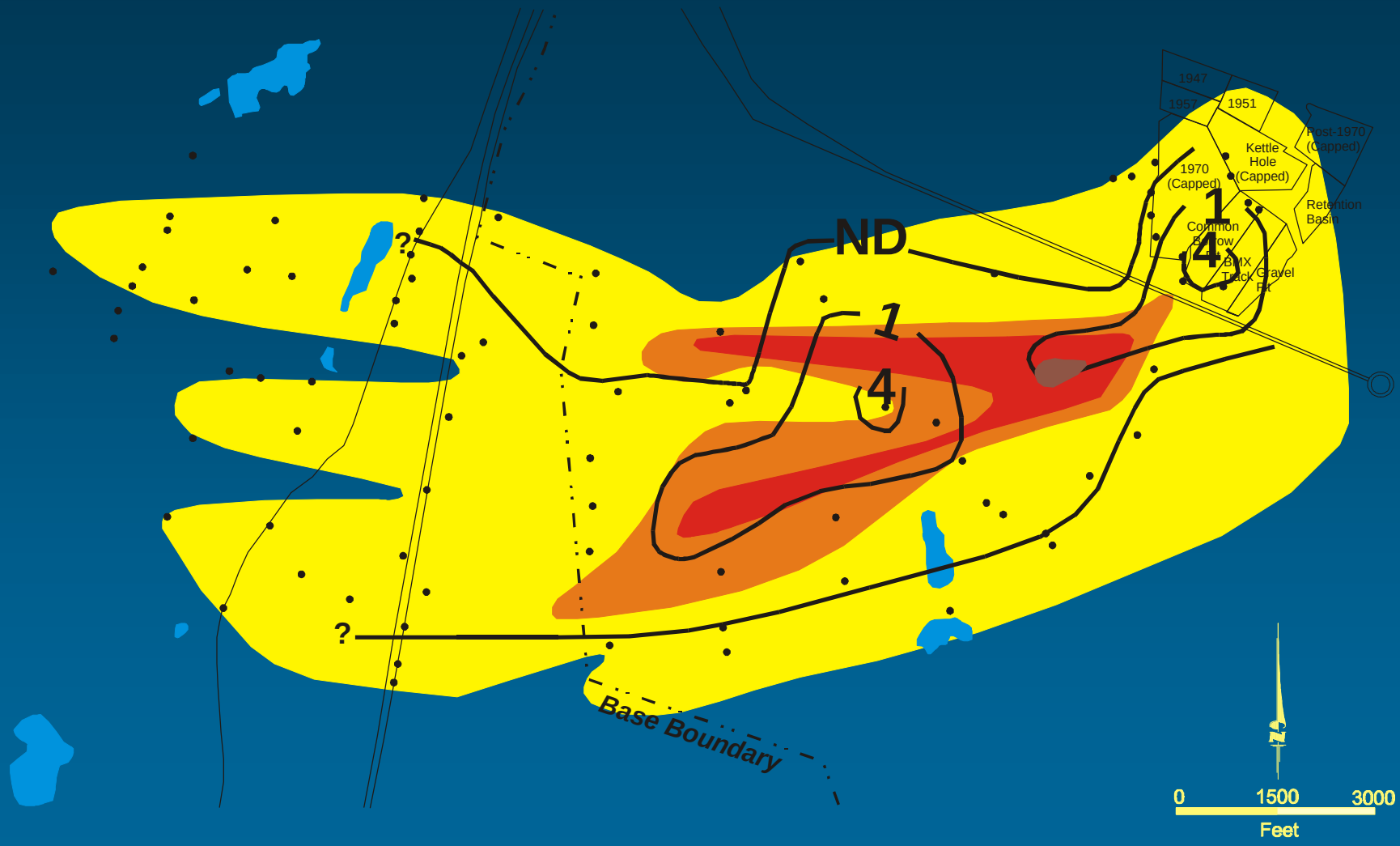
Fe(II) (mg/L) 4/98


1947
1957
1951
Post-1970 (Capped)
10
1970 (Capped)
(Capped)
Retention Basin
Common Borrow Pit
BMX Track
Gravel Pit
0.1
0.1
1
24
Base Boundary
N
0
1500
3000
Feet

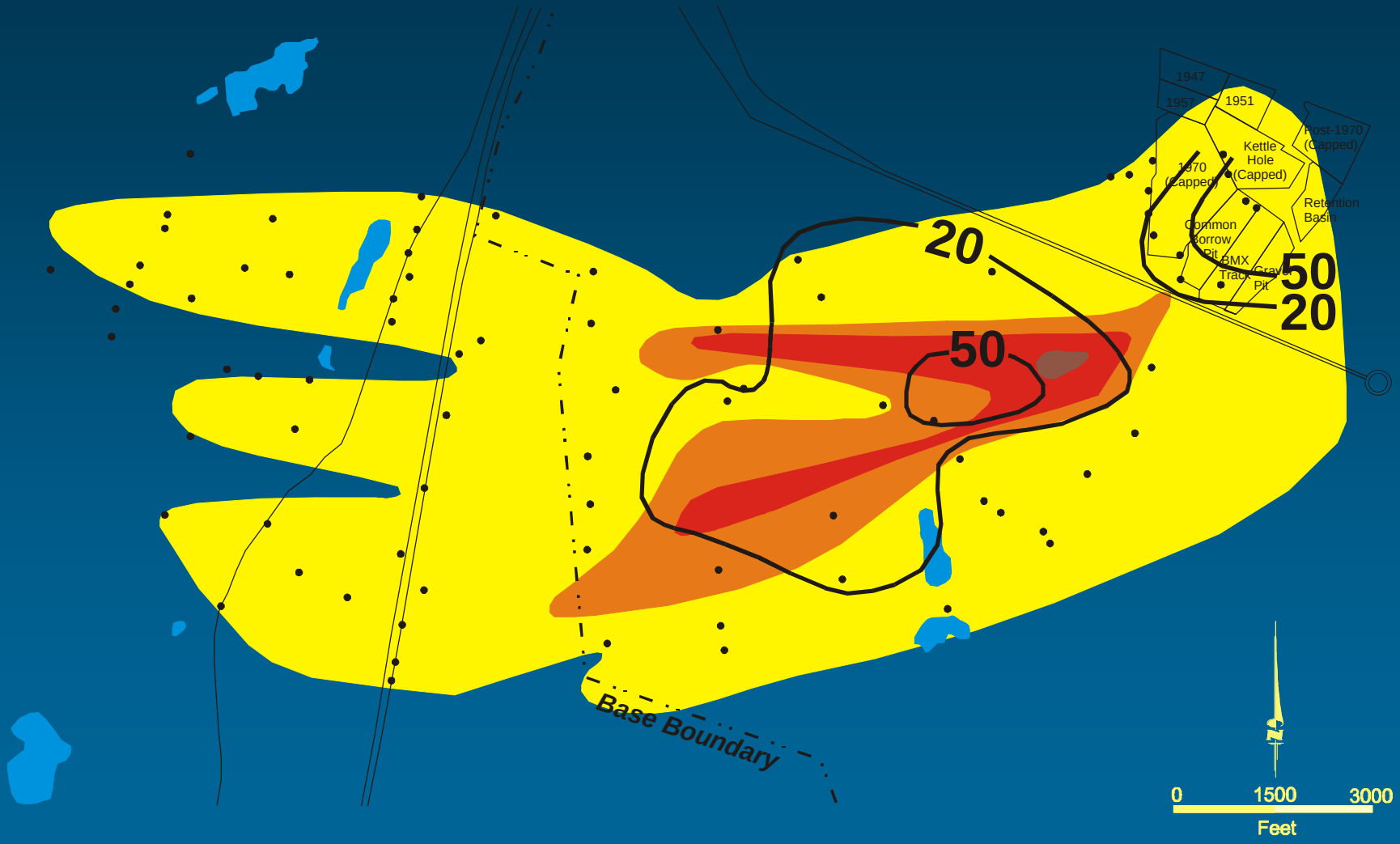
Sulfate (mg/L) 4/98



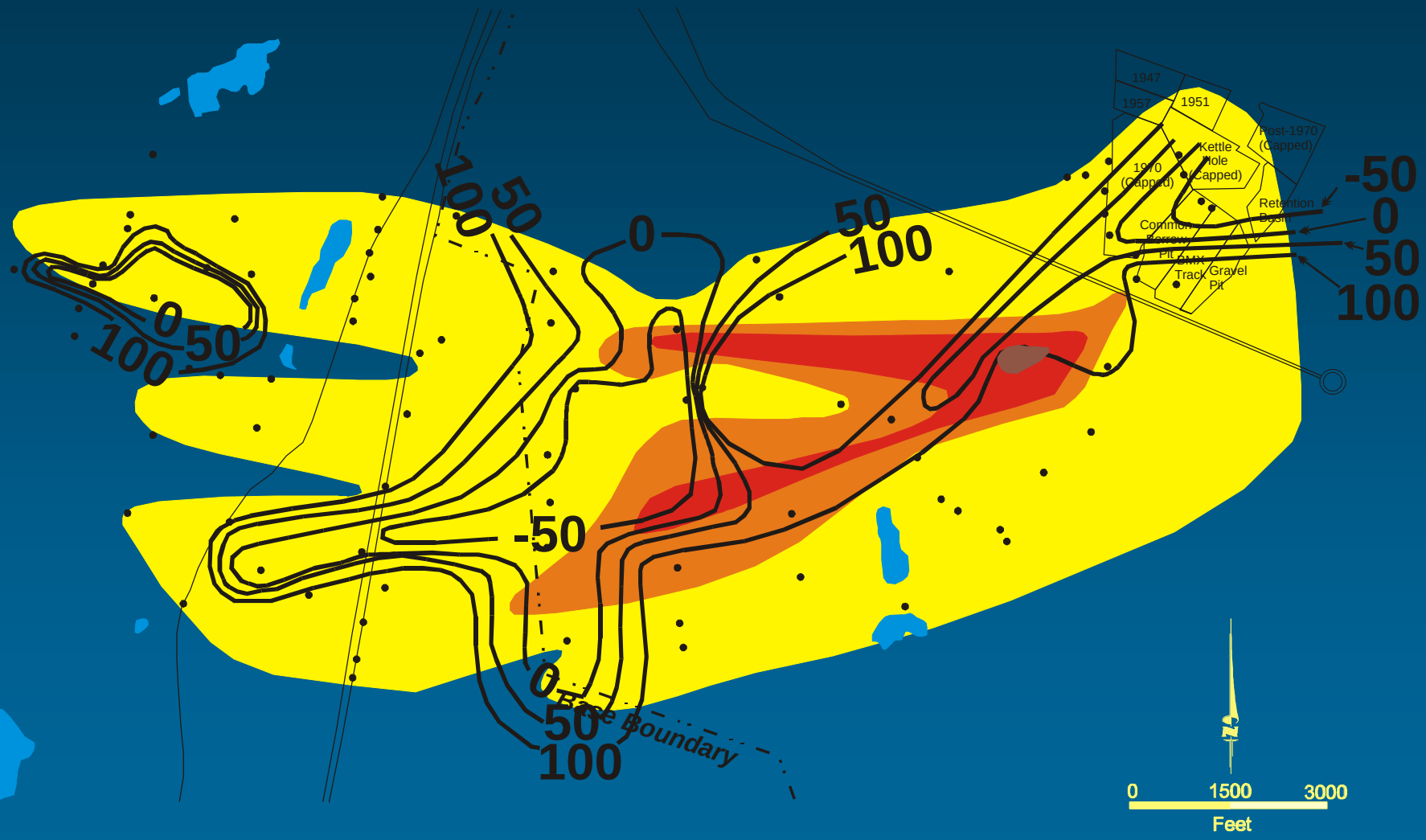
Methane (mg/L) 4/98



Carbon Dioxide (mg/L)



ORP (mV)


1947
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Retention Basin
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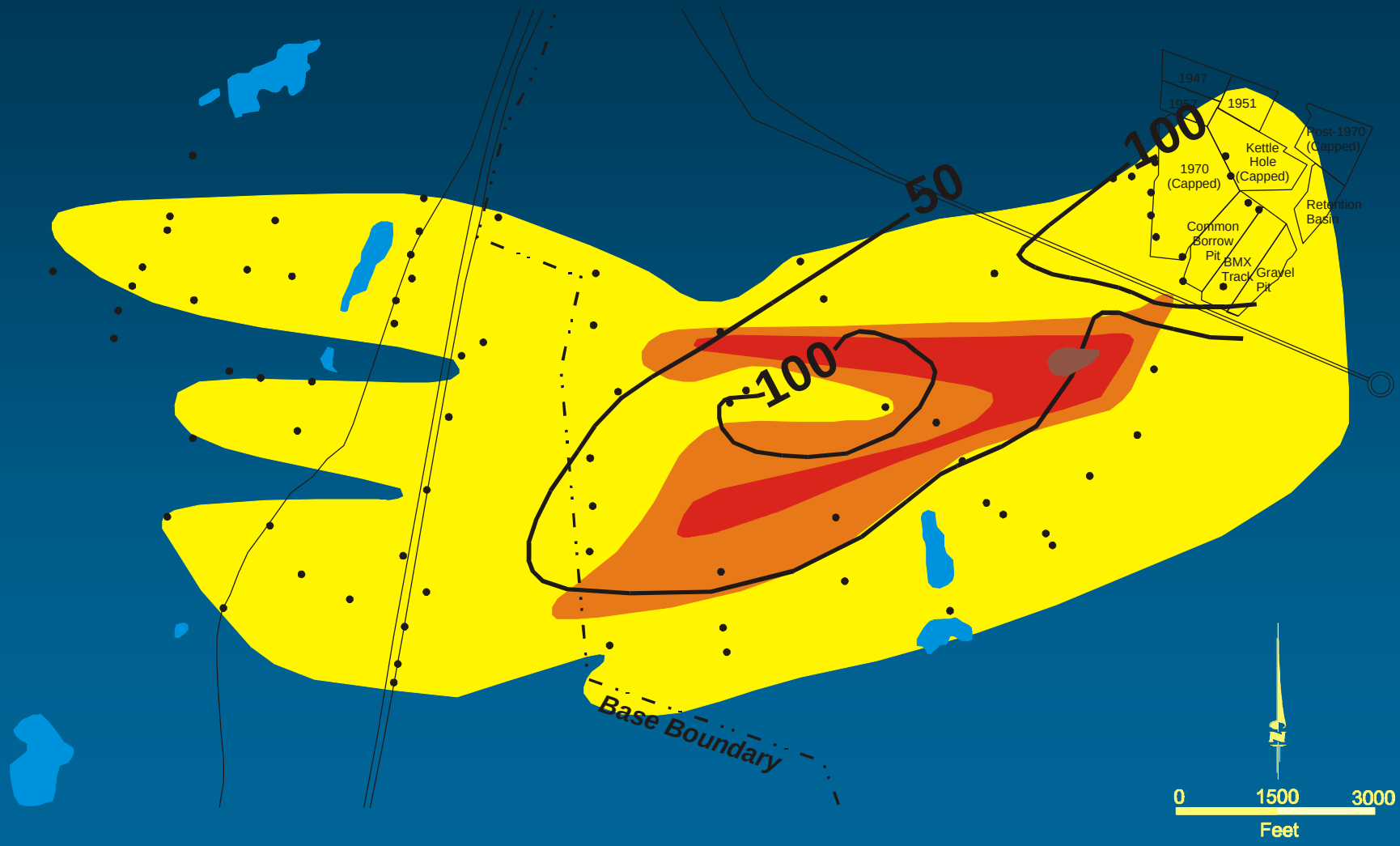
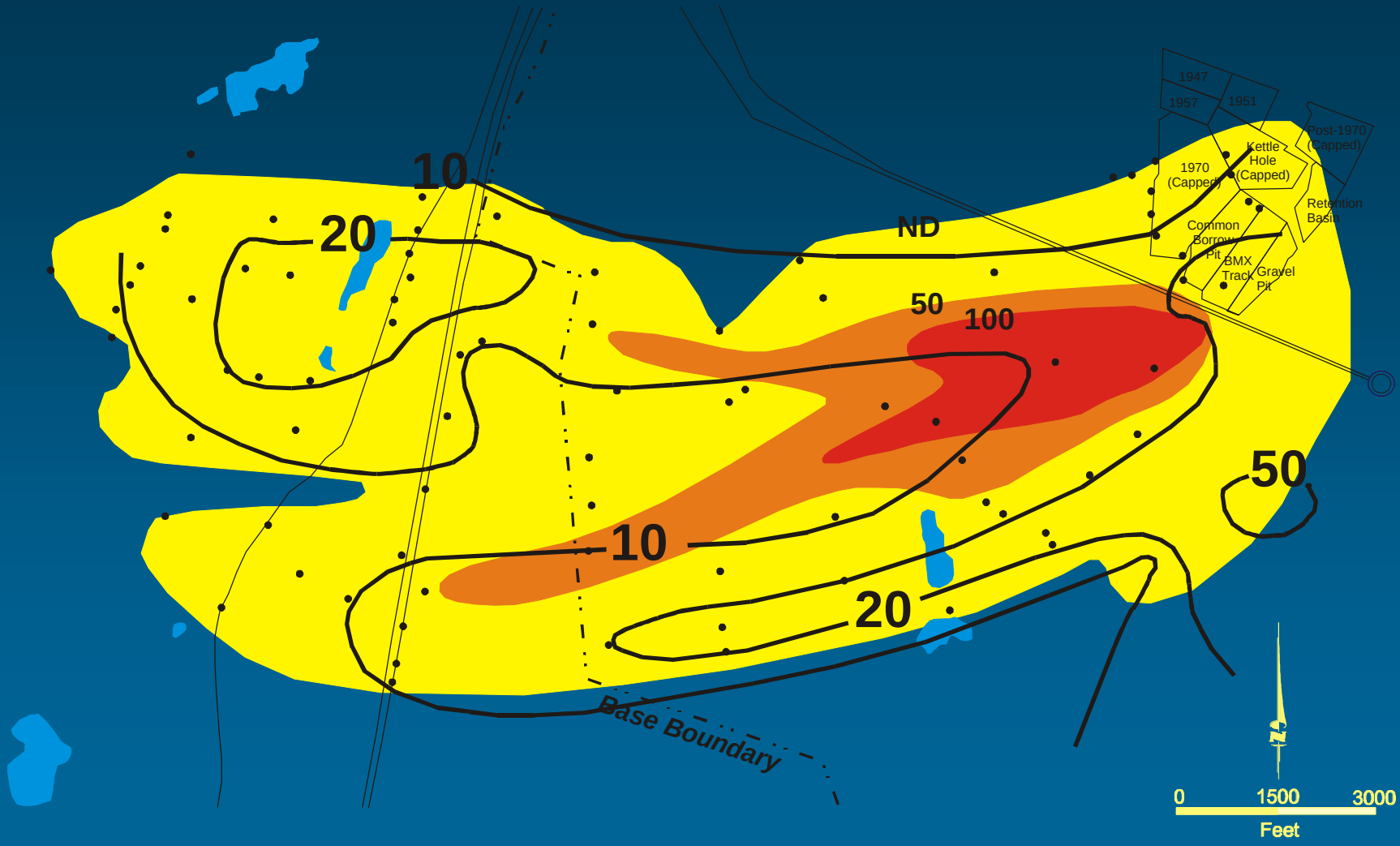
BMX Track
Gravel Pit
-50
0
50
100
100
50
0
50
100
0
50
100
-50
0
50
100
Base Boundary
N
0
1500
3000
Feet

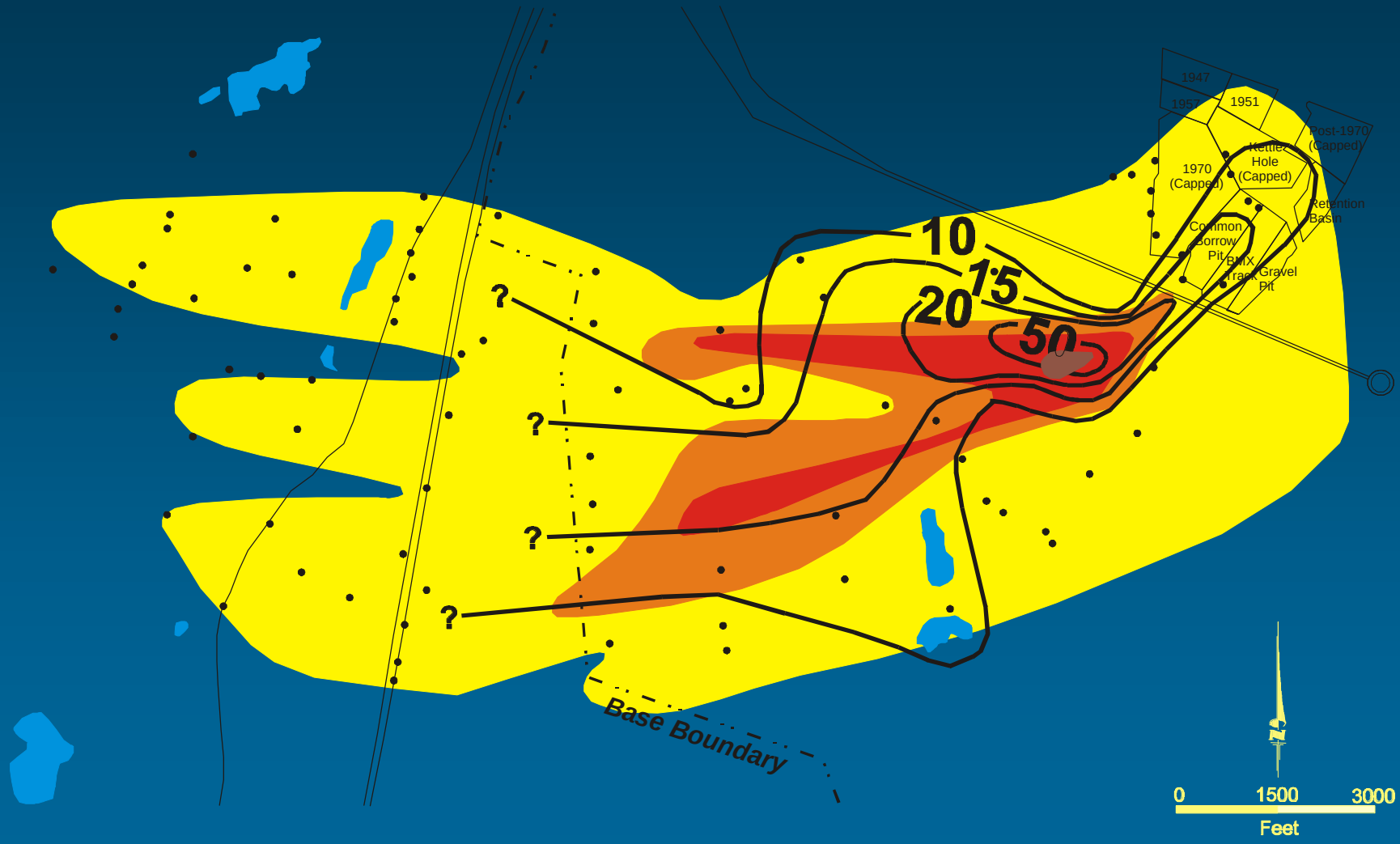
Alkalinity (mg/L)



Chloride (mg/L) - 1996



Chloride (mg/L) - 1998



Site-specific Geochemical Profile

Parameter	Background	Contaminated Zone
Oxygen (d)	11 mg/L	<0.5 mg/L
Nitrate	0.68 mg/L	ND
Iron(II)	<0.01 mg/L	18 mg/L
Sulfate	56 mg/L	ND
Methane (d)	<0.001 mg/L	4.4 mg/L
Carbon Dioxide (d)	<10 mg/L	190 mg/L
Alkalinity	14 - 37 mg/L	280 mg/L
ORP	~200 mV	-453 mV
Chloride	~10 mg/L	81 mg/L
Organic Carbon (d)	<0.76 mg/L	3.7 mg/L
Ethene	<0.1 ug/L	0.91 ug/L
Ethane	<0.1 ug/L	1.4 ug/L

Preliminary Screening Results

Analyte	Max Concentration	Value
Oxygen (d)	<0.5 mg/L	3
Nitrate	<0.6 mg/L	2
Iron II	18 mg/L	3
Sulfate	56 mg/L	2
Methane	4 mg/L	3
Redox	- 453 mV	2
Chloride	>2X Background	2
PCE (released)	0.02 mg/L	0
TCE (daughter)	0.03 mg/L	0
cis-DCE (none released)	0.04 mg/L	2
VC (none released)	0.0004 mg/L	2
	Total Points Awarded:	21

CONCLUSION: Strong Evidence for Biodegradation

Modeling Contaminant Transport at LF-1

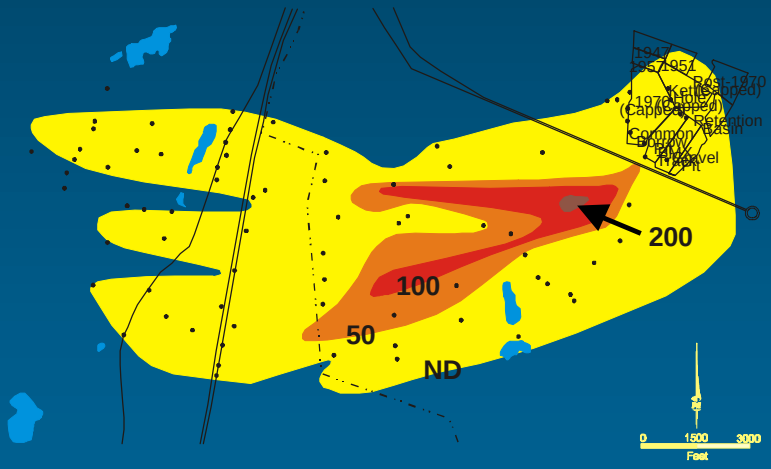
- **A Groundwater Flow and Solute Transport Model was used to Compare the Effectiveness of Natural Attenuation to Several Remedial Alternatives**
- **Modflow Coupled to ModflowT**

Modeling Contaminant Transport at LF-1

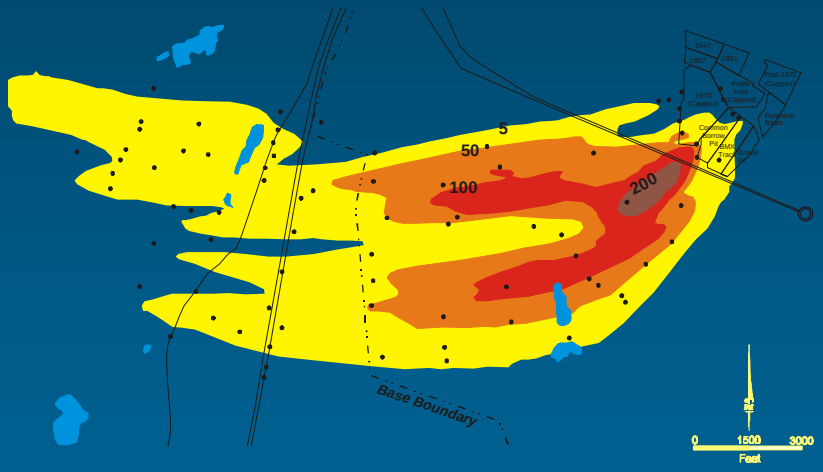
- **Complex Model**
  - **x = 29,040 feet**
  - **y = 16,500 feet**
  - **z = variable but on the order of 200 feet**
  - **21 layers**
  - **369,600 grid blocks!**

Observed vs Calibrated Plume

Observed Plume
1998



Calibrated Plume
1998



Observed Versus Simulated Mass vs Time

Year	Dissolved VOC Mass (kg), Field Data	Dissolved VOC Mass (kg), Simulated	Mass Loss via Biodegradation (kg), Simulated
1989	NA	4061	0
1990	3573*	3885	154
1991	NA	371	304
1992	NA	3548	450
1993	NA	3385	592
1994	3872	3227	730
1995	3819	3073	864
1996	3281	2923	994
1997	3218	2778	1120
1998	2542	2635	1242

Center of Mass and Mass Versus Time Calculations

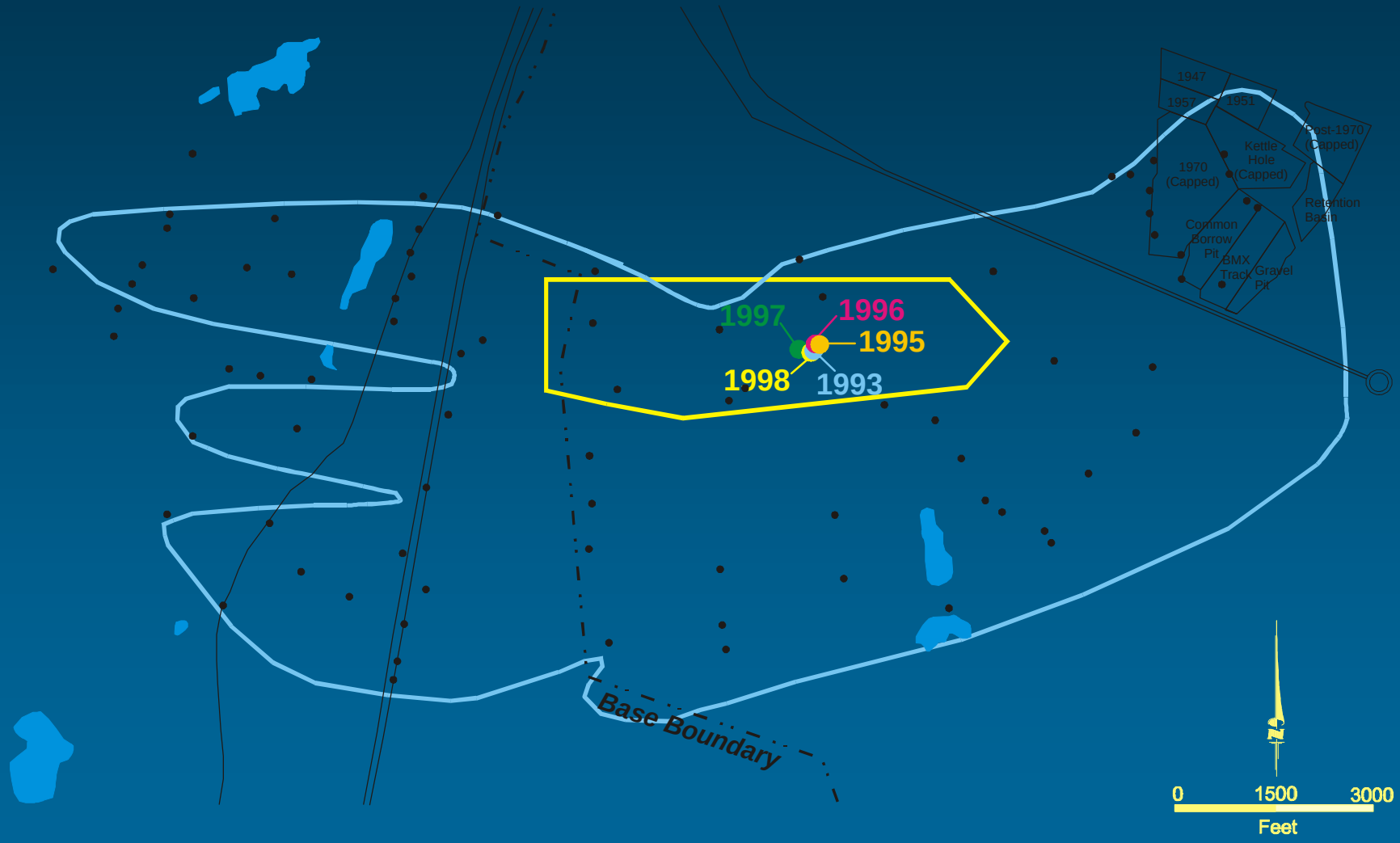
- Mass Estimates were independently conducted by two different methods
  - AutoCADD Integration Method (Lucas, M., 1998)
  - Numerical Model Methods (Schwind, P., 1998)

Center of Mass and Mass Versus Time Calculations

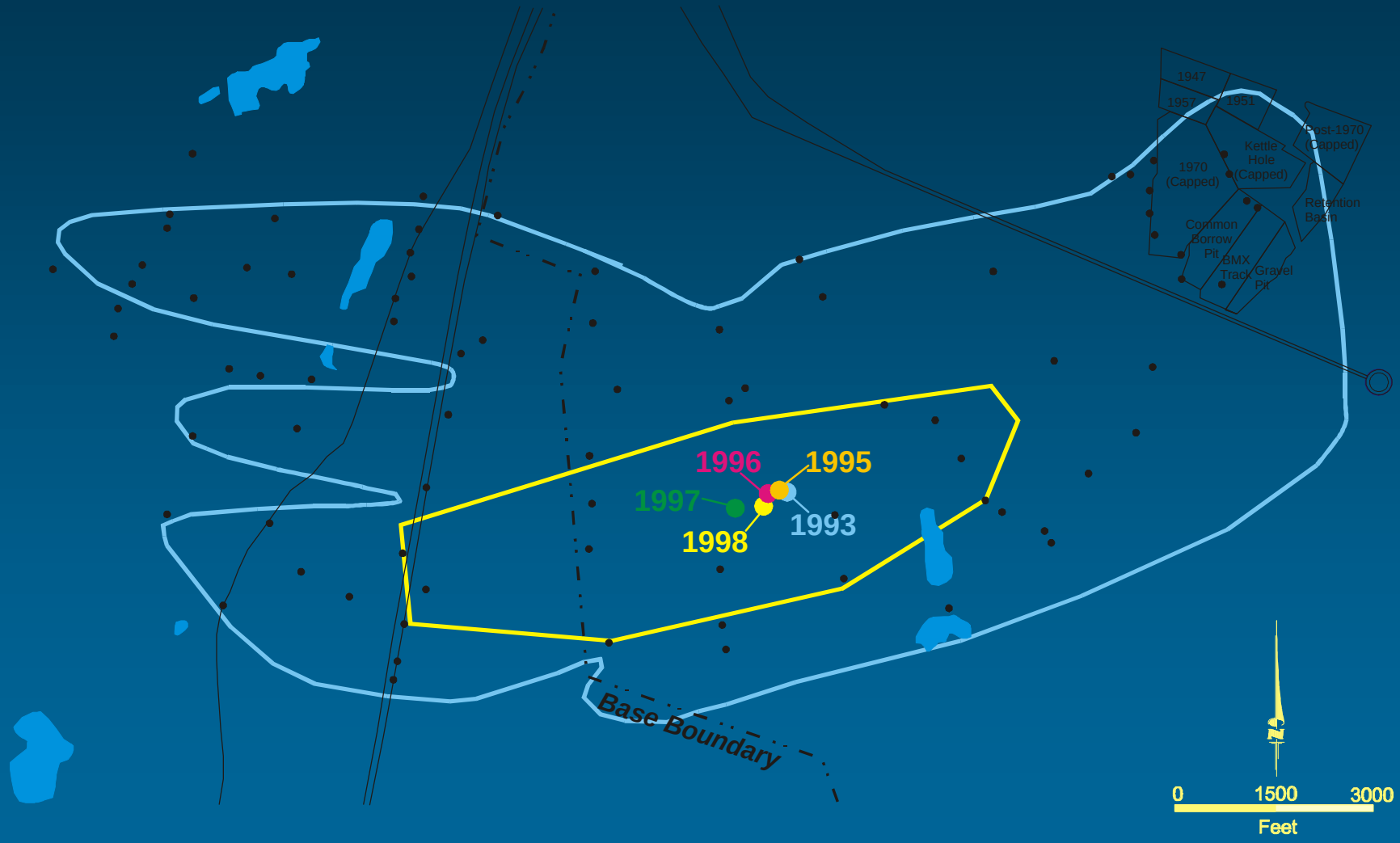
- Mass Estimates were conducted repeatedly
  - AutoCADD Integration before and after new monitoring well installation and sampling
  - Numerical Model before and after new monitoring well installation and sampling
  - After numerical model recalibration to simulate “warm-spots”
- Estimates were consistent throughout

Center of Mass–Zone A (1993-1996)

Center of Mass–Zone B (1993-1996)



Center of Mass–Zone C (1993-1996)



Center of Mass–Zone D (1993-1996)

Center of Mass–Zone E (1993-1996)

Focused Feasibility Study (FFS)

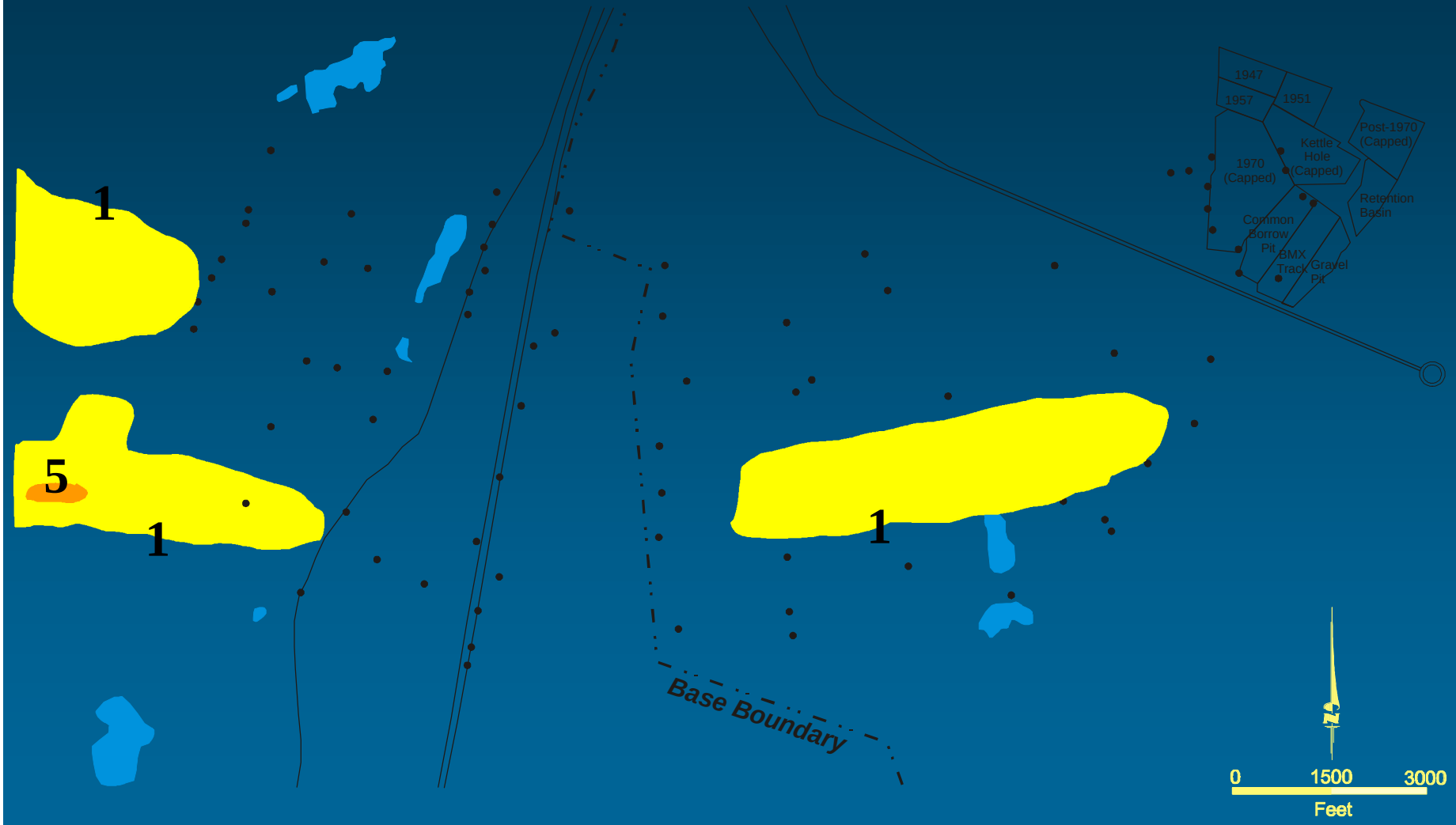
- 8 Unique Alternatives/Technologies
- Over 16 unique configurations
  - In addition, LF-1 Plume Response Decision Criteria Document evaluated 14 (11 unique to FFS) configurations
- Extraction, Treatment, and Reinjection Systems
  - 0.5 million gallons per day (mgd) to 8.7 mgd
  - Full plume interception through “warm spot” interceptions
  - No “pull back the whole plume” system feasible

Modeling Contaminant Transport at LF-1

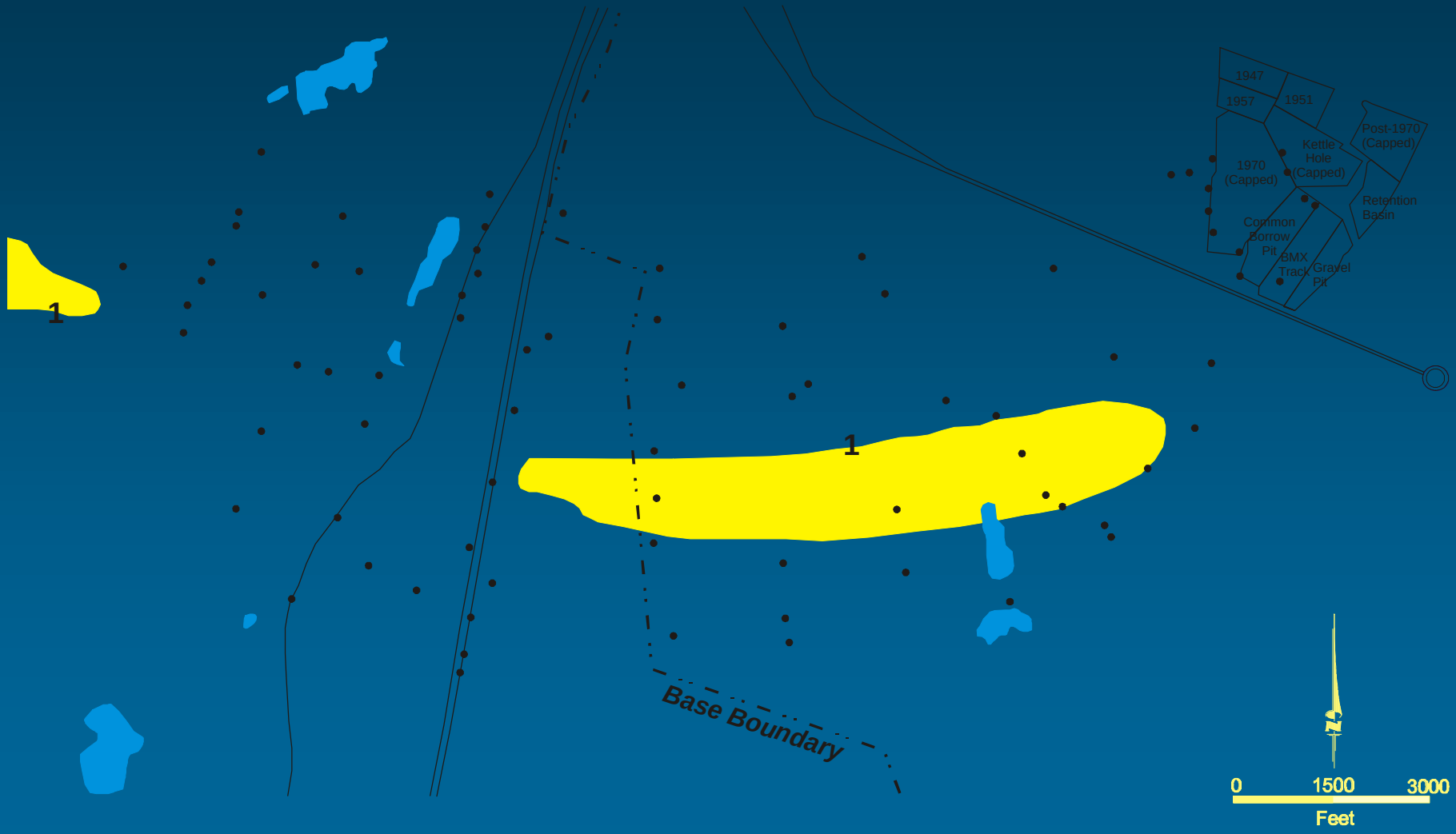
- **Natural Attenuation was Compared to 7 Extraction, Treatment, and Reinjection (ETR) Scenarios**
- **Some Very Interesting Things Came to Light**

Total VOCs 2048 MNA Only

Total VOCs 2048 Alternative 3E



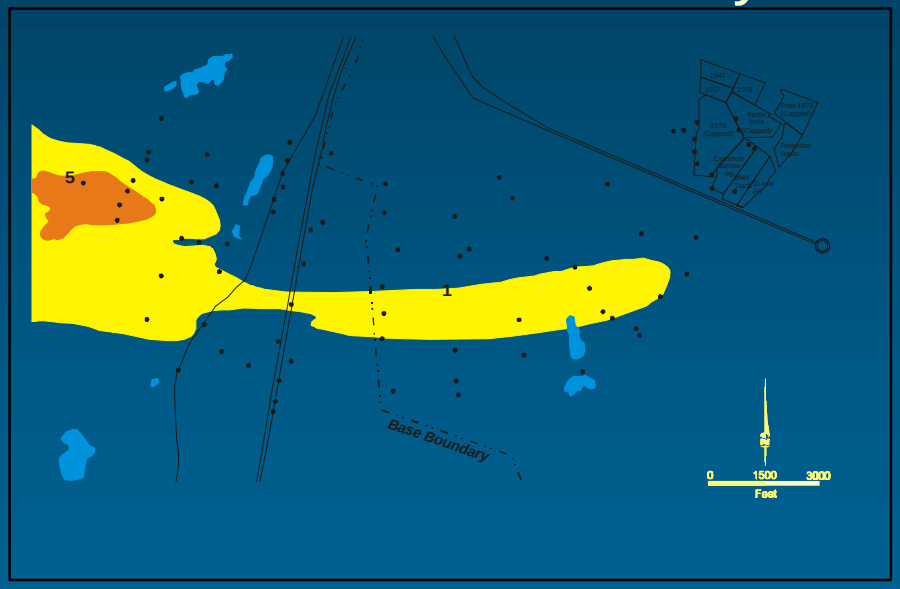
Total VOCs 2048 Alternative 3A



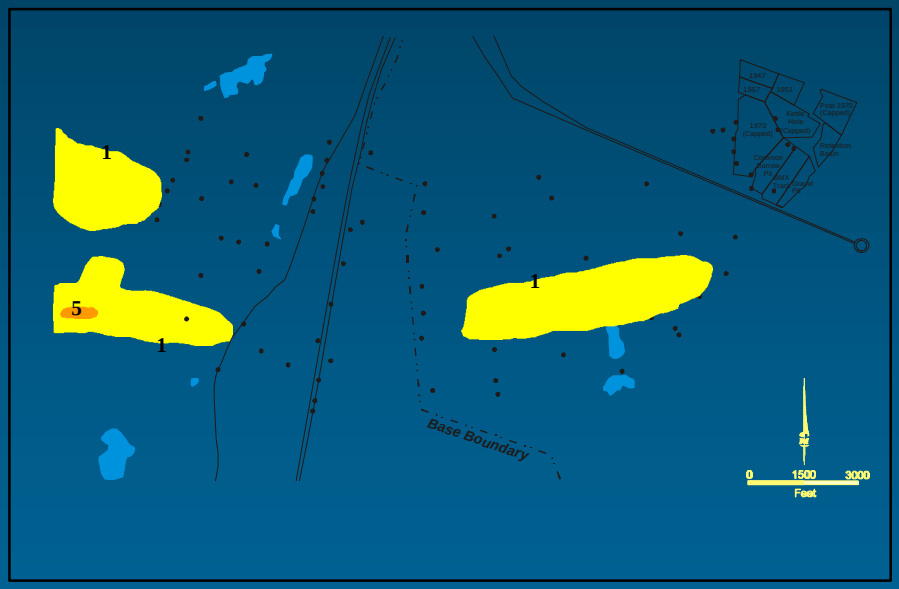
Total VOCs 2048 Alternative 3B

Comparison of MNA and Alternative 3E – Year 2048

Total VOCs
Natural Attenuation Only



Total VOCs
Alternative 3E



Not Much Difference in Contaminant Distribution
However, the Cost Difference between Alternative 3E and Monitored Natural Attenuation = $68,000,000

Comparison of Total VOC Mass Remaining

Alternative	Total VOC Mass Remaining in Modeled Subsurface (kg)						Cost (Millions)
	1998	2008	2018	2028	2038	2048	
2 – MNA	2,635	1,404	651	277	120	55.9	3
3A – ETR (ALTERNATIVE E)	2,635	1,186	434	133	37.1	10.4	160
3B – ETR (MODIFIED E)	2,635	1,058	376	130	46.3	17.4	120
3C – ETR (EPA)	2,635	1,054	375	130	45.4	16.3	106
3D – ETR (Cataumet)	2,635	1,300	571	235	97.2	42.8	40
3E – ETR (Warm Spots)	2,635	1,087	399	140	53.2	21.4	71
4A – Protection of Bourne Wells (ETR Modified 3B)	2,635	1,321	596	261	116	54.8	45
4B – Protection of Bourne Wells (ETR)	2,635	1,372	615	249	102	46.3	62

Comparison of Peak Total VOC Concentrations

Alternative	Peak Total VOC Aquifer Concentration (µg/L)	
	2018	2048
2 – MNA	52.7	7.8
3A – ETR (Alternative E)	53.1	3.2
3B – ETR (Modified E)	43.6	3.1
3C – ETR (EPA)	52.7	2.7
3D – ETR (Cataumet)	53.3	5.1
3E – ETR (Warm Spots)	52.9	5.2
4A – Protection of Bourne Wells (ETR Modified 3B)	41.8	6.2
4B – Protection of Bourne Wells (ETR)	52.8	7.0

Costs

Remedial Alternative	Mass Removed Over Natural Attenuation After 50 years (Kg)	Total Remediation System Cost (dollars)	Cost per Additional Kilogram Removed
MNA	0	3,000,000	0
3A	46	160,000,000	$3,500,000/Kg
3B	39	120,000,000	$3,000,000/Kg
3C	40	106,000,000	$2,650,000/Kg
3D	13	40,000,000	$3,000,000/Kg
3E	35	71,000,000	$2,000,000/Kg
4A	1	45,000,000	$45,000,000/Kg
4B	10	62,000,0000	$6,200,000/Kg

MNA vs the Selected ERT System

Criteria	ETR – 3E	MNA
20-year Peak Concentration	53 ug/L	53 ug/L
50-year Peak Concentration	5 ug/L	8 ug/L
Mass removed over last 9 years	Not Applicable	2700 lbs
Mass removed after 10 years	3400 lbs	2700 lbs
Mass removed after 20 years	4900 lbs	4400 lbs
Mass removed after 50 years	5800 lbs	5700 lbs

ETR - 3E: "Warm-spot ETRS; Northern and Southern Lobes; 1.7 mgd

MNA vs the Selected ERT System

Criteria	ETR – 3E	MNA
Capital Costs	$10.4M	$0.5M
20-year Lifecycle Cost	$35M	$1.4M
50-year Lifecycle Cost	$71M	$2.7M
Mass Removal Cost over last 9 years	NA	$130/lb
Mass Removal Costs after 10 years	$32,000K/lb*	$160/lb
Mass Removal Costs after 20 years	$69,000/lb*	$320/lb
Mass Removal Costs after 50 years	$710,000/lb*	$480/lb

* Mass removal costs via ETR, excluding mass removal via MNA

Technical Conclusions

- Peak concentrations over time not significantly different between MNA and ETR alternatives
- Contaminant removal over last 9 years via MNA is 3X greater than next 10 years via ETR - 3E
- Mass removal via ETR is inconsequential
- MNA will remove 5700 lbs over 50 years ($2.7M)
- ETR - 3E will remove an additional 76 lbs ($71M)
- Public, Regulators, DOD will still be dealing with a plume deep underneath residences in 20 years even if ETR - 3E is implemented
- ETR Exit Strategy -- no short-term exit likely… O&M costs high

Conclusions

- All of the ERT Systems were Extremely Expensive and Did Almost Nothing to Remediate the Aquifer
- In Addition, The ERT Systems did not Afford any Additional Protection of Human Health and the Environment
- In Fact, Many of the ERT Systems had Detrimental Environmental Impacts

Conclusions

- **Before AFCEE Evaluated Natural Attenuation at LF-1, Alternative 3A was the Selected Remedial Alternative (Cost = $160,000,000)**

- **The Detailed Evaluation of Natural Attenuation Saved the U.S. Air Force and Tax Payers $90,000,000**