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Variations in ARD from the Equity Silver Waste-Rock Dumps

by

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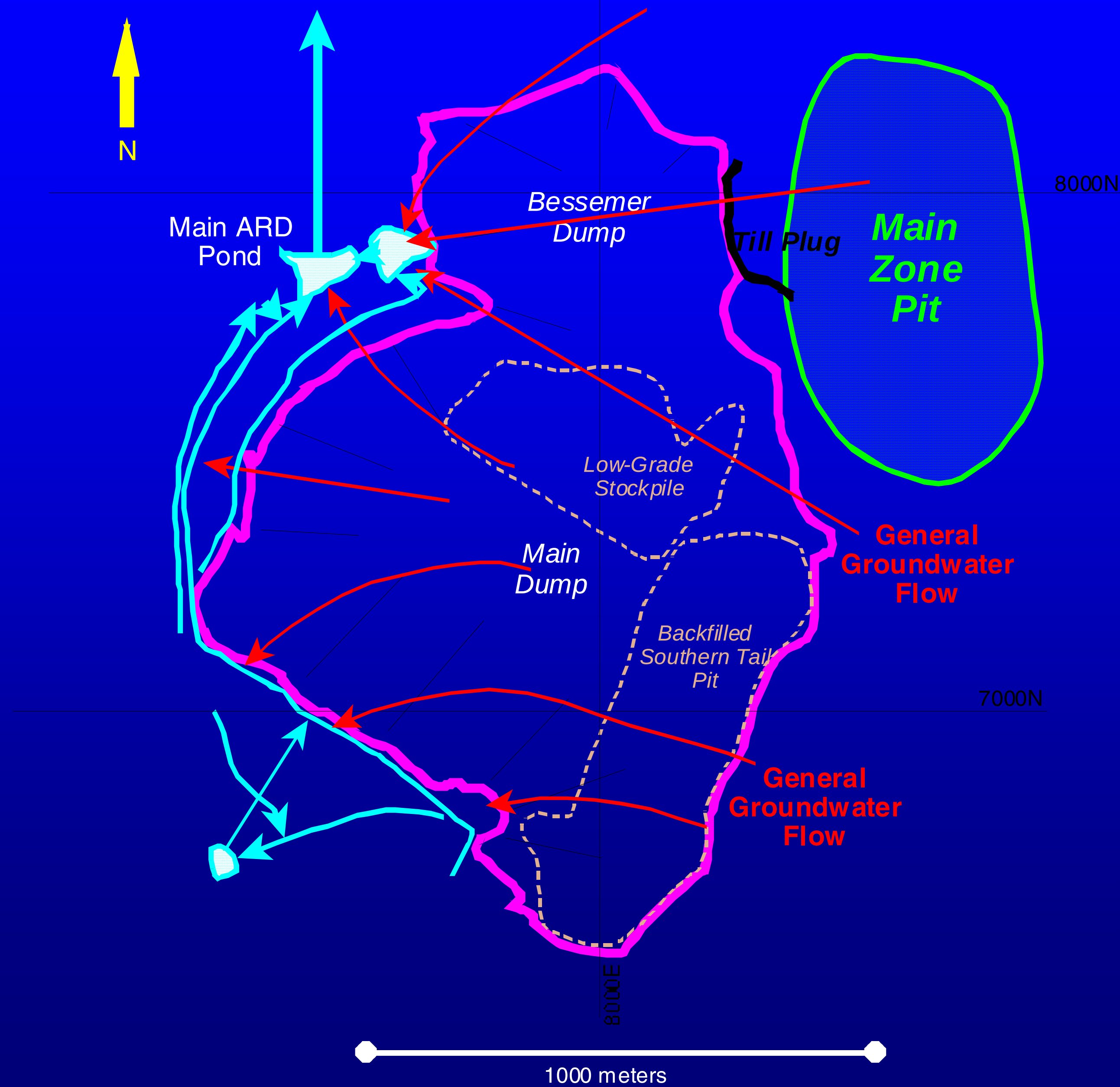
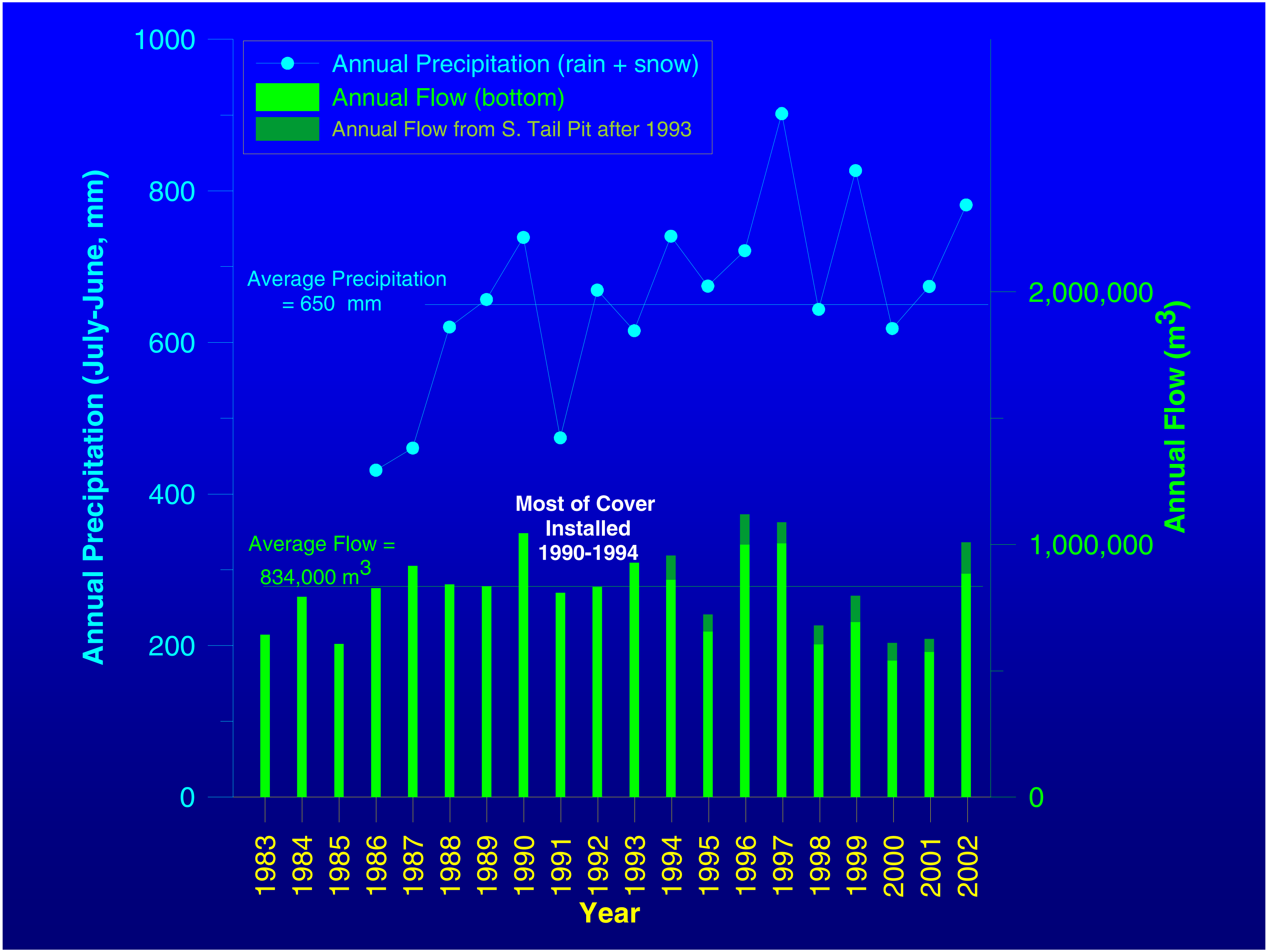
Simplified Layout of the Waste-Rock System at Equity Silver

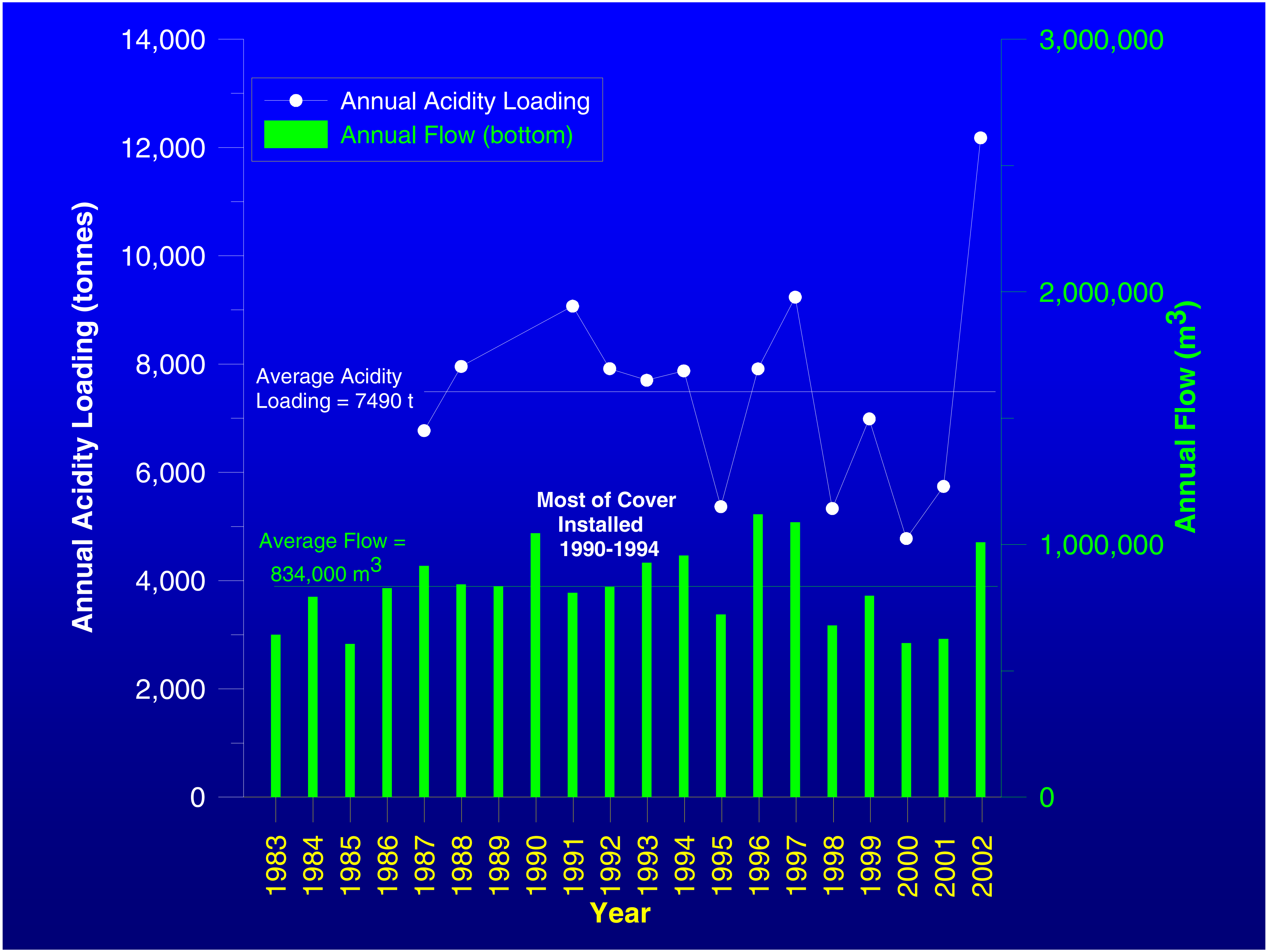


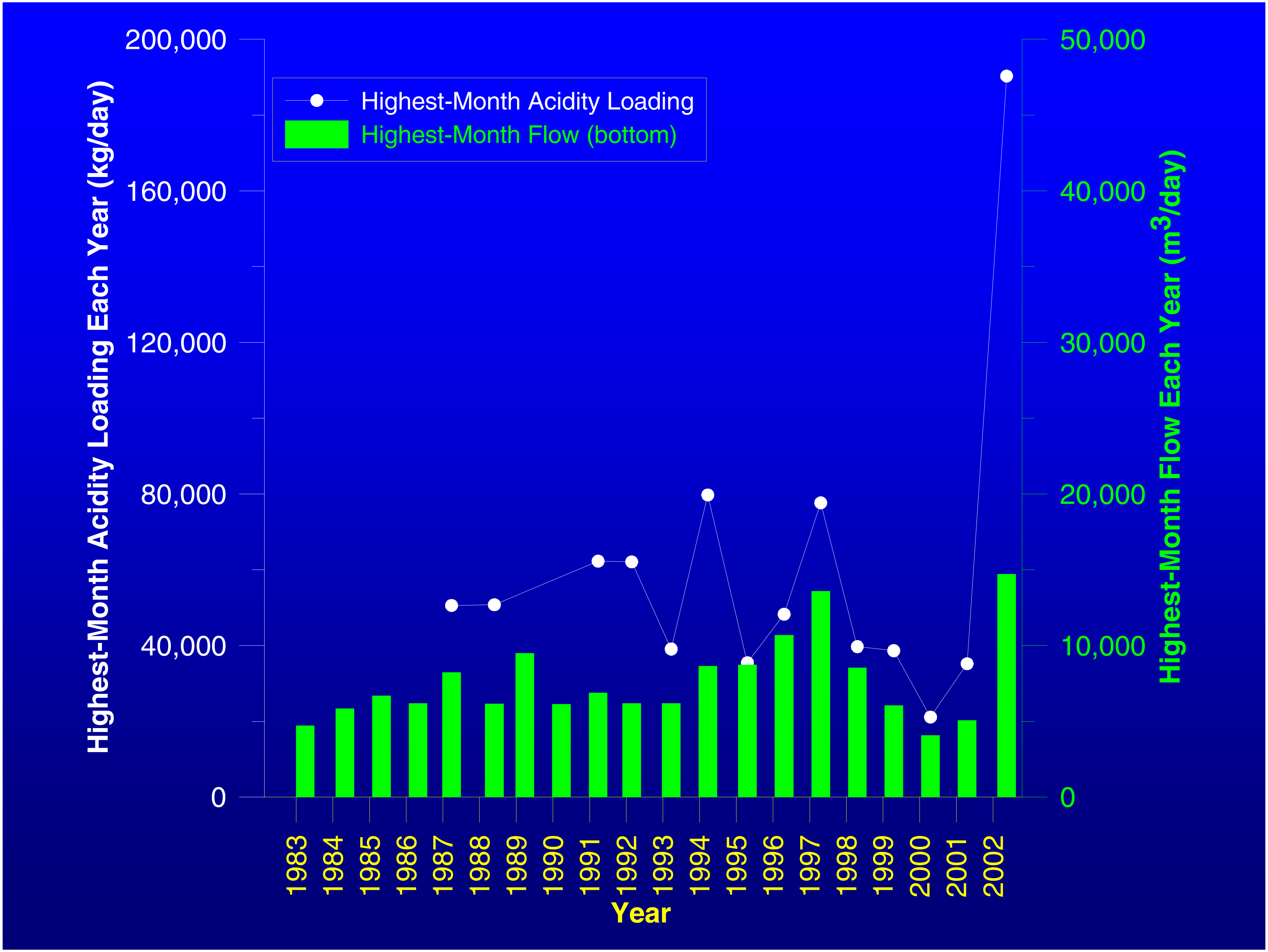
Summary of the Till Cover

- A compacted till (clay) cover, 0.5 m thick, was installed mostly in 1990-1994 over 132 ha of net-acid-generating waste rock (~80×10^6 t) for approximately CAD$5 million, or about CAD$35,000/ha (Aziz and Ferguson, 1997).
- An uncompacted upper layer, 0.3 m thick, was also included to hold excess moisture until it could evapotranspirate.
- This cover was designed so that (1) the amount of total annual precipitation entering the dump would be reduced from ~40% of precipitation to ~4% (a ten-fold reduction in the primary source of water for ARD) and (2) oxygen would no longer enter the waste rock.



Annual Precipitation (rain + snow)
Annual Flow (bottom)
Annual Flow from S. Tail Pit after 1993
Average Precipitation = 650 mm
Average Flow = 834,000 m3
Most of Cover Installed 1990-1994
Annual Precipitation (July-June, mm)
Annual Flow (m3)
1000
800
600
400
200
0
2,000,000
1,000,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Year


Annual Acidity Loading
Annual Flow (bottom)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
3,000,000
2,000,000
1,000,000
0
Annual Acidity Loading (tonnes)
Annual Flow (m3)
Average Acidity Loading = 7490 t
Average Flow = 834,000 m3
Most of Cover Installed 1990-1994
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Year



Highest-Month Acidity Loading
Highest-Month Flow (bottom)
Highest-Month Acidity Loading Each Year (kg/day)
Highest-Month Flow Each Year (m3/day)
200,000
160,000
120,000
80,000
40,000
0
50,000
40,000
30,000
20,000
10,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Year

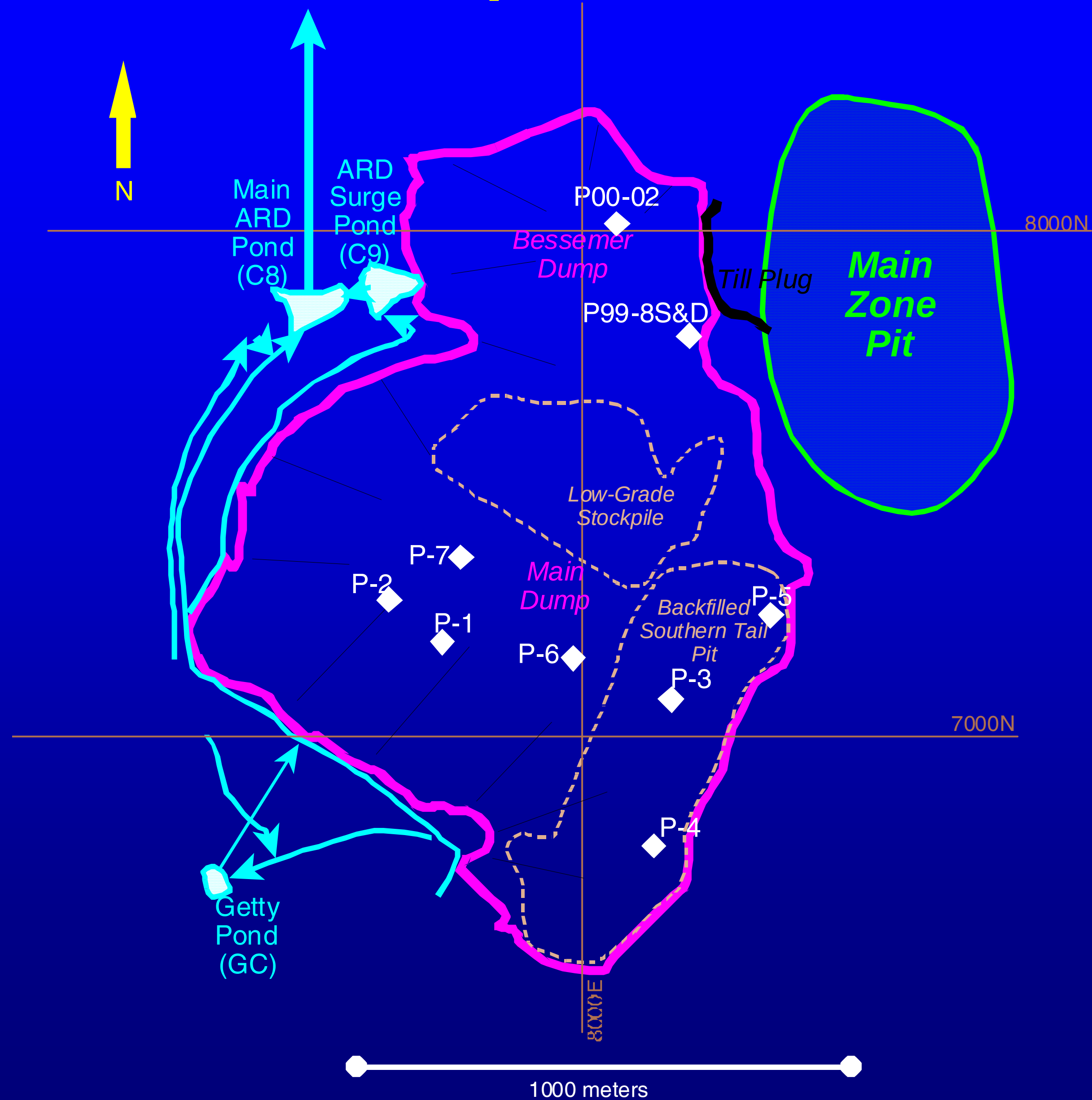
Return Periods for May 2002

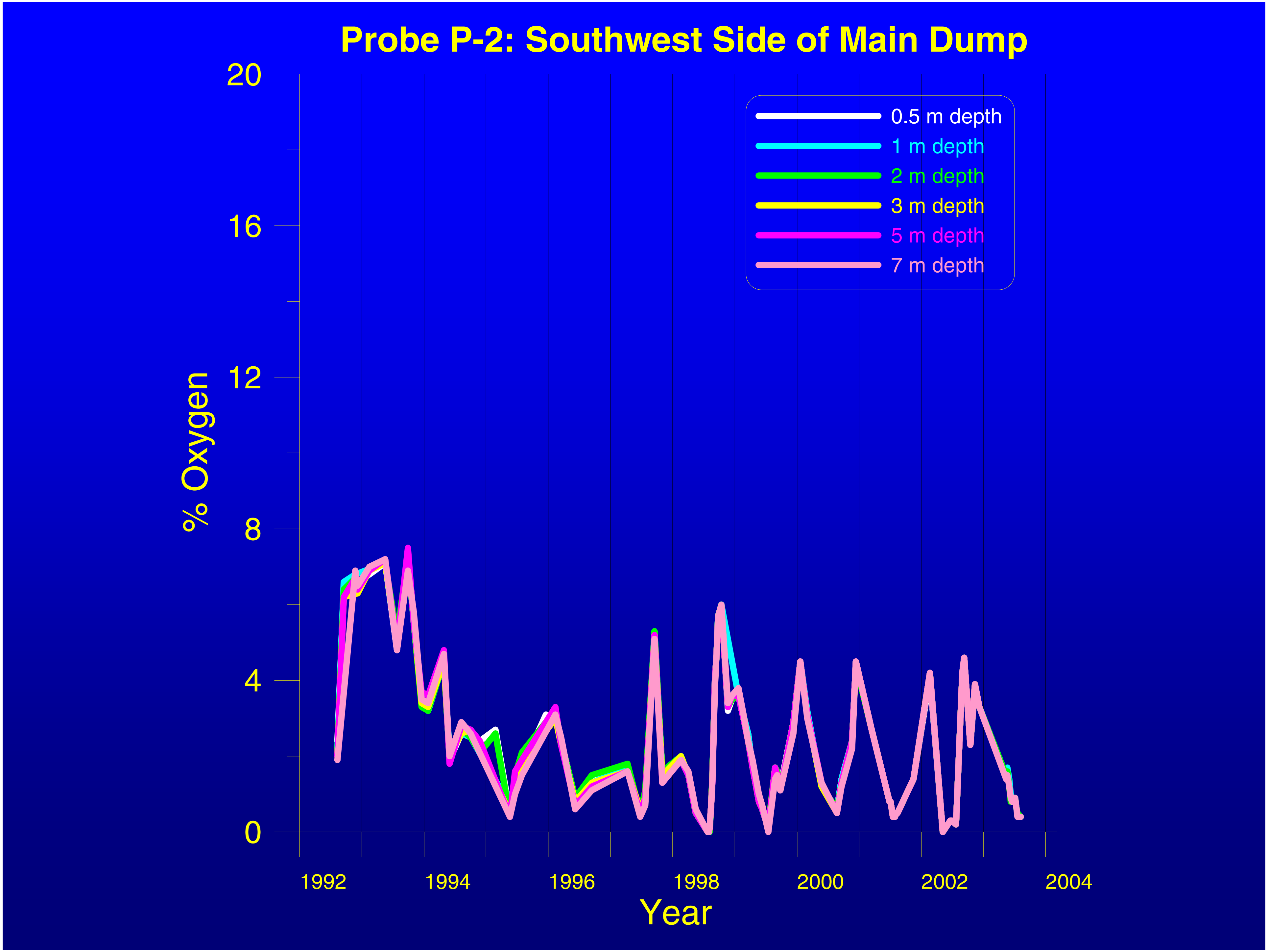
- Maximum 2002 snowpack: 25 years
- May 2002 total precipitation: 20 years
- Combined May 2002 snowmelt and precipitation: 35 years
- May 2002 acidity concentration: ~15 years
- May 2002 acidity loading: >200 years
- Annual 2002 acidity loading: ~50 years

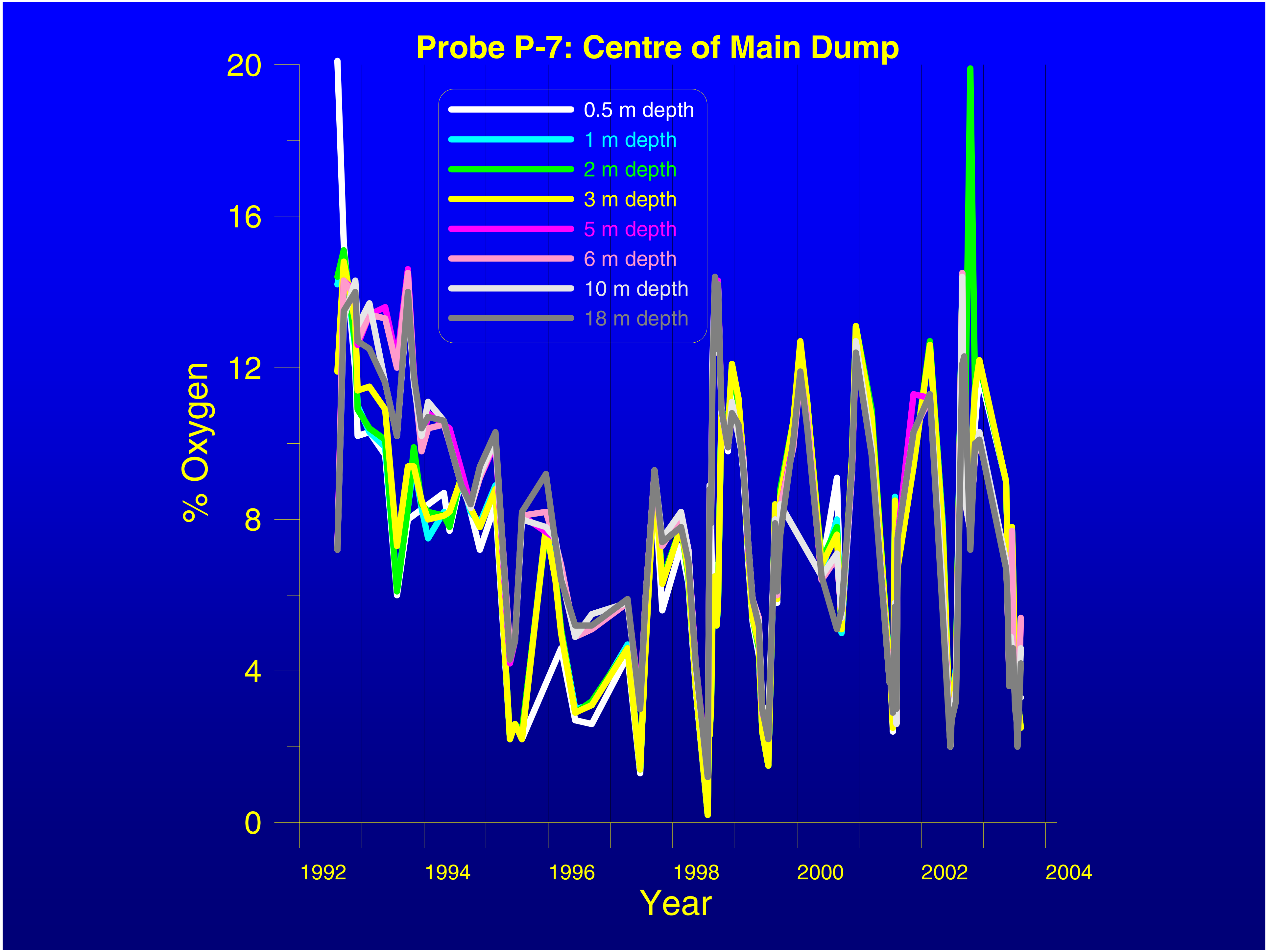
What Caused the Peak Values in 2002?

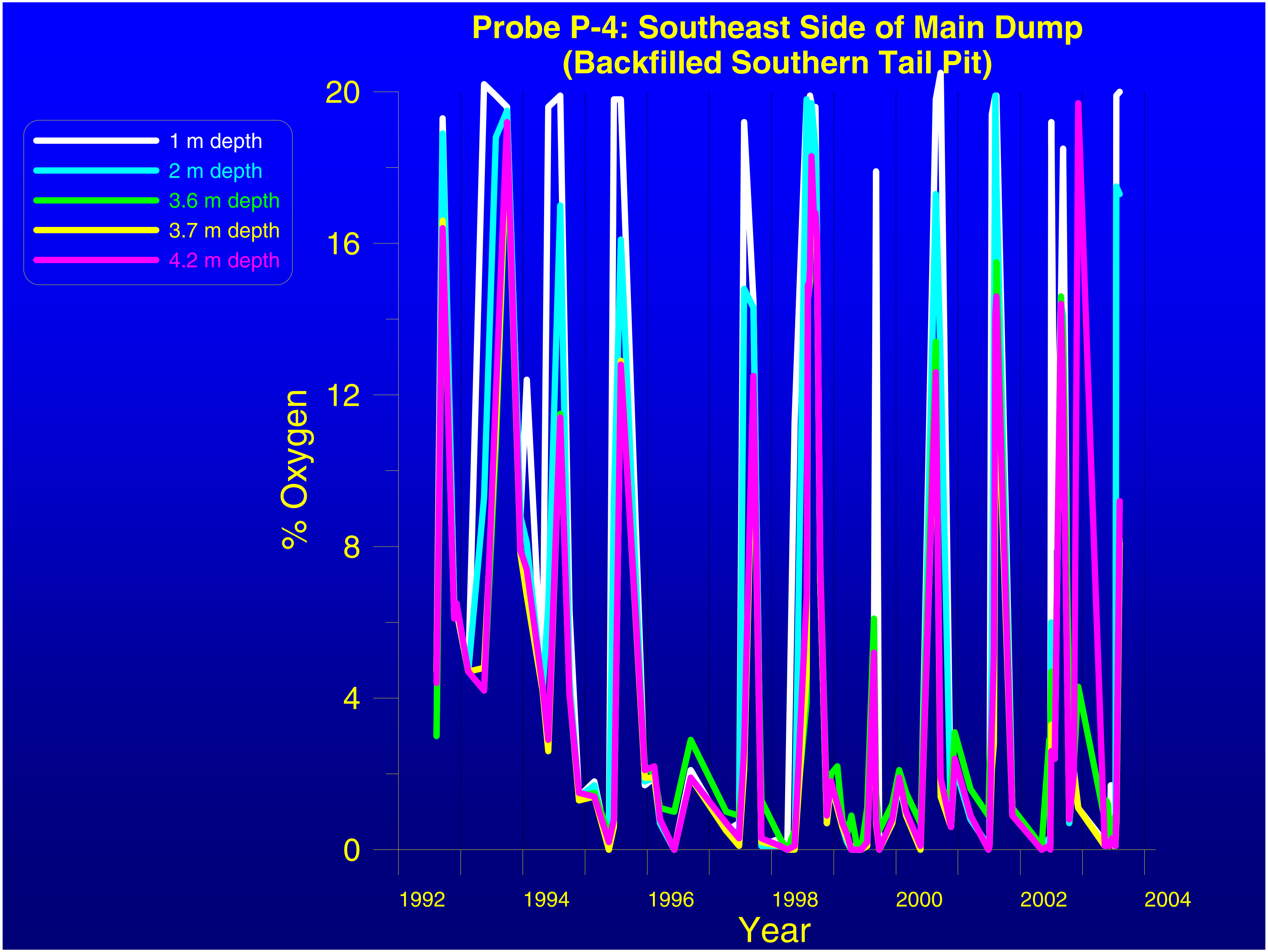
- Increased rate of sulphide oxidation due to increased oxygen influx?
- Increased rate of sulphide oxidation due to, or causing, increased internal temperatures?
- Change of internal flowpaths as reflected by permanent changes in groundwater levels?
- Much higher short-term flow of water through the waste rock as indicated by short-term increases in flows into lysimeters or in groundwater levels?

Gas-Temperature Probes

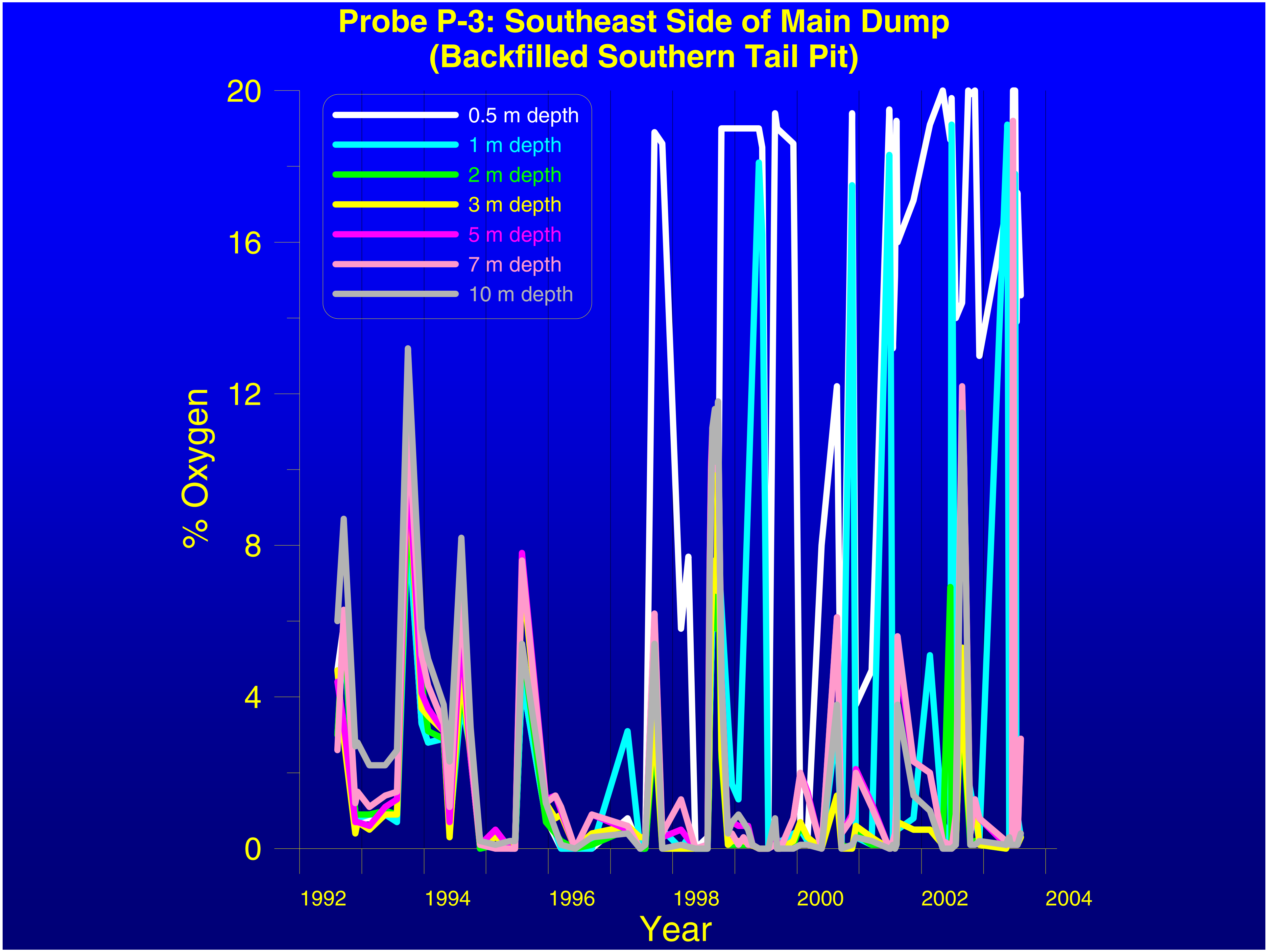



Probe P-2: Southwest Side of Main Dump
0.5 m depth
1 m depth
2 m depth
3 m depth
5 m depth
7 m depth
% Oxygen
20
16
12
8
4
0
1992
1994
1996
1998
2000
2002
2004
Year

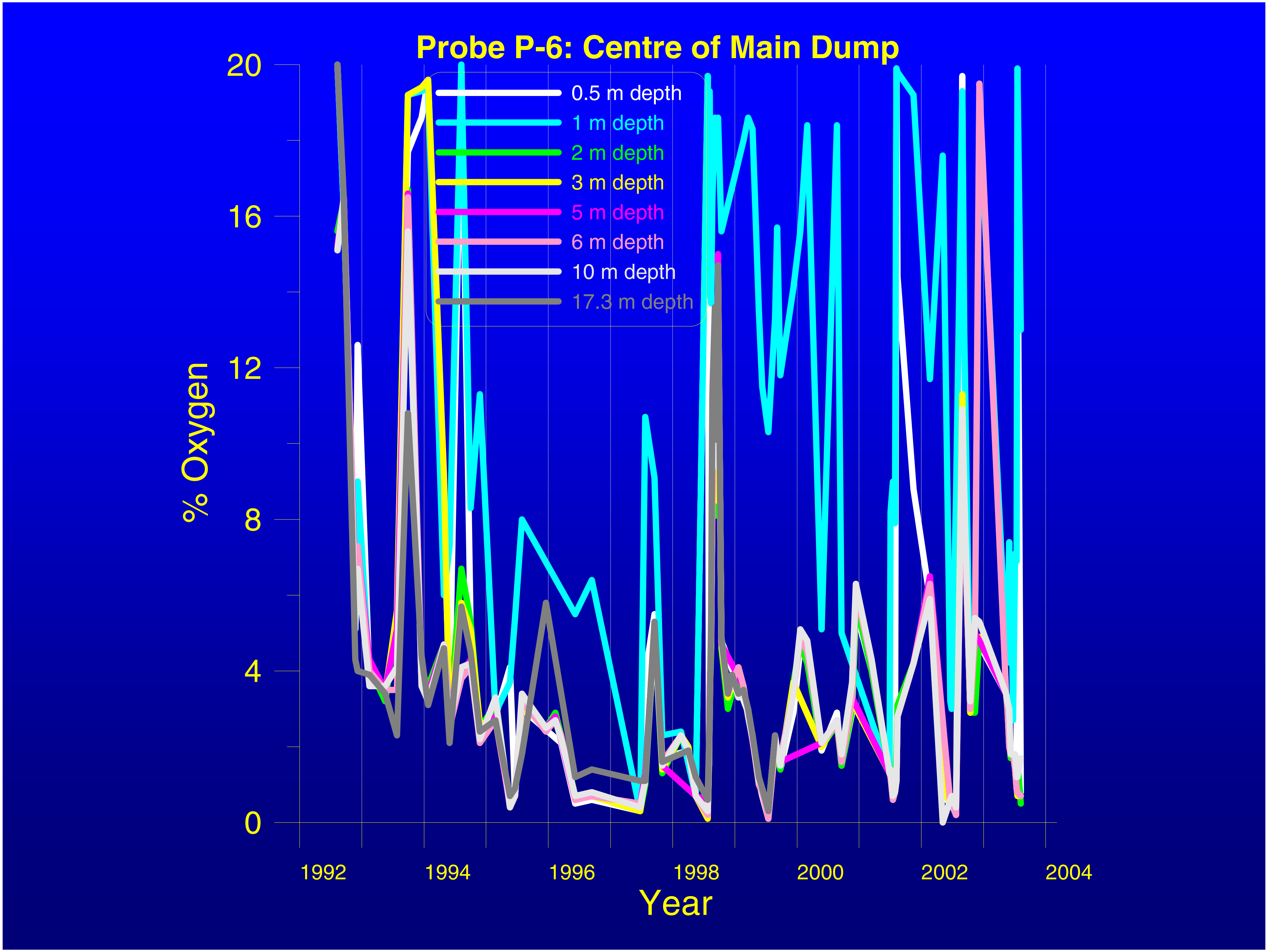

Probe P-7: Centre of Main Dump
0.5 m depth
1 m depth
2 m depth
3 m depth
5 m depth
6 m depth
10 m depth
18 m depth
% Oxygen
0
4
8
12
16
20
1992
1994
1996
1998
2000
2002
2004
Year



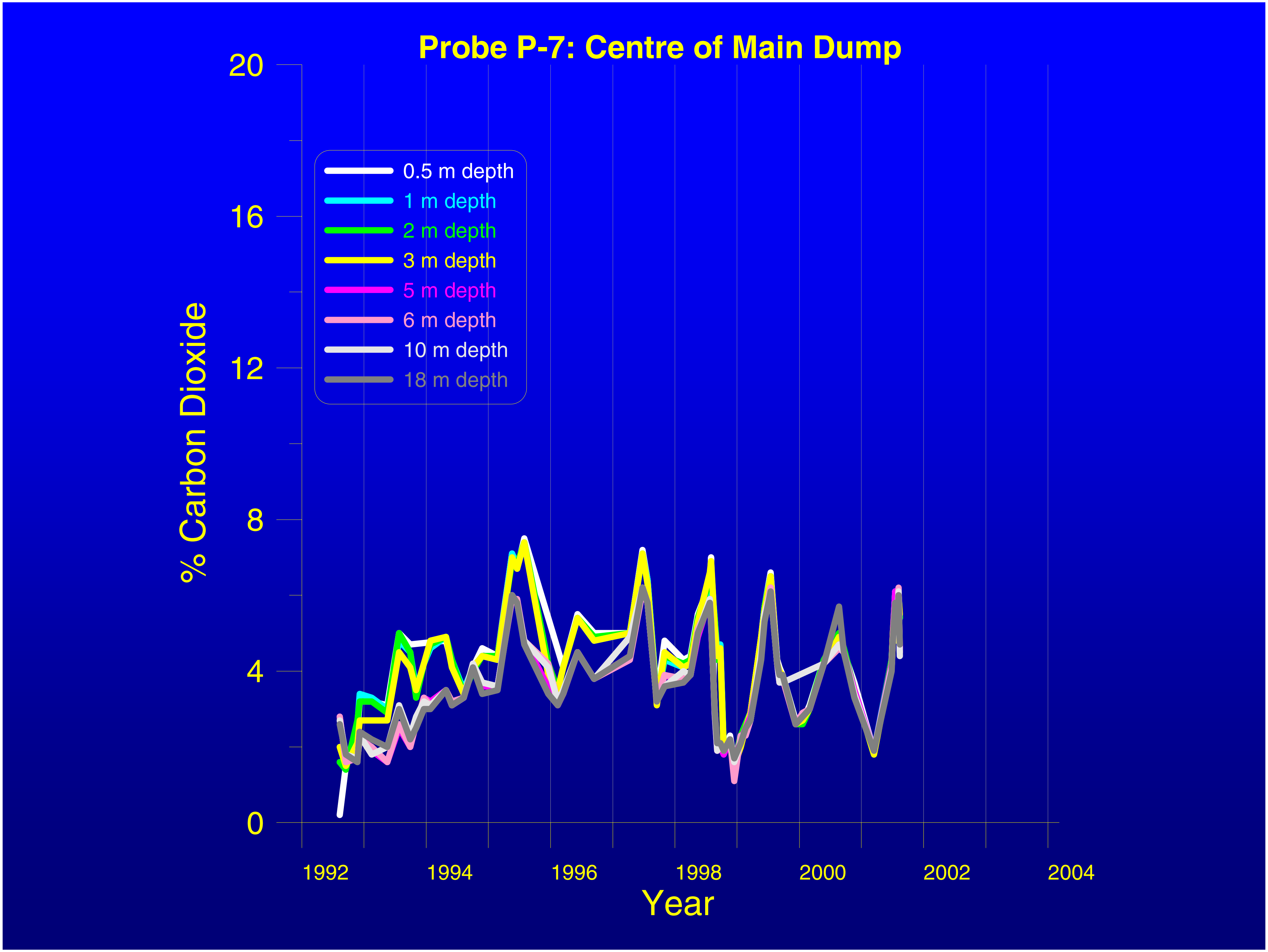
Probe P-4: Southeast Side of Main Dump
(Backfilled Southern Tail Pit)
1 m depth
2 m depth
3.6 m depth
3.7 m depth
4.2 m depth
% Oxygen
0
4
8
12
16
20
1992
1994
1996
1998
2000
2002
2004
Year



Probe P-3: Southeast Side of Main Dump
(Backfilled Southern Tail Pit)
0.5 m depth
1 m depth
2 m depth
3 m depth
5 m depth
7 m depth
10 m depth
% Oxygen
0
4
8
12
16
20
1992
1994
1996
1998
2000
2002
2004
Year



Probe P-6: Centre of Main Dump
0.5 m depth
1 m depth
2 m depth
3 m depth
5 m depth
6 m depth
10 m depth
17.3 m depth
% Oxygen
Year
0
4
8
12
16
20
1992
1994
1996
1998
2000
2002
2004

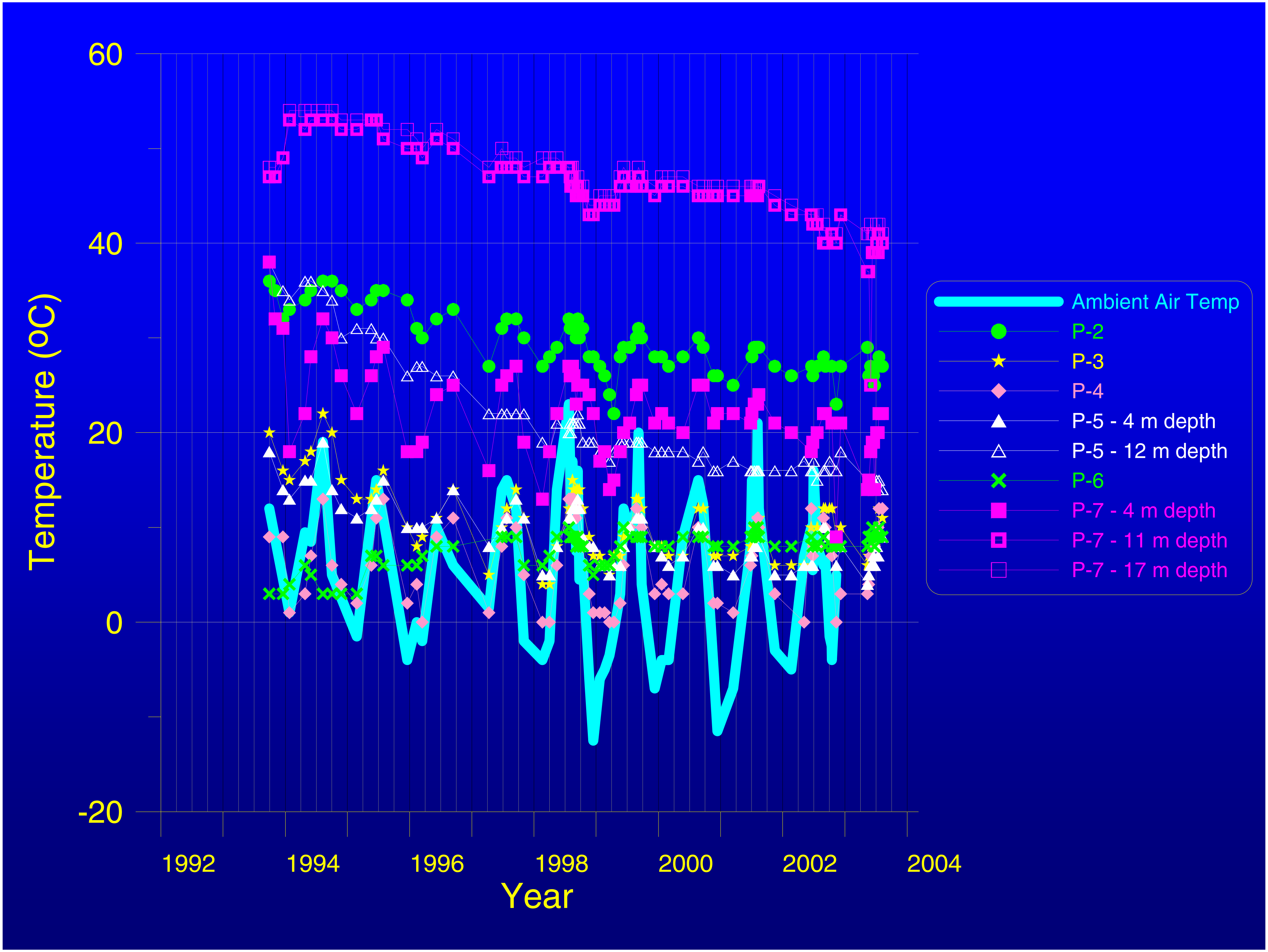


Probe P-7: Centre of Main Dump
20
16
12
8
4
0
% Carbon Dioxide
0.5 m depth
1 m depth
2 m depth
3 m depth
5 m depth
6 m depth
10 m depth
18 m depth
1992
1994
1996
1998
2000
2002
2004
Year

Summary of Gas Trends

- Temporal, lateral, and depth trends in oxygen are complex, and are not consistent with trends in carbon dioxide. All of this indicates the waste rock consists of numerous “cells” in which gas trends are unique.

- In any case, there were no unusual values or trends in 2002, ruling out accelerated oxidation due to increased oxygen supply.

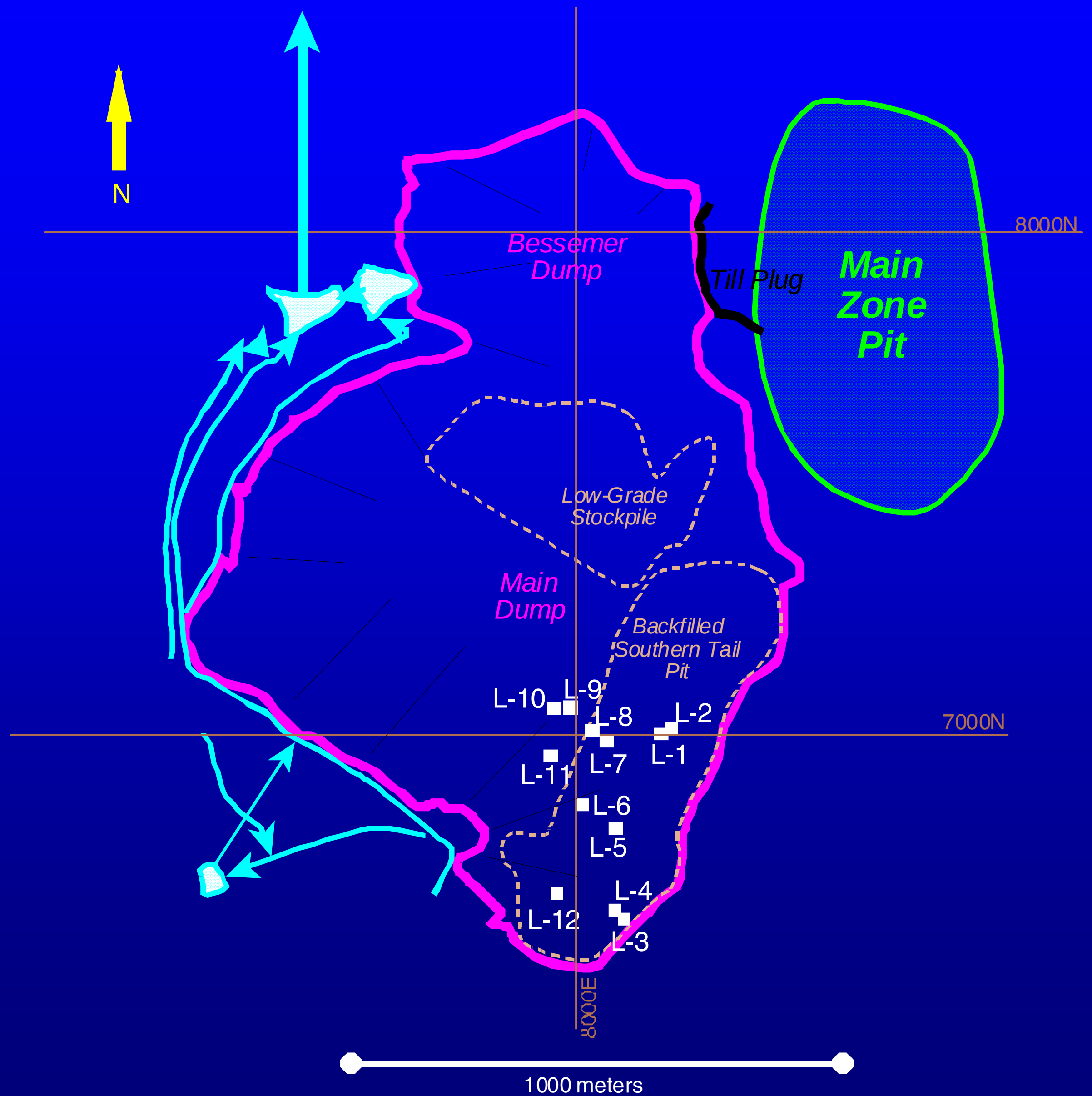


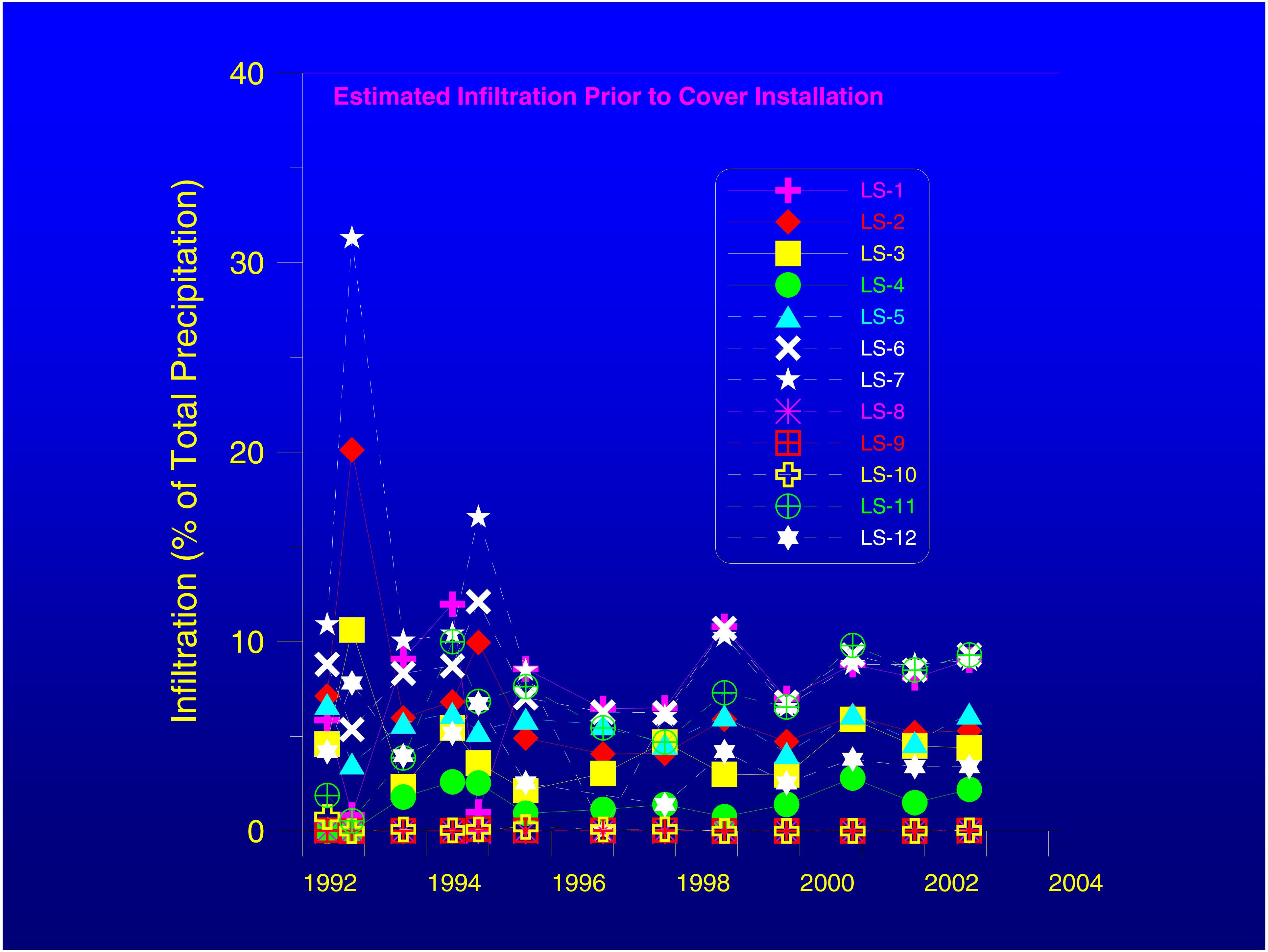
60
40
20
0
-20
Temperature (oC)
1992
1994
1996
1998
2000
2002
2004
Year
Ambient Air Temp
P-2
P-3
P-4
P-5 - 4 m depth
P-5 - 12 m depth
P-6
P-7 - 4 m depth
P-7 - 11 m depth
P-7 - 17 m depth

Summary of Temperature Trends

- All temperature probes displayed general cooling trends, at least from 1993 to 2002.
- The warmer probes decreased 5-20°C over this period.
- Many probes are close to the ambient air temperature and show fast, but subdued response to warming and cooling of ambient air.
- The temperature probes show no unusual trends or values in 2002, ruling out increased oxidation as a cause or effect in 2002.

Lysimeter Locations




Estimated Infiltration Prior to Cover Installation
Infiltration (% of Total Precipitation)
40
30
20
10
0
1992
1994
1996
1998
2000
2002
2004
LS-1
LS-2
LS-3
LS-4
LS-5
LS-6
LS-7
LS-8
LS-9
LS-10
LS-11
LS-12

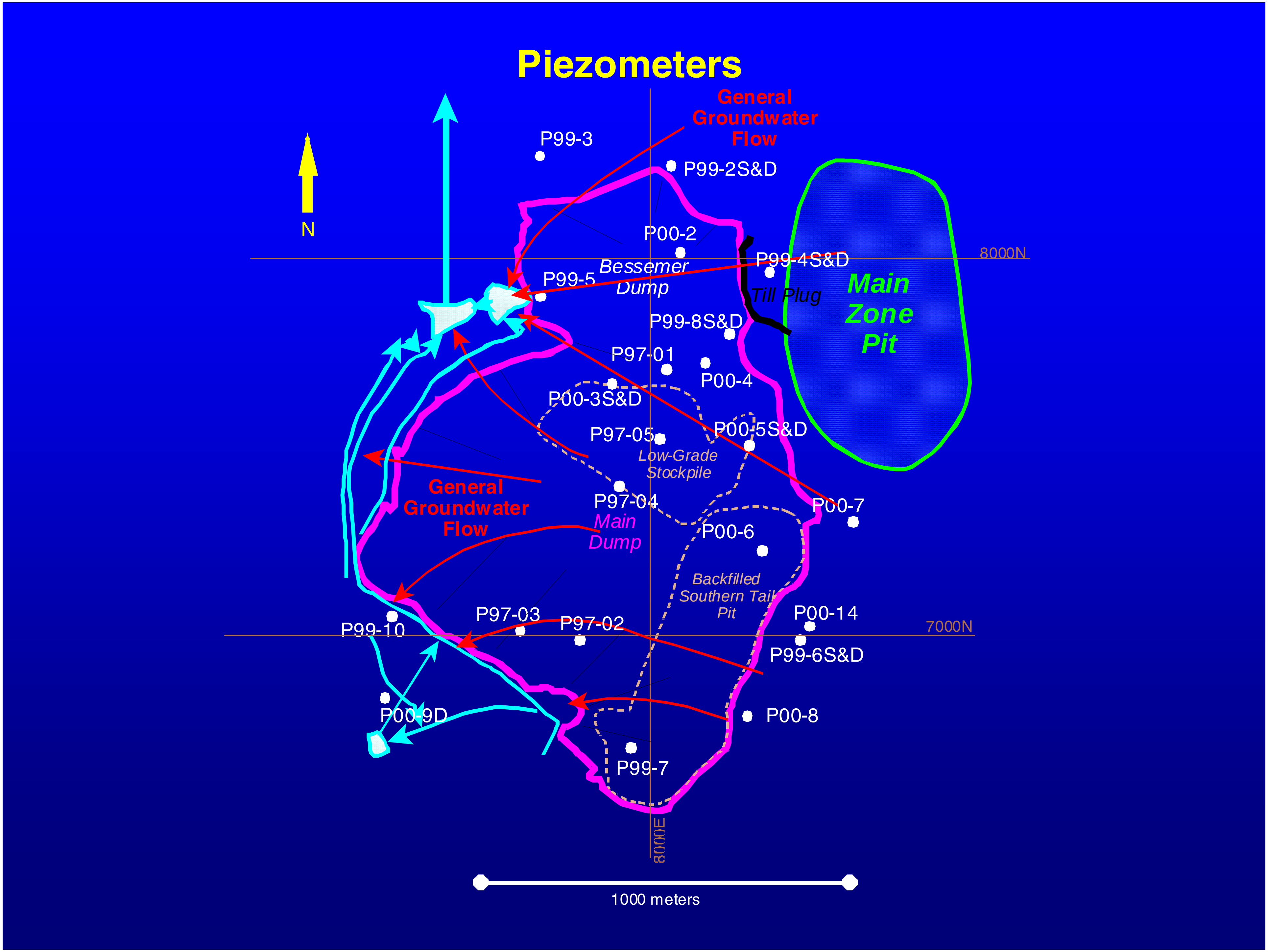
Changes in Cover Permeability and Infiltration Rate

Year	Permeability (m/s)	Infiltration (% of total precipitation)
1995 (O'Kane)	$2.0x10^{-10}$	5%
1998 (Saretzky)	$2.0x10^{-9}$	4%
2002 (WMC)		34% (19% minimum)
2002 (Nichol & Wilson)	$1.0x10^{-8}$ to $5.0x10^{-7}$	
2003 (Johnston)		4-14%

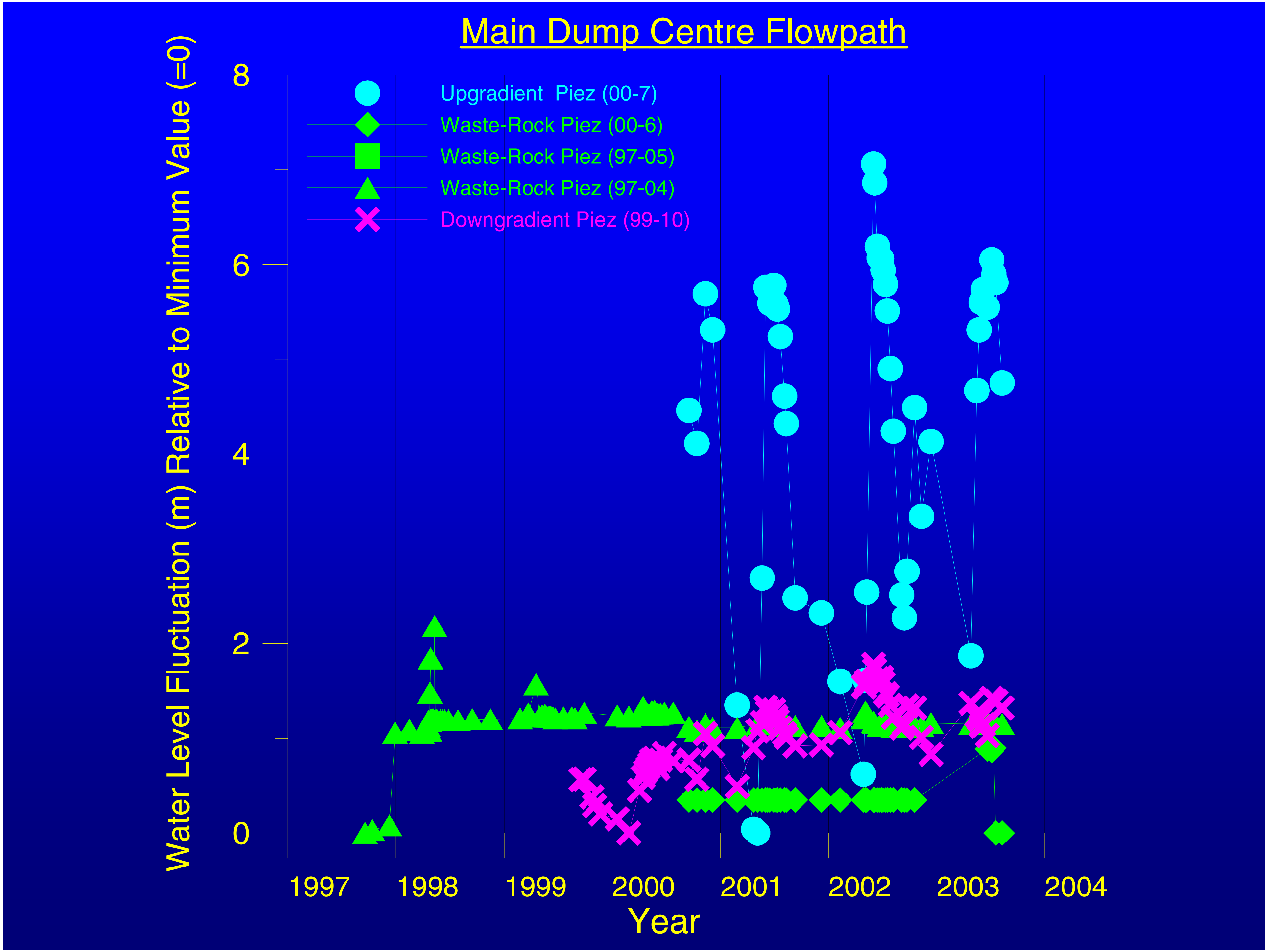
Best Estimates of Sources for the ARD

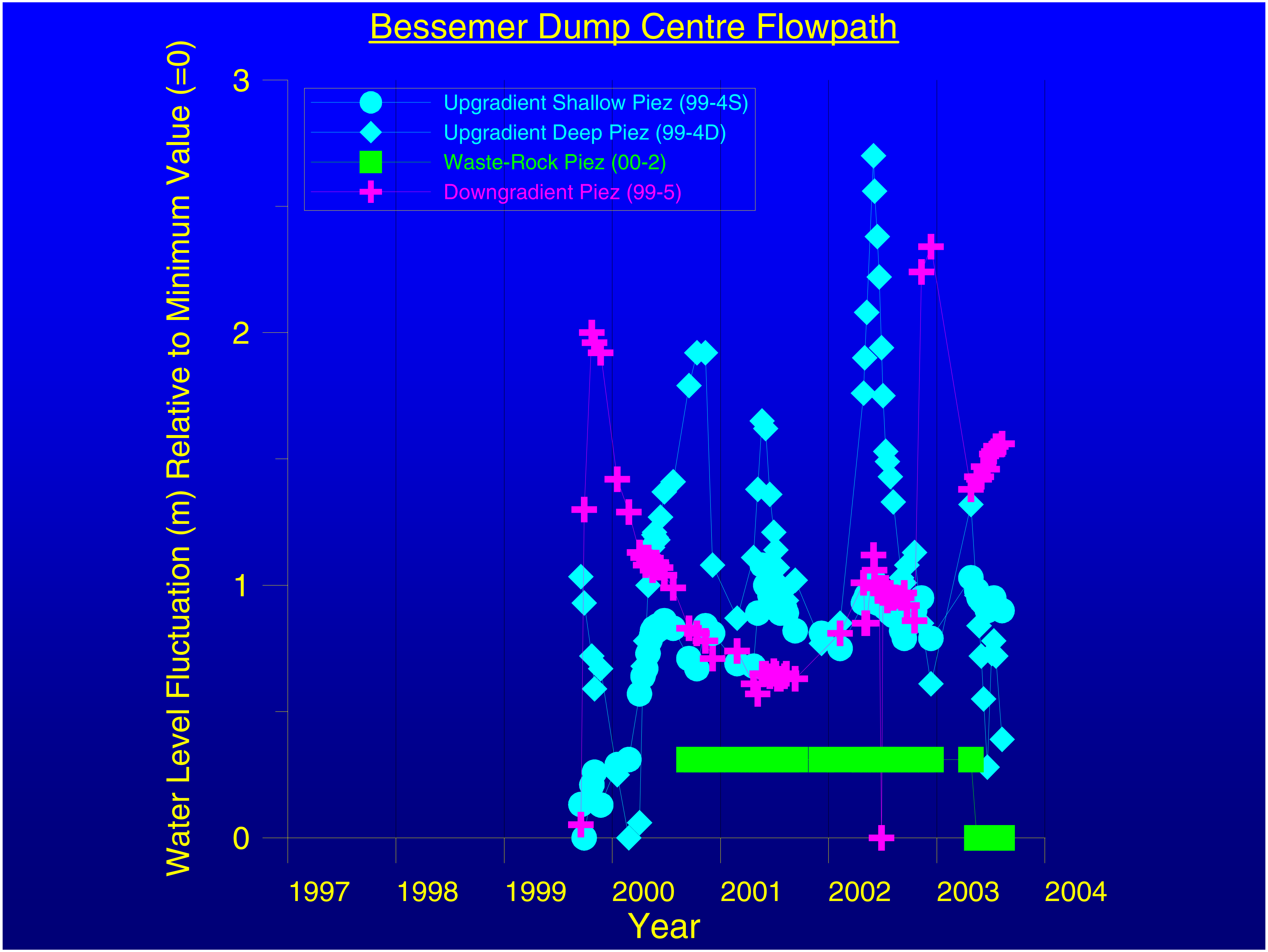
- The large-scale water balance in 2002 indicates infiltration through the cover is the dominant source of water into the waste rock and thus the dominant source of ARD.

- Also, the small-scale lysimeters and SoilCover model are not providing representative data on large-scale infiltration. This may be due to:
  - The originally reported till-cover permeability of $2x10^{-10}$ m/s was not achieved across all 132 ha of waste rock.
  - The permeability of the till has degraded through time.
  - Large-scale imperfections due to ongoing waste-rock settlement were not considered.

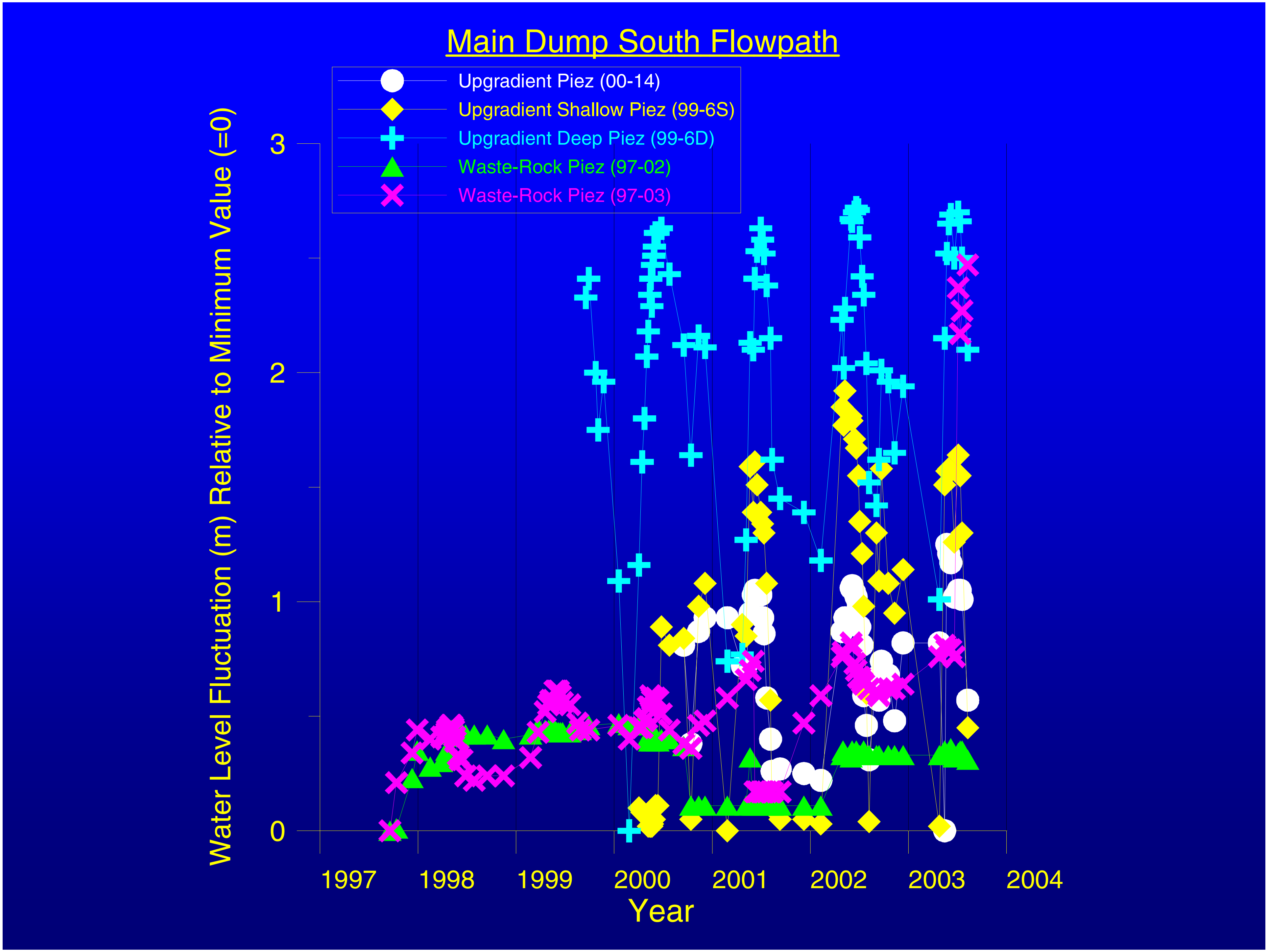


Piezometers
General Groundwater Flow
N
P99-3
P99-2S&D
P00-2
8000N
P99-4S&D
Bessemer Dump
P99-5
Main Zone Pit
Till Plug
P99-8S&D
P97-01
P00-4
P00-3S&D
P97-05
P00-5S&D
Low-Grade Stockpile
General Groundwater Flow
P97-04
P00-7
Main Dump
P00-6
Backfilled Southern Tail Pit
P00-14
P97-03
P97-02
7000N
P99-10
P99-6S&D
P00-9D
P00-8
P99-7
8000E
1000 meters


Main Dump Centre Flowpath
Upgradient Piez (00-7)
Waste-Rock Piez (00-6)
Waste-Rock Piez (97-05)
Waste-Rock Piez (97-04)
Downgradient Piez (99-10)
Water Level Fluctuation (m) Relative to Minimum Value (=0)
0
2
4
6
8
1997
1998
1999
2000
2001
2002
2003
2004
Year



Bessemer Dump Centre Flowpath
Upgradient Shallow Piez (99-4S)
Upgradient Deep Piez (99-4D)
Waste-Rock Piez (00-2)
Downgradient Piez (99-5)
Water Level Fluctuation (m) Relative to Minimum Value (=0)
3
2
1
0
1997
1998
1999
2000
2001
2002
2003
2004
Year

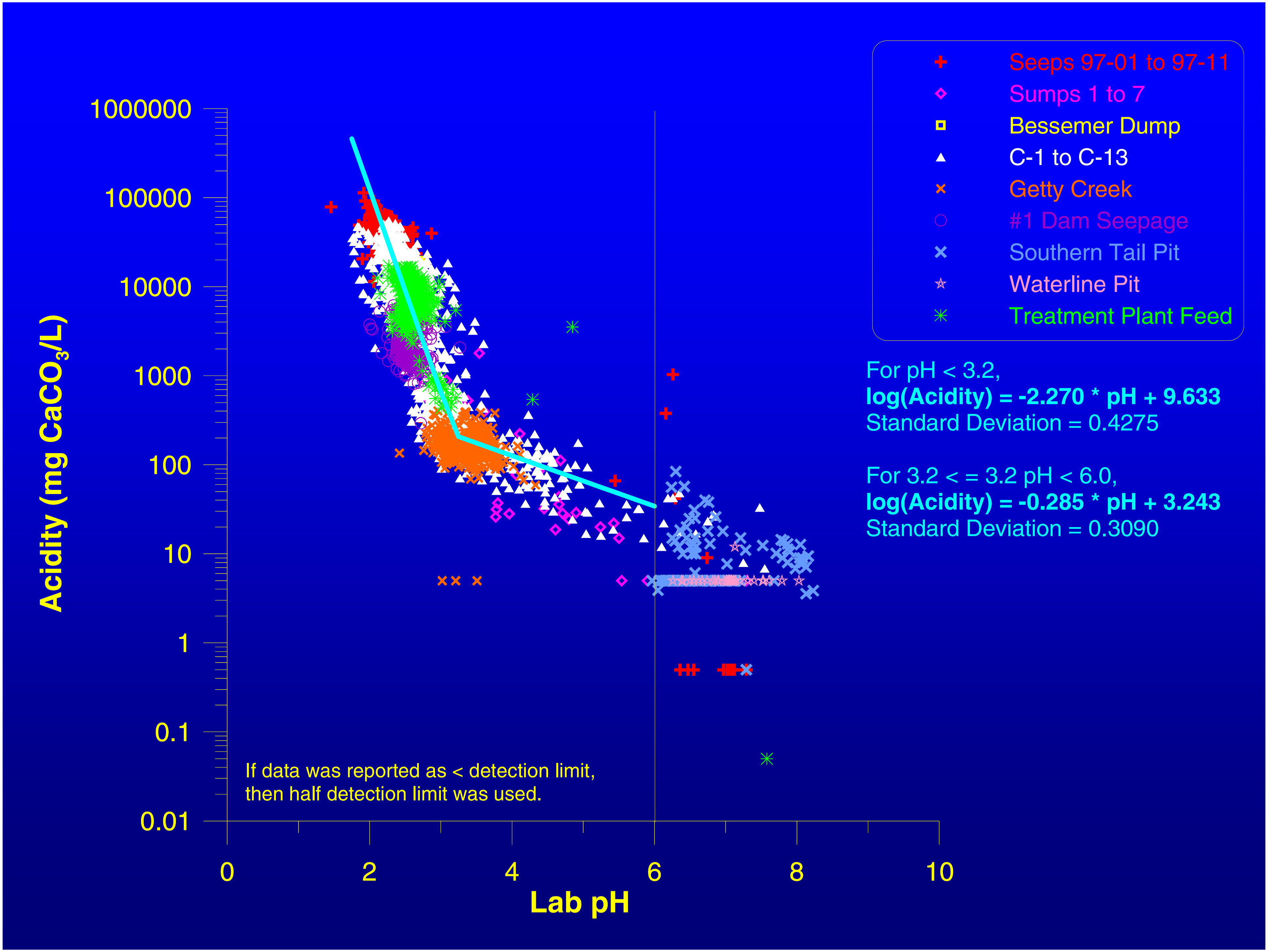


Main Dump South Flowpath
Upgradient Piez (00-14)
Upgradient Shallow Piez (99-6S)
Upgradient Deep Piez (99-6D)
Waste-Rock Piez (97-02)
Waste-Rock Piez (97-03)
Water Level Fluctuation (m) Relative to Minimum Value (=0)
0
1
2
3
1997
1998
1999
2000
2001
2002
2003
2004
Year

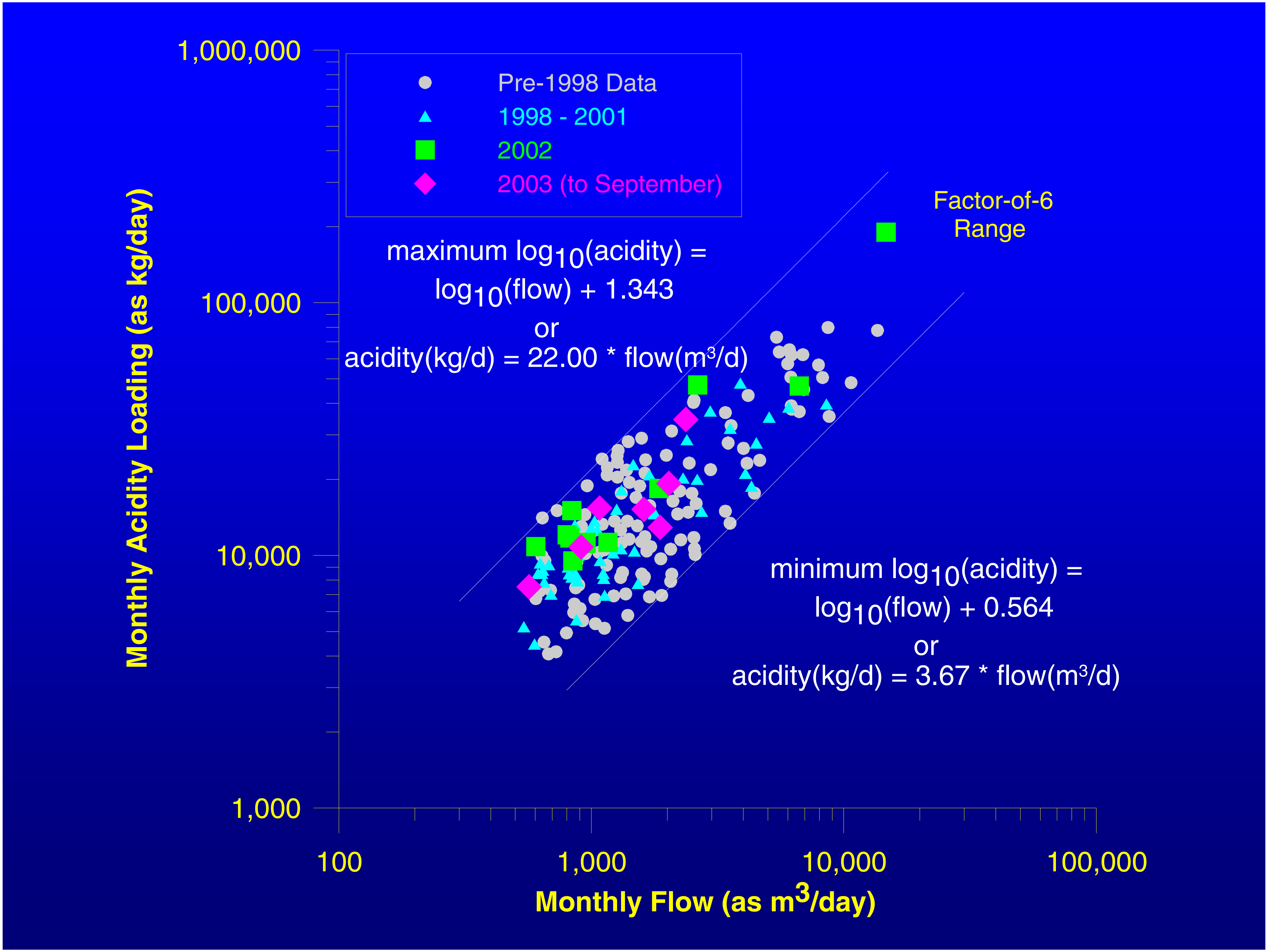
Summary of Potential Mechanisms for Peak 2002 Acidity Loading

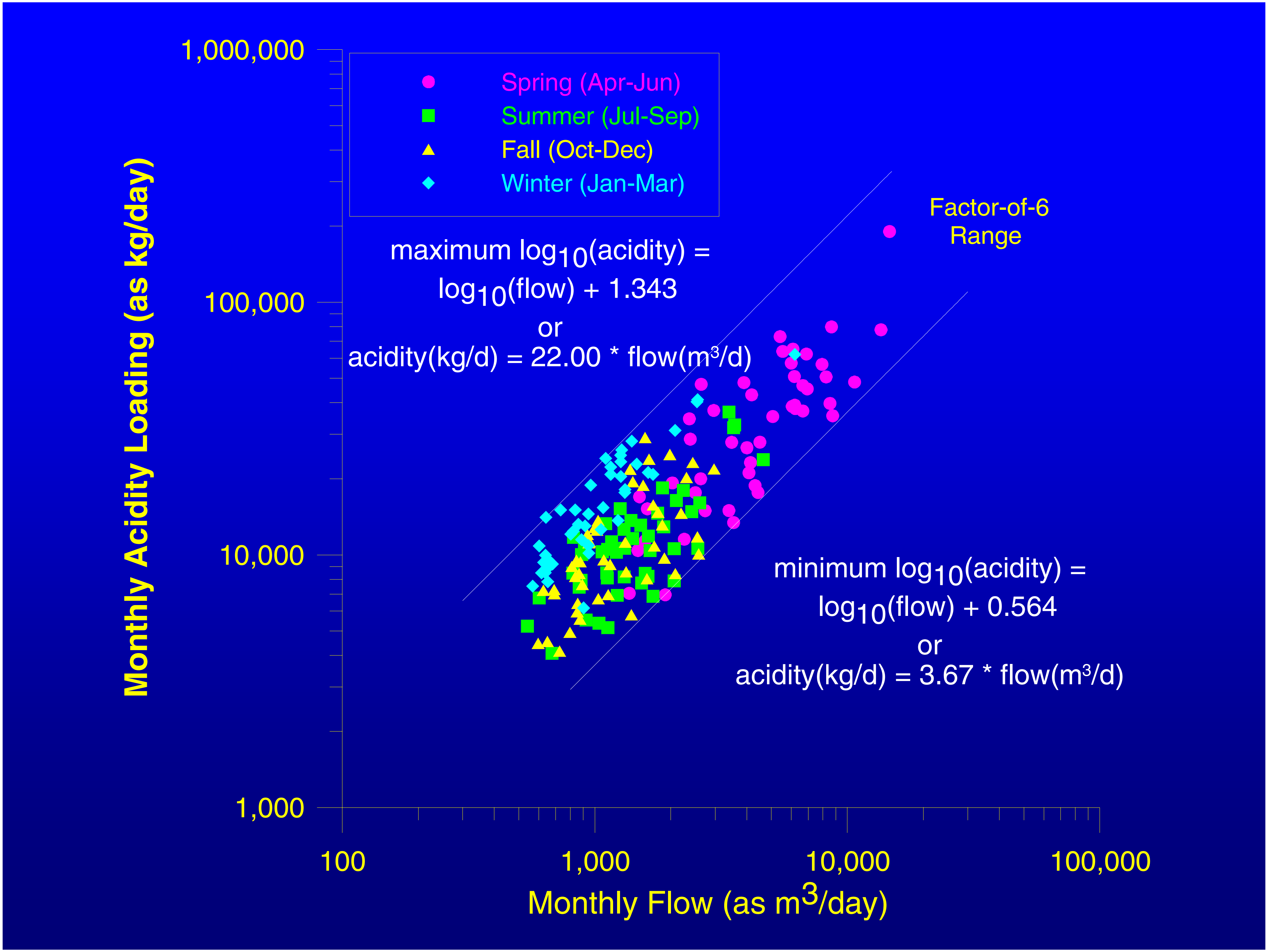
- No significant variations that could be interpreted as causes or effects of the peak acidity loadings in 2002 were noted with:
  - internal temperatures
  - gas levels, and
  - lysimeters.

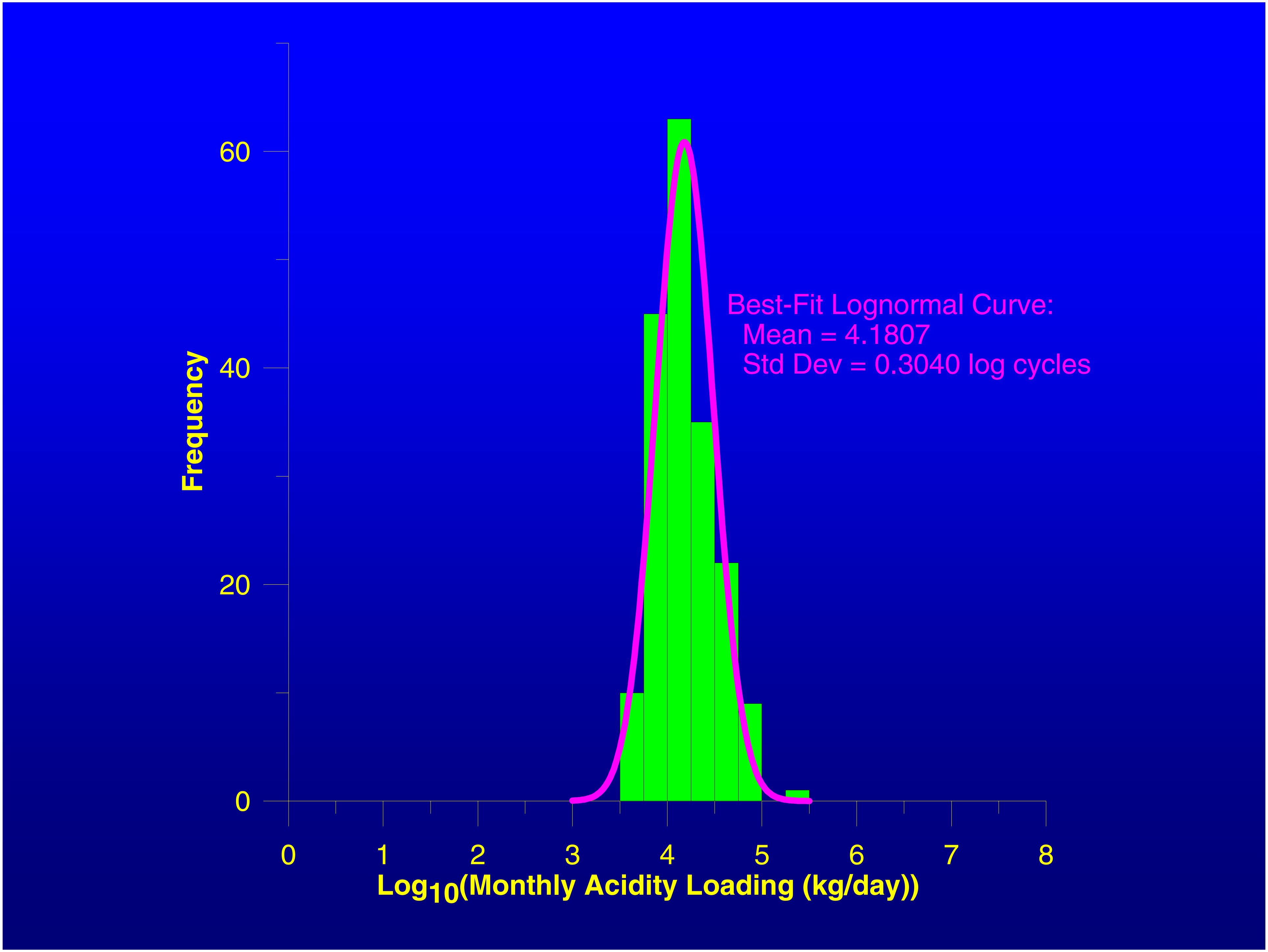
- On the other hand,
  - several piezometers in and around the waste rock showed unusually high peak water levels in spring 2002,
  - some previously dry piezometers experienced permanent increases in levels (although this could simply be trapped water), and
  - water levels in some piezometers peaked later in 2002 reflecting the spring groundwater travelling along slower flowpaths.



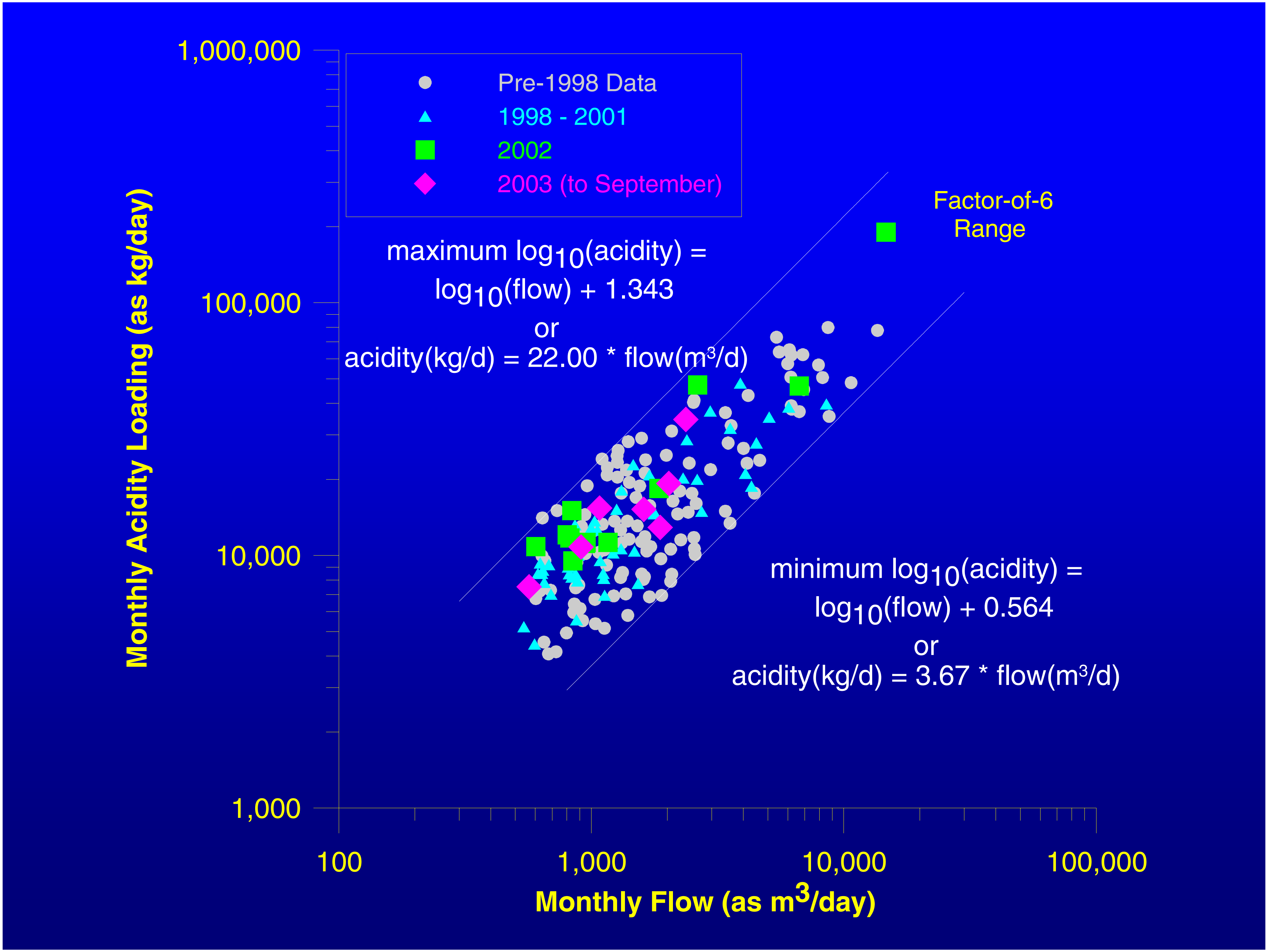
Seeps 97-01 to 97-11
Sumps 1 to 7
Bessemer Dump
C-1 to C-13
Getty Creek
#1 Dam Seepage
Southern Tail Pit
Waterline Pit
Treatment Plant Feed
For pH < 3.2,
log(Acidity) = -2.270 * pH + 9.633
Standard Deviation = 0.4275
For 3.2 < = 3.2 pH < 6.0,
log(Acidity) = -0.285 * pH + 3.243
Standard Deviation = 0.3090
Acidity (mg $CaCO_3$/L)
1000000
100000
10000
1000
100
10
1
0.1
0.01
0
2
4
6
8
10
Lab pH
If data was reported as < detection limit,
then half detection limit was used.

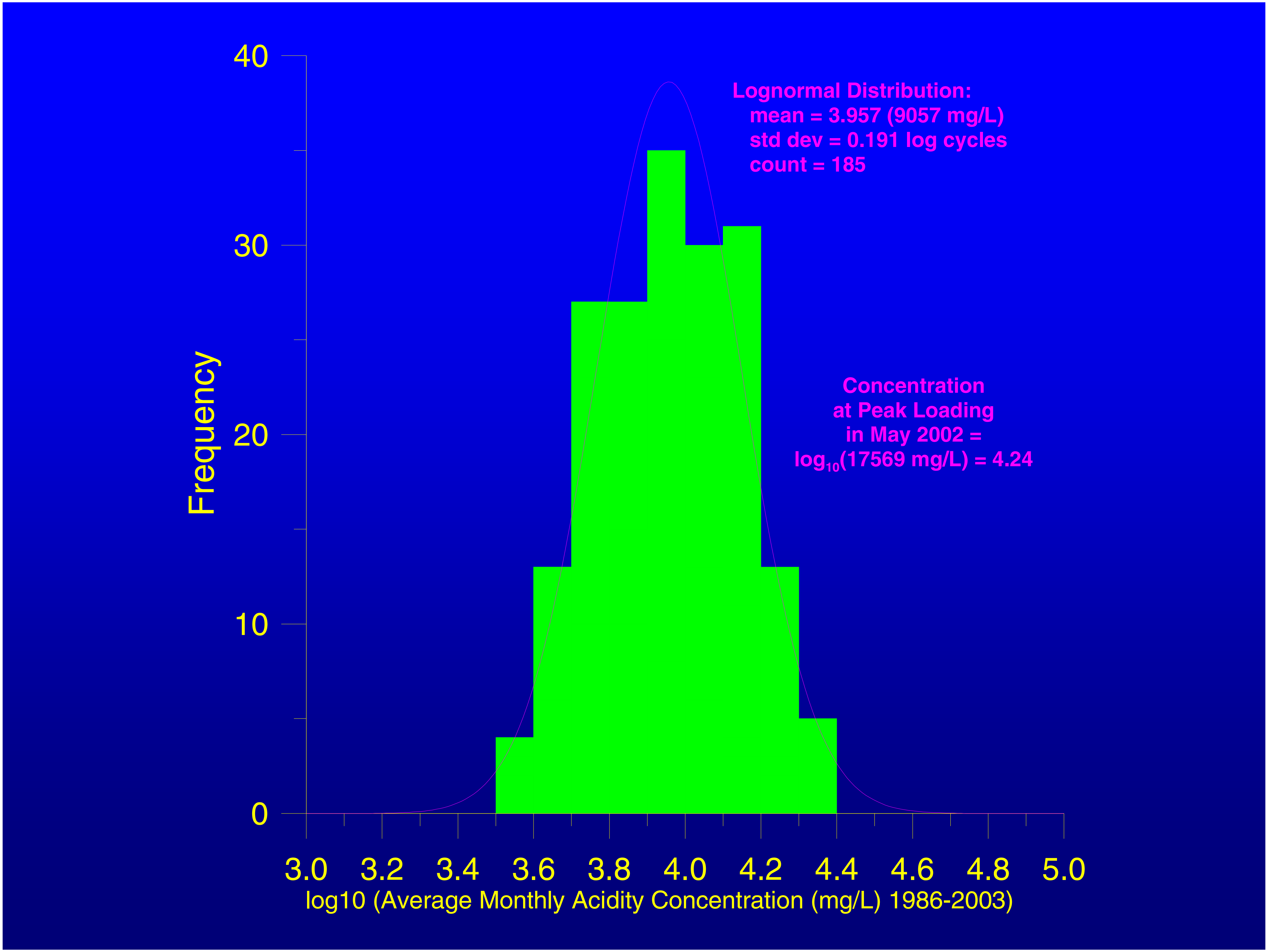

Pre-1998 Data
1998 - 2001
2002
2003 (to September)
maximum log10(acidity) =
log10(flow) + 1.343
or
acidity(kg/d) = 22.00 * flow(m3/d)
Factor-of-6
Range
minimum log10(acidity) =
log10(flow) + 0.564
or
acidity(kg/d) = 3.67 * flow(m3/d)
1,000,000
100,000
10,000
1,000
100
1,000
10,000
100,000
Monthly Acidity Loading (as kg/day)
Monthly Flow (as m3/day)


1,000,000
100,000
10,000
1,000
100
1,000
10,000
100,000
Monthly Acidity Loading (as kg/day)
Monthly Flow (as m3/day)
Spring (Apr-Jun)
Summer (Jul-Sep)
Fall (Oct-Dec)
Winter (Jan-Mar)
Factor-of-6 Range
maximum log10(acidity) = log10(flow) + 1.343 or acidity(kg/d) = 22.00 * flow(m3/d)
minimum log10(acidity) = log10(flow) + 0.564 or acidity(kg/d) = 3.67 * flow(m3/d)

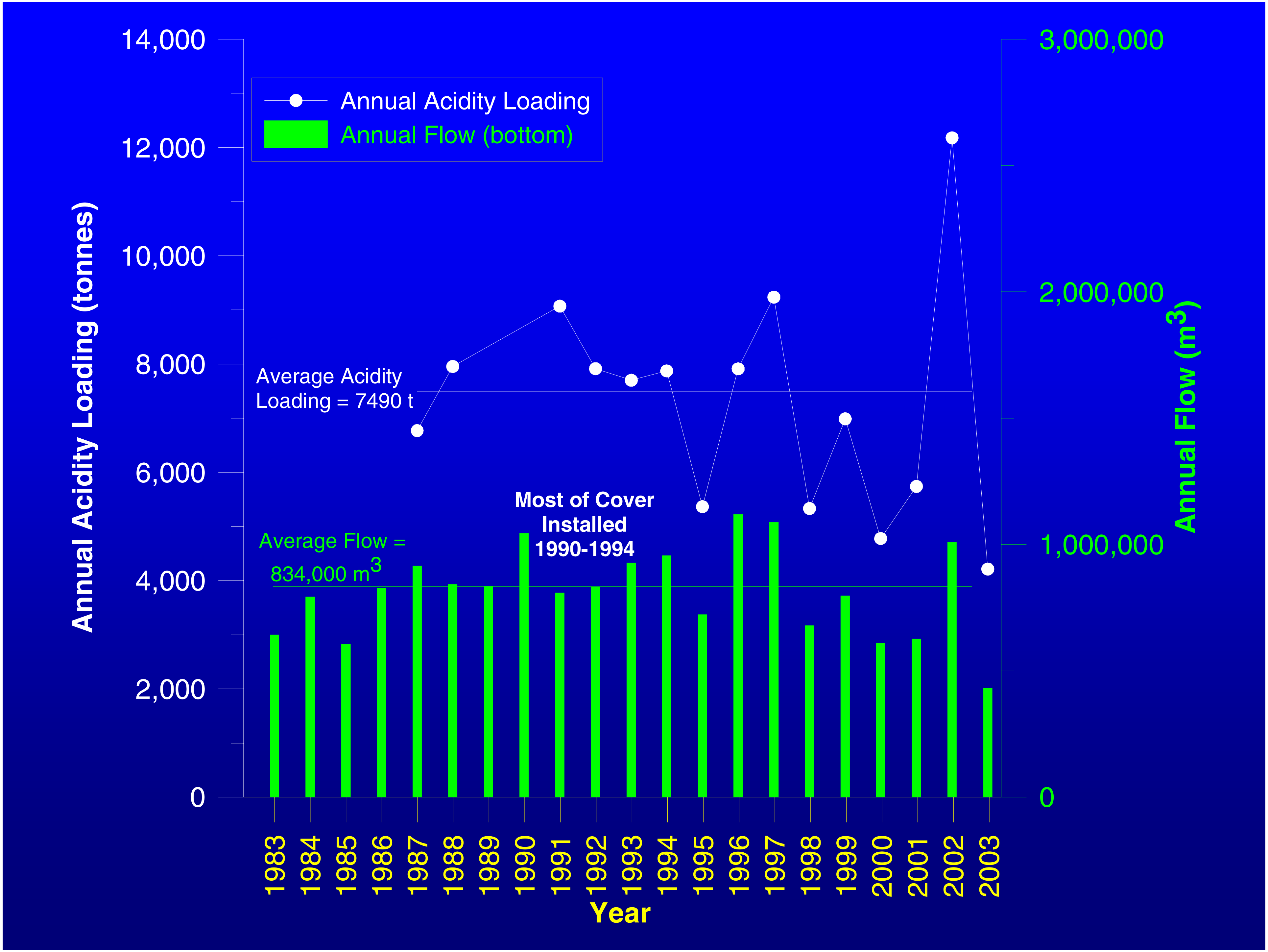


Best-Fit Lognormal Curve:
Mean = 4.1807
Std Dev = 0.3040 log cycles
Frequency
0
20
40
60
0
1
2
3
4
5
6
7
8
Log10(Monthly Acidity Loading (kg/day))

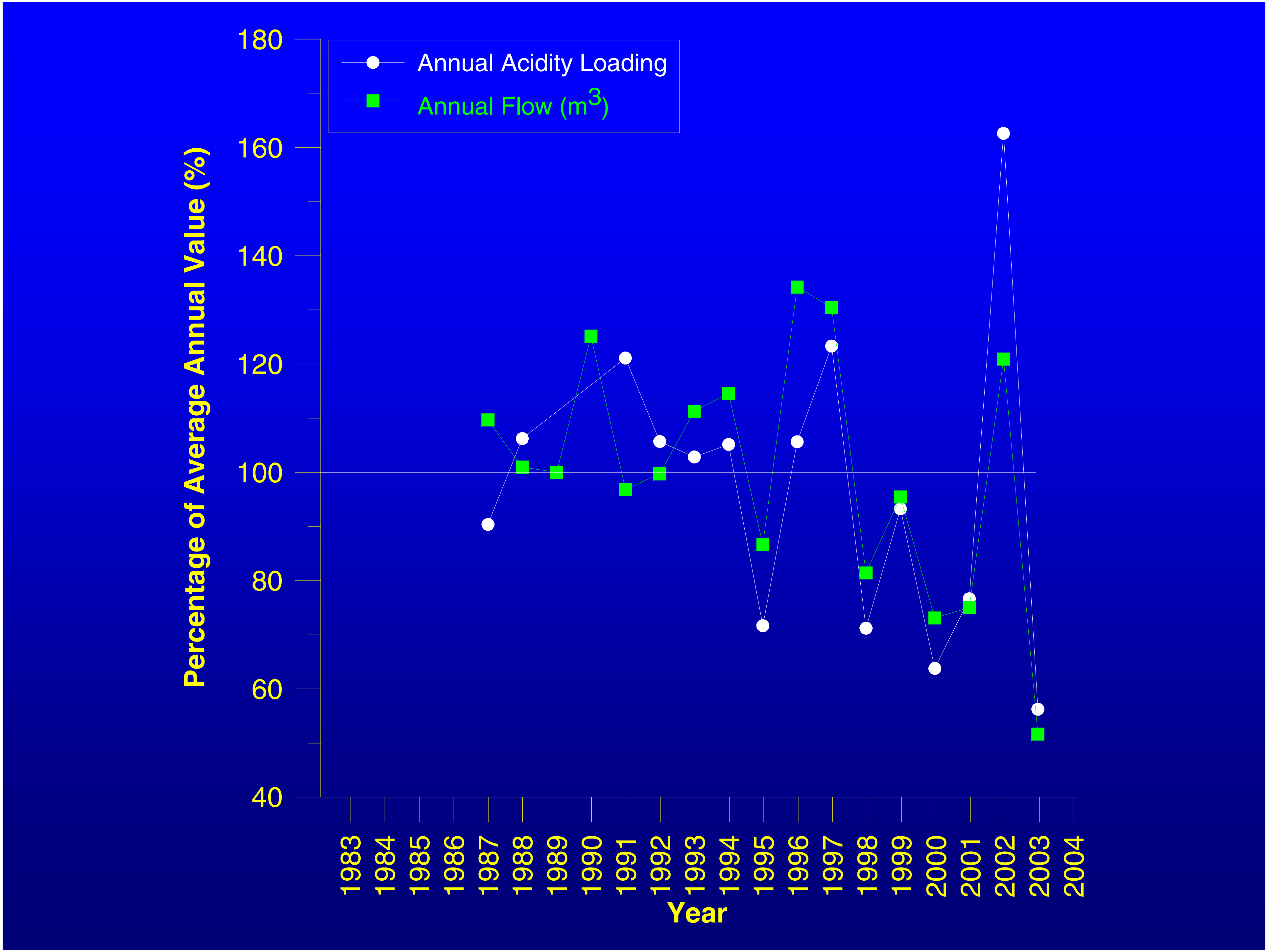

1,000,000
100,000
10,000
1,000
Monthly Acidity Loading (as kg/day)
Pre-1998 Data
1998 - 2001
2002
2003 (to September)
maximum log10(acidity) =
log10(flow) + 1.343
or
acidity(kg/d) = 22.00 * flow(m3/d)
Factor-of-6
Range
minimum log10(acidity) =
log10(flow) + 0.564
or
acidity(kg/d) = 3.67 * flow(m3/d)
100
1,000
10,000
100,000
Monthly Flow (as m3/day)



Lognormal Distribution:
mean = 3.957 (9057 mg/L)
std dev = 0.191 log cycles
count = 185
Concentration
at Peak Loading
in May 2002 =
log10(17569 mg/L) = 4.24
Frequency
40
30
20
10
0
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
log10 (Average Monthly Acidity Concentration (mg/L) 1986-2003)

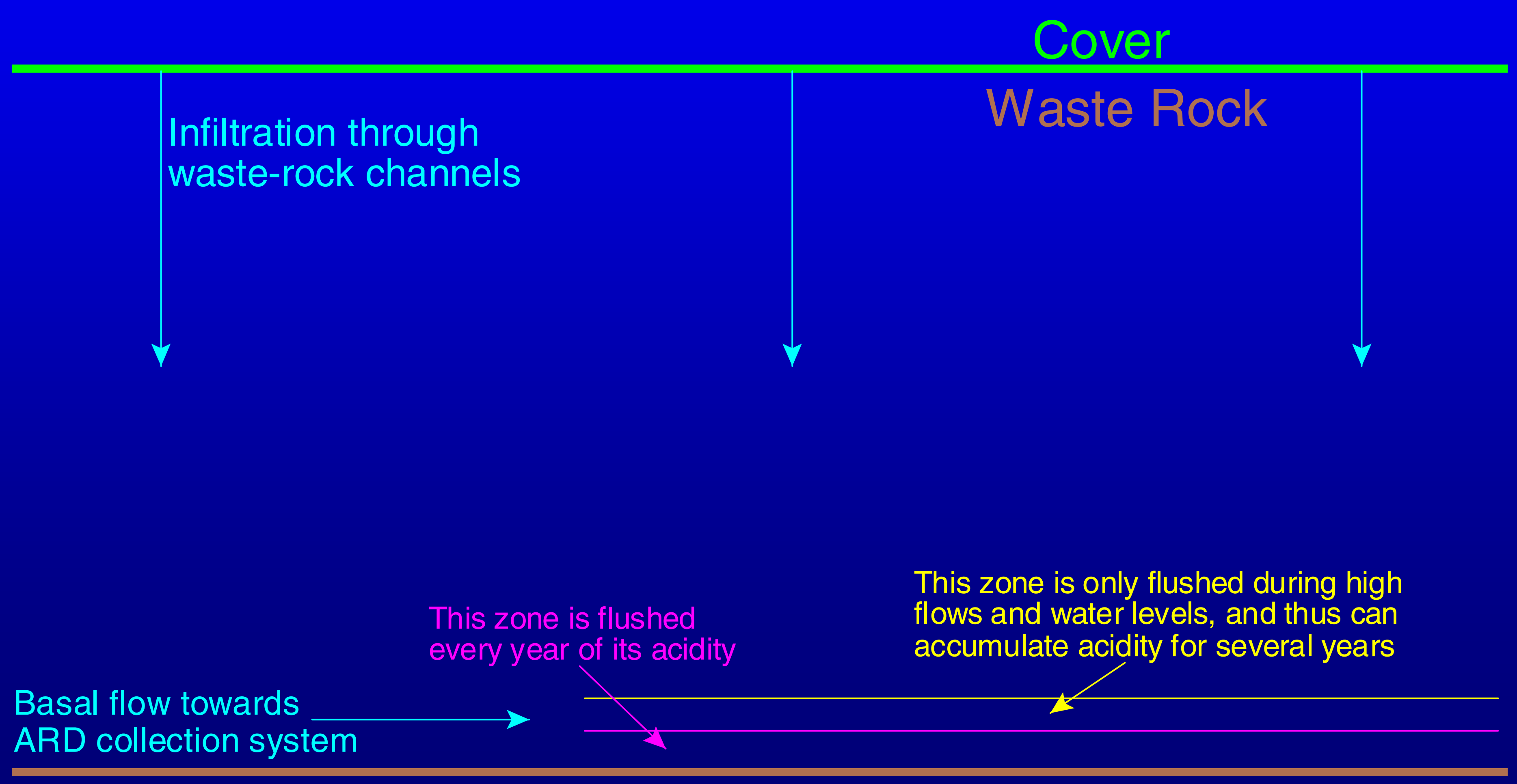


Annual Acidity Loading
Annual Flow (bottom)
Annual Acidity Loading (tonnes)
Annual Flow (m^3)
Average Acidity Loading = 7490 t
Average Flow = 834,000 m^3
Most of Cover Installed 1990-1994
Year
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
3,000,000
2,000,000
1,000,000
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003



Annual Acidity Loading
Annual Flow (m^3)
Percentage of Average Annual Value (%)
180
160
140
120
100
80
60
40
1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004
Year

Simple Schematic Diagram of the Mass-Balance Mechanism for Acidity Flushing from Waste Rock



Conclusion

- Year 2002 produced one of the highest annual flows and the highest monthly flow on record in May.
- Statistically, the annual acidity loading for 2002 was not highly unusual but was still unexpected (once ~ every 50 years), but a loading equal to or greater than May 2002 is expected less than once every 200 years.
- Monthly variations in acidity loadings at a particular value of flow reflect the range-of-six variation in aqueous acidity concentrations resembling a lognormal distribution.

Conclusion

- Waste rock not well flushed by groundwater in some past years was flushed in 2002, releasing additional, stored acidity.

- This review of data pertaining to potential mechanisms for the peak acidity loadings in 2002 has led to the geochemical mass-balance mechanism as the best explanation. Under this mechanism, a certain amount of acidity is generated each year in zones rinsed by water. If all the acidity is not fully flushed out each year due to low flows, the remainder accumulates each year until a high flow removes the accumulation as a large loading.

Conclusion

- Based on the geochemical mass-balance mechanism, the till cover makes little difference to the annual acidity production, but can influence the amount flushed annually from the waste rock.

- Under this mechanism, the high flush in 2002 likely removed much of the accumulated acidity in relatively normal flowpaths, but the relatively low flush in 2003 (to September) has led to new accumulation.

THE END