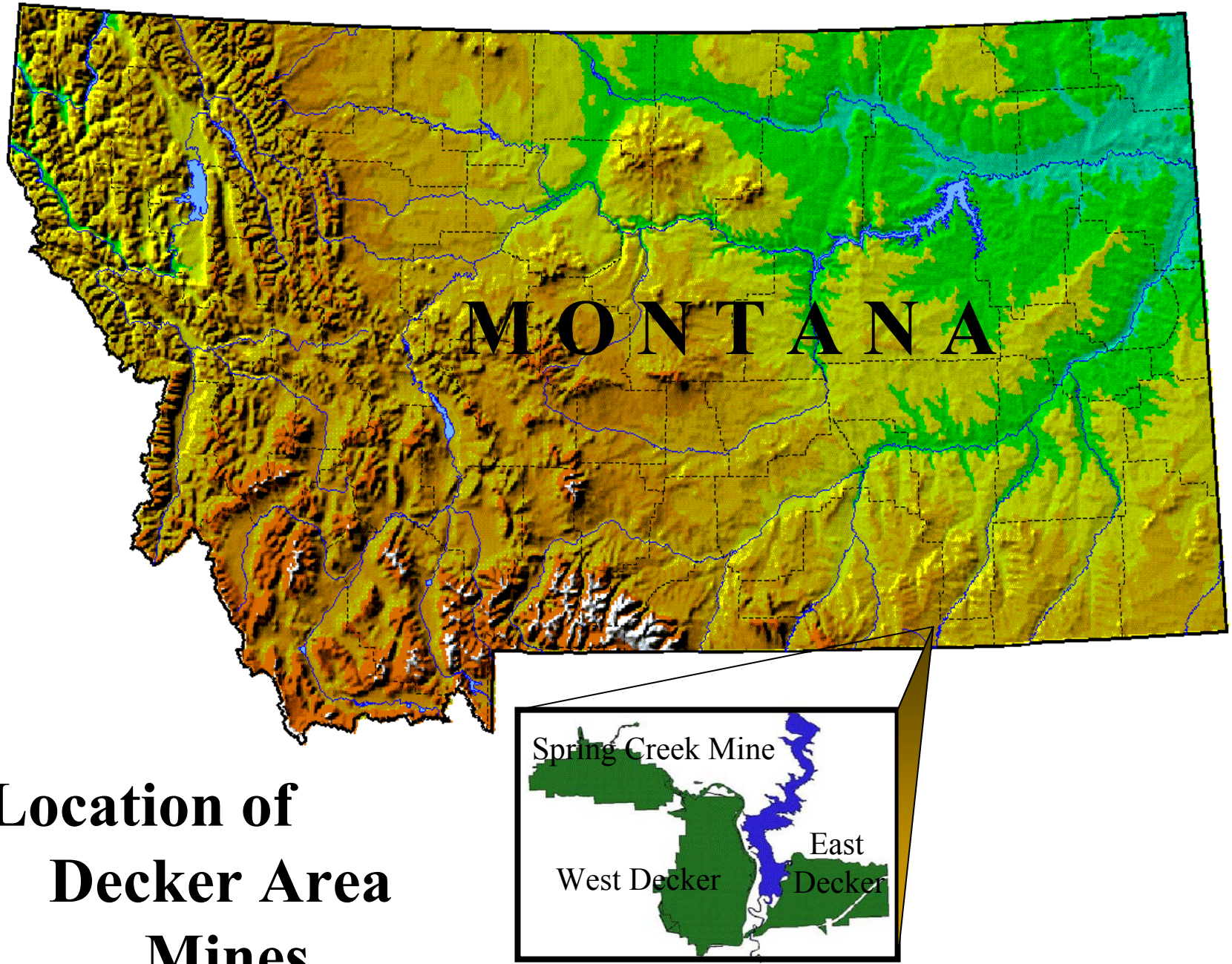
The Hydrology and Hydrologic Effects of Mining in the Decker, Montana, Area, 1972-98

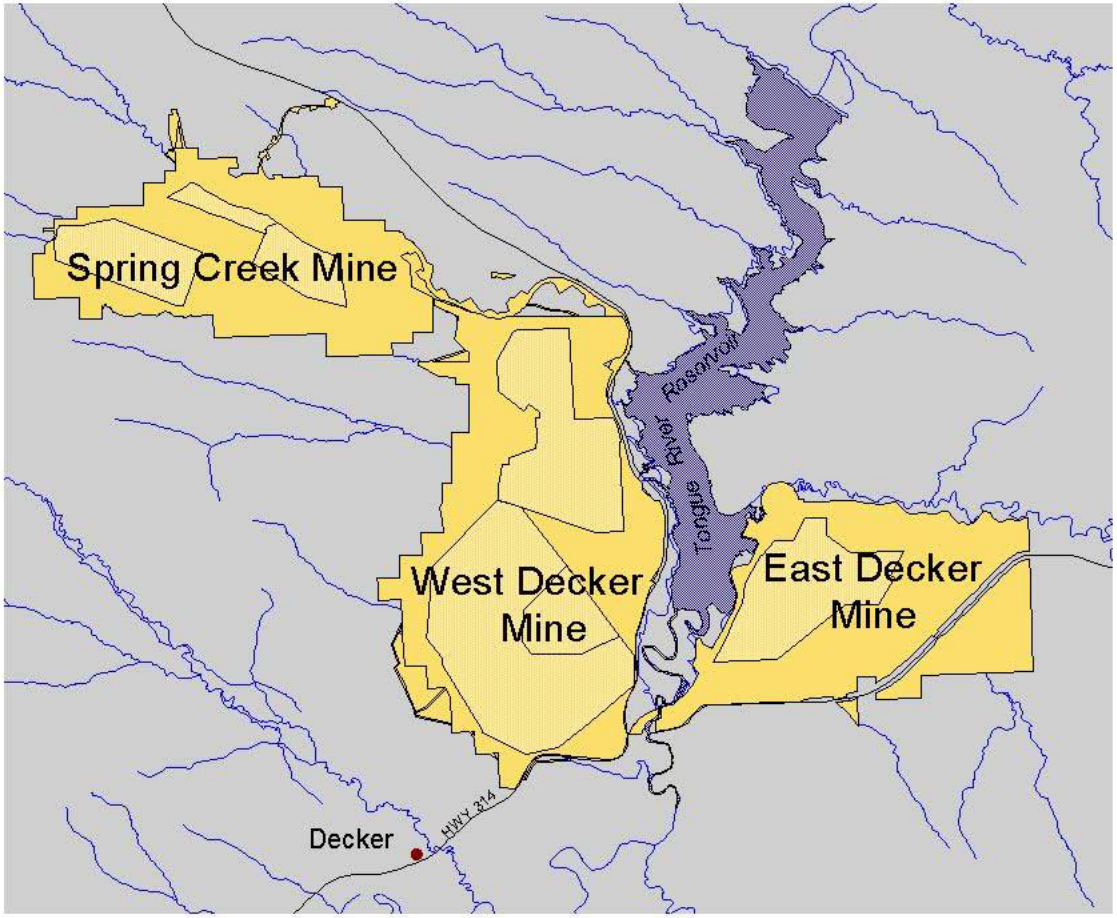
Angela McDannel, Ground-Water Hydrologist

Montana Department of Environmental Quality



Location of Decker Area Mines

Decker Area Mines



Permit Area

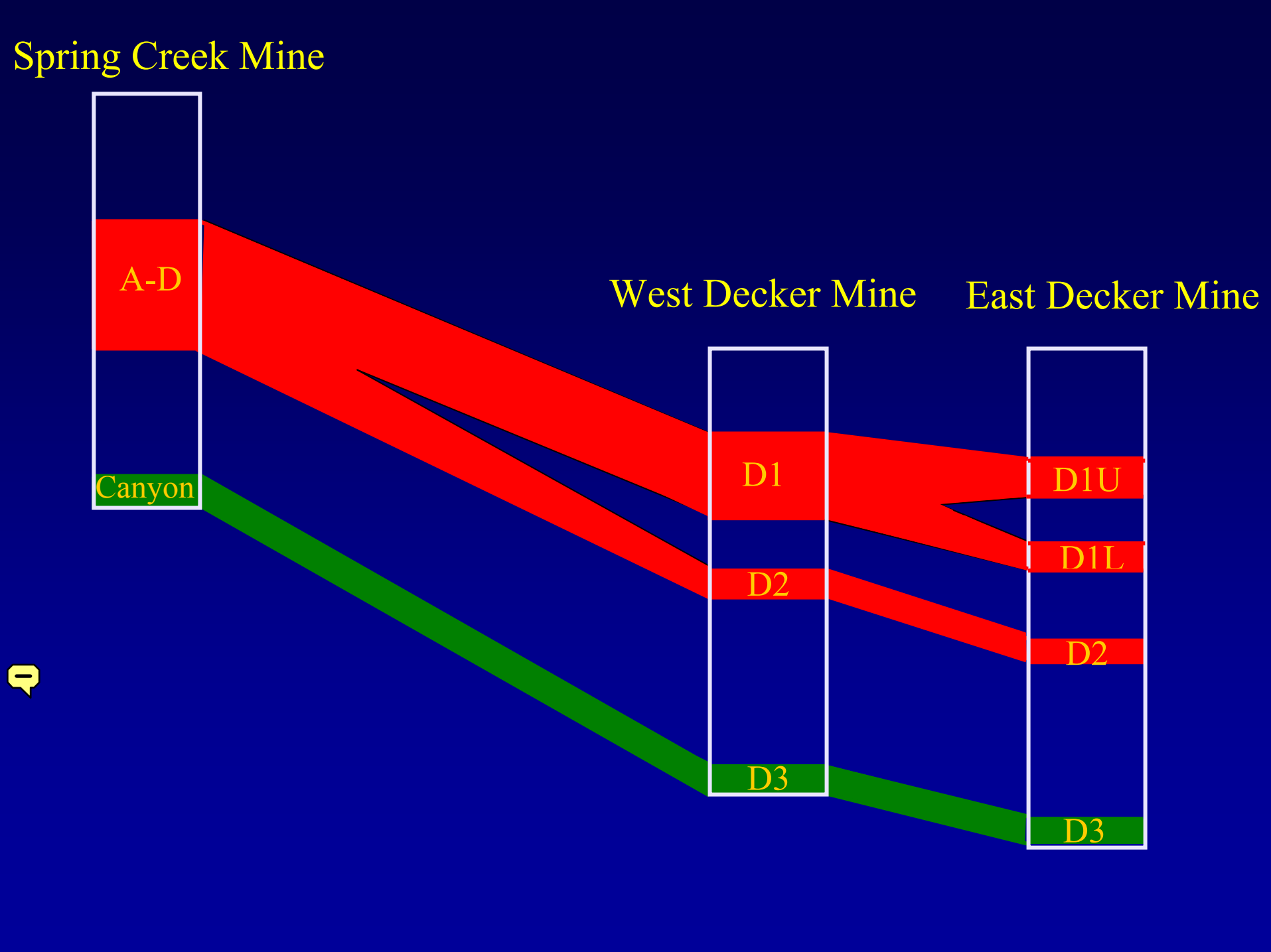
Pit Area

Tongue River Reservoir

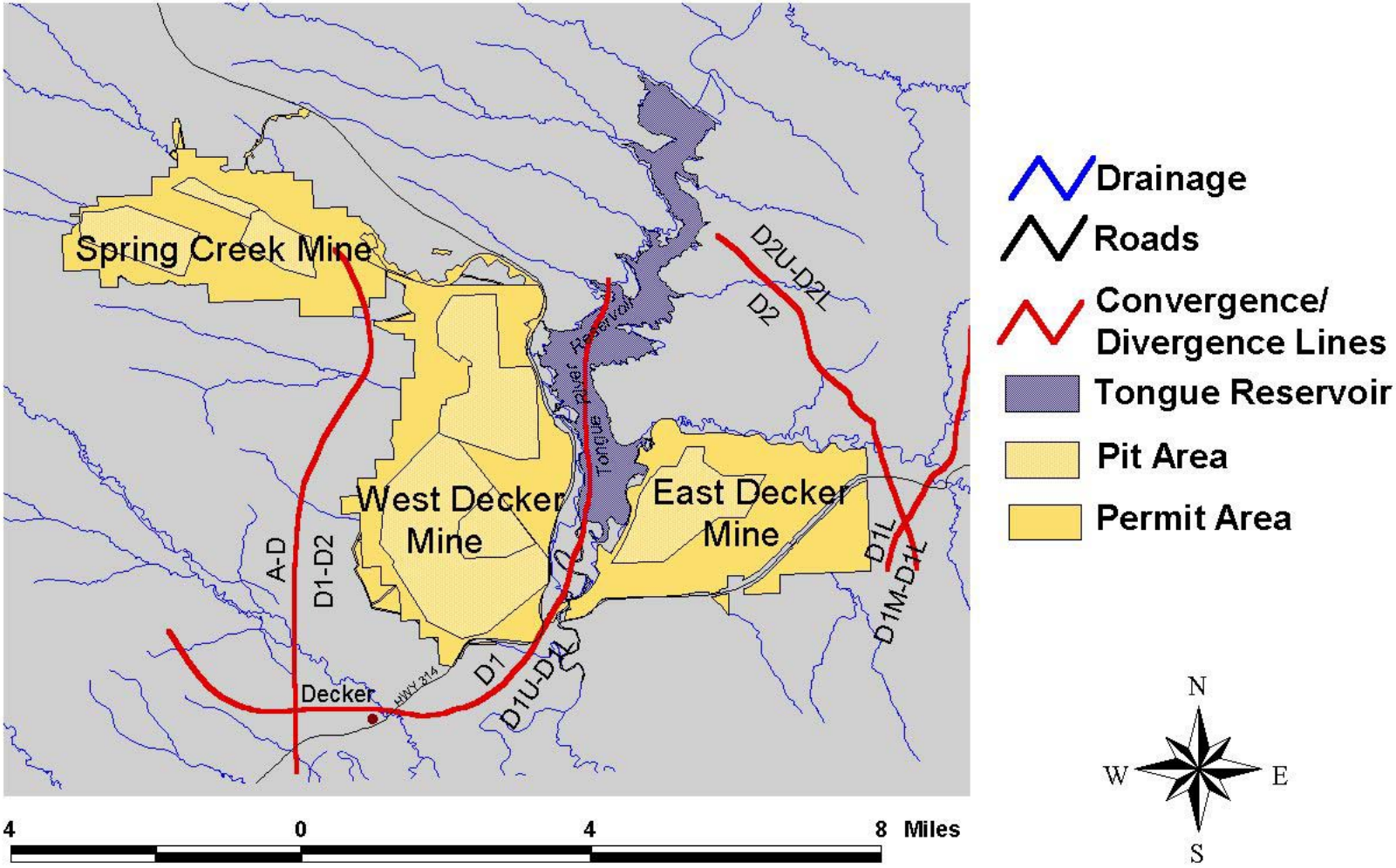
Roads

1 0 1 2 Miles

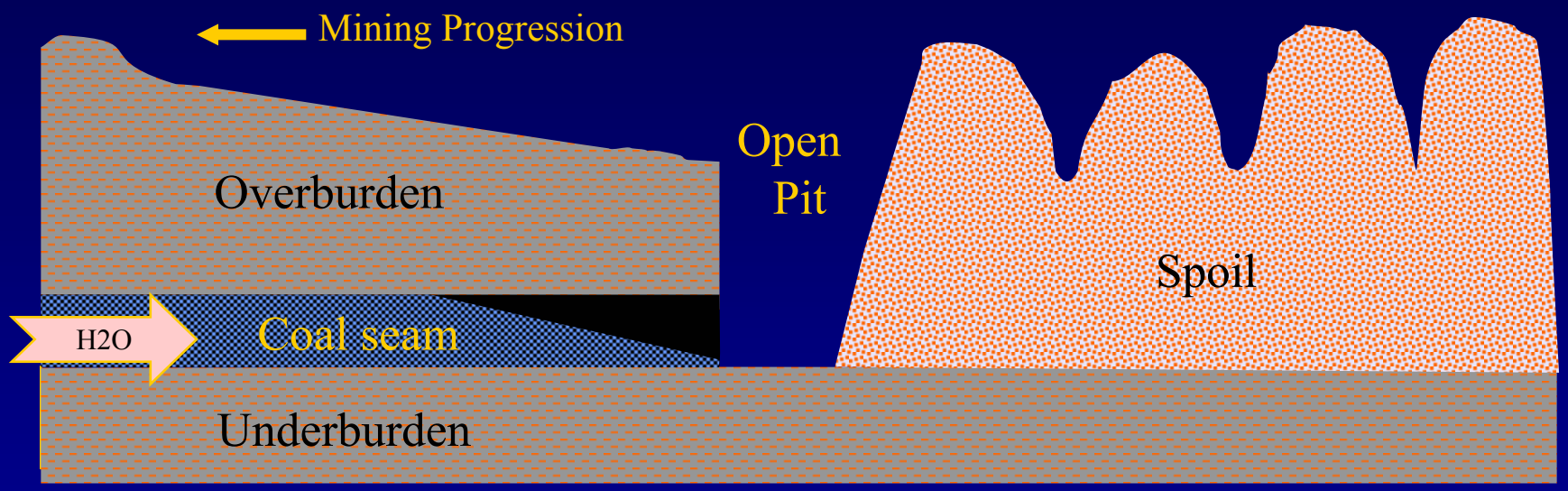
N
W E
S


Spring Creek Mine
A-D
Canyon
West Decker Mine
D1
D2
D3
East Decker Mine
D1U
D1L
D2
D3

Coal Convergence/Divergence Lines



Ground-Water Movement During Mining



Post-Reclamation Ground-Water Movement

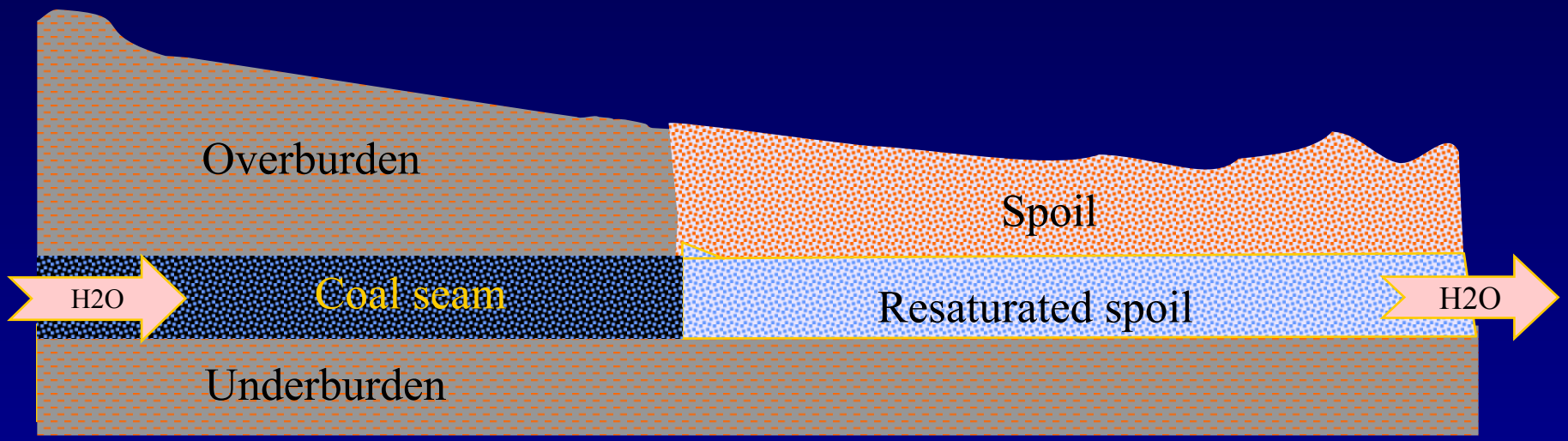


Table 2.1.--Range of values for hydrologic parameters determined for aquifers in the Decker area

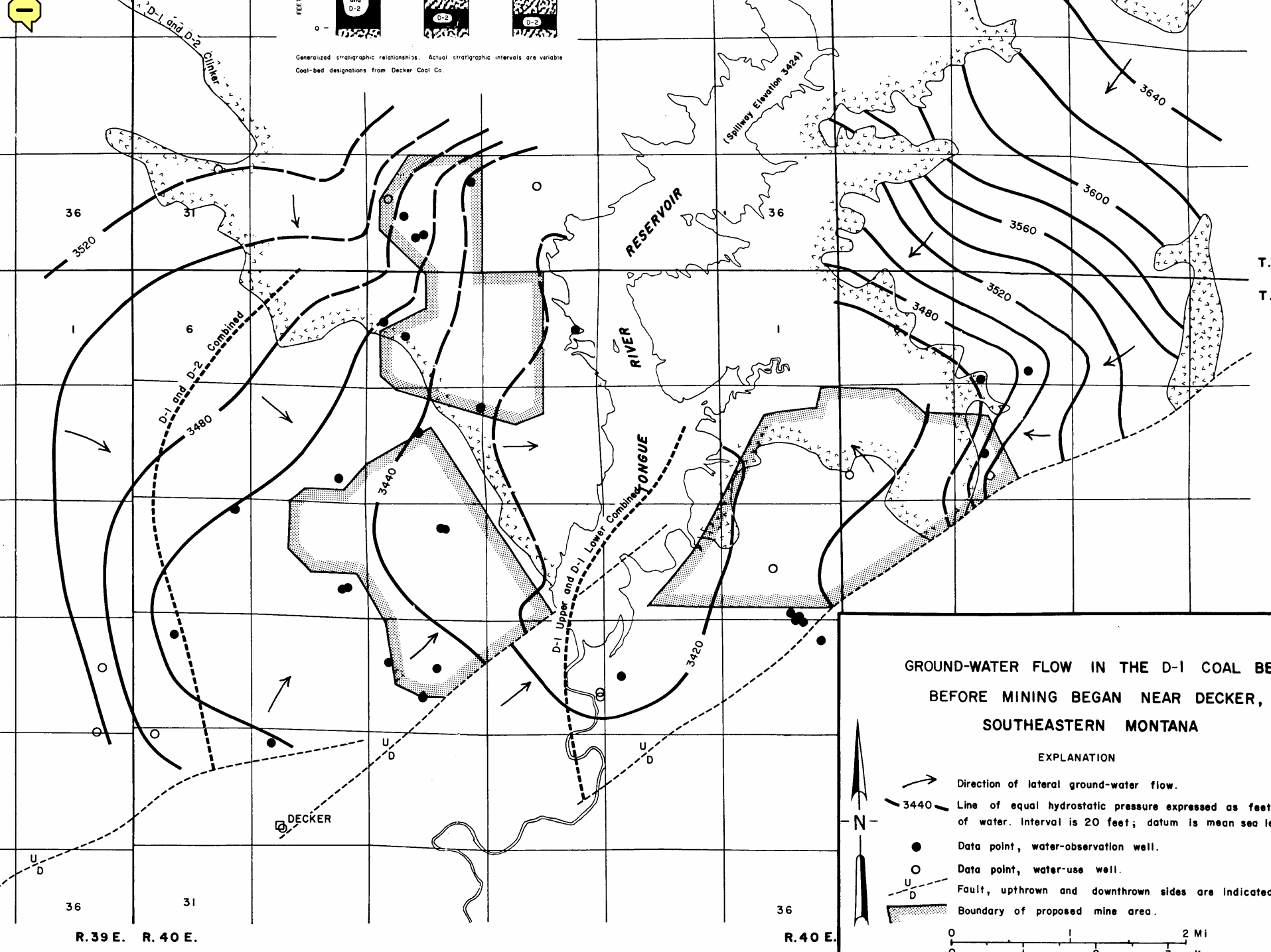
(Decker Coal Company, 1991; Spring Creek Coal Company, 1980).

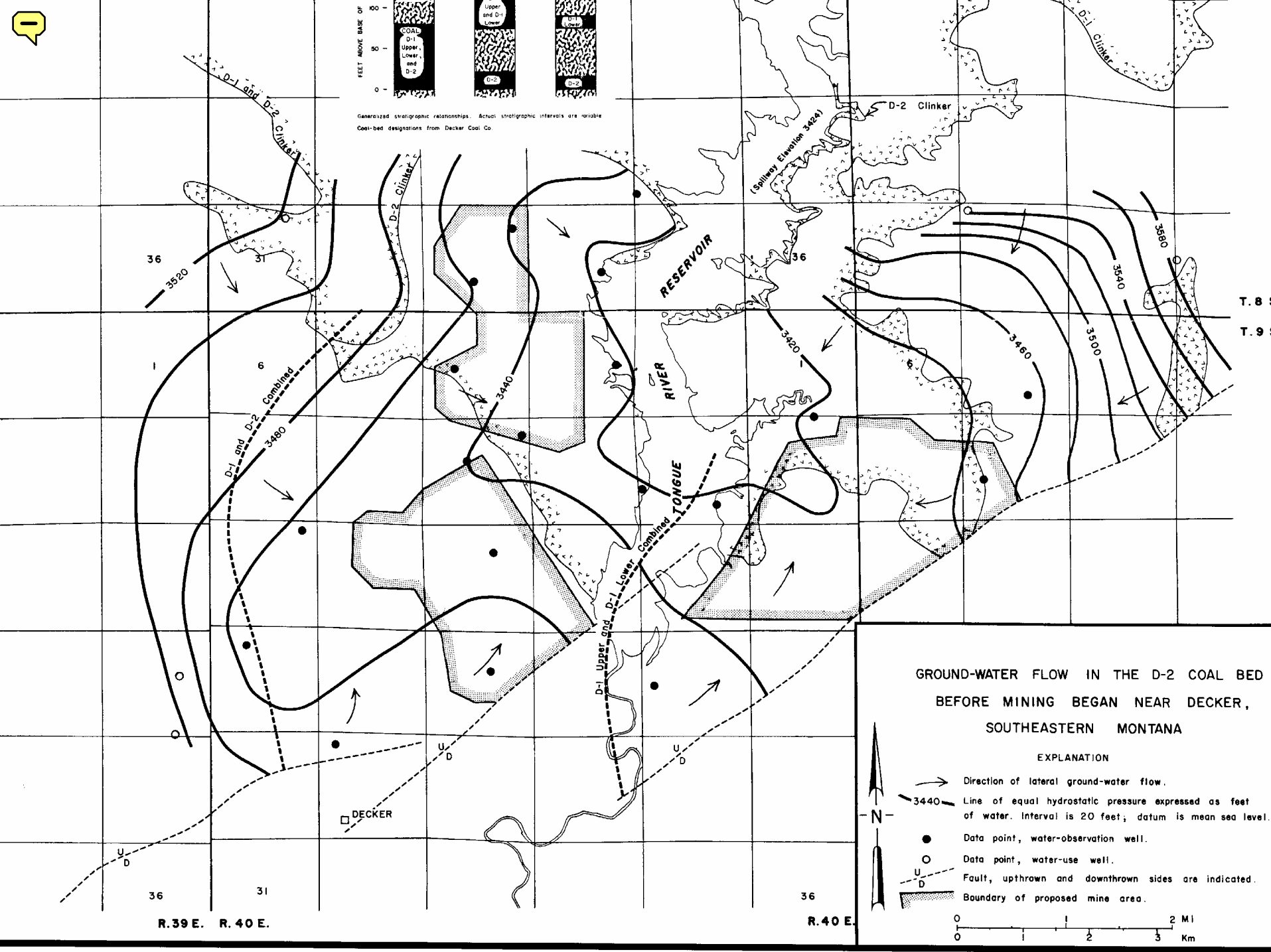
Aquifer	Transmissivity (g/d/f)	Storativity
D1L	96 - 5157	$6x10^{-5}$; $4x10^{-4}$
D1U	1 - 630	
D1	611	
D2	129 - 2020	$4x10^{-5}$
D3	287 - 449	
Anderson-Dietz	980 - 1320	$2x10^{-3}$; $1x10^{-3}$
Canyon	24 - 60	
Spoils	2368 - 3006	

15600 AMT
W\A

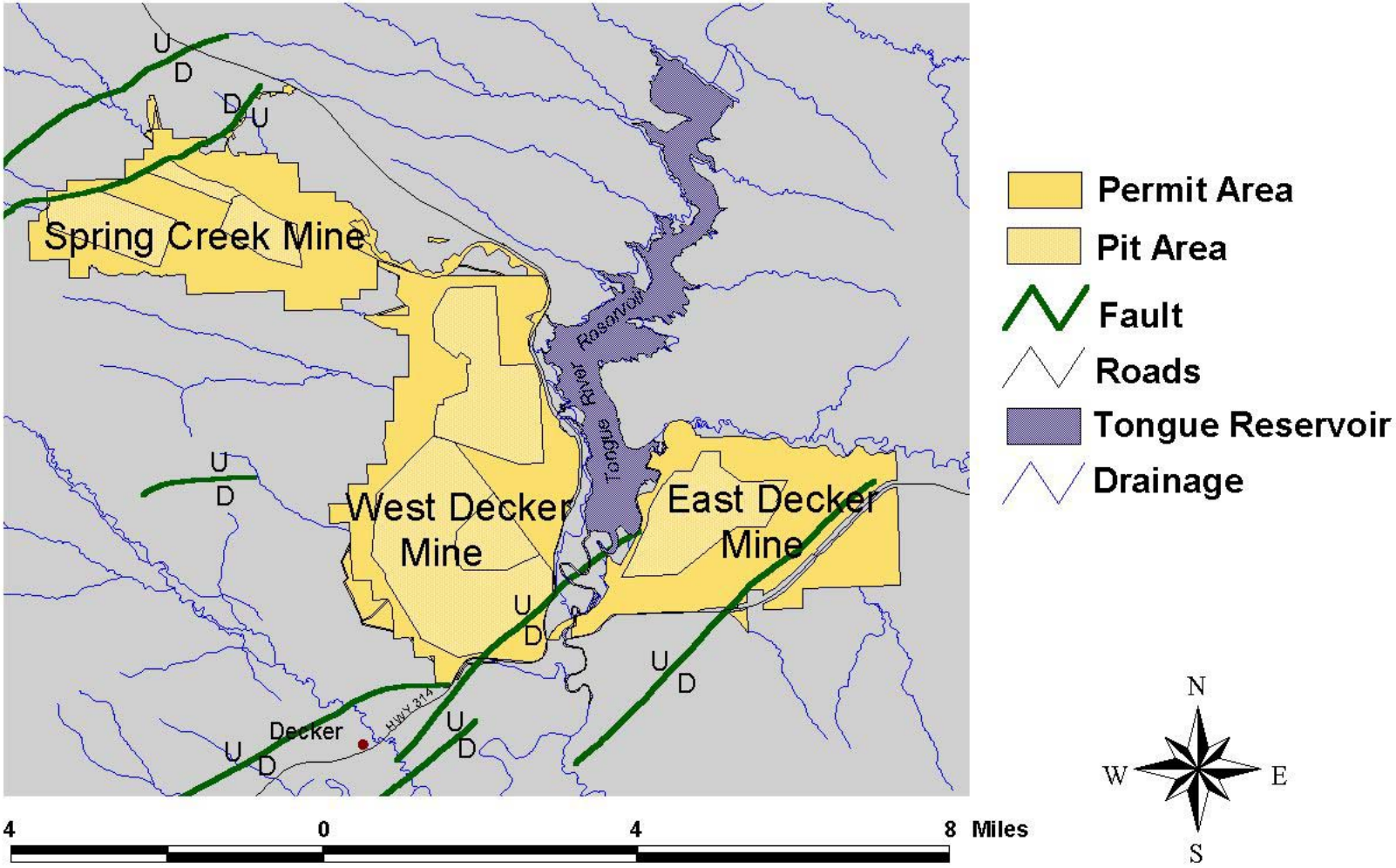
6 10'99
Direction of Ground-Water Movement

6 10'99


FEET
0
D-1 and D-2
D-2
D-2
Generalized stratigraphic relationships. Actual stratigraphic intervals are variable
Coal-bed designations from Decker Coal Co.
D-1 and D-2 Clinker
(Spillway Elevation 3424)
RESERVOIR
RIVER
TONGUE
D-1 and D-2 Combined
D-1 Upper and D-1 Lower Combined
3640
3600
3560
3520
3480
3440
3420
3520
3480
36
31
1
6
36
1
36
31
36
U
D
DECKER
R.39 E.
R.40 E.
R.40 E.
T.
T.
GROUND-WATER FLOW IN THE D-1 COAL BE
BEFORE MINING BEGAN NEAR DECKER,
SOUTHEASTERN MONTANA
EXPLANATION
Direction of lateral ground-water flow.
3440
Line of equal hydrostatic pressure expressed as feet
of water. Interval is 20 feet; datum is mean sea le
Data point, water-observation well.
Data point, water-use well.
U
D
Fault, upthrown and downthrown sides are indicated
Boundary of proposed mine area.
N
0
1
2 Mi

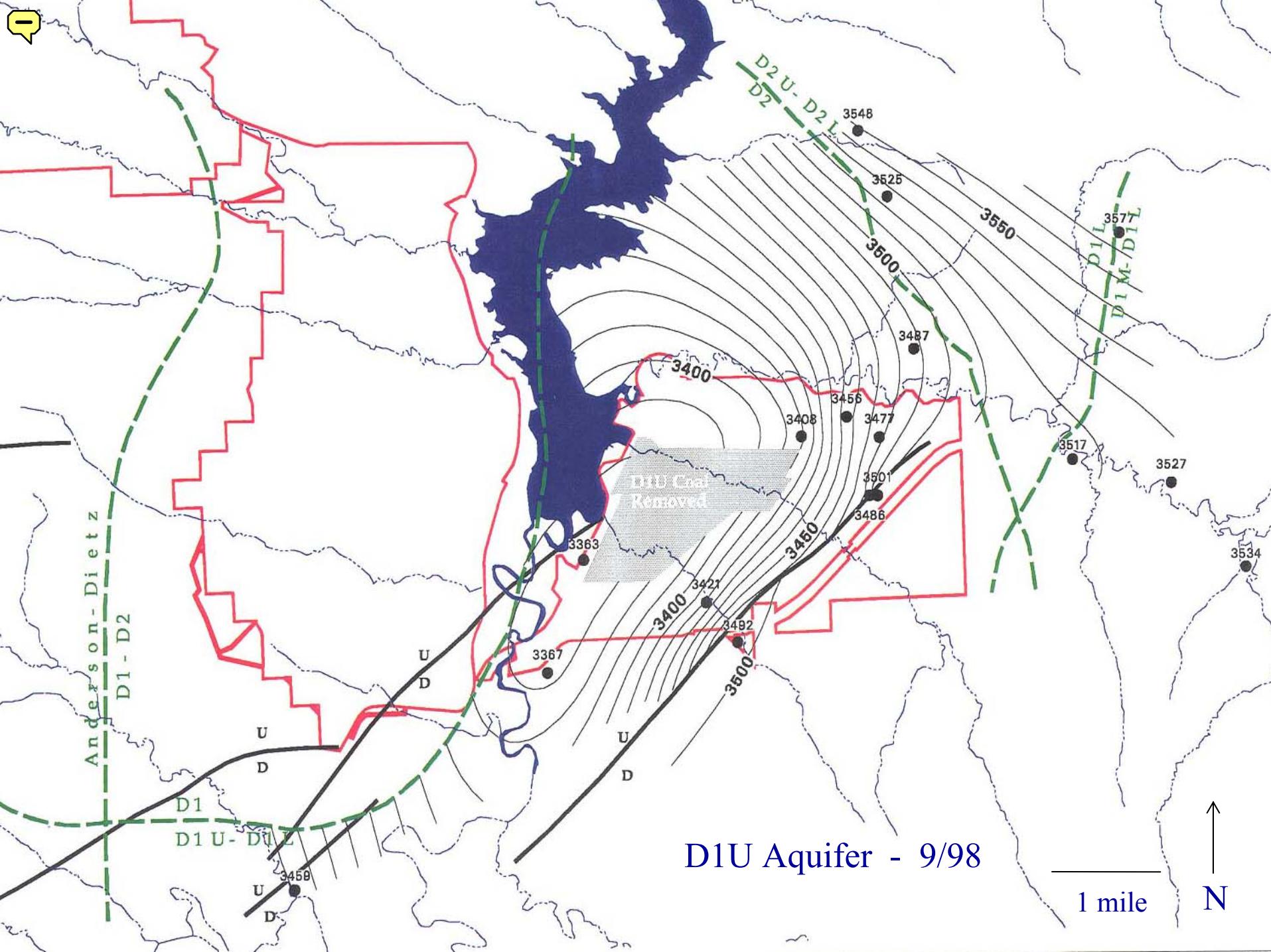

GROUND-WATER FLOW IN THE D-2 COAL BED BEFORE MINING BEGAN NEAR DECKER, SOUTHEASTERN MONTANA
EXPLANATION
Direction of lateral ground-water flow.
3440 Line of equal hydrostatic pressure expressed as feet of water. Interval is 20 feet; datum is mean sea level.
Data point, water-observation well.
Data point, water-use well.
Fault, upthrown and downthrown sides are indicated.
Boundary of proposed mine area.
N
0 1 2 MI
0 1 2 3 Km
FEET ABOVE BASE OF
100
50
0
COAL
D-1 Upper, Lower, and D-2
Upper and D-1 Lower
D-1 Lower
D-2
Generalized stratigraphic relationships. Actual stratigraphic intervals are variable
Coal-bed designations from Decker Coal Co.
D-1 and D-2 Clinker
D-2 Clinker
D-1 Clinker
(Spillway Elevation 3424)
RESERVOIR
RIVER
TONGUE
D-1 and D-2 Combined
D-1 Upper and D-1 Lower Combined
3520
3480
3440
3420
3460
3500
3540
3580
DECKER
36
31
1
6
T.8
T.9
R.39 E.
R.40 E.

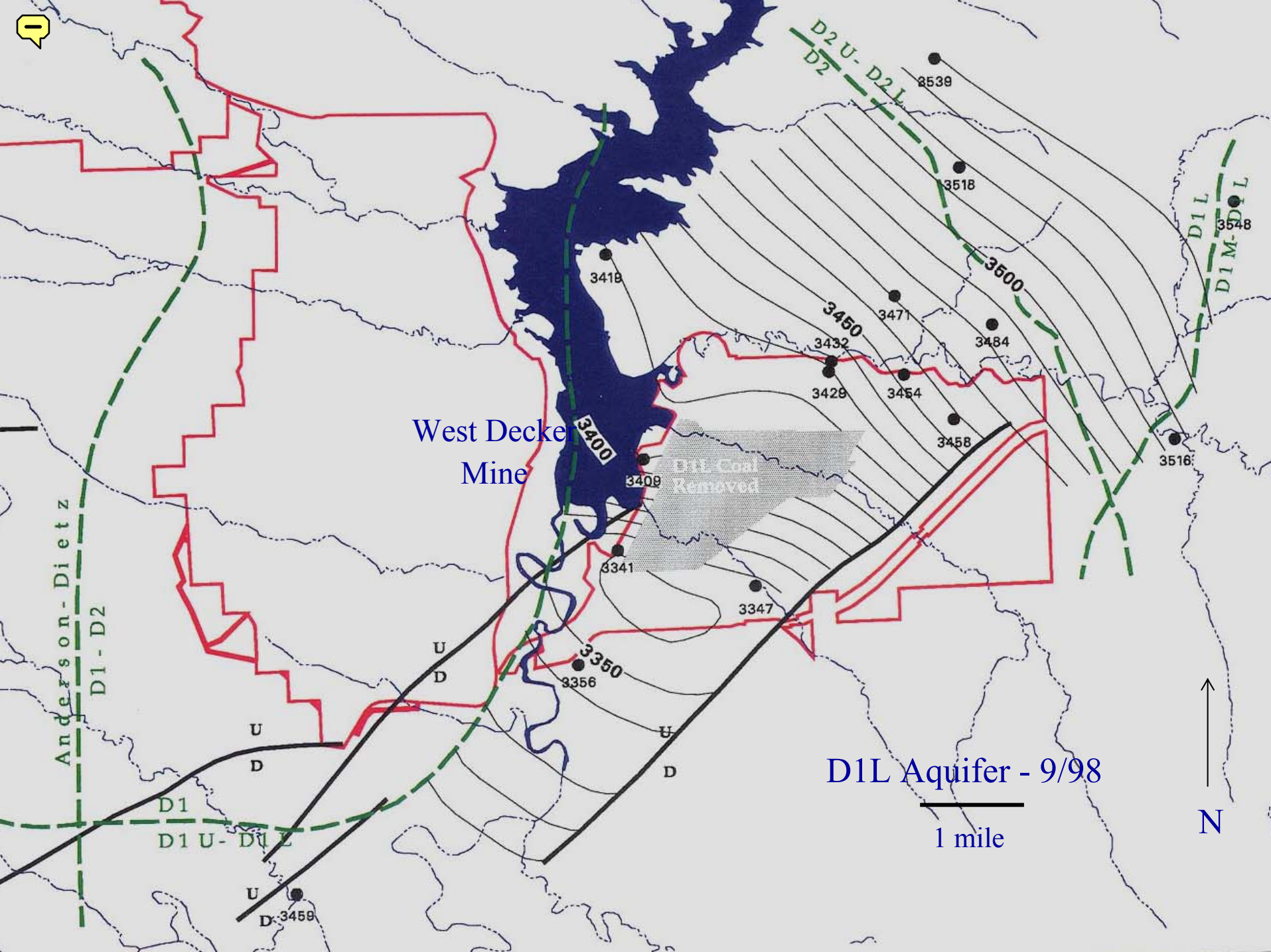
Decker Area Faults

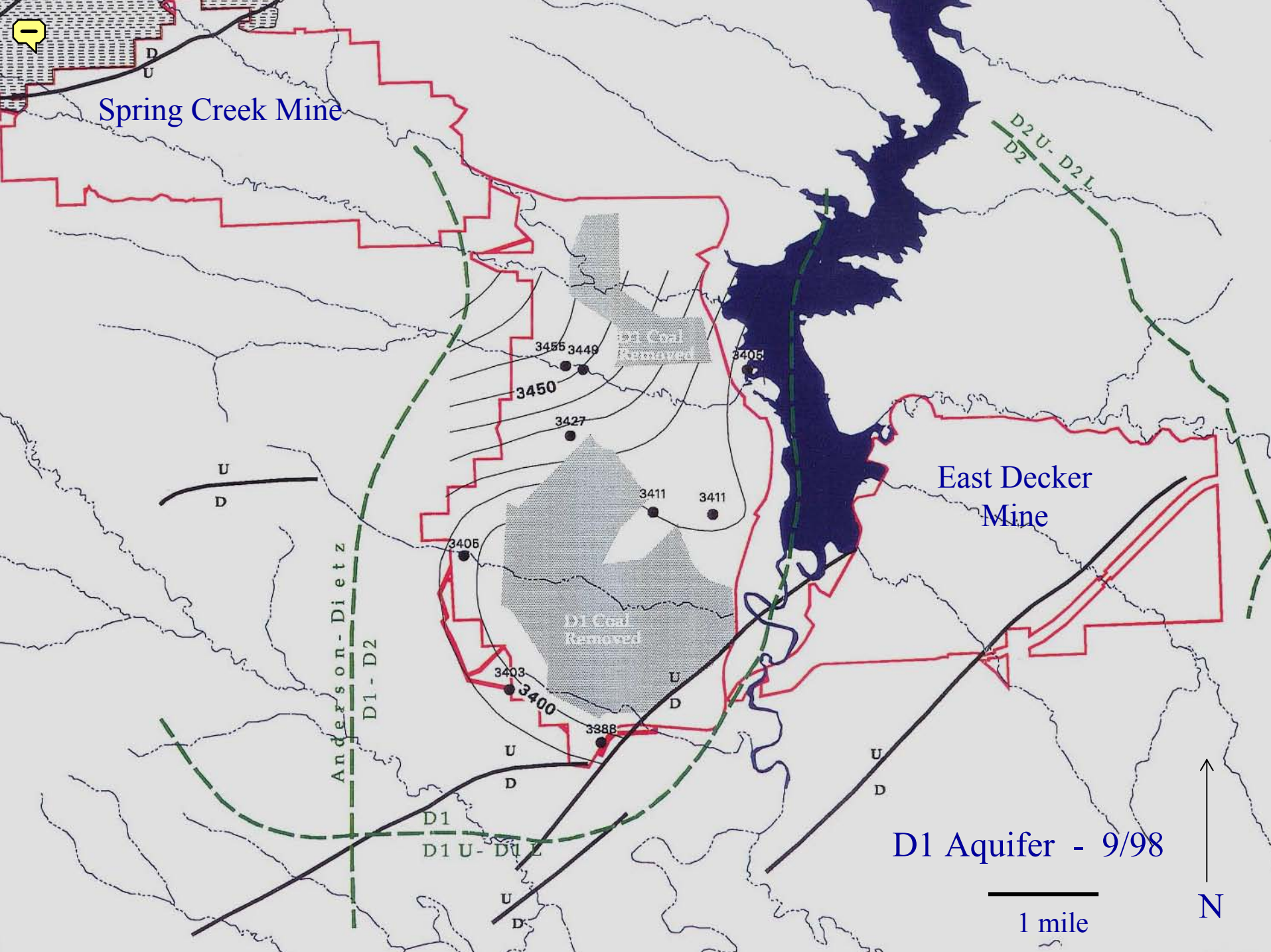


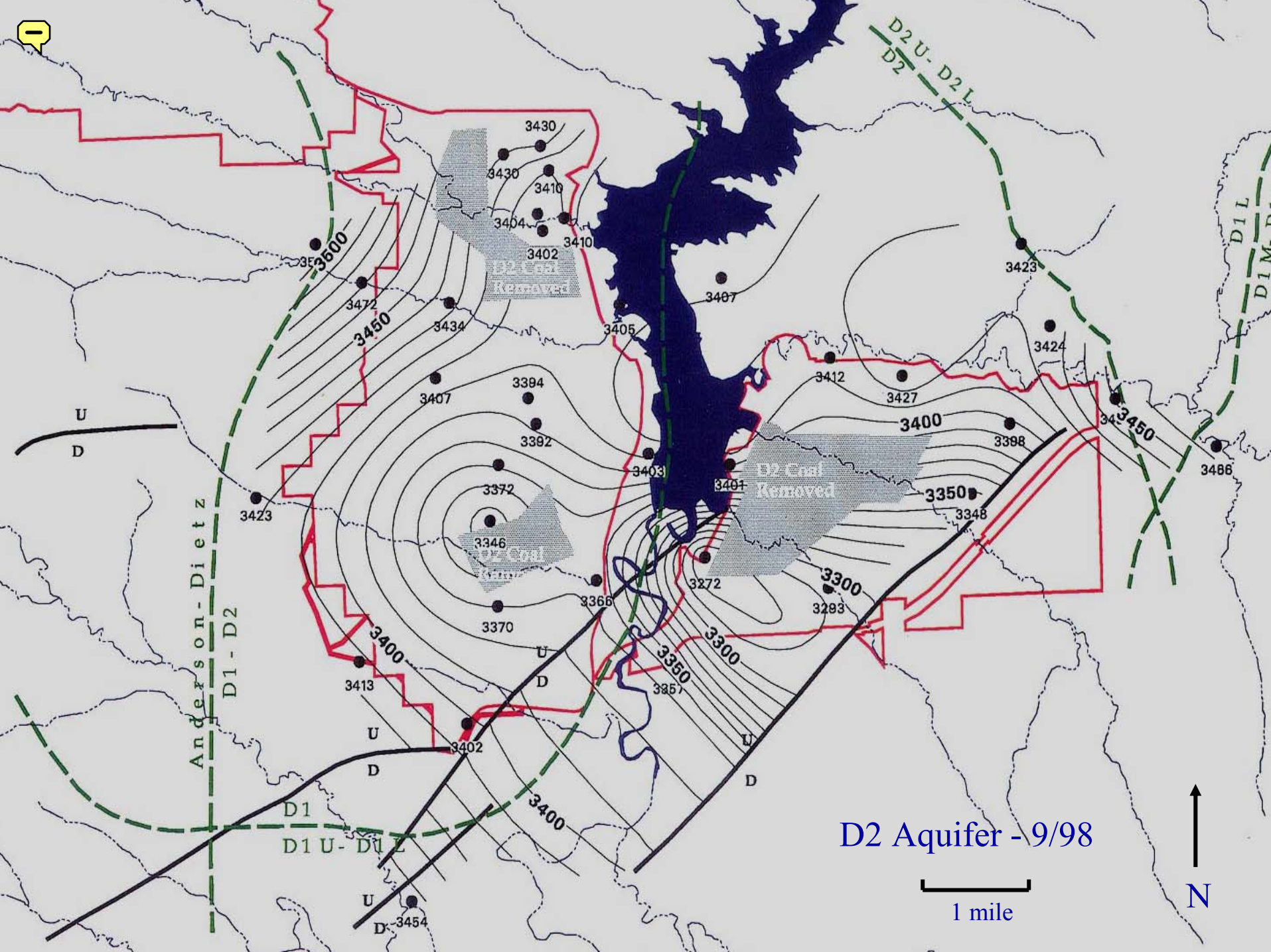
6 10'99

HORIZONS, INC.

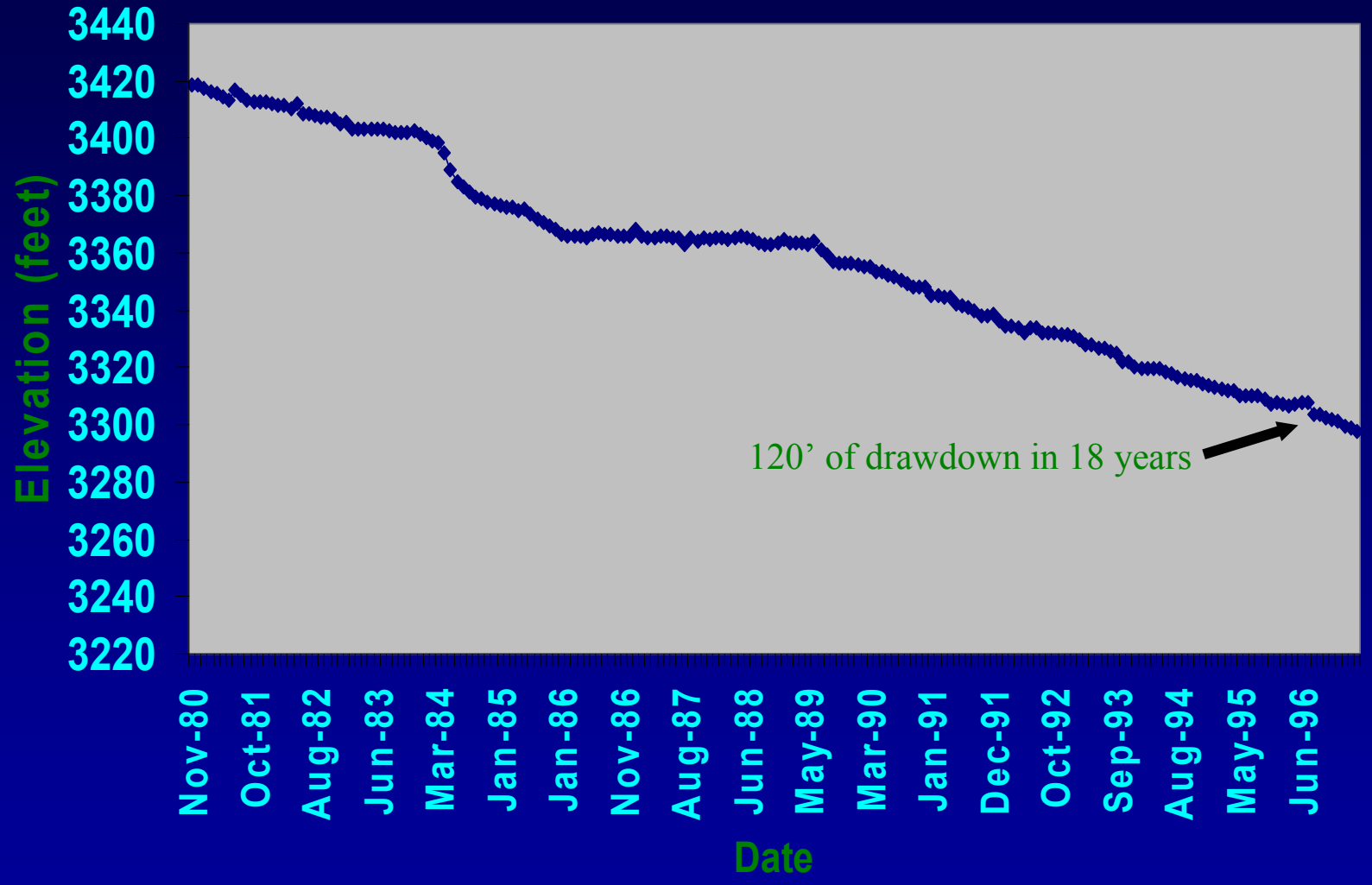

D1U Aquifer - 9/98
1 mile
N
D2 U - D2 L
D2
D1 L
D1 M - D1 L
Anderson - Dietz
D1 - D2
D1
D1 U - D1 L
D1U Coal Removed
3550
3500
3450
3400
3548
3525
3577
3487
3456
3408
3477
3517
3527
3501
3486
3534
3363
3421
3492
3367
3458
U
D

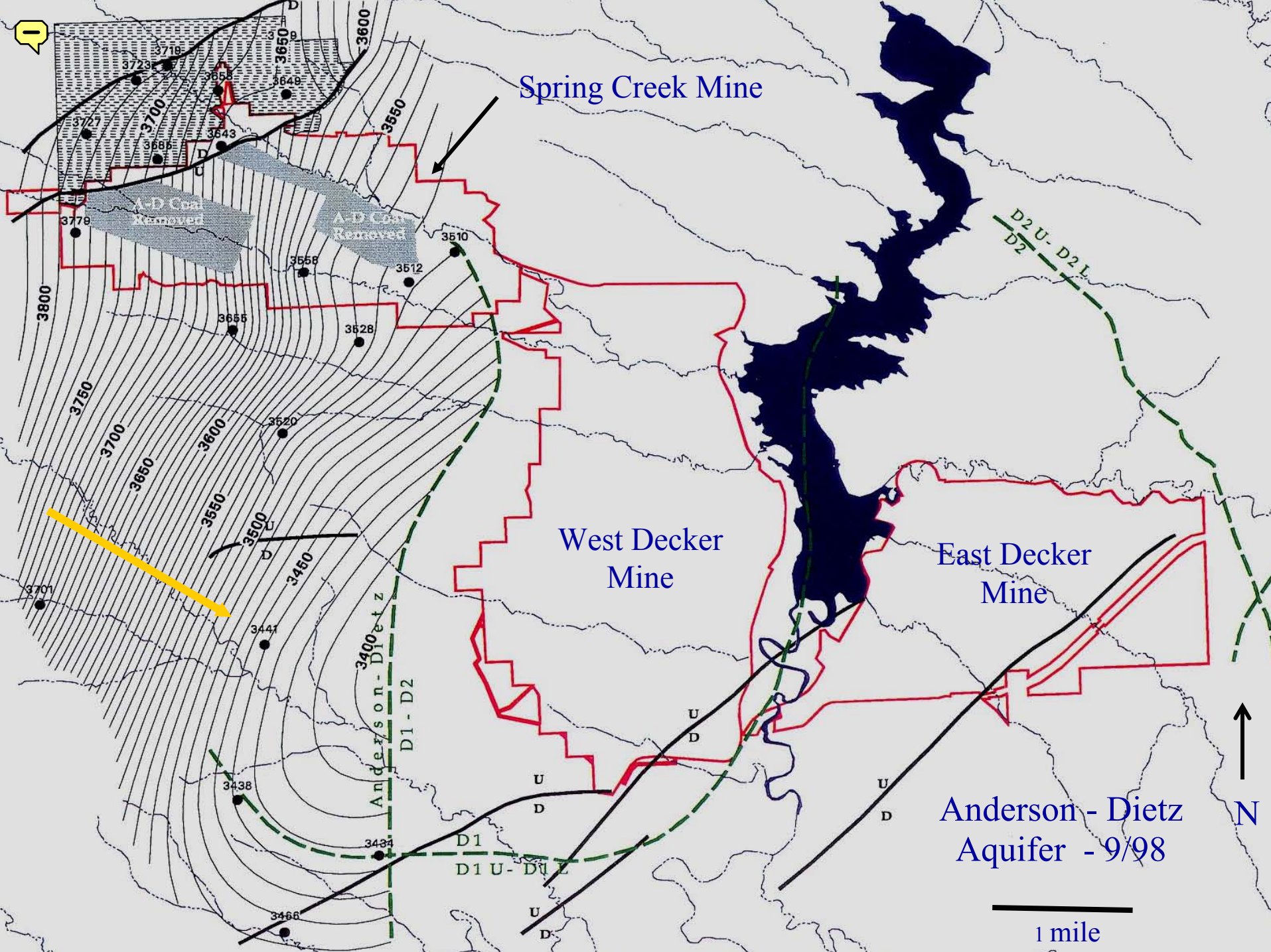

West Decker Mine
D1L Aquifer - 9/98
1 mile
N
D1L Coal Removed
3400
3450
3500
3350
3539
3518
3548
3419
3471
3484
3432
3429
3454
3458
3516
3409
3341
3347
3356
3459
D2 U- D2 L
D2
D1 L
D1 M- D1 L
Anderson-Dietz
D1 - D2
D1
D1 U- D1 L
U
D

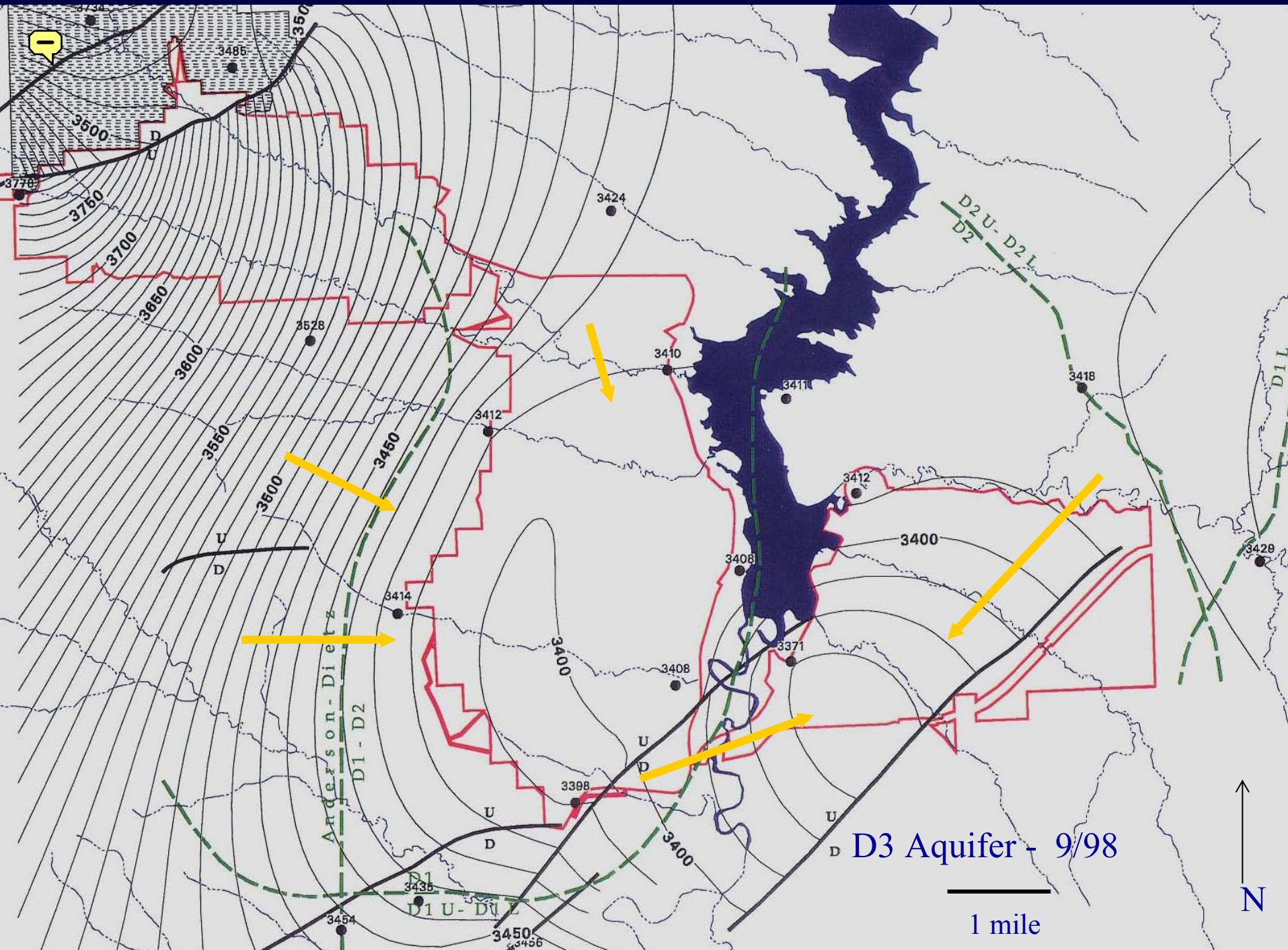

Spring Creek Mine
East Decker Mine
D1 Aquifer - 9/98
1 mile
N
D1 Coal Removed
D1 Coal Removed
3450
3400
3455
3449
3405
3427
3411
3411
3405
3403
3388
D2 U - D2 L
D2
Anderson - Dietz
D1 - D2
D1
D1 U - D1 L
U
D


D2 Aquifer - 9/98
1 mile
N
D2 U- D2 L
D2
D1 L
D1 M
Anderson- Dietz
D1 - D2
D1
D1 U- D1 L
D2 Coal Removed
3600
3450
3400
3350
3300
U
D
3430
3410
3404
3402
3472
3434
3407
3394
3392
3372
3346
3370
3413
3402
3454
3366
3357
3272
3293
3348
3398
3427
3412
3424
3423
3486
3405
3403
3401

Well 21180 - D2 Aquifer

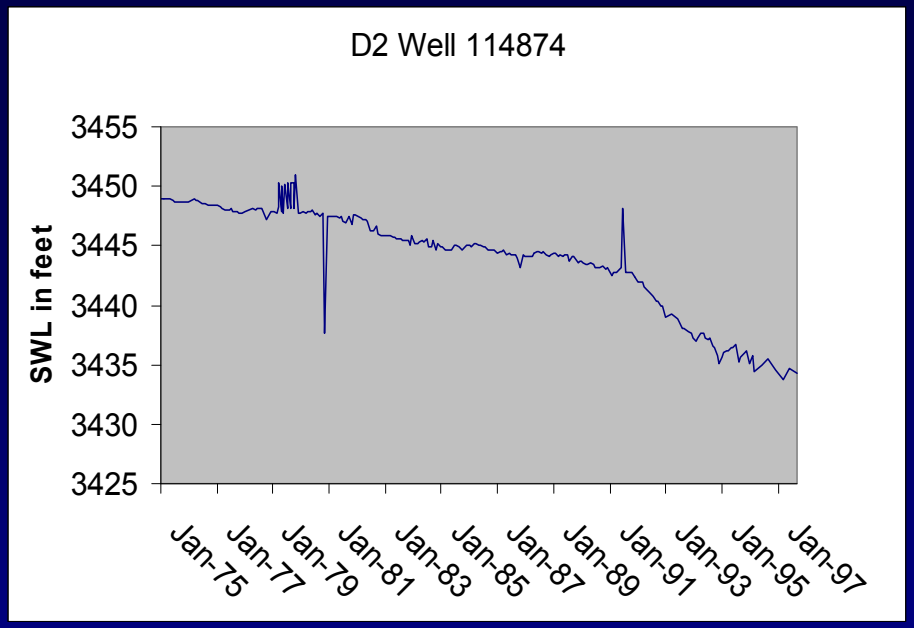


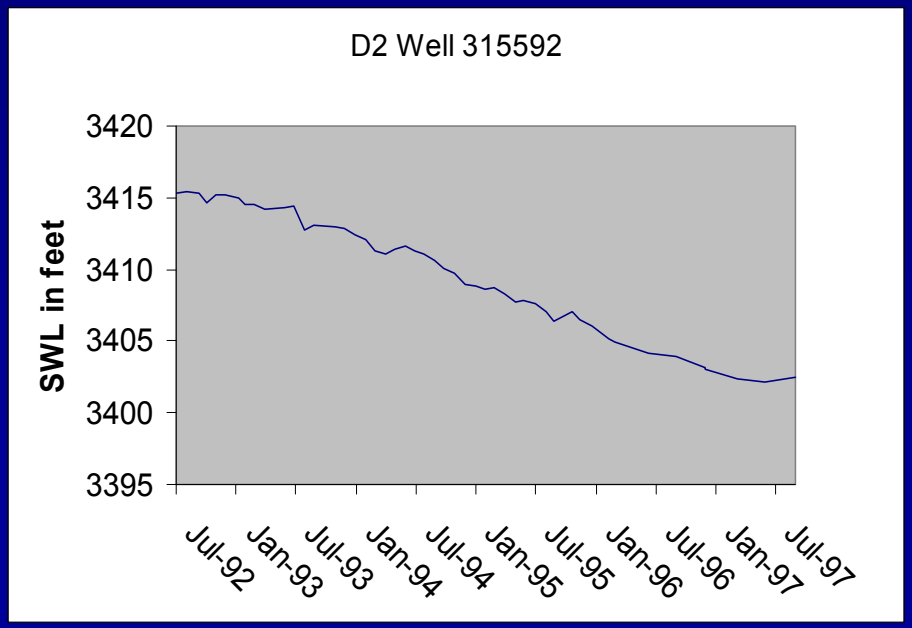

Spring Creek Mine
West Decker Mine
East Decker Mine
Anderson - Dietz Aquifer - 9/98
A-D Coal Removed
A-17 Coal Removed
D2 U - D2 L
D2
D1 - D2
D1
D1 U - D1 L
Anderson - Dietz
3800
3750
3700
3650
3600
3550
3500
3450
3400
3719
3723
3658
3649
3727
3686
3643
3779
3510
3556
3512
3655
3528
3520
3701
3441
3438
3434
3466
U
D
N
1 mile


D3 Aquifer - 9/98
1 mile
N
3500
3750
3700
3850
3600
3550
3450
3400
3485
3778
3424
3528
3410
3411
3418
3412
3414
3408
3371
3398
3435
3454
3429
D2 U - D2 L
D2
D1 - D2
D1
D1 U - D1 L
Anderson - Dietz
U
D

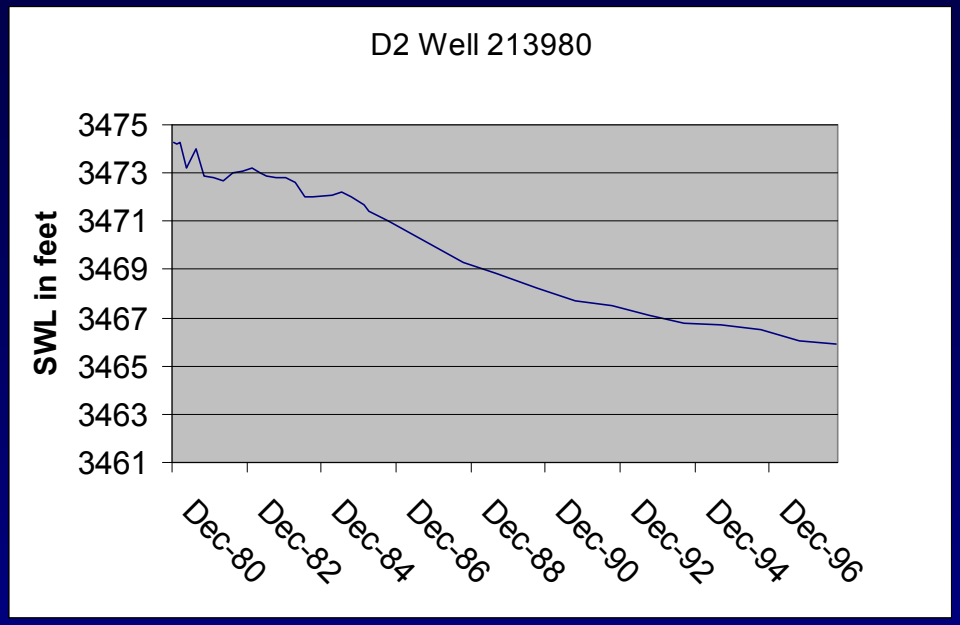
D2 Wells

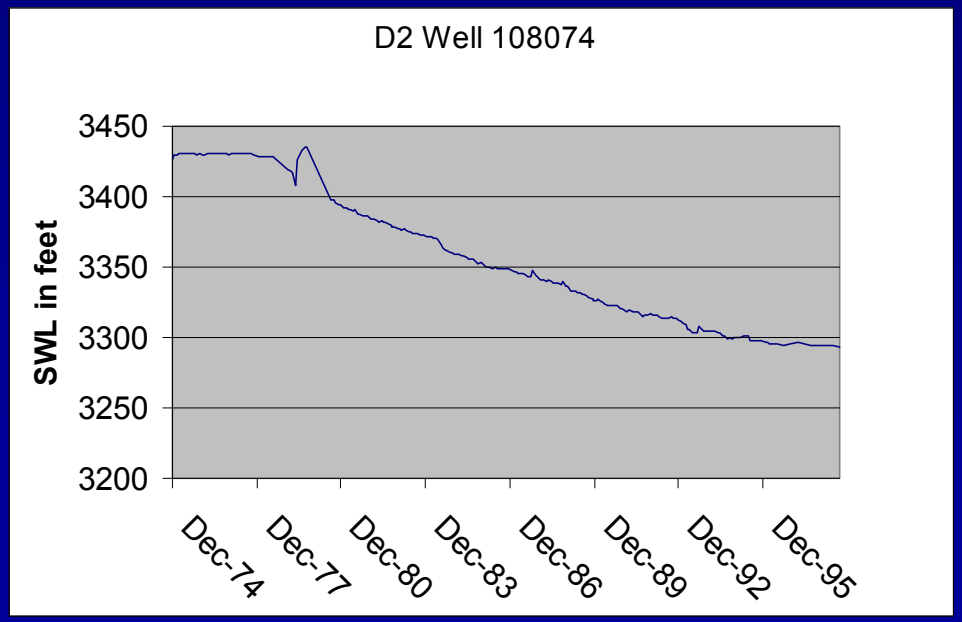
West Decker





East Decker

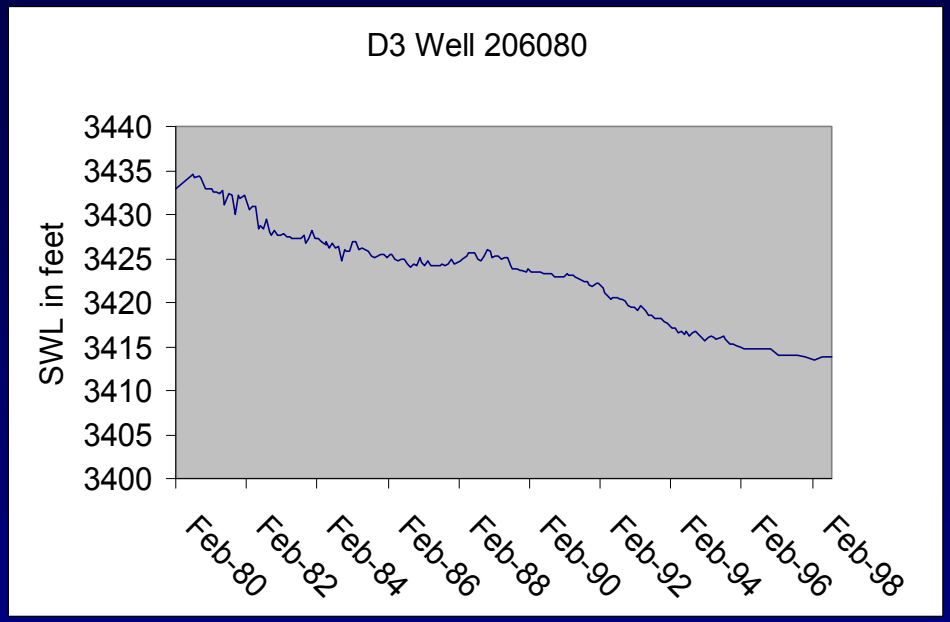


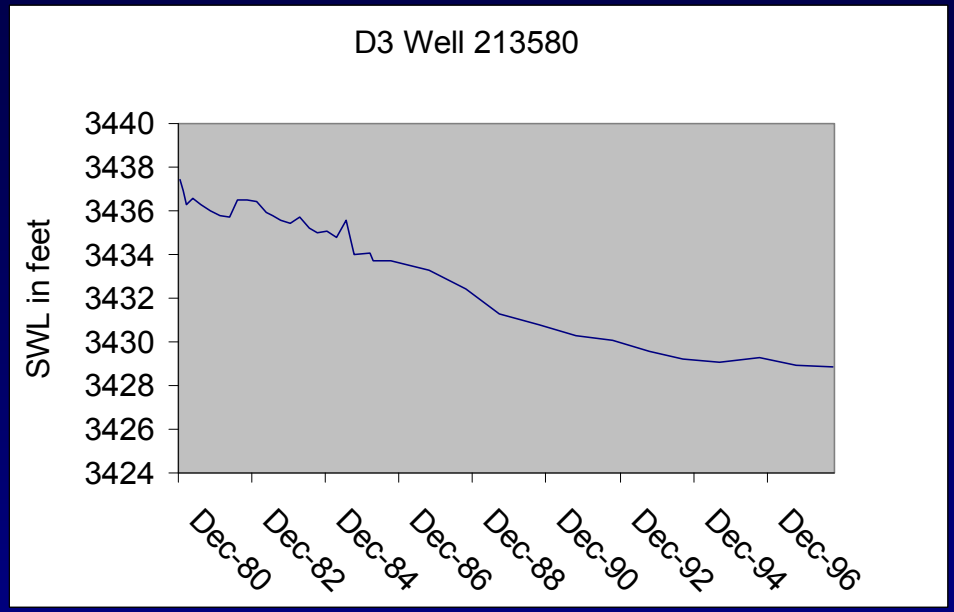


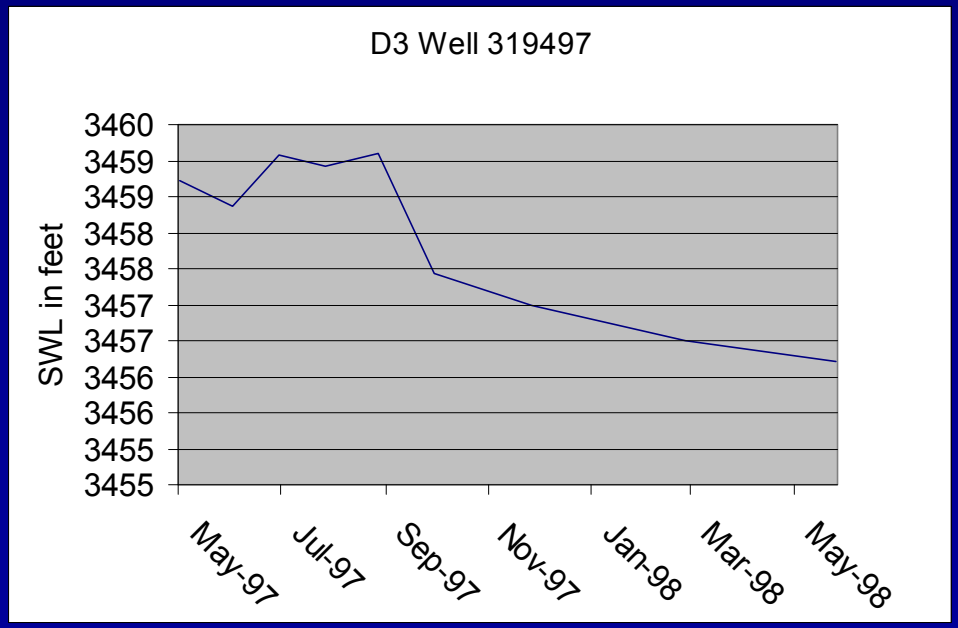
D3 Wells

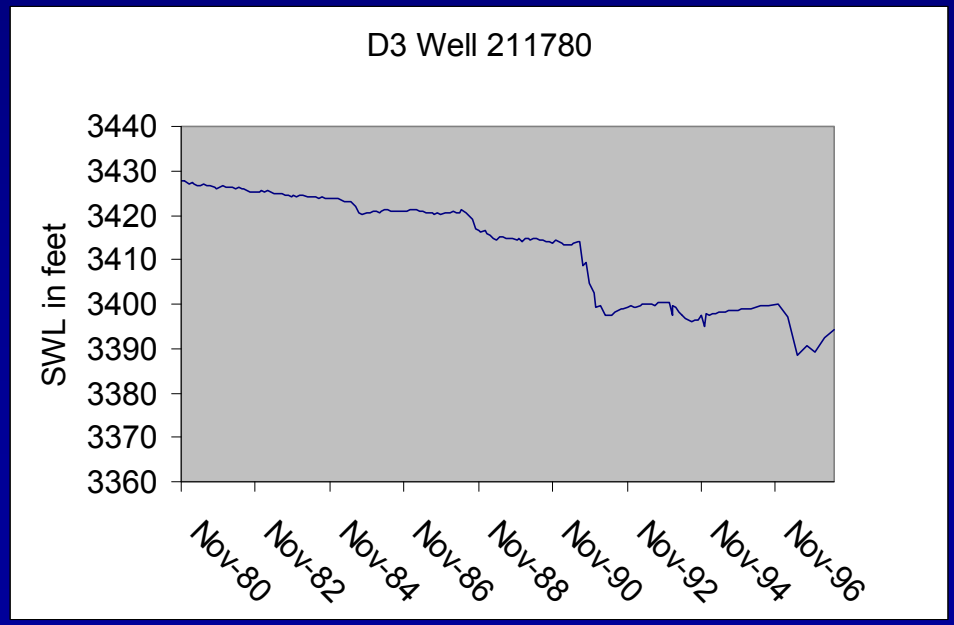
West Decker

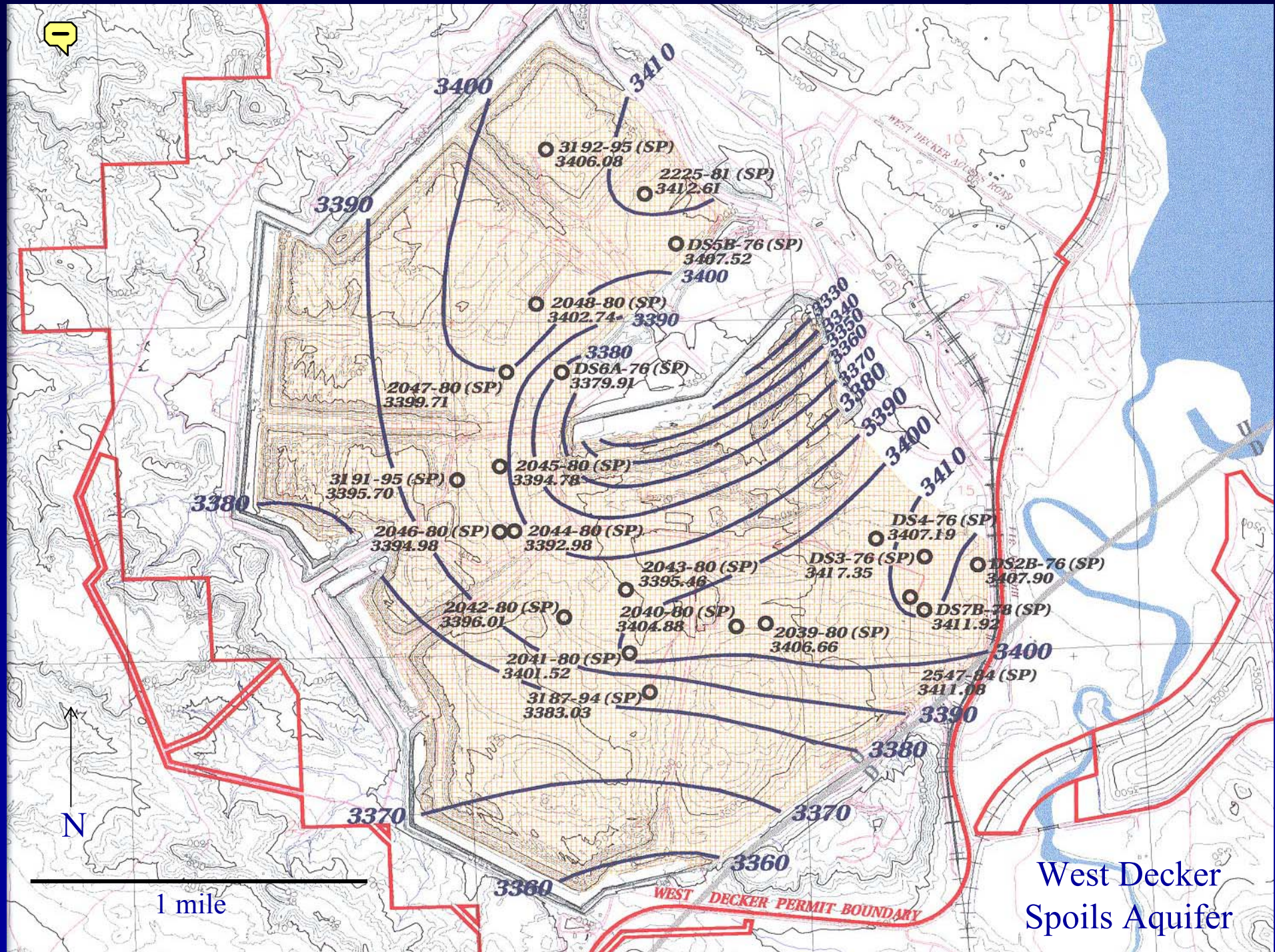
East Decker

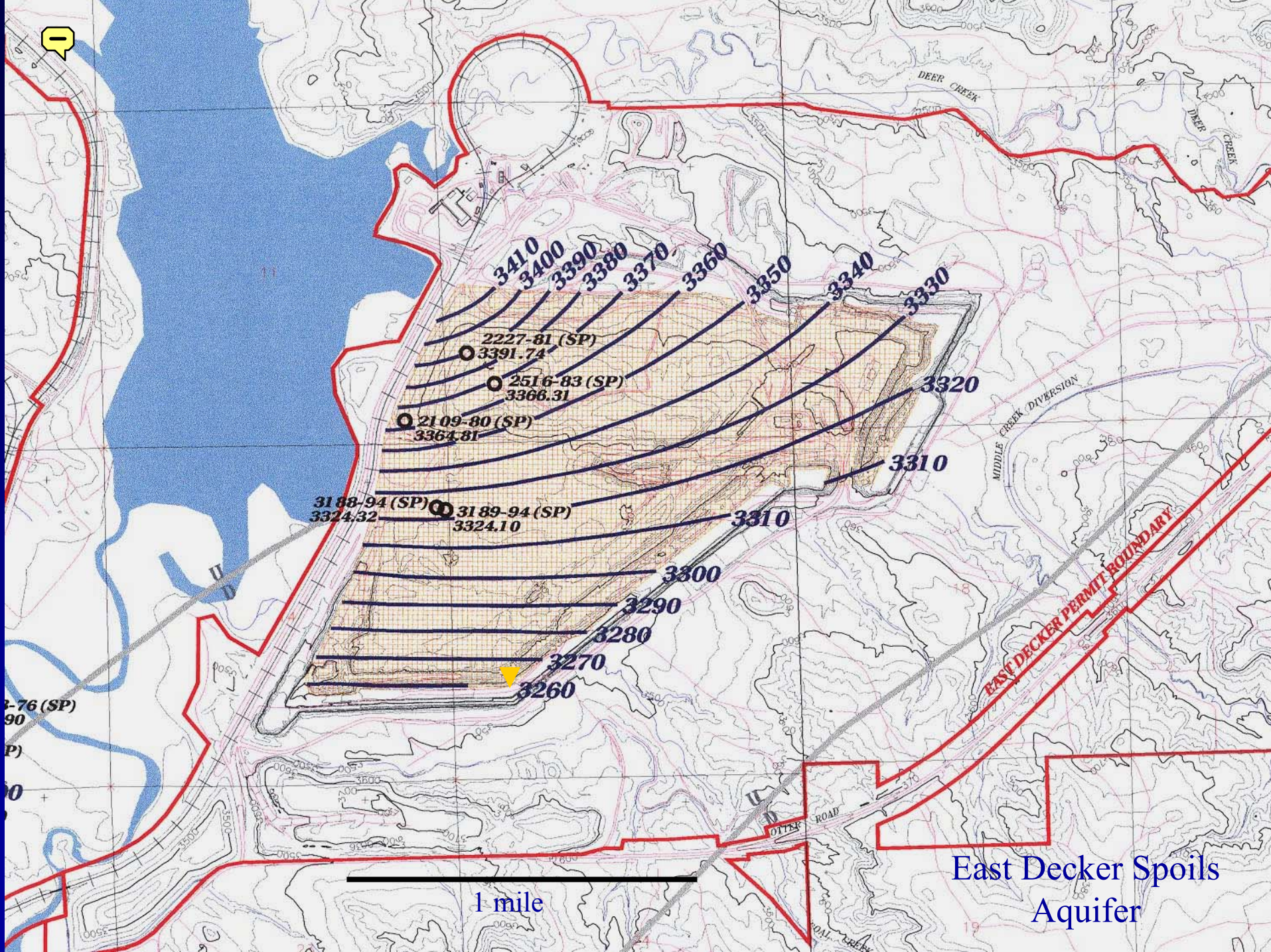








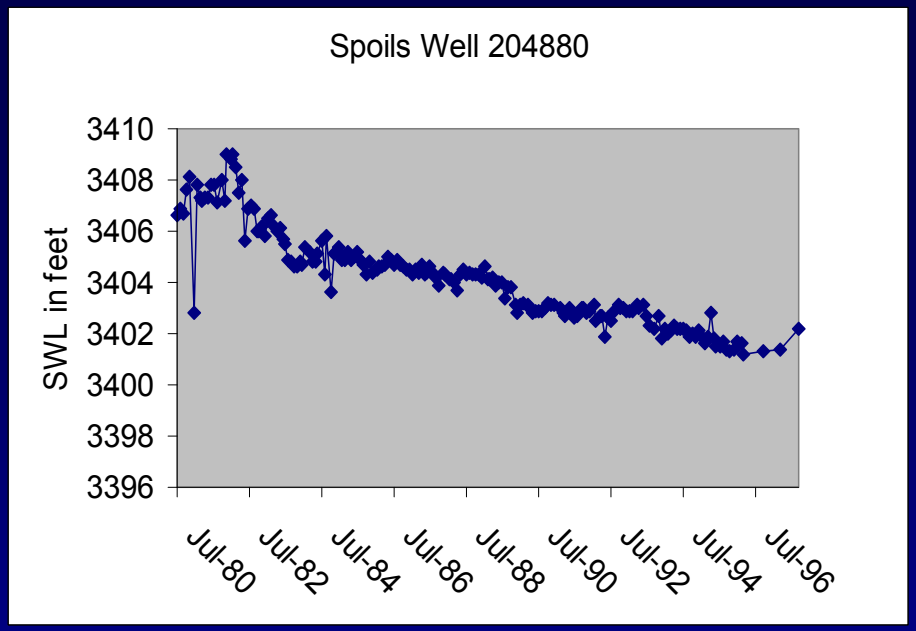

3400
3410
3192-95 (SP)
3406.08
2225-81 (SP)
3412.61
3390
DS5B-76 (SP)
3407.52
3400
2048-80 (SP)
3402.74
3390
3380
DS6A-76 (SP)
3379.91
2047-80 (SP)
3399.71
3330
3340
3350
3360
3370
3380
3390
3400
3410
2045-80 (SP)
3394.78
3191-95 (SP)
3395.70
3380
2046-80 (SP)
3394.98
2044-80 (SP)
3392.98
DS4-76 (SP)
3407.19
DS3-76 (SP)
3417.35
DS2B-76 (SP)
3407.90
2043-80 (SP)
3395.46
2042-80 (SP)
3396.01
2040-80 (SP)
3404.88
2039-80 (SP)
3406.66
DS7B-78 (SP)
3411.92
2041-80 (SP)
3401.52
3400
2547-84 (SP)
3411.08
3187-94 (SP)
3383.03
3390
3380
3370
3370
3360
3360
WEST DECKER PERMIT BOUNDARY
N
1 mile
West Decker
Spoils Aquifer

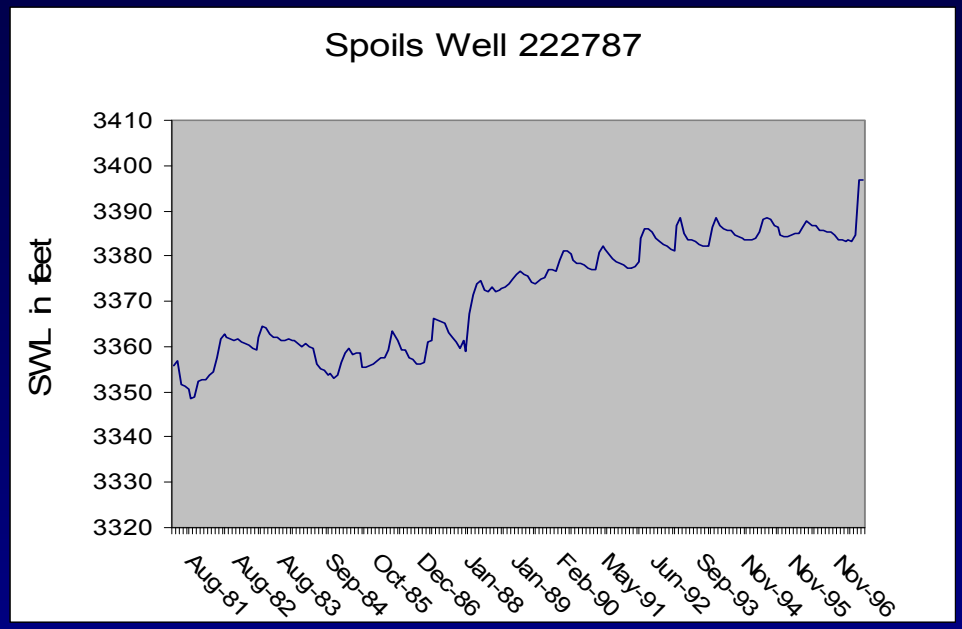

3410
3400
3390
3380
3370
3360
3350
3340
3330
3320
3310
3310
3300
3290
3280
3270
3260
2227-81 (SP)
3391.74
2516-83 (SP)
3366.31
2109-80 (SP)
3364.81
3188-94 (SP)
3324.32
3189-94 (SP)
3324.10
DEER CREEK
MIDDLE CREEK DIVERSION
EAST DECKER PERMIT BOUNDARY
OTTER ROAD
1 mile
East Decker Spoils Aquifer

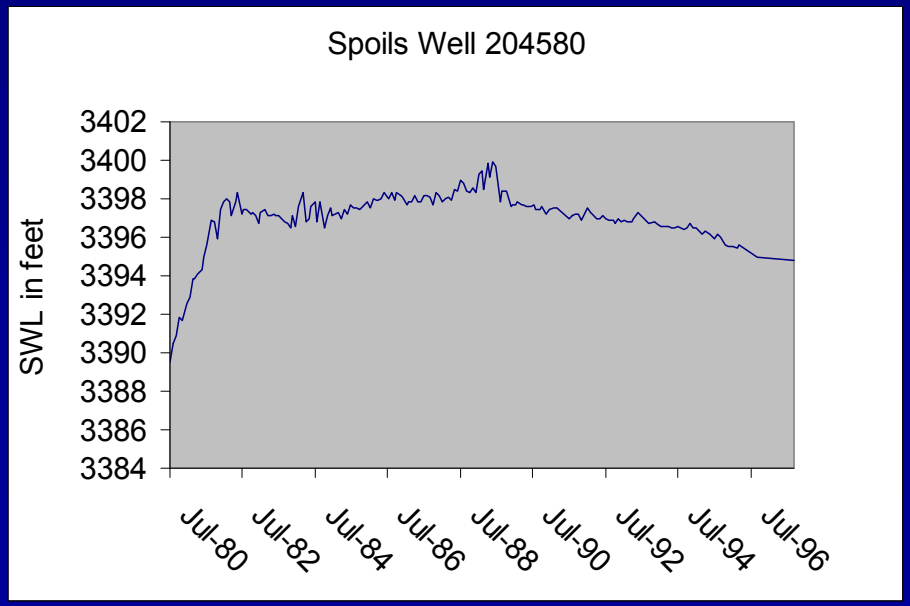
Spoils Wells

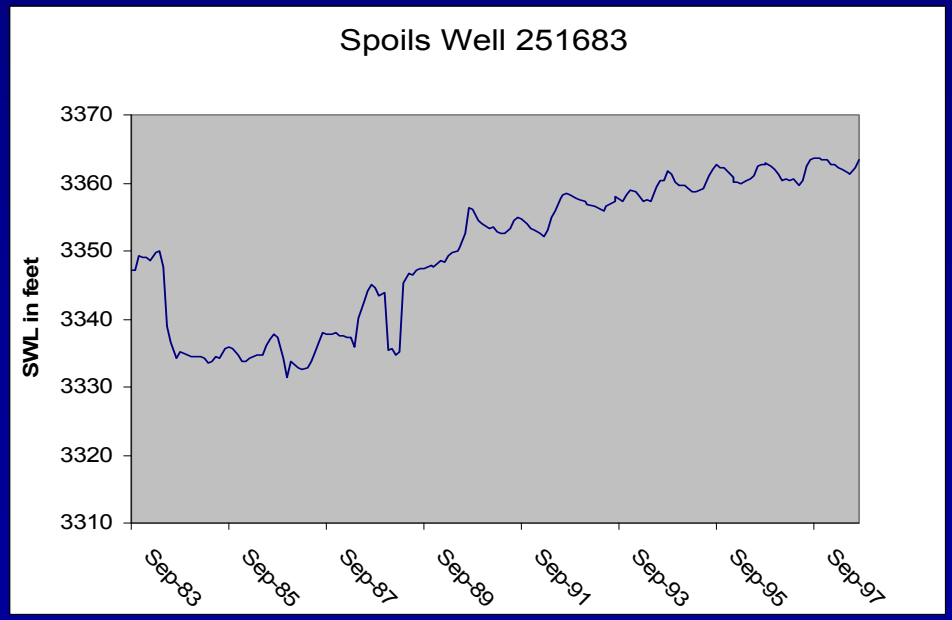
West Decker

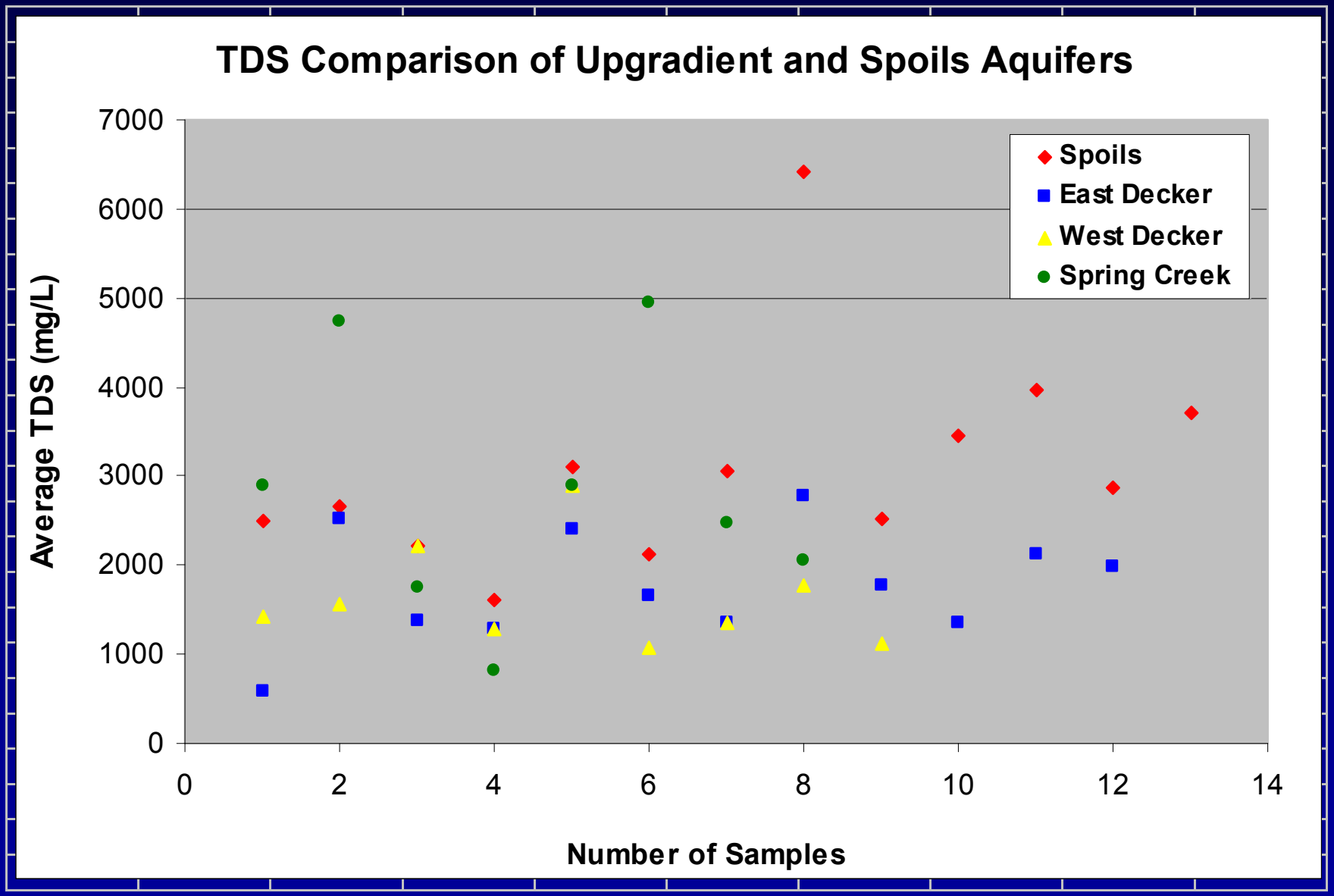
East Decker

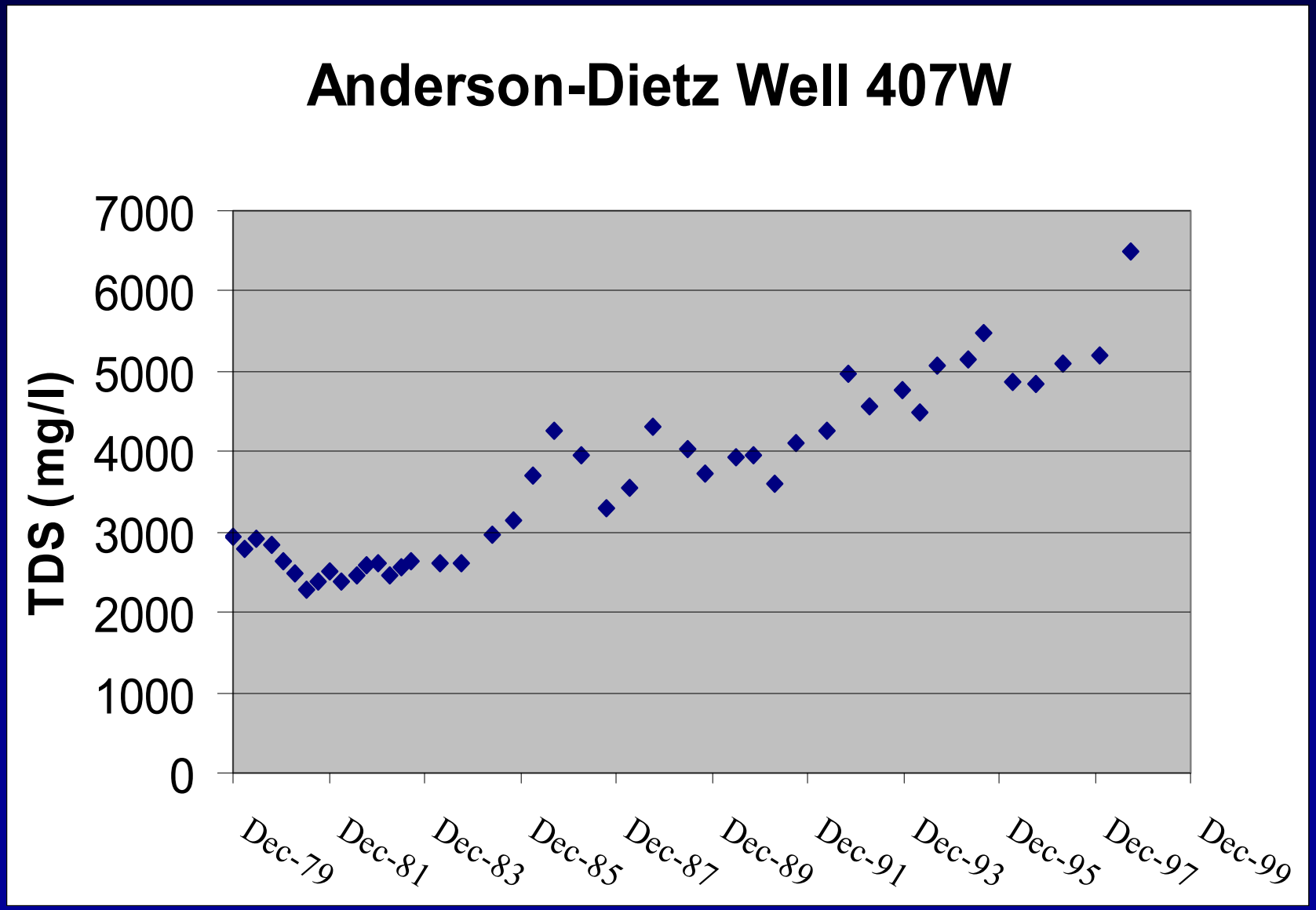


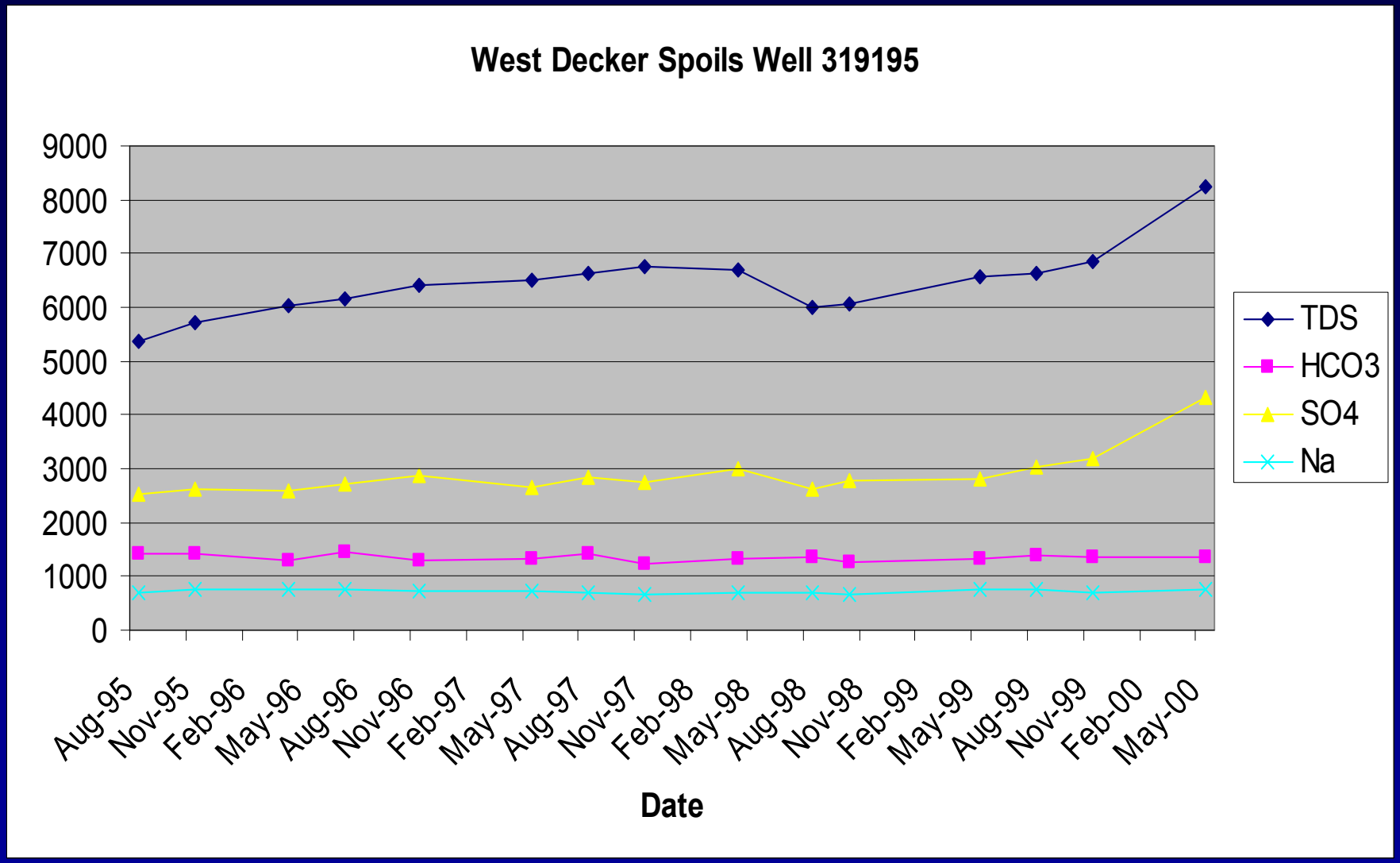


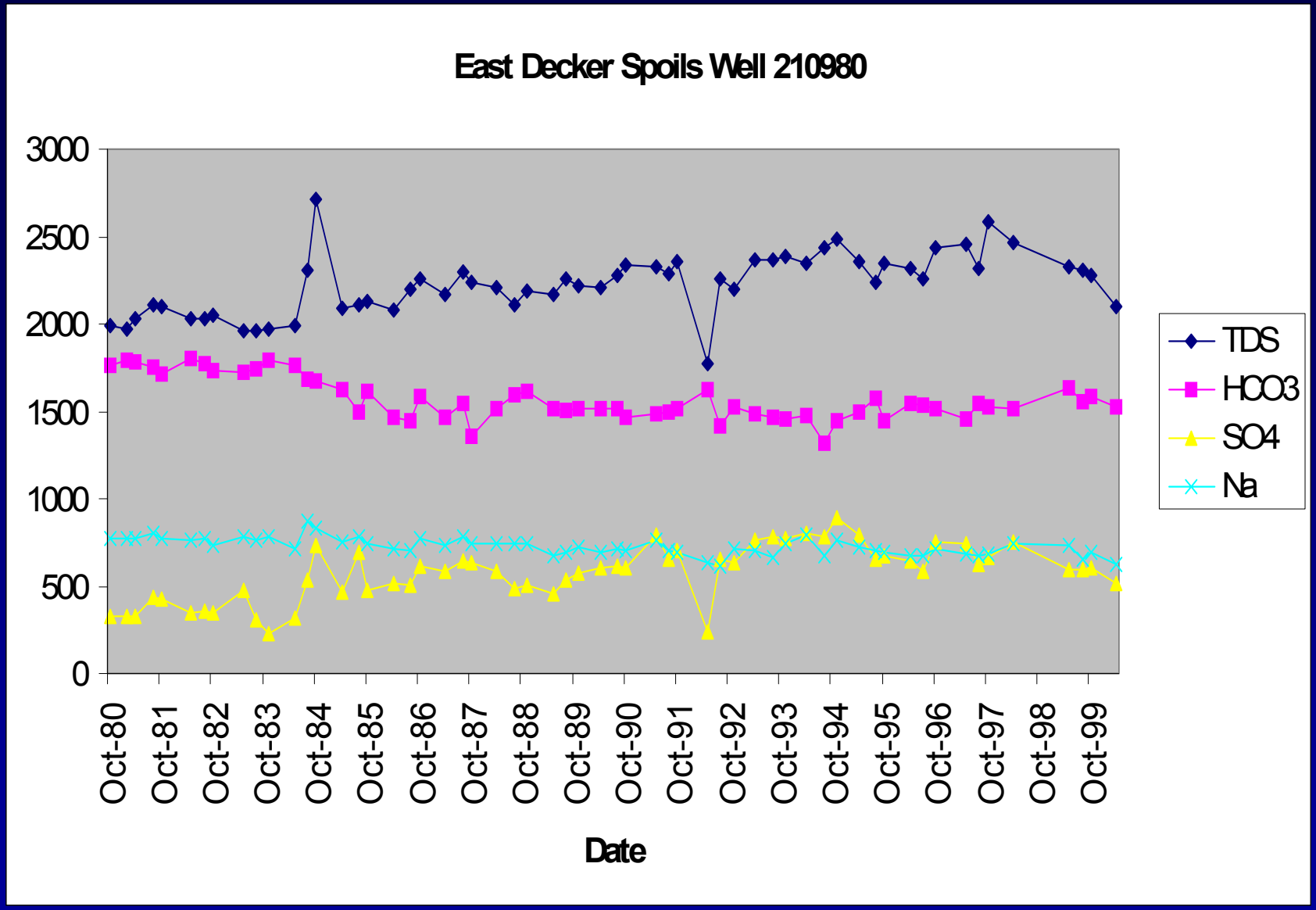


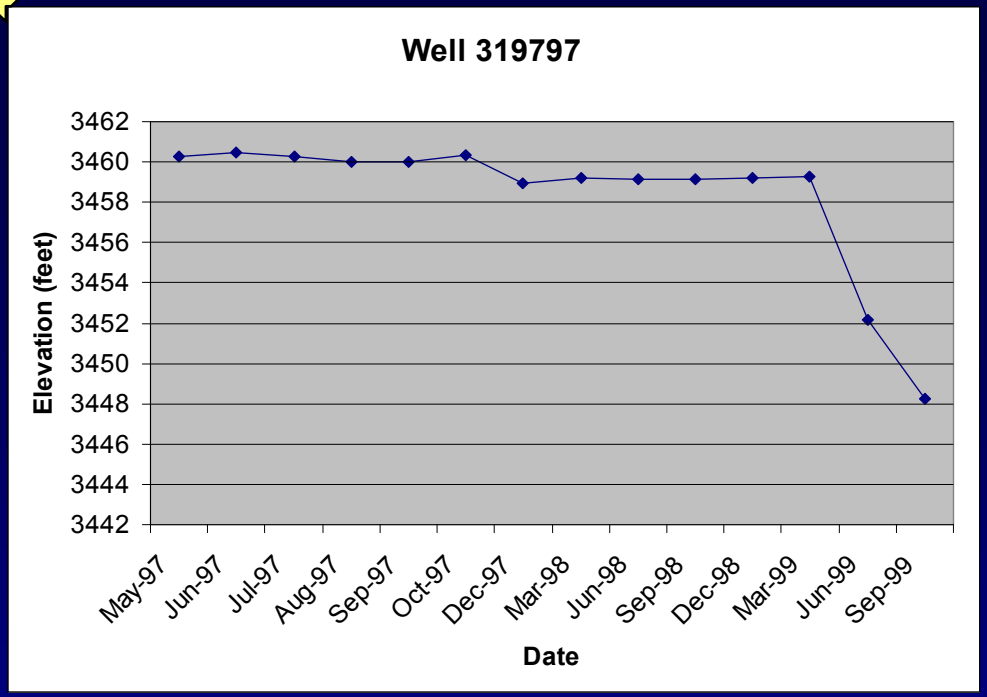



TDS Comparison of Upgradient and Spoils Aquifers
Average TDS (mg/L)
7000
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14
Number of Samples
Spoils
East Decker
West Decker
Spring Creek

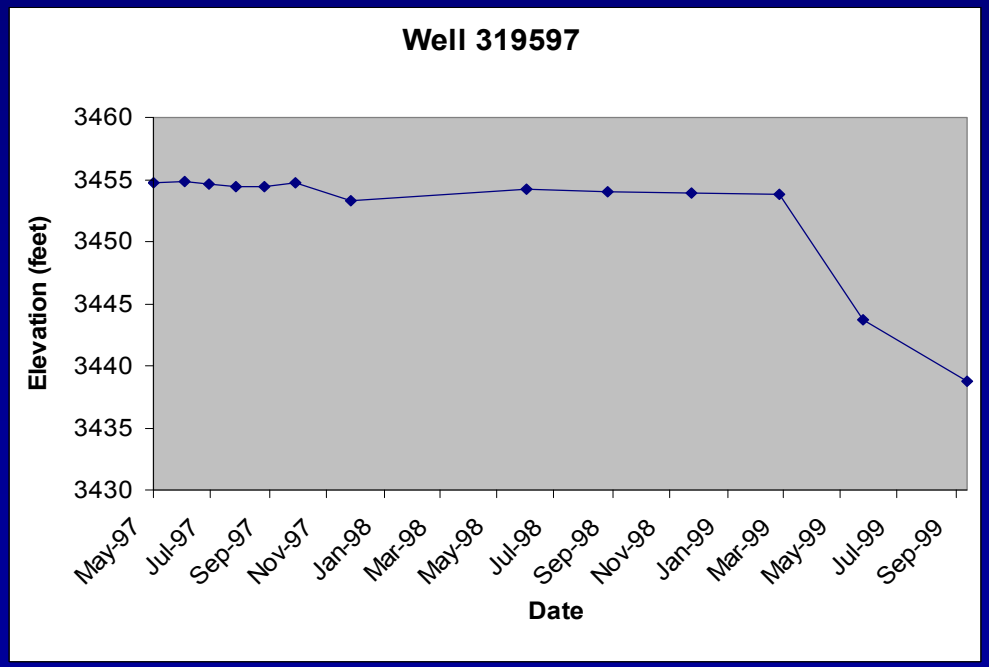

Anderson-Dietz Well 407W
TDS (mg/l)
7000
6000
5000
4000
3000
2000
1000
0
Dec-79
Dec-81
Dec-83
Dec-85
Dec-87
Dec-89
Dec-91
Dec-93
Dec-95
Dec-97
Dec-99


West Decker Spoils Well 319195
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Aug-95
Nov-95
Feb-96
May-96
Aug-96
Nov-96
Feb-97
May-97
Aug-97
Nov-97
Feb-98
May-98
Aug-98
Nov-98
Feb-99
May-99
Aug-99
Nov-99
Feb-00
May-00
Date
TDS
HCO3
SO4
Na


East Decker Spoils Well 210980
3000
2500
2000
1500
1000
500
0
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Date
TDS
HCO3
SO4
Na



Effects of Coal-Bed Methane Development on Aquifers in the Decker, Montana, Area



Montana Department of

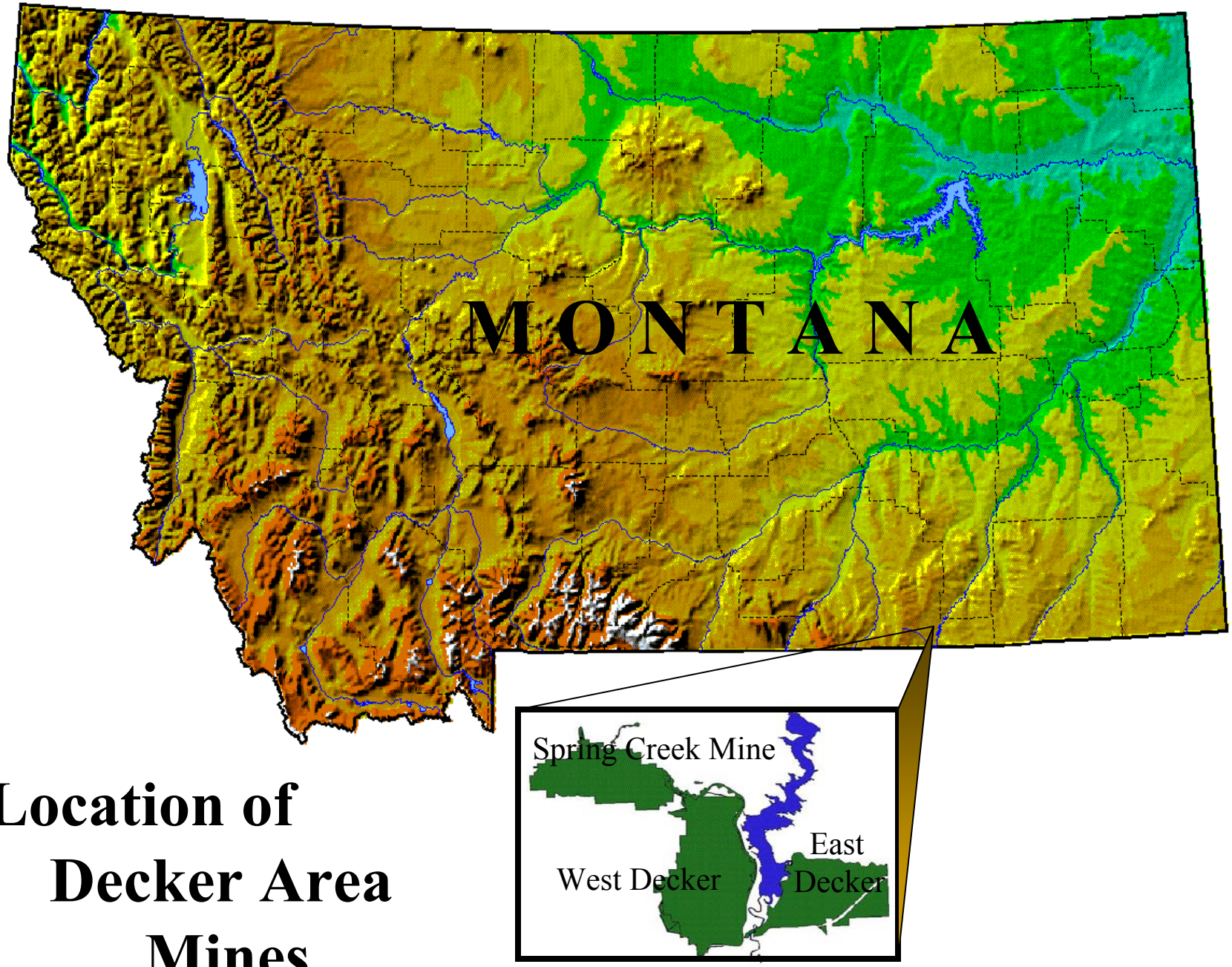
Environmental Quality

Cumulative Hydrologic Response of Ground Water to Strip Mining at the Decker and Spring Creek Mines, 1972 - 98

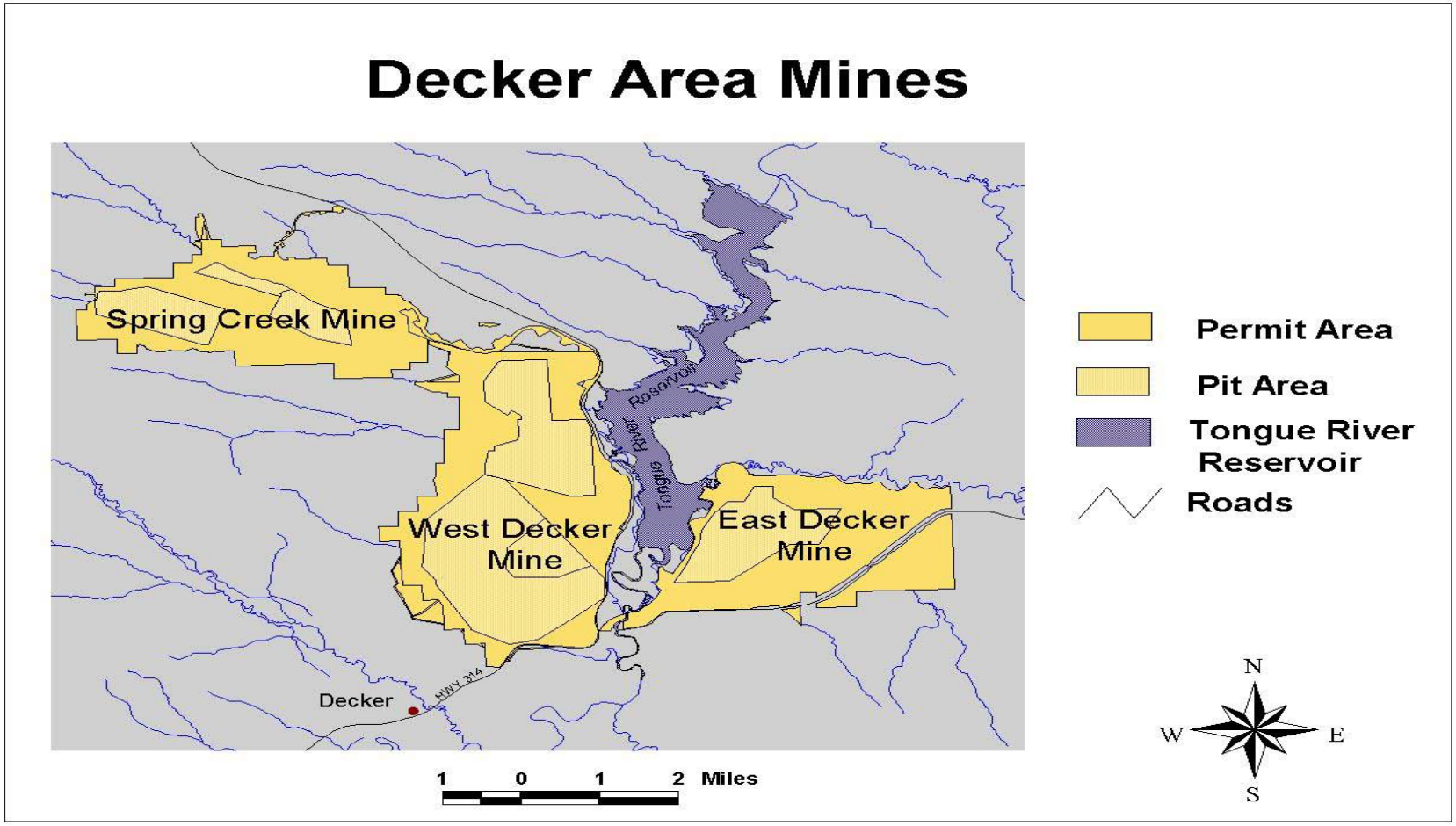
Angela McDannel

Industrial and Energy Minerals Bureau

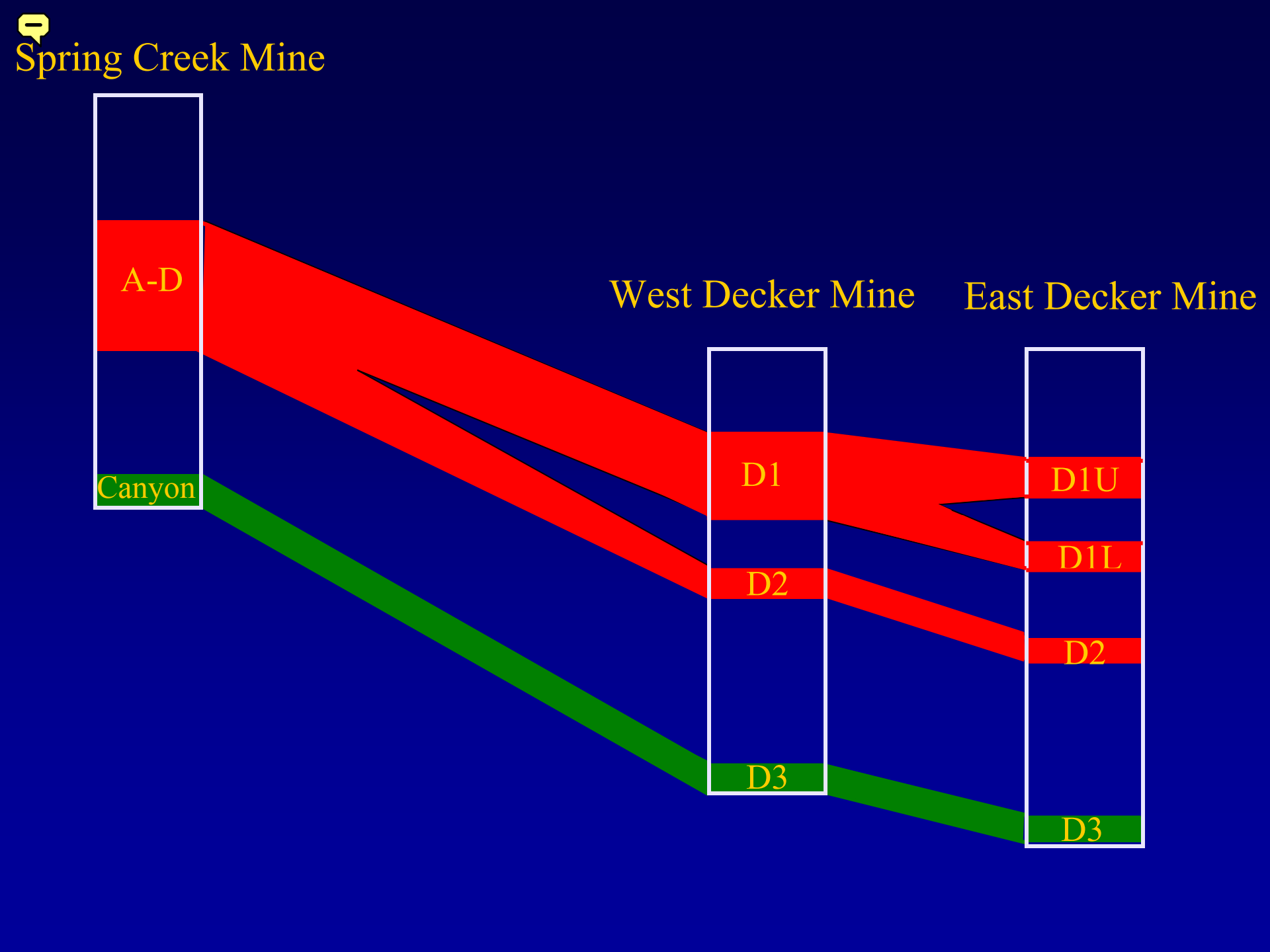
Montana Department of Environmental Quality



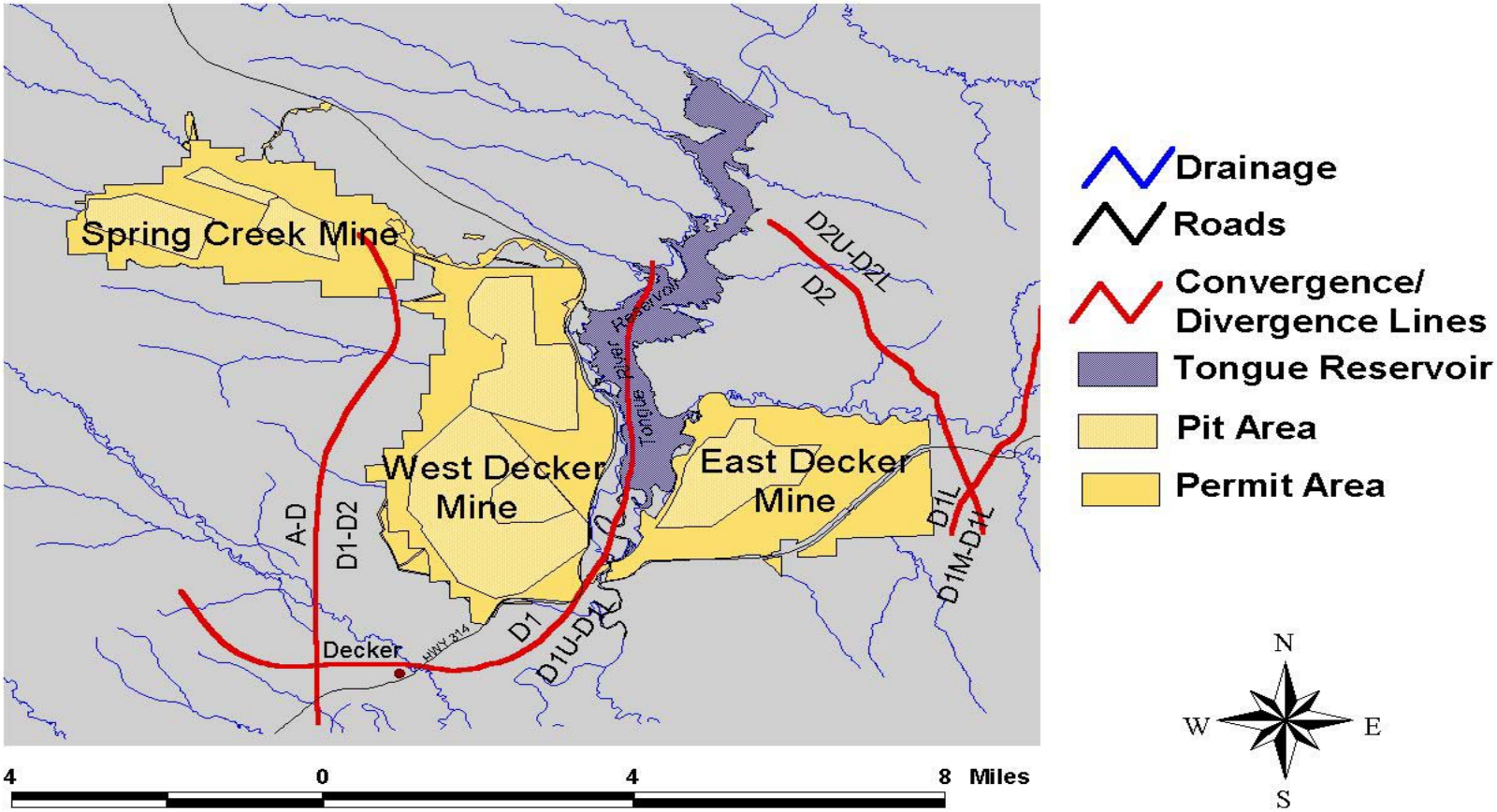
Location of Decker Area Mines



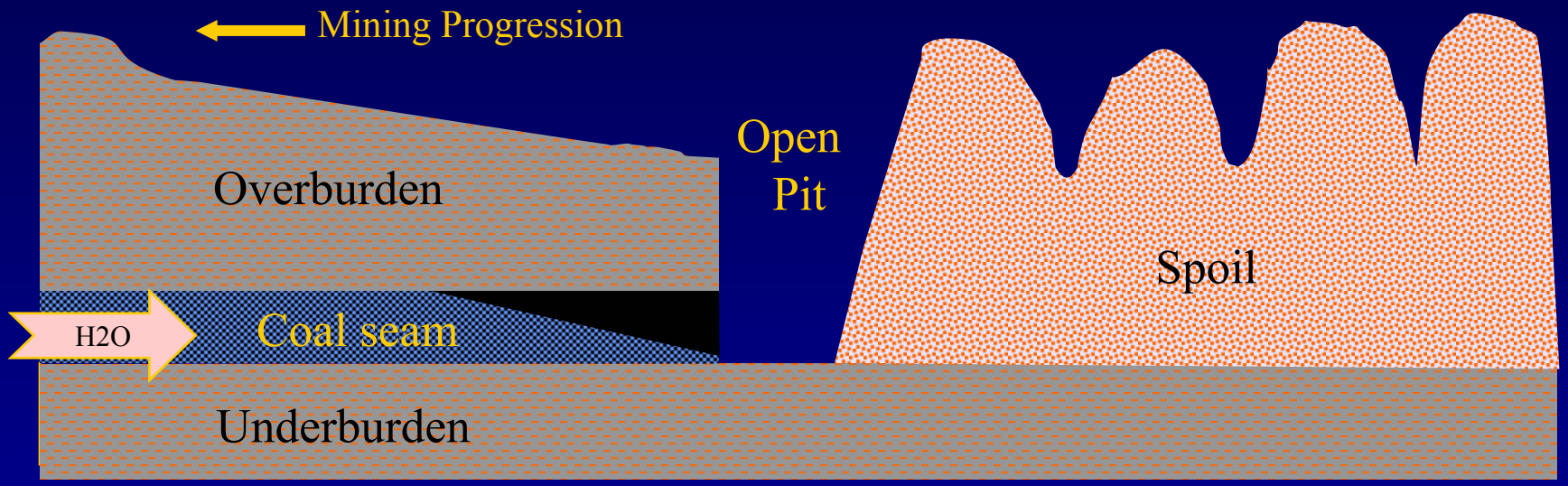
Relative location of the Decker area mines, main pit areas, and the Tongue River Reservoir.


Spring Creek Mine
A-D
Canyon
West Decker Mine
D1
D2
D3
East Decker Mine
D1U
D1L
D2
D3

Coal Convergence/Divergence Lines

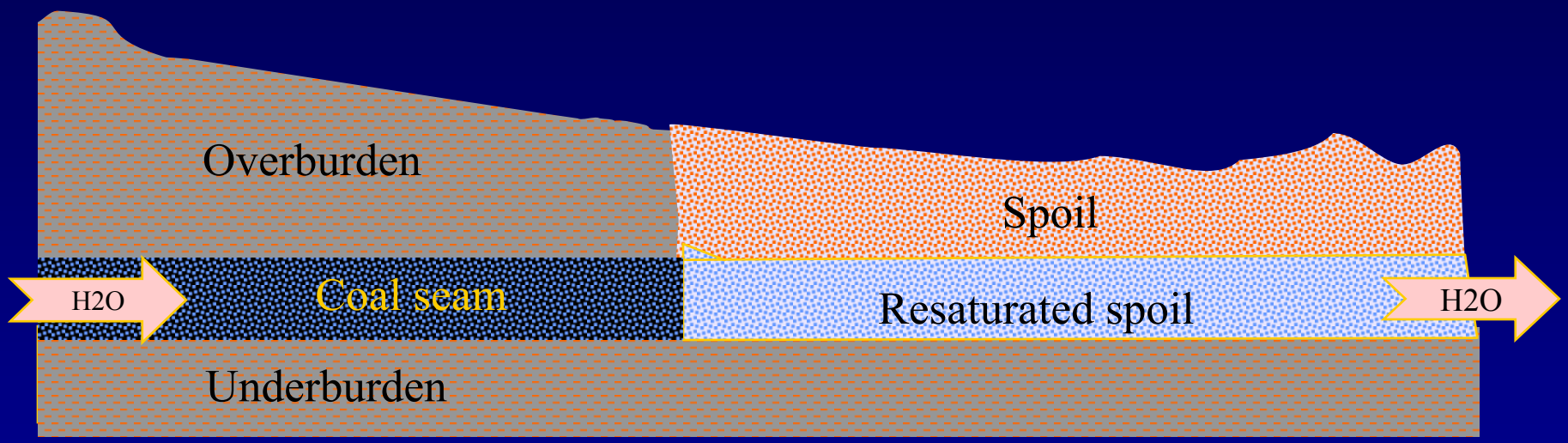


Approximate location of coal-seam convergence/divergence.



Ground-Water Movement During Mining

Upon completion of mining, the last pit is filled, spoil is graded to an acceptable topographic configuration, and water moves into and through the reclaimed spoils. Because the spoil is mainly a loose heap of what was previously bedded and sorted sedimentary rocks, the characteristics of the new, spoils aquifer are different from the coal seam aquifer that it has replaced. Typically, spoils aquifers are more transmissive than are coal aquifers. As overburden is fragmented and converted to spoil, mineral surfaces are exposed to ground water and are available for dissolution. Spoil water typically has a higher concentration of total dissolved solids (TDS) than do coal aquifers. In the Fort Union Formation, sodium and sulfate concentrations typically show the greatest increase.



Post-Reclamation Ground-Water Movement

Range of Values for Hydrologic Parameters in Shallow-Coal Aquifers in the Decker Area

(this information appears as table 2.1 in Decker Coal Company, 1991, and Spring Creek Coal Company, 1980)

Aquifer	Transmissivity (g/d/f)	Storativity
D1L	96 – 5,157	$6x10^{-5}$; $4x10^{-4}$
D1U	1 - 630	
D1	611	
D2	129 – 2,020	$4x10^{-5}$
D3	287 - 449	
Anderson-Dietz	980 – 1,320	$2x10^{-3}$; $1x10^{-3}$
Canyon	24 - 60	
Spoils	2,368 – 3,006	

Photograph showing the Decker mines straddling the Tongue River Reservoir.

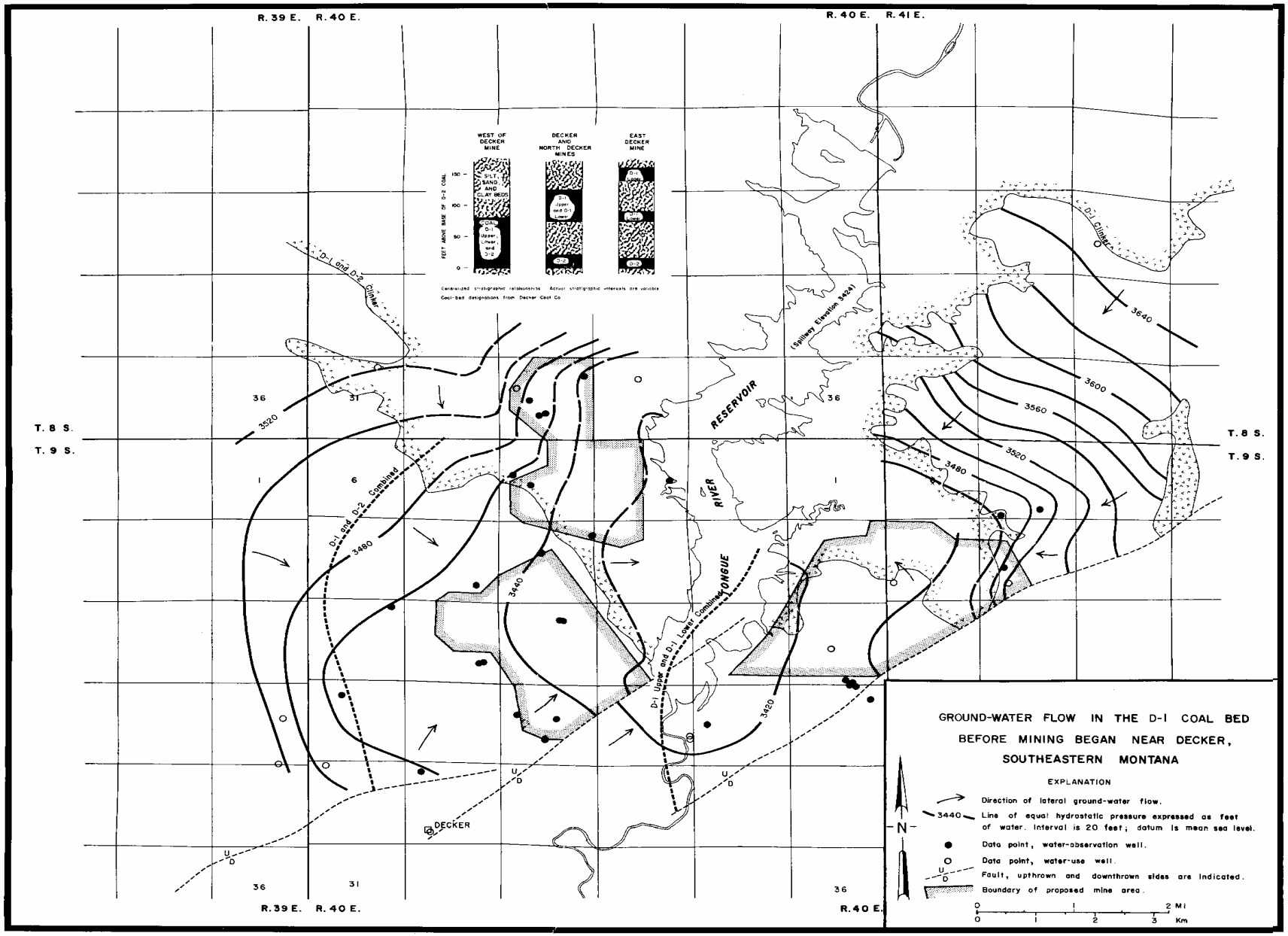
This next photograph looks eastward toward the reservoir across the West Decker pit area. In the immediate foreground of the photo are open pits that cut off the natural direction of recharge to reclaimed spoils in the middle ground.

Direction of Ground-Water Movement

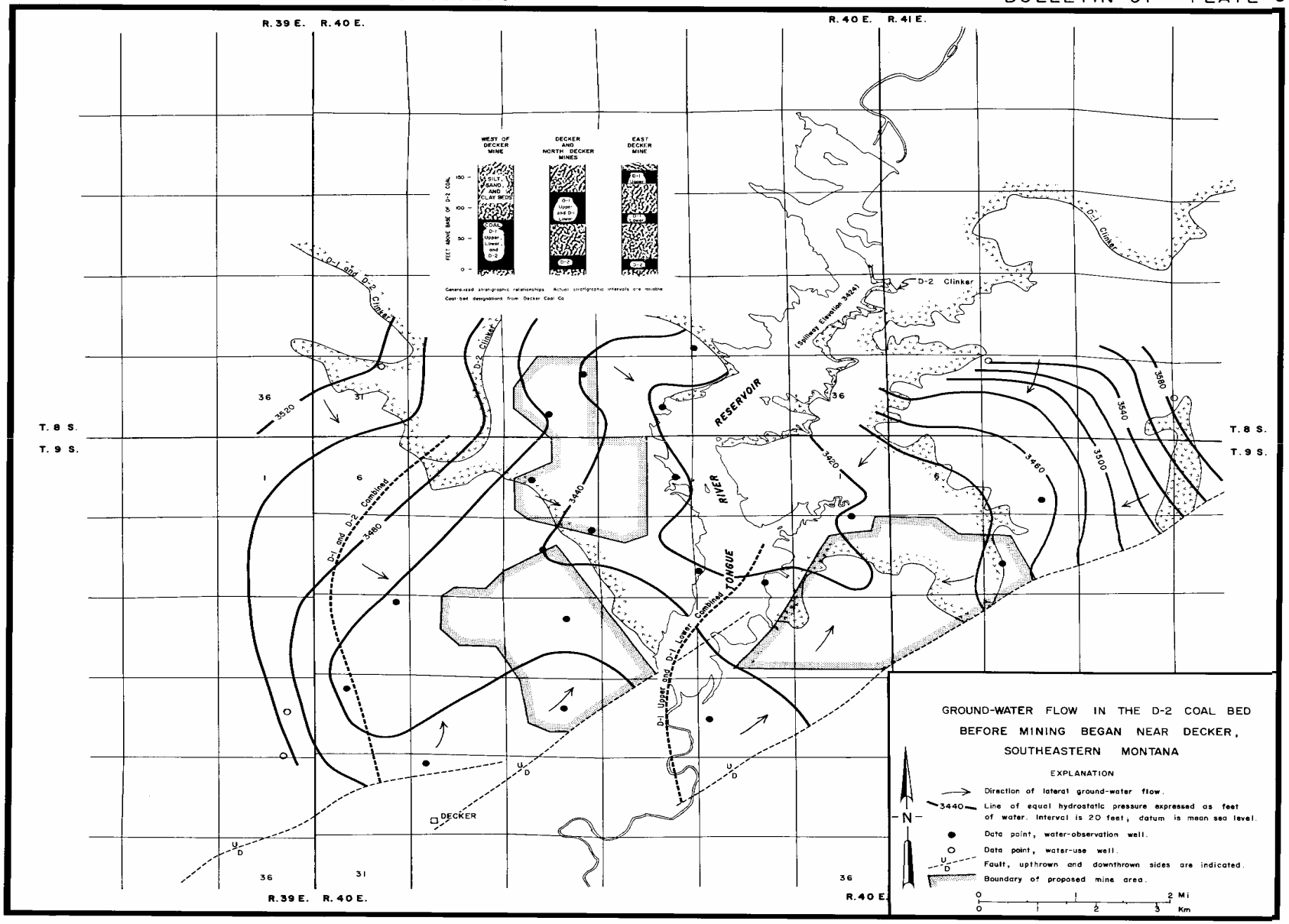
Photograph showing the three

pit areas at the Spring Creek mine.

Photograph showing mining in pit No. 1 at the Spring Creek mine.

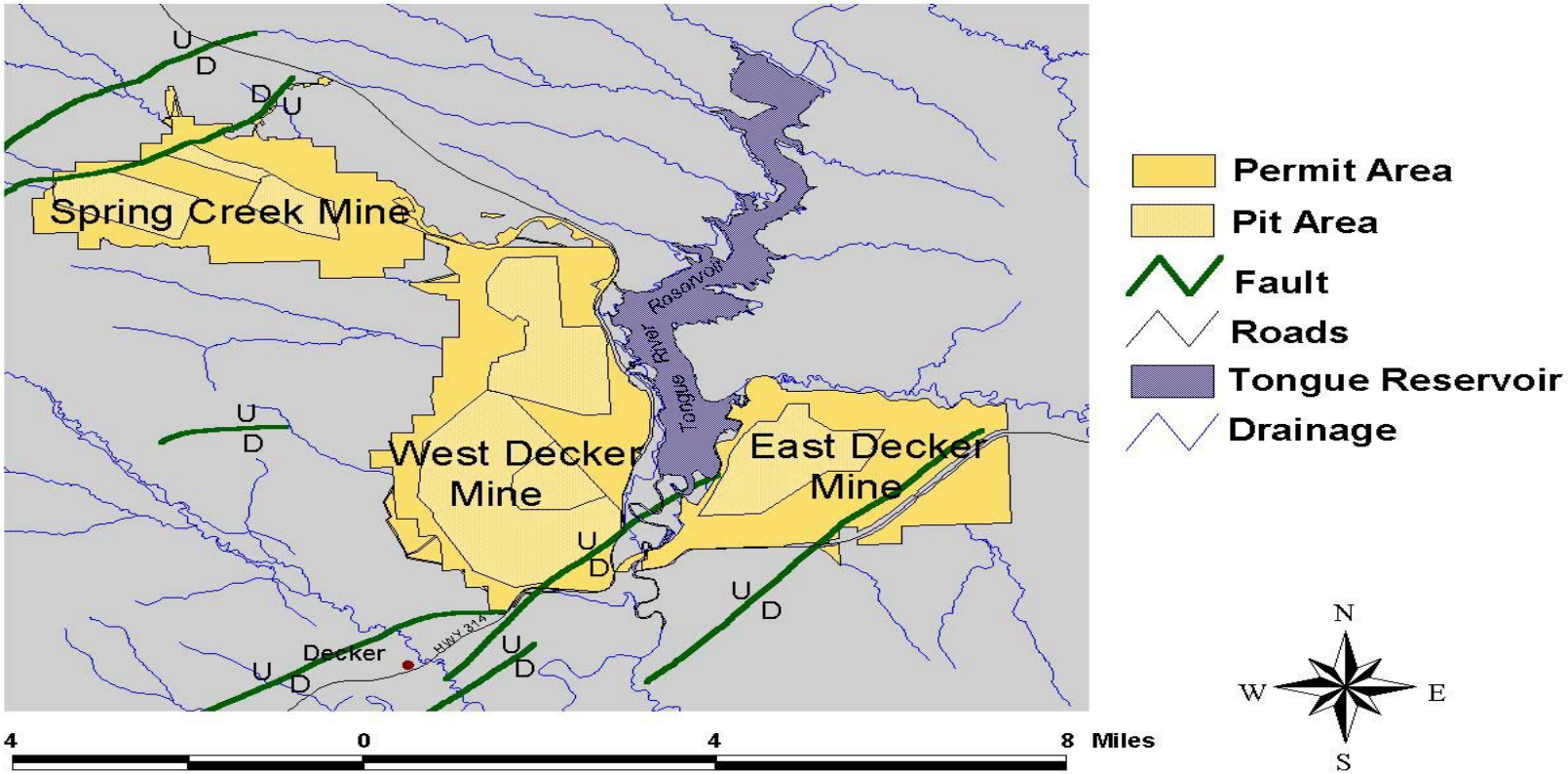


Base from U.S. Geological Survey 7 1/2 min. Half Moon Hill, Tongue River Dam, Spring Gulch, Pearl School, Decker, and Holmes Ranch quads.



Base from U.S. Geological Survey 7 1/2 min. Half Moon Hill, Tongue River Dam, Spring Gulch, Pearl School, Decker, and Holmes Ranch quads.

Decker Area Faults



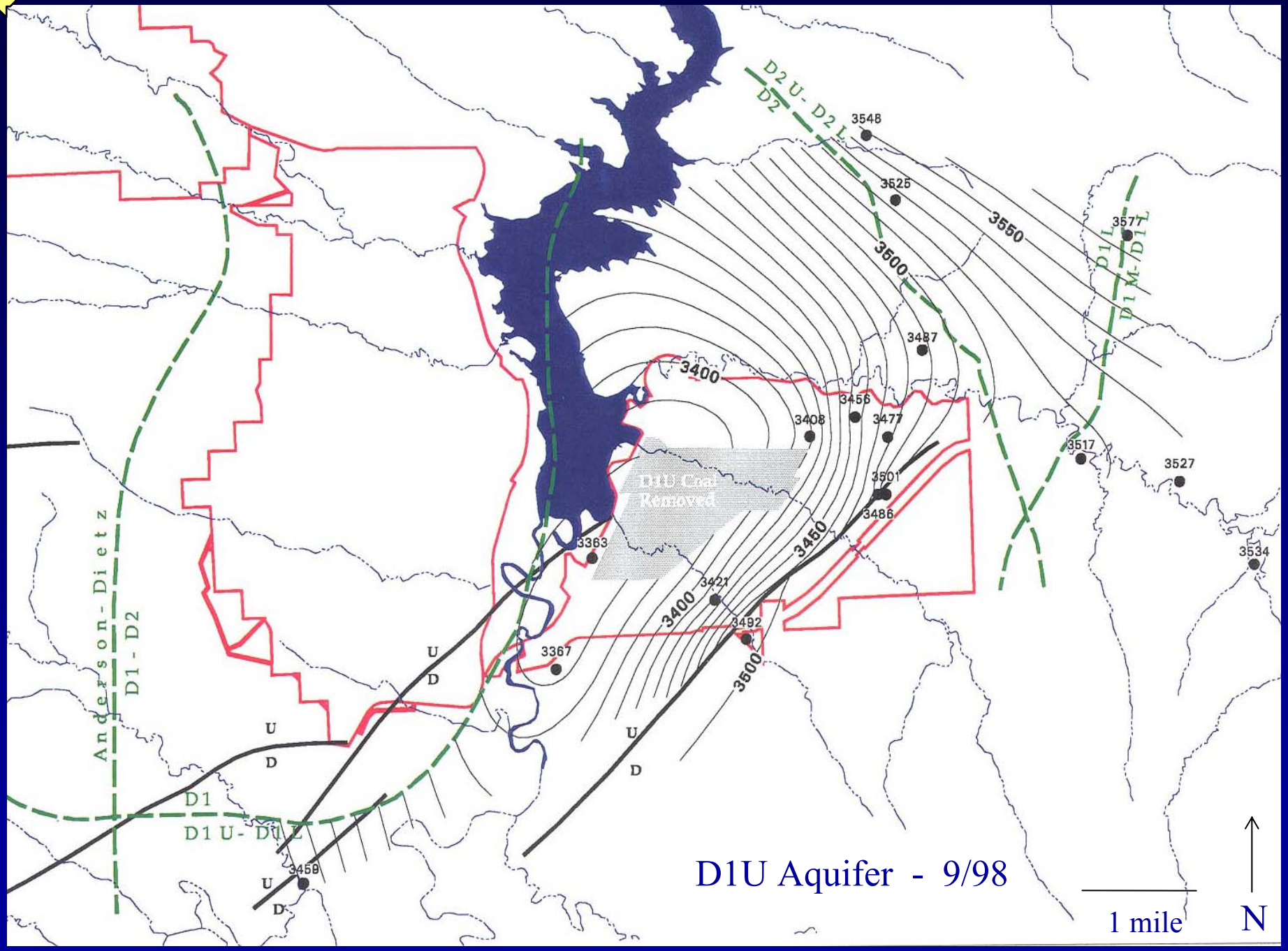
Numerous northeast-trending normal faults traverse the Decker area and create hydrologic boundaries that locally control drawdown.

Photograph showing the north pits at West Decker mine.

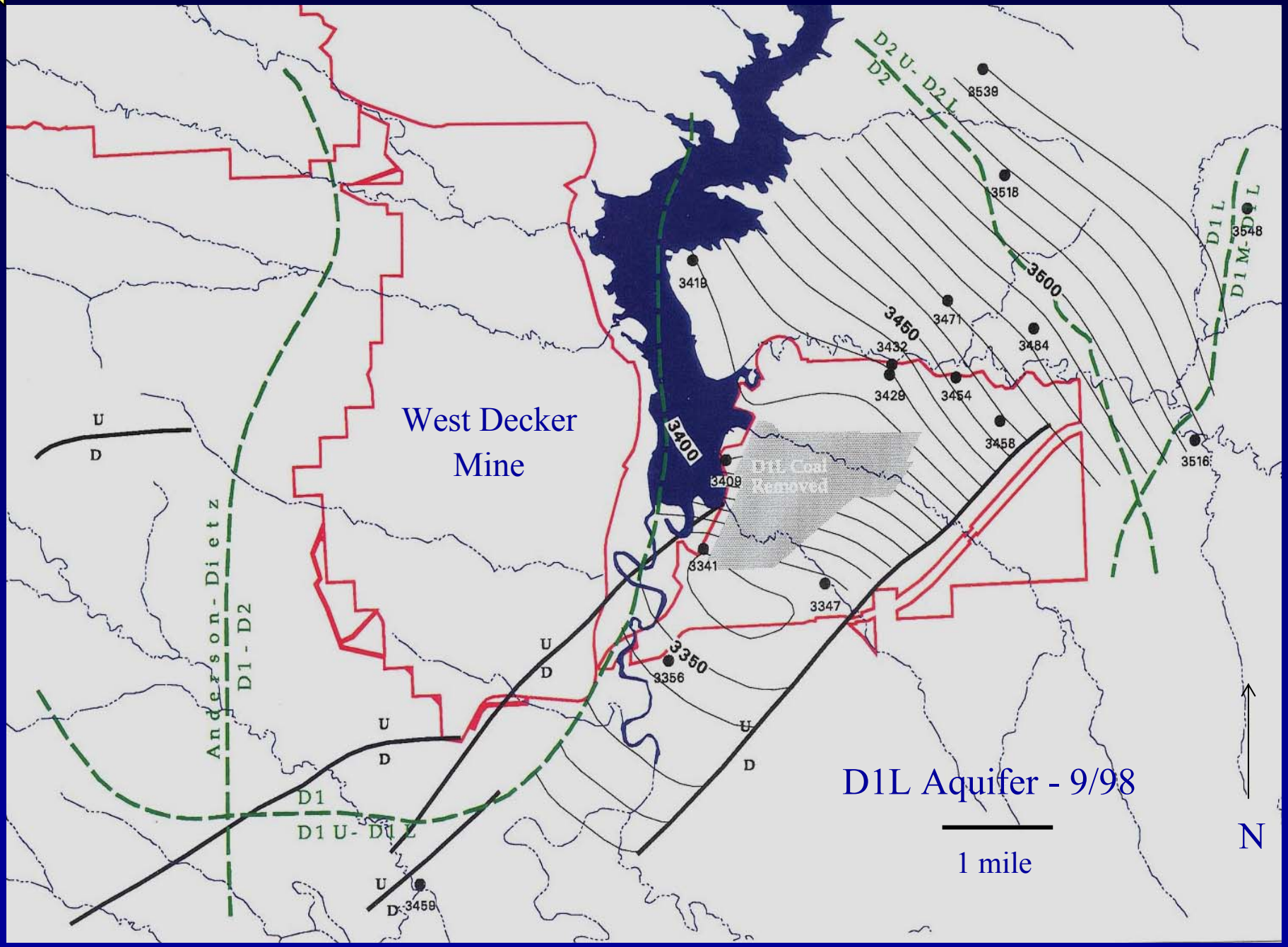
Photograph showing Tongue River Reservoir near its full-pool elevation, in May of 1999.

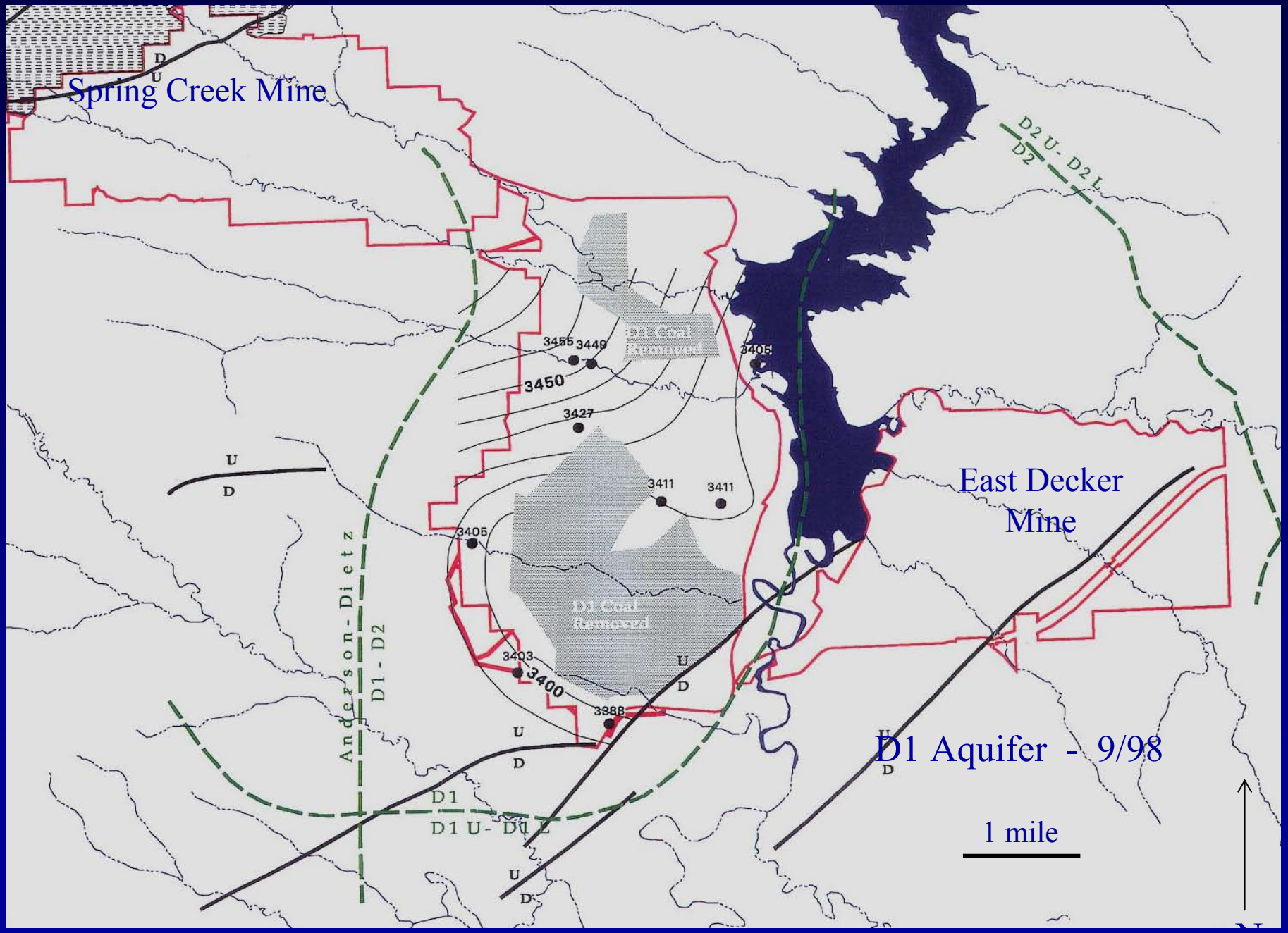
Water poured into the east end of the north pit from the reservoir at high-water stage during the early summer of 1999.

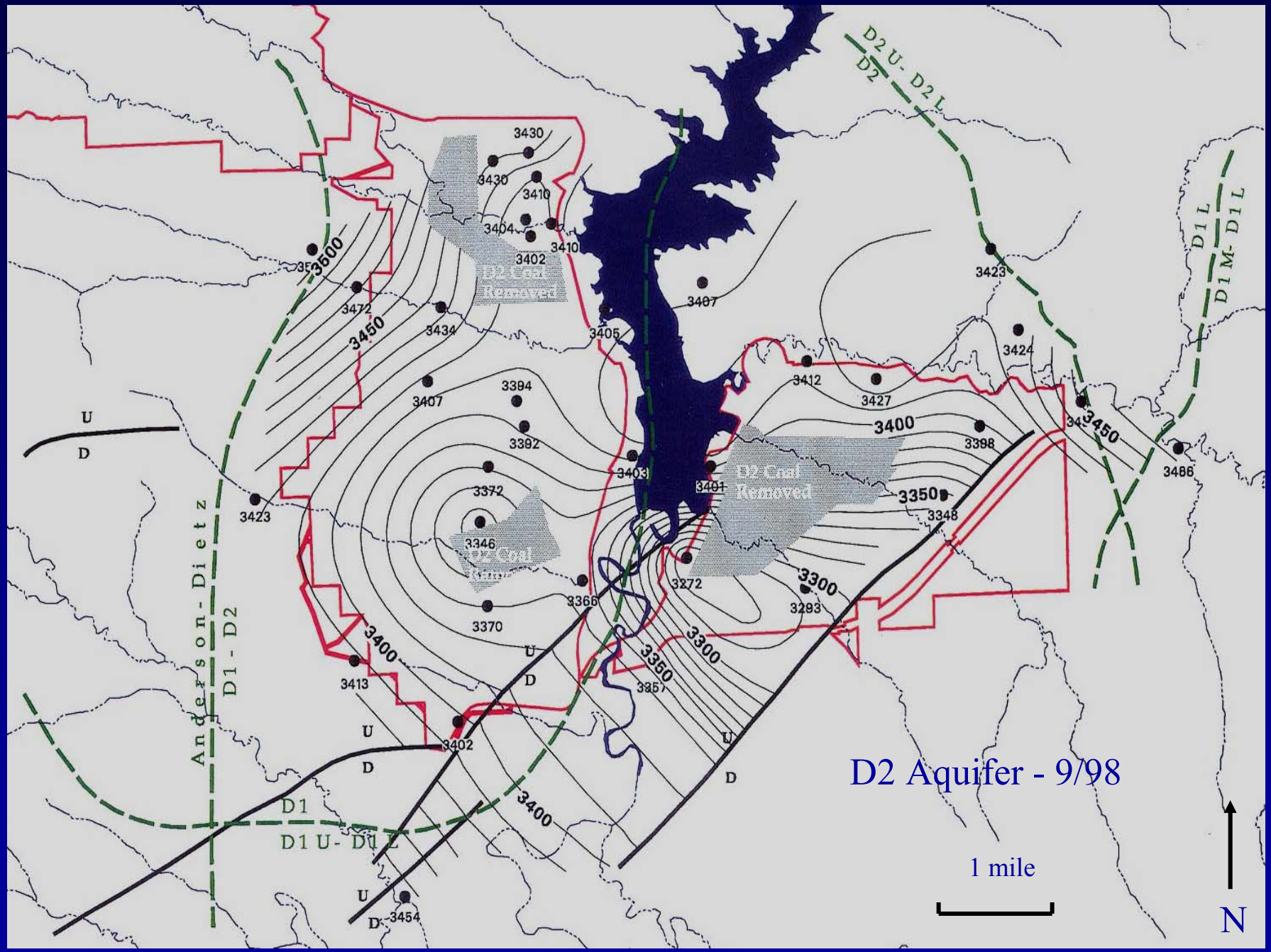
The map that follows shows the potentiometric surface in the D1 Upper aquifer at East Decker mine in the fall of 1998. The extent and depth of drawdown created by mining is strongly influenced by the normal fault southeast of the pit area.

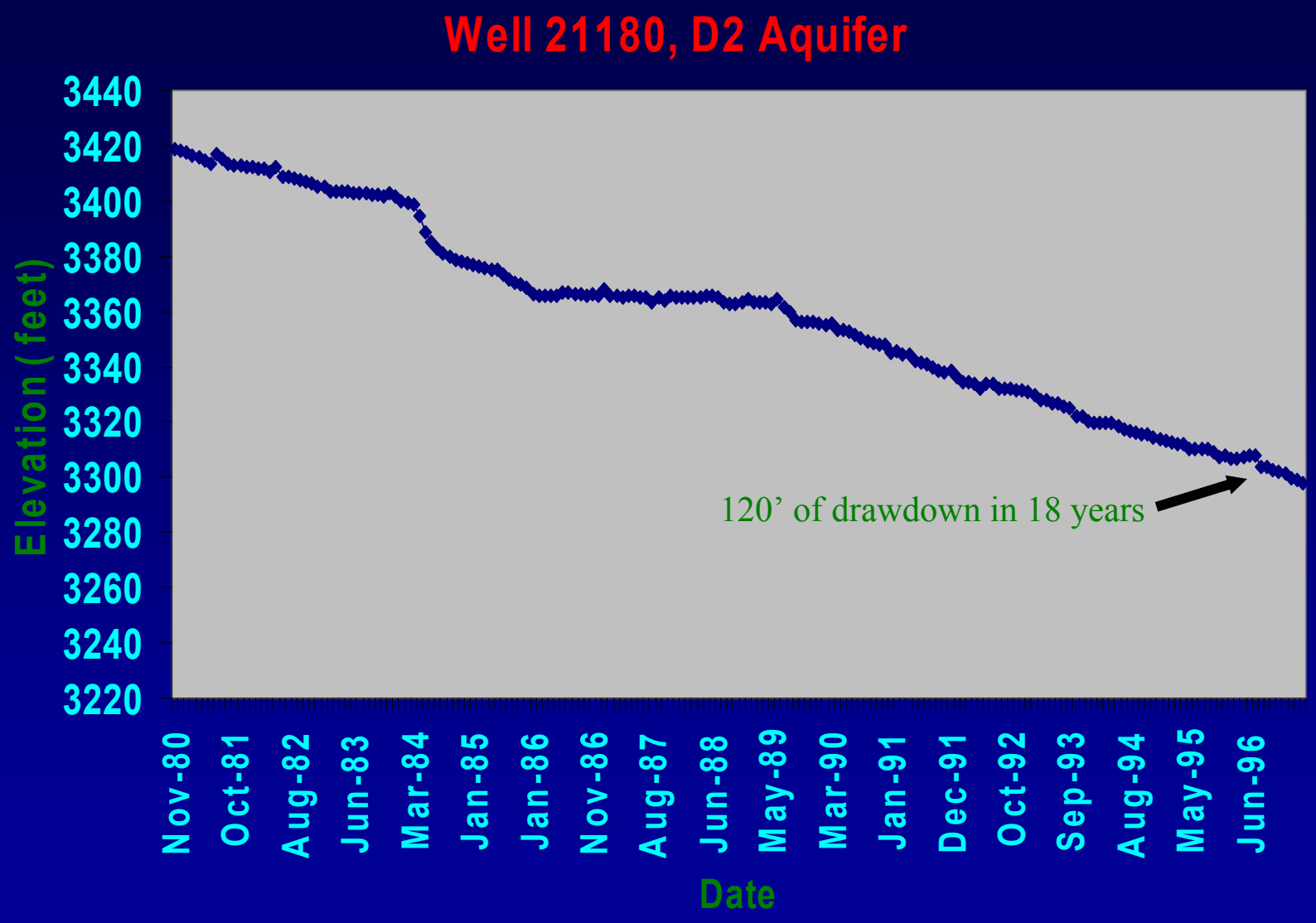

D1U Aquifer - 9/98
1 mile
N
D2 U - D2 L
D2
D1 L
D1 M - D1 L
Anderson - Dietz
D1 - D2
D1
D1 U - D1 L
D1U Coal Removed
3550
3500
3450
3400
3548
3525
3577
3487
3456
3408
3477
3517
3527
3501
3486
3534
3363
3421
3492
3367
3459
U
D

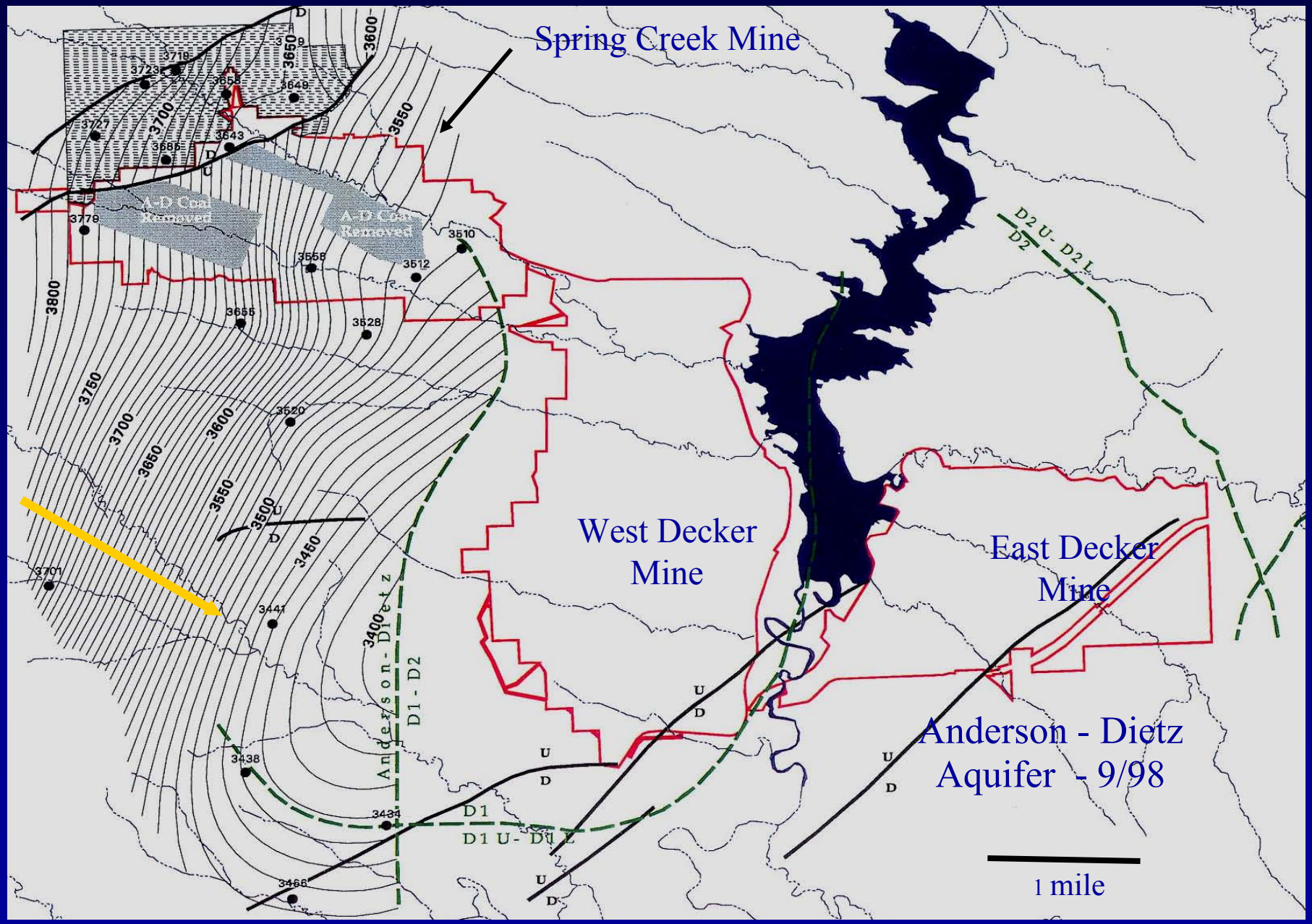
This map shows the potentiometric surface of the D1 Lower coal seam aquifer at the East Decker mine in the fall of 1998; the two maps immediately following it show the potentiometric surfaces of the D1 and D2 aquifers, respectively, at the West Decker mine during the same period. Steep drawdown is evident between the two faults that bound the East Decker pit area, which is the area of greatest mine-related drawdown in the Decker area.

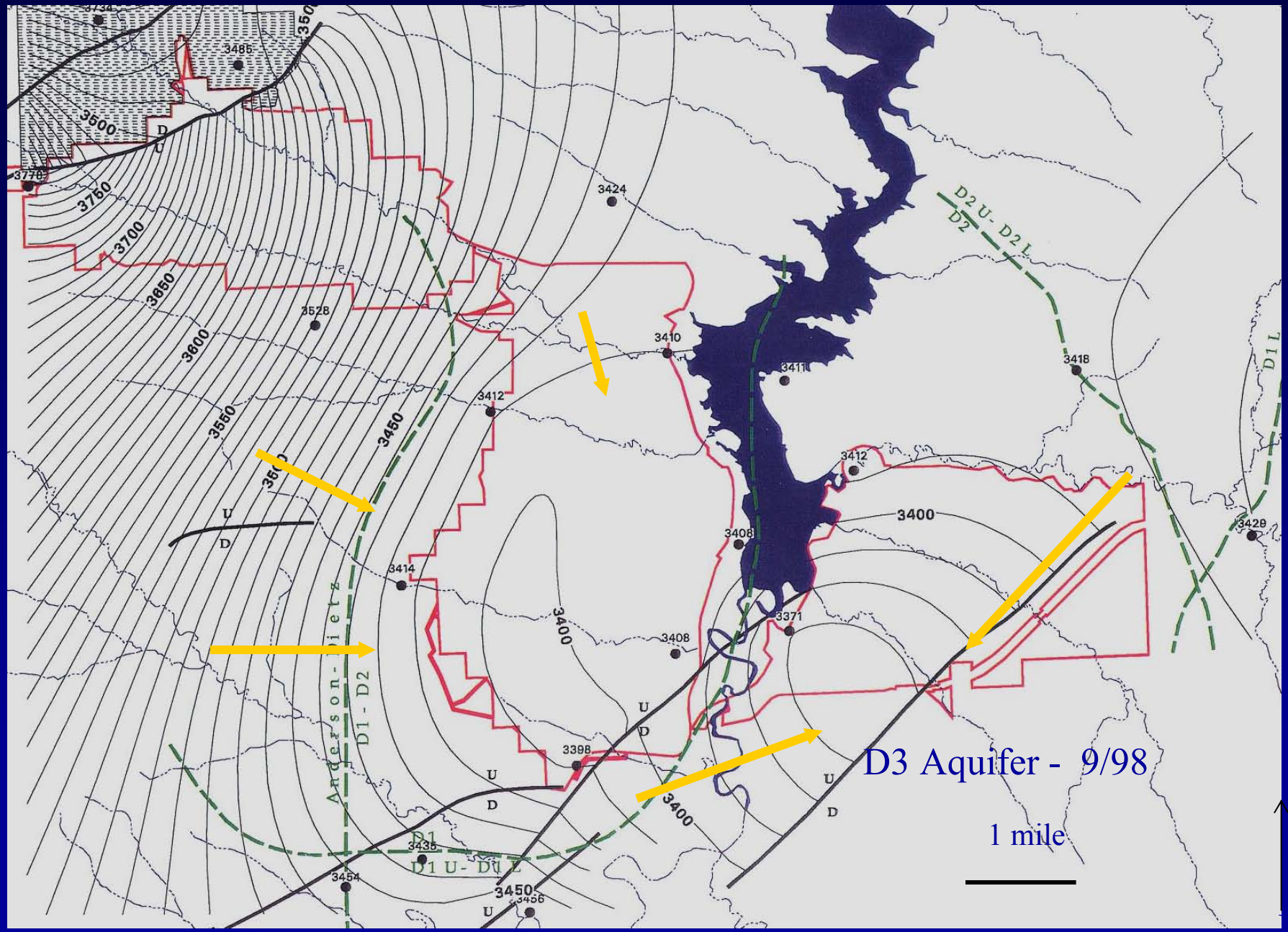

West Decker Mine
D1L Aquifer - 9/98
1 mile
N
D1L Coal Removed
3500
3450
3400
3350
D2 U- D2 L
D2
D1 L
D1 M- D1 L
Anderson- Dietz
D1 - D2
D1
D1 U- D1 L
U
D
3539
3518
3548
3419
3471
3484
3432
3429
3454
3458
3516
3409
3341
3347
3356
3459


Spring Creek Mine
D
U
D2 U - D2 L
D2
D1 Coal Removed
3456
3449
3405
3450
3427
U
D
3411
3411
East Decker Mine
3405
D1 Coal Removed
Anderson - Dietz
D1 - D2
3403
3400
U
D
3388
U
D
D1 Aquifer - 9/98
D1
D1 U - D1 L
U
D
1 mile


D2 Aquifer - 9/98
1 mile
N
D2 U- D2 L
D2
D1 L
D1 M- D1 L
Anderson- Dietz
D1 - D2
D1
D1 U- D1 L
D2 Coal Removed
3500
3450
3400
3350
3300
3430
3410
3404
3402
3472
3434
3407
3405
3394
3392
3403
3401
3372
3346
3366
3370
3272
3293
3357
3413
3402
3454
3423
3424
3412
3427
3398
3348
3486
U
D

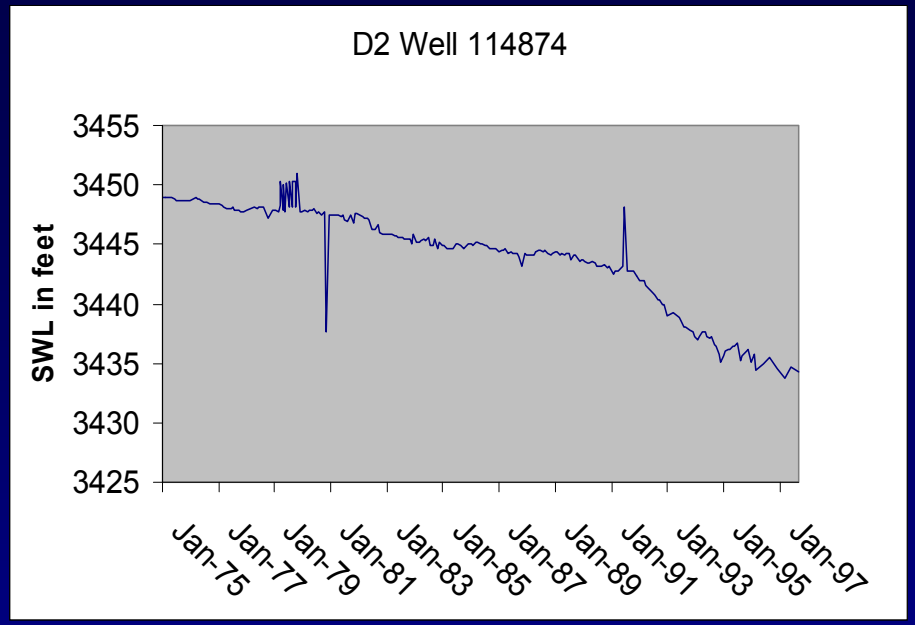

Well 21180, D2 Aquifer
Elevation (feet)
3440
3420
3400
3380
3360
3340
3320
3300
3280
3260
3240
3220
120' of drawdown in 18 years
Nov-80
Oct-81
Aug-82
Jun-83
Mar-84
Jan-85
Jan-86
Nov-86
Aug-87
Jun-88
May-89
Mar-90
Jan-91
Dec-91
Oct-92
Sep-93
Aug-94
May-95
Jun-96
Date

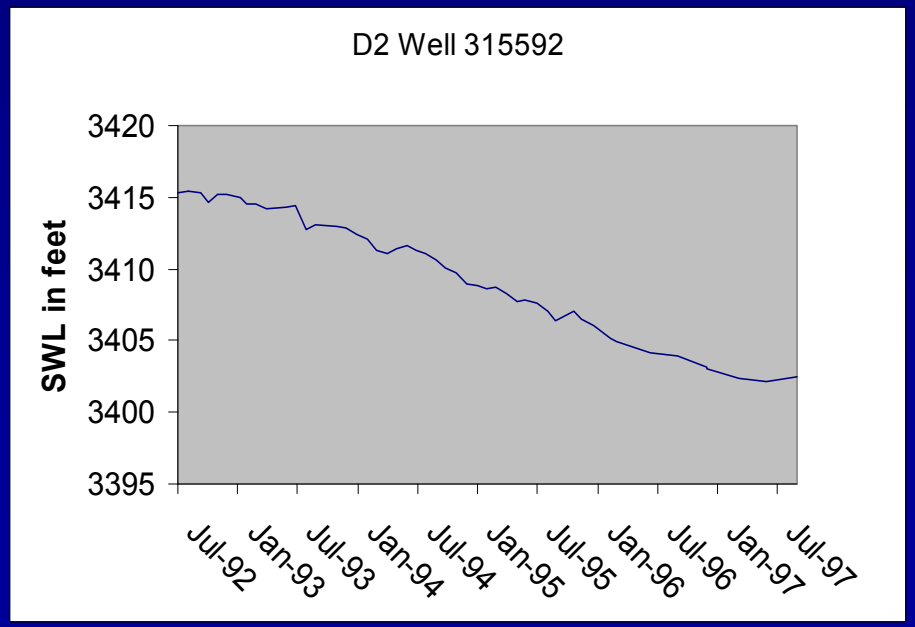

Spring Creek Mine
West Decker Mine
East Decker Mine
Anderson - Dietz Aquifer - 9/98
1 mile
A-D Coal Removed
A-D Coal Removed
D2 U- D2 L
D2
D1 - D2
Anderson - Dietz
D1
D1 U- D1 L
3800
3750
3700
3650
3600
3550
3500
3450
3400
3510
3512
3558
3655
3628
3620
3701
3441
3438
3434
3466
3779
3727
3723
3719
3685
3658
3649
3643


D3 Aquifer - 9/98
1 mile
3500
3750
3700
3650
3600
3550
3450
3400
3450
3485
3776
3424
3528
3410
3411
3418
3412
3412
3429
3406
3414
3371
3408
3398
3435
3454
3456
D2 U- D2 L
D2
D1 L
D1 - D2
Anderson-Dietz
D1
D1 U- D1 L
U
D

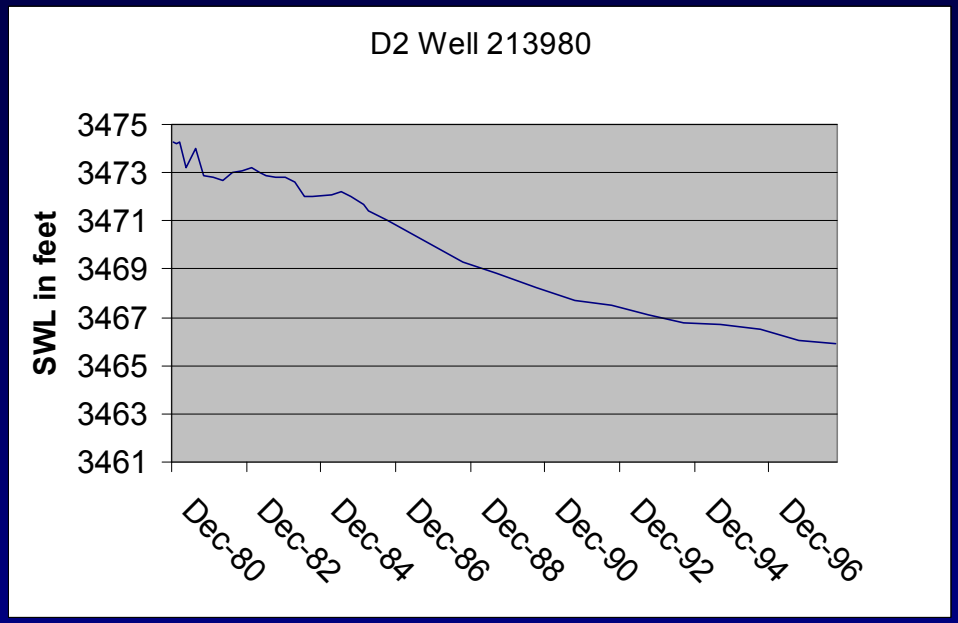
D2 Wells

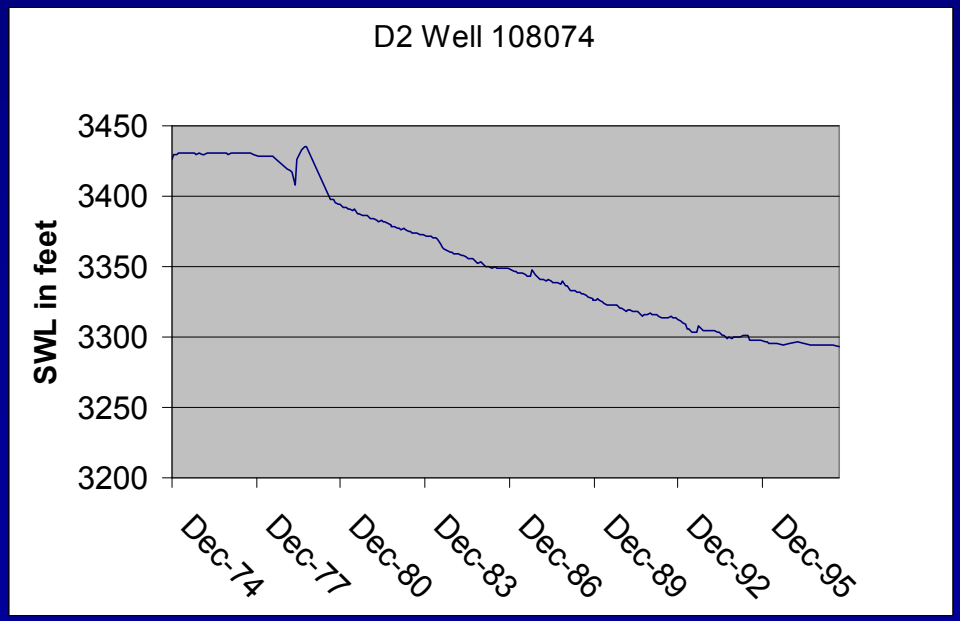
West Decker





East Decker

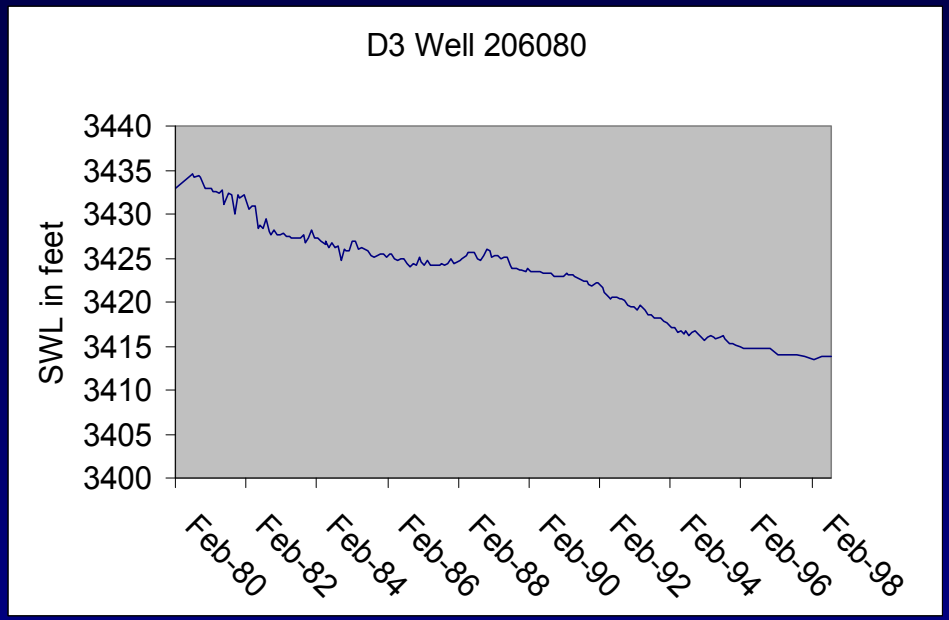


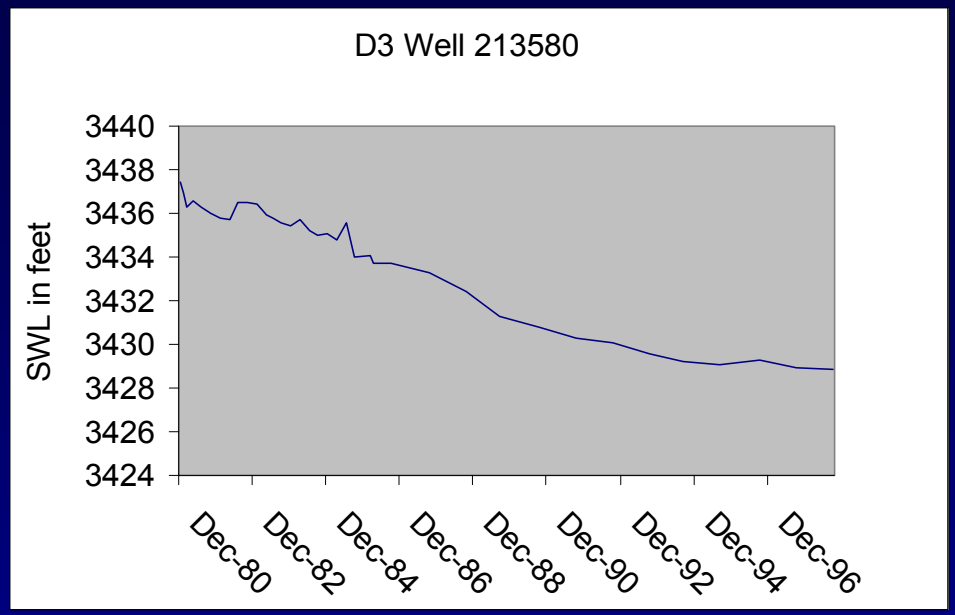


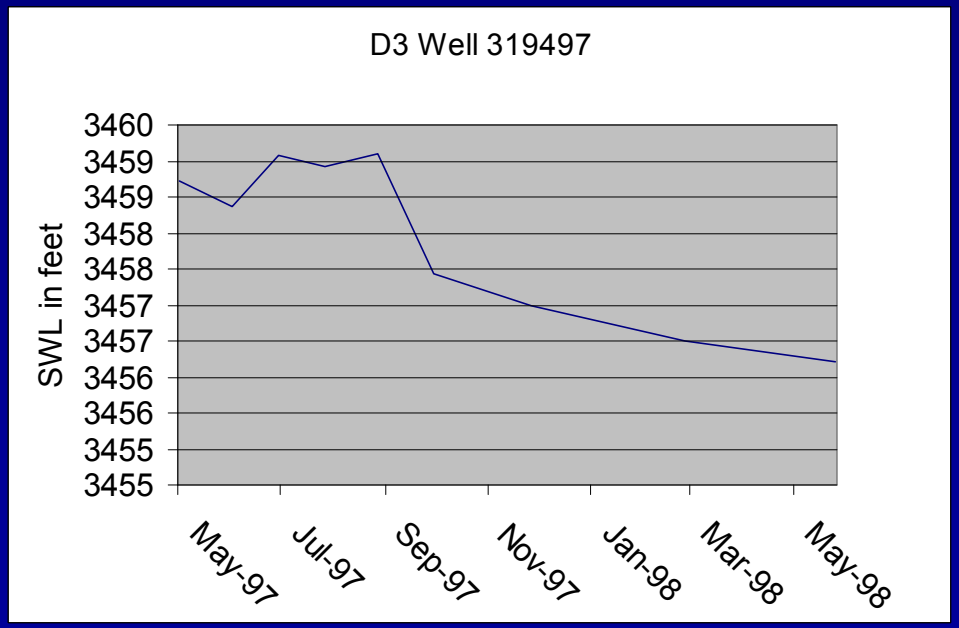
D3 Wells

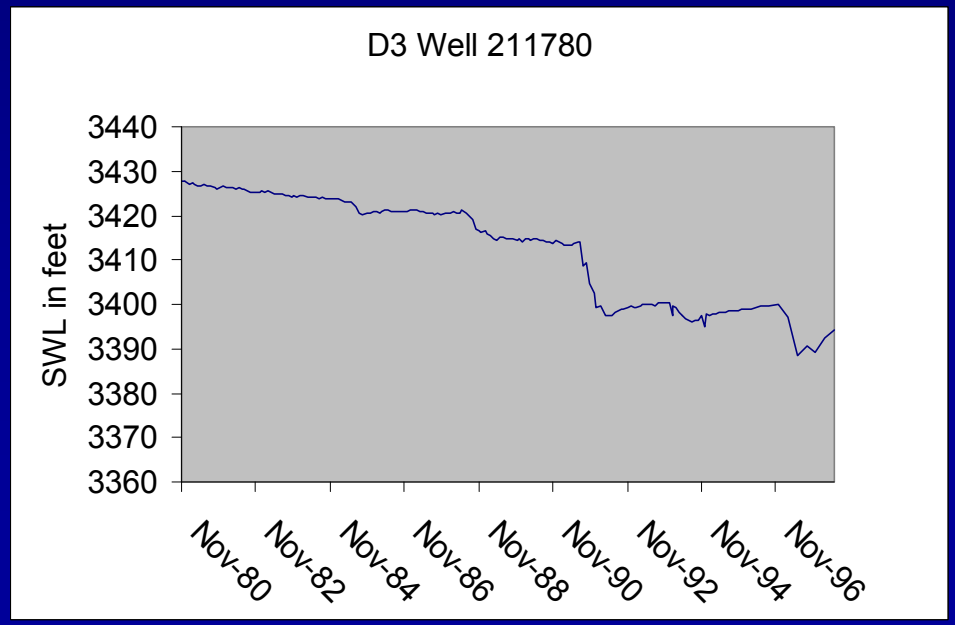
West Decker

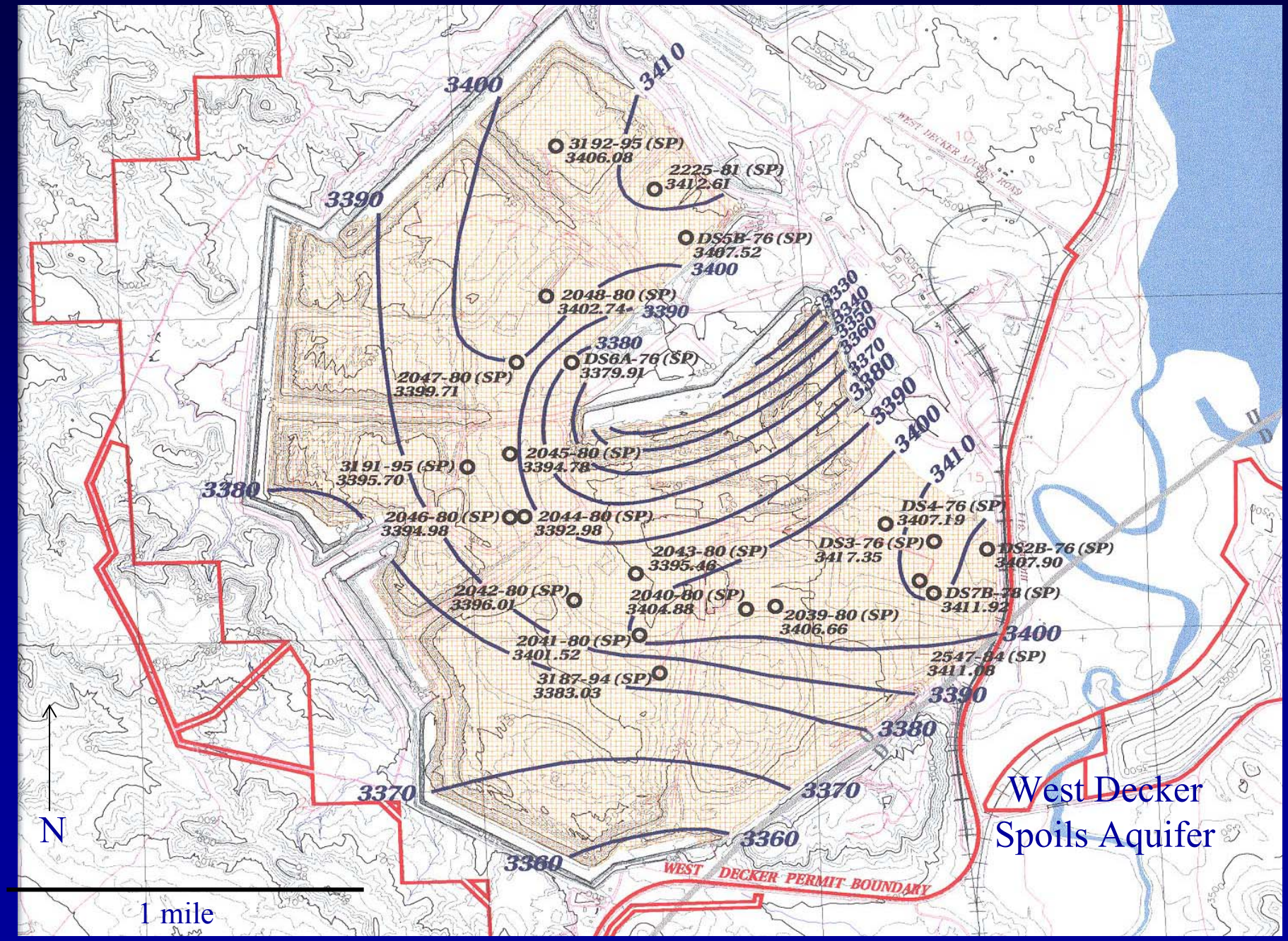
East Decker

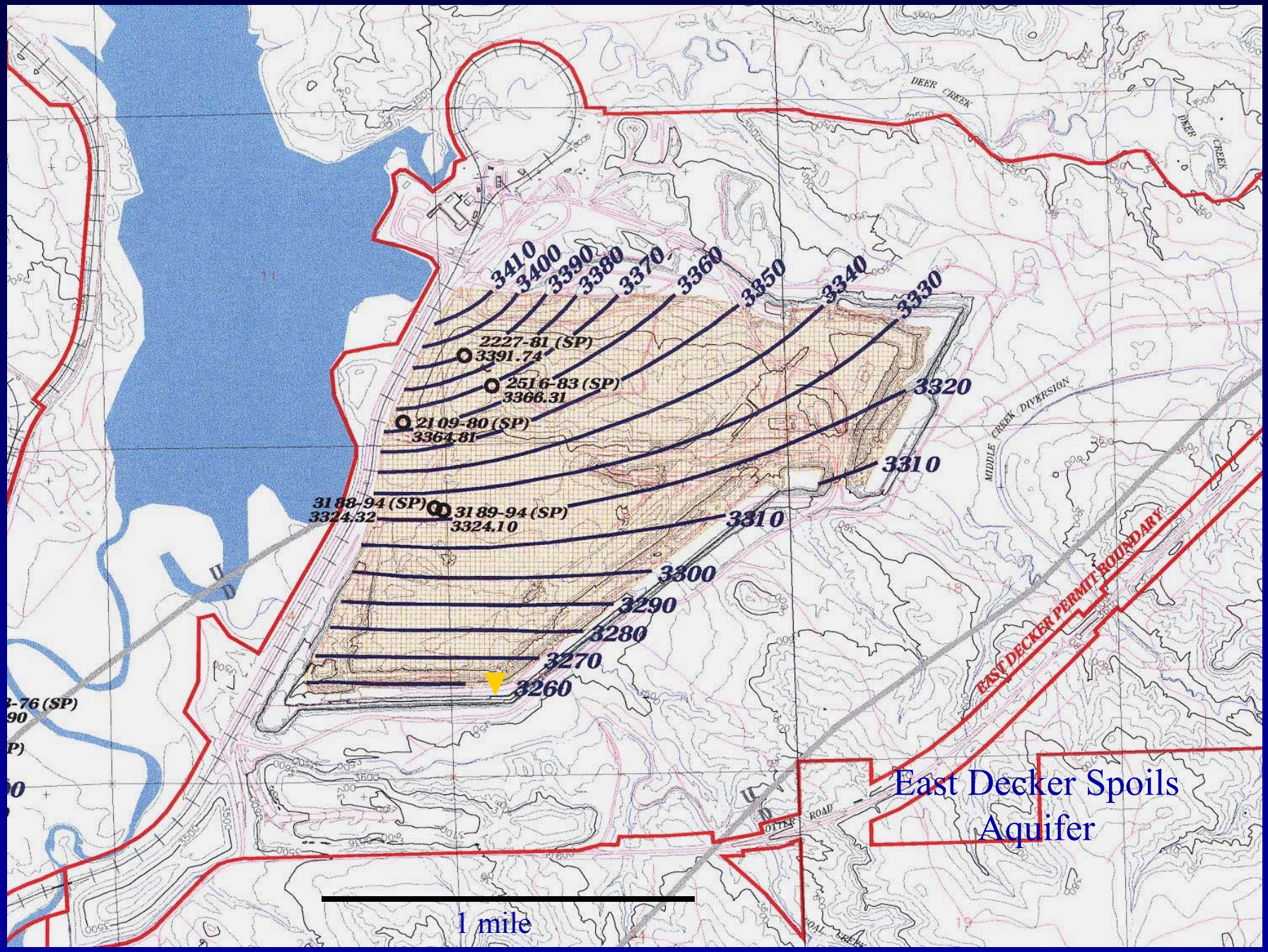








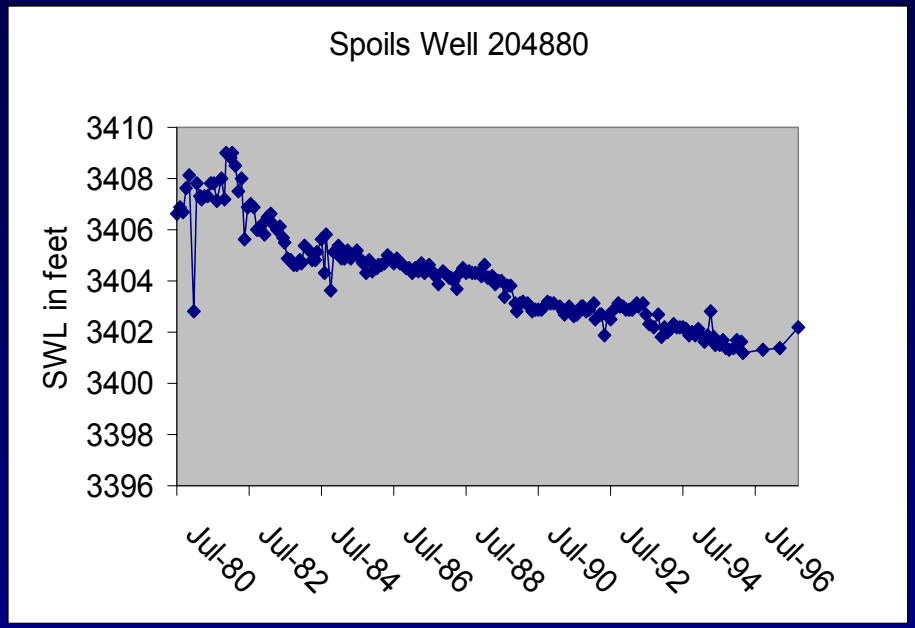

3400
3410
3192-95 (SP)
3406.08
2225-81 (SP)
3412.61
3390
DS5B-76 (SP)
3407.52
3400
2048-80 (SP)
3402.74
3390
3380
DS6A-76 (SP)
3379.91
2047-80 (SP)
3399.71
3330
3340
3350
3360
3370
3380
3390
3400
3410
2045-80 (SP)
3394.78
3191-95 (SP)
3395.70
3380
2046-80 (SP)
3394.98
2044-80 (SP)
3392.98
DS4-76 (SP)
3407.19
DS3-76 (SP)
3417.35
DS2B-76 (SP)
3407.90
2043-80 (SP)
3395.46
DS7B-78 (SP)
3411.92
2042-80 (SP)
3396.01
2040-80 (SP)
3404.88
2039-80 (SP)
3406.66
3400
2041-80 (SP)
3401.52
2547-84 (SP)
3411.08
3187-94 (SP)
3383.03
3390
3380
3370
3370
3360
3360
WEST DECKER PERMIT BOUNDARY
N
1 mile
West Decker
Spoils Aquifer

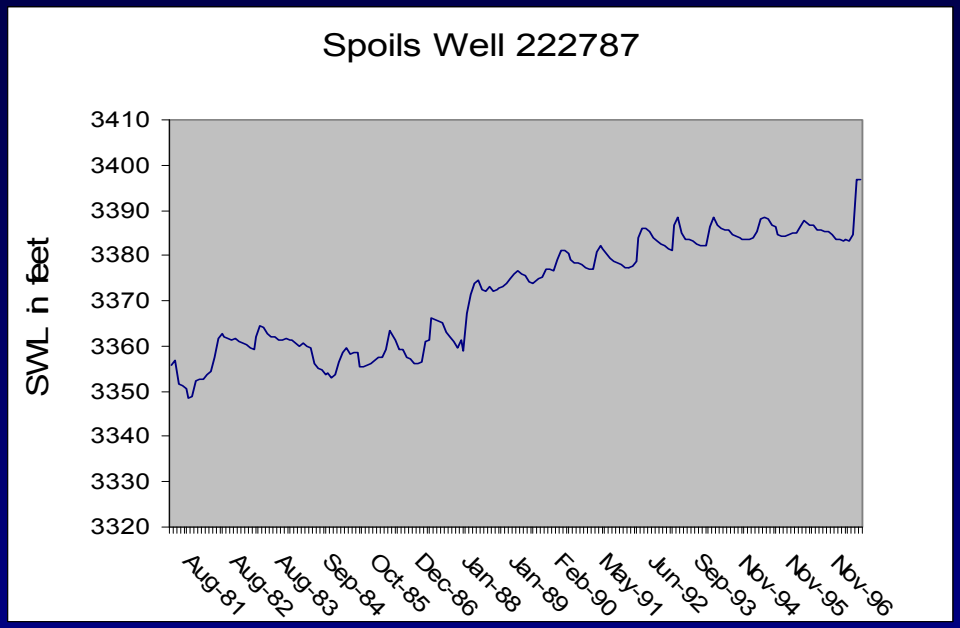

3410
3400
3390
3380
3370
3360
3350
3340
3330
3320
3310
3310
3300
3290
3280
3270
3260
2227-81 (SP)
3391.74
2516-83 (SP)
3366.31
2109-80 (SP)
3364.81
3188-94 (SP)
3324.32
3189-94 (SP)
3324.10
DEER CREEK
MIDDLE CREEK DIVERSION
EAST DECKER PERMIT BOUNDARY
OTTER ROAD
East Decker Spoils Aquifer
1 mile

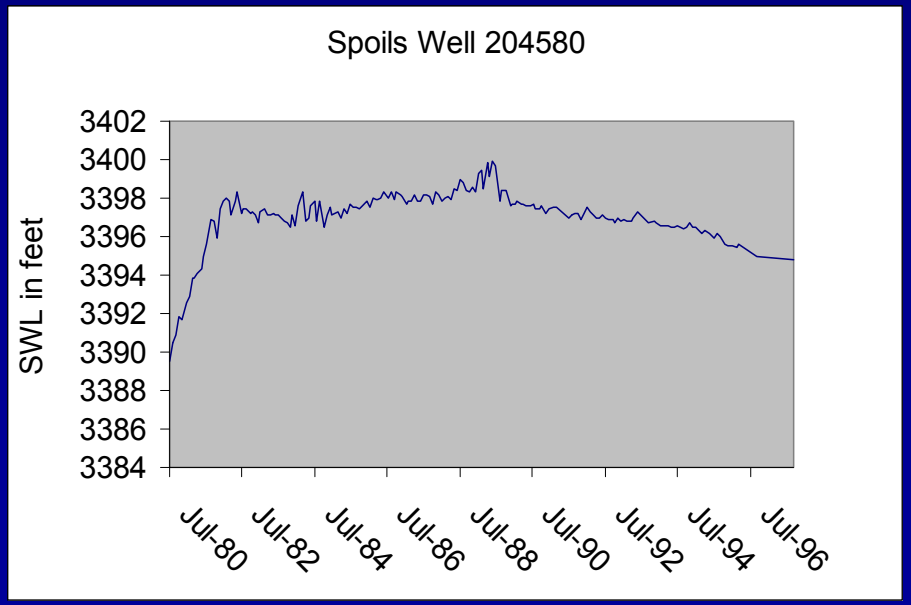
Spoils Wells

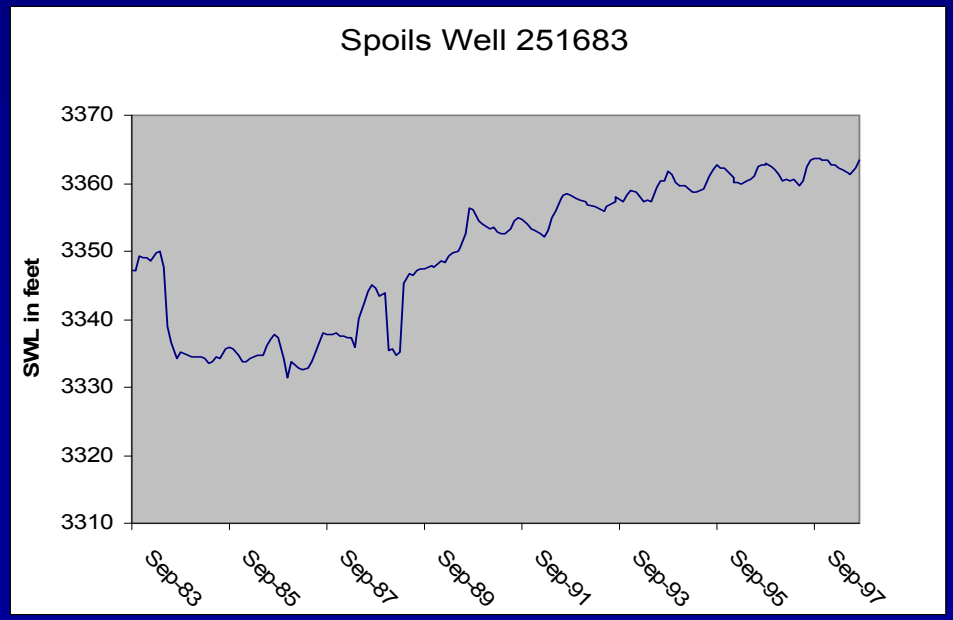
West Decker

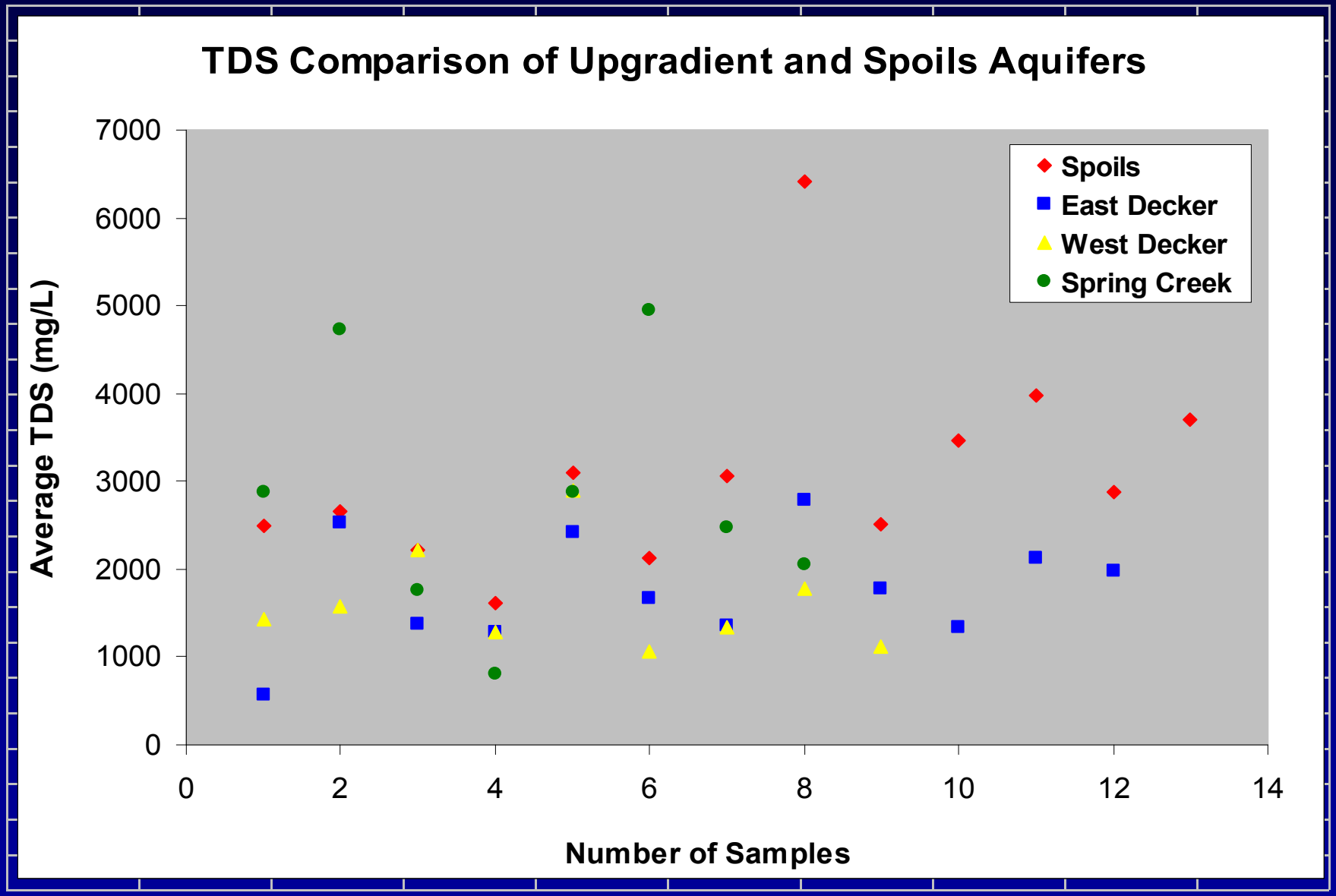
East Decker

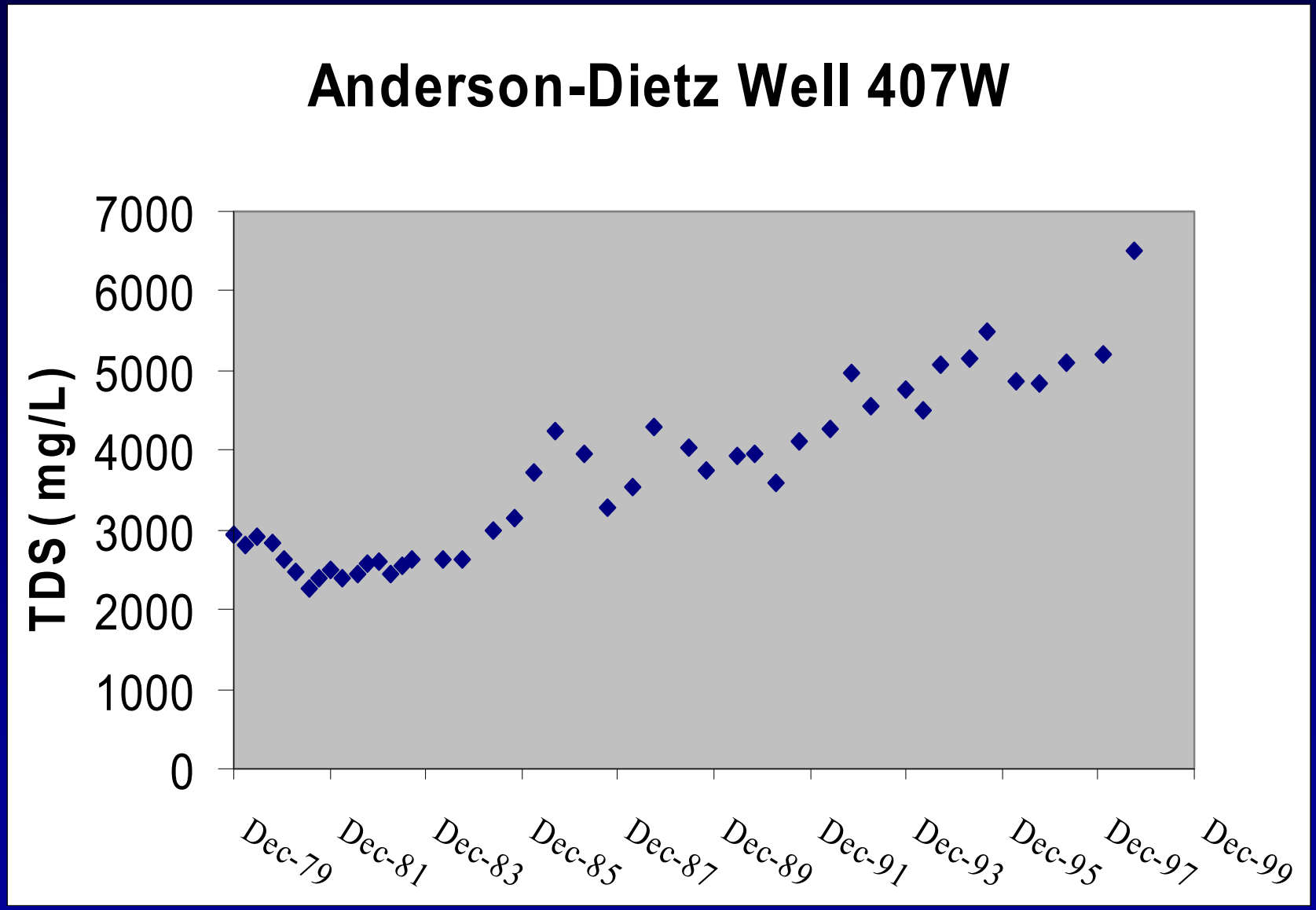


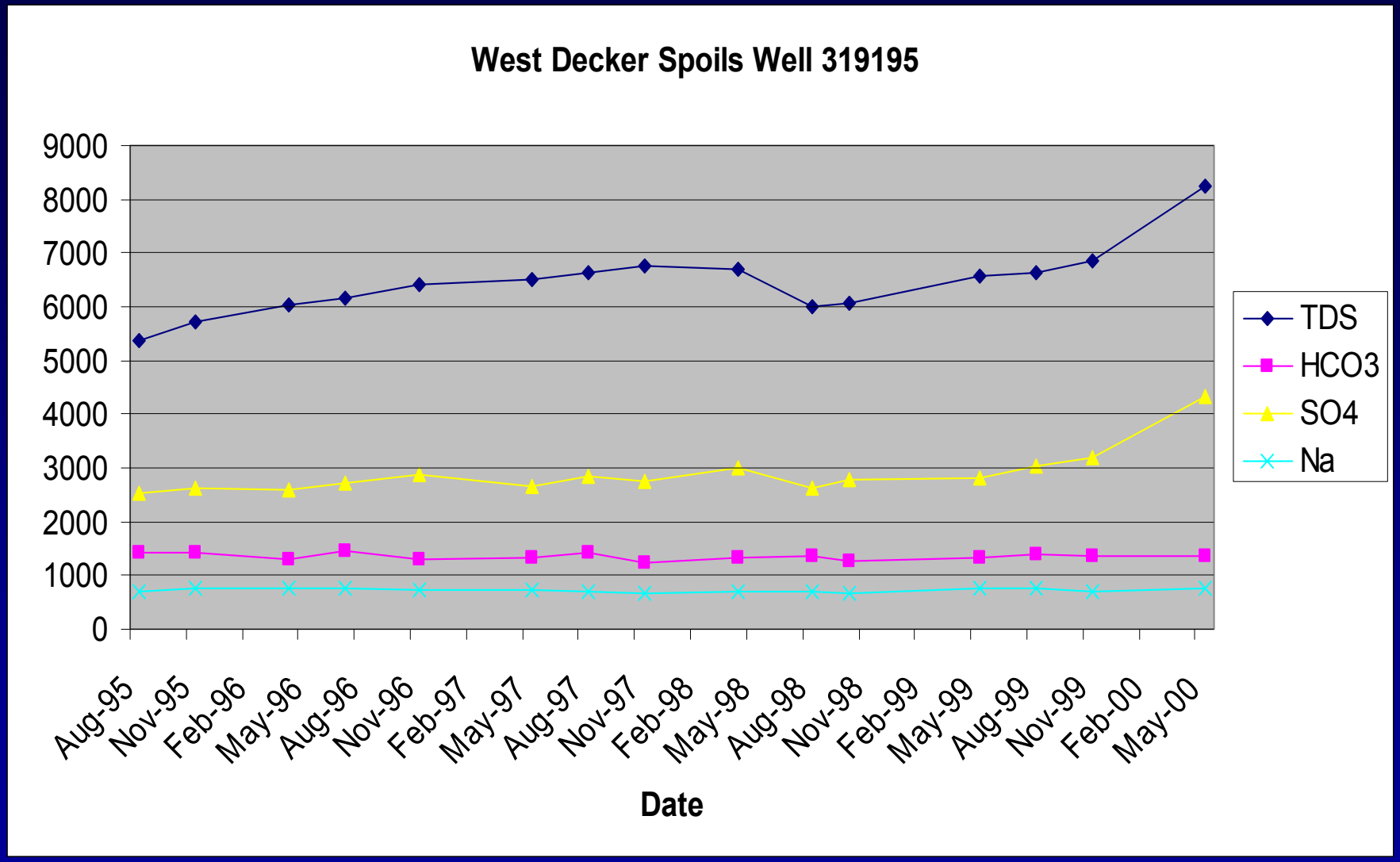


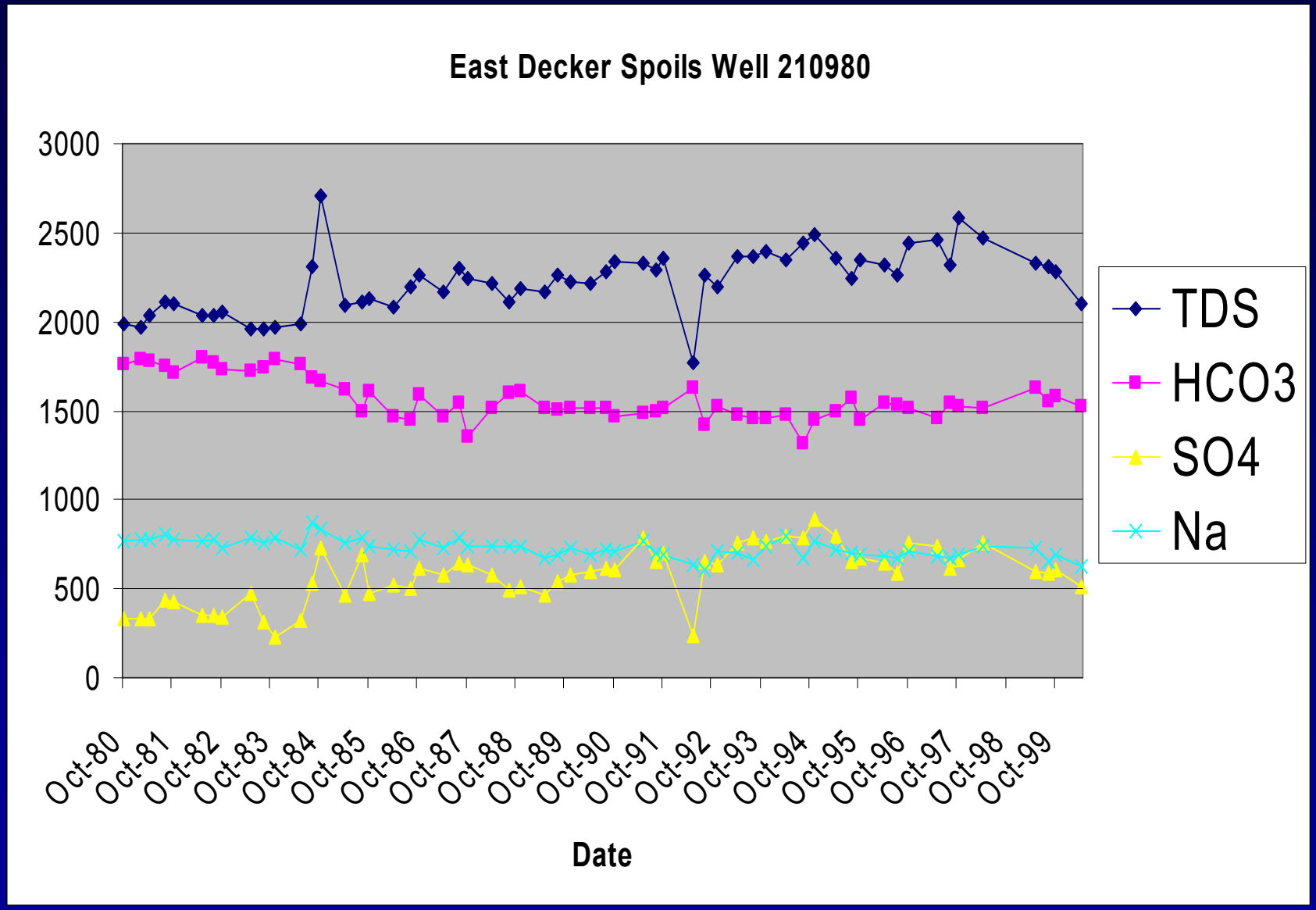


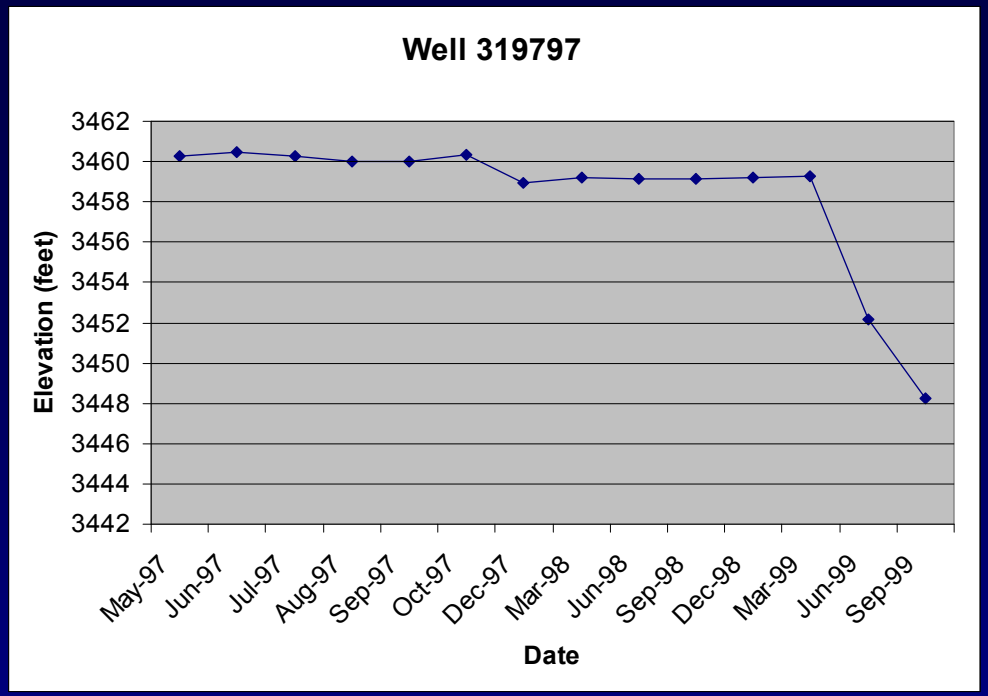



TDS Comparison of Upgradient and Spoils Aquifers
Average TDS (mg/L)
7000
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14
Number of Samples
Spoils
East Decker
West Decker
Spring Creek

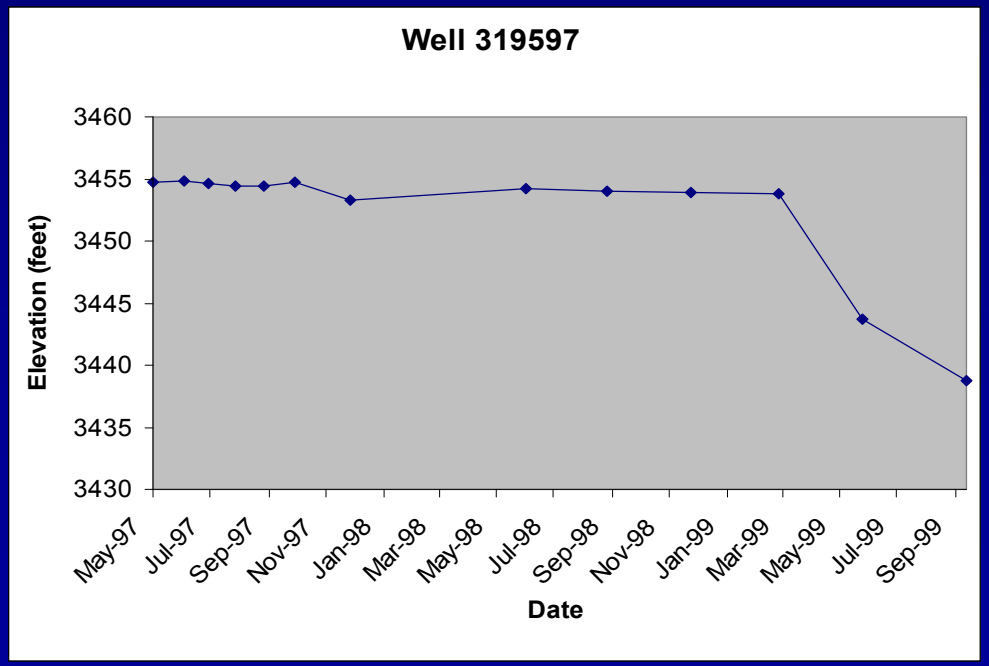

Anderson-Dietz Well 407W
TDS (mg/L)
7000
6000
5000
4000
3000
2000
1000
0
Dec-79
Dec-81
Dec-83
Dec-85
Dec-87
Dec-89
Dec-91
Dec-93
Dec-95
Dec-97
Dec-99


West Decker Spoils Well 319195
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Aug-95
Nov-95
Feb-96
May-96
Aug-96
Nov-96
Feb-97
May-97
Aug-97
Nov-97
Feb-98
May-98
Aug-98
Nov-98
Feb-99
May-99
Aug-99
Nov-99
Feb-00
May-00
Date
TDS
HCO3
SO4
Na


East Decker Spoils Well 210980
3000
2500
2000
1500
1000
500
0
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99
Date
TDS
HCO3
SO4
Na



Effects of Coal-Bed Methane Development on Aquifers in the Decker, Montana, Area



Montana Department of

Environmental Quality

Laboratory Data: Quality Assurance/Quality Control

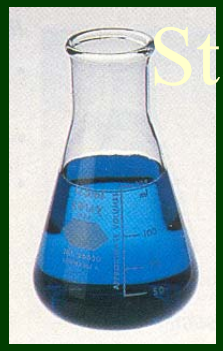
David Poelstra, Inter-Mountain Laboratories, Inc.

Quality Assurance/Quality Control

- Sample containers
- Sample login
- Standard operating procedures
- Lab auditing
- Correctness of analyses

Water Chemistry

- Surface water
- Ground water
- Drinking water
- Wastewater
- National Pollution Discharge Effluent Standards

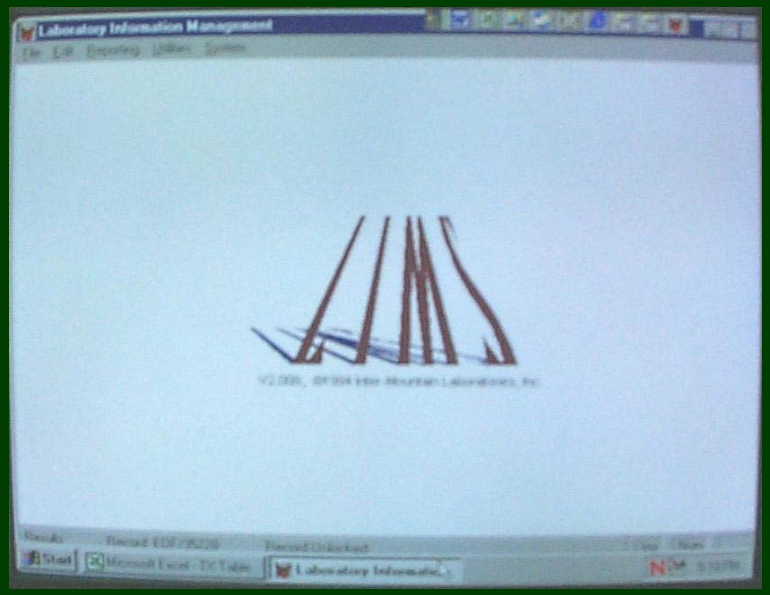


Sample Containers

- Clean
- Adequate volume
- Preservatives
- Sample information
- Chain of custody

Sample Login

- Unique lab identification
- Sample date and time
- Temperature
- Preservatives
- Chain of custody



NOTE: All Inter-Mountain Laboratories, Inc's, data are maintained within the Laboratory Information Management System (LIMS).

Standard Operating Procedures

- Each method of analysis must incorporate a standard operating procedure to ensure uniformity among analysts.

Lab Auditing

- Routine performance evaluation samples
- Internal audits
- External audits
- State certifications
- Corrective action plan

Correctness of Analyses

- Anion-cation balance:

$$\% \text{ difference} = 100 \frac{\Sigma \text{ cations} - \Sigma \text{ anions}}{\Sigma \text{ cations} + \Sigma \text{ anions}}$$

Anion Sum (meq/L)	Acceptable % Difference
0 – 3.0	± 0.2 meq/L
3.0 – 10.0	± 2%
10.0 – 800	± 5%

- Calculated total dissolved solids (TDS):

  Calculated TDS = 0.6(alkalinity) + Na^+ + K^+ + Ca^{2+} + Mg^{2+} + Cl^- + SO_4^{2-} + SiO_3^{2-} + NO_3^- + F^-

- Measured TDS = calculated TDS:

$$1.0 < \frac{\text{measured TDS}}{\text{calculated TDS}} < 1.2$$

- Measured electrical conductivity (EC) and ion sums:

  100 x anion (or cation) sum, meq/L = (0.9 – 1.1)EC

- Calculated TDS to EC ratio:

  calculated TDS/EC = 0.55-0.7

- Measured TDS to EC ratio:

  measured TDS/EC = 0.55-0.7

Contact Inter-Mountain Laboratories, Inc.

Headquarters/Laboratories:

- Headquarters
  555 Absaraka
  Sheridan, Wyoming 82801
  (307) 674-7506

- Sheridan Lab
  1633 Terra Avenue
  Sheridan, Wyoming 82801
  (307) 672-8945

- Gillette Lab
  1701 Phillips Circle
  Gillette, Wyoming 82718
  (307) 682-8945

- Farmington Lab
  2506 West Main Street
  Farmington, New Mexico 87401
  (505) 326-4737

- College Station Lab
  11183 SH 30
  College Station, Texas 77845
  (409) 776-8945

Website: http://www.imline.com

Belle Ayr Mine
Hydrologic Monitoring History

Phil Dinsmoor and Robert Stowe
RAG Coal West, Inc.

Initial Permit (14 pages)

Hydrologic commitments:

- Divert Caballo Creek
- Monitor pH before discharge

Mining begins in 1972

The Surface Mining Control and Reclamation Act (SMCRA)

SMCRA, passed in August 1977, mandates:

- Bonding surface coal-mining and reclamation operations
- Describing the hydrology (surface and ground water) and geology of permit areas
- A minimum requirement for reclamation and operation plans
- Protecting the hydrologic balance

Gillette Area Groundwater Monitoring Organization (GAGMO)

- Initiated, by Jim Brown, in 1980
- Mapped ground-water levels
- Tabulated data describing ground-water levels
- Collected data on October 1 of each year
- Used by industry to document impacts on the hydrologic balance

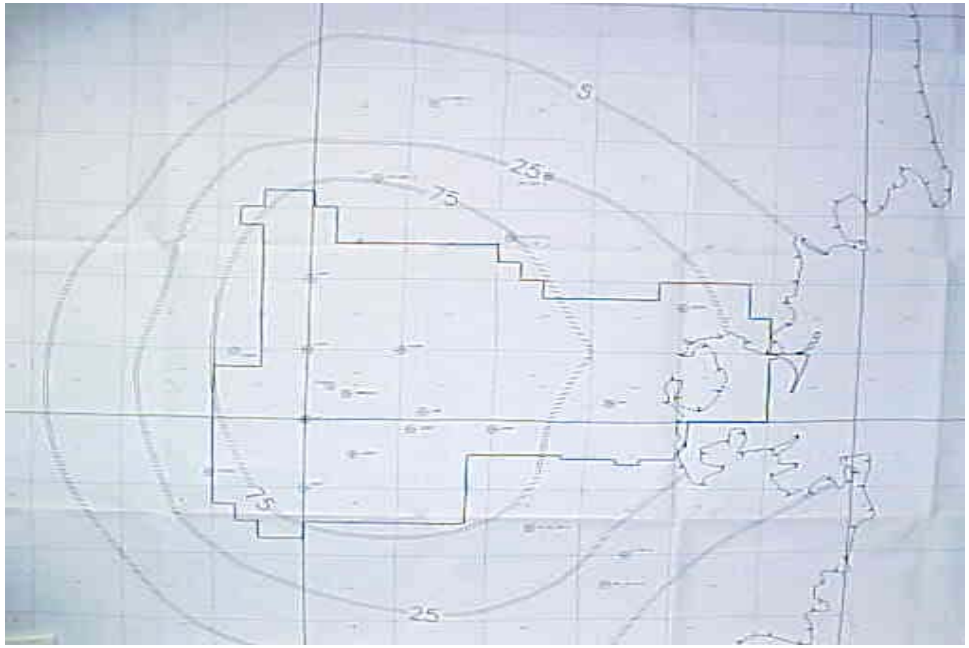
Probable Hydrologic Consequence (PHC) Findings and Cumulative Hydrologic Impact Assessments (CHIA's)

Wyoming Department of Environmental Quality (DEQ), Land Quality Division (LQD), established drawdown requirements:

- Drawdown in overburden attributable to any given mine must be limited to 5 feet
- Drawdown in overburden attributable to the cumulative effects of regional mines must be limited to 5 feet
- Drawdown in coal attributable to any given mine must be limited to 5 feet
- Drawdown in coal attributable to the cumulative effects of regional mines must be limited to 5 feet
- Approved mine plans must predict when ground water will recharge backfill

PHC Findings and CHIA's

Most companies used digital models to predict drawdown extent and recharge time:



Monitoring During Mining at Belle Ayr

- Original permit has expanded to 16 volumes
- 2 paragraphs describing hydrologic commitments has expanded to 3 volumes of text, 40 maps, and 7 appendices

Monitoring During Mining at Belle Ayr

- First surface-water stations and monitoring wells were established in the early 1970's

Monitoring During Mining at Belle Ayr

- First stream gage upstream of a mined area was established in 1972
- First gage downstream of a mined area was constructed in 1975
- Second upstream gage was placed at an upstream lease boundary in 1977

Monitoring During Mining at Belle Ayr

- Third upstream gage was placed upstream of new coal leases in 1981

Monitoring During Mining at Belle Ayr

- First well for facilities was drilled in 1972
- Three coal and one overburden monitoring wells were drilled in February 1973

Monitoring During Mining at Belle Ayr

- Baseline surface- and ground-water conditions were measured and documented in the early 1970's

Monitoring During Mining at Belle Ayr

Initially, RAG Coal West, Inc.:

- Kept data in notebooks
- Stored water-level data in mainframe spreadsheets
- Wrote a water-quality program for this mainframe
- Chose HydroDat software to track water-quality data, generate reports, and transmit these data to regulatory agencies

Now, we store water-level data on PC spreadsheets

What Do Our Data Show?

- Belle Ayr's largest runoff event was not gauged:
  - This event occurred in May 1978
  - A large reservoir is located less than 1 mile from the upstream gage
- Many months of no flow have been recorded

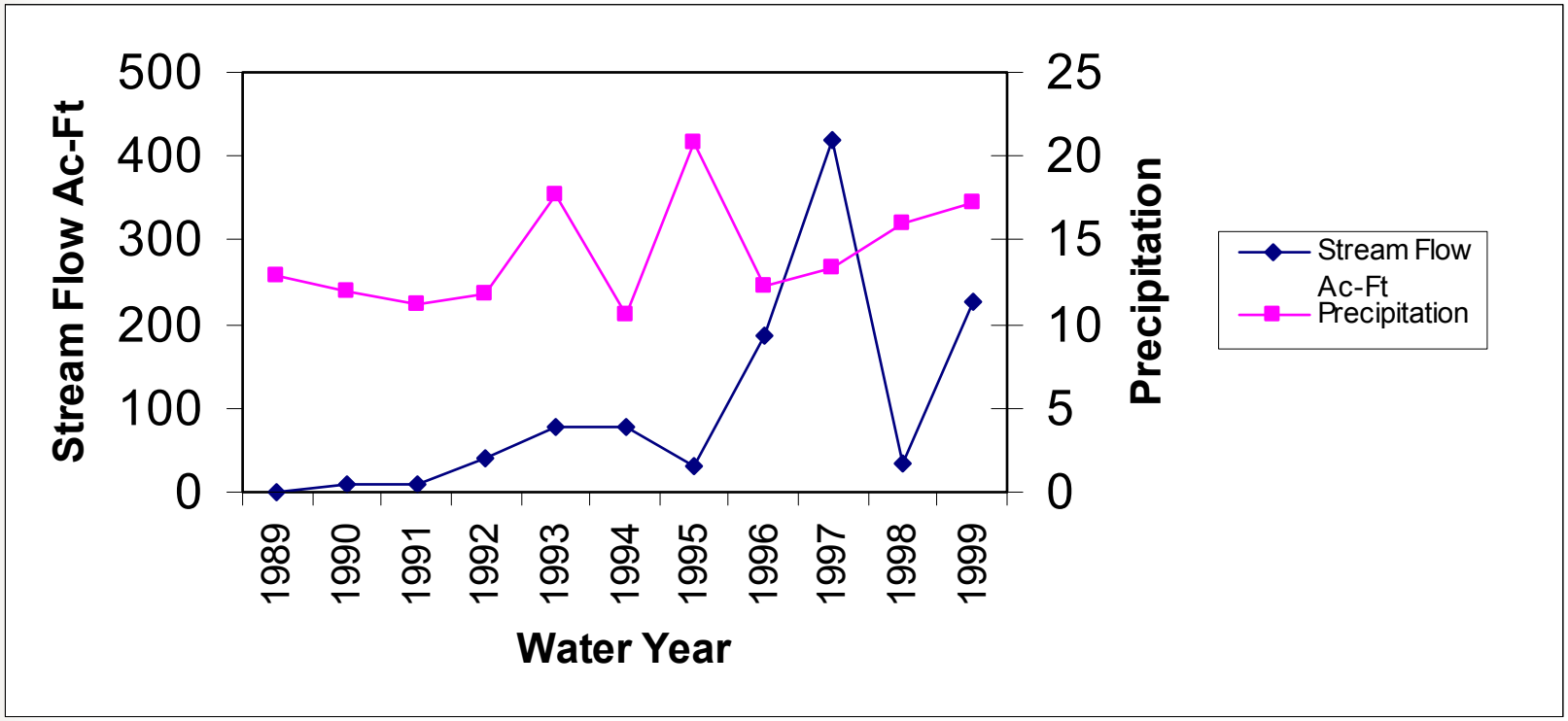
What Do Our Data Show?

- Coal-bed methane (CBM) discharges water into Caballo Creek drainage

What Do Our Data Show?

- Number of months with flow has increased:
  - 1989-94: 6.7 months/year
  - 1995-99: 10.2 months/year
- Amount of flow has increased:
  - 1989-94: 36.4 ac-ft/year
  - 1995-99: 178.7 ac-ft/year

What Do Our Data Show?



What Do Our Data Show?

Total dissolved solids (TDS) in Caballo Creek:

- Upstream mean TDS = 5,881 mg/L
- Downstream mean TDS = 2,886 mg/L

What Do Our Data Show?

Total suspended solids (TSS) in Caballo Creek:

- Upstream mean TSS = 26 mg/L
- Downstream mean TSS = 16 mg/L

What Do Our Data Show?

pH of Caballo Creek:

- Upstream median pH = 8.0
- Downstream median pH = 7.9

What Do Our Data Show?

Water quality of the 13 backfill wells:

- TDS readings were less than 5,000 mg/L (which is the livestock limit) in 11 of the 13 wells
- No toxic concentrations of chemicals containing trace metals were found
- Occasionally, pH readings were beyond the 6.5 to 8.5 range

What Do Our Data Show?

- In 1995, 5-foot drawdowns in coal extended 2 miles west of Highway 59
- Our modeled drawdown for 1995 showed 5-foot drawdowns in coal extending 2.5 miles west of this highway

What Do Our Data Show?

- In 1998, 5-foot drawdown in overburden closely matched the modeled 5-foot drawdown contour

What Do Our Data Show?

In 1995, evident CBM effects were:

- 9 of 13 coal-monitoring wells were emitting gas
- Water levels in western wells dropped dramatically
- GAGMO's 1995 water-level map showed a ground-water divide

What Do Our Data Show?

CBM effects:

- 1999 GAGMO map shows the coal ground-water divide to be located less than ½ mile west of the Belle Ayr pit

What Do Our Data Show?

CBM effects:

- There are more than 100 feet of drawdown in coal in the CBM cone of depression
- Wyoming DEQ, LQD, will have a difficult time preparing a CHIA describing CBM impacts

Summary

- RAG Coal West, Inc., has a large volume of Belle Ayr hydrologic data spanning more than 25 years
- These data were gathered as documentation in support of bond release

Summary

- Some of the data are not helpful in determining current impacts

Recharge from Clinker in the Powder River Basin

Edward L. Heffern
Geologist, Branch of Solid Minerals
U.S. Bureau of Land Management
Cheyenne, Wyoming

Clinker is:

- rock that has been baked and melted by the natural burning of coal beds;
- mostly red, yellow, and black; and
- highly fractured.

What causes coal outcrops to burn?

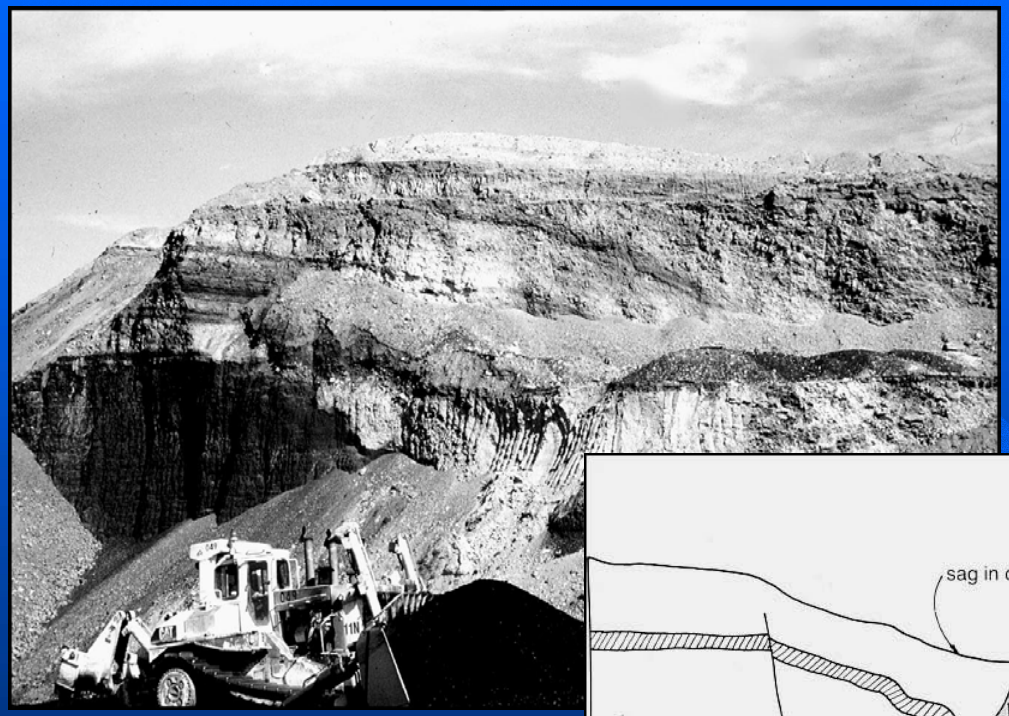
Burning coal bed south of Colstrip, Montana

- Being located above a water table;
- Spontaneous combustion, including:
  - The heat of a wetting reaction and
  - Oxidation reactions;
- Wildfire, including:
  - Range fires that ignite coal and
  - Trees rooted in coal beds; and
- Human causes.

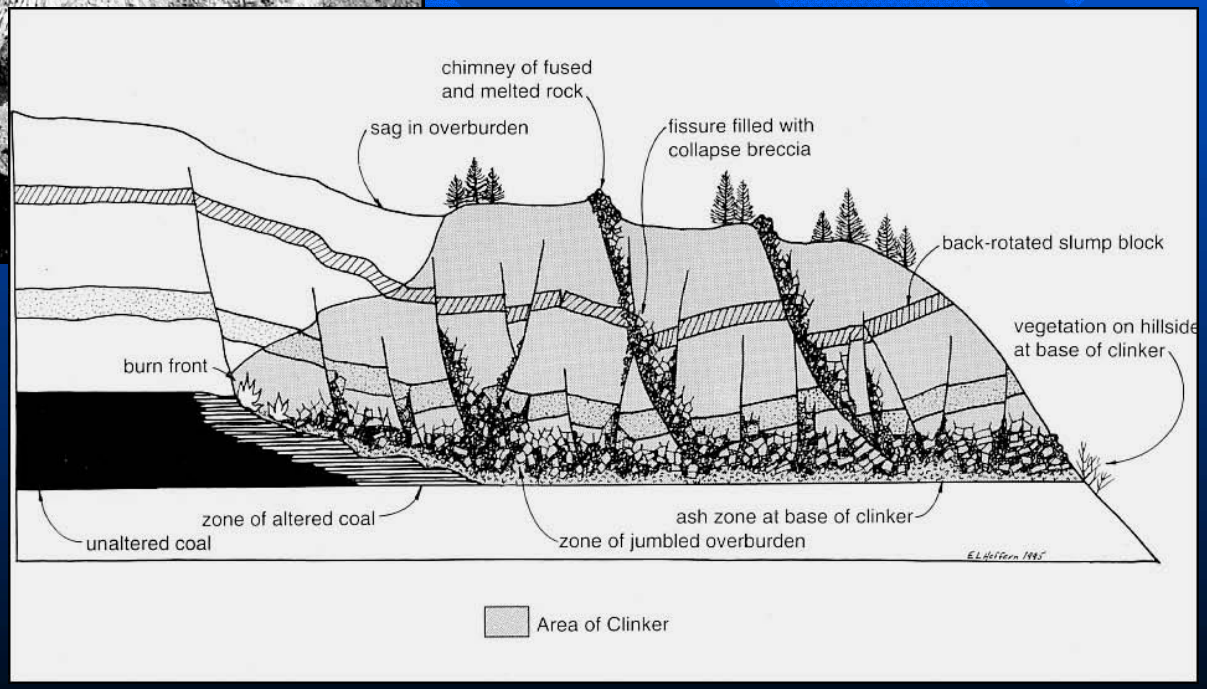
What is the structure of clinker?

- It is formed by overburden that has collapsed into void where coal used to be.
- It is highly brecciated.
- It has chimneys of darker melted and fused rock that form in fractures.
- It has an ash/rubble zone at its base.
- It evinces little or no heating of underlying strata.

Cross-Section of Clinker and Coal



- The burn front retreats from the outcrop.
- Overburden sags into a void.



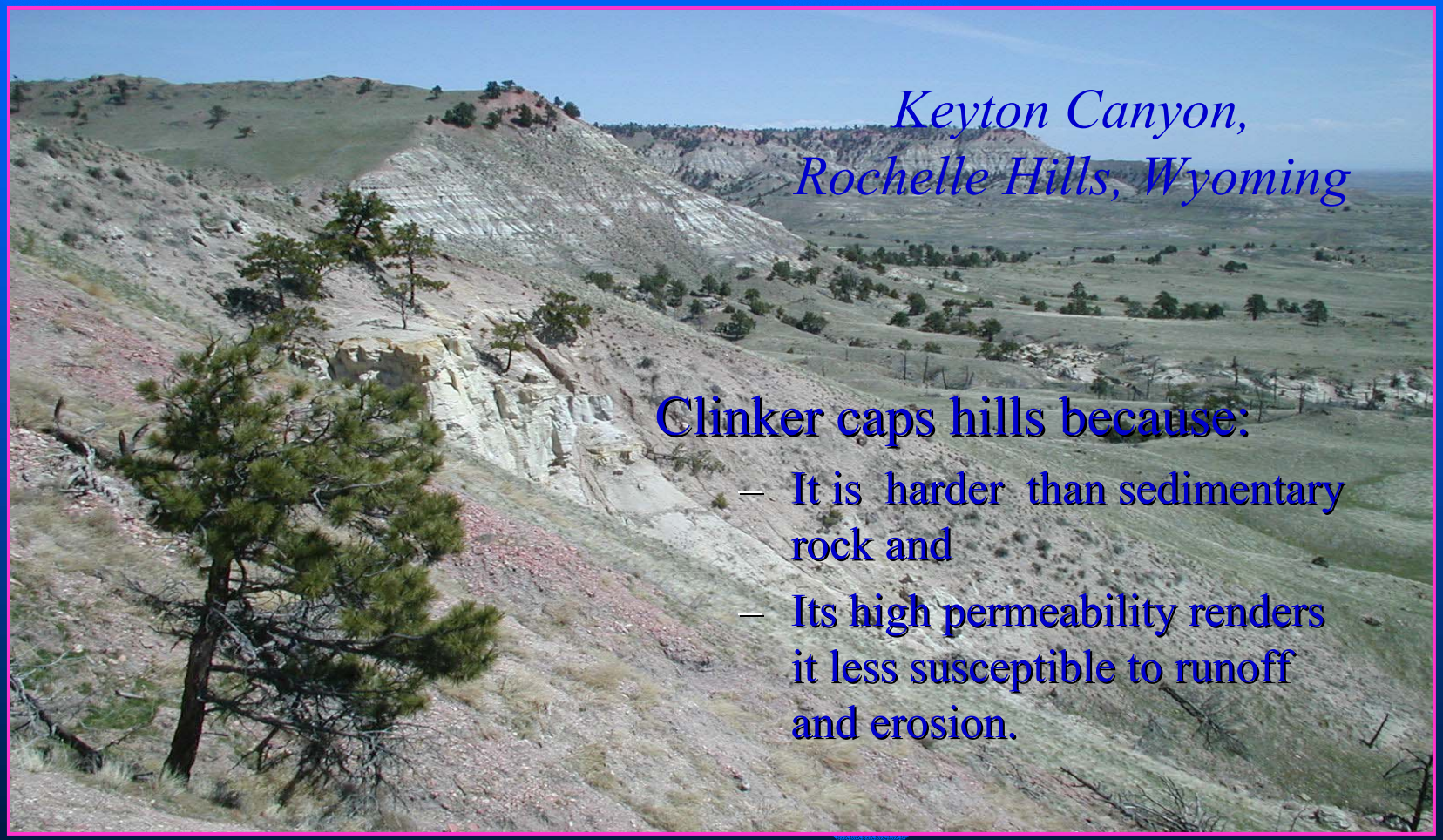
Clinker is common along the edges of coal mines.

Clinker chimney east of Belle Ayr and Caballo mines

The Role of Clinker in the Landscape

- Covers large areas of the Powder River Basin (PRB) in Montana and Wyoming;
- Forms hard caprock on hills and ridges;
- Protects underlying strata from erosion;
- Creates broken topography; and
- Increases the variety of ecological niches.

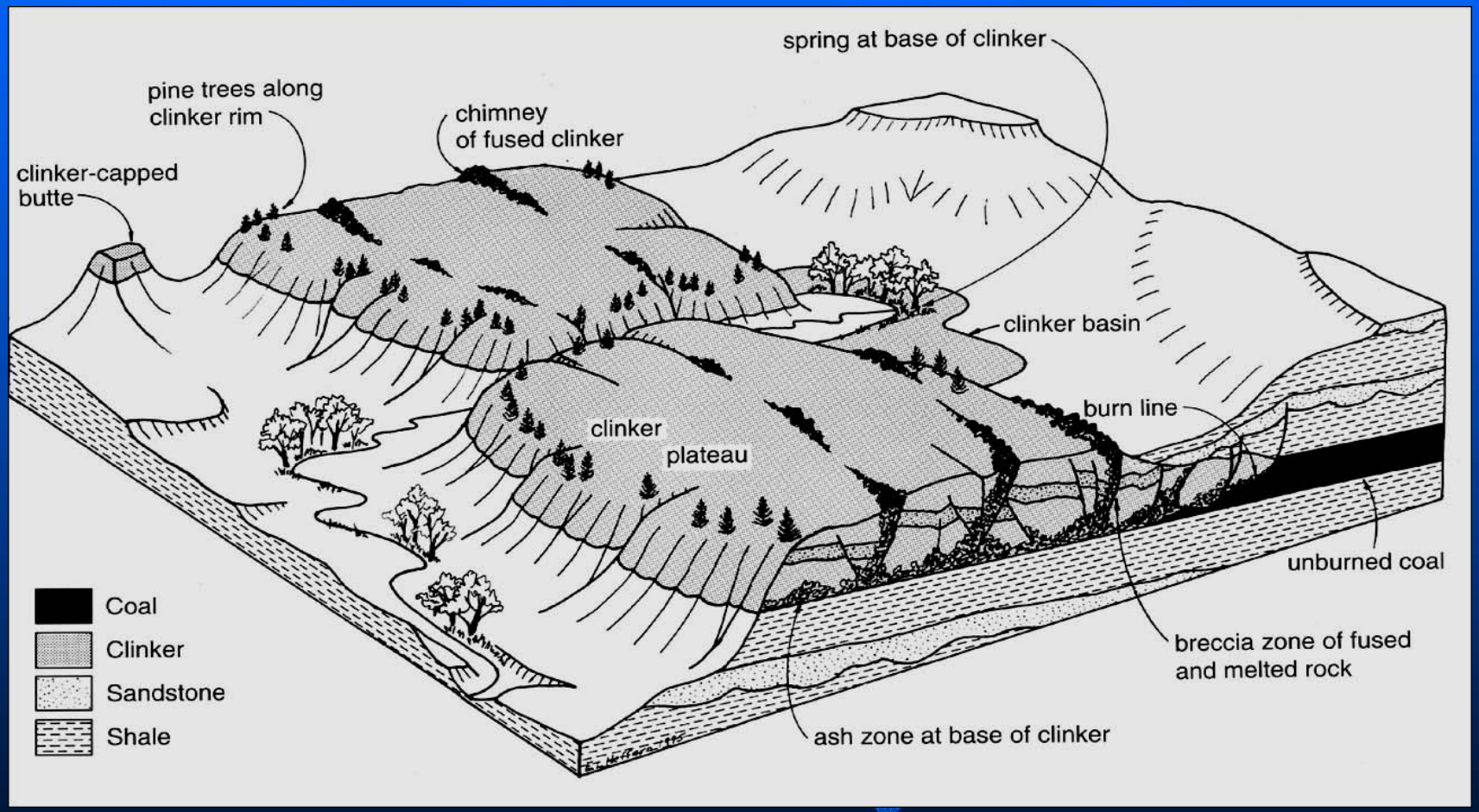
Clinker as Caprock



Clinker caps hills because:

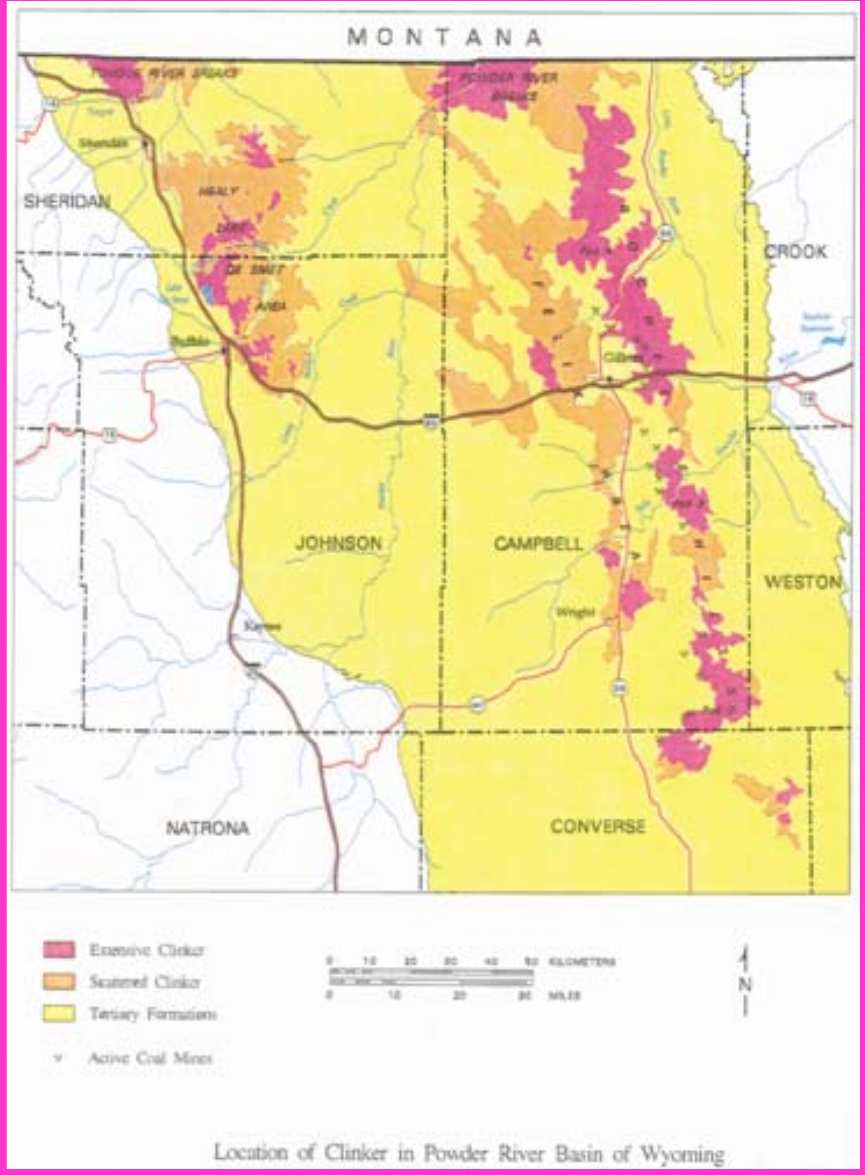
- It is harder than sedimentary rock and
- Its high permeability renders it less susceptible to runoff and erosion.

A Typical Clinker Landscape



The Extent of Clinker

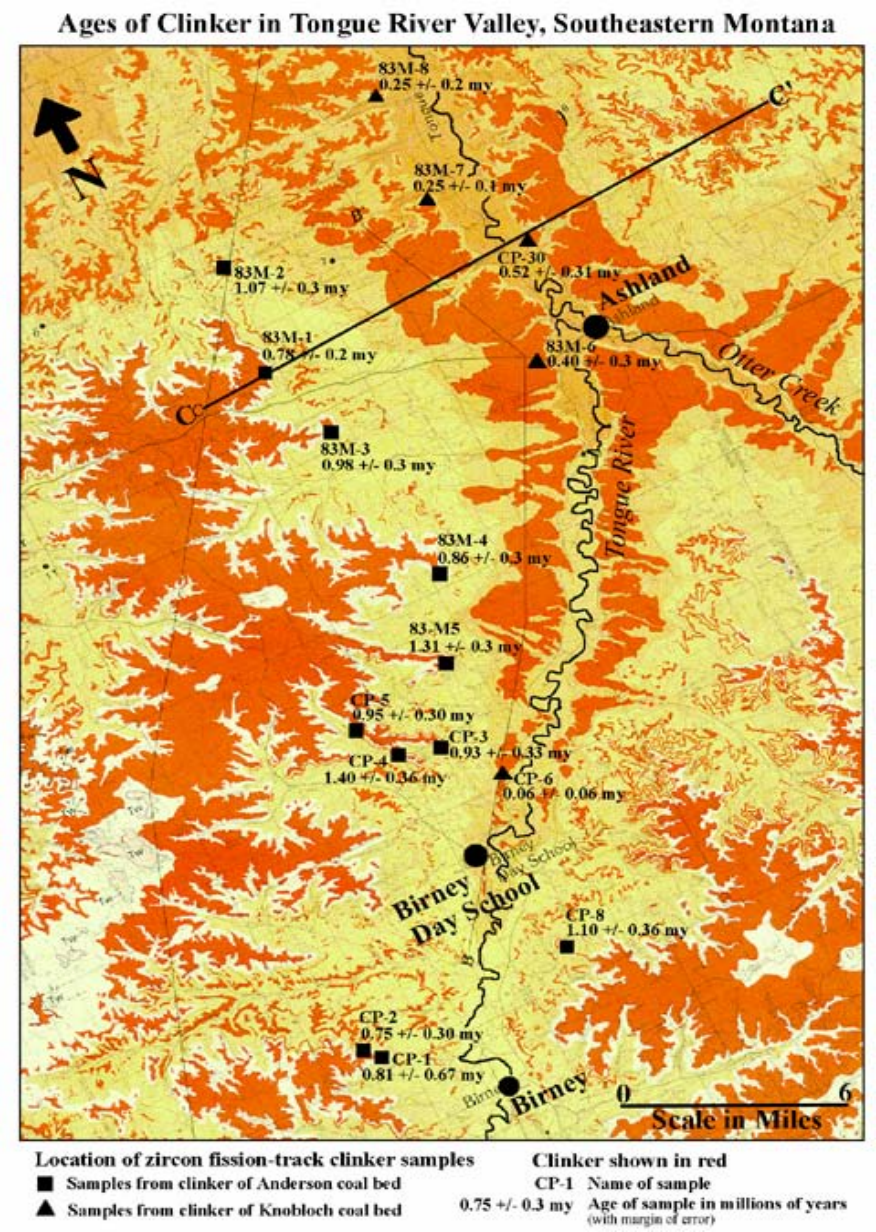
- Clinker covers 1,600 mi^2 in the PRB, specifically:
  - 1,100 mi^2 in Montana and
  - 500 mi^2 in Wyoming.
- Clinker *in place* represents the natural burning of 20 to 50 billion tons of coal in the past 3 million years.
- Much additional clinker and coal have eroded away.



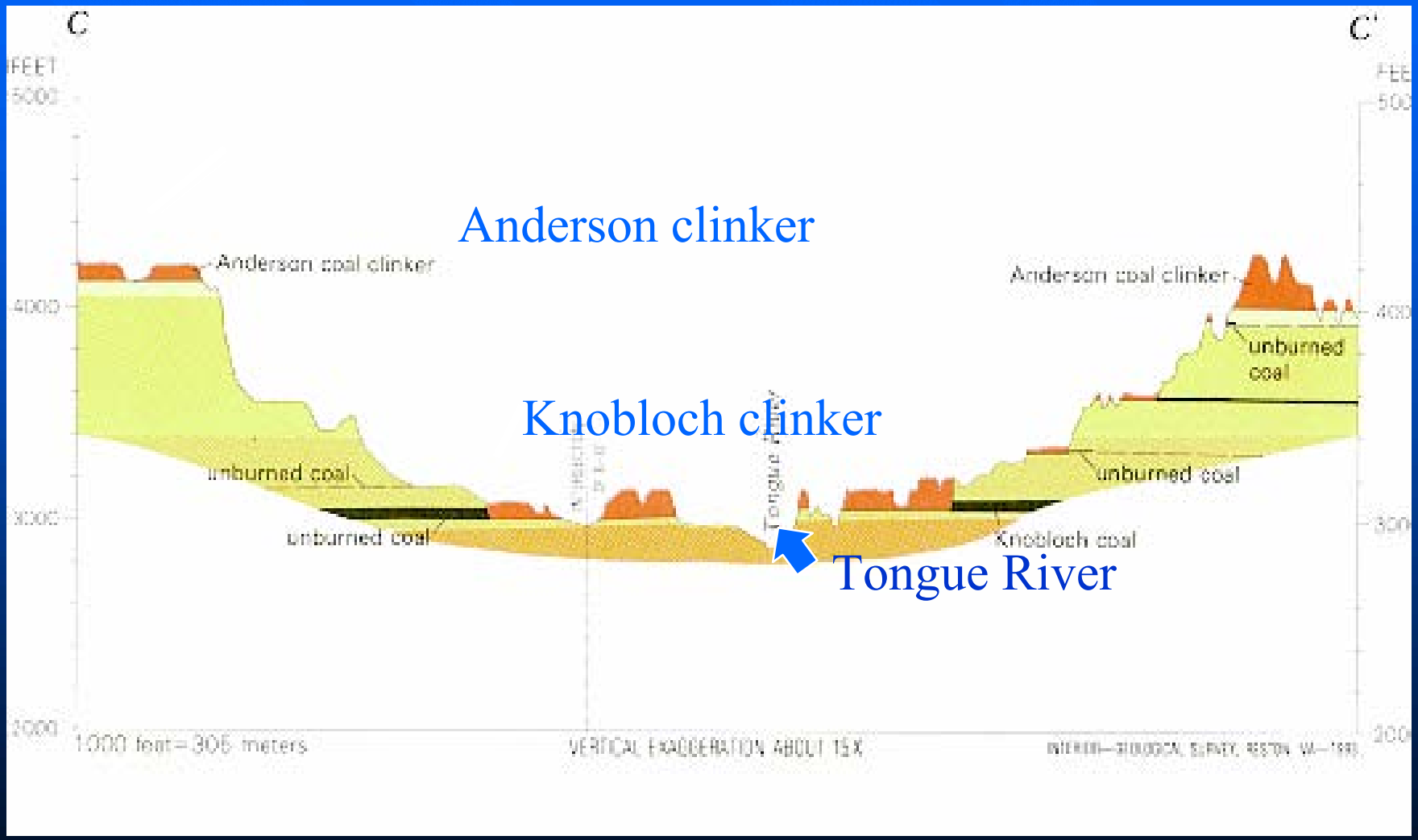
Location of Clinker in Powder River Basin of Wyoming

Tongue River Valley, Montana

- Anderson coal burned some 1.4 to 1.7 million years ago, leaving clinker (among other by-products) as its residue. A zircon fission track dates this recorded age of burning.
- Anderson coal clinker caps plateaus 1,000 feet above the current river level.
- Knobloch coal burned 0.5 and 0.6 million years ago at locations 300 feet above Tongue River north of Ashland and near the present river level north of Birney, respectively.
- Knobloch coal clinker forms the terrace above the current river level.



Cross-Section C-C' Across the Tongue River Valley



The Hydrogeology of Clinker

- Water storage and flow
- Water quality
- Effects on coal mining

Crazy Head Springs

Water Storage in Clinker

Clinker:

- Has high permeability and infiltration rates;
- Has transmissivities of 1,000 to 1,000,000 ft^2/d;
- Occurs as unconfined aquifers with storativities of 0.1 to 0.3; and
- Owing to fracture permeability, stores large amounts of rainfall and snowmelt, protecting them from evaporation.

Clinker-dominated watersheds have attenuated peak flows and, during periods of lower flow, discharge water gradually to streams.

Water Influences Ecology of Clinker Areas

- Well-drained soils and water at depth encourage Ponderosa pine to grow.

Clinker Basins

- Enclosed or hourglass-shaped depressions are formed by the episodic burning of coal.
- Lake DeSmet occupies a depression caused by the burning of 200-foot-thick Healy coal bed.
- Springs may occur at outlets of basins.

Lake DeSmet

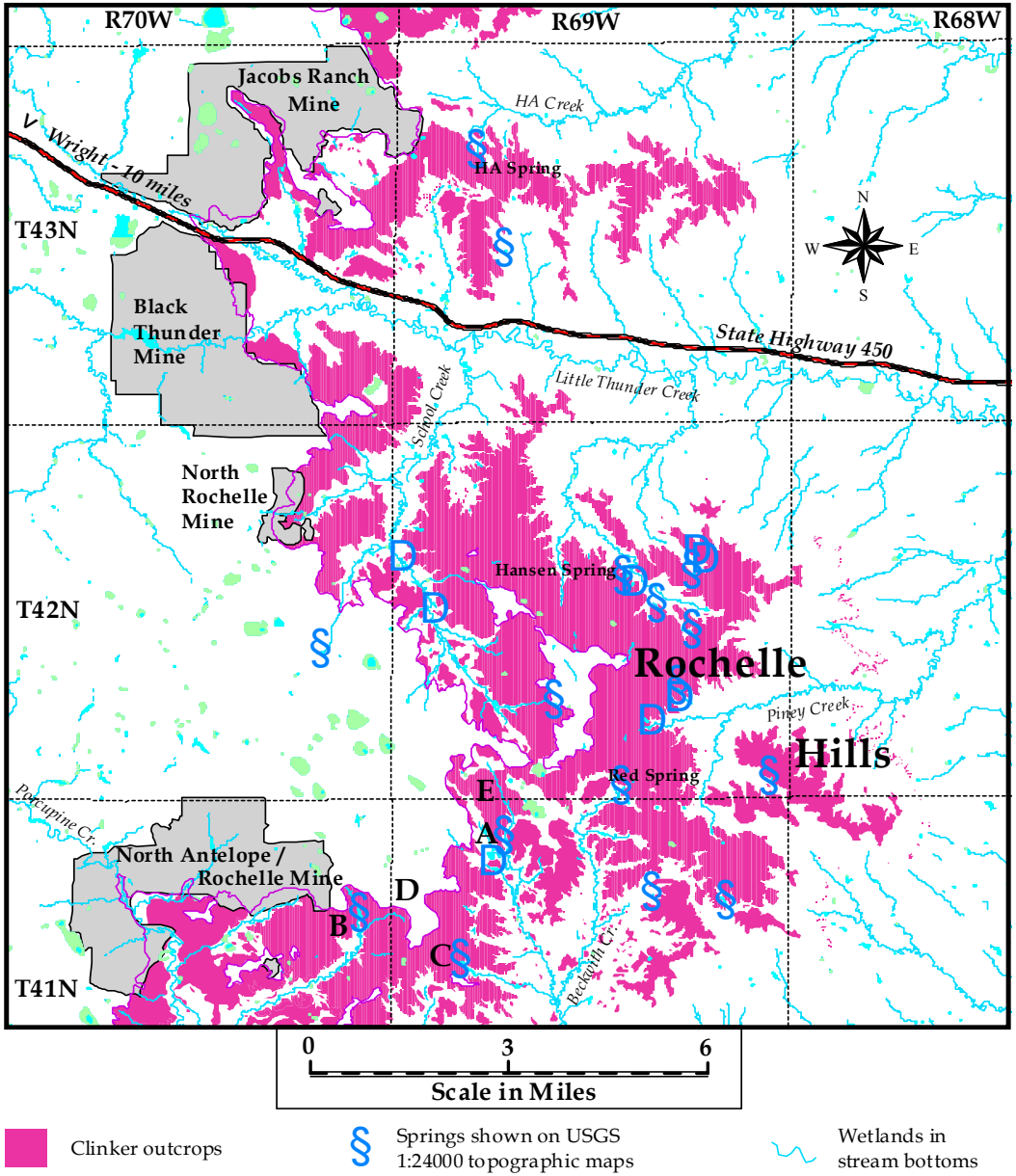
Recharge from Clinker

Clinker plateaus in Rochelle Hills, Wyoming, recharge ground water to coal, spoil, and sandstone layers downdip to the west:

Red Spring

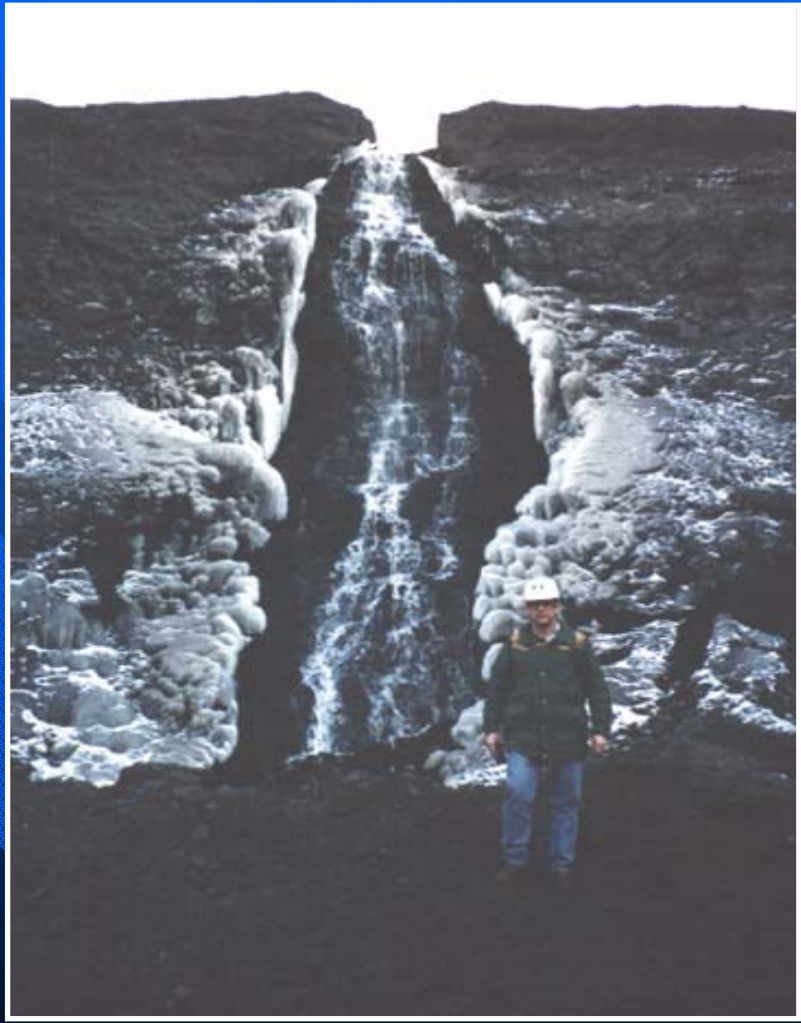
- Most springs in area emerge from the base of the clinker.
- Moyer Springs supports trout and has water rights that predate mining in the vicinity.

Wetlands and springs near clinker of the Wyodak coal bed, southern Rochelle Hills, Wyoming.

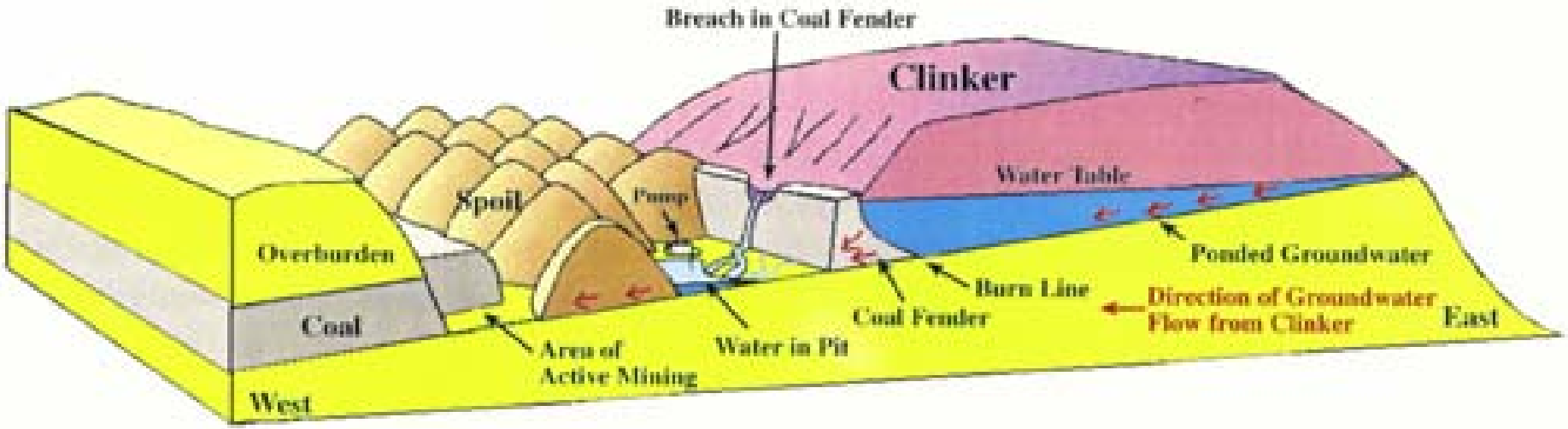


Effects on Coal Mines

- Saturated clinker delivers flows into mine pits.
- Water in pits may destabilize spoil piles.
- Some mines leave a fender of unmined, less permeable coal to serve as a dam against inflow.



Inflow from Clinker into a Mine Pit

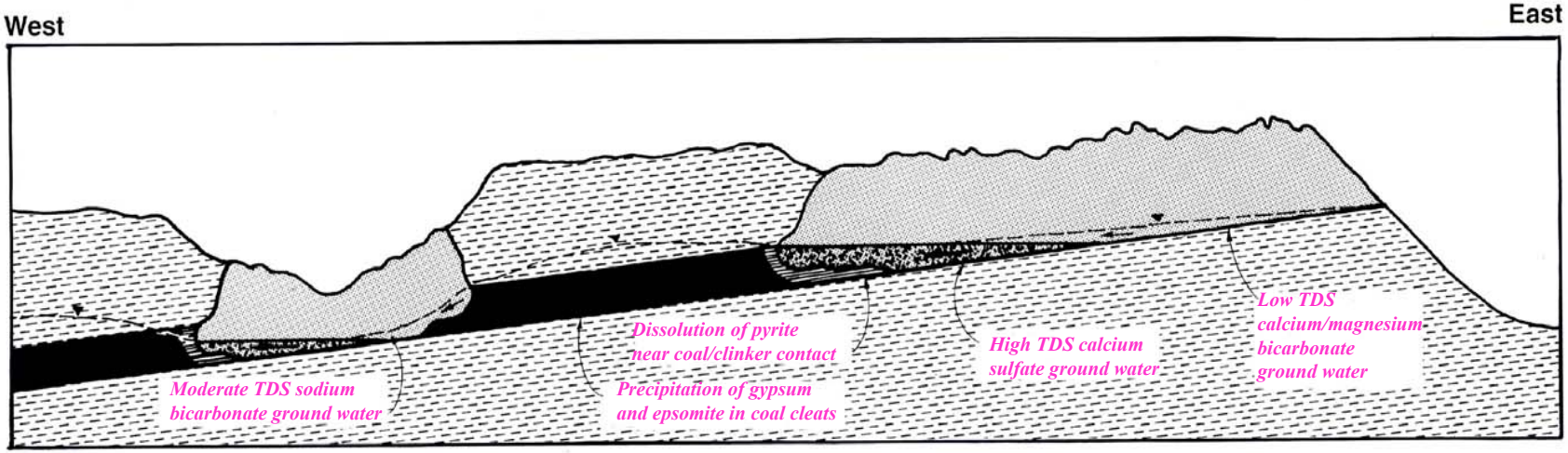


Schematic of Groundwater Inflow Into Mine Pit From Clinker Updip Rochelle Hills, Wyoming

The Quality of Water in Rochelle Hills Clinker Varies

- According to Wyoming coal-mine permit data, quality ranges from under 200 mg/L to over 10,000 mg/L total dissolved solids (TDS).
- Clinker water-quality is better in well-drained portions of Rochelle Hills where soluble ash has dissolved away.
- Quality is poorer (higher TDS and sulfate levels) where water is dammed against a contact with less permeable coal downdip.

The Quality of Water Changes Along Its Flowpath

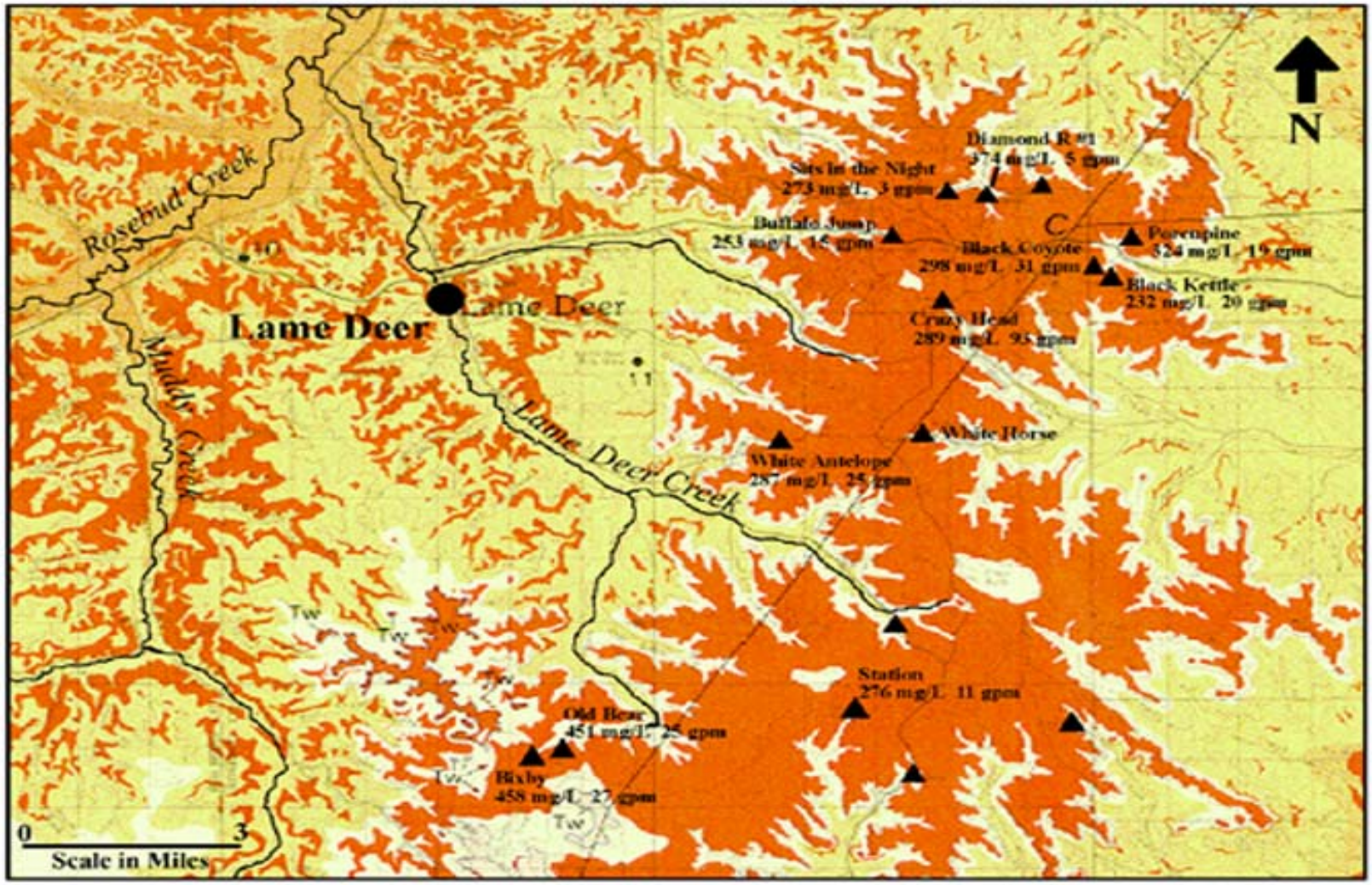


Rochelle Hills, Wyoming (eastern limb of the PRB)

Springs in Clinker in Lame Deer/Ashland Divide, Montana

- Flow of up to 93 gallons per minute;
- TDS content of 230 to 460 mg/L;
- Calcium bicarbonate type;
- Local source of drinking water;
- Headwaters of Lame Deer Creek; and
- Low TDS content of 614 mg/L in creek.

Springs Emerging from the Base of the Anderson Clinker
Lame Deer - Ashland Divide, Northern Cheyenne Reservation, Montana



Crazy Head Name of spring
289 mg/L Total dissolved solids in milligrams per liter
93 gpm Flow in gallons per minute

▲ **Clinker springs noted on USGS topo maps**
Clinker is shown in red
Map data from Heffern, Coates, Whiteman and Ellis, 1993, and Woessner and others, 1981

A Conceptual Model

Water quality in clinker is better (low TDS and sulfate levels) where:

- Vertical recharge from precipitation is greater, and there is little or no recharge from streams crossing clinker areas;
- There is little or no lateral recharge from unburned coal or overburden updip;
- Enough time has passed and ground-water flow is great enough to leach and carry away soluble components in ash from clinker;
- There is little or no ponding of water along burn lines; and
- The residence time for water in clinker is short.

Areas of Best Quality Water

Water quality in clinker is best where:

- There are extensive plateaus capped by older clinker in which burning has removed almost all coal and
- These areas are well-drained, lack lateral inflow from coal, and are nearly entirely recharged from precipitation.

The isotopic dating of clinker water would help refine ideas regarding where the highest quality water occurs.

Summary

- The natural burning of coal is an important part of PRB's ecosystem and of the evolution of its landscape.
- Clinker plays an important part in recharging springs, streams, and aquifers.
- Water quality in clinker varies with geologic setting; in some areas, clinker provides the best quality water in the region.

Two Articles and a Map, Published by the Wyoming Geological Association, Regarding Clinker

- Heffern, E. L. and Coates, D.A., 2000. Hydrogeology and Ecology of Clinker in the Powder River Basin, Wyoming and Montana, *in* Miller, R., ed., Coal Bed Methane and Tertiary Geology of the Powder River Basin: 1999 Wyoming Geological Association 50th Annual Field Conference Guidebook, p. 231-52.

- Coates, D.A. and Heffern, E.L., 2000. Origin and Geomorphology of Clinker in the Powder River Basin, Wyoming and Montana, *in* Miller, R., ed., Coal Bed Methane and Tertiary Geology of the Powder River Basin: 1999 Wyoming Geological Association 50th Annual Field Conference Guidebook, p. 211-29.

Wyoming Geological Association Clinker Map

The map published as plate 1 in the 50th Annual Field Conference Guidebook appears as appendix E to these proceedings. This map:

- Covers the eastern Powder River Basin from Buckskin mine north of Gillette to Antelope mine south of Wright;
- Shows 153 mi^2 of clinker in the map area;
- Shows the premining full-seam cropline of Wyodak coal;
- Shows areas mined through 1997;
- Was derived from public data , including U.S. Geological Survey geologic maps, Montana Department of Environmental Quality mine permits, and Bureau of Land Management color infrared photos; and
- Better defines areas of recharge to downdip coal.

SEEPS BELOW SEDIMENTATION PONDS: ASSESSMENT OF THE SIGNIFICANCE OF THEIR IMPACTS TO THE HYDROLOGIC BALANCE

John Cochran

Peabody Western Coal Company

Peabody Western Coal Company (PWCC), Black Mesa Mining Complex

- **Black Mesa and Kayenta mines:**
  - **Supply coal to Navajo Generating Station and Mohave Power Plant**
  - **Mine 12 million tons per year combined**

- **Located in Northeastern Arizona on Navajo and Hopi Reservations**

NPDES Permit No. AZ0022179

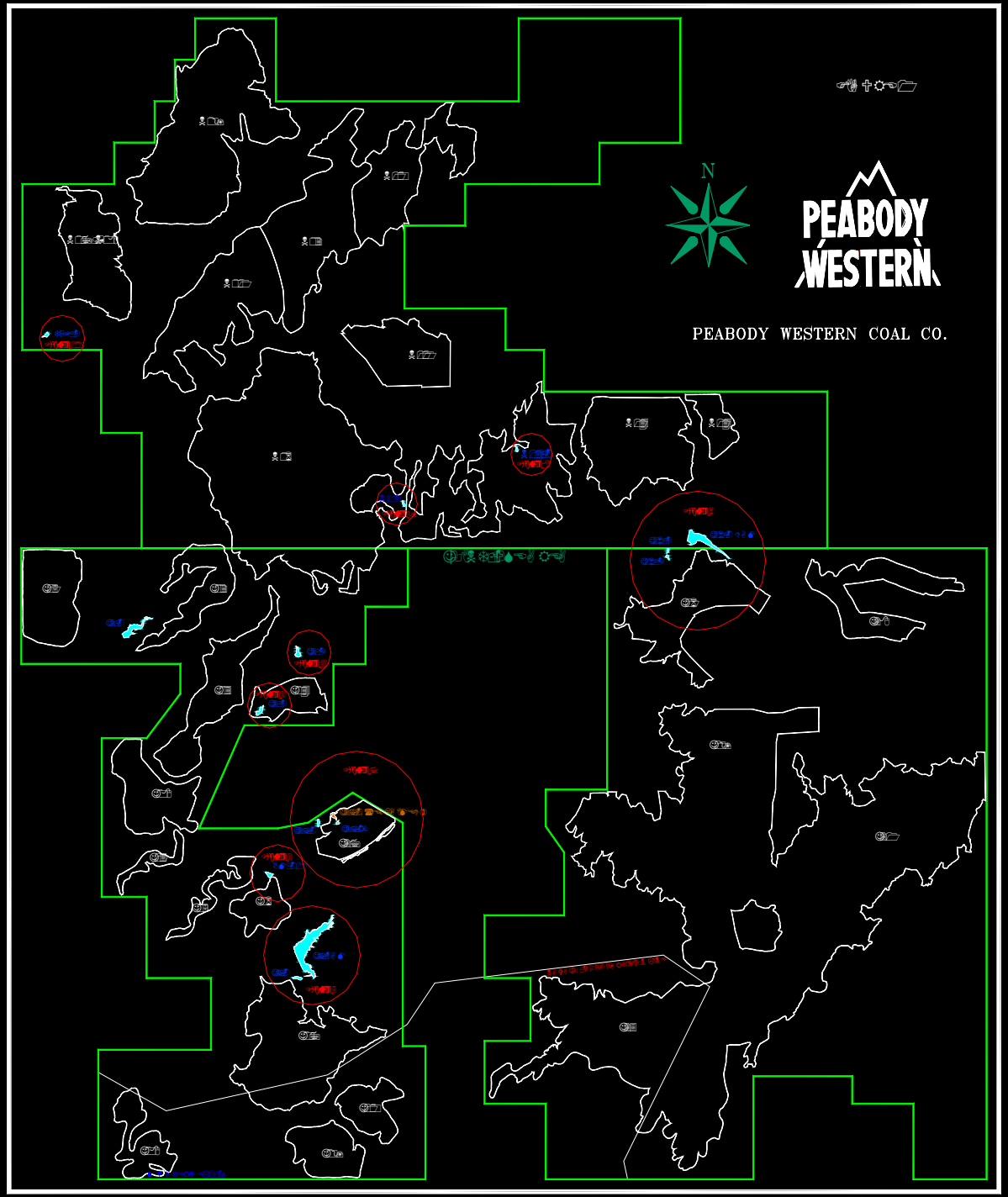
- First issued in 1984
- 100 permitted outfalls (sediment ponds)
- 40 CFR 434 effluent limitation guidelines
- Representative sampling allowed by inflow category
- Discharges are periodic, infrequent, relatively small, dependent on precipitation
- Monitoring and reporting of seeps below permitted outfalls included in a recent modification to the permit (March 1999)
- Permit expired in May of 2000, currently administratively extended until ?

NPDES Permit No. AZ0022179 Seep History

- **Annual compliance evaluation inspections (CEI) since 1985**
- **Seeps noted below several outfalls during 1987 and 1991, U.S. Environmental Protection Agency (EPA) requested monitoring and reporting (Fe, pH, other)**
- **1995 permit renewal included requirement to develop and implement comprehensive study of seeps, and to submit a report:**
  - **All outfalls included**
  - **Impoundment and seep water studied**
  - **Flow, pH, iron, nitrate, selenium**
  - **Geology, source of seeps**
- **Study completed by late fall 1995; report submitted to EPA, Region 9, by August 1996**
  - **Study found ten seeps below eight outfalls**
  - **Low pH below four outfalls, high iron at two outfalls, high selenium below two outfalls, high nitrate below two outfalls**
  - **Impoundment and seep water quality variable**
  - **Coal riders and carbonaceous shales nearby greatly influence seep water quality**
- **EPA considered incorporating seeps in the permit as point sources, problematic**
- **EPA requested that Peabody Western Coal Company (PWCC) develop a seepage management plan in lieu of permitting seeps as point sources**

Seepage Management Plan

- Submitted to EPA in October 1997; implementation required by April 1999 NPDES modification
- Plan components: monitoring and management
- Monitoring
  - Quarterly OSM pond inspections
  - Semi-annual seep inspections
  - Embankment, toe, downstream channel ~ 100 yards
  - Flow, iron, selenium, nitrate, pH, field parameters
- Management
  - Dewatering
  - Fencing and riprap
  - Vegetation enhancement
  - Additional options : spring boxes, coffer dams and pump-back, passive treatment, pond removal
- Annual Reporting
  - First submittal April 2000
  - Inspection summaries, data collected
  - Potential threats to livestock health
  - Assessment of impacts to the hydrologic balance
  - Recommended changes to the management plan


N
PEABODY
WESTERN
PEABODY WESTERN COAL CO.

Livestock Drinking Water Standards

Analyte	Standard	Units	Agency
Aluminum (TR)	5.0	mg/L	NAS
Arsenic (TR)	200.0	ug/L	AZDEQ
Boron (D)	5000.0	ug/L	AZDEQ
Cadmium (TR)	50.0	ug/L	AZDEQ
Chloride	1000.0	mg/L	WYO
Chromium (TR)	1000.0	ug/L	AZDEQ
Copper (TR)	500.0	ug/L	AZDEQ
Fluoride	2.0	mg/L	NAS
Lead (TR)	100.0	ug/L	AZDEQ
Mercury (TR)	10.0	ug/L	AZDEQ
Nitrate	100.0	mg/L	NAS
Nitrite	10.0	mg/L	NAS
PH	6.5 - 9.0	S.U.	AZDEQ
Selenium (TR)	50.0	ug/L	AZDEQ
TD S	5000.0	mg/L	WYO
Sulfate	3000.0	mg/L	WYO
Vanadium (TR)	100.0	ug/L	NAS
Zinc (TR)	25.0	mg/L	AZDEQ

AZDEQ - (ADEQ, 1994)
NAS - (NAS/NAE, 1972)
WYO - (Wyoming DEQ, 1980)
(D) - Dissolved
(TR) - Total Recoverable

1999 Livestock Drinking Water Exceedences - Seeps

Analyte	Standard	Sites	Sites	Freq.	Value Range
Aluminum (TR)	5 mg/L	3	BM-A1-S1	1/1	13.6
			J16-E-S1	1/1	17.2
			N6-F-S1	1/1	154.0
Lead (TR)	100 ug/L	7	BM-A1-S1*	1/1	< 200.0
			J27-A-S2*	1/1	< 200.0
			N14-B-S1*	1/1	< 200.0
			N14-B-S2*	1/1	< 200.0
			J16-A-S1*	1/2	< 200.0
			J16-E-S1*	1/1	< 400.0
			N6-F-S1*	1/1	< 200.0
Nitrate (as N)	100 mg/L	1	BM-A1-S1	1/2	111.0
Field pH	6.5-9.0	4	BM-A1-S1	2/2	4.72 - 5.21
			N14-B-S1	1/4	6.42
			J16-E-S1	1/1	4.04
			N6-F-S1	2/2	4.10 - 4.28
Selenium (TR)	50 ug/L	3	J7-DAM-S1	1/1	64.0
			J7-DAM-S3	1/1	60.0
			J16-E-S1	1/1	160.0
TDS	5,000 mg/l	3	J7-A-S1	1/1	5940.0
			J16-E-S1	1/1	10800.0
			N6-F-S1	1/1	7270.0
Sulfate	3,000 mg/L	3	J7-A-S1	1/1	3030.0
			J16-E-S1	1/1	7720.0
			N6-F-S1	1/1	5200.0

TR - Total Recoverable

* - Sample below method detection limit (MDL) and MDL greater than standard

Seeps Unsuitable for Livestock

- **Seeps below outfalls BM-A1, J7-DAM, J16-E, and N6-F were deemed potential threats to livestock health**

- **BM-A1 Seep**
  - **Exceeded pH, Al (tr), nitrate**
  - **Seep flows from November through April; low flow < 0.5 gallons per minute, dries up when ET (*spell out please*) kicks on**

- **J7-DAM Seeps**
  - **two of three seeps measured exceeded Se**
  - **Confluence of all seeps < 12 µg/L**

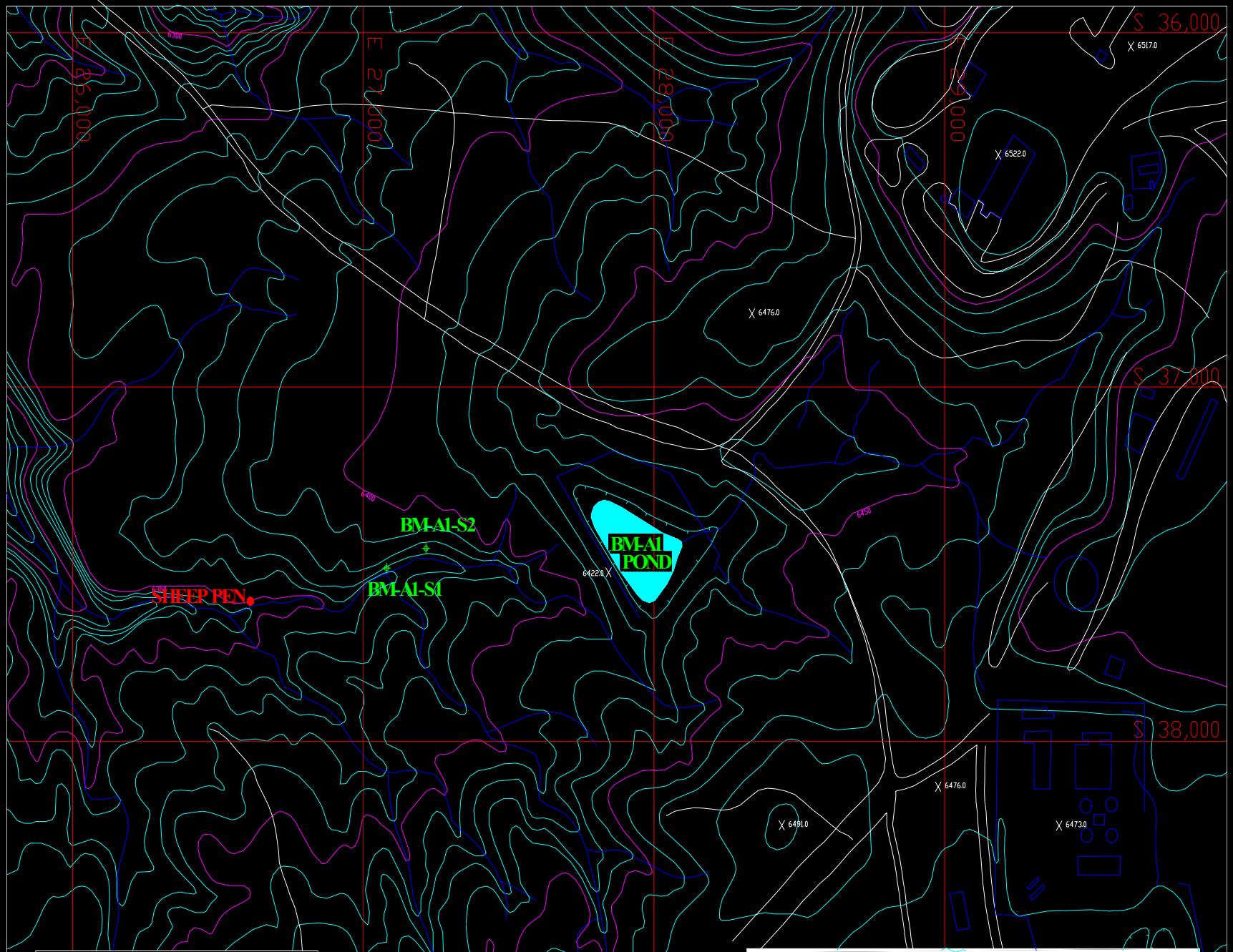
- **J16-E Seep**
  - **Exceedences of pH, Se (tr), Al (tr), total dissolved solids (TDS), sulfate**
  - **Completely contained by adjacent, downgradient Pond J16-D**

- **N6-F Seep**
  - **Exceedences of pH, Al (tr), TDS, Sulfate**
  - **Small pools only, limited reach (250 yards)**

- **Further assessments of the impacts of seeps on the hydrologic balance focused on seeps below these four outfalls**

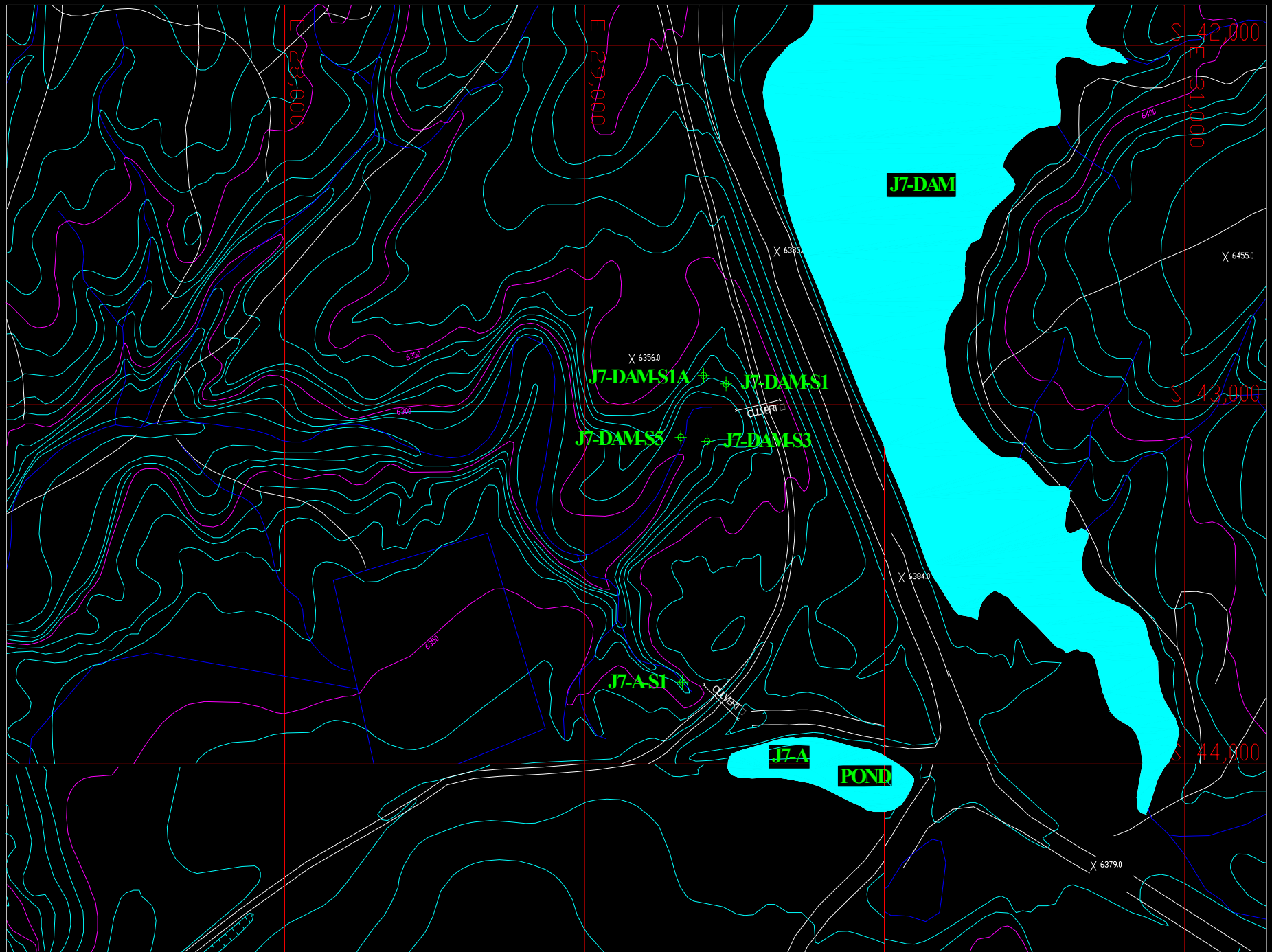
Hydrologic Monitoring Program

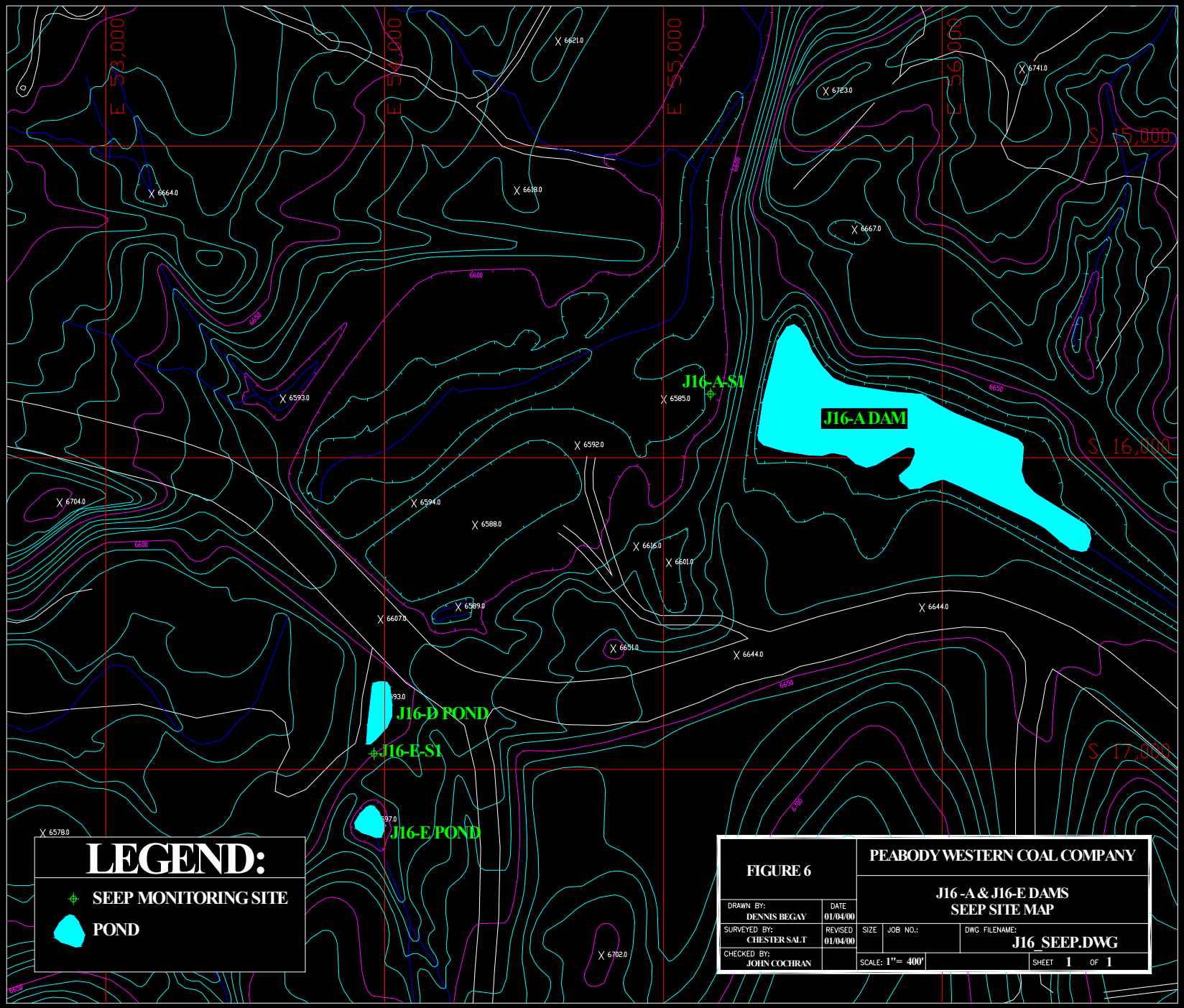
- **OSM-approved hydrologic monitoring program operated on Black Mesa since 1980**
- **Shallow (< 70 feet total depth) monitoring wells constructed in alluvium (unconsolidated stream-laid deposits) along the main washes and tributaries of Black Mesa**
- **Stream monitoring sites located on the main washes and tributaries of Black Mesa**
- **Several alluvial wells and stream monitoring sites are located either upgradient or downgradient of the four outfalls**
- **Water-quality data have been collected from these sites since at least 1986,; these data provide a basis for evaluating impacts to the prevailing hydrologic balance that may result from seeps below the four outfalls**

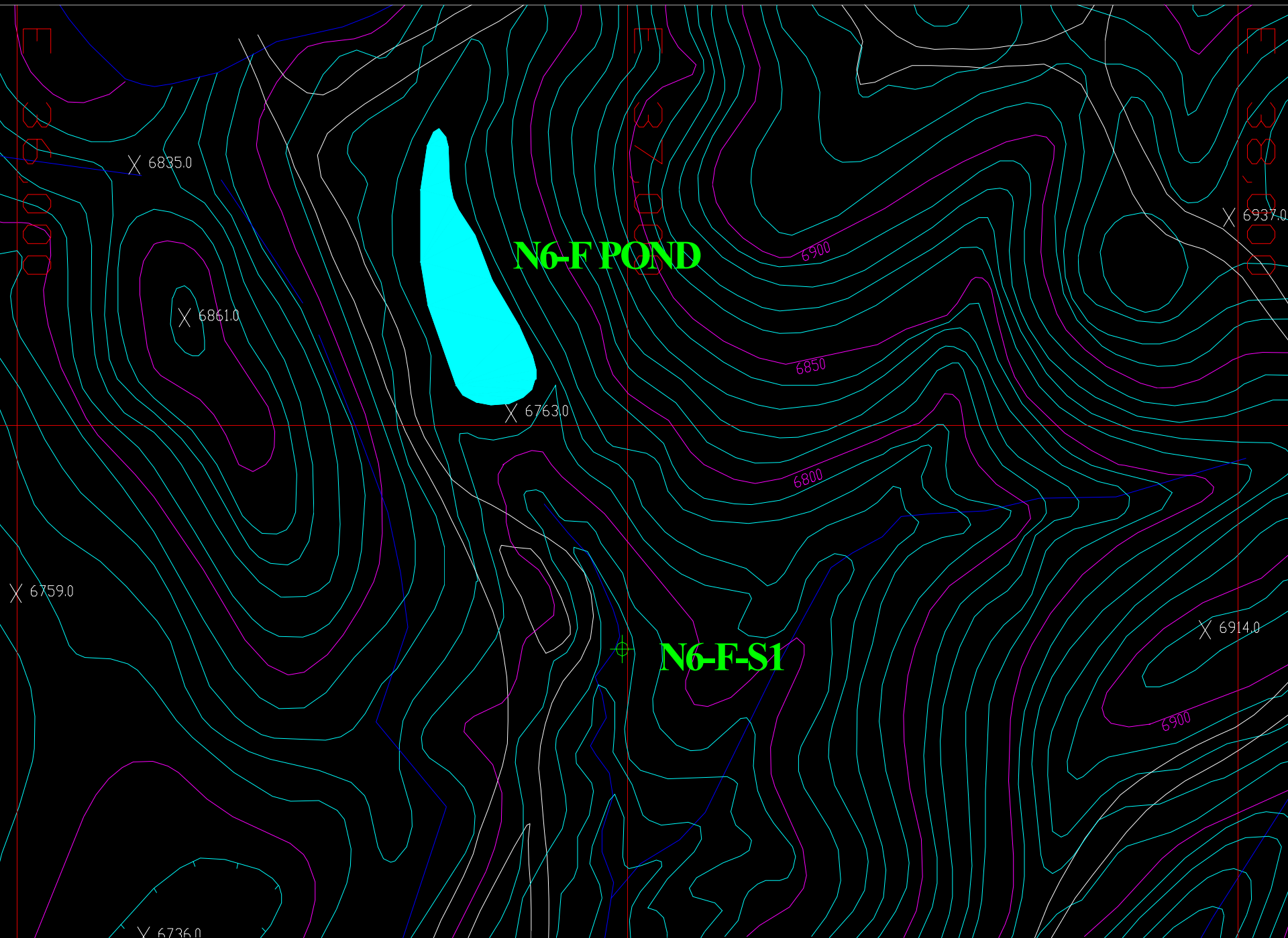


LEGEND

PEABODY WESTERN COAL COMPANY


J7-DAM
J7-DAM-S1A
J7-DAM-S1
J7-DAM-S5
J7-DAM-S3
J7-A-S1
J7-A
POND
CULVERT
CULVERT
6356.0
6385
6455.0
6384.0
6379.0
6350
6400
6450
S 42,000
S 43,000
S 44,000


E 53,000
E 54,000
E 55,000
E 56,000
S 15,000
S 16,000
S 17,000
6621.0
6741.0
6723.0
6664.0
6618.0
6667.0
6600
6650
6593.0
6585.0
J16-A-S1
J16-A DAM
6592.0
6704.0
6594.0
6588.0
6616.0
6601.0
6589.0
6607.0
6644.0
6651.0
6644.0
6593.0
J16-D POND
J16-E-S1
6597.0
J16-E POND
6578.0
6702.0
6700
LEGEND:
SEEP MONITORING SITE
POND
FIGURE 6
PEABODY WESTERN COAL COMPANY
J16 -A & J16-E DAMS
SEEP SITE MAP
DRAWN BY: DENNIS BEGAY
DATE 01/04/00
SURVEYED BY: CHESTER SALT
REVISED 01/04/00
CHECKED BY: JOHN COCHRAN
SIZE
JOB NO.:
DWG FILENAME: J16_SEEP.DWG
SCALE: 1"= 400'
SHEET 1 OF 1


N6-F POND
N6-F-S1
6835.0
6861.0
6763.0
6759.0
6937.0
6914.0
6736.0
6900
6850
6800
6900

Analytical Methods

- **Statistics, trend tests, and time-series plots were run for each parameter that exceeded livestock drinking-water standards**

- **Basic statistics of waterquality records at each well and stream site were reviewed, including means, maximums, and ranges**

- **Trend analyses of water quality data: statistical and graphical techniques**

  - **Routinely used by PWCC for annual reports to OSM**
  - **Can indicate changes in water-quality impacts owing to mining-related activities**

- **Mann-Kendall trend test**

- **Sen Slope estimator**

- **Lowess curve fitting technique**

Impacts Below Outfall BM-A1

- **Water quality data from alluvial wells 93 and 95 and from streamsite 26 analyzed**
- **Maximum values of Al (tr) at all three sites have been much higher than at BM-A1-S1**
  - **Al (tr) at site 26 averages over 350 mg/L owing to high sediment loads and the total recoverable digestion process**
- **All three sites typically show pH values greater than 7**
- **Nitrate at all three sites has never exceeded 15 mg/L**
- **No positive trends detected for Al (tr) at any of the three downgradient sites**
- **No positive trends were detected for field pH; negative trends were detected for lab pH**
  - **No lab pH values have been lower than 7**
- **No trends for nitrate were determined for the two alluvial wells**
- **A positive trend for nitrate was determined at ite 26**
  - **Highest value 14.9 mg/L in 1992**
  - **No values > 8 mg/lLsince 1992; Lowess plot indicates downward trend for nitrate at 26 since 1992**
- **Trend tests indicate no impacts from the seep have occurred downgradient**
- **Al (tr) is strongly correlated with suspended sediment, common in flash floods, often found in saturated unconsolidated stream-laid deposits**
- **The low pH at the seep is localized; seep water buffered by alkaline channel materials within 1/4 mile (Sheep Pen)**
- **Impacts are localized**

Impacts below Outfall J7-DAM

- **Water-quality data from alluvial well 29 and streamsite 155 analyzed**
- **Selenium levels at well 29 have not exceeded 20 µg/L and have not exceeded 14 µg/L at site 155**
- **No positive trends for selenium were determined at either well 29 or site 155**
- **Trend tests indicate no impacts from the seeps have occurred downgradient**
- **Sampling at J7-DAM-S5 (seep flow coalesced) indicate selenium concentrations lower to less than 12 µg/L within 270 feet downgradient of the seeps**
- **Fencing in 1999 around the seeps below J7-DAM to prevent livestock access (just below J7-DAM-S5)**
- **Planting of willows and cottonwoods during 1999 in the vicinity of seeps**
- **Impacts are localized**

Impacts below Outfall J16-E

- **Water quality data from alluvial wells 88 and 89R and streamsite 35 were evaluated**
- **Al (tr) values at all three sites are similar to those in the two wells and streamsite located below BM-A1**
- **Selenium values measured at all three sites have not exceeded 10 µg/L**
- **Values for pH at all three sites have not been below 6.5 (standard lower limit)**
- **Sulfate and TDS at streamsite 35 have averaged very low concentrations (both less than 500 mg/L)**
- **TDS and sulfate at well 88 averages greater than livestock standards, and at well 89R, lower than the standards**
- **No positive trends for selenium, Al (tr), or sulfate were detected at any of the three sites**
- **Negative trends for pH were detected at both wells, but the mean values at both wells are greater than 7.2**
- **A positive trend for TDS was detected at only well 89R, but no measurement has exceeded the livestock standard of 5,000 mg/L**
- **Trend tests indicate no impacts have occurred downgradient**
- **Seep water from J16-E-S1 flows to an adjacent sediment pond,; no potential to discharge downgradient**
- **Fencing of both pond areas including the seep face was completed in the spring of 2000 to prevent livestock access**
- **Impacts are localized**

Impacts below Outfall N6-F

- **Trend tests performed for pH and Al (tr) at sites below BM-A1 show no impacts have occurred**

- **Seepage below outfall N6-F occurs as very shallow, disconnected pools in a limited reach of channel about 250 feet in length; no pooled or flowing water was noted further downstream**

- **No change in length of the wet portion of the channel or the amount of pooled water was noted**

- **Recent observations (May 2000 quarterly inspections) of the reach below outfall N6-F show all pools have completely dried up**

- **Impacts are localized**

Constituent Concentrations and Flow Rates Used for Mixing Analyses

	Contributing Sources			Receiving Sources		
Chemical Constituent	Site ID	Value (mg/L)	Flow (cfs)	Site ID	Value (mglL)	Flow (cfs)
Nitrate	BM-A1-S2	111.0	0.00089	SW26	2.68	3.75
Sulfate	J16-E-S1	7720.0	0.00223	SW155	144.6	5.73
TDS	J16-E-S1	10800.0	0.00223	SW155	342.6	5.73
Se (TR)	J16-E-S1	0.160	0.00223	SW35	0.0036	9.53
Al (TR)	N6-F-S1	154.0	0.00223 (1)	SW35	274.0	9.53

(mgLl) - milligrams per liter
(cfs) - cubic feet per second
(TR) - total recoverable
(1) - No flow from N6-F-S1 (pool); used flow rate measured at J16-E-S1

Mixing Calculations and Results

	Contributing Sources		Receiving Sources		
Chemical Constituent	Site ID	Chemical Load	Site ID	Chemical Load	Resultant Concentration (mg/L)
Nitrate	BM-A1-S2	0.0002667	SW26	0.027135	2.71
Sulfate	J16-E-S1	0.0464821	SW155	2.237106	147.68
TDS	J16-E-S1	0.0650268	SW155	5.300365	346.99
Se (TR)	J16-E-S1	9.6336 E-07	SW35	9.2632 E-05	0.0036
Al (TR)	N6-F-S1	9.2723 E-05	SW35	7.050294	274.25

(mg/L)- milligrams per liter
(TR) - total recoverable

Conclusions

- **Seeps below four of the 13 outfalls inspected during 1999 show notable exceedences of livestock drinking-water standards and exhibit water quality that may be a threat to livestock health**

- **No significant impacts from the seeps have been detected at shallow alluvial wells or stream-monitoring sites downgradient of the four outfalls**

- **Any impacts to the hydrologic balance are local and can be minimized by implementing management plans**

- **Monitoring conducted in 1999 and during the 1995 seep study indicate the following key points:**
  - **The pH of water controls solubility and transport of metals**
  - **Channel bed and bank materials in the vicinity of seeps are alkaline and provide buffering effect on low pH water**
  - **Some constituents are as high or higher in the natural system**
  - **Seep flow rates and associated chemical loads are relatively low in comparison with flow rates and loads historically documented in stream flows**

Management Plan Modifications for 2000

- **The April 2000 submittal reiterates plans implemented in 1999**
  - **Fencing, riprap, and vegetation enhancement below outfall J7-DAM**
  - **Vegetation enhancement above outfall BM-A1**

- **For 2000, PWCC proposes:**
  - **To fence the seep area at outfall J16-E was proposed and was completed in the spring of 2000**
  - **To rock riprap 250 feet of channel below outfall N6-F to prevent livestock access**
  - **To install a passive treatment system below outfall BM-A1**
    - **Shallow trenches dug across short valley width at two locations**
    - **Geofilter bags containing crushed limestone put in, along with backfill with larger sized limestone upstream and downstream of both trenches**

Adequacy and Utility of Premining Water-Resource Data

John W. Kern,
Spectrum Consulting Services, Inc.

David Bickel,
North Dakota Public Service Commission

Adequacy Is Determined by Objectives: What Is Needed?

- Webster's New World Dictionary defines "ad·e·quate *adj.*" as:

  1. enough or good enough for what is required or needed; sufficient; suitable

  2. barely satisfactory; acceptable but not remarkable

Mining and Reclamation Dynamic:

- Premining condition (this is the baseline condition)
- Mining phase (intervention is occurring)
- Postmining phase (reclamation [*not restoration*] is complete)
- These are three distinct phases; postmining conditions do not represent a return to the premining state (dynamic is A-B-C, not A-B-A)

Monitoring Data Must Be Sufficient To:

- Develop a fact-based conceptual model of ground water and surface-water systems
- Describe the ground water and surface-water systems
- Demonstrate satisfactory protection of resources during mining
- Demonstrate adequate reclamation after the intervention of mining

Statistical Adequacy:

- “Adequate data” are often defined as the minimum size a sample can be and still support statistical comparisons of premining to postmining conditions
- There may be some guilt by association with Surface Mining Control and Reclamation Act (SMCRA) requirements to demonstrate successful revegetation
- SMCRA does not include specific statistical requirements for water-resource data

Statistical Adequacy--continued:

- Baseline data must be adequate to reasonably document, at the time of final bond release, that reclamation has been successful and that water resources are protected
- The ability to document successful reclamation is necessary for both industry and the regulatory authorities

Adequacy v. Utility:

- Baseline sampling designs should really be treated more like long-term monitoring plans
- Rather than measuring reclamation success on the basis of “adequate data,” it may be more appropriate to measure on the basis of useful data

Monitoring for Multiple Objectives:

- Characterize, in basic terms, the water-bearing units
- Sample flow systems, including hydrostratigraphic units occurring below all mined areas, upslope and downslope of the area of disturbance
- Sample outside the probable radius of influence to document maximum area of effects
- Sample within the probable radius of influence (positioned to survive mining) to determine the onset, patterns, and magnitude of effect

Monitoring for Multiple Objectives--continued:

- Collect samples between mined areas and sensitive or at-risk features (as, for example, water supplies, alluvial valley floors, and critical fish/wildlife habitat) in order to predict impacts and/or assess the probable contribution of mining to observed effects
- Acquire basic hydraulic information, upon which the engineering designs for pit dewatering and mine-water management can be based
- Meet National Pollutant Discharge Elimination System and storm-water monitoring requirements

Final Bond Release:

- Unlike a determination of having met revegetation requirements, the final bond-release decision is not based on prespecified criteria
- Because specific hydrologic criteria have not been spelled out, sample/data adequacy cannot be prespecified
- The adequacy of any data will only be known when “adequate reclamation is or is not demonstrated”

Data Utility:

- The prudent approach seems to be to generate data and analyses that maximize utility
- Bond-release decisions are likely to be based upon weight-of-evidence type arguments rather than statistical tests of hypothesis
- Strong data and defensible analyses should serve as insurance against contentions over final bond release

Data Utility--continued:

- Weight-of-evidence decisions are based upon:
  - Literature reviews and expert opinion
  - Modeling
    - Ground water
    - Surface
    - Fate and transport
  - Basic data from the site under consideration
  - Consideration of one or more statistical analysis that provides supporting evidence (unlike “regulatory decisions,” which can be based on a single statistical test)
- As their name implies, such decisions favor evidence in proportion as it weighs heavily
- Arguments founded primarily on basic data tend themselves to carry more weight in the most contentious situations

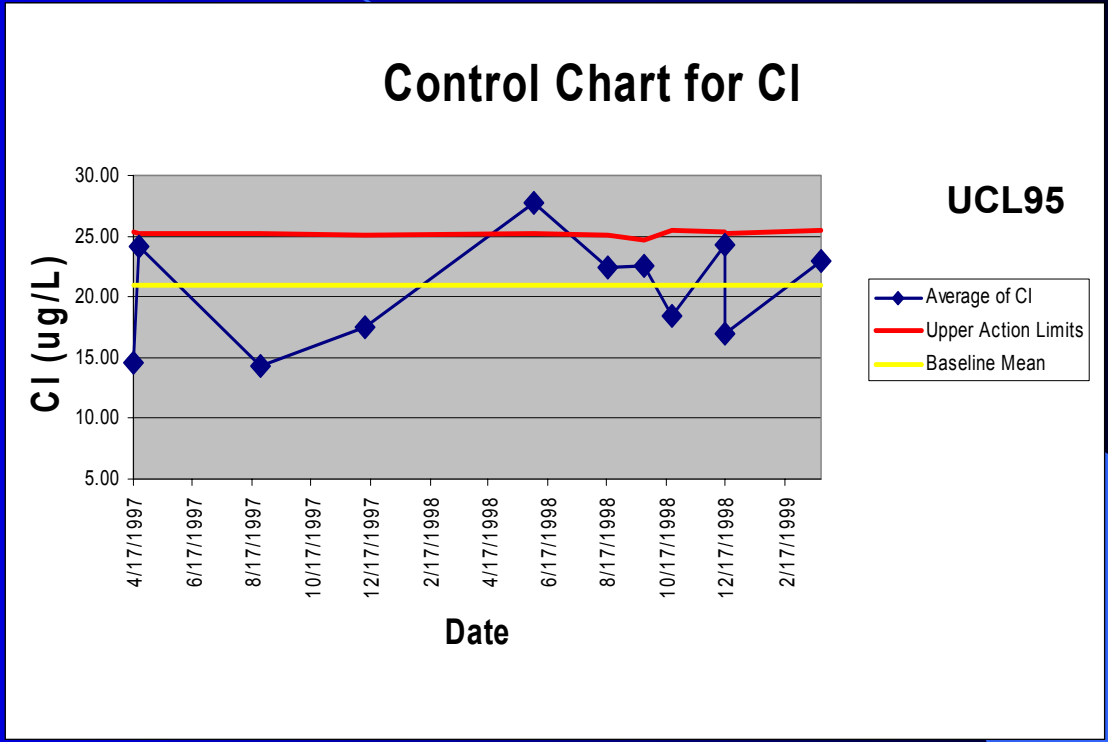
Statistical Analyses Should Be Used to Increase the Utility of Monitoring Data:

- Geostatistics demonstrate the precision of contour maps:
  - Graphical display is essential
  - Demonstration of good precision provides defensibility
- Control charts quantify when and where mining effects have occurred
- Arguments are strengthened with references such as:
  - Paired watersheds, which compare Before/After Control-Impact designs
  - Analyses that incorporate nonmining factors as, for example, climate or quantifiable human impacts

Control Chart for Water-Quality Parameters

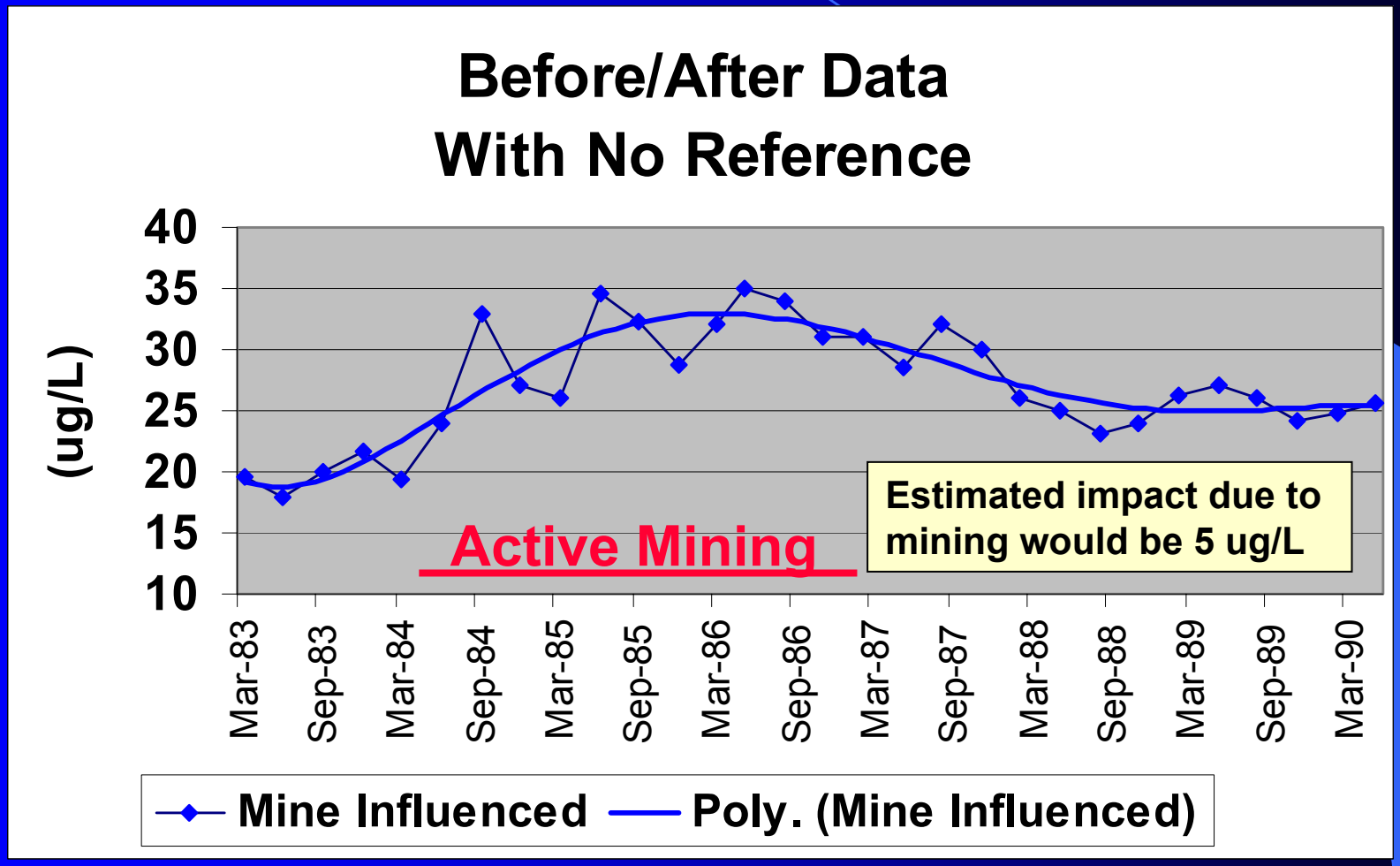
Control limits are posited on the basis of natural variations in baseline data

Cl concentration was outside control limits on one occasion, but continued monitoring indicated that water quality had returned to baseline conditions

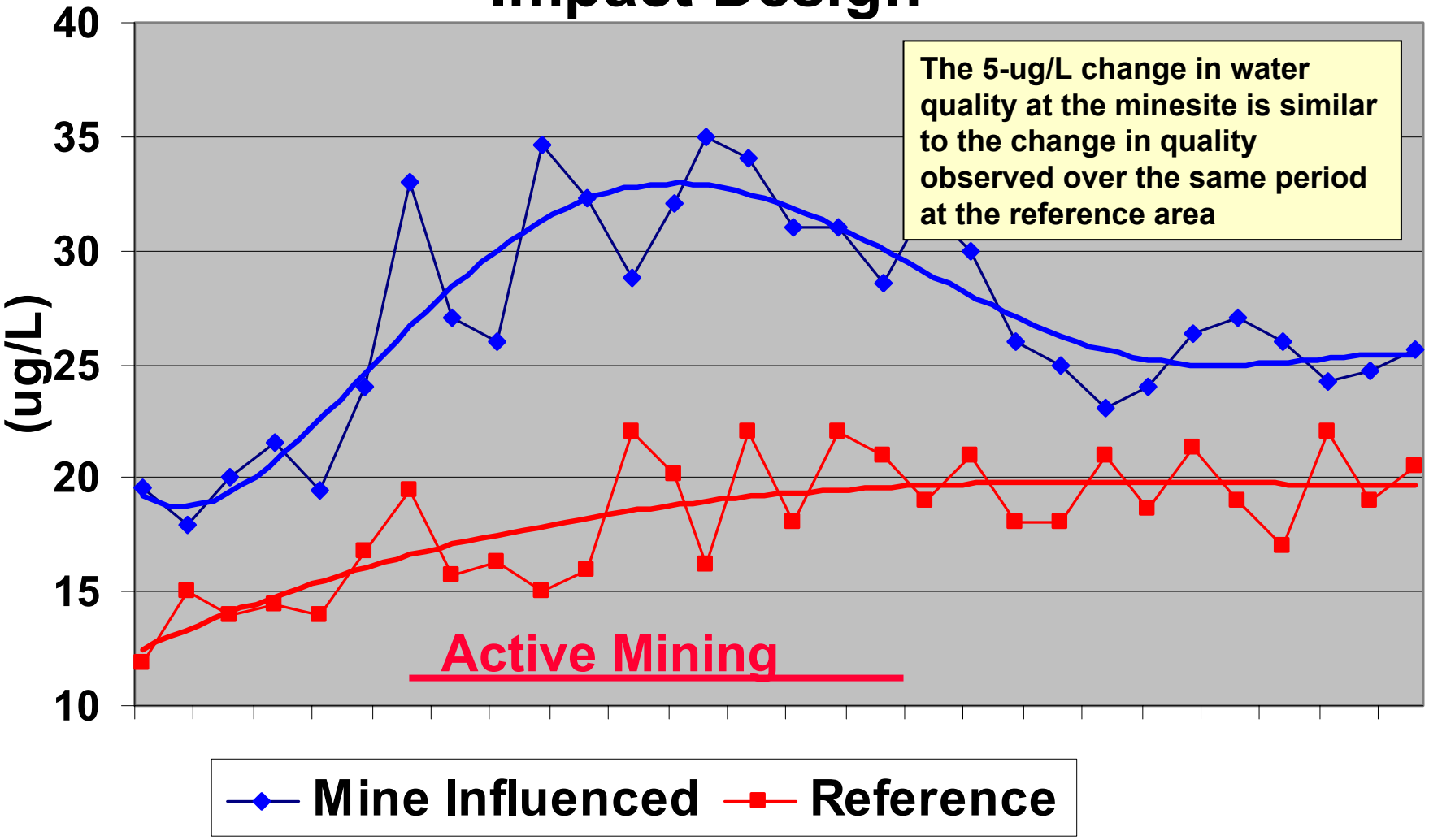


Changes in average, variability, and trends are measured relative to the natural variation observed in baseline data

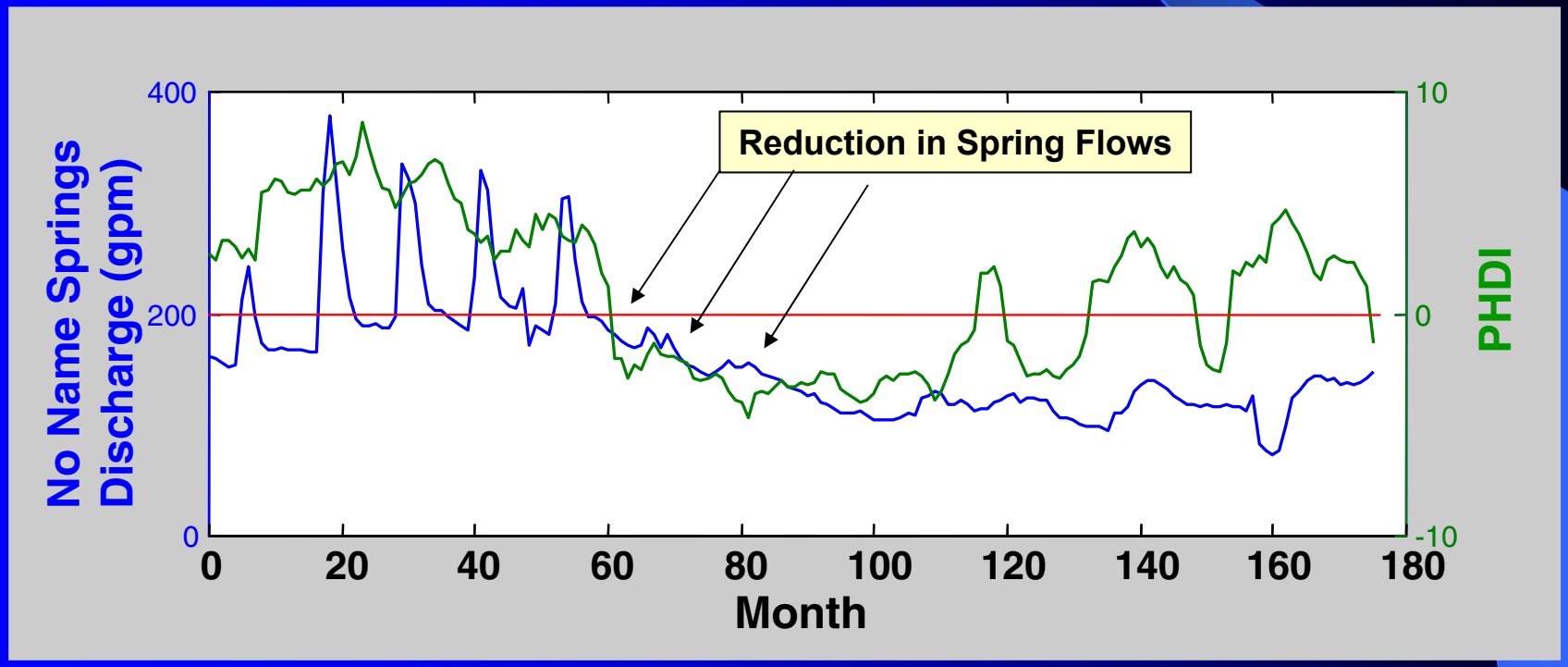
Before/After Control-Impact Designs:



Before/After Control-Impact Design



Changes in Hydrologic Function May Be Associated With Long-Term Climate Patterns:



Changes in Hydrologic Function May Be Associated With Long-Term Climate Patterns--continued:

- The control chart provides a tool for environmental management that is particularly useful during the life of a mine
- Incorporating reference-area data in the before/after control-impact design provides a means to evaluate potential mining effects relative to natural trends that may not be associated with mining
- Other covariates, such as climate indices, discharge rates, or land-use practices, may explain changes in hydrologic function

Data-Utility Summary:

- The greatest monitoring resources should be data most likely to support arguments related to contentious issues
- Monitoring the primary resource may not be adequate if mining effects are coincident with other decades-long trends
- Resources should be allocated to the collection of covariate data regarding the most contentious issues, among them:
  - paired watersheds
  - discharge, mine-pit pumping rates, and climate indices
- Utility is enhanced with defensible statistical methods

Removing Sedimentation Ponds in North Dakota

Larry L. Larson, Environmental Engineer
North Dakota Public Service Commission

Surface Mining Control and Reclamation Act Program Goals

- Mine coal with minimum disturbance
- Protect the environment during mining
- Reclaim the disturbance contemporaneously
- Return disturbed lands to a productivity equal to or better than their productivity before mining

Sedimentation ponds protect the environment during mining and reclamation operations

Ultimate Goal: Return of Lands to Equal or Better Productivity
Mined lands

History Of Pond Removals in North Dakota

- In 1987, North Dakota developed a policy memorandum for pond removals
- In 1988, the first ponds were removed
- Over 50 ponds have been removed since 1988

Guidelines

- Sedimentation ponds cannot be removed from a permit area until 2 years after the last augmented seeding of the area
- No major violation occurred at a North Dakota mine discharge point during the 24 months preceding this presentation

Pond Removal Requests

- Site-specific reclamation plan must be submitted to the North Dakota Public Service Commission, Reclamation Division, and to the North Dakota Department of Health
- Removal-request maps must show all ponds, watershed boundaries, structures (roads, stockpiles, diversions, etc.) and must identify proposed locations of and access trails to all best-management-practice sites
- Each removal request must include a grading plan

Reclamation Plans

- Each site-specific reclamation plan must include general information about the mining and reclamation history within the watershed
- Each plan should detail dewatering, sediment-removal, and grading proposals
- Reclamation proposed by a plan should be in accordance with best management practices
- Plans should propose vegetation establishment and stabilization
- Plans should take account of equipment access

General Information

GENERAL

As outlined in PSC Policy Memorandum 19 to Mine Operators, The Coteau Properties Company requests permission to remove and reclaim sedimentation pond P-B17-01 and its associated disturbance areas. NDPDES discharge point 015 will also be eliminated with the removal of this pond. This reclamation plan provides detailed plans pertaining to the removal of pond P-B17-01. Items addressed in this reclamation plan include reclamation timing and details, postmining land use, vegetation establishment, equipment access, and best management practices for erosion control. Attachment 1 is a postmining topography map showing watershed boundaries for pond P-B17-01. Attachment 2 is an aerial photo showing the general location of the pond and its associated disturbances, coal loading limits, and temporary structures located within the watershed.

The postmining watershed for pond P-B17-01, as shown on Attachment 1, consists of approximately 1,123 acres. Coal removal, as shown on Attachment 2, took place within this watershed from 1983 to 1989.

Reclamation of this area was conducted between 1984 and 1996 with all reclaimed areas located within this watershed returned to normal land use in 1996. Therefore, the criteria referred to in paragraphs one and two of Policy Memorandum 19 has been met.

Several temporary features that have recently been, or are projected to be, reclaimed prior to removal of pond P-B17-01 are located within this watershed. These features account for approximately 4.7 percent (53 acres) of the total watershed of pond P-B17-01. These features are more accurately described as SS pile 38 and the drainage below it, SS pile 44, PTS piles 75 and 49, and TS pile 47.

SS pile 38 and its drainage are already removed and seeded, SS pile 44 will be respread during ramp 3 reclamation, PTS piles 75 and 49, and TS pile 47 will be respread in ramp 3 and on the base of SS pile 44. These operations will take place just prior to the removal of P-B17-01.

Three temporary features within this watershed will be reduced or eliminated with the reclamation of P-B17-01. These features are SS pile 24, TS pile 51, and the OB backfill pile for P-B17-01. These features occupy approximately 55 acres within the watershed, of which 30-35 acres will be restored to original land use after these features are used to reclaim P-B17-01. The overburden pile will be returned to the basin of pond P-B17-01. SS pile 24 and TS pile 51 will be removed from the south to the north, thereby eliminating the southern portions (approximately ½) of the piles. These reclaimed portions will be returned to their normal land use in conjunction with pond reclamation.

Long-term features account for approximately 11 percent of the watershed (127 acres). These features are more accurately described as follows:

The SW corner of the AVS Ash Pit located in the SE¼SW¼ Section 7.
The East Mine Area conveyor and its associated topsoil piles.
The East Mine Area haulage road/SS pile 80.
SS pile 36 and sump S-B17-01.
The SPGM access trail located in the E½SW¼ Section 17.

Watershed information

History

Other activities

Pond-related disturbances

Reclamation Details

RECLAMATION DETAILS

Water contained in sedimentation sump S-B17-01will be removed to the extent possible prior to commencement of filling of the pond's containment area. Small trenches leading to sumps will be constructed at least 30 days prior to pond removal. This dewatering system will enhance the drying process of the pond bottom. Removal of this water will be conducted in accordance with NDPDES effluent limits set for the pond. Water removed from these sumps will not be discharged off the mine site if a question of effluent quality exists.

Option 1 under paragraph five of PSC Policy Memorandum 19 to Mine Operators has been selected to delete discharge points from the NDPDES permit. In accordance with option 1, proper notification of reclamation activities will be given.

Sediment which has accumulated over the years into pond P-B17-01 is not of a significant quantity and will be buried in-place with reclamation of the pond. Extra care will be taken during commencement of pond removal operations to ensure that accumulated sediment is properly covered with backfill overburden.

Pond P-B17-01 is basically a dugout with a shallow but long earthen embankment that spans across a drainage and connects hills on the north and south sides of the pond. Several predisturbance wetland/depressional areas were located in the drainage that traverses the pond area from west to east. Reclamation of the pond will generally consist of backfilling the excavated areas to the approximate original topography of the pond. Due to the large disturbance area that will require backfill and the upstream disturbance from stockpiles required to reclaim the pond, reclamation activities will be conducted to contain any water that may run across disturbed areas until the entire project is very nearly completed. Although site conditions usually dictate reclamation methods and procedures, plans currently consist of splitting the pond reclamation into two halves. The north half and the south half of the main drainage that carries water through the pond area. The pond embankment will remain in place as long as possible and serve as a large sump to contain any runoff received during reclamation of the pond. The drainage will be the first portion of the pond to be reconstructed to overburden grade. From this drain, overburden will be replaced in the pond to the north, then to the south, leaving an approximate 75 foot wide trench without overburden backfill the entire length of the pond embankment. This trench will serve as the water management for the project until such time as the overburden stockpile area and at least the west ½ of the pond reclamation area have SPGM respread completed on them. At this time, the embankment will be used as backfill for the trench, and the remainder of the pond area and SS pile 24 will have SPGM replaced on it.

Land use areas shown on Attachment 2 will be respread with SPGM as follows:

Land Use	SS Respread Depth	TS Respread Depth
Rangeland	40 inches	8 inches
Cropland	36.2 inches	11.8 inches
Prime Farmland	34.6 inches	13.4 inches

Dewatering plan

Sediment removal

Detailed information regarding grading and water management during grading

Vegetation Establishment

VEGETATION ESTABLISHMENT

With completion of this project expected in late October, vegetation establishment will be very limited in 1998. Cropland areas will be mulched with a straw mulch applied and crimped at a rate of 1.5 to 2 tons per acre. In the spring of 1999, they will be incorporated into the normal cropping rotation for the area. Rangeland areas will be dormant seeded and mulched and crimped at 1.5 to 2 tons of straw per acre. If field conditions will not allow for a dormant seeding, rangeland areas will be mulched and crimped to stabilize them for the winter and will be seeded in the spring of 1999. The general guidelines for vegetation establishment at the Freedom Mine can be found in Section 4.4.1 of Permit NACT-8203. The pre and postmining land use for this area is shown on Attachment 2.

Significant flows of water are expected in the reclaimed drainage channel due to the large watershed area draining through the area. It is anticipated that the entire drainage that runs through the reclaimed pond area will need to be armored with erosion control blanket and closely monitored during spring runoff to ensure preservation of the drainage until vegetation is established. Along with erosion control blankets, any or all of the best management practices described in the following section may be used to reduce the potential for erosion in the reclaimed areas.

Seeding and mulching

Drainage-channel stabilization

Best Management Practices

BEST MANAGEMENT PRACTICES

Best management practices will be incorporated into the pond reclamation plan. Site specific review will determine the best practice to use in each situation that exists or may arise. The on-site Environmental Specialist will be responsible for assigning and implementing the appropriate best management practice for each situation. Special consideration will be given to areas that have the potential for concentrated water flows and all storm outfall areas. Best management practices will also be employed for any minor erosion features that may develop after project completion. Examples of best management practices that may be used include, but are not limited to, straw bale dikes, erosion control blankets, contour seeding, straw mulch, use of cover crops, back-filling and blading, reseeding or interseeding, and silt fences.

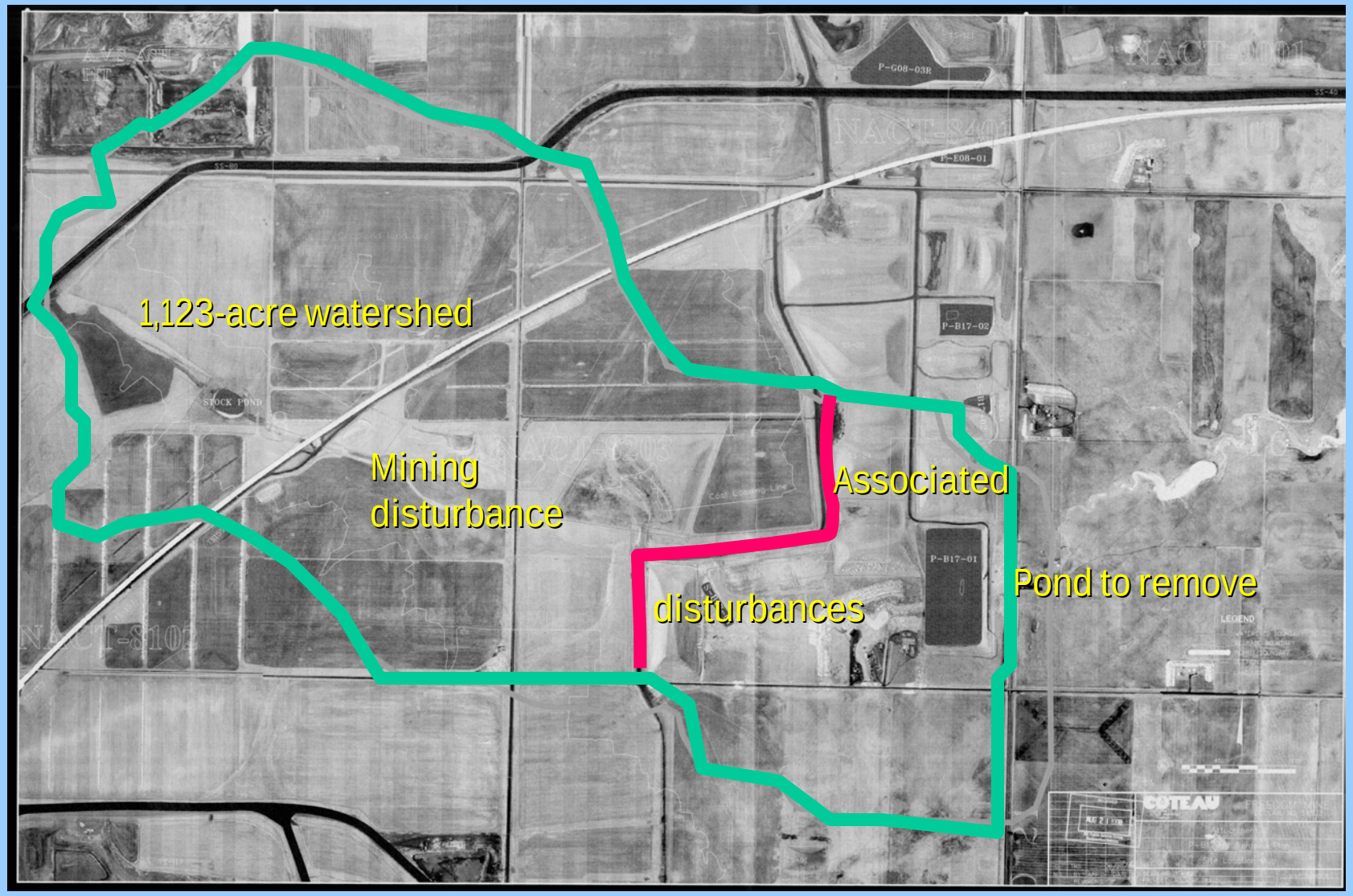
Equipment Access

EQUIPMENT ACCESS

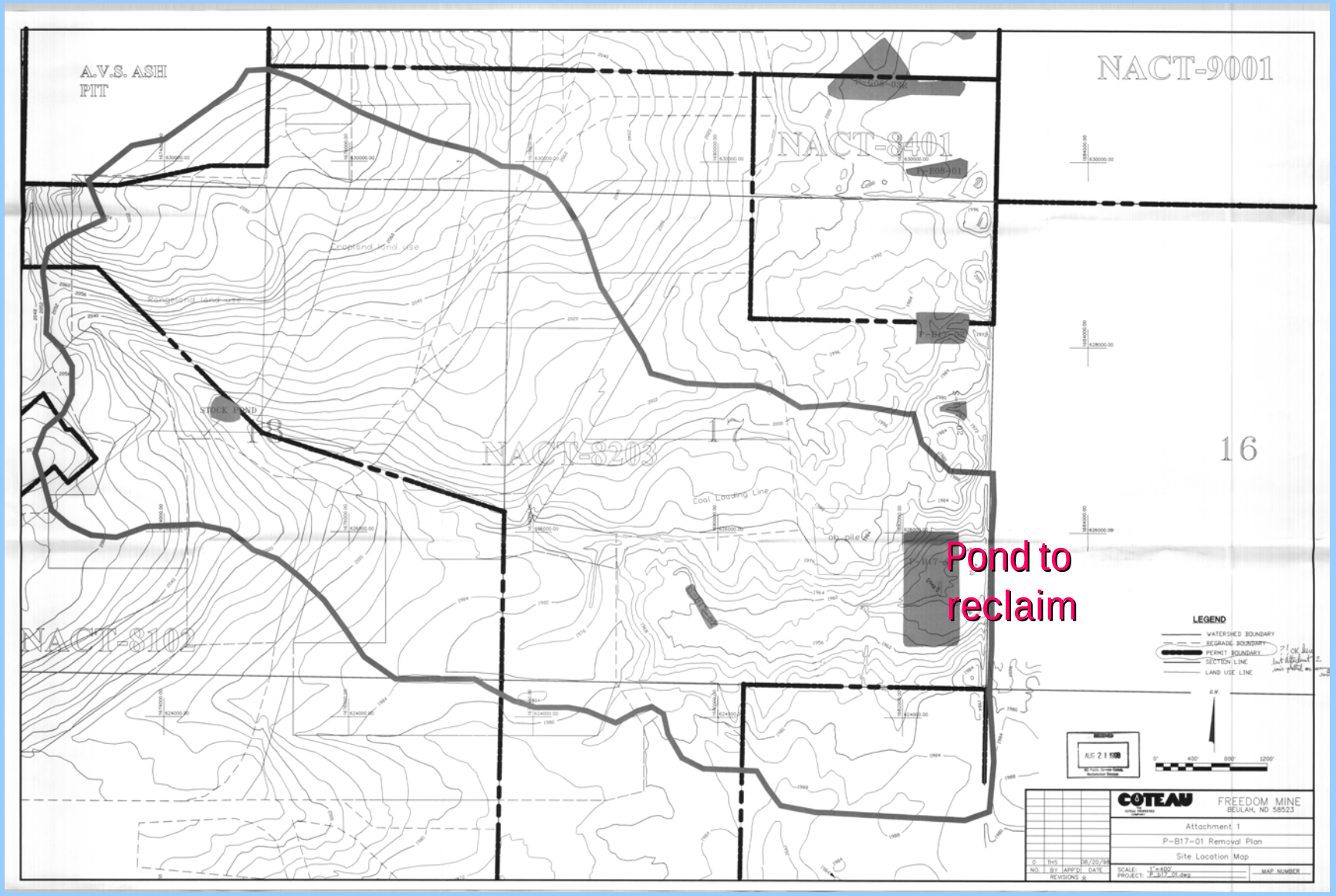
Heavy equipment access will be restricted to disturbed areas as much as possible. An existing overburden road enters the pond site from the north, and the overburden backfill pile is located directly northwest of the pond. Therefore, all heavy equipment access should be on overburden until SPGM respread is in progress.

It will not be necessary to maintain a permanent access to this area once reclaimed. Access for small vehicles for normal maintenance or inspection will be randomly picked as weather and farming activity dictate. County Road 21 and an unnamed section line road run very near the pond site on the east and south sides, respectively. These roads will allow access adjacent to the site for walking inspections of the reclaimed site. Access on the reclaimed site with vehicles will be limited to those times that will not cause rutting or erosion in the reclaimed areas.

Aerial Photo Map



Topographic Map for Grades



Site Inspection

- Check the cover for controlling erosion
- Ensure the use of best management practices on cropland areas
- Verify the proposed locations of best-management-practice sites
- Review the proposed grading plan
- Review proposed access plans

Approval Letter

- A consensus between the North Dakota Department of Health and the North Dakota Public Service Commission, Reclamation Division
- Contains all specific conditions related to proposed reclamation procedures

Sediment Disposal

Sediment Disposal

Sediment Disposal and Grading

Grading

Grading

Topsoiling

Erosion Blankets in Drainage

Reclaimed Pond

Reclaimed Pond

Reclaimed Pond

Reclaimed Ponds

Where Does This Fit into Bond Release?

- North Dakota's Public Service Commission may grant final bond release in less than 10 years for permit areas surrounded by larger reclaimed tracts
- The Commission may issue policy memoranda on small-area variances

Variances For Small Areas

Such variances may be granted for areas that:

- Are small
- Include only ponds, diversions, stockpiles, and/or their associated access trails
- Meet the standards of the surrounding bond-release area

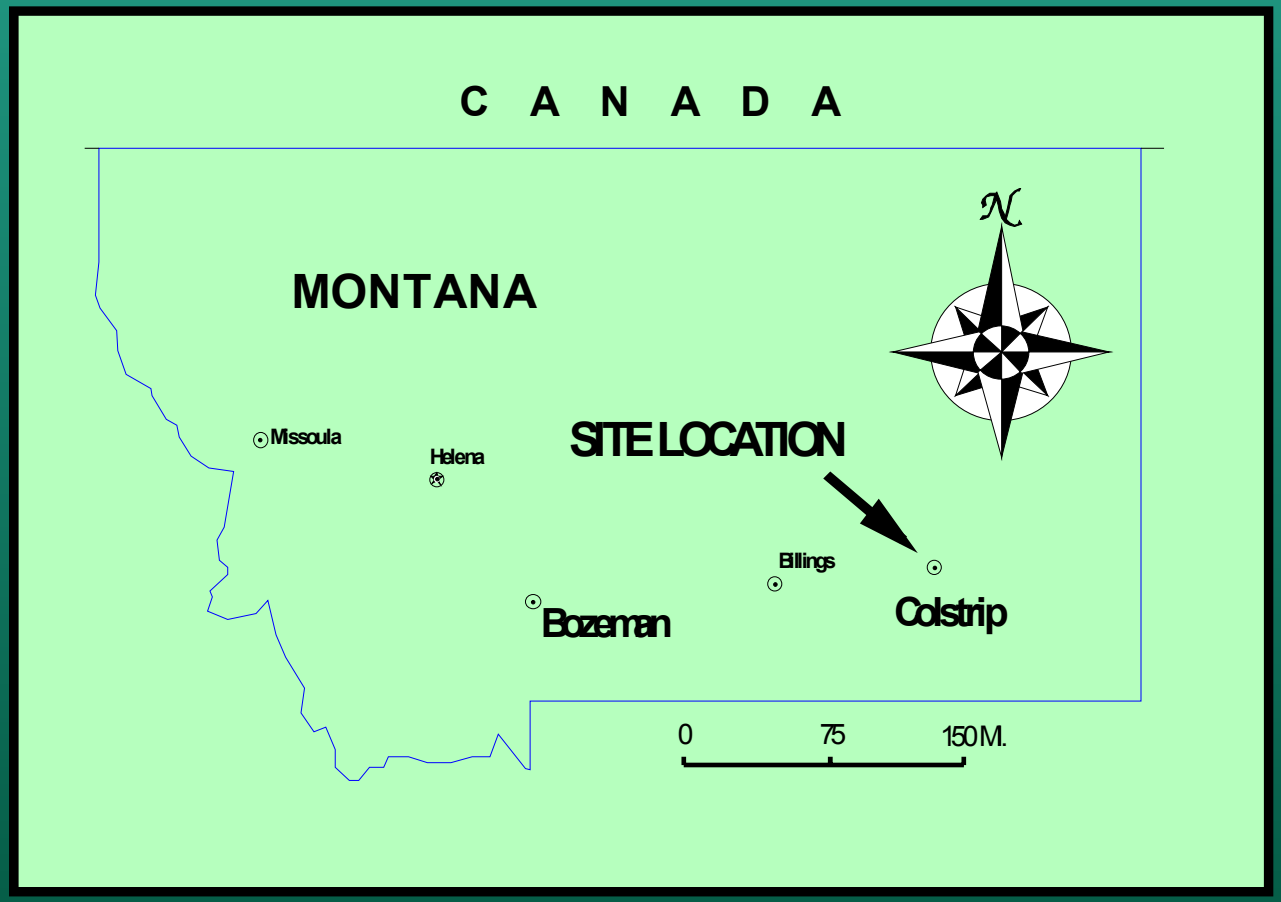
GONE FISHING

Use of a Regional Ground-Water Model to Predict Relative Impacts of Life-of-Mine Plans for Rosebud Area C, Near Colstrip, Montana

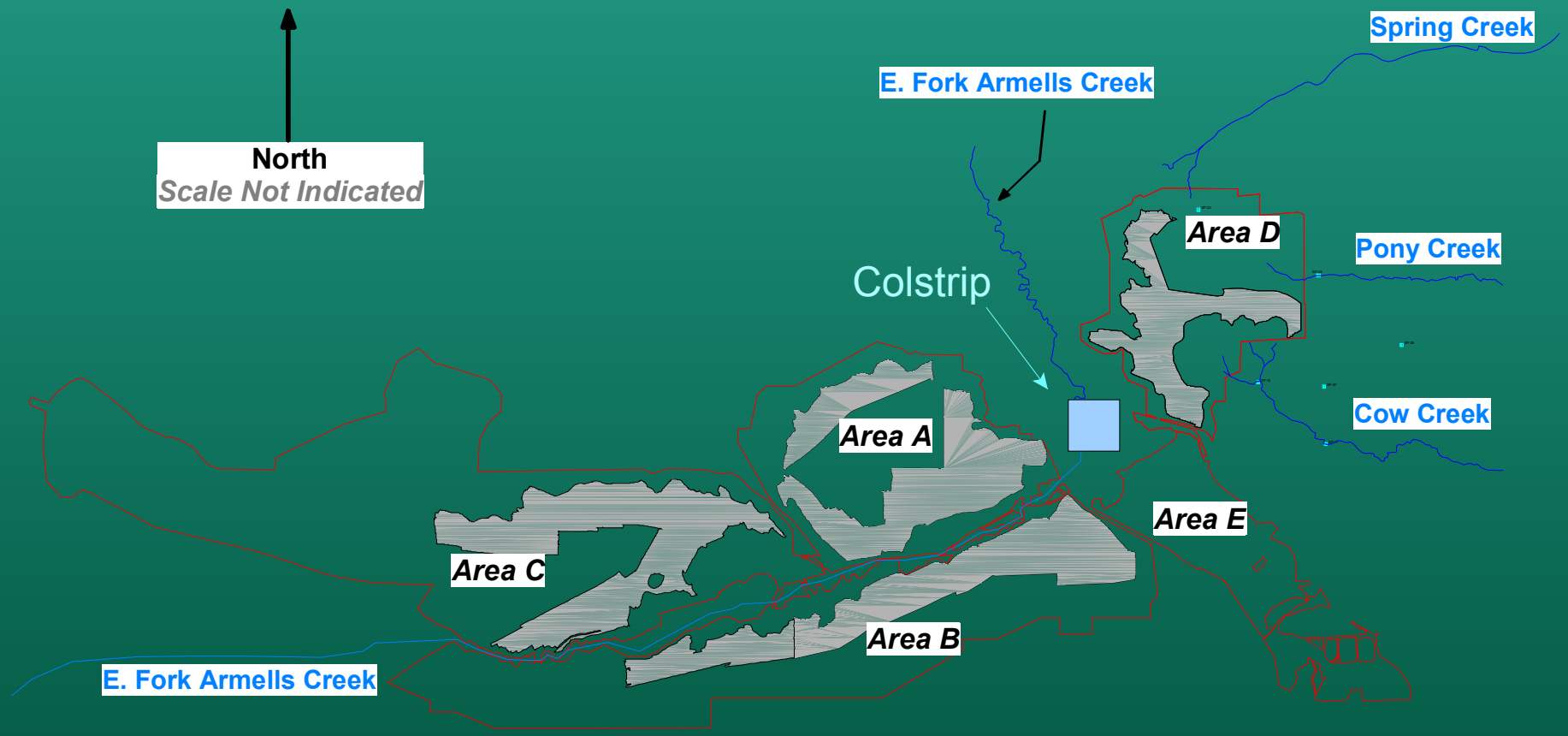
Michael Nicklin, Ph.D., P.E.
Nicklin Earth & Water, Inc.

Greg Liebelt
Western Energy Company

Project Location



Western Energy Company
Mining Activity Near Colstrip, Montana



Colstrip Mining Operation

Blasting Activity

Fracturing/Removal of Overburden Coal

Background for Area C Ground-Water Modeling Effort

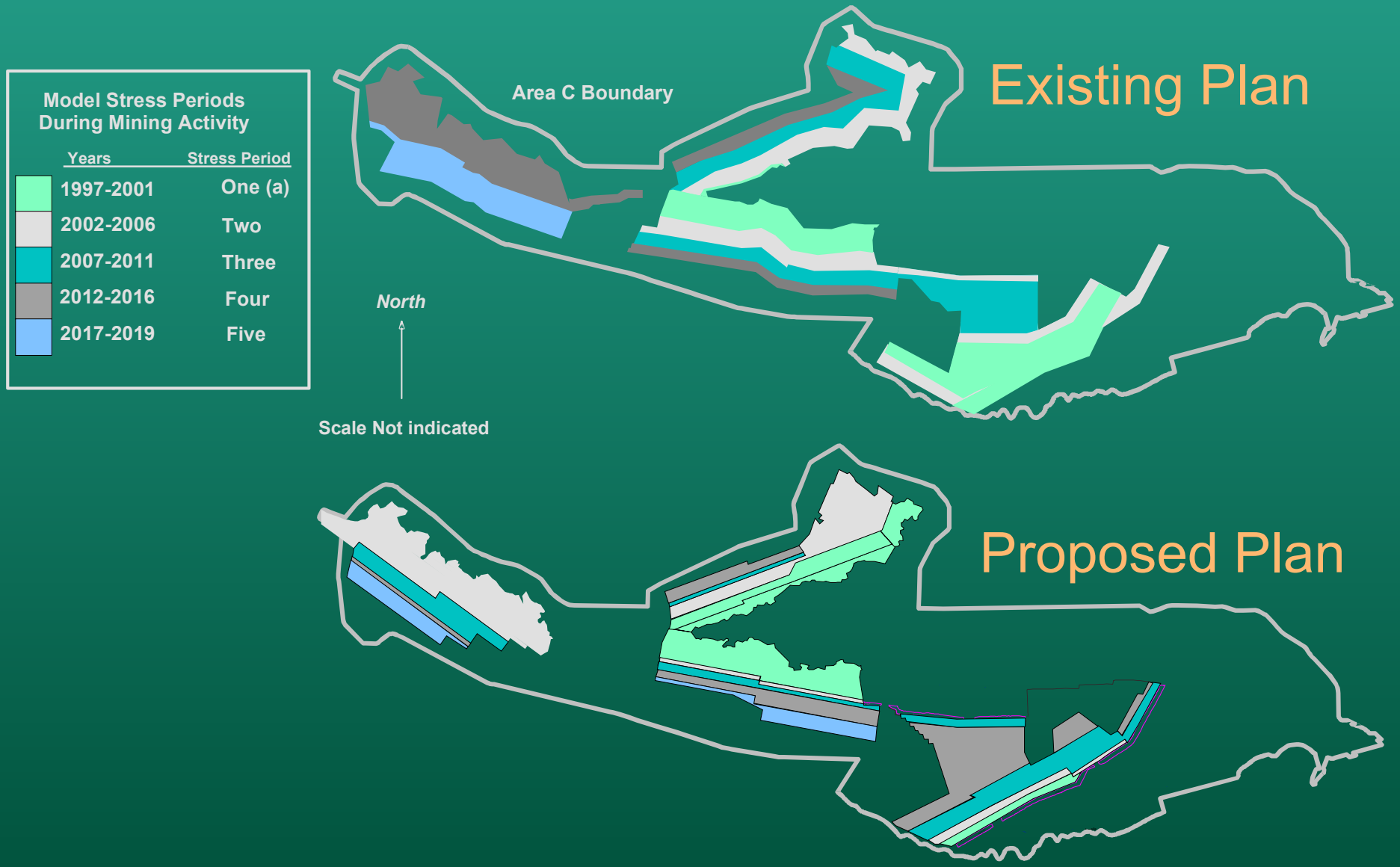
- Western Energy proposed revising an existing mine plan ***(existing plan)*** for Area C.

- The proposed mine plan ***(proposed plan)*** differed from the existing plan in that the proposed plan called for:
  - Longer highwall cuts.
  - Many of the highwalls to be open for longer periods during mining.
  - A different sequencing in mining activity.

- Montana Department of Environmental Quality (DEQ) requested further evaluation to predict the relative consequences of and differences between the two plans.

- Montana DEQ also requested a review and evaluation of the mining responses to date (ground truthing).

Mining Plans - Area C



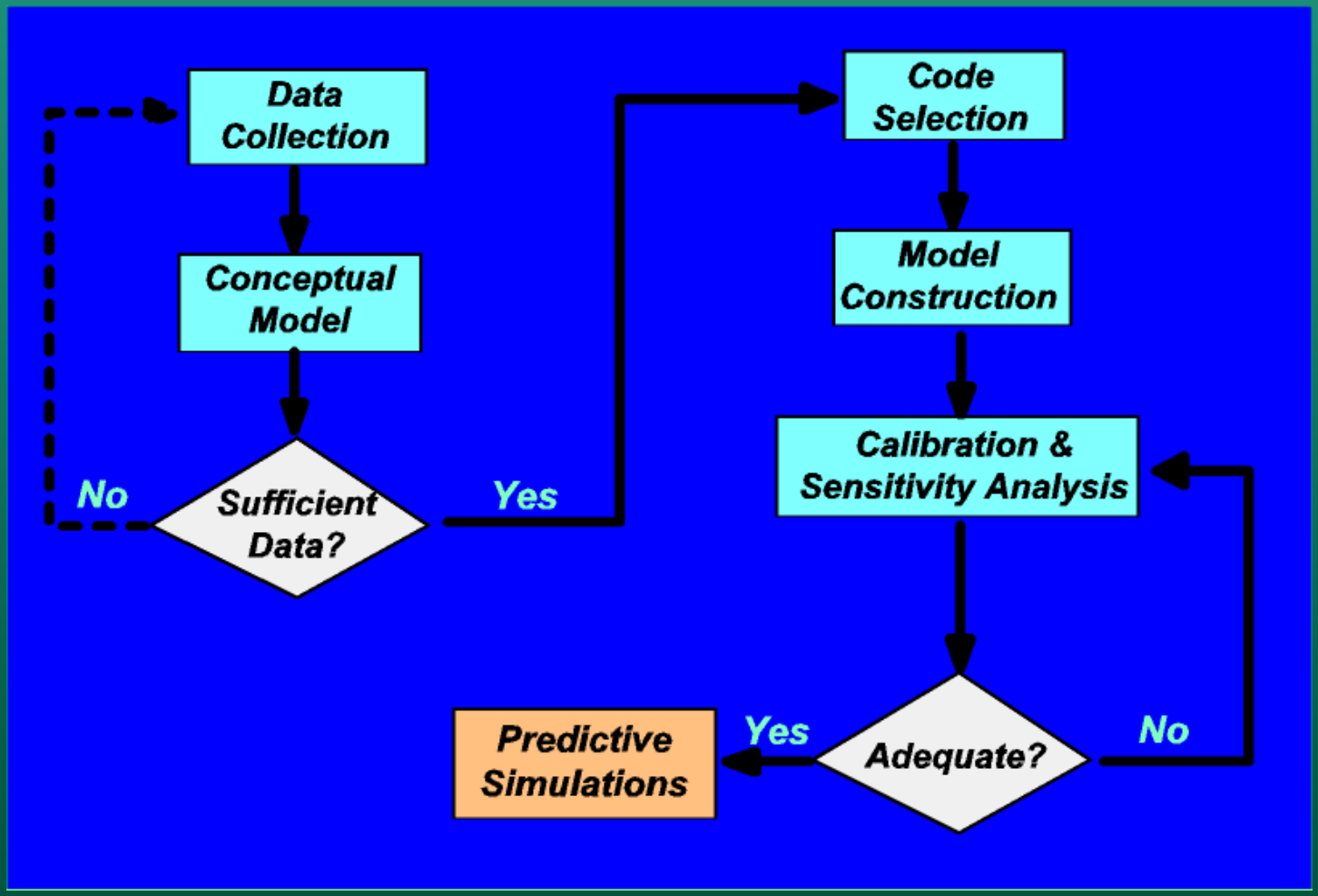
A Ground-Water Modeling Effort

Established as a Tool to Address Montana DEQ Concerns

- Phase 1: Developing a hydrogeologic system conceptual summary.
- Phase 2: Defining the model structure and completing the model calibration effort.
- Phase 3: Using the calibrated model to evaluate hydrologic response.

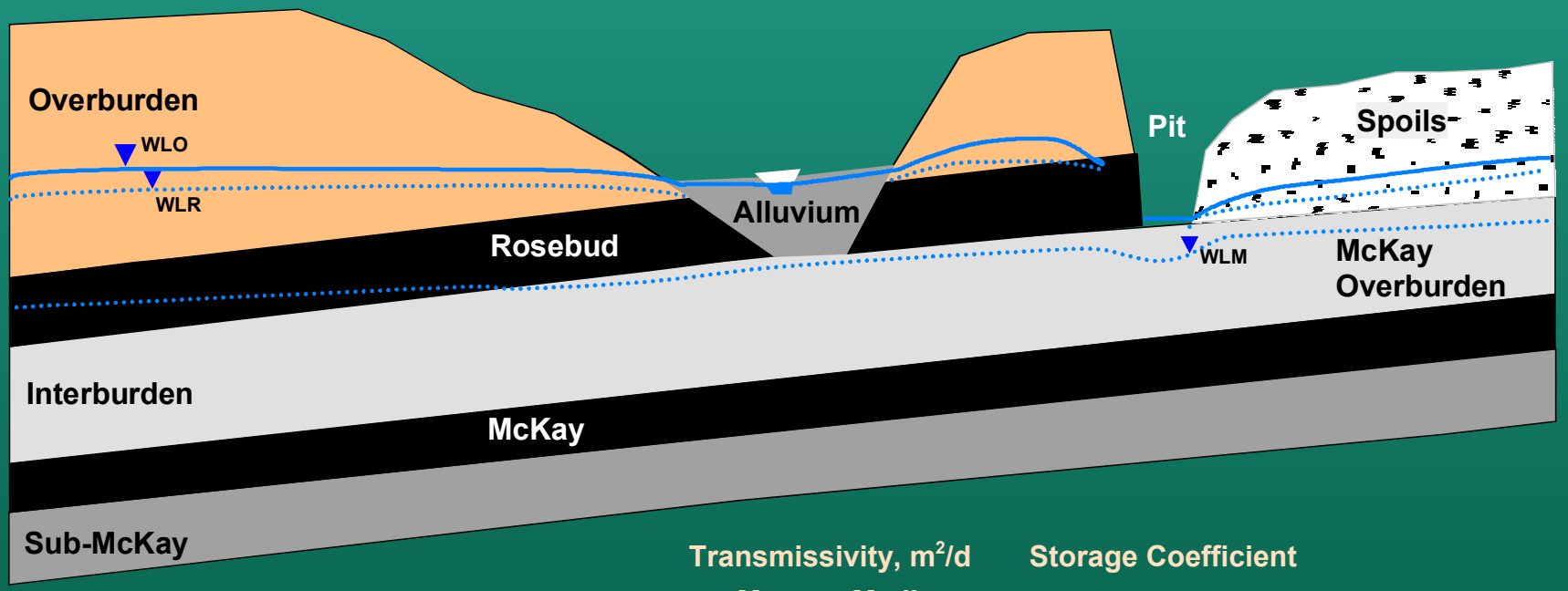
(*NOTE: Montana DEQ participated in every phase of the modeling effort.)*

Flow Chart of Modeling Process



General Coal Geology

Water Level Monitoring Wells in Overburden (WLO)
Water Level Monitoring Wells in Rosebud (WLR)
Water Level Monitoring Wells in McKay (WLM)



	Transmissivity, m^2/d		Storage Coefficient
	Mean	*Median*	
Alluvium (Armells) - Moderate Yields	156	123	[0.1 to 0.3]
Overburden - low to very low yields	111	0.7	[0.006 to 0.03]
Rosebud Coal - low to very low yields	6.5	0.4	[0.000015]
Interburden - low to very low yields	0.5	0.1	[no data in EIS, probably low]
McKay Overburden	19	7.1	[no data in EIS, probably low]
McKay Coal - very low yields	1.81	1.3	[no data in EIS, probably low]
Sub McKay - low	10.7	5.8	[no data in EIS, probably low]
Spoils - low to very low	24.8	0.8	[no data in EIS, probably high]

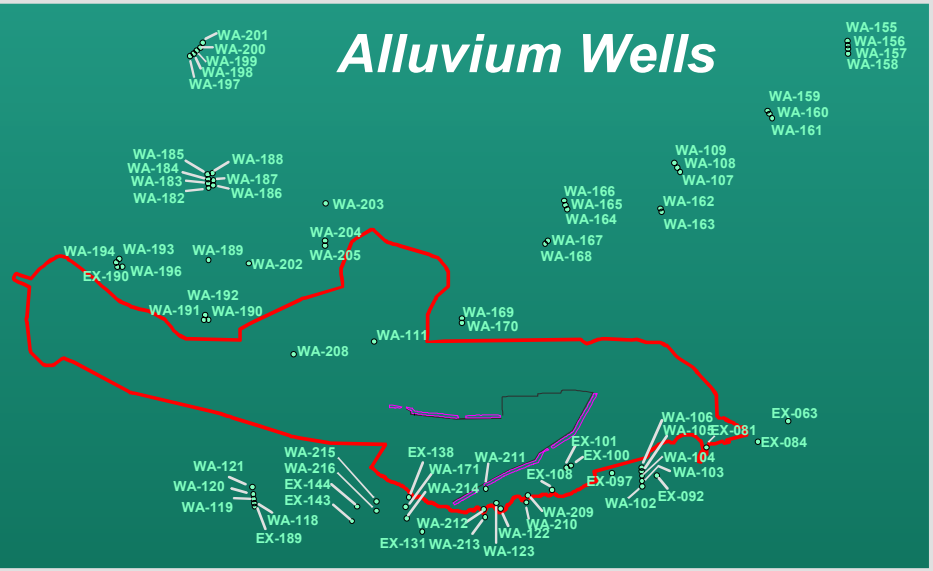
Ground-Water Database

- Historical water-level data: 241 monitoring wells, some of them measured since the early 1980's; 96 of these wells were useful for modeling effort.
- Aquifer parameter data (EIS, 1983).
- Observation data from mine operations (e.g., relative amounts of water resulting from dewatering operations).

Monitoring Wells

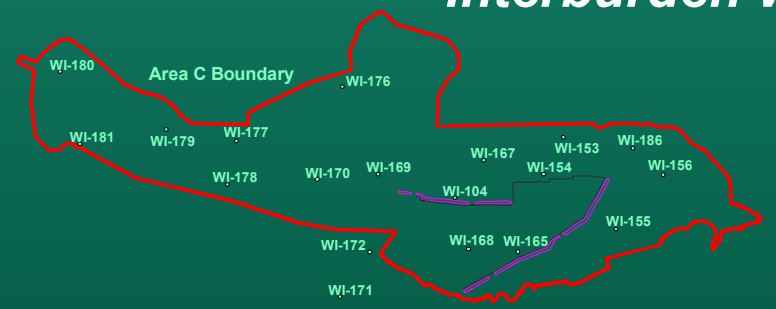
Overburden Wells

Alluvium Wells

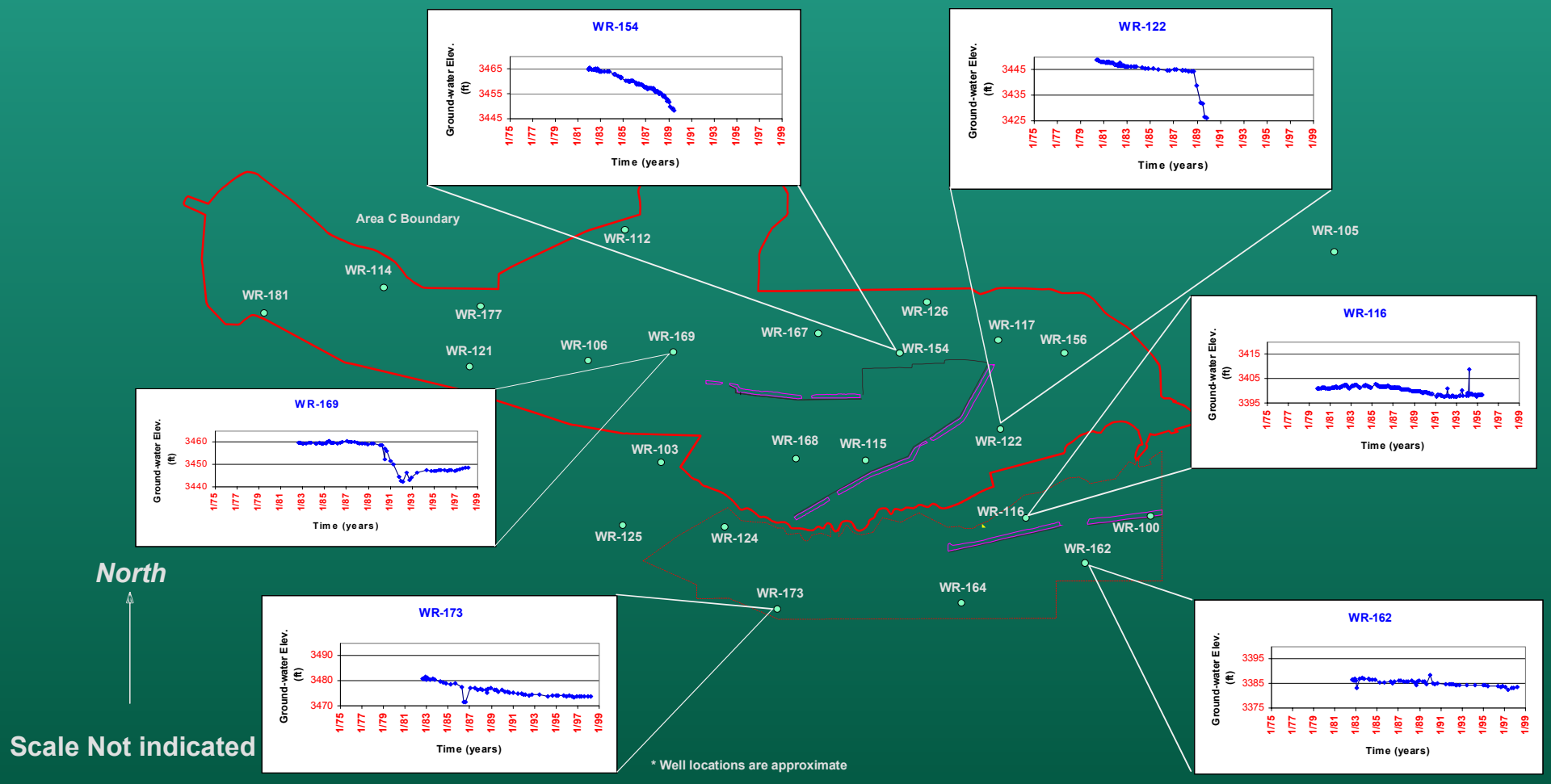


Rosebud Coal Wells

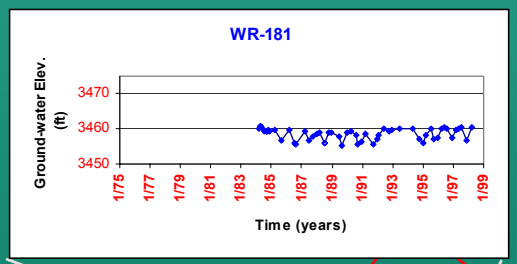
Interburden Wells

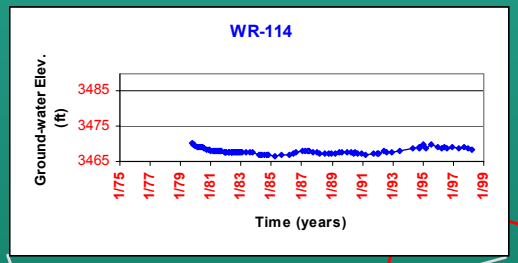


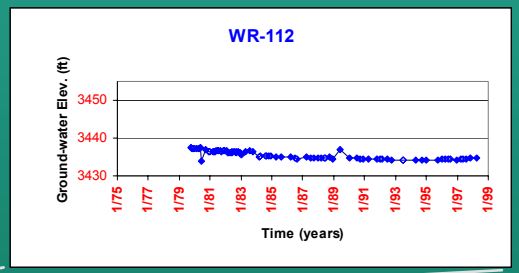
Rosebud Coal-Monitoring Well Response to Previous Mining Near Active/Historic Mining

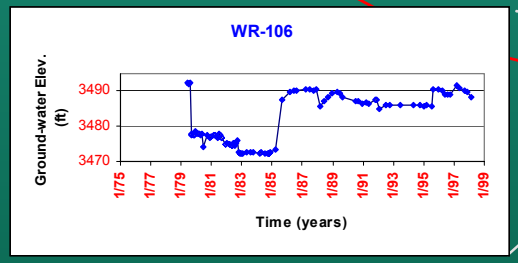


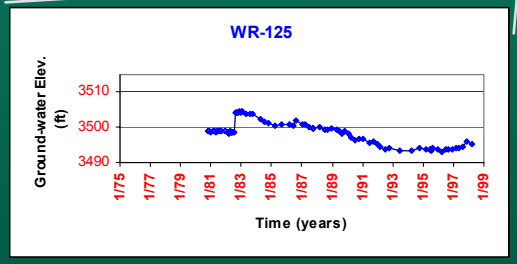
Rosebud Coal-Monitoring Well Response to Previous Mining Away from Active/Historic Mining

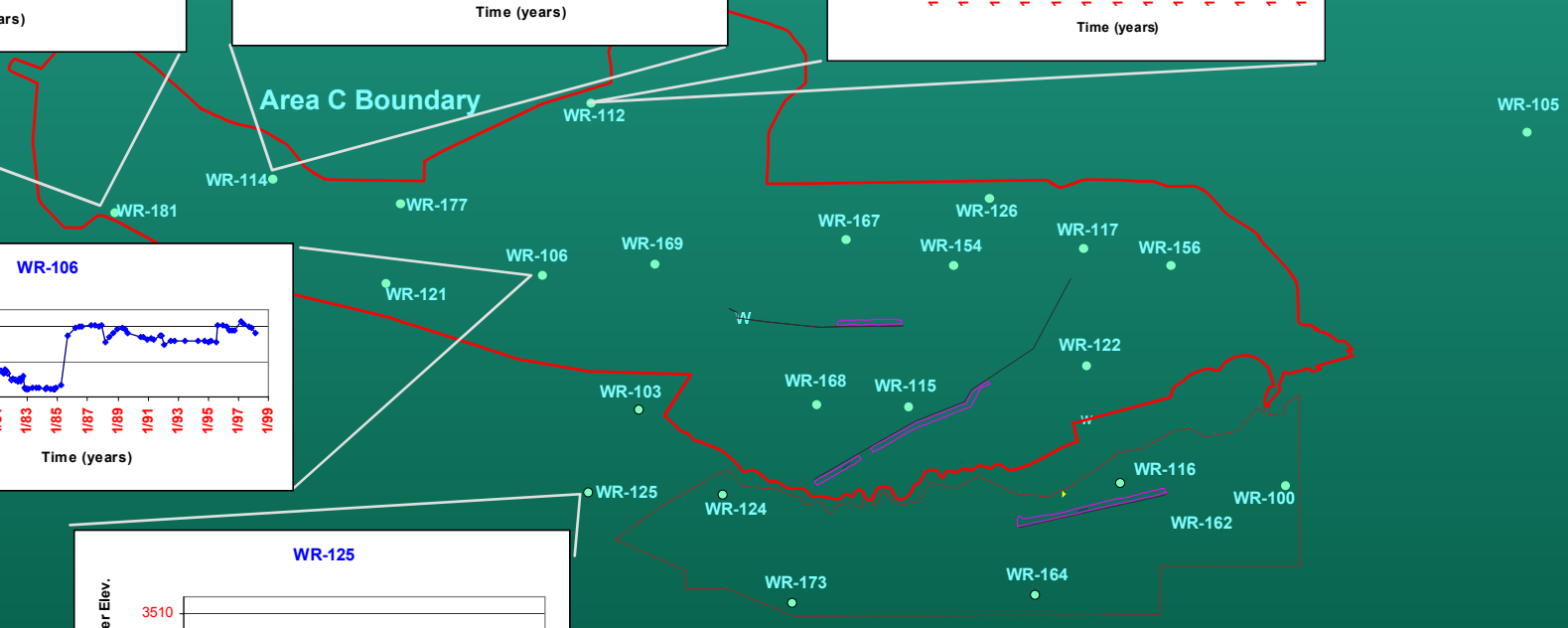












North

Scale Not indicated

General Conclusions Regarding Well Observations in Area C

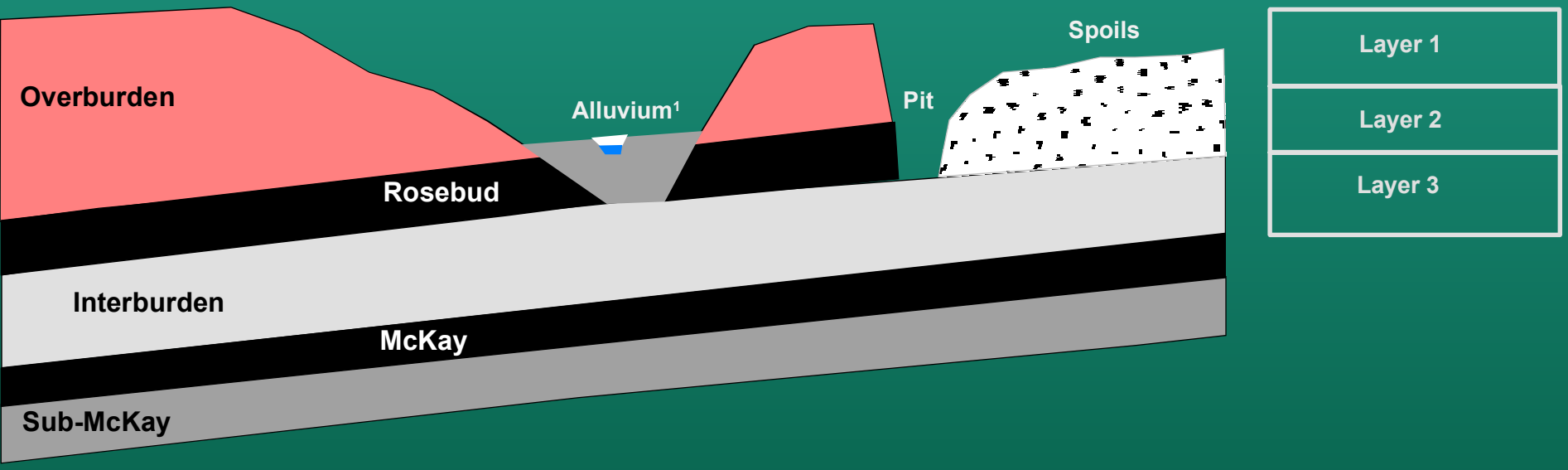
- Vertical hydraulic gradient is generally downward, and vertical impedence is high.
- Relative zone of mining-activity influence (e.g., drawdown) is generally limited to within 1 kilometer of active mining.
- Discharges in vicinity of mining cuts are relatively low, except in vicinity of alluvium (~ 500 m^3/day).

Model Tools

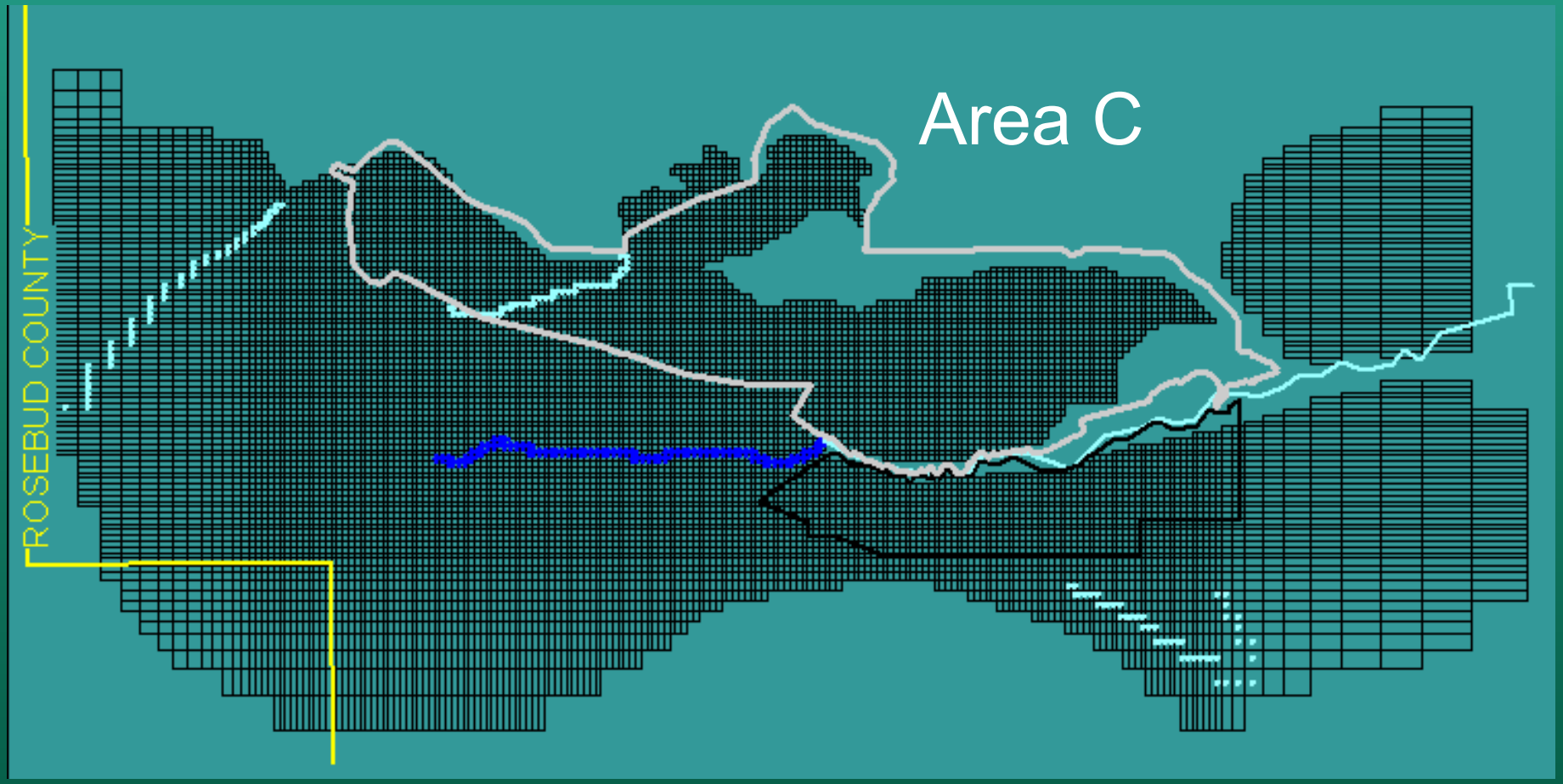
Western Energy Area C Ground-Water Model

- U.S. Geological Survey — MODFLOW
- Conceptual model development — Groundwater Modeling System (GMS)
- Steady-state calibration — Groundwater Vistas
- Transient calibration and application — GMS

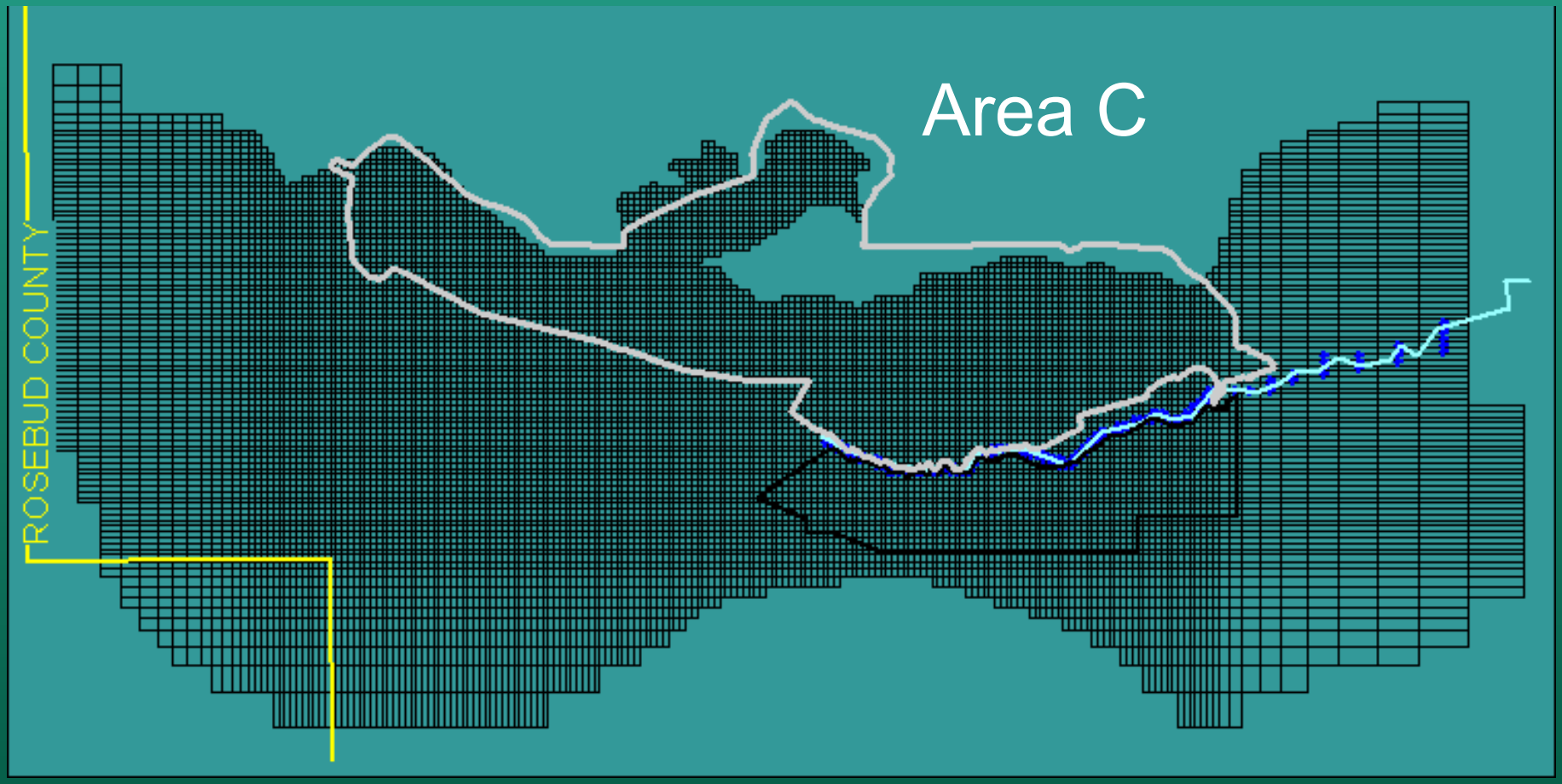
Vertical Model Structure



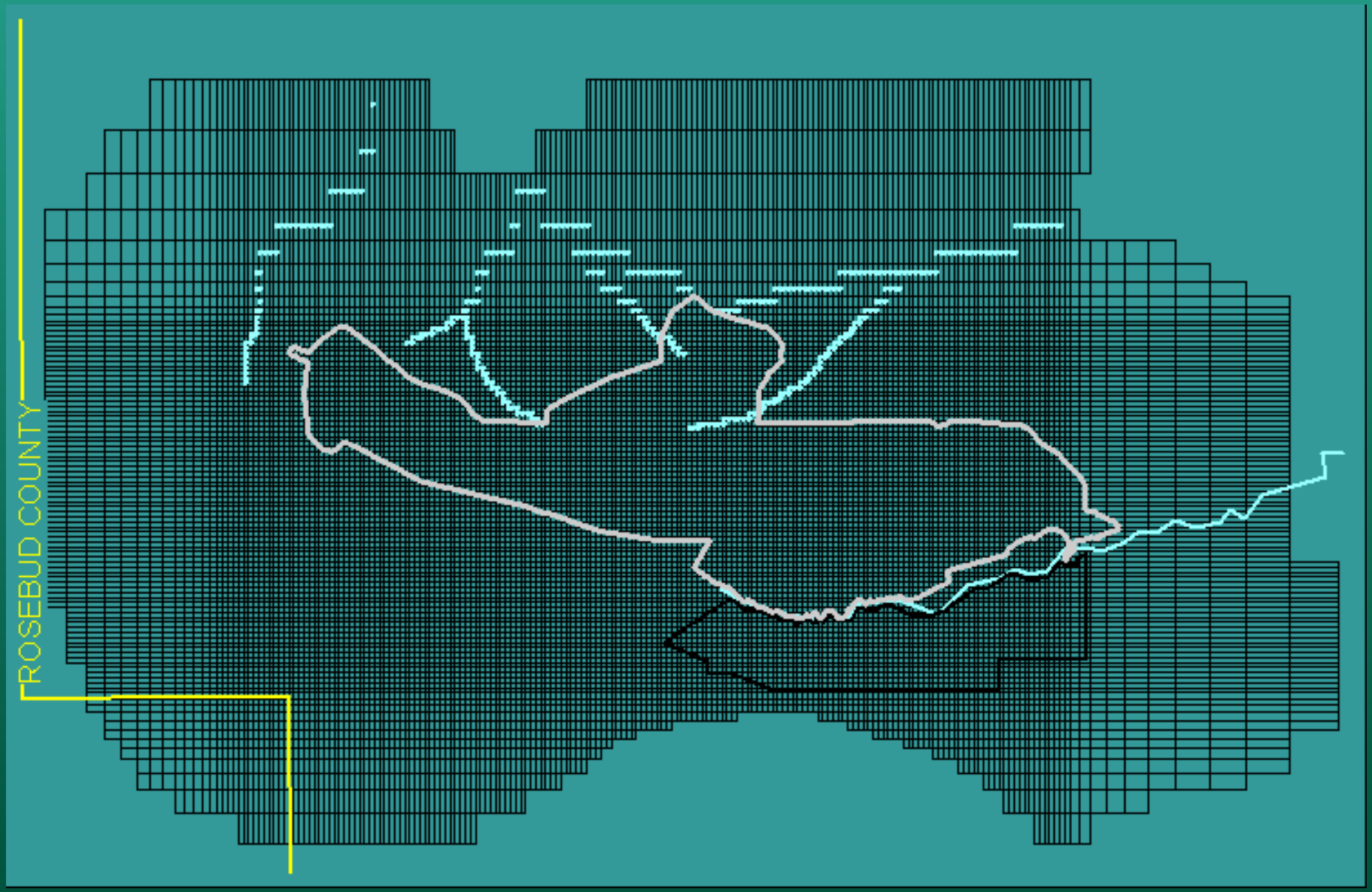
Model Layer 1



Model Layer 2



Model Layer 3



Model Calibration Stages

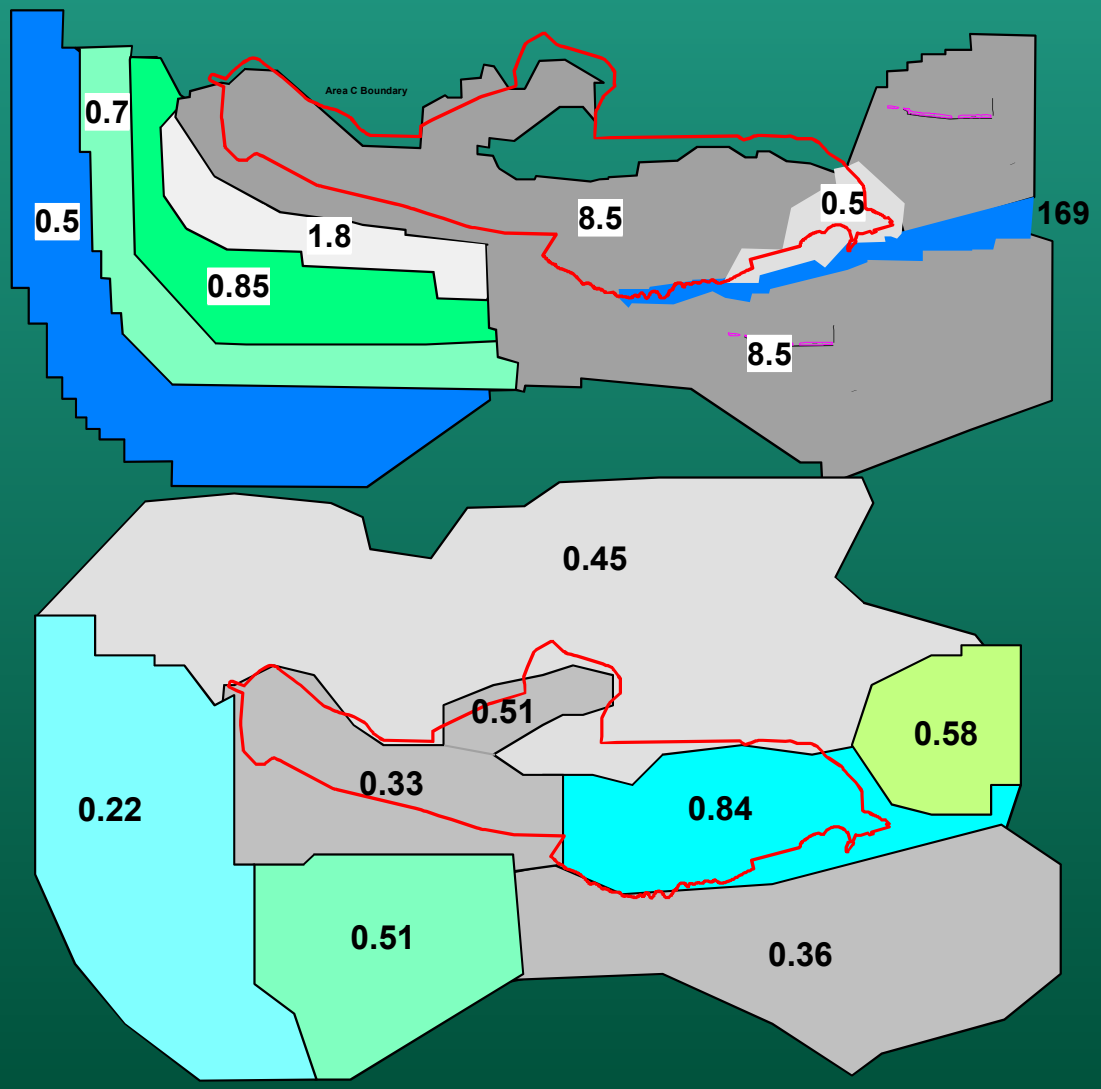
Area C Ground-Water Model

- Model steady-state calibration to “premining” (generally 1983) observation data.
- Model transient calibration using monitoring data from early mining to current mining. *(NOTE: Transient calibration effort was iterative.)*
- Perform sensitivity analysis for all calibration phases.

Calibrated Model Parameters

- Transmissivity range (m^2/day):
  - Overburden (0.6 to 2)
  - Alluvium (28 to 170)
  - Rosebud coal (0.5 to 8.5 [or 1.6 to 91 ft^2/day])
- Vertical conductivity/horizontal conductivity:
  - Overburden (10^{-5} to 10^{-2})
  - Coal (10^{-2})
- Recharge range:
  - From 0.2 to 0.84 cm/year (or ~ 0.1 to 0.3 in/year)

Zonation, Key Parameters

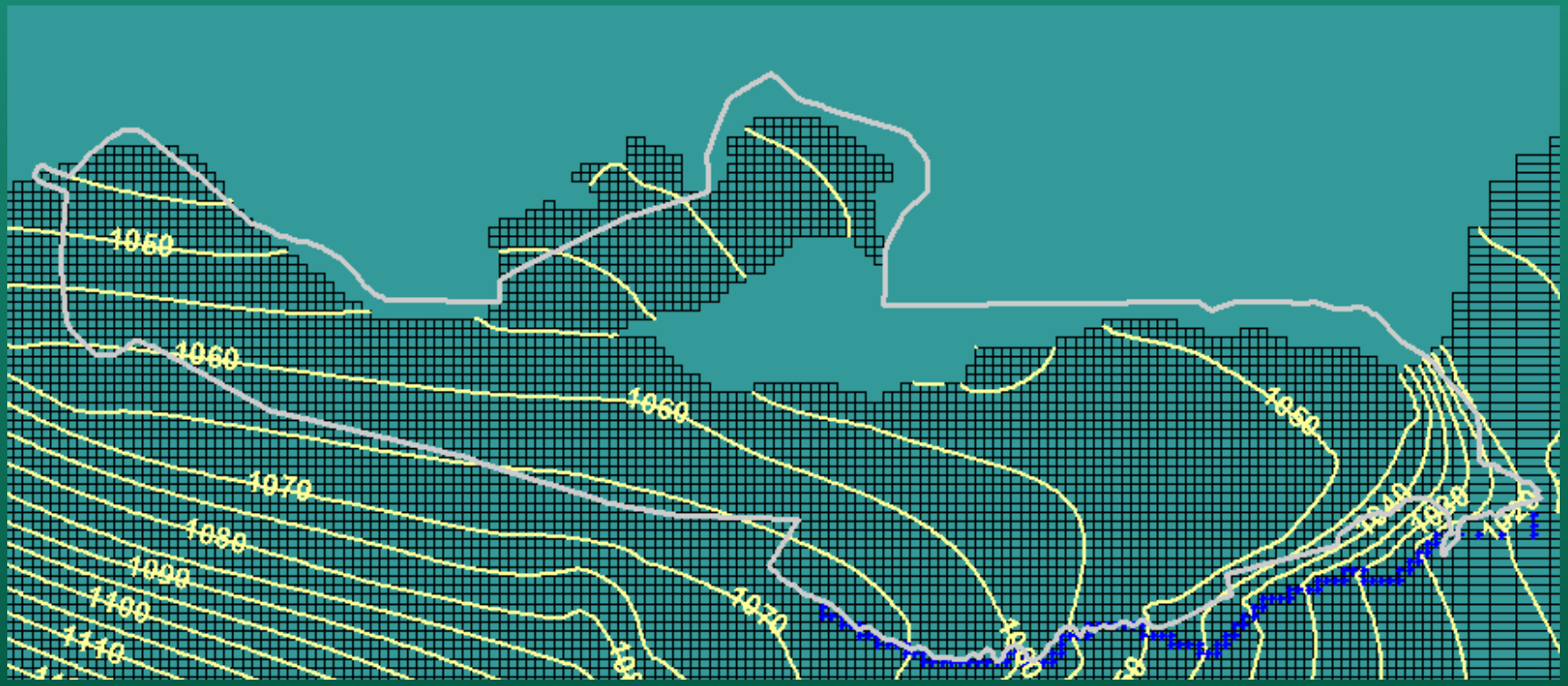


Layer 2 Transmissivity m^2/day

Recharge, cm/year

Potentometric Heads, Layer 2

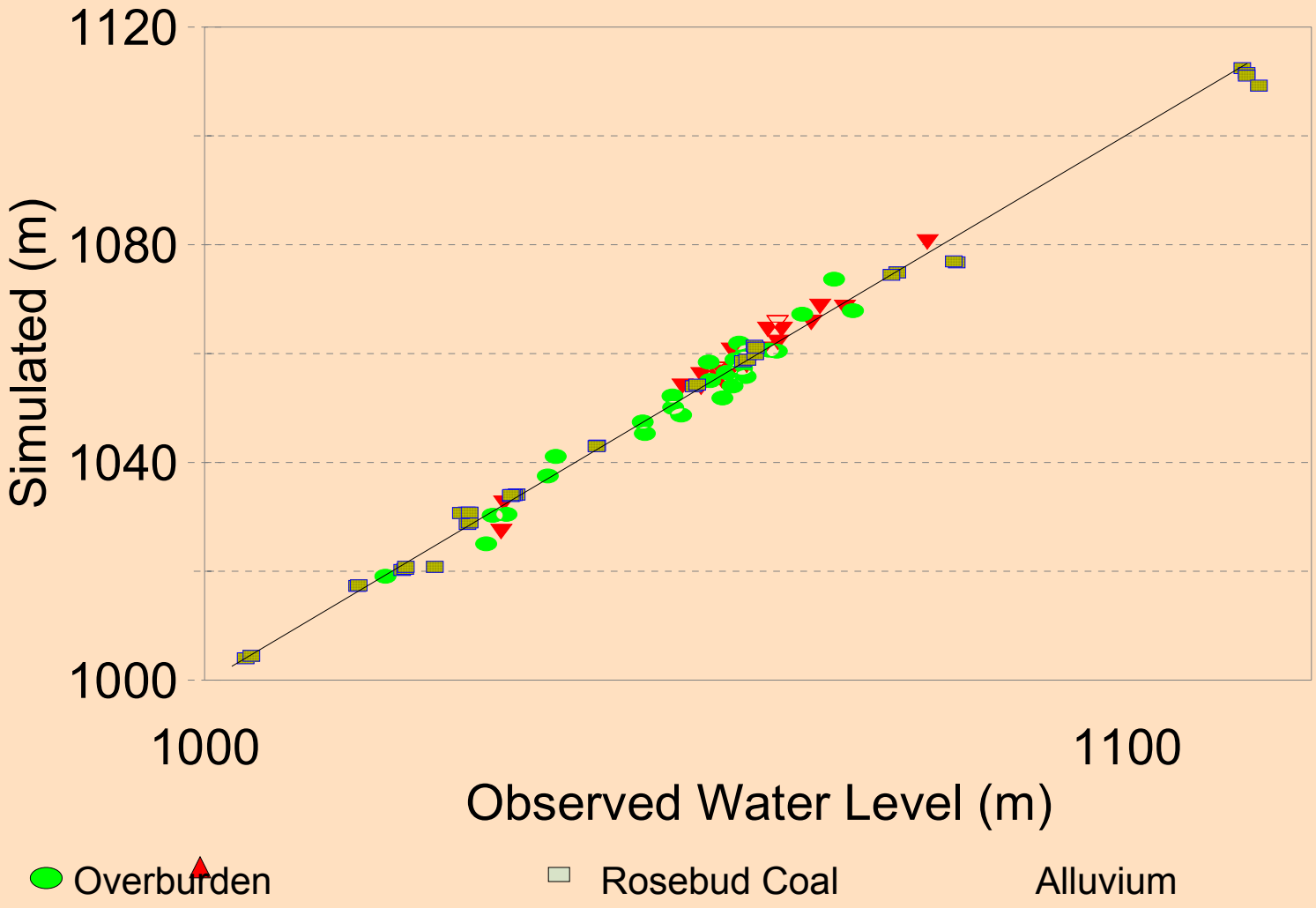
(units of measurement are meters)



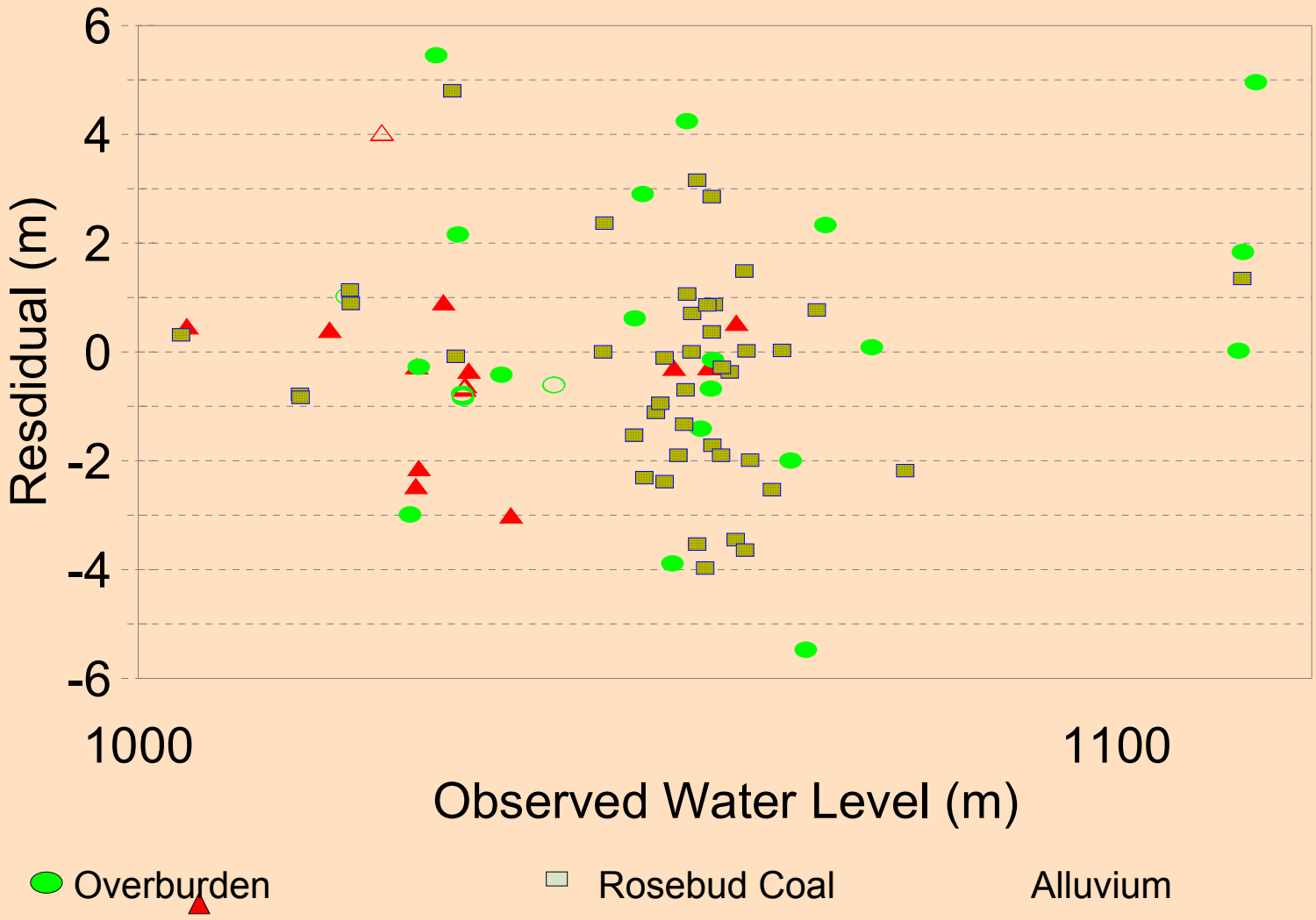
Steady-State Calibration Results

	Overburden (m) *(ft)*		Rosebud (m) *(ft)*		Alluvium (m)*(ft)*	
Number	22		27		47	
Residual Mean	***-0.78***	***(-2.56 ft)***	***0.21***	***(-0.69 ft)***	***-0.12***	***(-0.29ft)***
Residual Std. Dev.	0.58		0.78		0.46	
Sum of Squares	93.31		147.66		54.93	
Abs. Residual Mean	***1.57***	***(5.16 ft)***	***2.05***	***(6.71 ft)***	***1.16***	***(3.79 ft)***
Minimum Residual	-3.63	*(-11.89 ft)*	-5.47	*(-17.93 ft)*	-2.98	*(-9.77 ft)*
Max. Residual	4.81	*(15.78 ft)*	5.47	*(17.93 ft)*	4.96	*(16.28 ft)*
Head Range	46.26		50.70		133.77	

Observed v. Simulated

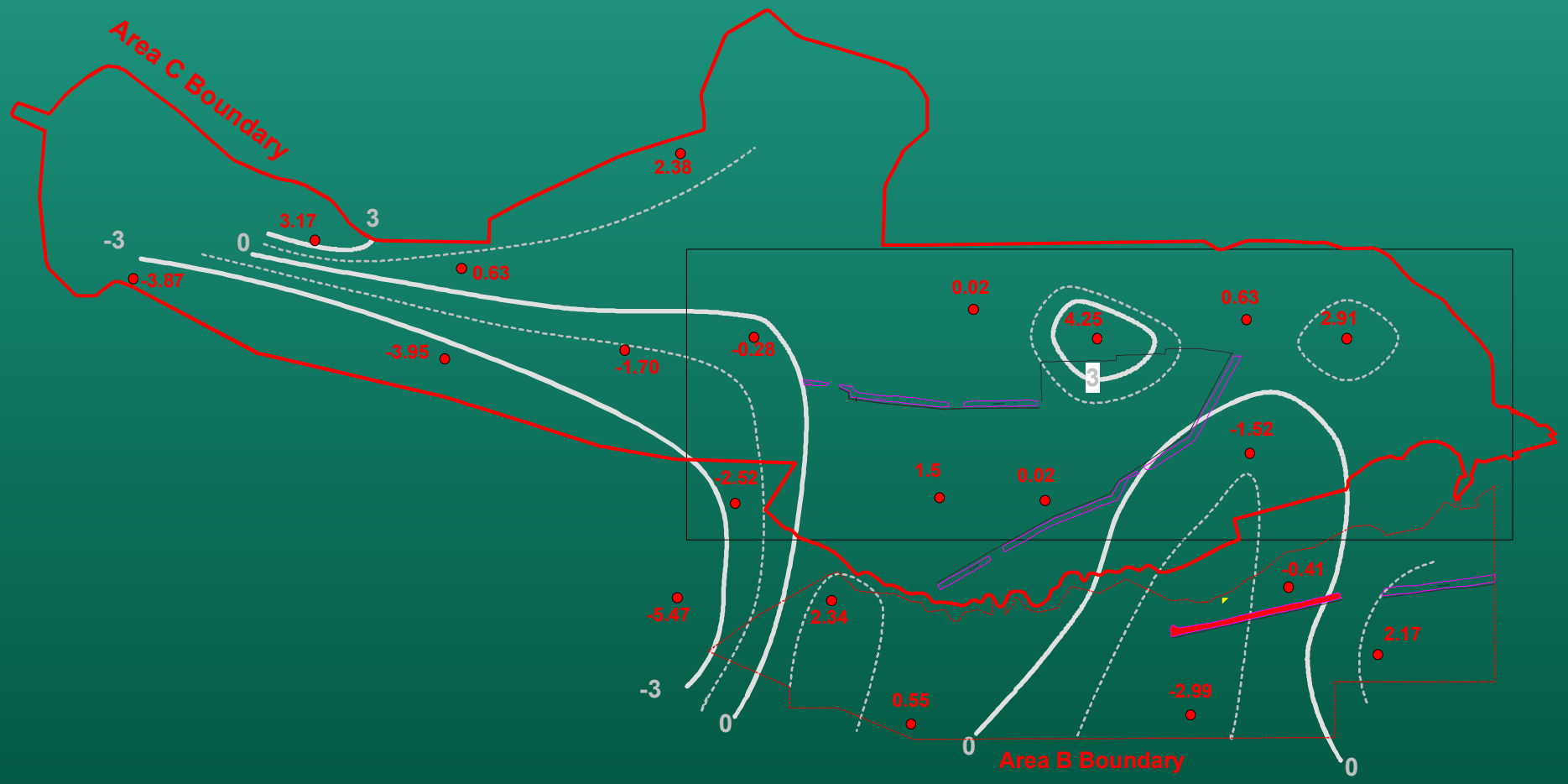


Residual Plot v. Observed Water Levels

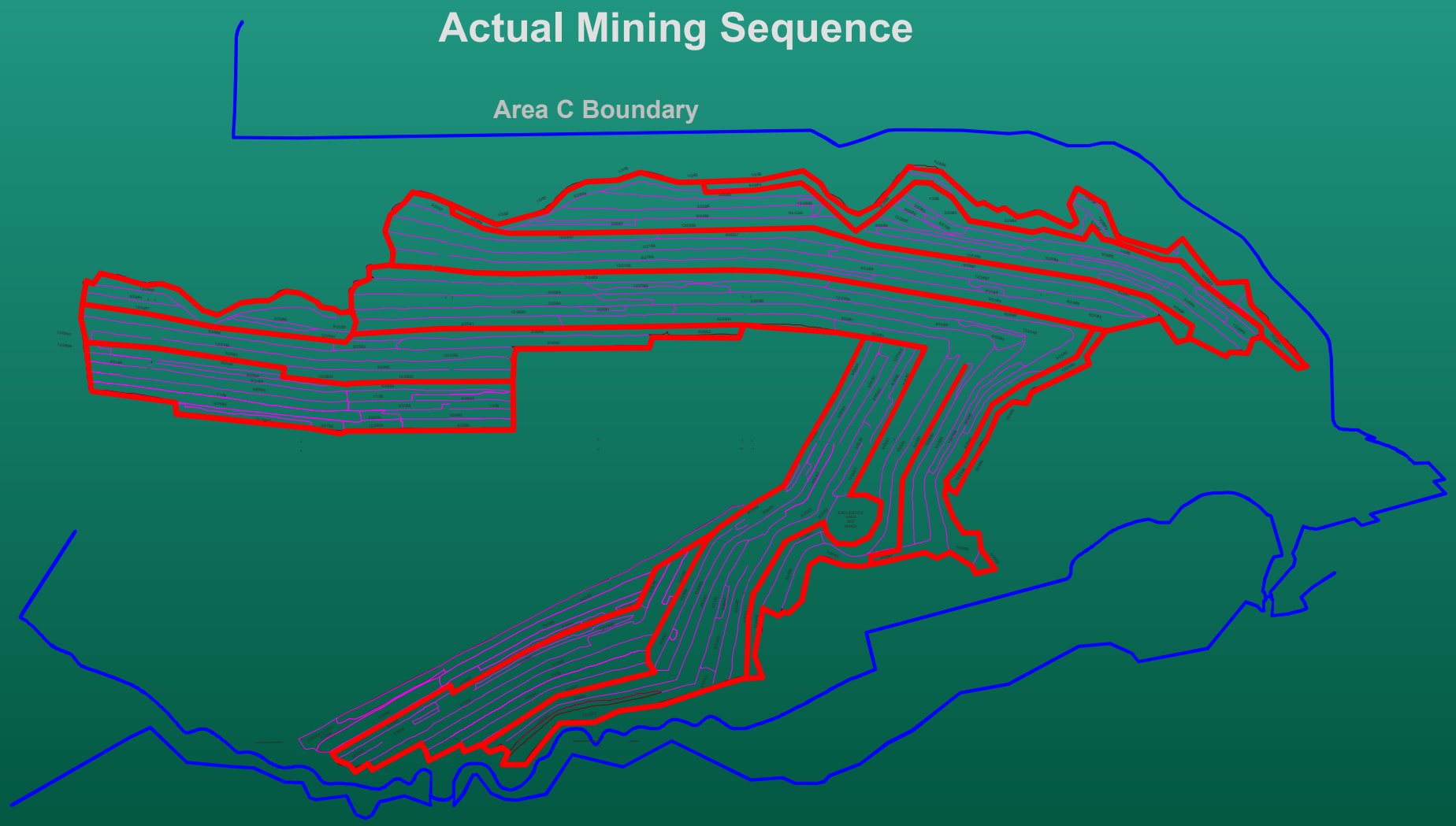


Steady-State Model Residual Plot, Layer 2

(units of measurement are meters; wells shows are Rosebud wells)

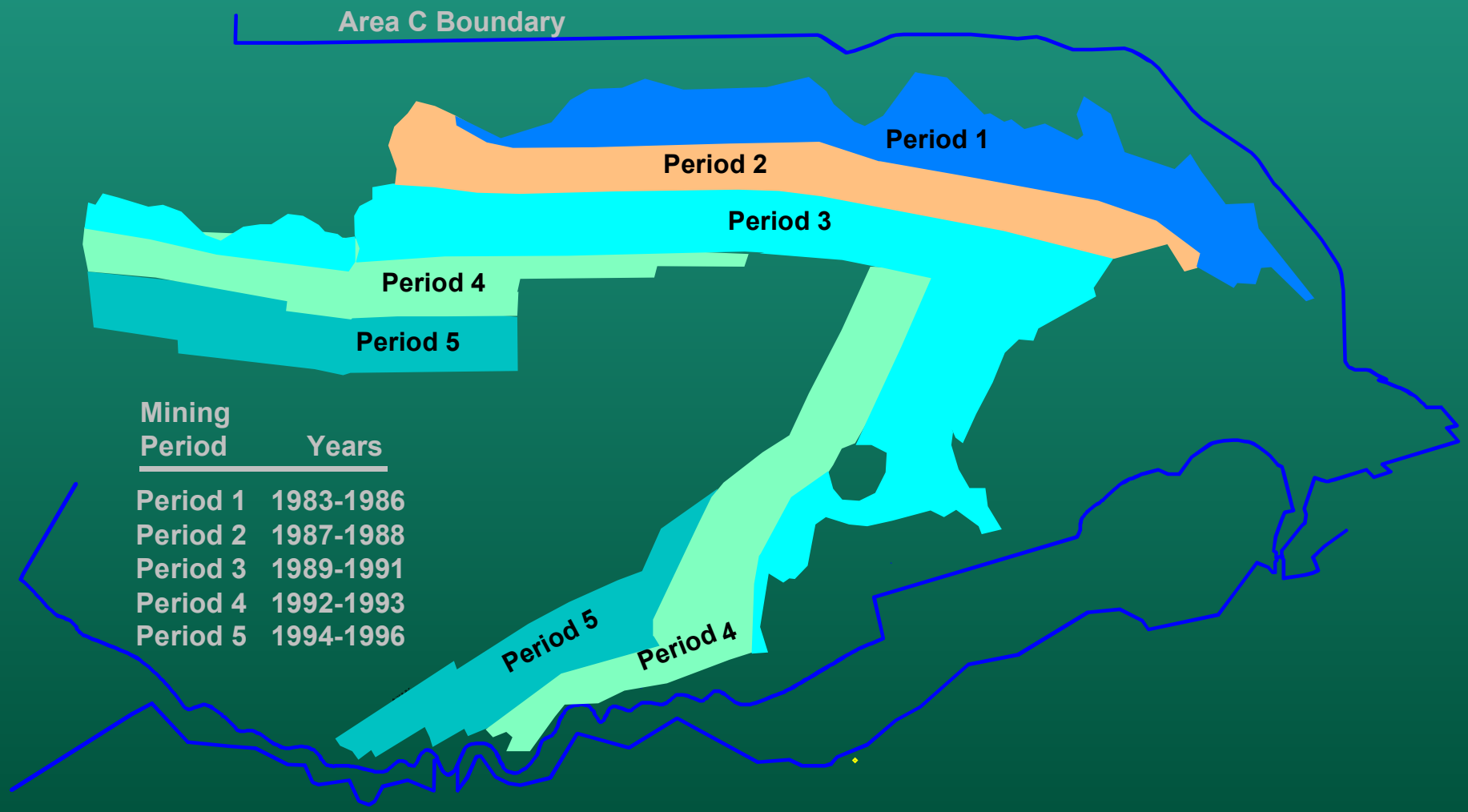


Transient Calibration/Application Phases



Simplication of Mining Process

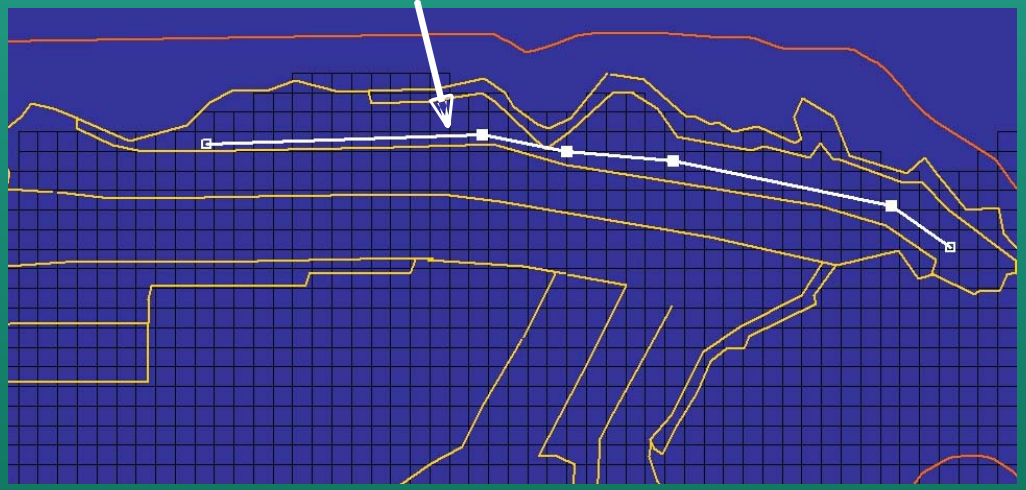
Representation of Historic Mining Through 1996



Mining Period	Years
Period 1	1983-1986
Period 2	1987-1988
Period 3	1989-1991
Period 4	1992-1993
Period 5	1994-1996

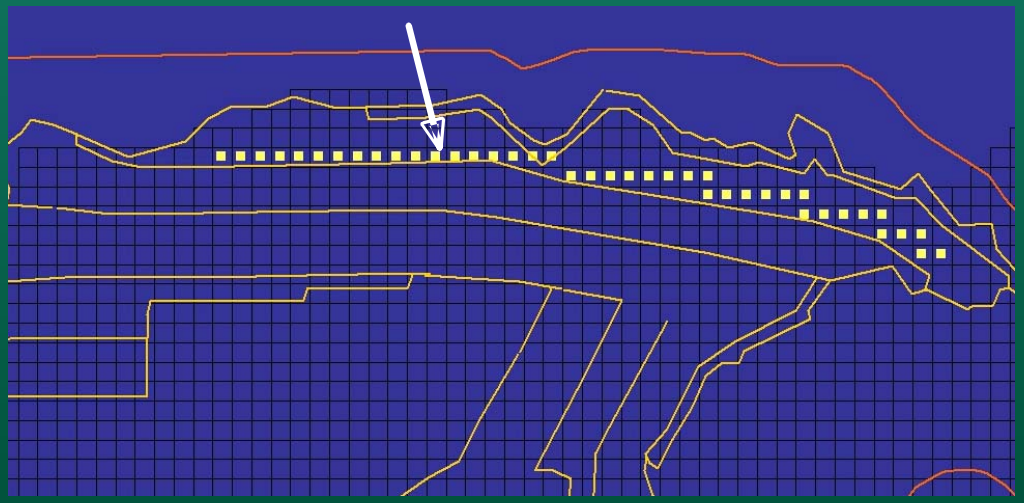
Using GMS to Represent Mining Activity

ARC Possessing
Drain Characteristics



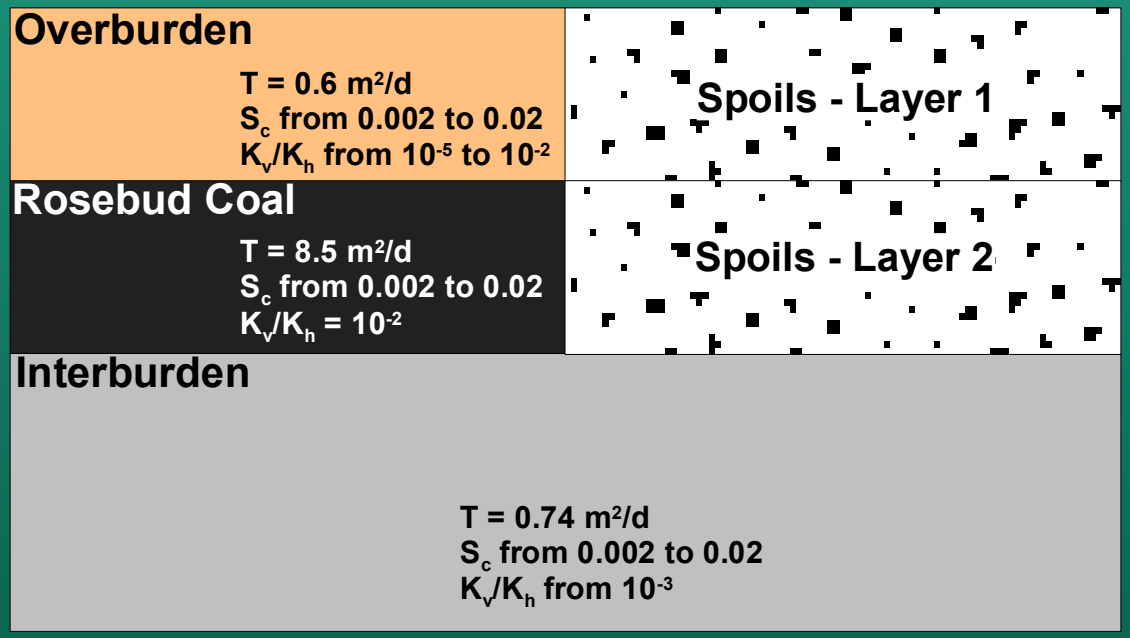
Arcs are created to represent drains in GMS. The arcs contain drain elevation data and drain conductance information. The elevations of the drains were assigned on the basis of WECO contour data for the base of the Rosebud Coal.

ARC is Transformed
to MODFLOW drain cells



The Arc data were transformed to model cell drains for MODFLOW. Once a mining stress period is completed, a new ARC is created for the next mining sequence and the former drain features are removed. The process is repeated until the entire mining plan period is completely emulated.

Transition of Parameters: Overburden and Rosebud Coal Replaced with Spoils



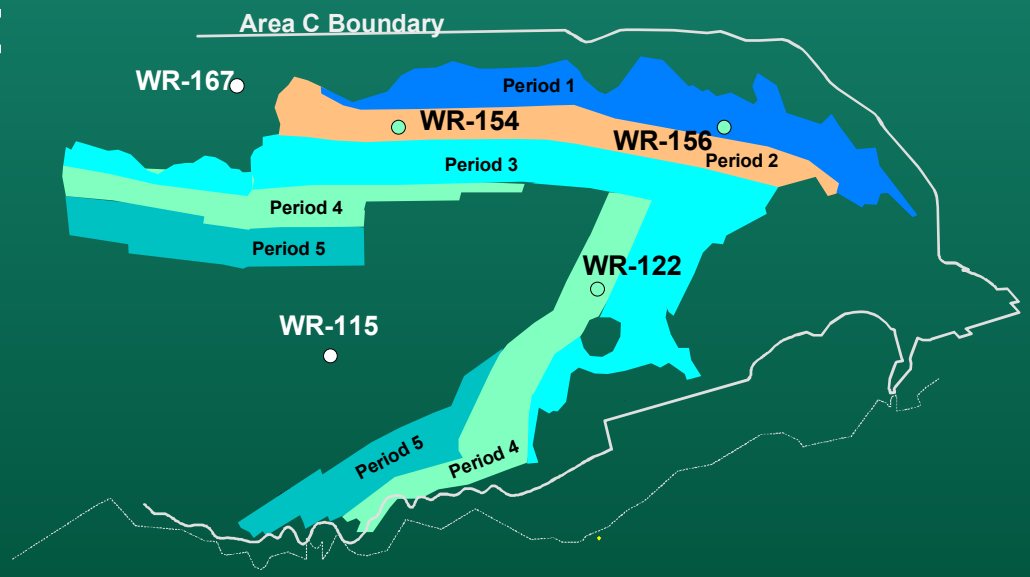
The parameters in the section that had been mined during the previous time step are replaced with model parameters representative of mine spoils.

Spoils for Layer 1 and 2
$T = 4.6\ m^2/day$ (each)
S_c from 0.1 to 0.3
$K_v/K_h = 10^{-1}$

Transient Calibration

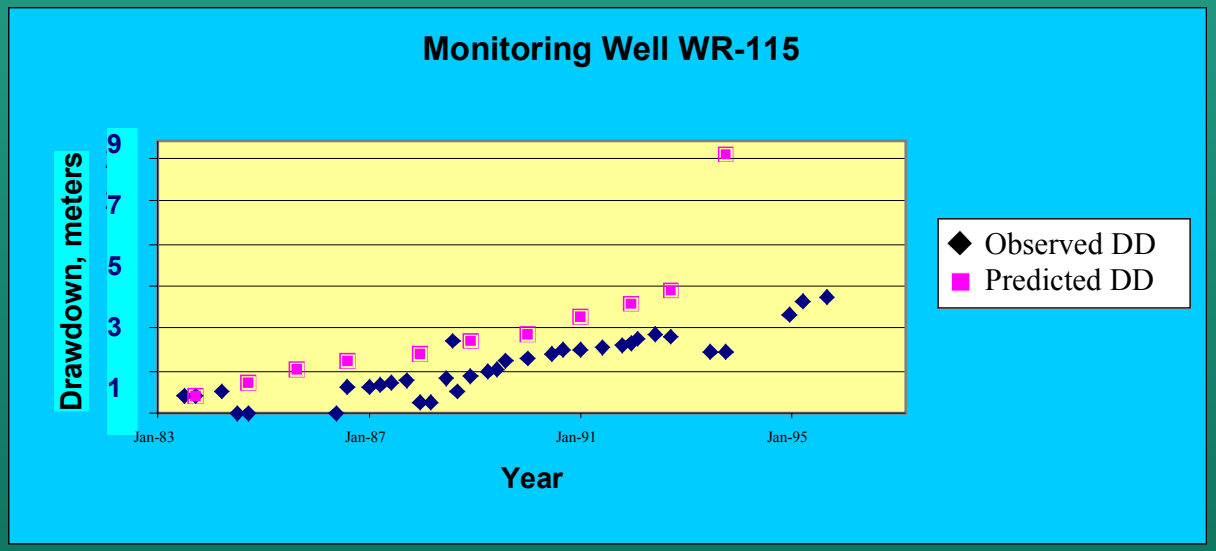
Based Upon Mining Sequences

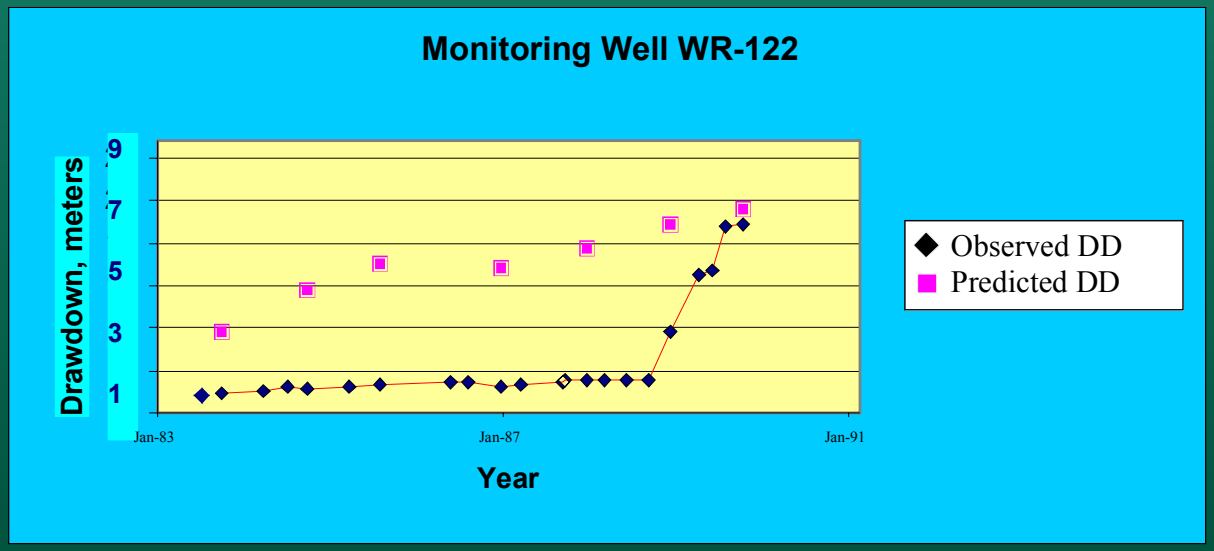
- Transient calibration used long-term observations made at wells in the vicinity of mining.
- These wells were:
  - WR-115
  - WR-122
  - WR-154
  - WR-156
  - WR-167



Example of Transient Calibration Process for Wells WR-115 and WR-122

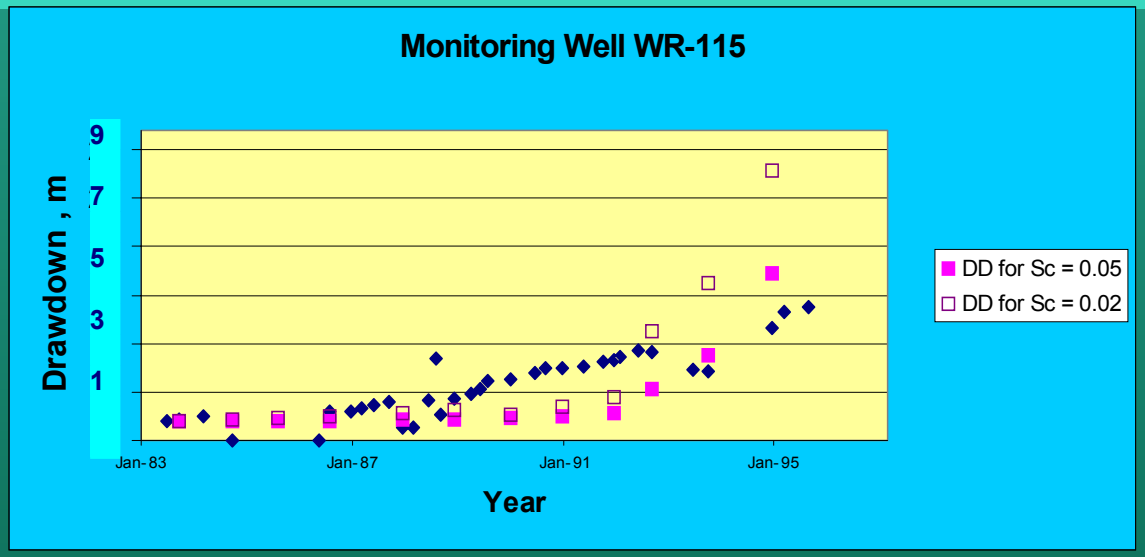
$S_c = 0.002$

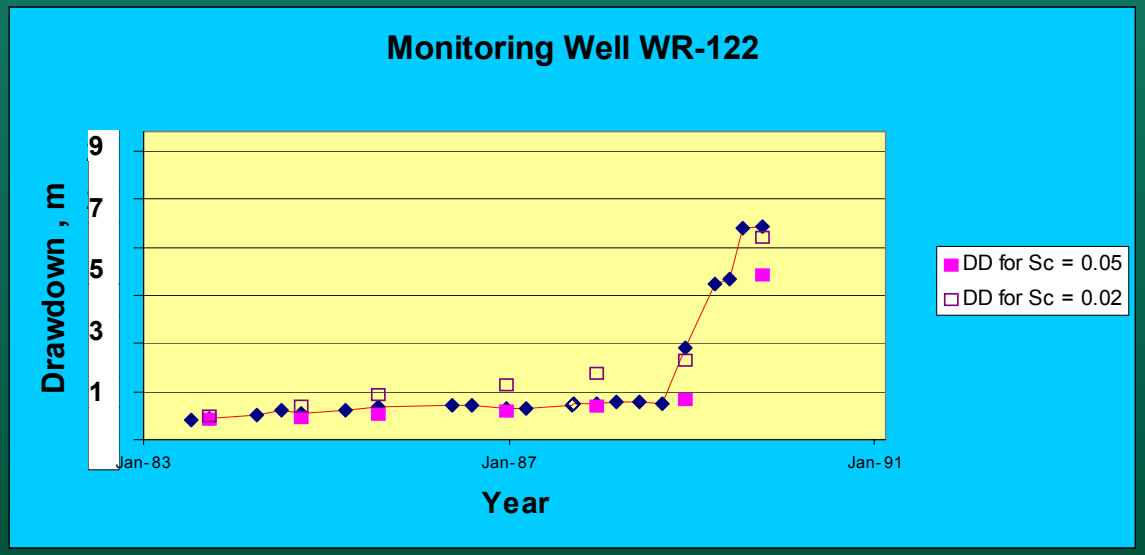




Example of Transient Calibration Process for Wells WR-115 and WR-122

S_c = 0.02 to 0.05

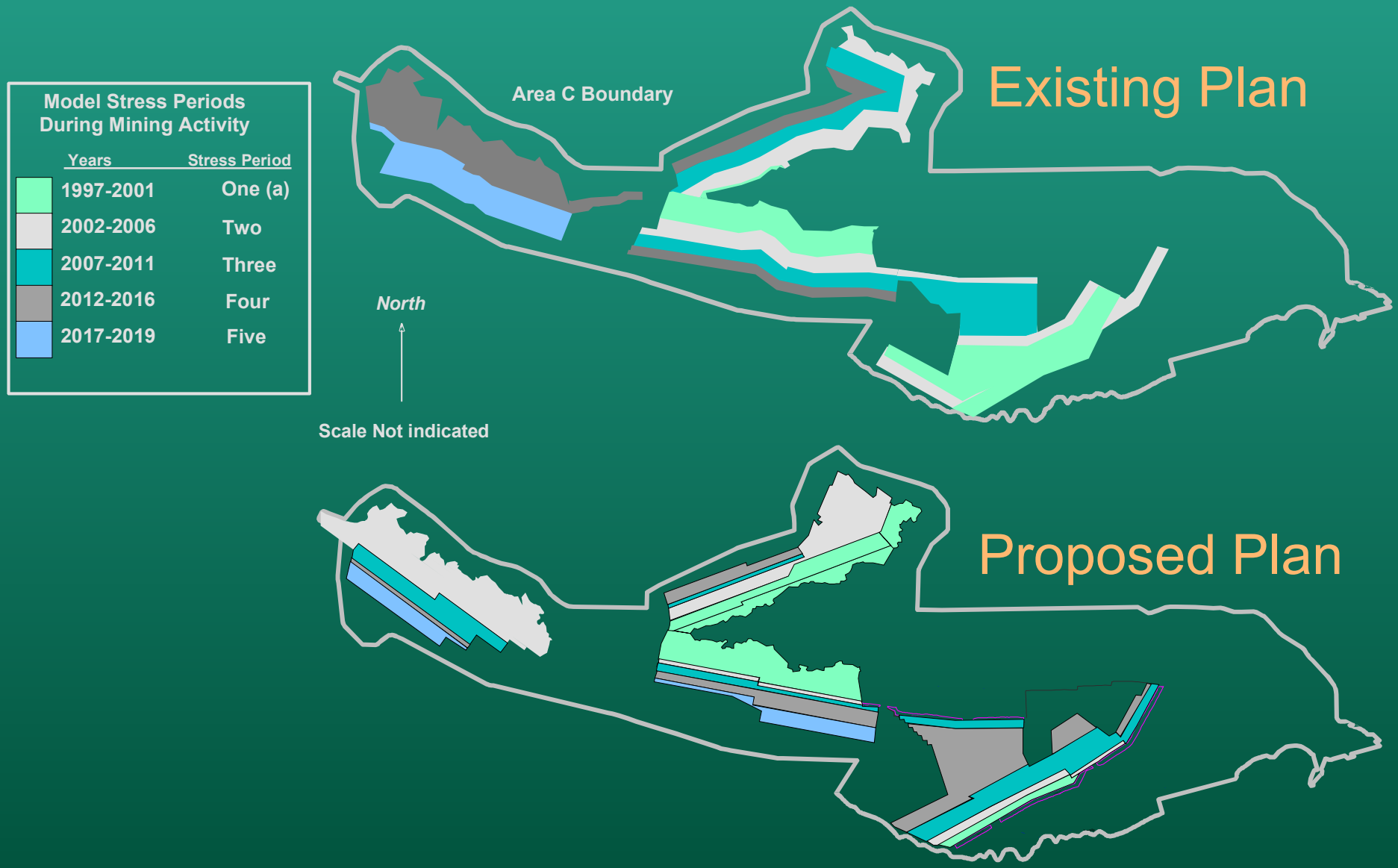




Flow Evaluation

- Extraction rates from pits: worked to obtain flow rates similar to those observed at mine operations.
- Extraction rates near E. Fork Armells: compared model results to these rates during mining (~ 2,600 m^3/day). (NOTE: Rates computed for E. Fork Armells's rate were similar to rates observed in the field [~ 550 gpm].)
- Differences in extraction rates for existing and proposed mine plans: evaluation predicted extraction rate for proposed plan to be ~64 to 112 gpm greater than for existing plan.

Procedure Applied to Mining Activity Called for Under Existing and Proposed Mine Plans



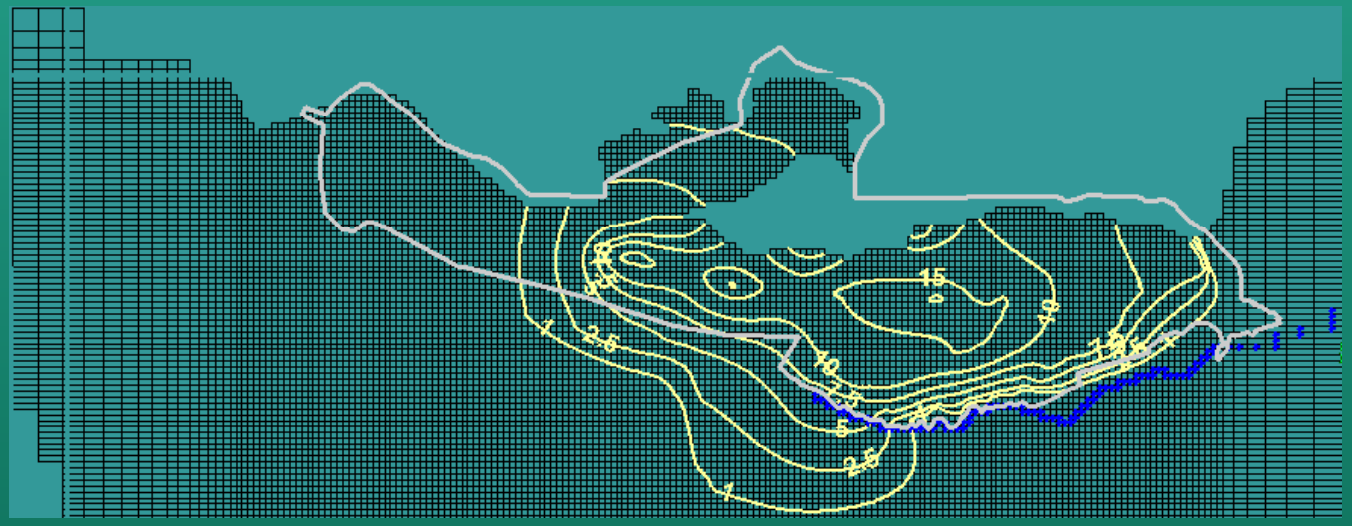
Predictions Evaluated Relative to Operations Projected Under the Two Plans

- Parameters at issue during mining were:
  - Potentiometric response
  - Mass balance
- With respect to each of these parameters, found and compared differences in the same parameters after mining.

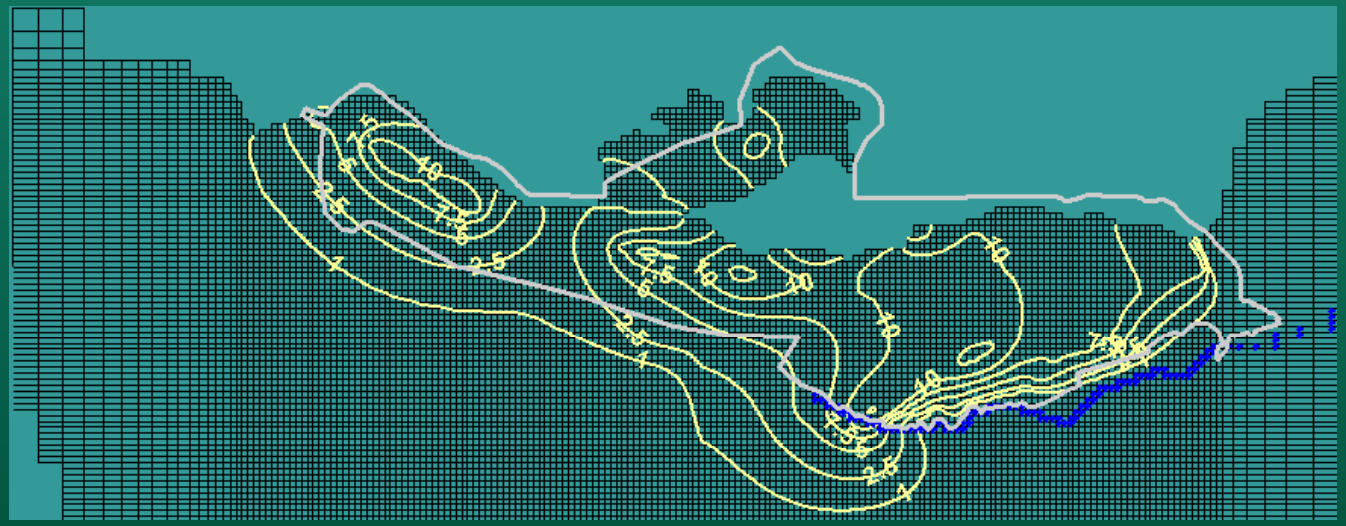
Example of Predicted Response During Future Mining

(units of measurement are meters)

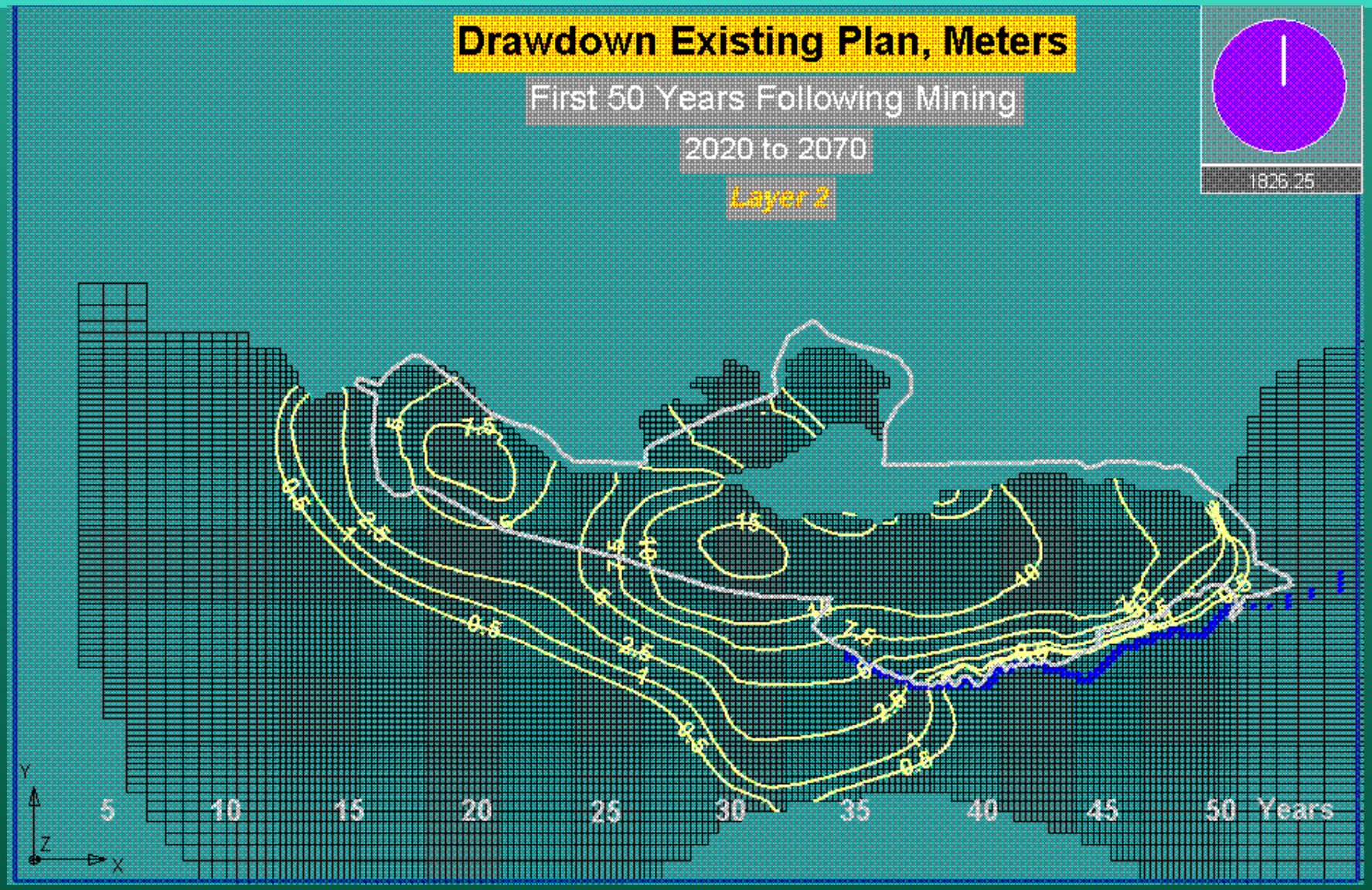
Drawdown,
Existing Plan,
Year 2006



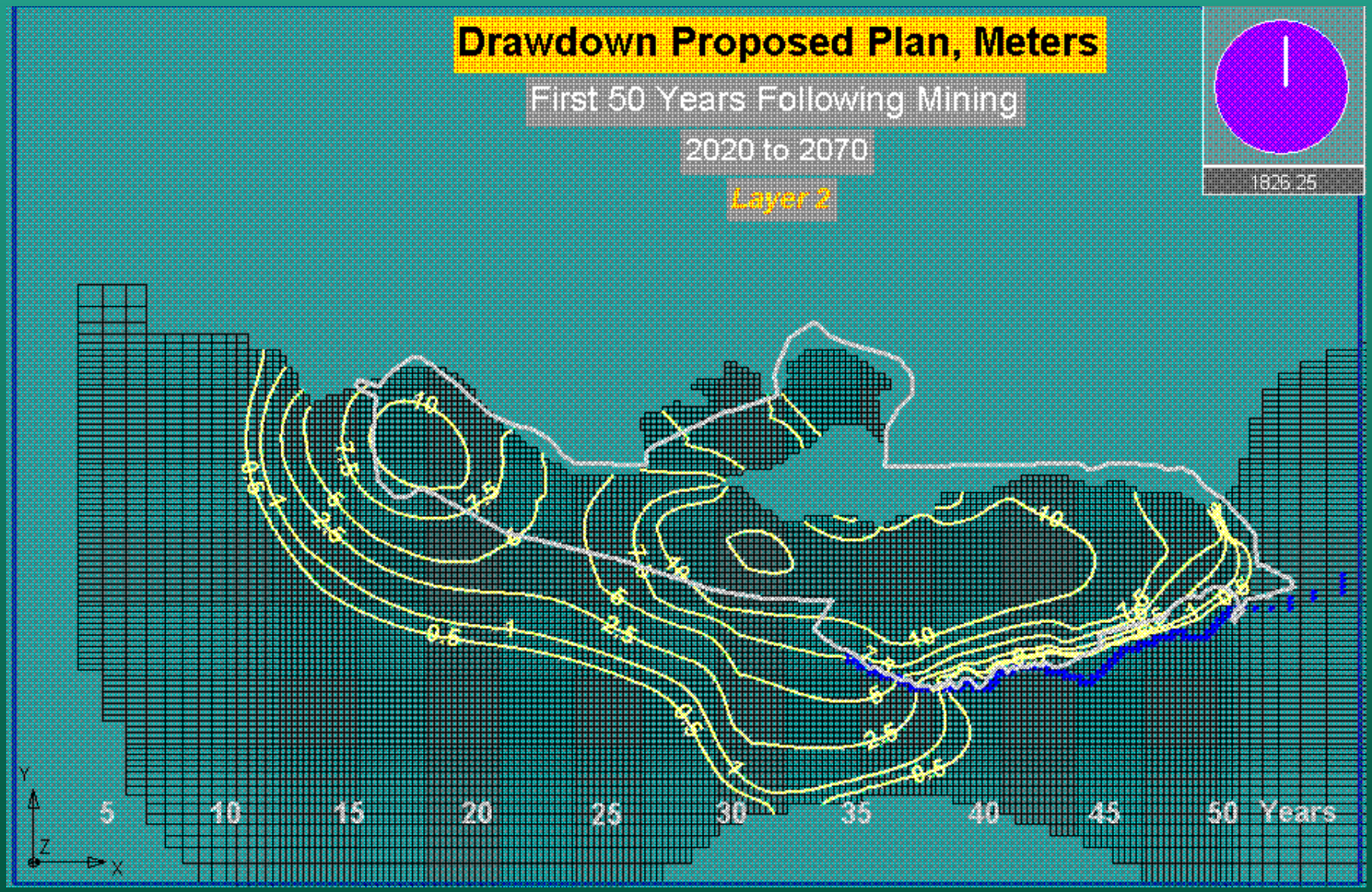
Drawdown,
Proposed Plan,
Year 2006



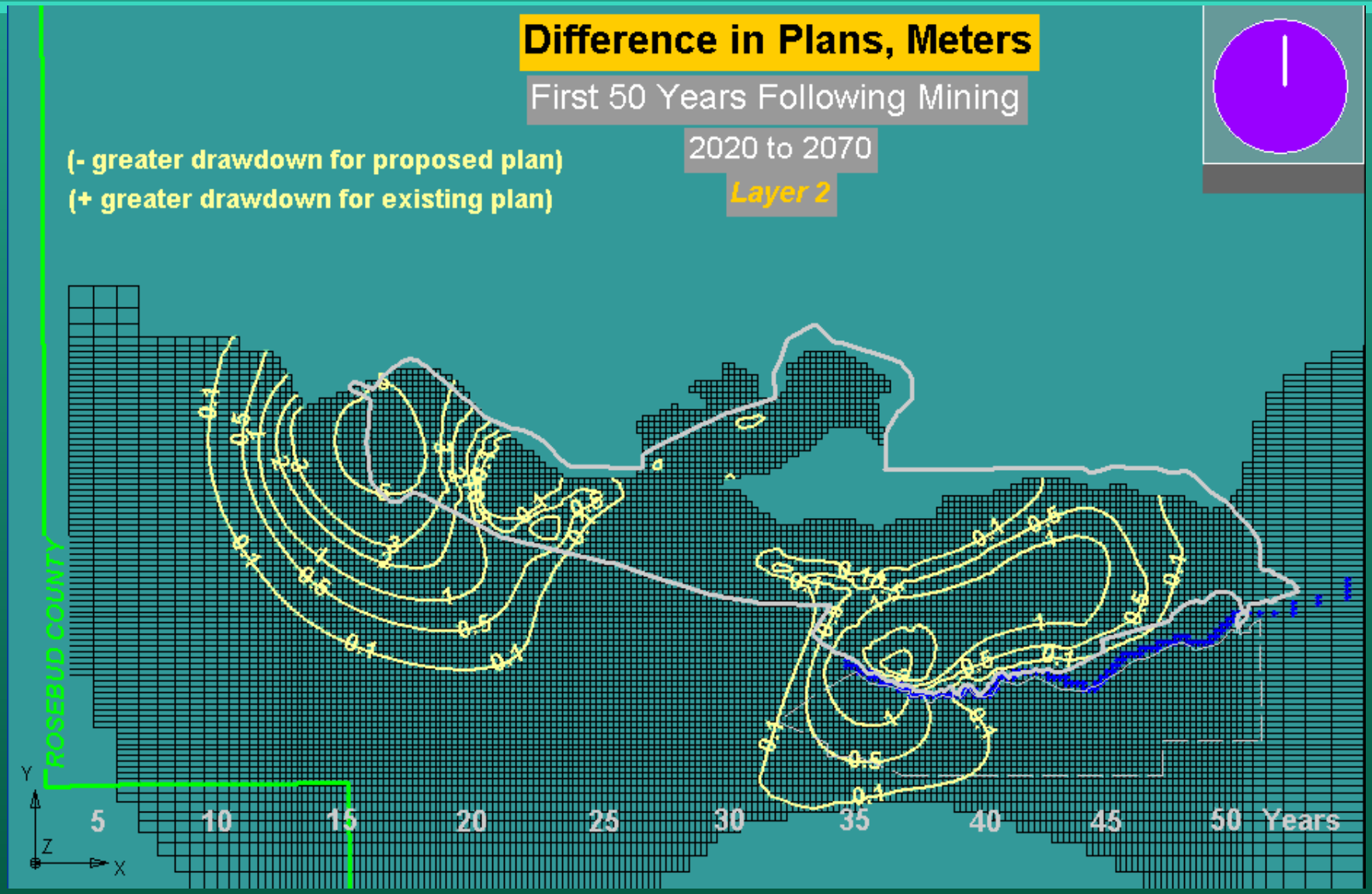
Predicted Long-Term Postmining Response



Predicted Long-Term Postmining Response



Predicted Long-Term Post Mine Response



Summary and Conclusions

- Model produces conservative results.
- Transmissivity parameters and recharge values correpond well with data presented in the EIS.
- Pumping test storage coefficients not representative of long-term yields.
- Differences in the plans predicted mainly associated with mine sequencing changes.
- Proposed Plan predicted to extract ~ 350 to 610 m^3/day (~64 gpm to 112 gpm) greater for Proposed Plan than Existing Plan over life of mine.

Limitations

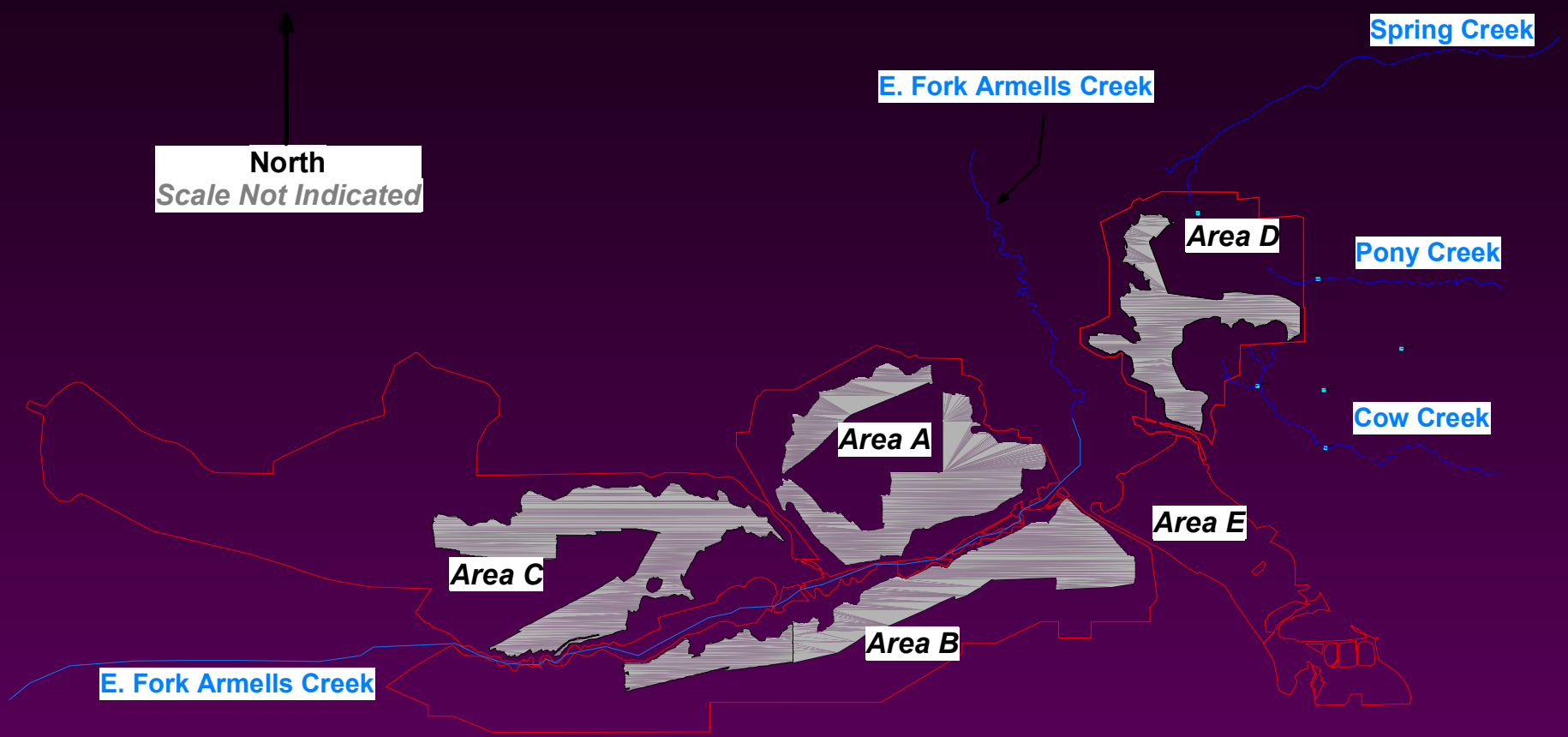
- Model assumes each layer is of constant thickness.
- Mine dewatering is assumed to be continuous. It actually varies in time during mining activity.
- There is significant parameter uncertainty.
- Nature of hydrologic flow regime outside Area C is unknown or not well quantified, particularly to the southwest.
- Solutions are not unique.
- Models are predictive tools representing simplications of complex systems.

Use of a Localized Ground-Water Model to Predict Relative Impacts of the Life-of-Mine Plan for Rosebud Area D, Near Colstrip, Montana

Michael Nicklin, Ph.D., P.E.
Nicklin Earth & Water, Inc.

Greg Liebelt
Western Energy Company

Western Energy Company
Mining Activity Near Colstrip, Montana



Model Objectives

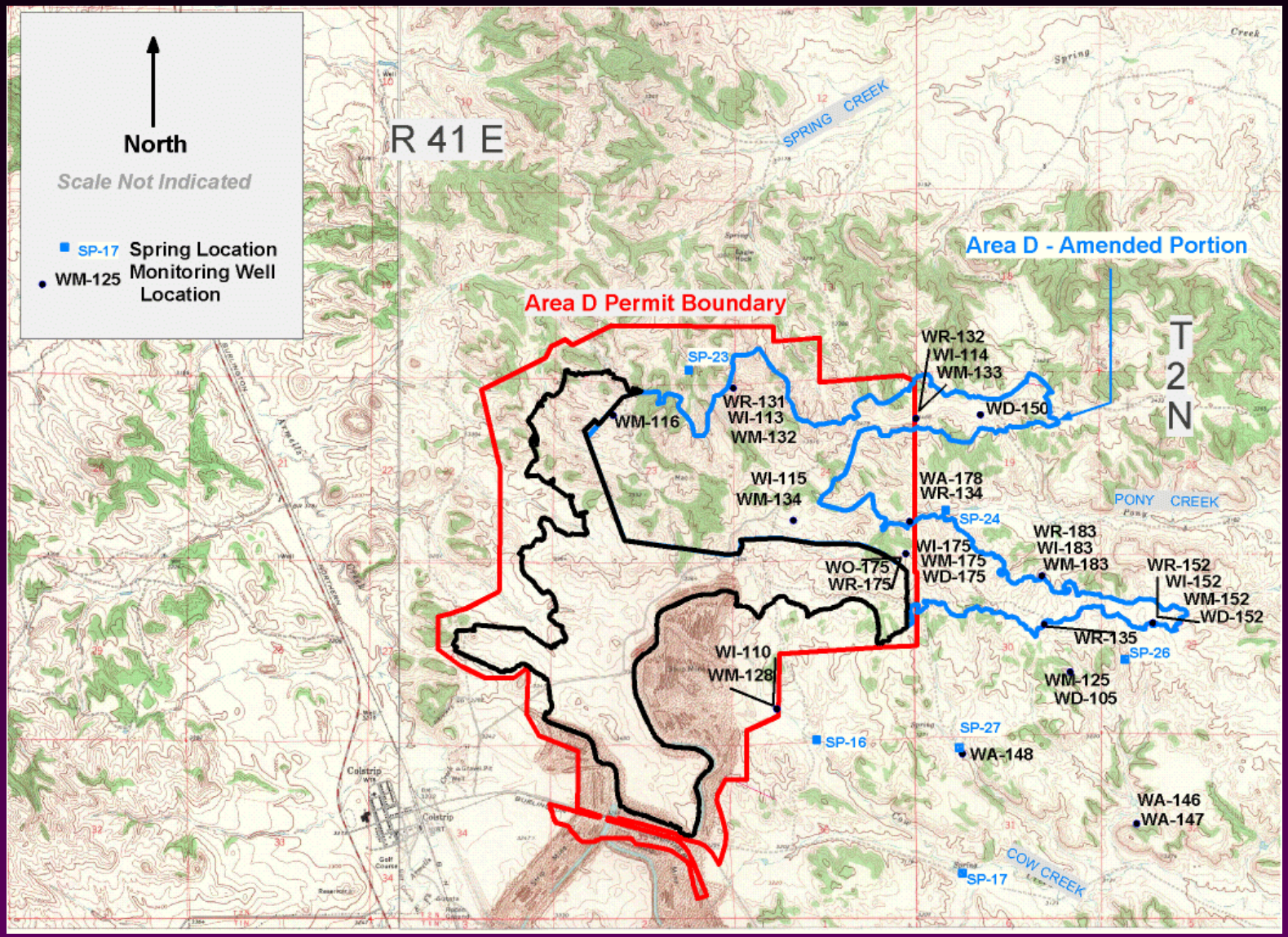
Western Energy Area D Model

- Objective 1: Develop a conceptual understanding of the hydrogeologic regime in the vicinity of Area D.
- Objective 2: Develop a model of predictive capability.
- Objective 3: Predict temporal and long-term responses associated with mining activity in Area D under both the permitted mine plan and an amended mine plan.

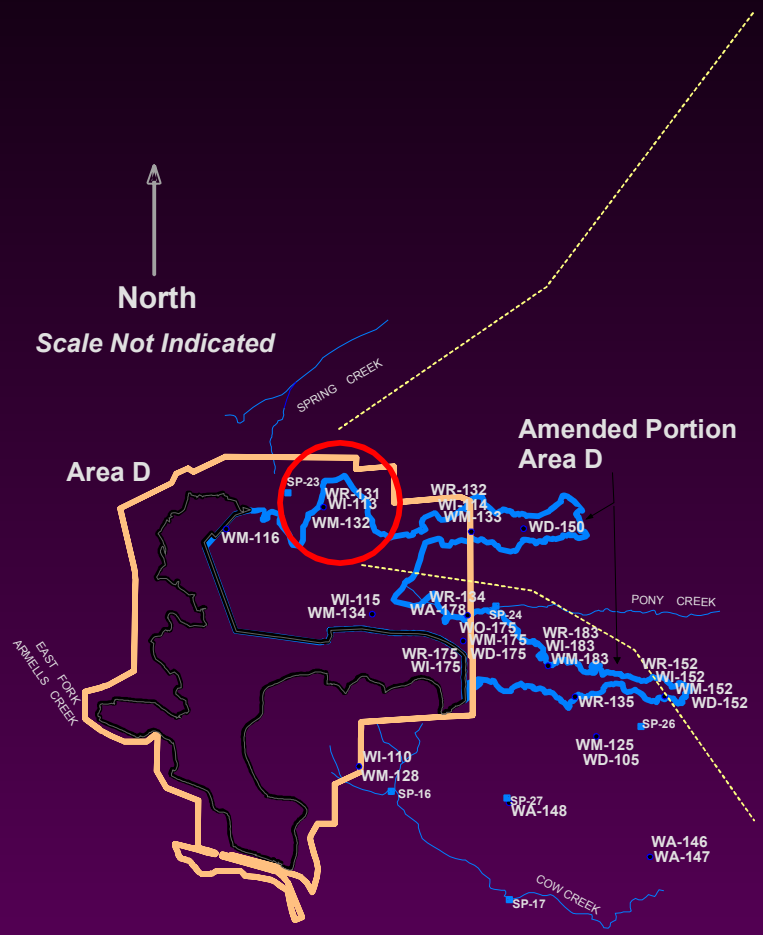
Some Conceptual Issues

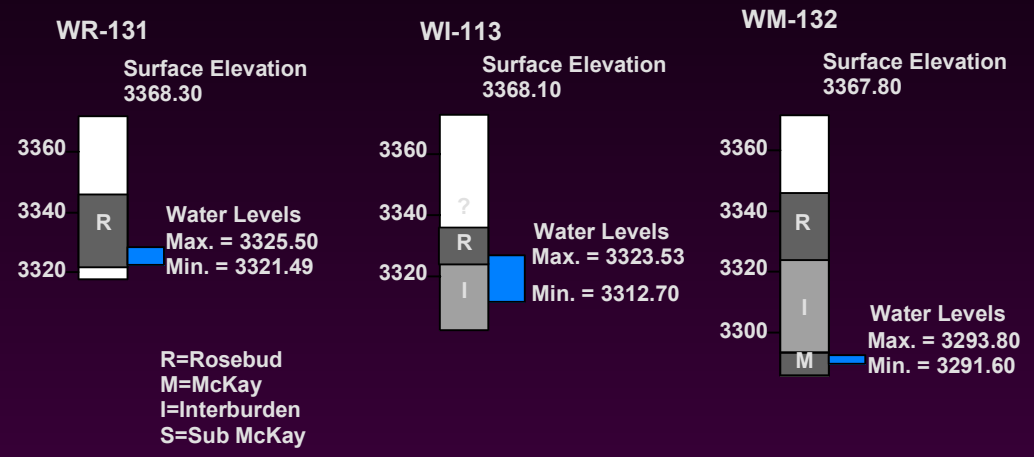
- Area D is isolated from regional flow sources. It is a hydrologic "island."
- Area D has limited water quantities.
- There is significant vertical impedance of flow.
- Relative separation between the potentiometric heads of Rosebud coal and McKay coal decreases directionally in proportion to thinning interburden.
- A main source of stock water in the area is "springs" or shallow ground water.

Topographic Setting



An Example of Vertical Impedance

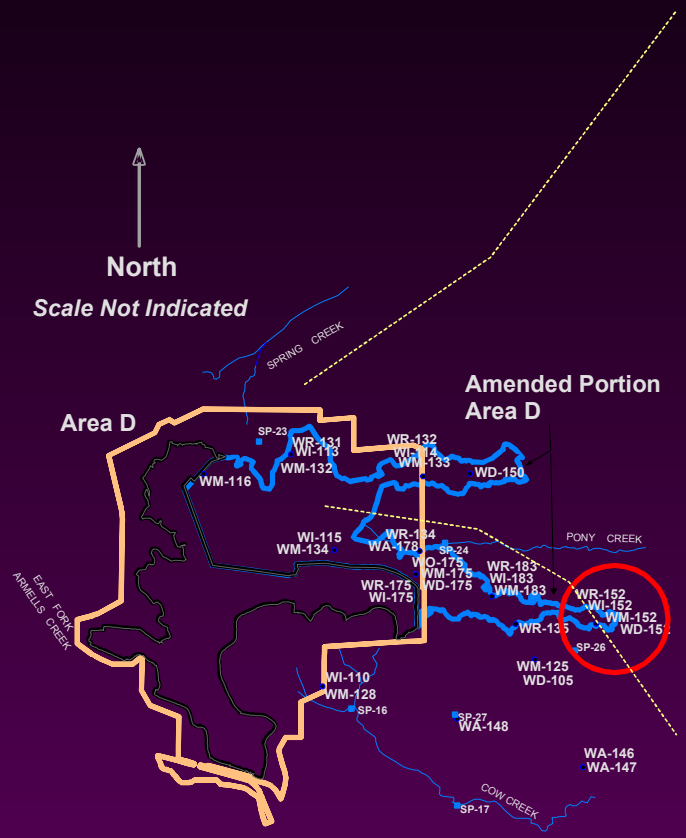


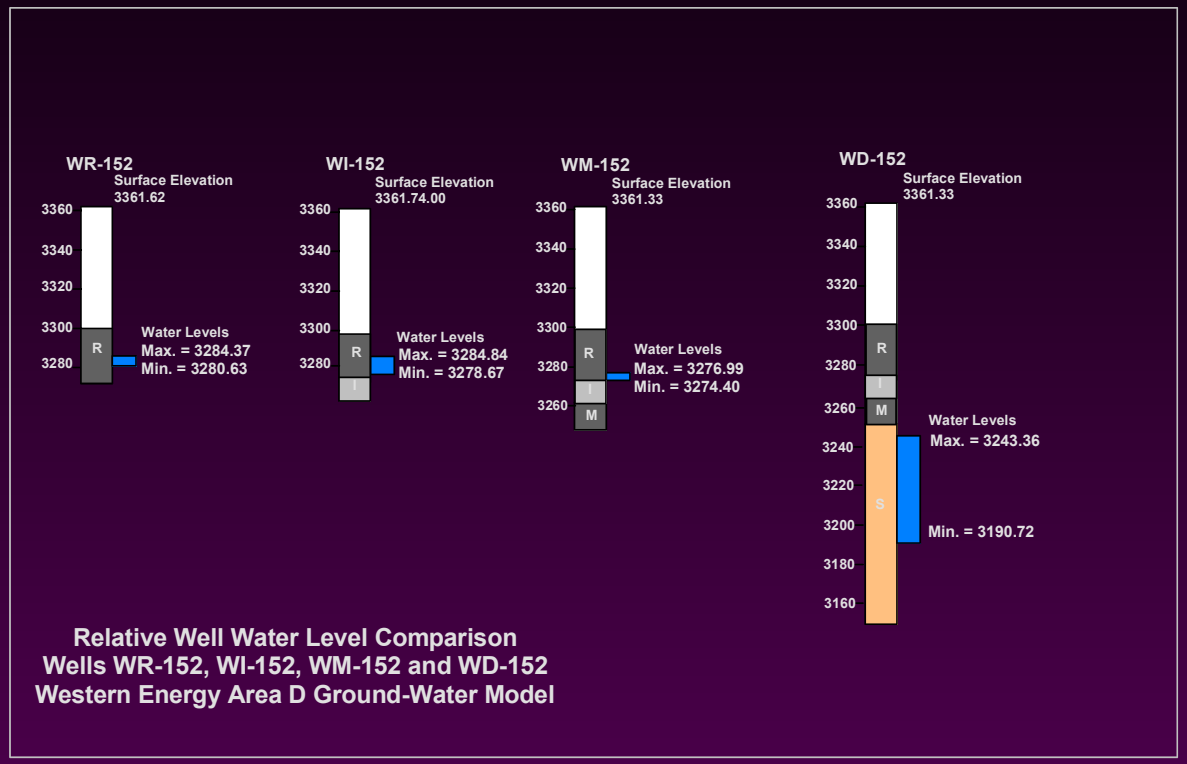


Relative Well Water Level Comparison
Wells WR-131, WI-113 and WM-132
Western Energy Area D Ground-Water Model

NICKLIN
EARTH & WATER, INC.

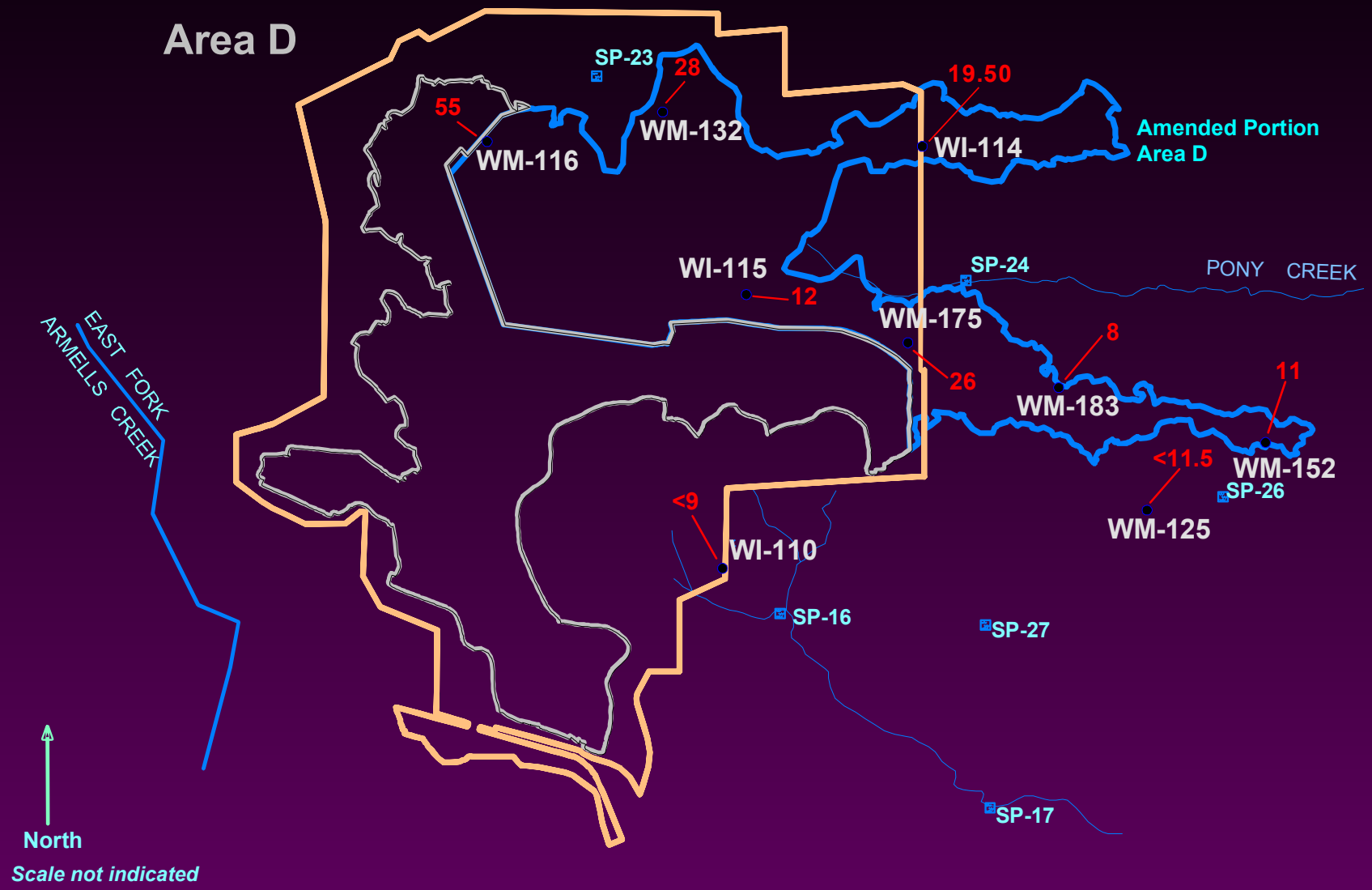
Another Example of Vertical Impedance





NICKLIN
EARTH & WATER, INC.

Thinning Interburden



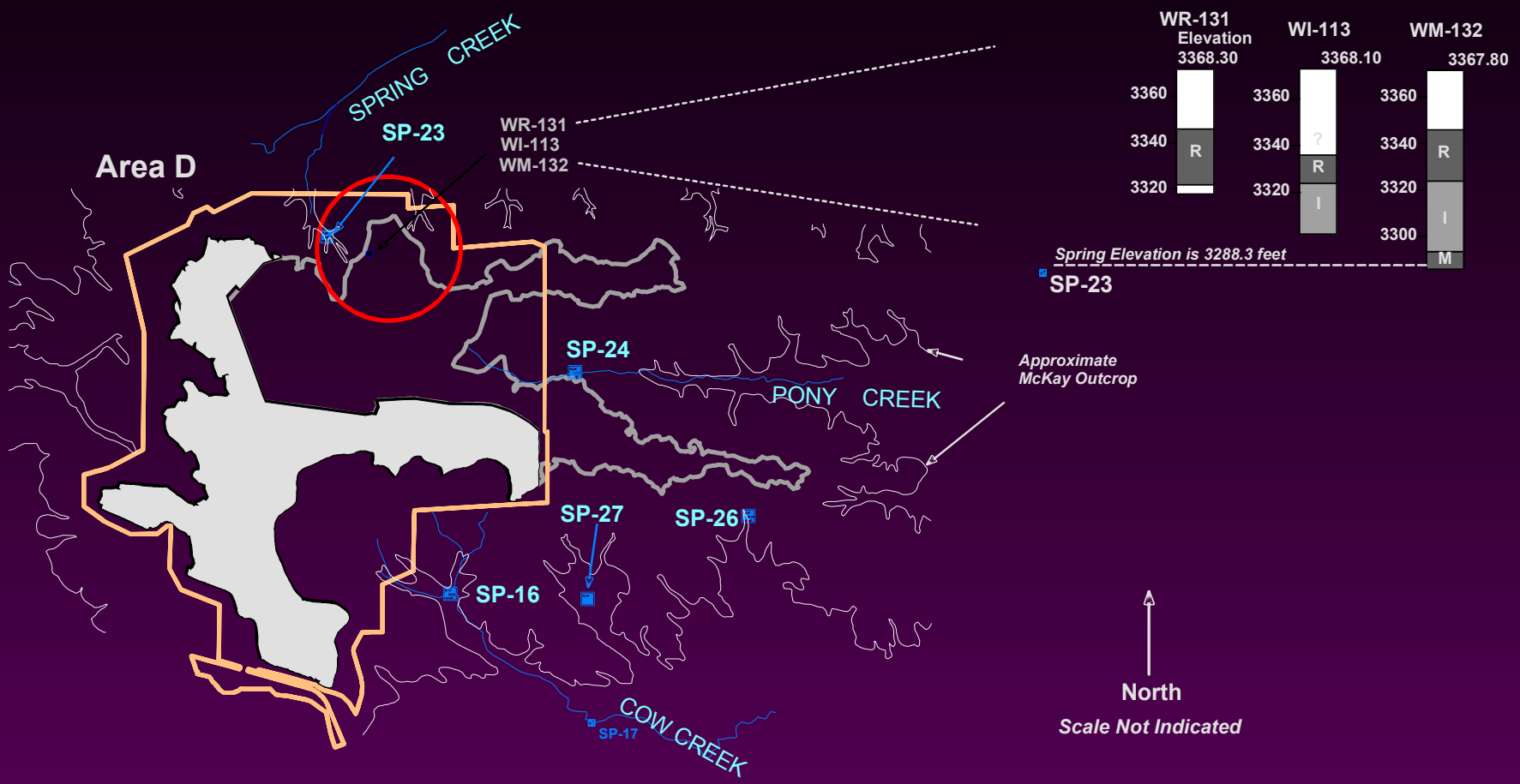
Some Wyoming Department of Environmental Quality Concerns

- From what units do the springs issue?
  - Rosebud coal?
  - McKay coal?
- There is a potential for springs to be lost or spring flow to be reduced.
- Blasting activity may alter the vertical hydraulic conductivity of interburden.

Potentiometric Head Difference, Rosebud Coal Compared to McKay Coal

(units of measurement are feet)

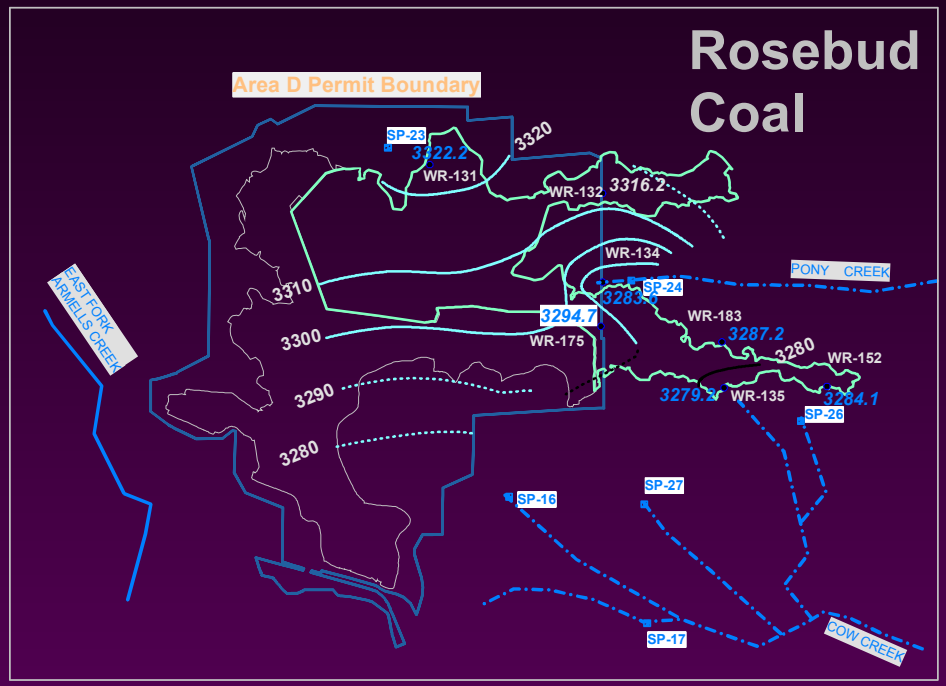
Source of Springs[2]

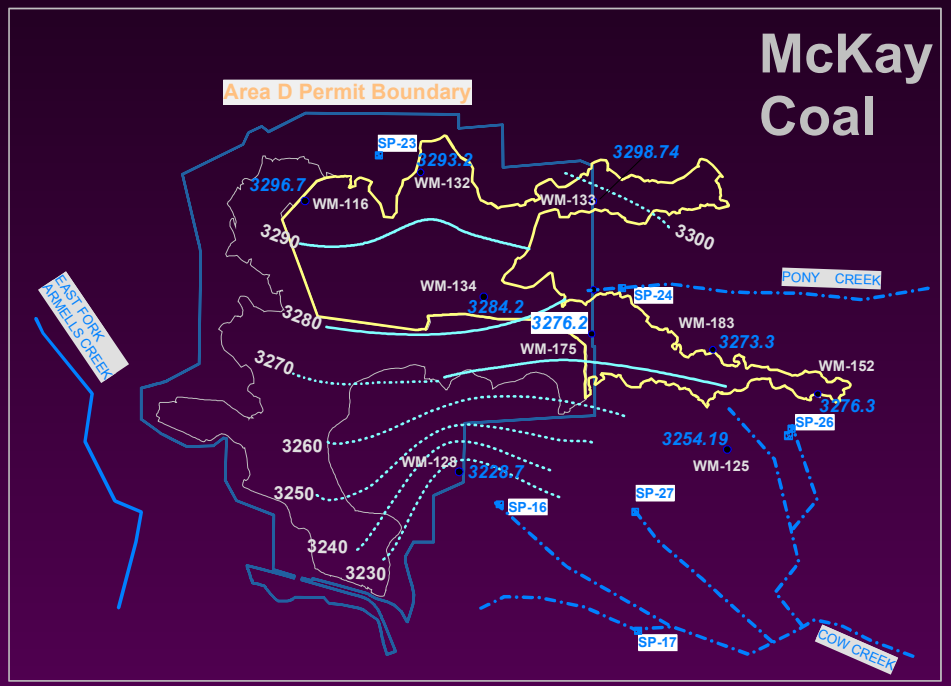


[2]Determined on the basis of coal-outcrop mapping and boring logs.

Potentiometric Maps, Rosebud Coal and McKay Coal

(units of measurement are feet; __)

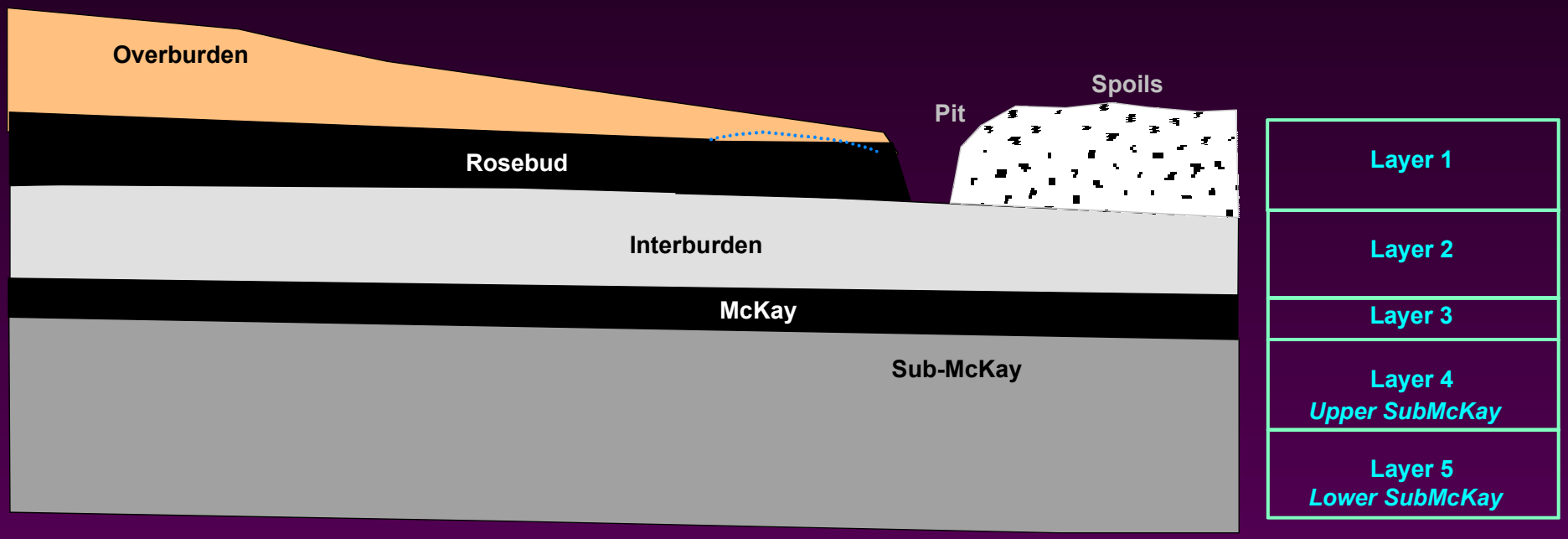




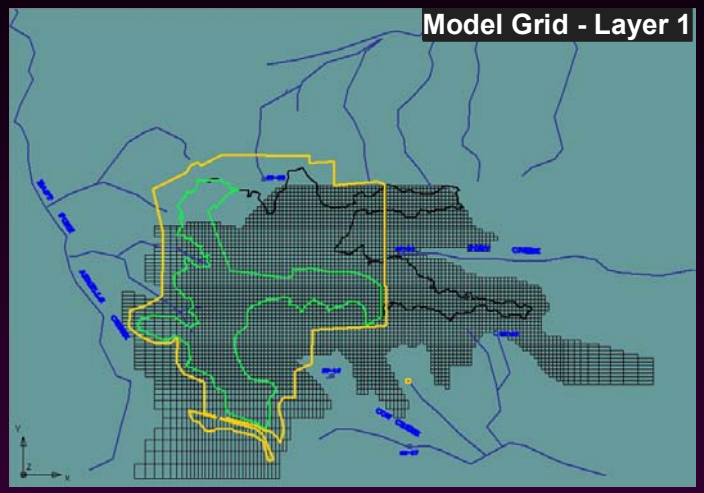
Model Construction

Five-Layer Model, Vertical Orientation

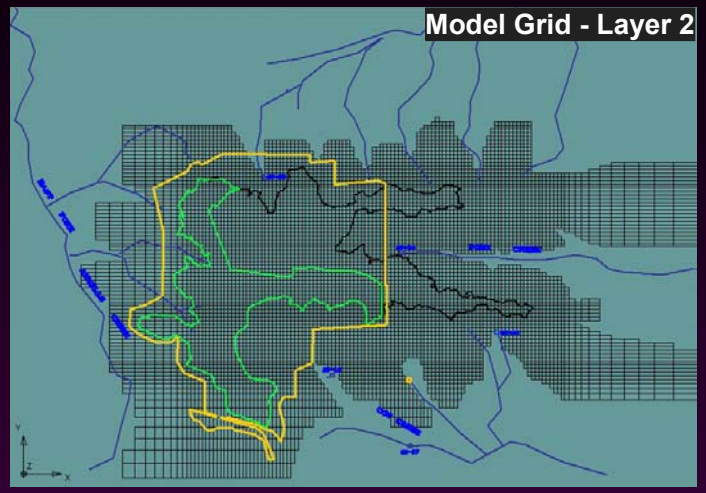
General Model Layer Representation



Horizontal Grid Structure

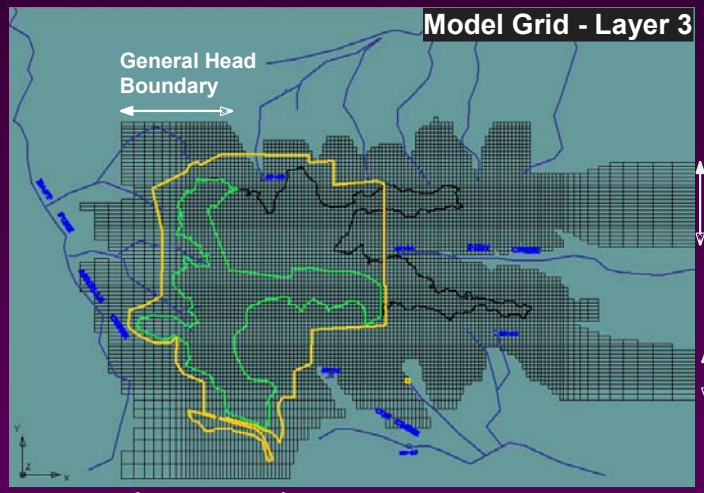


General Head Boundary



General Head Boundary

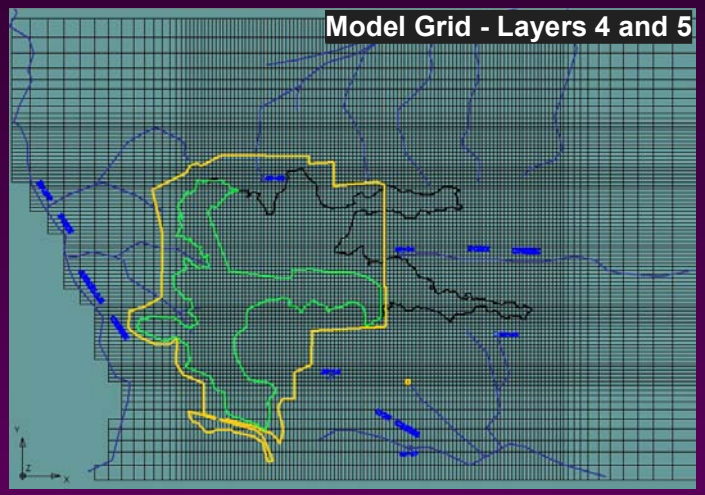
General Head Boundary



General Head Boundary

General Head Boundary

General Head Boundary

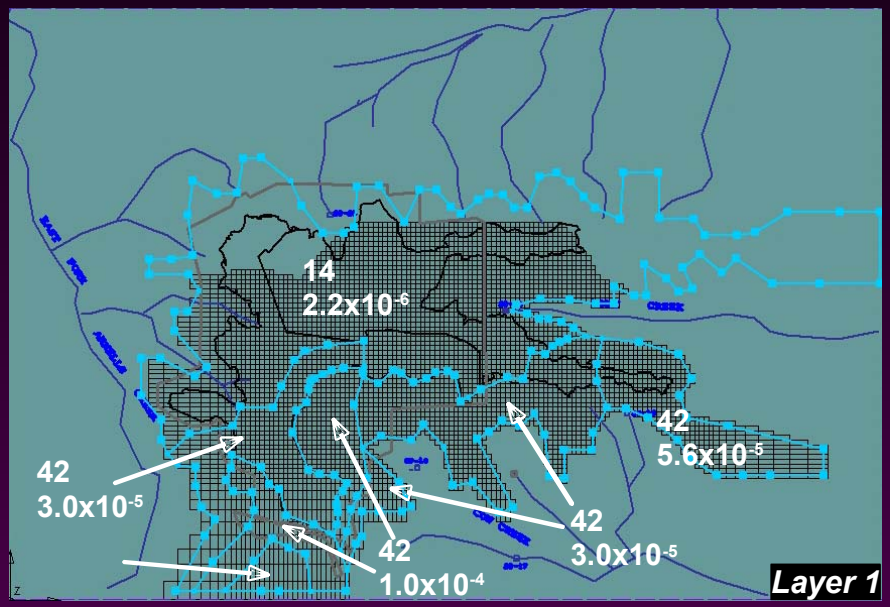


General Head Boundary

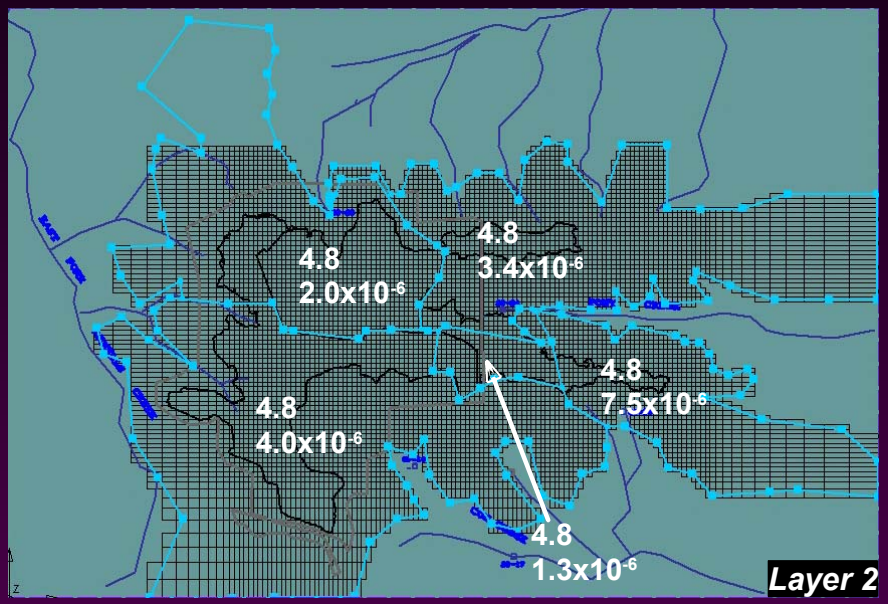
General Head Boundary

Calibration Process

(focus was principally on vertical leakage, less on horizontal hydraulic conductivity)

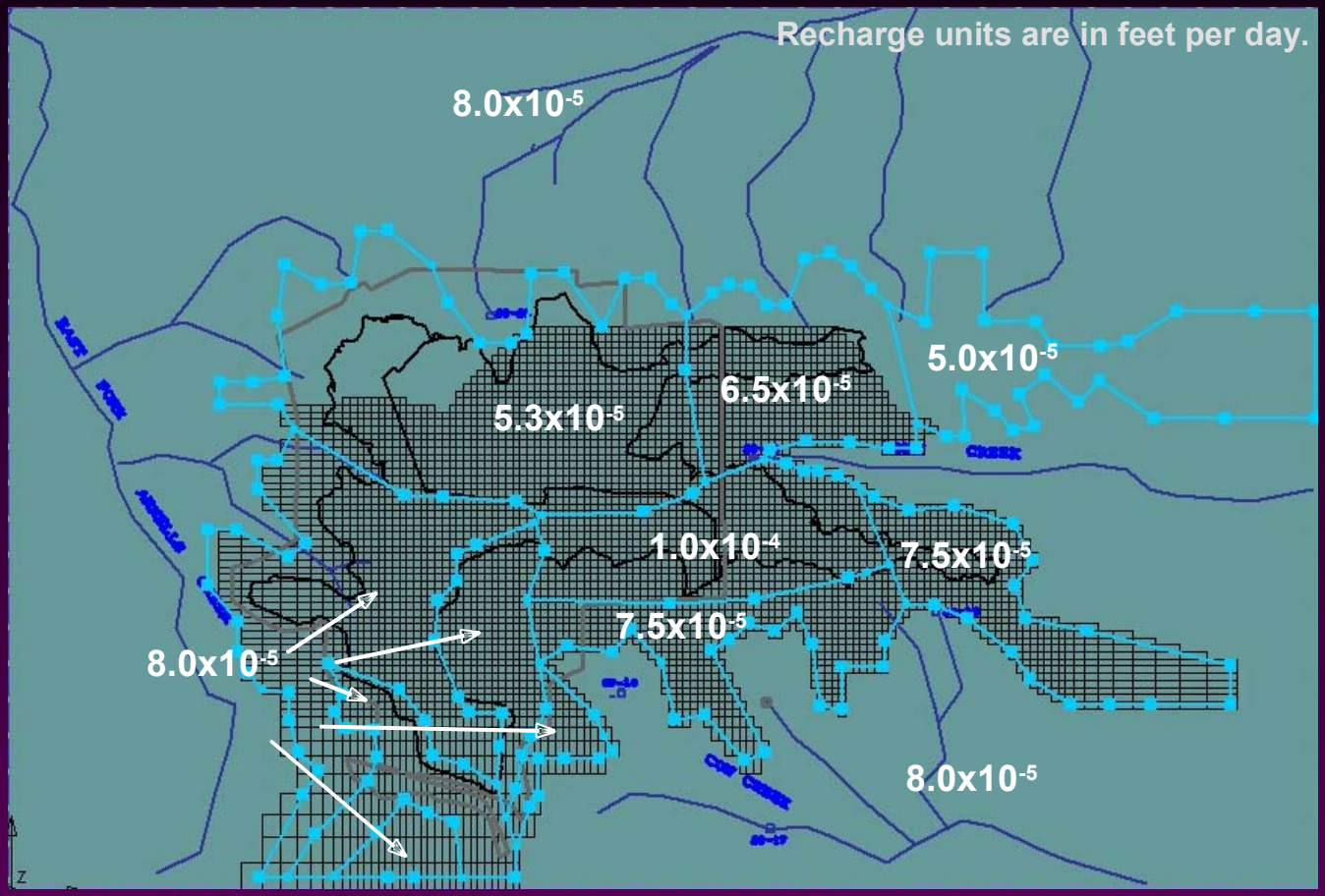


Note: It was assumed that transmissivities would increase to the south in association with greater saturated thickness in the Rosebud Coal. In addition, it was assumed that leakance between the Rosebud Coal and Interburden increased to the southeast.

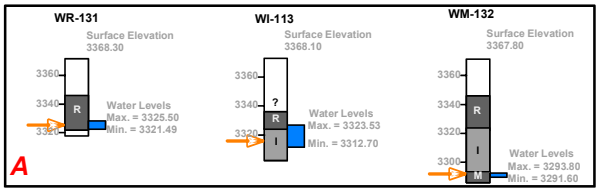


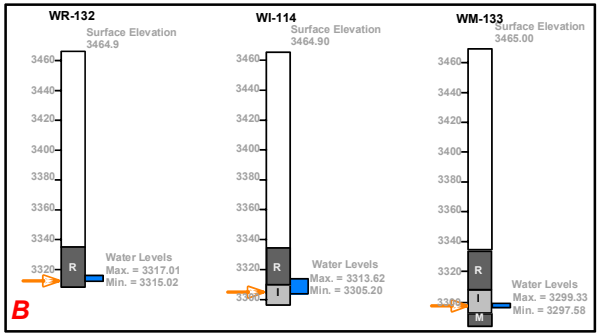
Note: It was assumed that transmissivity in the Interburden was constant over the model domain. In addition, it was assumed that leakance between the Interburden and McKay Coal increased to the southeast.

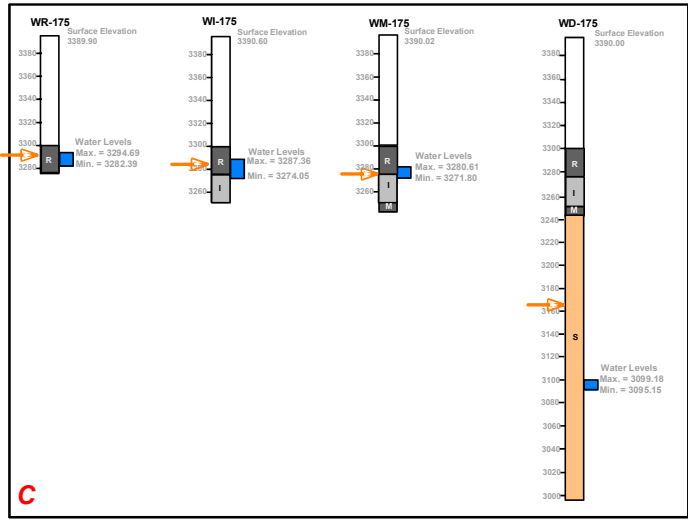
Recharge

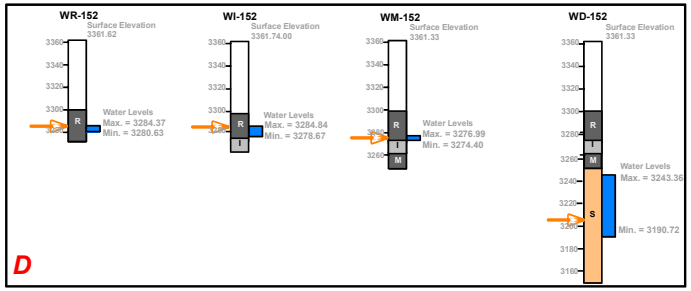

Recharge units are in feet per day.
8.0x10-5
5.0x10-5
6.5x10-5
5.3x10-5
1.0x10-4
7.5x10-5
7.5x10-5
8.0x10-5
8.0x10-5

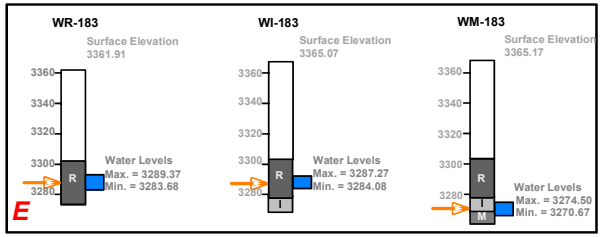
Comparison of Observed to Simulated Potentiometric Head (feet, msl)

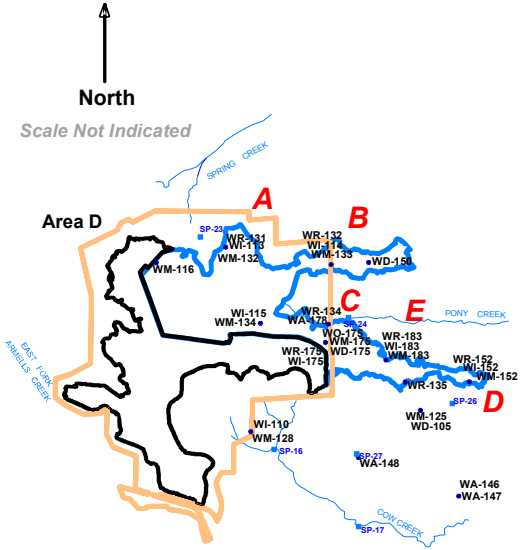








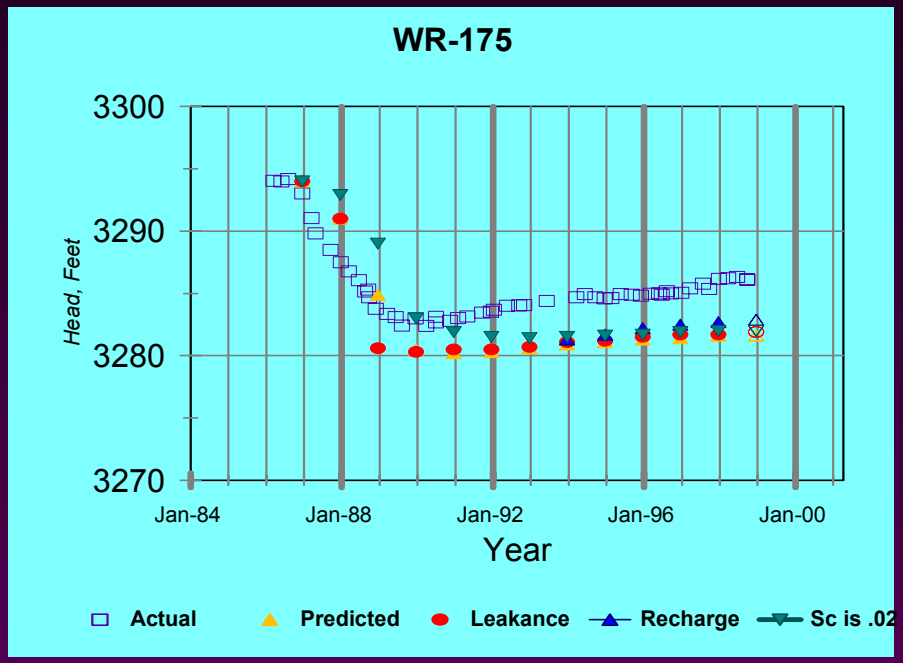


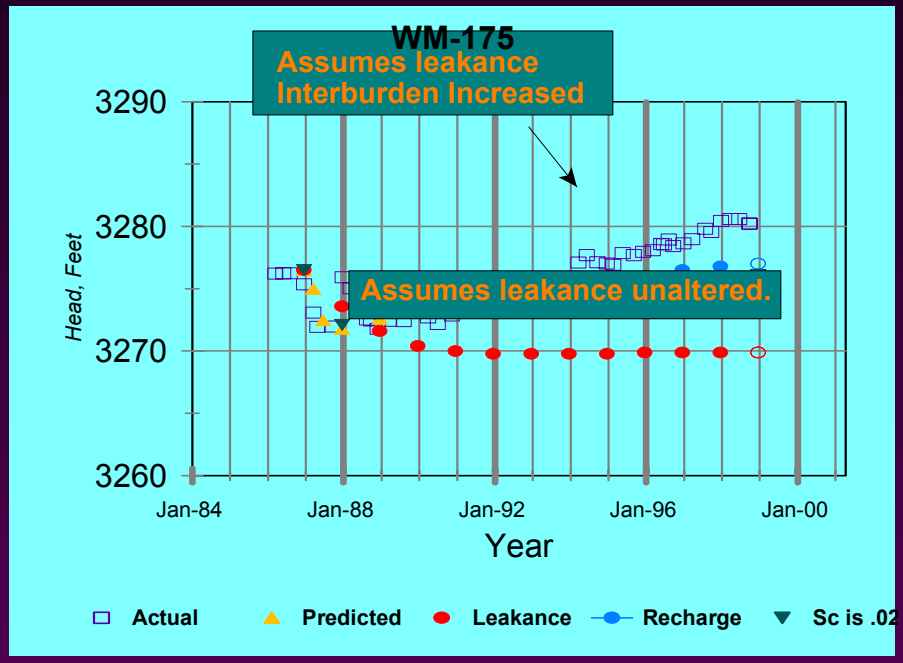


R = Rosebud
M = McKay
I = Interburden
S = Sub McKay
Model Predicted Heads

Is Blasting Activity Increasing the Vertical Hydraulic Conductivity of the Interburden?

Evaluation of Simulated v. Observed Conductivity for Rosebud and McKay Wells Nearer Previous Mining Activity

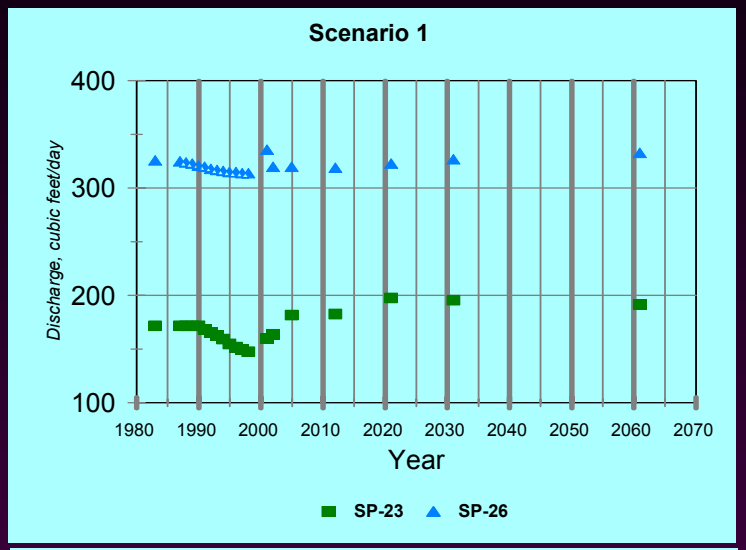




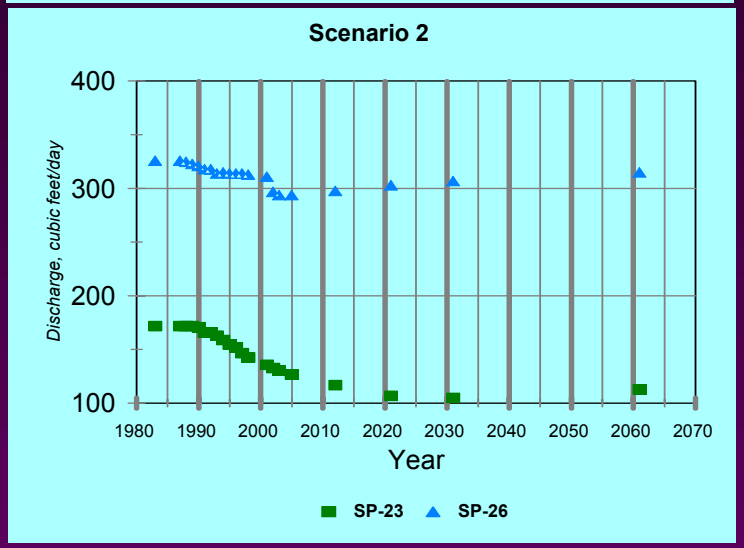
Implication for McKay Springs

Scale Not Indicated

Interburden Vertical Conductivity Is Increased by Blasting



Interburden Vertical Conductivity Remains the Same



OSM'S CHIA:

BLACK MESA/ KAYENTA MINE

Phillip Reinholtz and Brenda A. Steele

Western Regional Coordinating Center

Office of Surface Mining

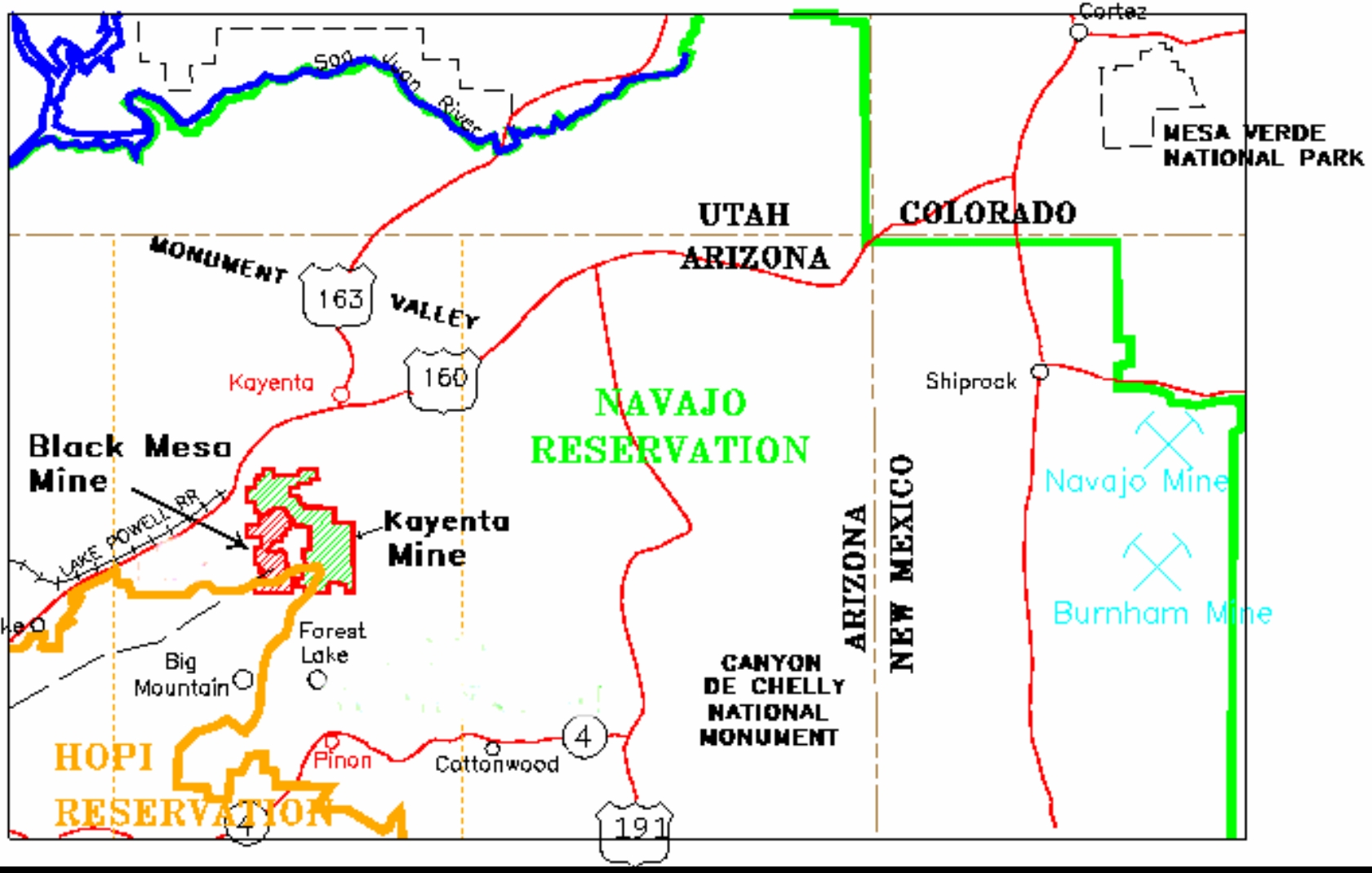
August 2000

CHIA BACKGROUND

- Prepared by OSM - Regulatory Authority on Indian Lands.
- Finalized in April 1989 and took almost four years to prepare.
- Prepared, in part, to provide technical basis for the hydrology portions of the Black Mesa Environmental Impact Statement.
- Prepared in accordance to 1985 *DRAFT* "Guidance for Preparation of Cumulative Hydrologic Impact Assessment (CHIA).

BLACK MESA / KAYENTA MINE

- Consists of two adjacent mines in the northeastern corner of Arizona operated by Peabody Western Coal Company
- Two mines cover approximately 63,000 acres (101.3 square miles) of Hopi and Navajo Tribal land.
- Mining conducted through lease agreements with the Navajo Nation and Hopi Tribe.
- Mining operations have been ongoing since about 1970 and are anticipated to continue until at least 2011.
- Most of the mining is currently on Navajo Nation land and mining began on Hopi land in 1998.
- Produces about 12 million tons of coal annually.


Cortez
San Juan River
MESA VERDE NATIONAL PARK
UTAH
COLORADO
ARIZONA
MONUMENT
VALLEY
163
160
Kayenta
Shiprock
NAVAJO RESERVATION
Black Mesa Mine
Kayenta Mine
LAKE POWELL RR
Navajo Mine
Burnham Mine
ARIZONA
NEW MEXICO
Red Lake
Big Mountain
Forest Lake
CANYON DE CHELLY NATIONAL MONUMENT
4
Pinon
Cottonwood
HOPI RESERVATION
191

WHY TWO MINES?

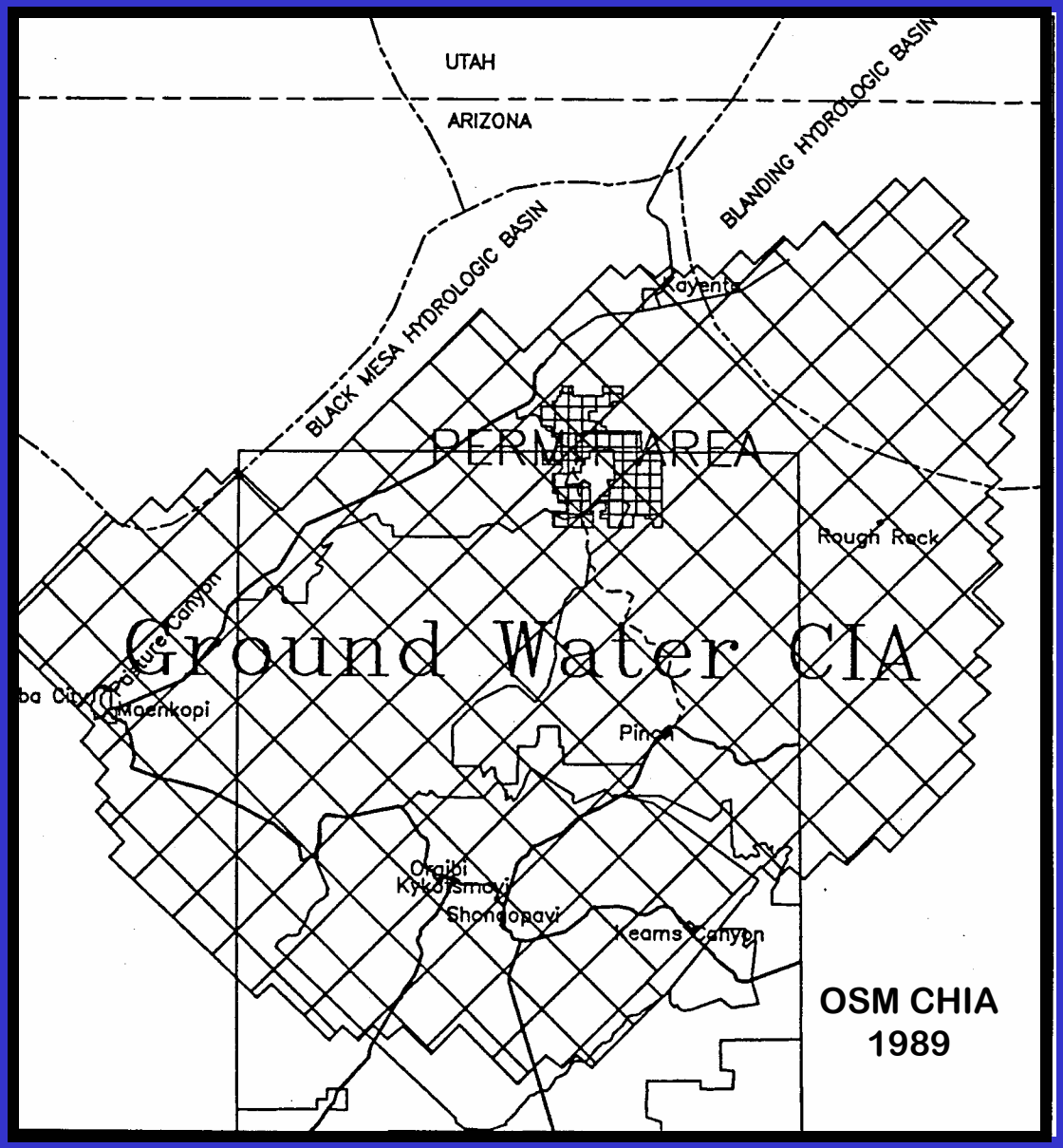
- Coal is dedicated to different power plants.
- Kayenta mine is dedicated to the Navajo Generating Station located near Page, Arizona and is transported by railroad.
- Black Mesa mine is dedicated to the Mohave Generating Station located near Laughlin, Nevada and is transported by slurry pipeline.
- Kayenta permit is operating in accordance to a permanent program permit issued in 1990.
- Black Mesa is operating in accordance with initial regulatory program (no permit required) because of ongoing litigation on the Little Colorado River. Permit issuance is delayed.

CHIA DEVELOPMENT STEPS

- Delineation of cumulative impact areas for surface water and ground water.

SURFACE-WATER CIA - 3800 sq. miles

GROUND-WATER CIA - 4800 sq. miles



CHIA DEVELOPMENT STEPS

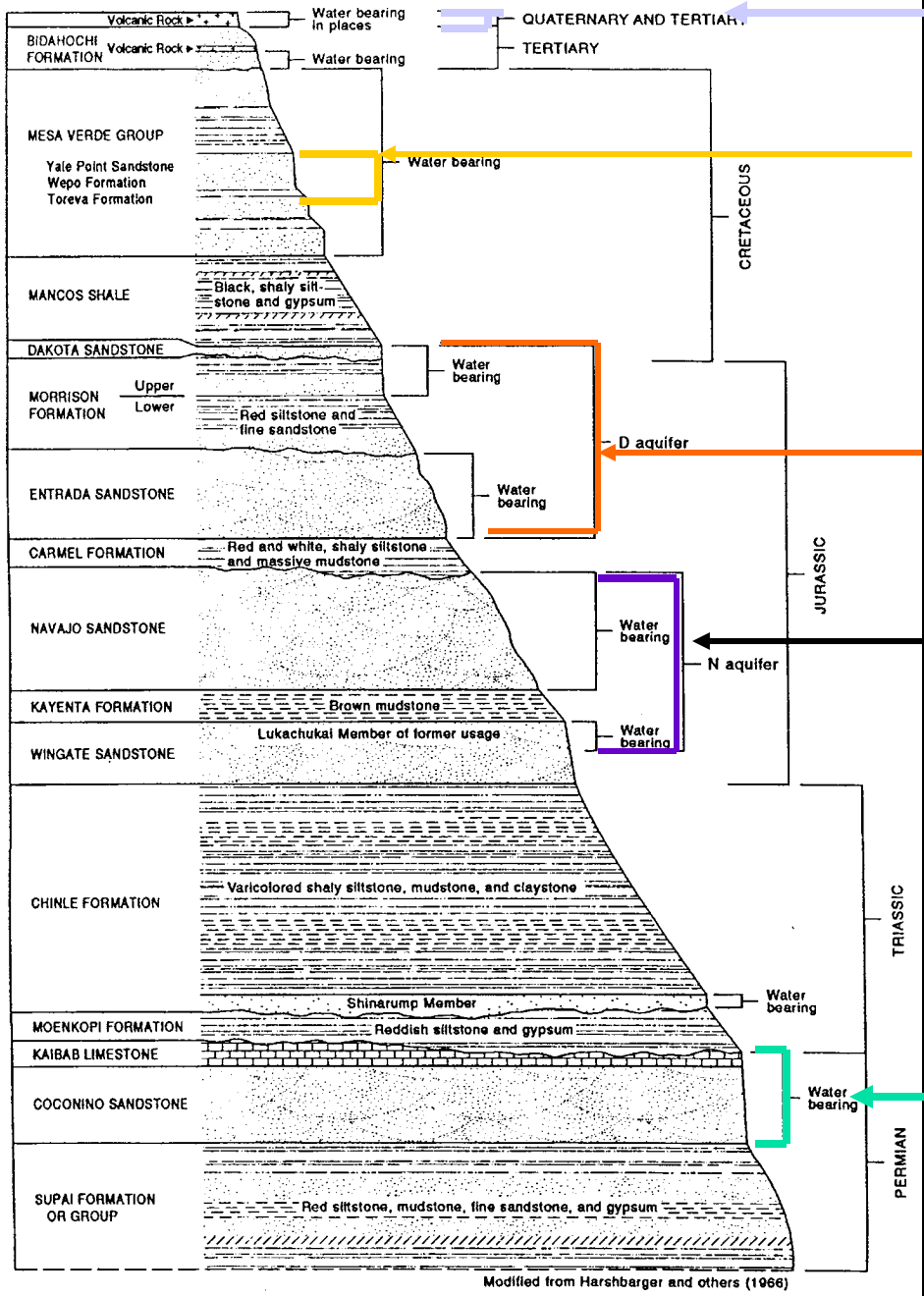
- Delineation of cumulative impact areas for surface water and ground water.
- Definition of baseline conditions for surface water and ground water.

SURFACE-WATER BASELINE

- Baseline year 1985 but other data used.
- Baseline conditions were based on data collected from both affected (mined) and nearby undisturbed (unaffected) areas.
- Describe surface-water hydrology prior to start of significant impoundment construction.
- Alluvial water levels used as a means to measure effects to the surface-water regime.
- Water quality data from 600 surface-water samples used.
- Water quality of alluvial, Wepo and impoundments also evaluated.

GROUND-WATER BASELINE

- Information from 1324 wells and springs available.
- Major water bearing units potentially impacted by mining evaluated were C Aquifer, N Aquifer, D Aquifer , the Toreva and Wepo and the Quaternary Alluvium.
- Main emphasis was on the N Aquifer because it is the main water source for local communities and is used for Peabody's coal slurry operation.



Modified from Harshbarger and others (1966)

Quaternary Alluvium

Wepo / Toreva

D Aquifer

N Aquifer

C Aquifer

CHIA DEVELOPMENT STEPS

- Delineation of cumulative impact areas for surface water and ground water.
- Definition of baseline conditions for surface water and ground water.
- Identification of hydrologic concerns for surface water and ground water.

METHODOLOGY

Identified primarily through the NEPA scoping process as part of the EIS development and through meetings with the Navajo and Hopi Tribes.

Process included public meetings, field investigations and direct input from the Tribes.

MAJOR CONCERNS

- Diminution of water quantity and quality to users of both surface and ground water.
- Protection of both existing and future uses.
- Uses considered included domestic and municipal pumping; spring use for domestic, agricultural, livestock and religious purposes; agricultural uses of surface flow; proposed future ground-water use and recreational uses of surface water.

CHIA DEVELOPMENT STEPS

- Delineation of cumulative impact areas for surface water and ground water.
- Definition of baseline conditions for surface water and ground water.
- Identification of hydrologic concerns for surface water and ground water.
- Development of material damage criteria.

WHAT IS MATERIAL DAMAGE?

Changes in the hydrologic balance, with respect to the CHIA, caused by surface mining and reclamation operations to the extent that these changes would SIGNIFICANTLY affect present and potential uses as defined by the regulatory authority.

Included off-permit uses of water for the support of human activities.

Duration and magnitude of impacts considered.

MATERIAL DAMAGE CRITERIA

- Established at levels above which damage to the hydrologic balance would manifest itself as an economic loss to current or present users.
- Would result in significant reduction in the capability of an area to support fish and wildlife communities.
- Would cause a significant adverse change to the hydrologic system outside the permit area.
- Quantitative versus qualitative.

CHIA DEVELOPMENT STEPS

- Delineation of cumulative impact areas for surface water and ground water.
- Definition of baseline conditions for surface water and ground water.
- Identification of hydrologic concerns for surface water and ground water.
- Development of material damage criteria.
- Analysis of cumulative hydrologic impacts.

SURFACE-WATER IMPACTS

Analysis based on relationship of down gradient alluvial water levels and water quality to disturbed surface area covered by impoundments.

GROUND-WATER IMPACTS

Analysis based on comprehensive well and spring inventory to assess water use and an USGS N-Aquifer simulation using different pumping scenarios.

OSM concluded that none of the projected impacts exceeded material damage criteria.

N - AQUIFER USAGE

- Main source to over 500 wells and springs.
- Good quality with low TDS and sulfates.
- Approximately 3900 acre-feet of D- and N-Aquifer water used per year for slurry and mine operations.
- Local communities use about 3000 acre-feet per year.
- Confined in the area of the mine.
- Recharge estimated to be 13,000 acre-feet where the aquifer is exposed.

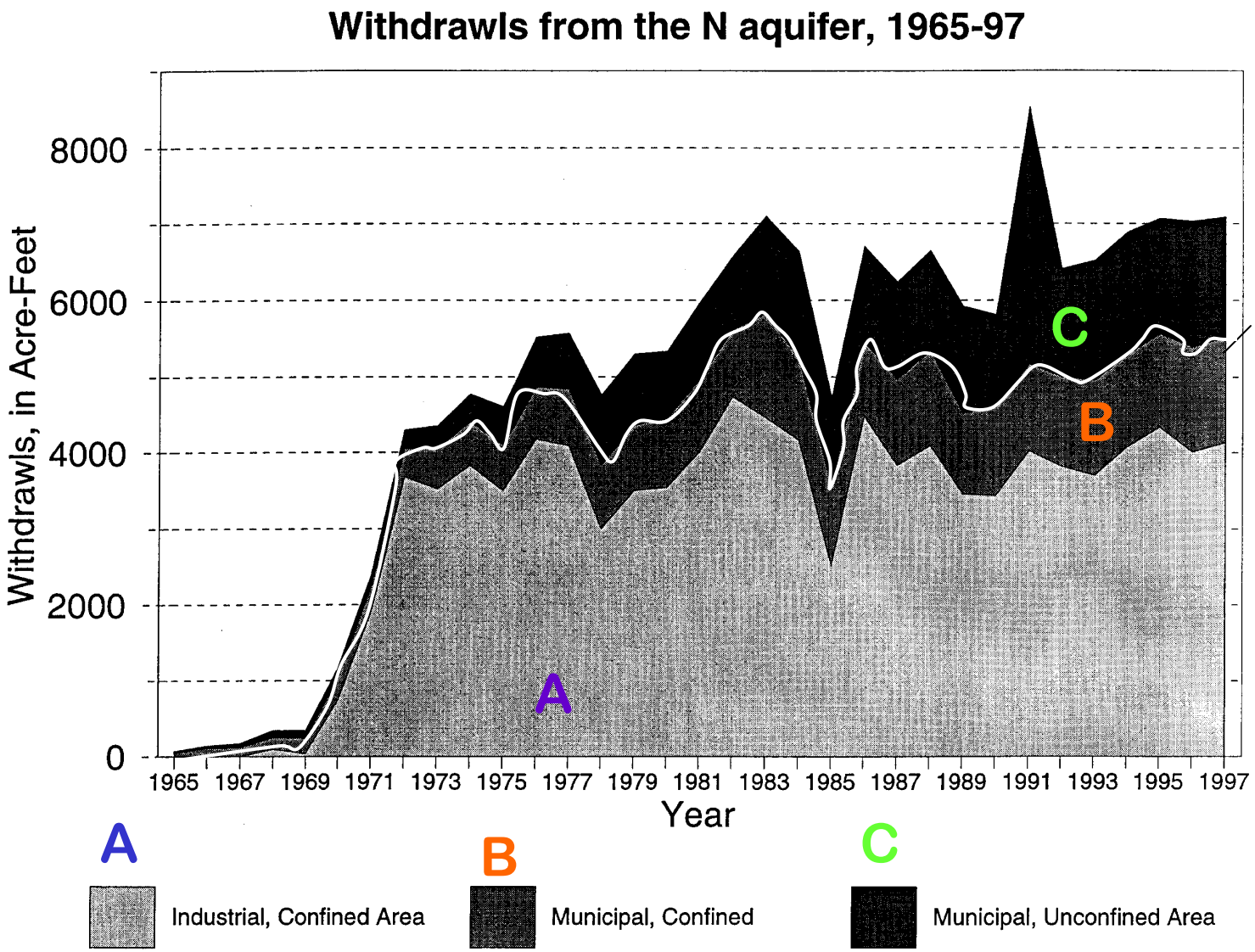
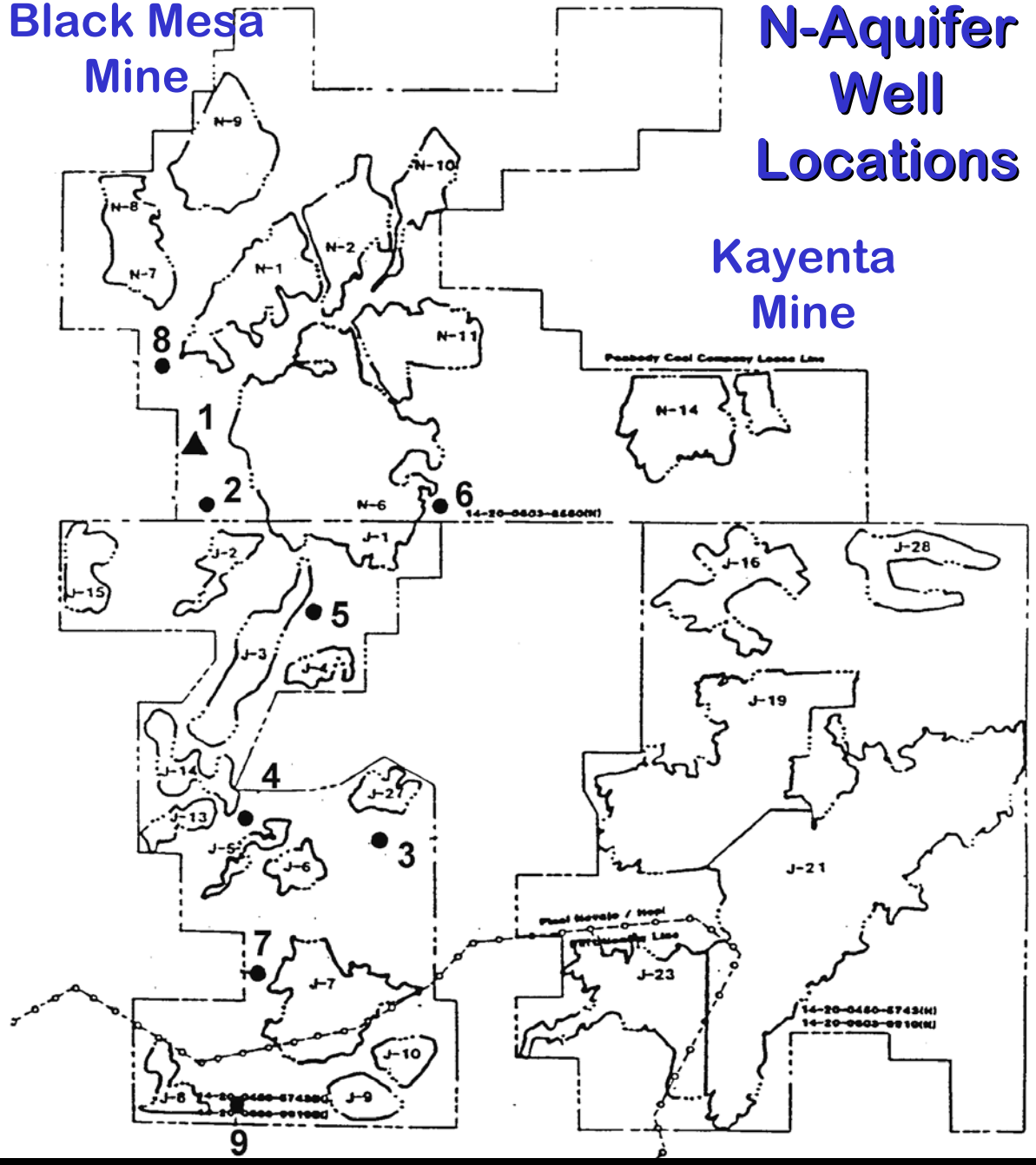


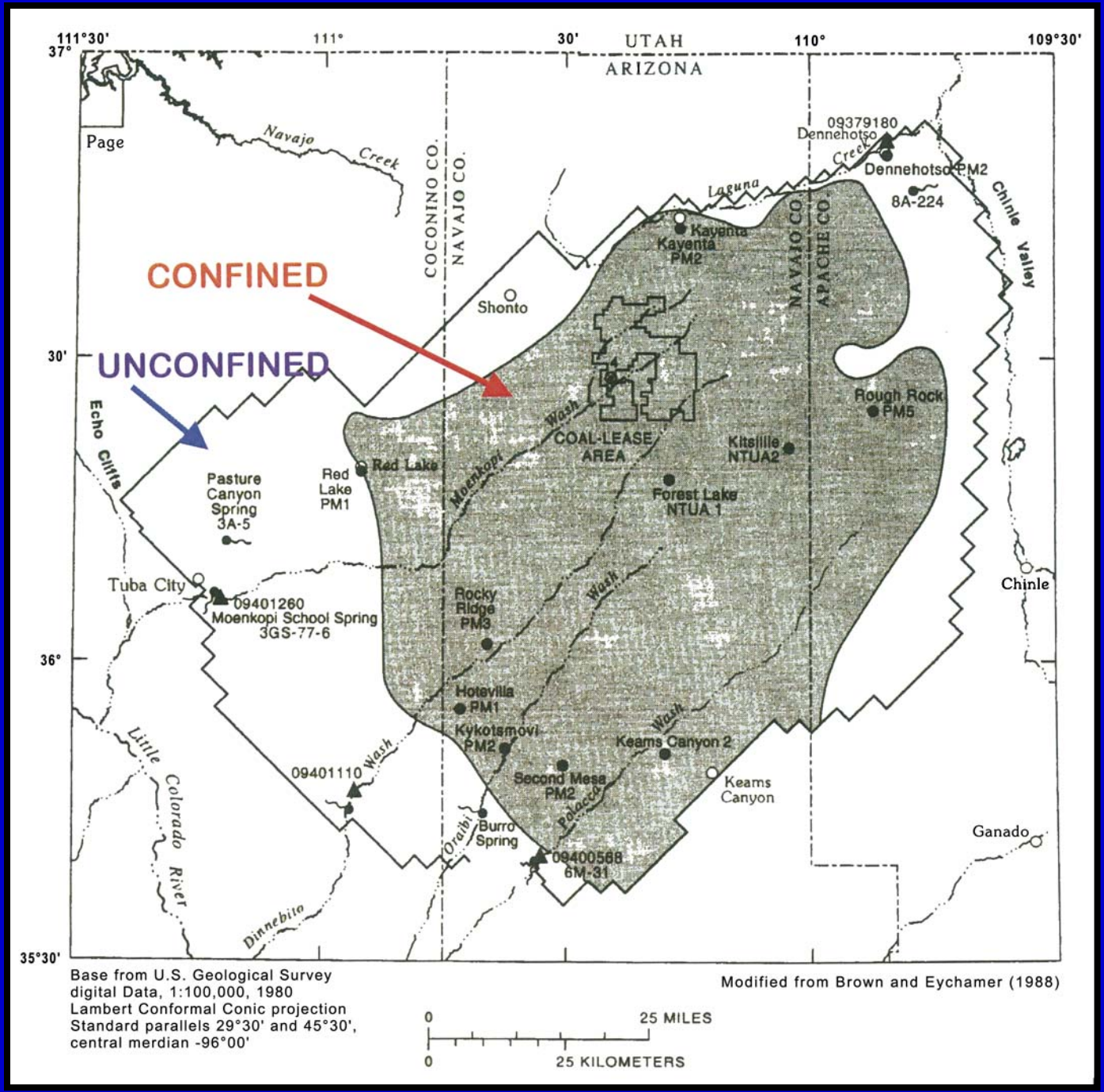
Figure C-1.--Withdrawls from the N aquifer, 1965-97 (from Littin, Baum, and Truini, 1998)

N - AQUIFER MONITORING

- Peabody and USGS are monitoring N Aquifer.
- Peabody monitors 8 wells on the Black Mesa mine for continuous water level and quarterly water quality.
- USGS monitors a network of ground-water, surface-water and water-quality stations.
- USGS has run several computer simulations using a 2D numerical computer model to evaluate drawdown impacts from mining and the local communities and recovery time of the aquifer.
- For an independent check Peabody recently developed a regional 3D numerical computer model that incorporates a framework geologic model.
- To ensure no material damage is occurring OSM regularly analyzes USGS and Peabody information.

N-Aquifer Well Locations




111°30'
111°
30'
UTAH
110°
109°30'
37°
ARIZONA
Page
Navajo Creek
COCONINO CO.
NAVAJO CO.
09379180
Dennehotso
Dennehotso PM2
8A-224
Laguna Creek
Chinle Valley
Kayenta
Kayenta PM2
NAVAJO CO.
APACHE CO.
CONFINED
Shonto
UNCONFINED
30'
Echo Cliffs
Rough Rock PM5
Moenkopi Wash
COAL-LEASE AREA
Kitsillie NTUA2
Red Lake
Red Lake PM1
Pasture Canyon Spring 3A-5
Forest Lake NTUA 1
Tuba City
09401260
Moenkopi School Spring
3GS-77-6
Rocky Ridge PM3
Wash
Chinle
36°
Hotevilla PM1
Kykotsmovi PM2
Keams Canyon 2
Little Colorado River
09401110
Wash
Second Mesa PM2
Polacca Wash
Keams Canyon
Oraibi Wash
Burro Spring
Ganado
09400568
6M-31
Dinnebito
35°30'
Base from U.S. Geological Survey
digital Data, 1:100,000, 1980
Lambert Conformal Conic projection
Standard parallels 29°30' and 45°30',
central merdian -96°00'
Modified from Brown and Eychamer (1988)
0
25 MILES
0
25 KILOMETERS

CHIA CONCERN #1

Structural stability of N Aquifer due to reduction of potentiometric head

MATERIAL DAMAGE CRITERION

Maintain potentiometric head 100 feet above the top of N Aquifer at any point to preserve confined state of aquifer

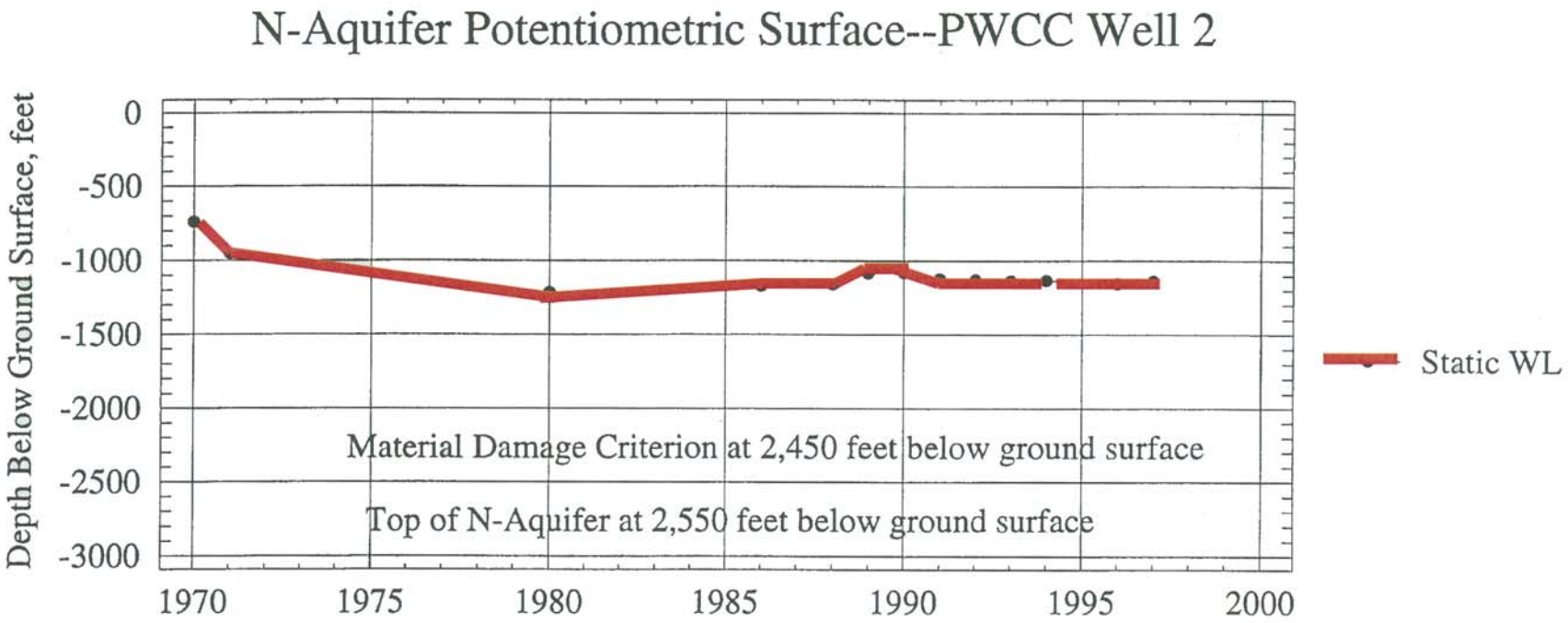


Figure D-1. Average Non-Pumping Water Level in PWCC Well No. 2

RESULTS

- Estimated on the basis of Peabody's well-monitoring data, the lowest potentiometric head of the N Aquifer in 1998 is 775 feet above the top on the aquifer.
- USGS 1994 model run concluded simulated water-level declines at several locations outside the mine.
- Material damage has not occurred.

CHIA CONCERN #2

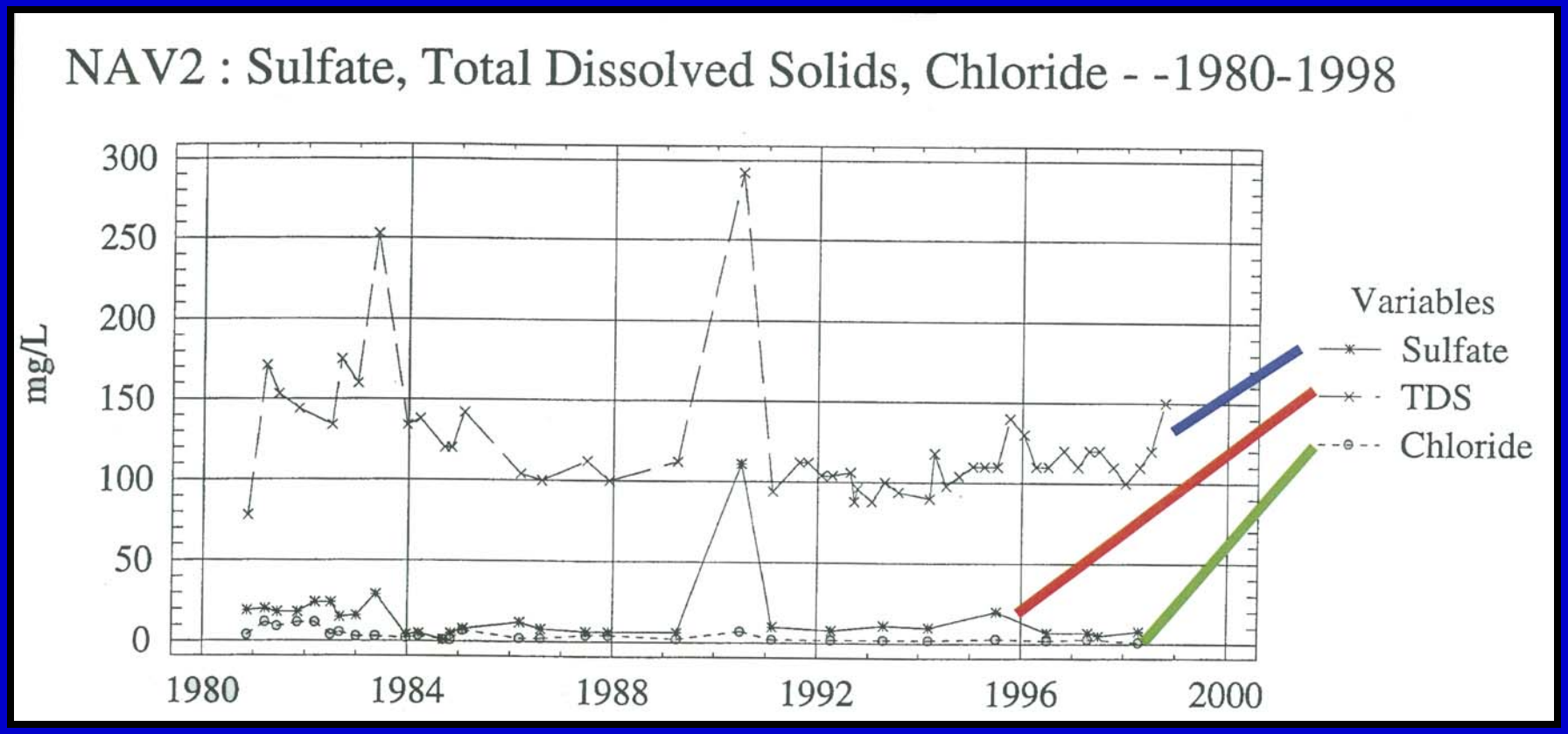
Degradation of N-Aquifer water quality due to increased migration rate of water from D-Aquifer.

MATERIAL DAMAGE CRITERION

A value of leakage from D Aquifer not to exceed 10% from mine related withdrawls.

EVALUATION METHODOLOGY

- No direct measurements done on D Aquifer.
- USGS predicted any increase in leakage from the D Aquifer would first appear as increased levels of TDS or specific electrical conductance, chloride and sulfate.
- Peabody is using non-parametric statistics to evaluate water-quality data because of seasonality.


NAV2 : Sulfate, Total Dissolved Solids, Chloride - -1980-1998
mg/L
300
250
200
150
100
50
0
1980
1984
1988
1992
1996
2000
Variables
Sulfate
TDS
Chloride

RESULTS

- Water quality has changed over time but regional water quality is stable.
- No significant change in water quality.
- Water remains suitable for both domestic and livestock use.
- Difficult to determine actual cause of change - well completion for many of the wells is in both the D and the N Aquifers.

CHIA CONCERN #3

Reduction of N-Aquifer spring discharge rates due to alteration of potentiometric surface.

MATERIAL DAMAGE CRITERION

A discharge reduction of 10 % or more, caused by mine related withdrawls based on results of N-Aquifer simulation.

EVALUATION METHODOLOGY

- USGS 1994 simulation included N Aquifer spring flow.

RESULTS

The simulated low-flows in the springs near Tuba City decreased by less than 1 % under all pumpage scenarios.

CHIA CONCERN #4

Reduction of alluvial flow rates due to reduction of N-Aquifer discharge to alluvium.

MATERIAL DAMAGE CRITERION

A discharge reduction of 10 % or more, caused by mining.

EVALUATION METHODOLOGY

USGS 1994 simulation included N-Aquifer discharge to the alluvium.

RESULTS

Mine related withdrawls resulted in a reduction of 3.7 % low flow in Laguna Creek. The simulated low flow in Moenkopi Wash decreased by less than 1 %.

WHAT NEXT?

- **Monitoring of the N Aquifer continues by both USGS and Peabody.**
- **OSM is working with the Department to obtain additional funding to have the USGS do a technical evaluation of Peabody's 3D model.**
- **Alternative water sources to replaceN-Aquifer water are being evaluated, such as a pipeline from Lake Powell.**

Sediment-Storage Design Considerations for Temporary Structures: SEDCAD 4 and RUSLE

Richard C. Warner, Ph.D.
University of Kentucky

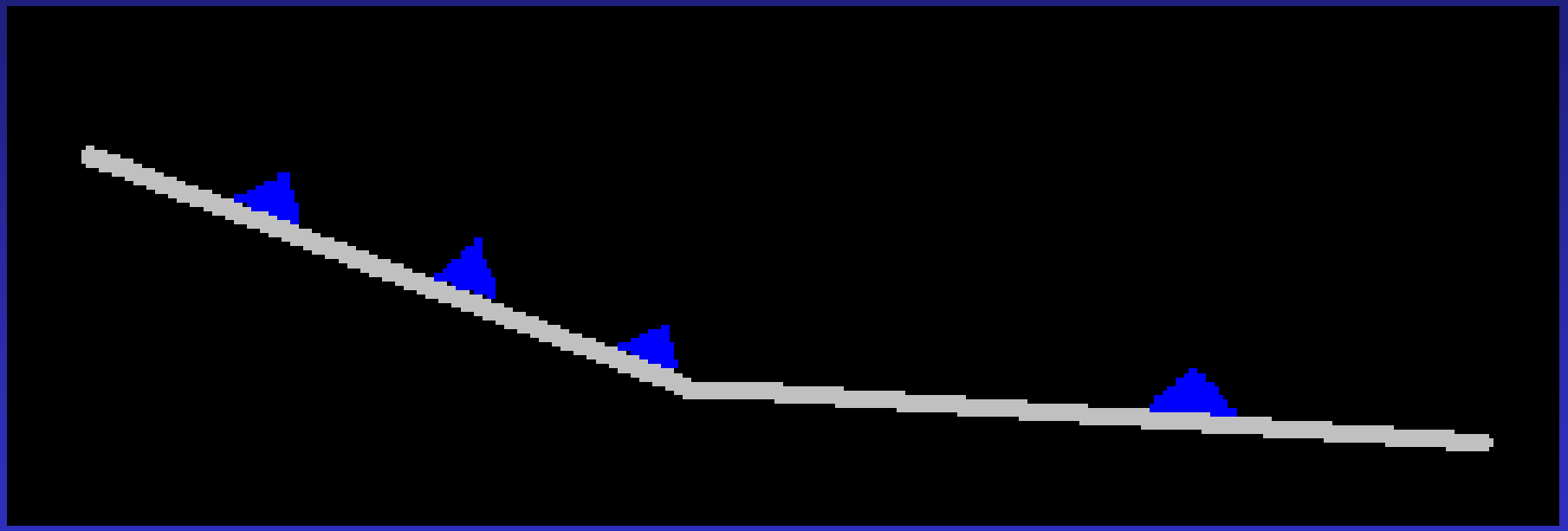
Sediment Storage

- It's your choice: where do you want to retain your sediment?
- Design considerations:
  - Stability of structure
  - Potential for failure
  - Potential for passive dewatering
- Access, so as to facilitate sediment removal
- Remove ***sediment,*** NOT ***soup***

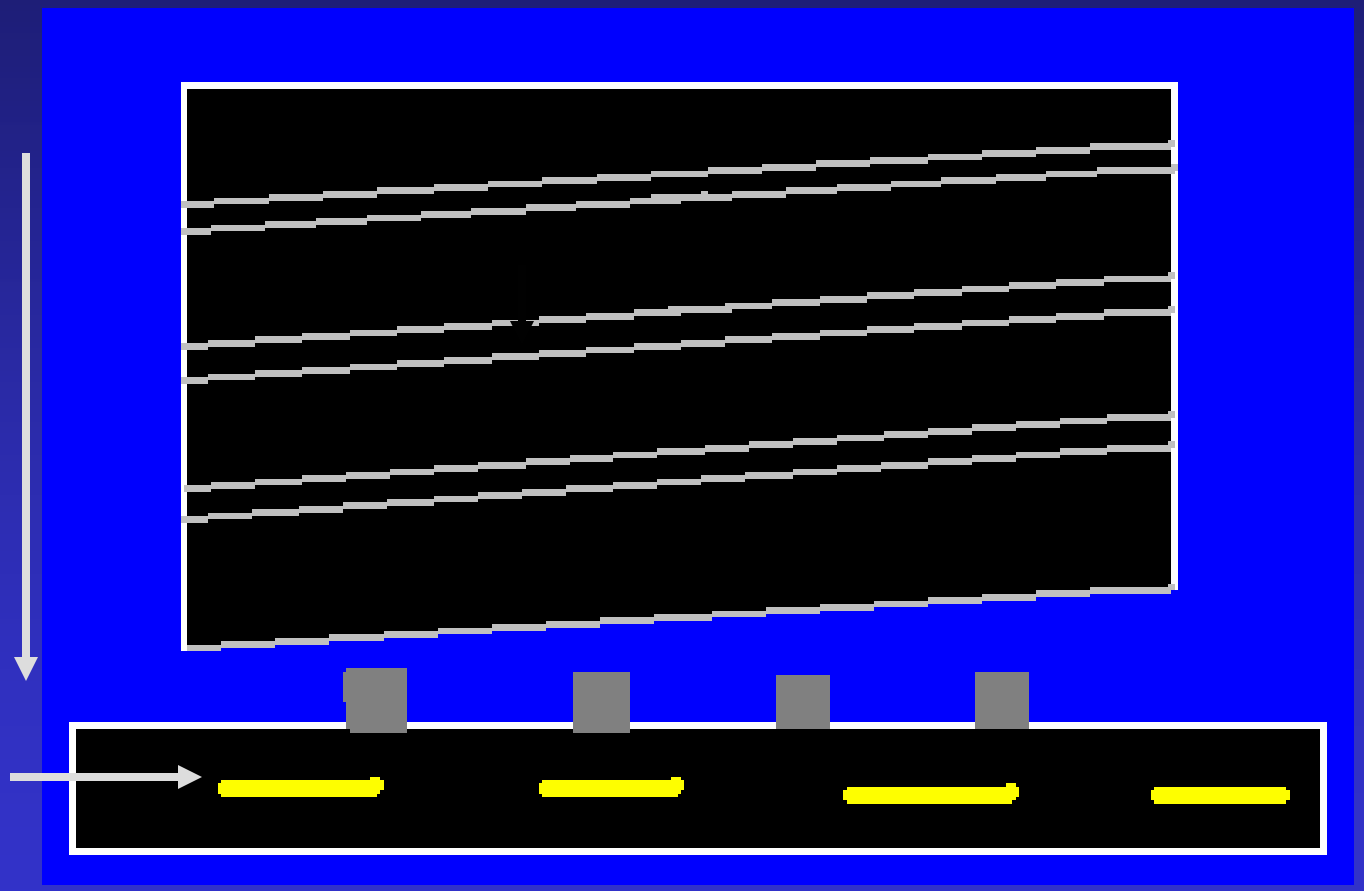
The System Is the Solution

- The most efficient design is the one that allows storm-water and sediment controls themselves to function as the system whereby sediment is conveyed to down-gradient control structures that are specifically designed both to passively dewater it and to accommodate its removal

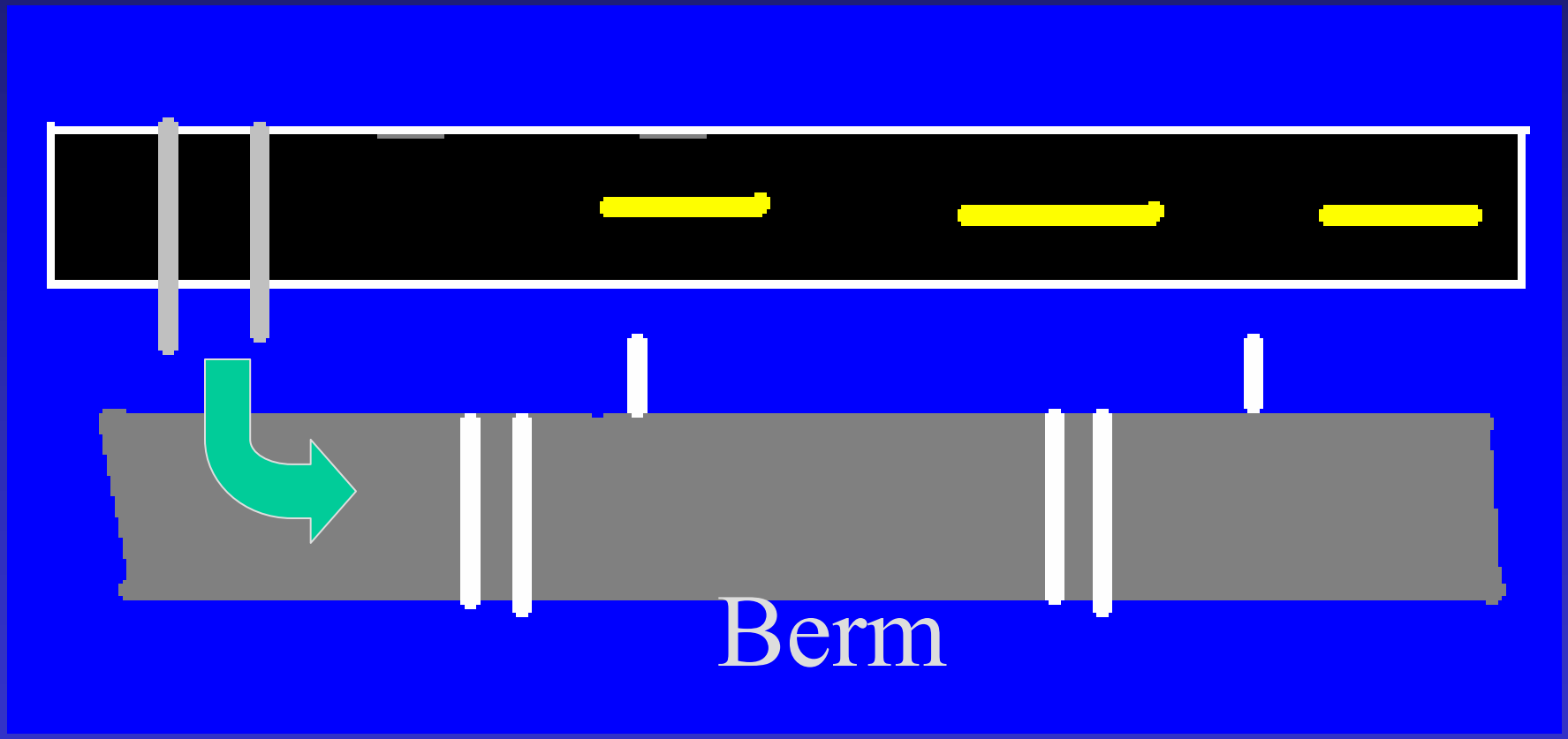
Slope Configuration and Terraces

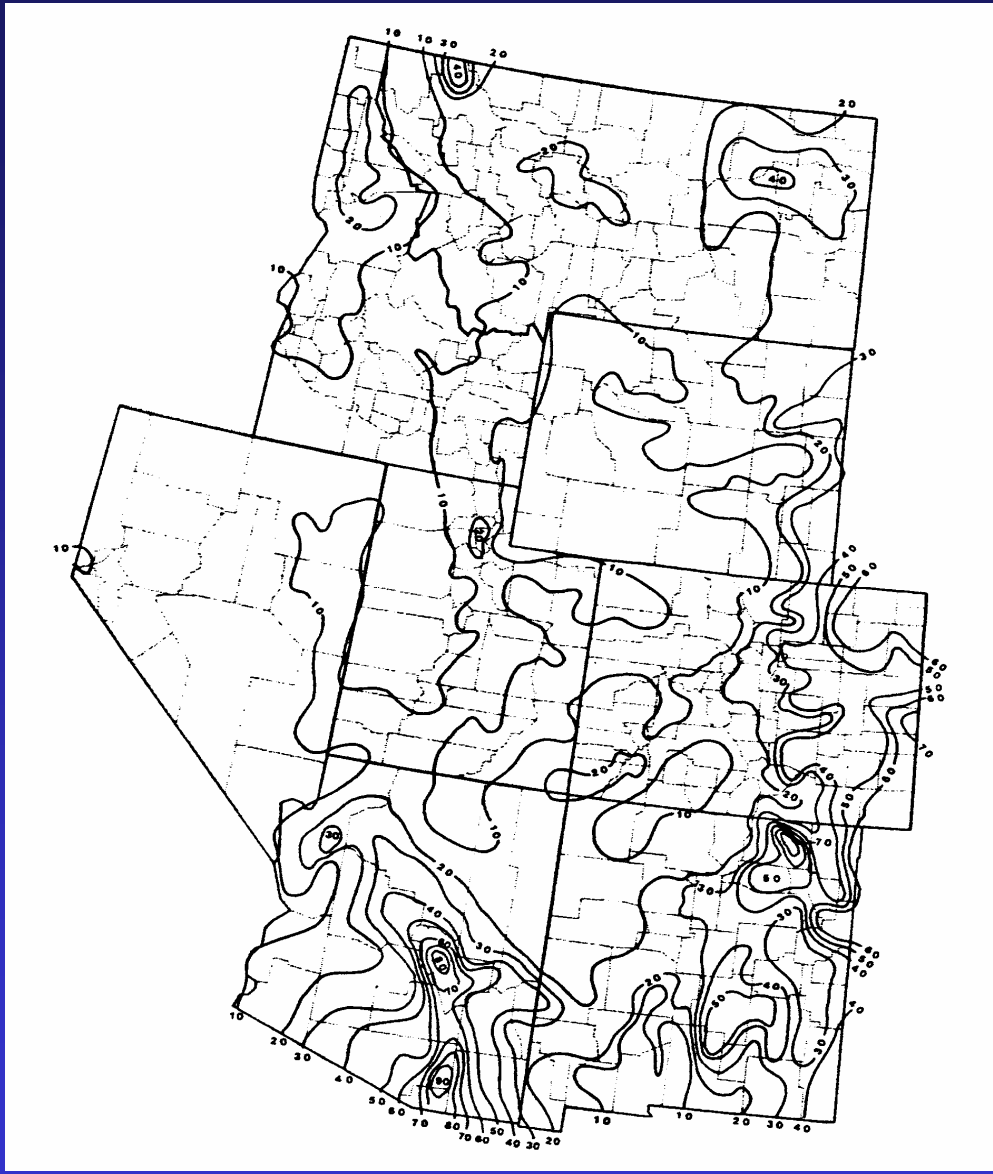


Terraces and Sediment Traps



Weep Berms





Isoerodent map of the western United States (units are ft*tonf*in [ac*h*yr]$^{-1}$)

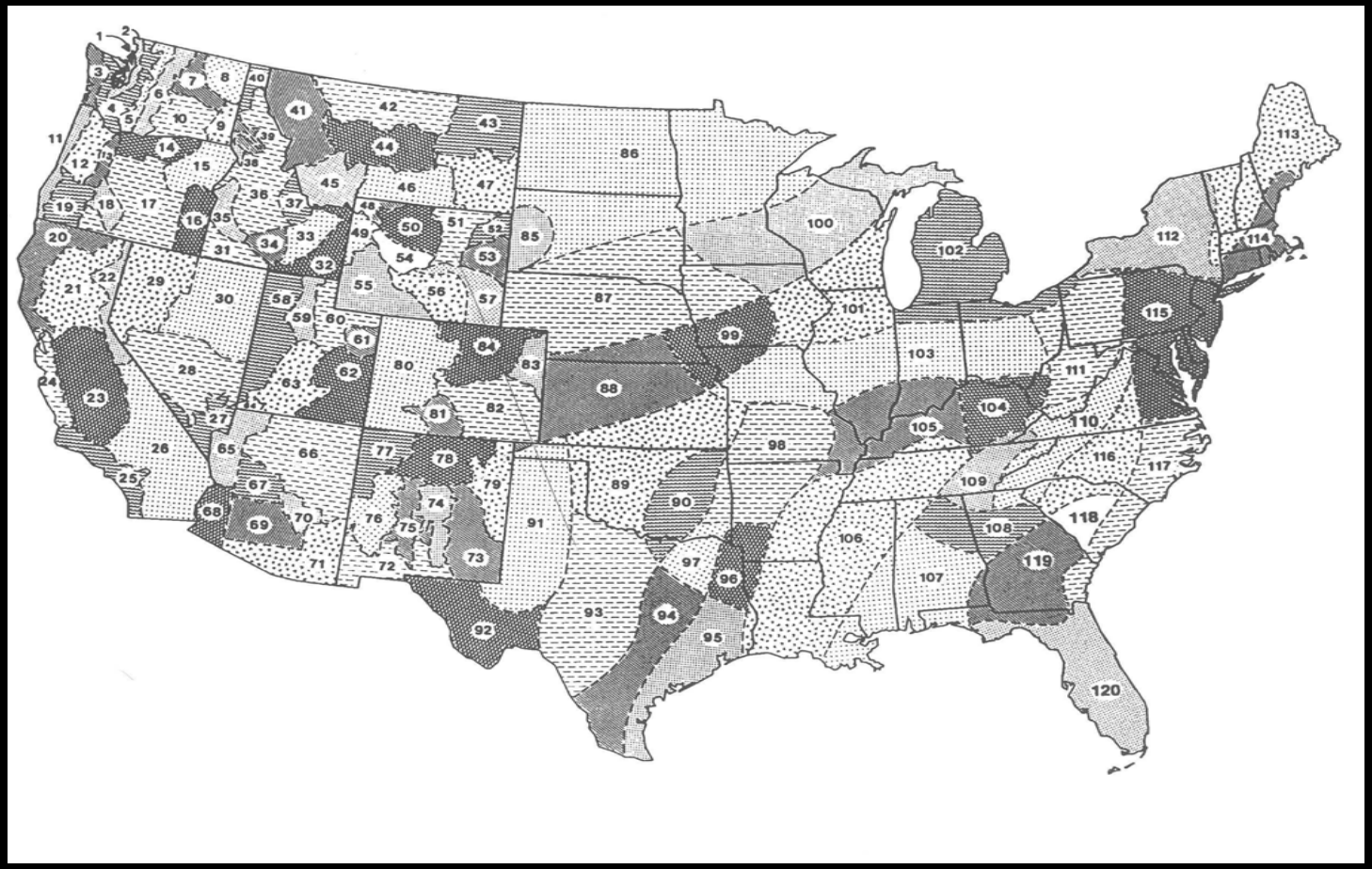


Figure 1.—EI-distribution zones for the contiguous United States. ("EI" is a parameter equal to the product of "total storm energy times the maximum 30-minute intensity."

Figure 2-7, U.S. Department of Agriculture Handbook No. 703.

Table 1.—*EI as a percentage of average annual values for geographic areas shown in fig. 1*

EI number	Periods 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
101	0.0	0.0	0.0	1.0	2.0	3.0	4.0	6.0	9.0	14.0	20.0	28.0	39.0	52.0	63.0	72.0	80.0	87.0	91.0	94.0	97.0	98.0	99.0	100.0
102	0.0	0.0	1.0	2.0	3.0	4.0	6.0	8.0	11.0	15.0	22.0	31.0	40.0	49.0	59.0	69.0	78.0	85.0	91.0	94.0	96.0	98.0	99.0	100.0
103	0.0	1.0	2.0	3.0	4.0	6.0	8.0	10.0	14.0	18.0	25.0	34.0	45.0	56.0	64.0	72.0	79.0	84.0	89.0	92.0	95.0	97.0	98.0	99.0
104	0.0	2.0	3.0	5.0	7.0	10.0	13.0	16.0	19.0	23.0	27.0	34.0	44.0	54.0	63.0	72.0	80.0	85.0	89.0	91.0	93.0	95.0	96.0	98.0
105	0.0	1.0	3.0	6.0	9.0	12.0	16.0	21.0	26.0	31.0	37.0	43.0	50.0	57.0	64.0	71.0	77.0	81.0	85.0	88.0	91.0	93.0	95.0	97.0
106	0.0	3.0	6.0	9.0	13.0	17.0	21.0	27.0	33.0	38.0	44.0	49.0	55.0	61.0	67.0	71.0	75.0	78.0	81.0	84.0	86.0	90.0	94.0	97.0
107	0.0	3.0	5.0	7.0	10.0	14.0	18.0	23.0	27.0	31.0	35.0	39.0	45.0	53.0	60.0	67.0	74.0	80.0	84.0	86.0	88.0	90.0	93.0	95.0
108	0.0	3.0	6.0	9.0	12.0	16.0	20.0	24.0	28.0	33.0	38.0	43.0	50.0	59.0	69.0	75.0	80.0	84.0	87.0	90.0	92.0	94.0	96.0	98.0
109	0.0	3.0	6.0	10.0	13.0	16.0	19.0	23.0	26.0	29.0	33.0	39.0	47.0	58.0	68.0	75.0	80.0	83.0	86.0	88.0	90.0	92.0	95.0	97.0
110	0.0	1.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	21.0	25.0	29.0	36.0	45.0	56.0	68.0	77.0	83.0	88.0	91.0	93.0	95.0	97.0	99.0
111	0.0	1.0	2.0	3.0	4.0	5.0	6.0	8.0	11.0	15.0	20.0	28.0	41.0	54.0	65.0	74.0	82.0	87.0	92.0	94.0	96.0	97.0	98.0	99.0
112	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	7.0	12.0	17.0	24.0	33.0	42.0	55.0	67.0	76.0	83.0	89.0	92.0	94.0	96.0	98.0	99.0
113	0.0	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0	13.0	17.0	22.0	31.0	42.0	52.0	60.0	68.0	75.0	80.0	85.0	89.0	92.0	96.0	98.0
114	0.0	1.0	2.0	4.0	6.0	8.0	11.0	13.0	15.0	18.0	21.0	26.0	32.0	38.0	46.0	55.0	64.0	71.0	77.0	81.0	85.0	89.0	93.0	97.0
115	0.0	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0	14.0	19.0	26.0	34.0	45.0	56.0	66.0	76.0	82.0	86.0	90.0	93.0	95.0	97.0	99.0
116	0.0	1.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	21.0	25.0	29.0	36.0	45.0	56.0	68.0	77.0	83.0	88.0	91.0	93.0	95.0	97.0	99.0
117	0.0	1.0	2.0	3.0	4.0	5.0	7.0	9.0	11.0	14.0	17.0	22.0	31.0	42.0	54.0	65.0	74.0	83.0	89.0	92.0	95.0	97.0	98.0	99.0
118	0.0	1.0	2.0	3.0	5.0	7.0	10.0	14.0	18.0	22.0	27.0	32.0	37.0	46.0	58.0	69.0	80.0	89.0	93.0	94.0	95.0	96.0	97.0	97.0
119	0.0	2.0	4.0	6.0	8.0	12.0	16.0	20.0	25.0	30.0	35.0	41.0	47.0	56.0	67.0	75.0	81.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0
120	0.0	1.0	2.0	4.0	6.0	7.0	9.0	12.0	15.0	18.0	23.0	31.0	40.0	48.0	57.0	63.0	72.0	78.0	88.0	92.0	96.0	97.0	98.0	99.0
[2]121	0.0	8.0	16.0	25.0	33.0	41.0	46.0	50.0	53.0	54.0	55.0	56.0	56.5	57.0	57.8	58.0	58.8	60.0	61.0	63.0	66.5	72.0	80.0	90.0
122	0.0	7.0	14.0	20.0	25.5	33.5	38.0	43.0	46.0	50.0	52.5	54.5	56.0	58.0	59.0	60.0	61.5	63.0	65.0	68.0	72.0	79.0	86.0	93.0
123	0.0	4.0	8.0	12.0	17.0	23.0	29.0	34.0	38.0	44.0	49.0	53.0	56.0	59.0	62.0	65.0	69.0	72.0	75.0	79.0	83.0	88.0	93.0	96.0
124	0.0	4.0	9.0	15.0	23.0	29.0	34.0	40.0	44.0	48.0	50.0	51.0	52.0	53.0	55.0	57.0	60.0	62.0	64.0	67.0	72.0	80.0	88.0	95.0
125	0.0	7.0	12.0	17.0	24.0	30.0	39.0	45.0	50.0	53.0	55.0	56.0	57.0	58.0	59.0	61.0	62.0	63.0	64.0	66.0	70.0	77.0	84.0	92.0

Table 2-1, U.S. Department of Agriculture Handbook No. 703.

Cover Management

- The Revised Universal Soil Loss Equation (RUSLE) and random surface roughness:
  - Random surface roughness results from clods and aggregates produced by various soil-disturbing activities
  - Depressions among the clods cause water to pond, slow runoff, increase infiltration, and store sediment
  - To calculate random surface roughness, estimate or measure the average distance between highest and lowest points along furrows or ridges on a soil surface; on the basis of these estimates or measurements, use RUSLE equations to arrive at a figure for random surface roughness (using this calculation method, if, for example, average distance equals 9 inches, RUSLE random roughness would equal 1.75 inches)
  - RUSLE will automatically diminish its calculation of surface roughness through time as a function of accumulated rainfall volume and rainfall energy

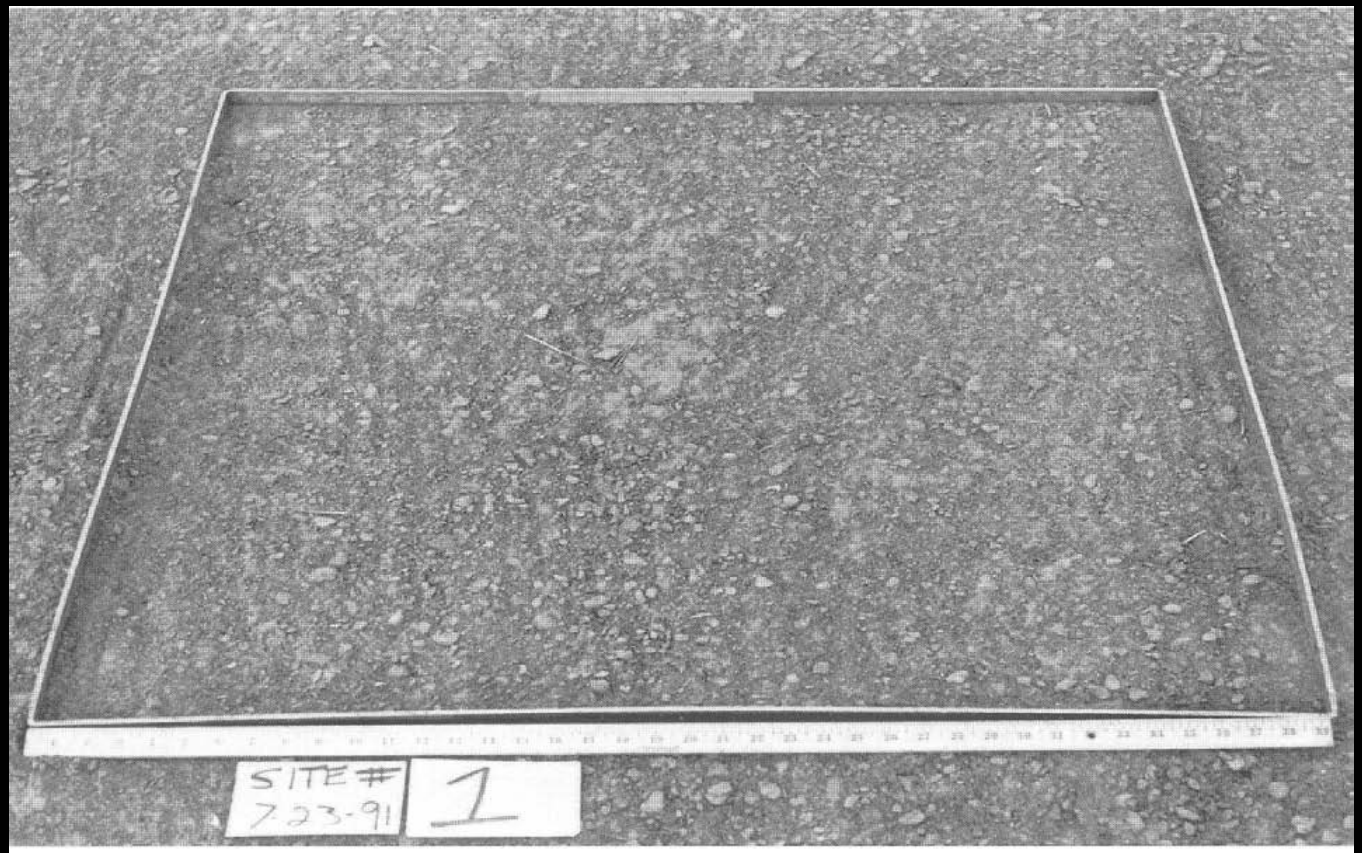


Figure C-1. Random roughness, R_t, of 0.25 in, site 1

Figure 2.—Photograph showing a random surface roughness, R_t, of 0.25 inches at site 1, Palouse Conservation Field Station, Pullman, Washington.

Figure C-1, U. S. Department of Agriculture Handbook No. 703.

Figure 3.—Photograph showing a random surface roughness, R_t, of 0.65 inches at site 2, Palouse Conservation Field Station, Pullman, Washington.

Figure C-3, U. S. Department of Agriculture Handbook No. 703.

Figure 4.—Photograph showing a random surface roughness, R_t, of 1.05 inches at site 9, Palouse Conservation Field Station, Pullman, Washington.

Figure C-6, U. S. Department of Agriculture Handbook No. 703.

Figure 5.—Photograph showing a random surface roughness, R_t, of 1.70 inches at site 3, Palouse Conservation Field Station, Pullman, Washington.

Figure C-8, U.S. Department of Agriculture Handbook No. 703.

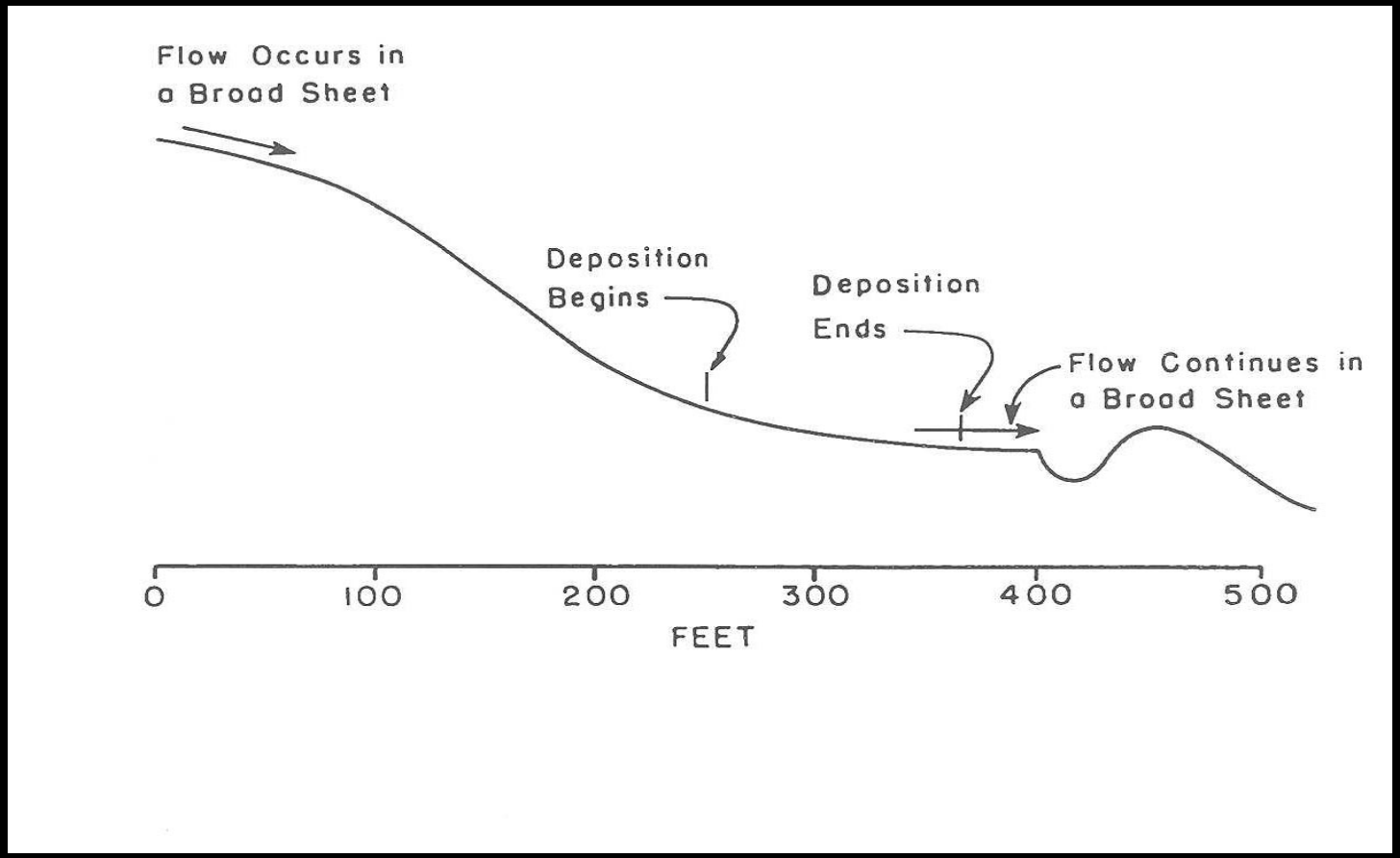


Figure 6.—Illustration showing deposition beginning and ending on a slope.

Figure 4-3, U. S. Department of Agriculture Handbook No. 703.

Figure 7.—Photograph showing dendritic rill pattern on a concave, north-facing slope for which estimated soil loss was 82 tons/acre (taken from Frazier, B. E., D. K. McCool, and C. F. Engle, 1983, Soil erosion in the Palouse: An aerial perspective: J. Soil Water Conserv., vol. 38. p. 70-74).

Figure 4-4, U. S. Department of Agriculture Handbook No. 703.

Hillslope Length and Gradient

Hillslope profile forms:

- Uniform
  - Moderately erosive
- Concave
  - Least erosive, because steepest where flow is least
  - Most deposition occurs at toe of slope where slope lessens
- Convex
  - Most erosive
  - Steepest at toe of slope where runoff is greatest
- Complex (convex-concave)
  - *Optimal:* convex at top of slope and concave at toe

Support-Practice (P) Factors

- Sediment yields from concave hillslopes:
  - Depositional area at base of hillslope should be described with at least four segments
  - Gradient of last segment requires careful delineation owing to its great effect on sediment yield
  - Gradient at lower end of hillslope controls sediment amount leaving hillslope
  - Degree of concavity = ratio of gradient at upper end of hillslope to the average gradient for entire slope
  - Sediment-delivery ratios are affected by cover-management conditions along hillslopes

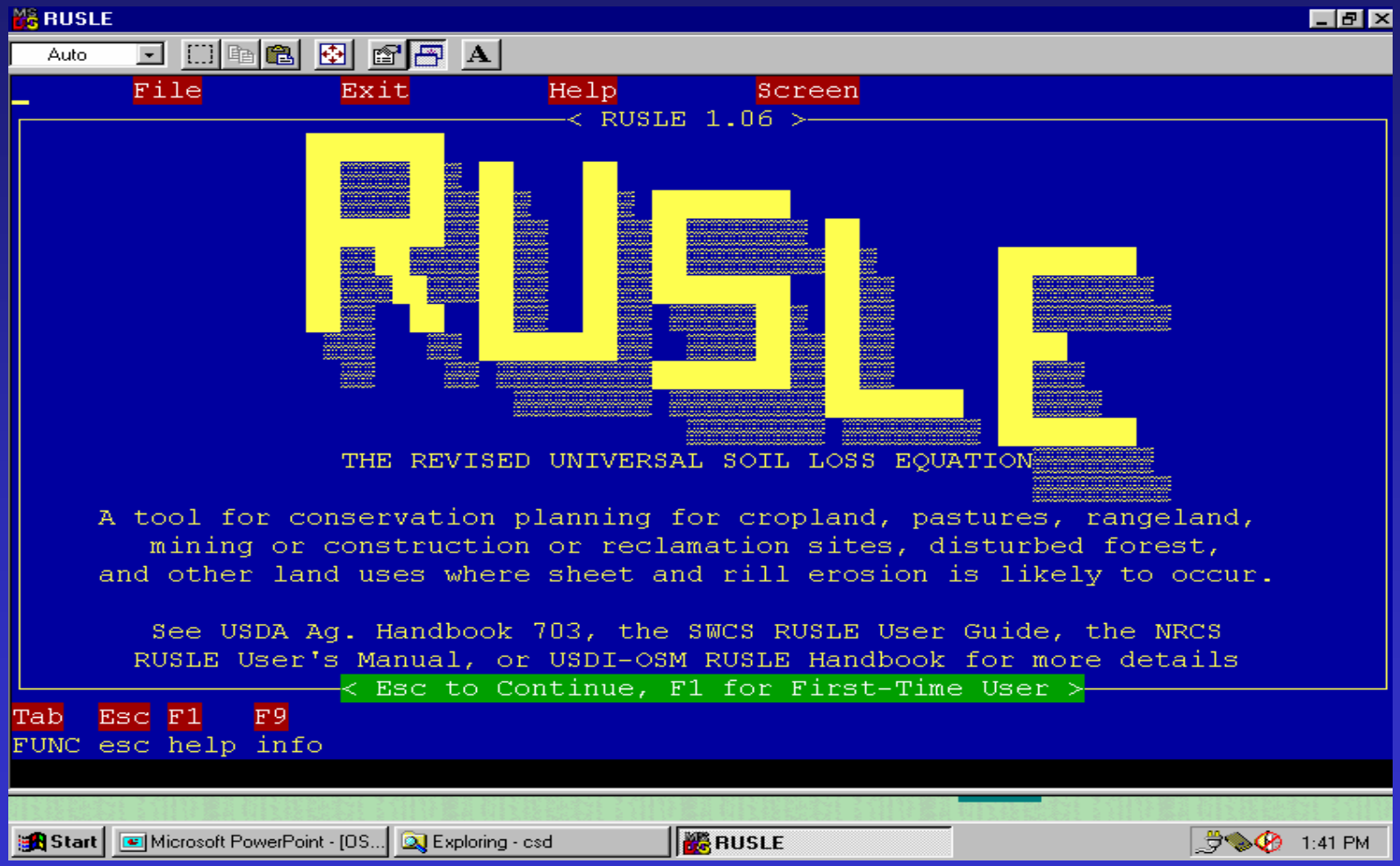
P Factors—continued

- Terracing:
  - Reduces interrill and rill erosion
  - Breaks hillslope into shorter hillslope lengths
  - In level, low-gradient, or closed outlets, traps much of the sediment eroded from inter-terrace surfaces above within deposition along terracing
- Terrace P sub-factors:
  - Conservation planning (terraces protect soil resources)
  - Sediment yield (sub-factors allow for estimating sediment quantity leaving a slope)
  - Sediment-delivery ratio (deposition depends upon extent to which sediment load exceeds transport capacity)
  - Transport capacity (transport capacity is a function of runoff and grade of terrace channel, and deposition depends upon sediment characteristics)

RUSLE Predictions

- Terrace gradient and sediment load
- Terrace gradient and soil texture
- Soil texture and geographical location

RUSLE Predictions



Terrace Design Considerations

- Location
- Size
- Gradient
- Outlet
- Length
- Installation
- Cost
- Other on-slope controls
- Runoff
- Transport capacity
- Deposition

Terrace Location

- Slope configuration
- Uniform spacing
- Non-uniform spacing
- Failure potential

Terrace Gradient

- Increase/decrease sediment deposition
- Erosion/deposition
- Uniform/variable slope
- Cross dikes

Terrace Size

- Height
- Storage volume
  - Storm
  - Sediment
- Cross dikes
- Failure potential

Terrace Length

- Number and size of downdrains
- Failure potential

SEDCAD 4

SEDCAD 4 Design Inputs

- Design storm
- Eroded particle-size distribution
- Networking
- Sub-watershed
- Structure design

The Components of a Design Storm

- Duration
- Rainfall depth
- Type- or actual-storm distribution data (a "type" storm is a standard-distribution storm described by the Natural Resource Conservation Service, data for which may be used when no actual storm data are available; an "actual" storm, on the other hand, as its name implies, is a real storm whose distribution has been measured)

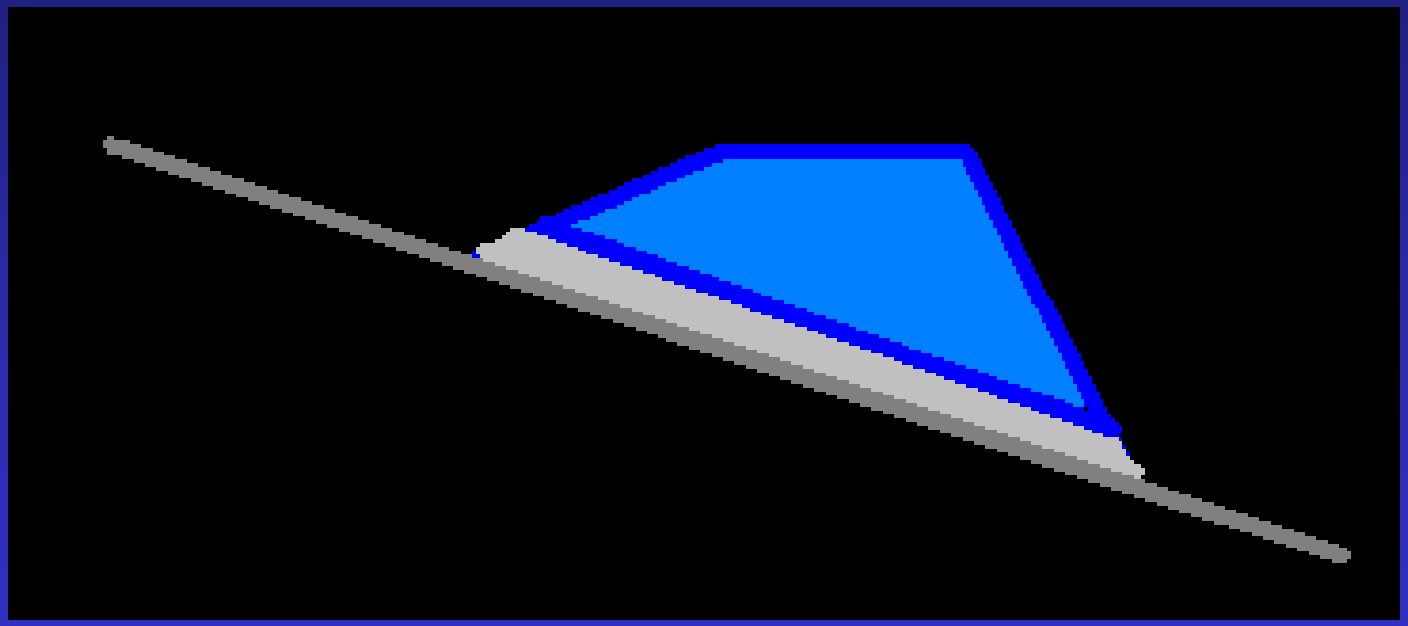
The Components of Eroded Particle-Size Distribution

- Diameter (in millimeters)
- Percentage finer particles

The Components of a Sub-Watershed

- Area (inter-terrace area)
- Time of concentration (Tc)
- Natural Resource Conservation Service curve number (CN)
- Unit hydrograph shape (UHS)
- Soil-erodibility factor (K)
- Length between terraces (L)
- Gradient (S)
- Cover-management factor (C)

Check Dam



6 16 00

ALLUVIAL VALLEY FLOORS: RECLAMATION BOND-RELEASE CRITERIA

Richard A. Chancellor, Administrator
Wyoming Department of Environmental Quality,
Land Quality Division

SMCRA Requirements

- Section 515(b)(10)(F) of SMCRA calls for preserving, throughout the mining and reclamation process, the essential hydrologic functions of alluvial valley floors (AVF's) in the arid and semi-arid areas of the country:

OSM

- “Alluvial Valley Floor Identification and Study Guidelines”
- Draft published July 26, 1983
- Was never finalized

OSM

- Section 515(b)(10)(F) of SMCRA (page III-10) requires that the essential hydrologic functions of all AVF's be preserved during mining and reclamation operations. The term "preserve" is understood to have two meanings, depending on whether the AVF in question is within or outside an "affected area."

OSM

- For AVF's within an affected area, the term "preserve" means that essential hydrologic functions must be reestablished during reclamation.

- For AVF's offsite (outside the affected area), the essential hydrologic functions must be "preserved"--that is, maintained--at all times.

OSM

- OSM defines three general types of AVF's:
  - Subirrigated valleys
  - Surface-water irrigated valleys
  - Valleys with the capability to be surface-water irrigated

Subirrigated Valleys

- These valleys support either rangeland important to a grazing operation or a cropped area. Subirrigated valleys pose the greatest problems for reclamation-plan development, because of the need to reestablish an alluvial aquifer with adequate water quantity to support the kinds of vegetation that existed before mining.

Surface-Water Irrigated Valleys

- These valleys are part of an existing agricultural operation, and reclamation will focus on restoring the irrigated land use. Such reclamation involves restoration of stable stream channels, land surfaces, and suitable soils. This kind of reclamation is generally considered easier than restoration of subirrigation.

Valleys with the capability to be surface-water irrigated

- These valleys, not now in any “developed” agricultural use, are the easiest to reclaim. The goal of reclamation in such valleys is to restore the physical characteristics that give the valley its capability to be surface-water irrigated. In other words, the stream channel, valley topography, and soils must be restored to their premining condition.

Bond-Release Criteria (Performance Standards)

- Restore the essential hydrologic functions of the AVF (note that this is different from restoring the AVF's physical characteristics.)

Essential Hydrologic Functions of an AVF

- Collecting, storing, regulating, and making the natural flow of surface water, ground water, or both, usefully available for agricultural activities by reason of the valley floor's topographic position, the landscape, and the physical properties of its underlying materials. A combination of these functions provides a water supply during extended periods of low precipitation.

Functions of an AVF--continued

- Collecting water
- Storing water (permeability, infiltration, and porosity)
- Regulating the flow of water (profile and slope of the valley, its sinuosity and cross-sections, and the interchange of water between streams and aquifers)

Monitoring

- The monitoring system shall provide sufficient information to allow a regulatory authority to determine that the essential hydrologic functions of an AVF are being preserved outside the permit area or reestablished within the permit area.

Monitoring: Land Quality Division Guideline No. 9 Regarding AVF's

- Monitoring plans should commit an operator to annually gathering sufficient information (e.g., infrared aerial photography, annual surface photographic locations) to demonstrate that vegetation associated with the "unaffected AVF's" continues to grow to roughly the same extent as it did at baseline and/or during base year.

Guideline No. 9 Regarding AVF's--continued

- Such monitoring should also provide sufficient information from alluvial ground-water wells and surface-water monitoring stations to determine if the mining operations are adversely affecting the supply of water to "unaffected AVF's." The monitoring plan should include a description of the frequency and locations of monitoring.

Summary of Bond-Release Criteria

- Water availability
- Water storage
- Water regulation
- Indicator plant species

RESTORED AVF'S

- No AVF's have received final bond release

- Buckskin mine has restored an AVF:
  - Normal bathtub design
  - Alluvial material
  - Built a series of baffles to help store water
  - Received an "Excellence in Surface Mining" award from OSM

Coal-Bed Methane

- Enhanced availability of water:
  - May create or enlarge “natural” AVF’s before baseline studies are completed
  - May “artificially” restore the essential hydrologic function when an operator has failed to do so.

WYOMING
CUMULATIVE HYDROLOGIC IMPACT ASSESSMENT AND COAL-BED METHANE

Scott L. Miller
Wyoming Department of Environmental Quality,
Land Quality Division

10 21 '99

Summary

- Who does a cumulative hydrologic impact assessment (CHIA) in Wyoming?
- When is a CHIA done?
- Why is a CHIA done?
- How is a CHIA done?
- What factors are considered?
- Other factors—coal-bed methane

Who does a CHIA in Wyoming?

- CHIA's in Wyoming are performed by the Wyoming Department of Environmental Quality, Land Quality Division

When is a CHIA done?

A CHIA is performed for:

- New permit applications
- Permit amendments
- Permit modifications proposing impacts to the hydrologic balance

LIEBHERR
T 282
T 282
LIEBHERR

Why is a CHIA done?

- A CHIA is performed to determine whether a mining operation has been designed to prevent material damage to the hydrologic balance.
- Material damage is significant long-term or permanent adverse changes to surface- and ground-water quality and quantity.

How is a CHIA done?

A CHIA is performed using:

- Qualitative assessment techniques
- Quantitative assessment techniques

Basic CHIA Process

- Identify the cumulative impact area (CIA)
- Review baseline data for mines in the CIA
- Review the probable hydrologic consequences (PHC) document, the mine plan, other (models)
- Compare predictions with annual report data and the coal permitting and reclamation (CPR) database
- Determine impacts to the hydrologic system
- Make a material damage determination

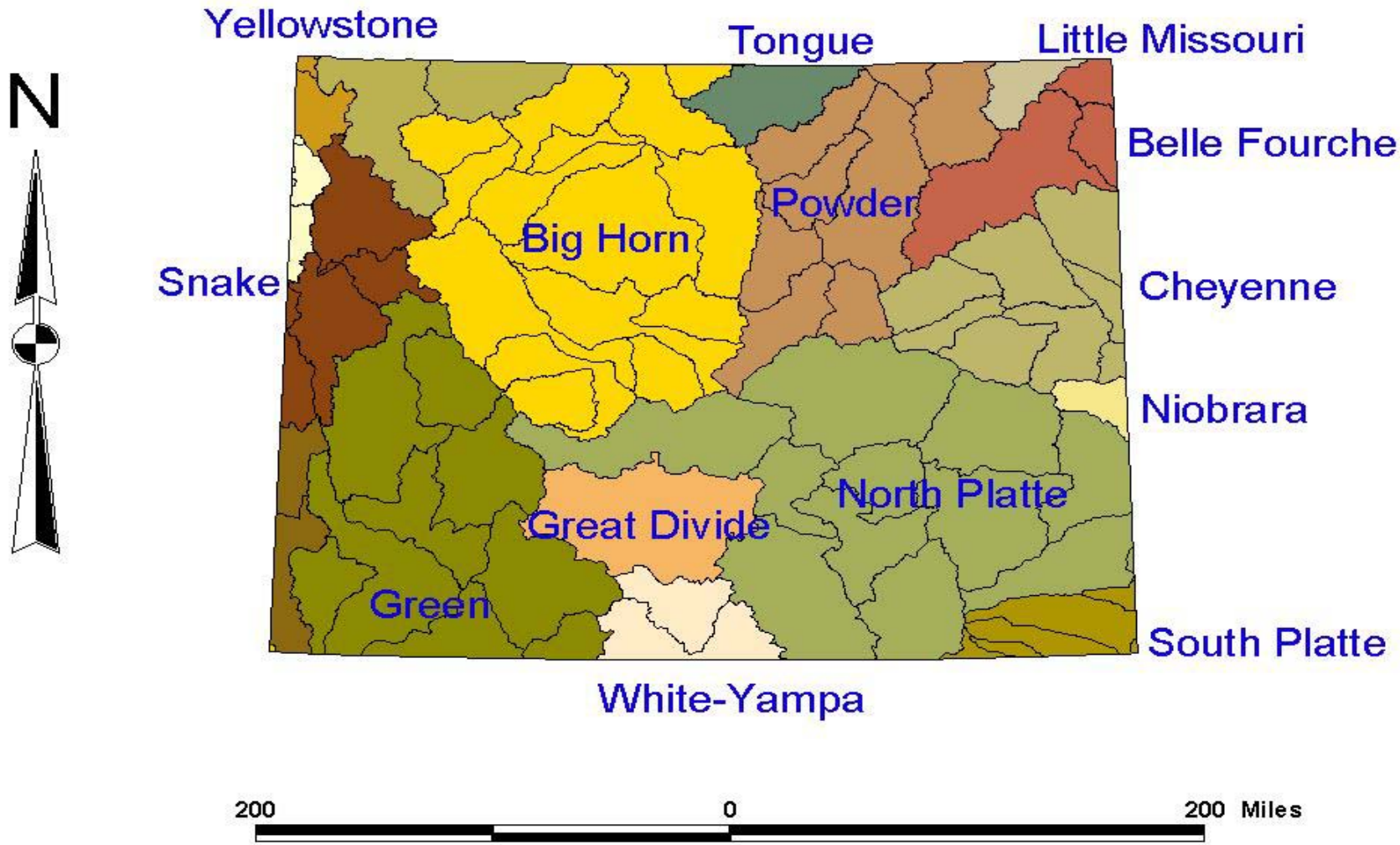
CHIA Considerations

- Current and proposed mines in CIA
- No surface mines approved unless designed to prevent material damage to the hydrologic balance
- CHIA must be sufficient to determine whether mine is designed to prevent material damage to the hydrologic balance

Powder River Basin CHIA Priorities

- 23 of 37 surface coal mines in Wyoming are located in the Powder River Basin, in the northeastern part of the State.
- CHIA's in the Powder River Basin focus on major drainage basins:
  - Little Powder River Basin
  - Cheyenne River Basin
  - Belle Fourche River Basin

WYOMING


Yellowstone
Tongue
Little Missouri
N
Belle Fourche
Powder
Big Horn
Snake
Cheyenne
Niobrara
North Platte
Great Divide
Green
South Platte
White-Yampa
200
0
200 Miles

CPR Database

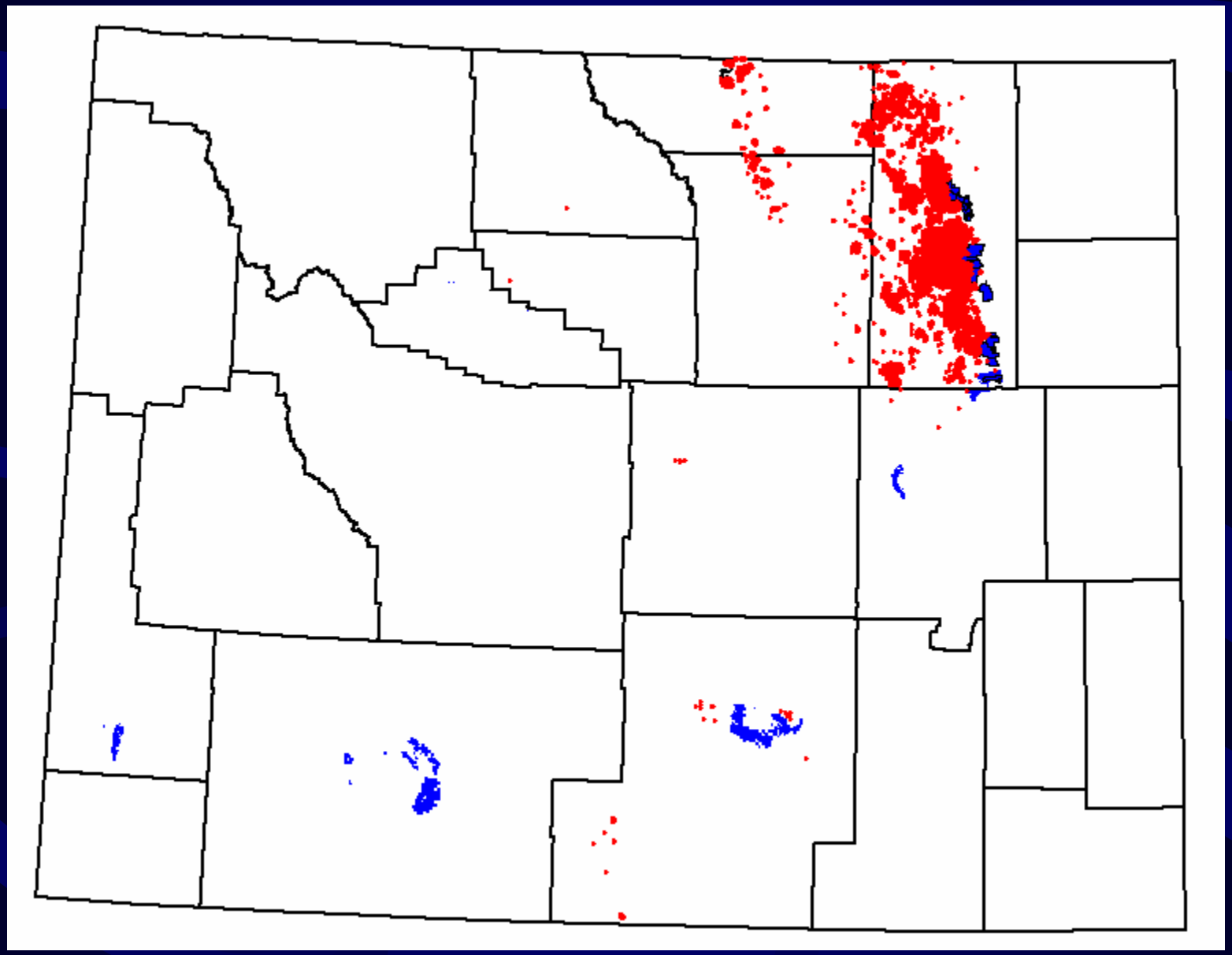
The CPR database consists of surface- and ground-water quantity and quality data for all potentially impacted aquifers:

- updated annually
- data provided by the operators
- operator contacted if anomalous data identified

Coal-Bed Methane

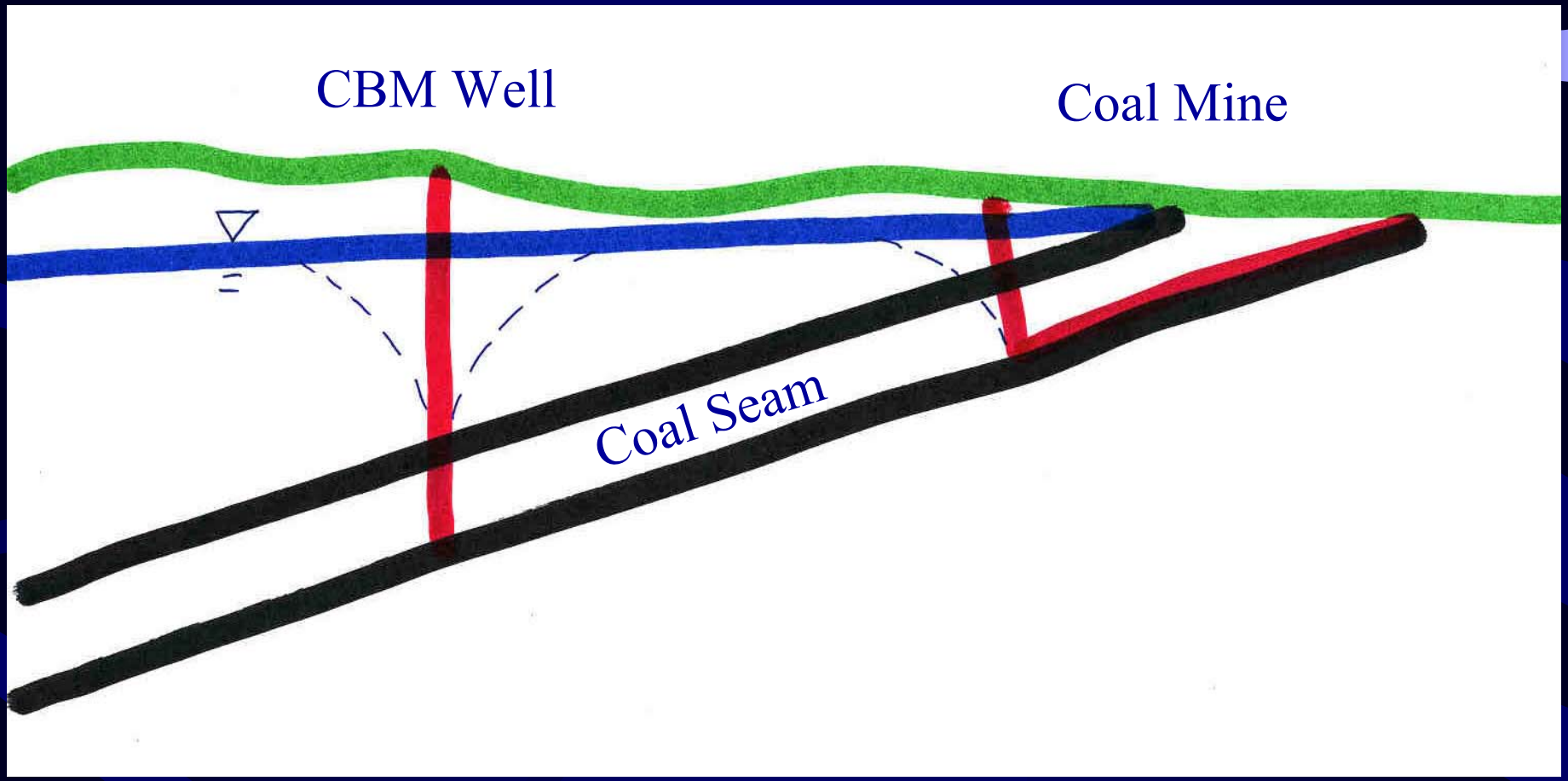
- Coal-bed methane (CBM) development in the Powder River Basin has become major issue:
  - Began in early 1990's on a small scale
  - "Boom" began in late 1990's, as the resource became realized
  - Growth, development, and production continue to exceed expectations
  - Conflict developing between surface and subsurface owners

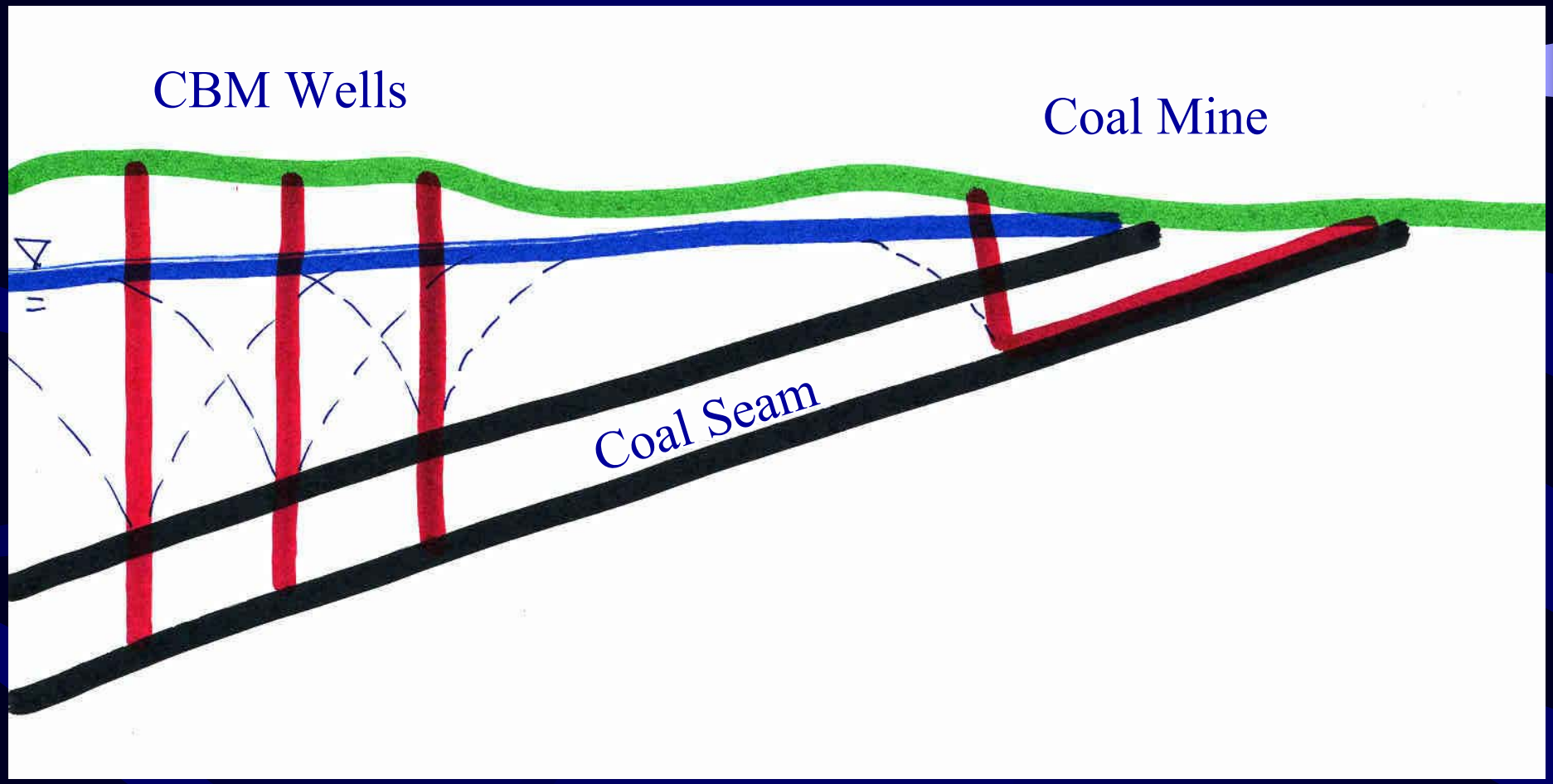
WYOMING

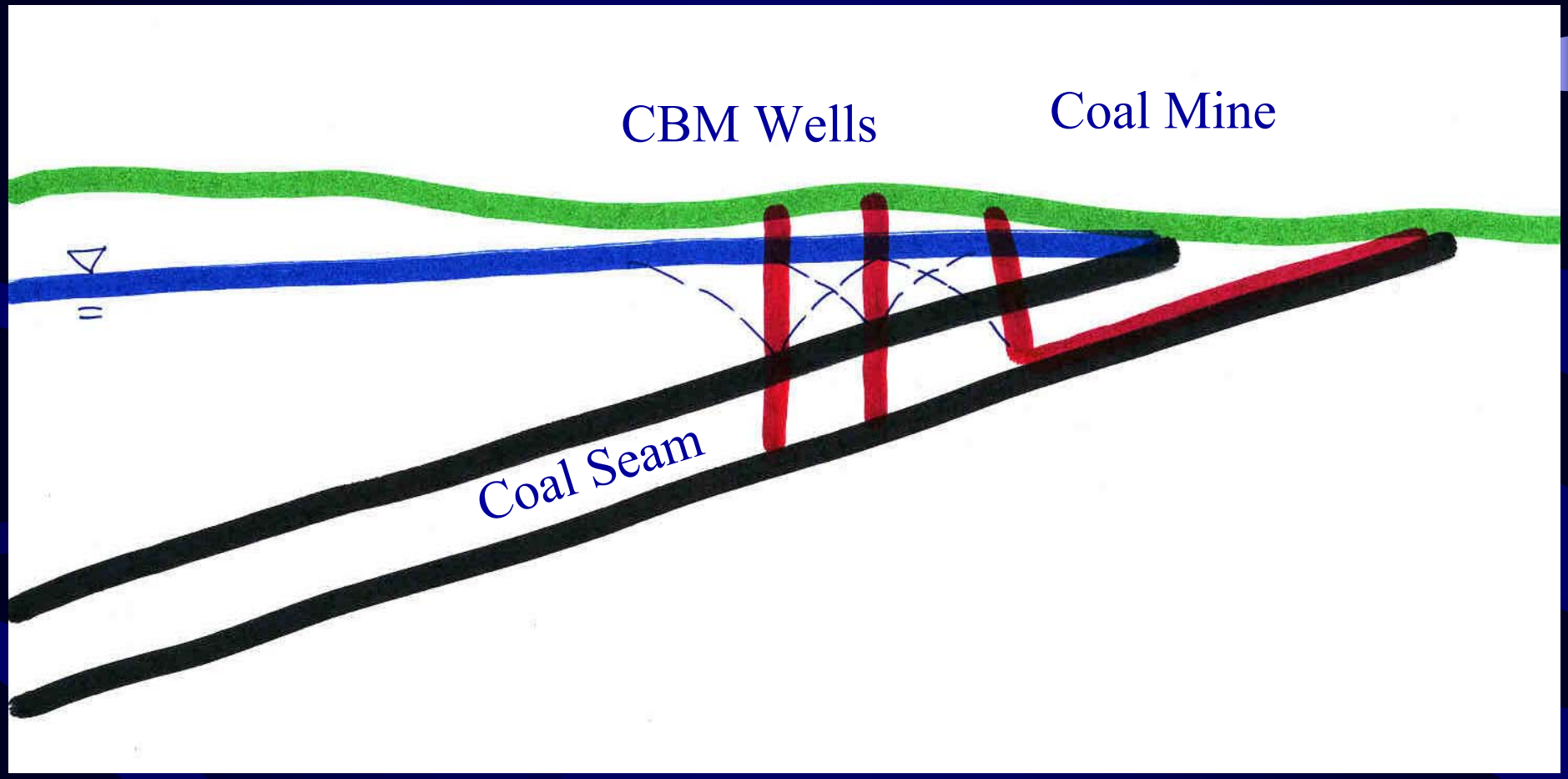


CBM

- To produce CBM from coal seams:
  - Coal is a confined aquifer
  - Overlying ground-water head provides pressure to keep methane in coal
  - Pump ground water from coal aquifer to reduce potentiometric surface and overlying pressure
  - Methane released from coal and collected


CBM Well
Coal Mine
Coal Seam


CBM Wells
Coal Mine
Coal Seam


CBM Wells
Coal Mine
Coal Seam

Conflict Arising

- Coal mines v. CBM industry
- Coal mines:
  - highly regulated
  - accountable for hydrologic impacts
- CBM industry:
  - loosely regulated
  - accountable for hydrologic impacts?

Conflict Arising

- Coal mines v. CBM industry
  - coal mines must reclaim for bond release
  - hydrologic system must be recovering for bond release
  - nearby CBM industry is affecting hydrologic system
  - define responsibility for impacts?

Regulatory Jurisdiction

- Coal mines regulated by:
  - Wyoming Department of Environmental Quality, Land Quality Division
- CBM industry regulated by:
  - Wyoming State Engineer Office (well permitting)
  - Wyoming Department of Environmental Quality, Water Quality Division (discharge quality)
  - U.S. Bureau of Land Management (Federal land issues)
  - Wyoming Department of Environmental Quality, Land Quality Division (no jurisdiction!)

Wyoming Department of Environmental Quality Position

- CHIA is not required to address CBM impacts, only mining impacts
- However, CBM impacts are affecting hydrology, which in turn affects the CHIA
- Currently looking at issue of how to evaluate impacts to hydrologic system when CBM and coal-mine impacts overlap

Conclusions

- The who, what, when, where, why, and how of CHIA's in Wyoming are similar to those of CHIA's in other States
- CBM impacts becoming contentious issue between surface and subsurface owners
- Wyoming Department of Environmental Quality is currently evaluating how to evaluate impacts to hydrologic system when CBM and coal-mine impacts overlap

ASSESSING SEDIMENTATION AND LANDFORM STABILITY IN RECLAIMED AREAS USING BASELINE SEDIMENT DATA COLLECTED IN RECEIVING STREAMS

H. T. Smith, Peabody Western Coal Company

Alan Best, B&G Systems, Inc.

Goals

To demonstrate that Peabody Western Coal Company (PWCC) is dealing with an environment where there is an excess of available sediment for erosion and to provide an analytical tool for determining if sediment yields from reclaimed areas are contributing additional solids to streamflows.

To provide a suitable demonstration to OSM that pond-removal and bond-release criteria and considerations for coal mines in the Southwest must be revised, particularly in regards to evaluating upland hillslope stability.

I. The Regulatory Requirements

30 CFR 780.21 requires the permittee to:

1. Provide surface-water information with its permit application.

2. Conduct surface-water monitoring to provide information on baseline total suspended solids.

3. Confirm the suitability of the surface water for current and approved postmining land uses and to achieve the objectives of protection of the hydrologic balance.

4. Develop a Hydrologic Restoration Plan to <u>prevent to the extent possible</u>, using best technology currently available, additional contributions of suspended solids to streamflow.

30 CFR 715.17(b)(2) requires the permittee to:

1. Monitor surface-water flow and quality in regraded and stabilized reclaimed areas to document that runoff from reclaimed lands will minimize disturbance to the hydrologic balance.

2. Demonstrate that runoff will support the approved postmining land use.

3. <u>These data shall provide a basis for the regulatory authority to approve the removal of water-quality or flow-control systems and grant the achievement of protection of the hydrologic balance</u>.

II. The Montoring Approach

A. The nature of the beast

1. **Sediment yield as a function of effective precipitation**
2. **Hjulstrom Diagram**
3. **Characteristics of the channels**

B. Main channel-monitoring approach

1. **Sampler housing designs**
2. **Samplers and sampler design**
3. **Nature of storms**
4. **Nature of runoff events**
5. **Continuous flow monitoring with ultrasonic pulse gages**
6. **Flow peaks measured in slope -area sections**

C. Small watershed monitoring approach

1. **Typical interim-law areas**
2. **Flume designs on reclaimed drainages**
3. **Samplers for small watershed flumes**

III. The Analysis Of Data Populations

A. Compile sediment-load v. flow-discharge data.

B. Construct log-log plots of sediment load v. discharge.

C. Calculate the Mann Kendall test for trend to confirm the data have a trend.

D. Calculate the Sen estimator of trend slope and calculate the Sen trend line.

E. Calculate the nonparametric prediction intervals around the Sen trend line at a 0.05 alpha level to identify probable outliers.

F. Flag outliers and exclude from analyses.

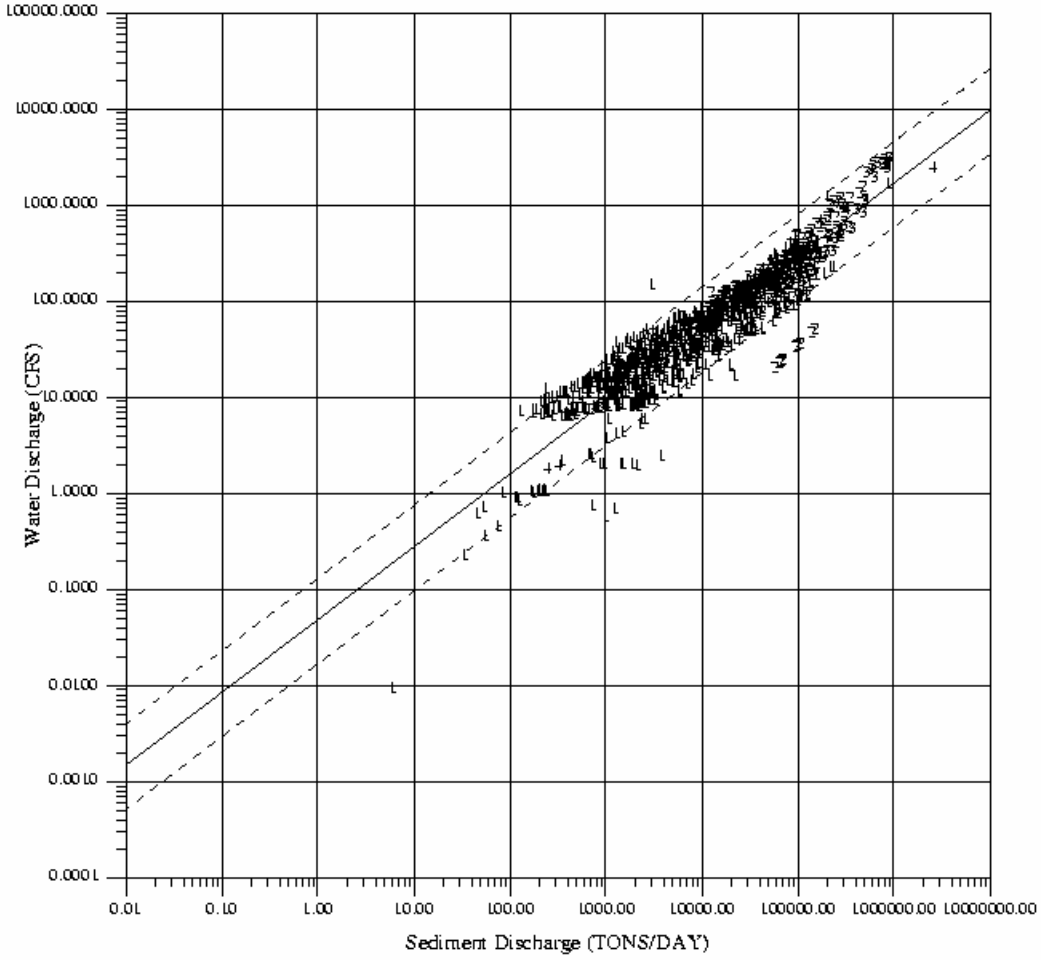
G. Perform comparisons of median pairs for every combination of two sites using nonparametric prediction intervals.

H. Perform comparisons of slopes for every combination of two sites using Sen confidence intervals around each slope.

Site SW16

Water Discharge Versus Sediment Discharge
Regression With All Samples

Sen Line: log(sediment) = 4.0005 + 1.3203 log(discharge), 0.050 Alpha

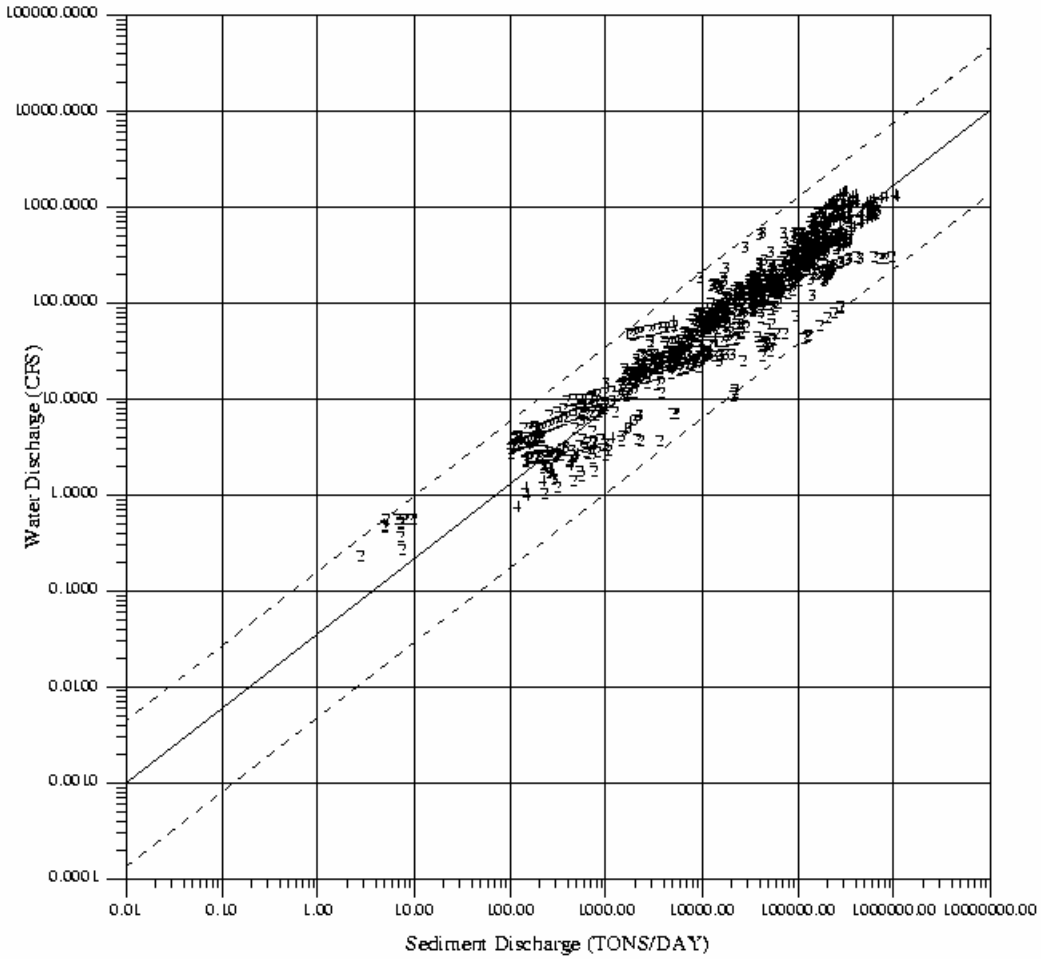


1 = PT1-16 (lowest), 2 = PT2-16, 3 = PT3-16, 4 = PT+16

Site FLUM15

Water Discharge Versus Sediment Discharge
Regression Without Outliers

Sen Line: log(sediment) = 4.2806 + 1.2843 log(discharge), 0.000 Alpha

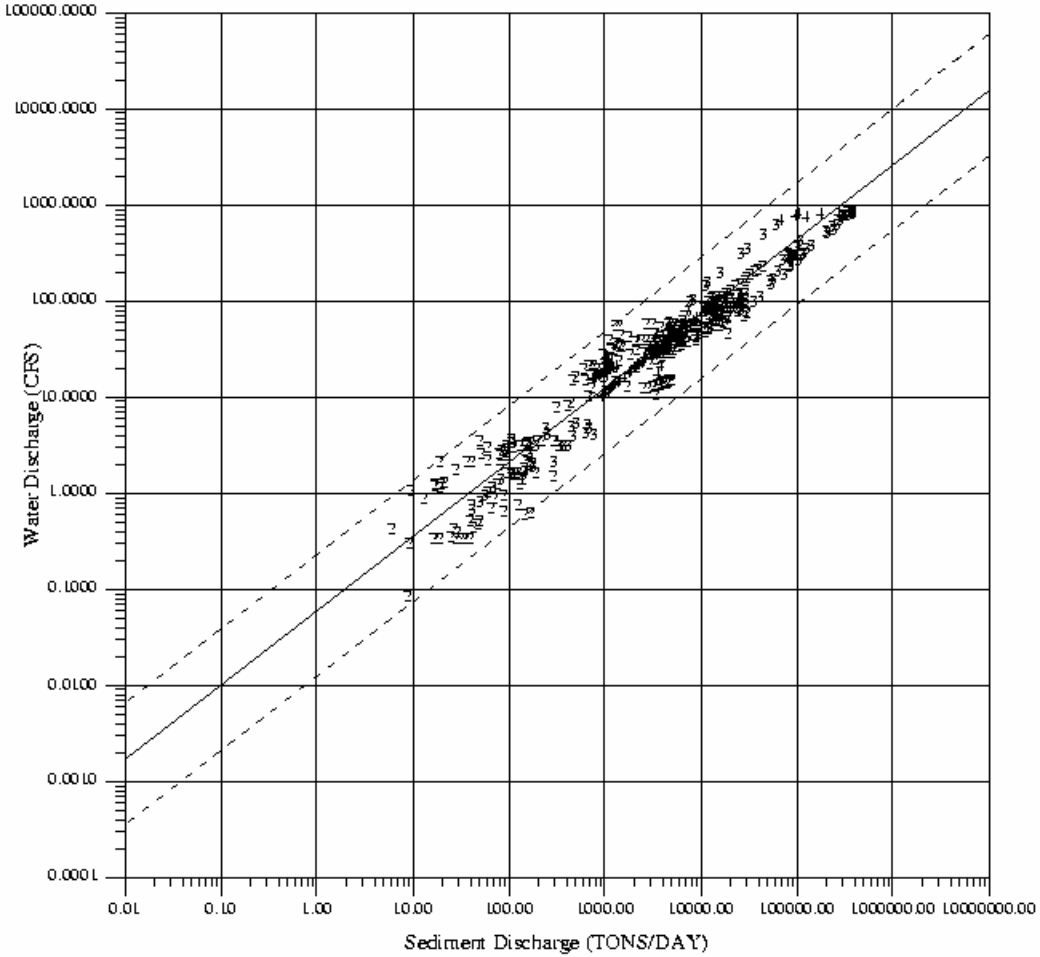


1 = FLUM15 (lowest), 2 = PT1-15, 3 = PT2-15, 4 = PT3-15

Site FLUM18

Water Discharge Versus Sediment Discharge
Regression Without Outliers

Sen Line: log(sediment) = 3.6510 + 1.2928 log(discharge), 0.000 Alpha

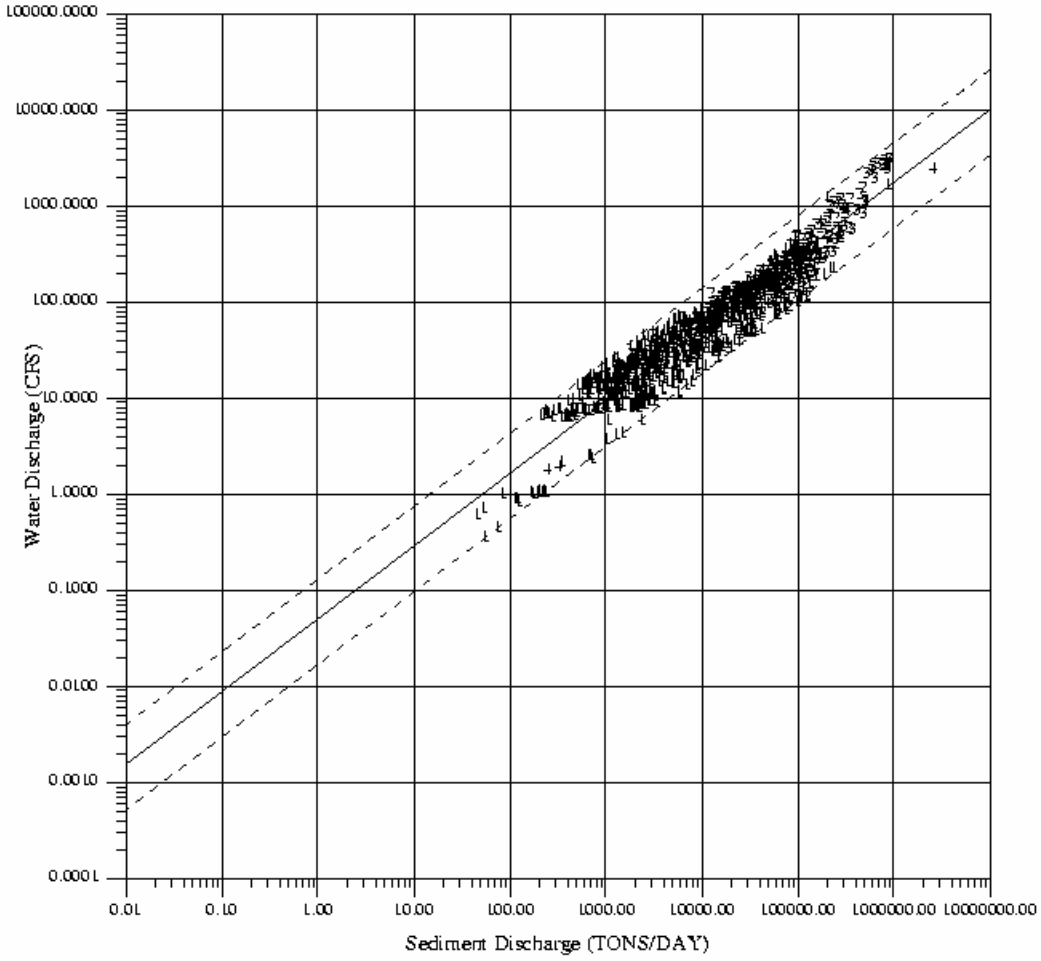


1 = FLUM18 (lowest), 2 = PT1-18, 3 = PT2-18, 4 = PT3-18

Site SW16

Water Discharge Versus Sediment Discharge
Regression Without Outliers

Sen Line: log(sediment) = 3.9527 + 1.3207 log(discharge), 0.000 Alpha

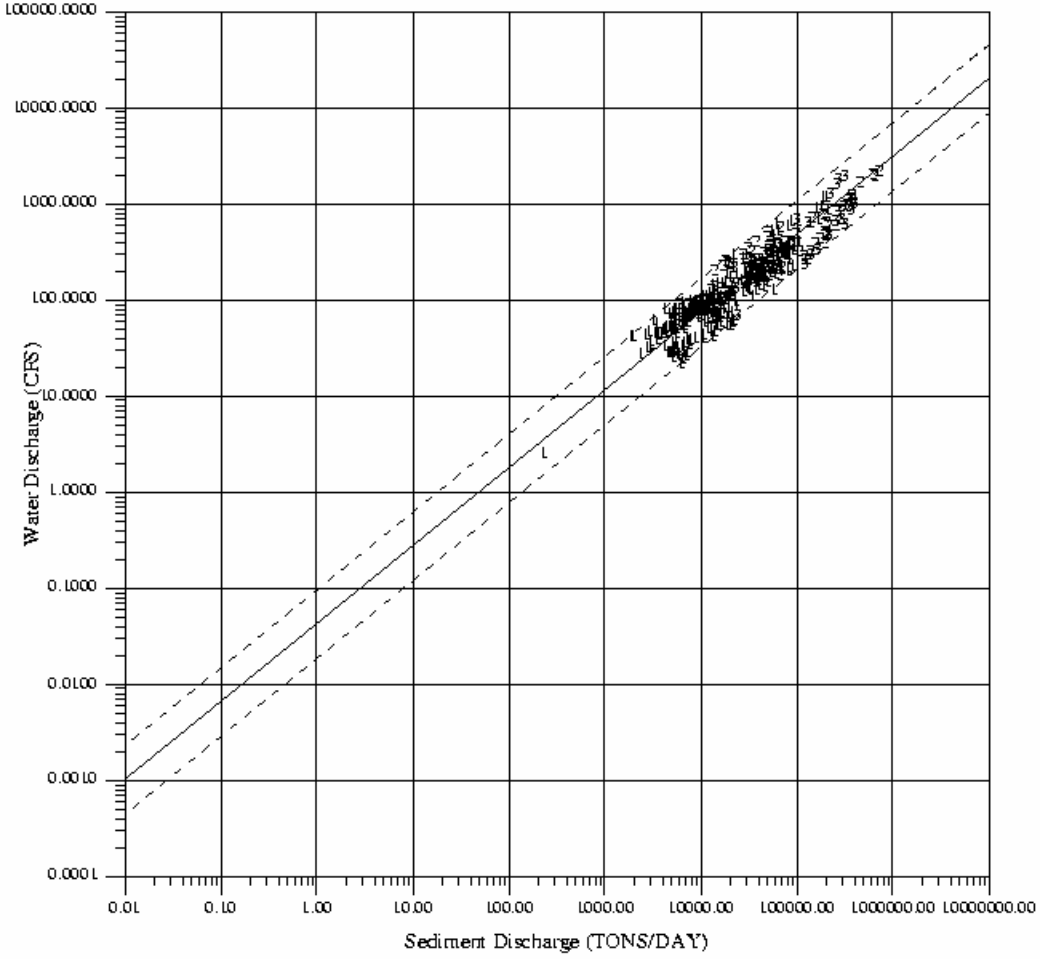


1 = PT1-16 (lowest), 2 = PT2-16, 3 = PT3-16, 4 = PT4-16

Site SW35

Water Discharge Versus Sediment Discharge
Regression Without Outliers

Sen Line: log(sediment) = 3.8848 + 1.2337 log(discharge), 0.000 Alpha

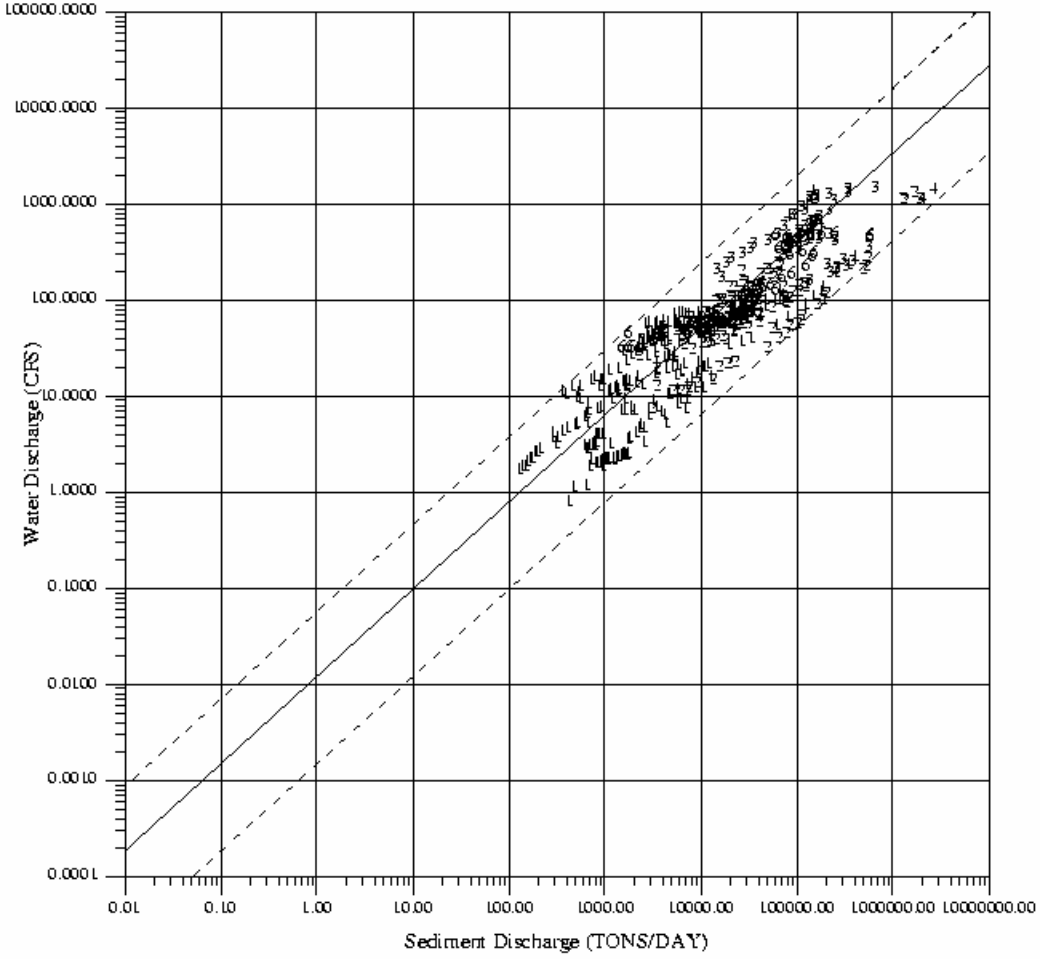


1 = PT1-35 (lowest), 2 = PT2-35, 3 = PT3-35, 4 = PT4-35

Site SW50

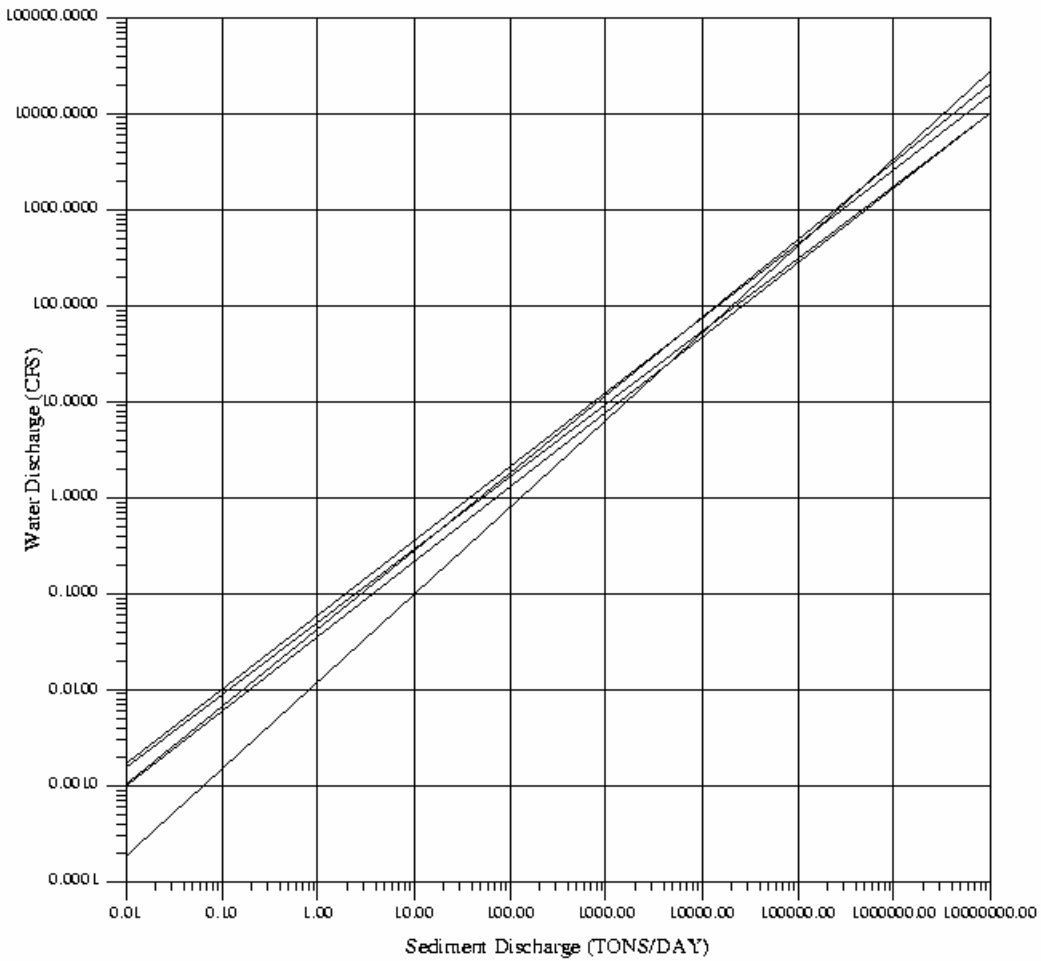
Water Discharge Versus Sediment Discharge
Regression Without Outliers

Sen Line: log(sediment) = 4.8697 + 1.1013 log(discharge), 0.000 Alpha



1 = PT1-50 (lowest), 2 = PT2-50, 3 = PT3-50, 4 = PT4-50, 5 = PT5-50, 6 = PTA-50

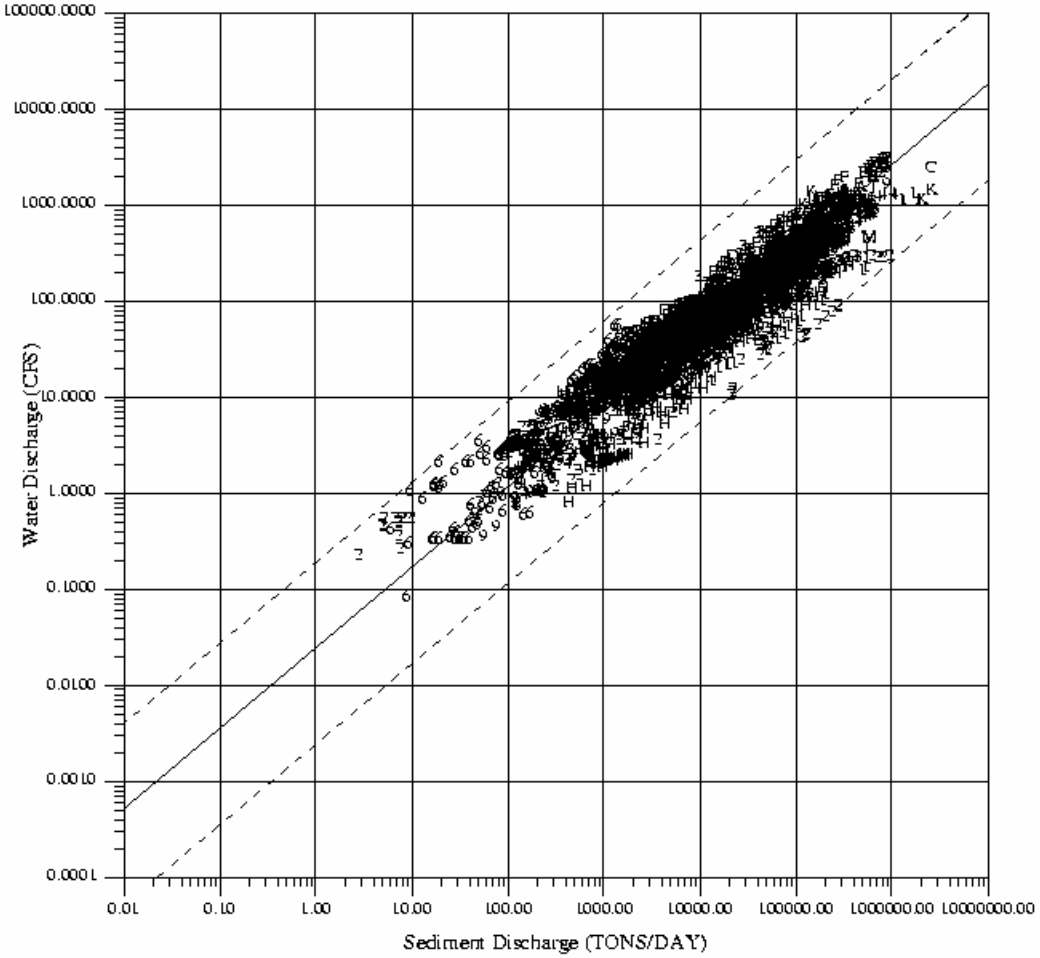
Comparison of Sen Slope Lines at Five Main Channel-Monitoring Sites



Sites FLUM15, FLUM18, SW16, SW35, SW50

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SWS16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha

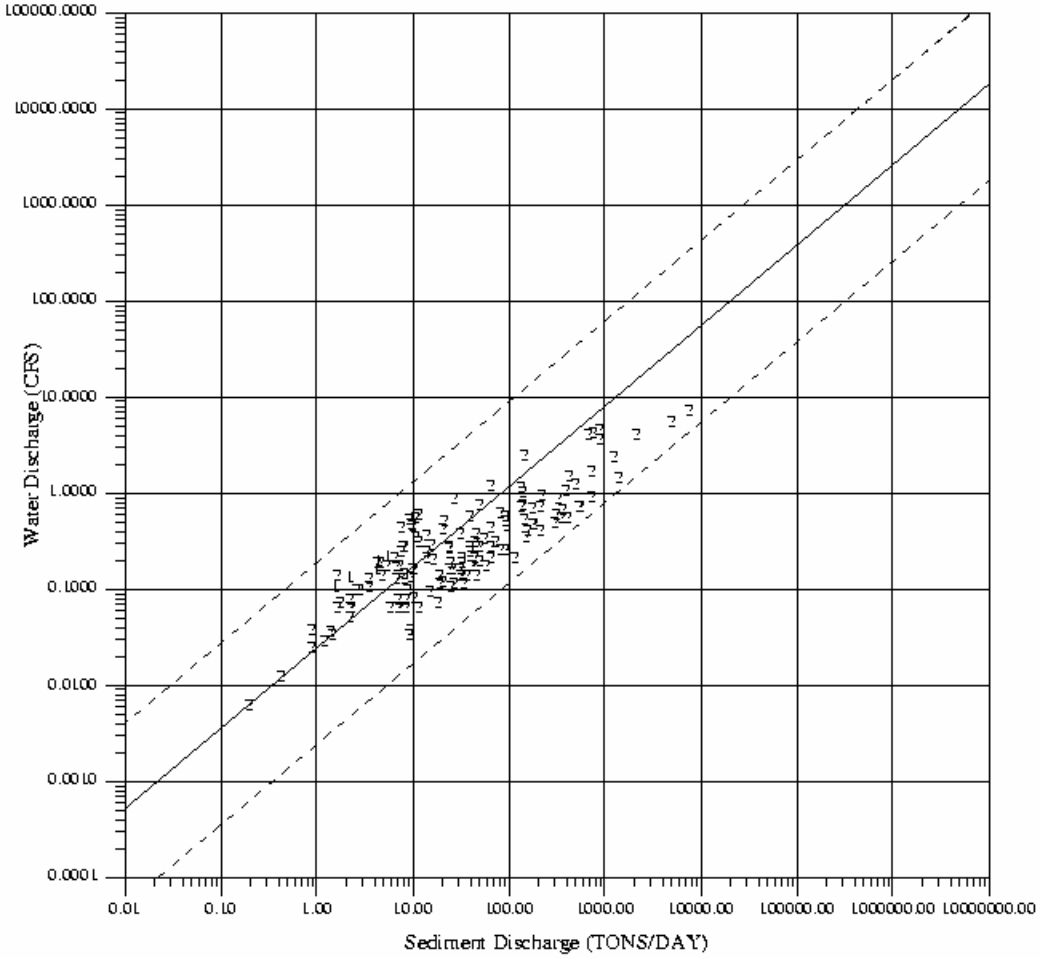


1 = FLUM15, 2 = PT1-15, 3 = PT2-15, 4 = PT3-15, 5 = FLUM18, 6 = PT1-18, 7 = PT2-18, 8 = PT3-18, 9 = PT1-16
A = PT2-16, B = PT3-16, C = PT4-16, D = PT1-35, E = PT2-35, F = PT3-35, G = PT4-35, H = PT1-50, I = PT2-50
J = PT3-50, K = PT4-50, L = PT5-50, M = PTA-50

Site FLUM227

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SW16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha

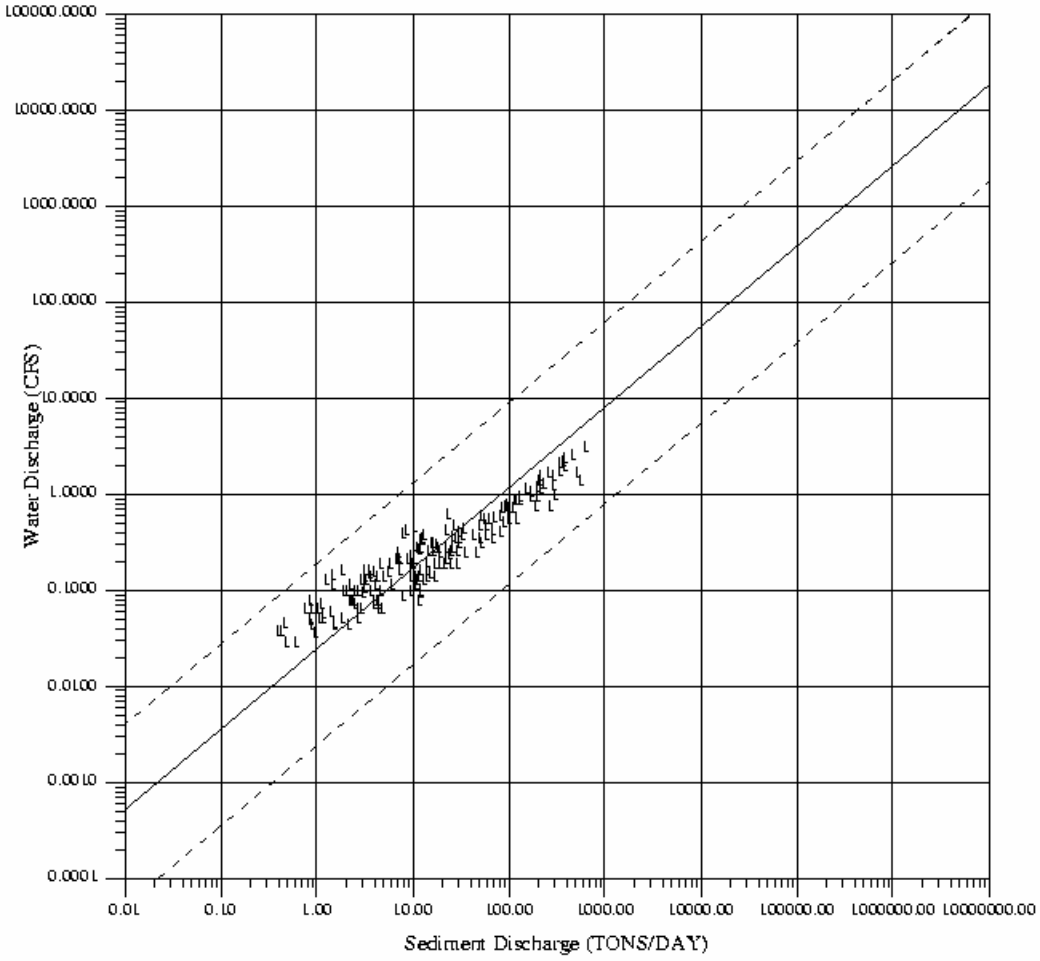


1 = DU227 (lowest), 2 = PTL-227

Site FLUM228

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SW16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha

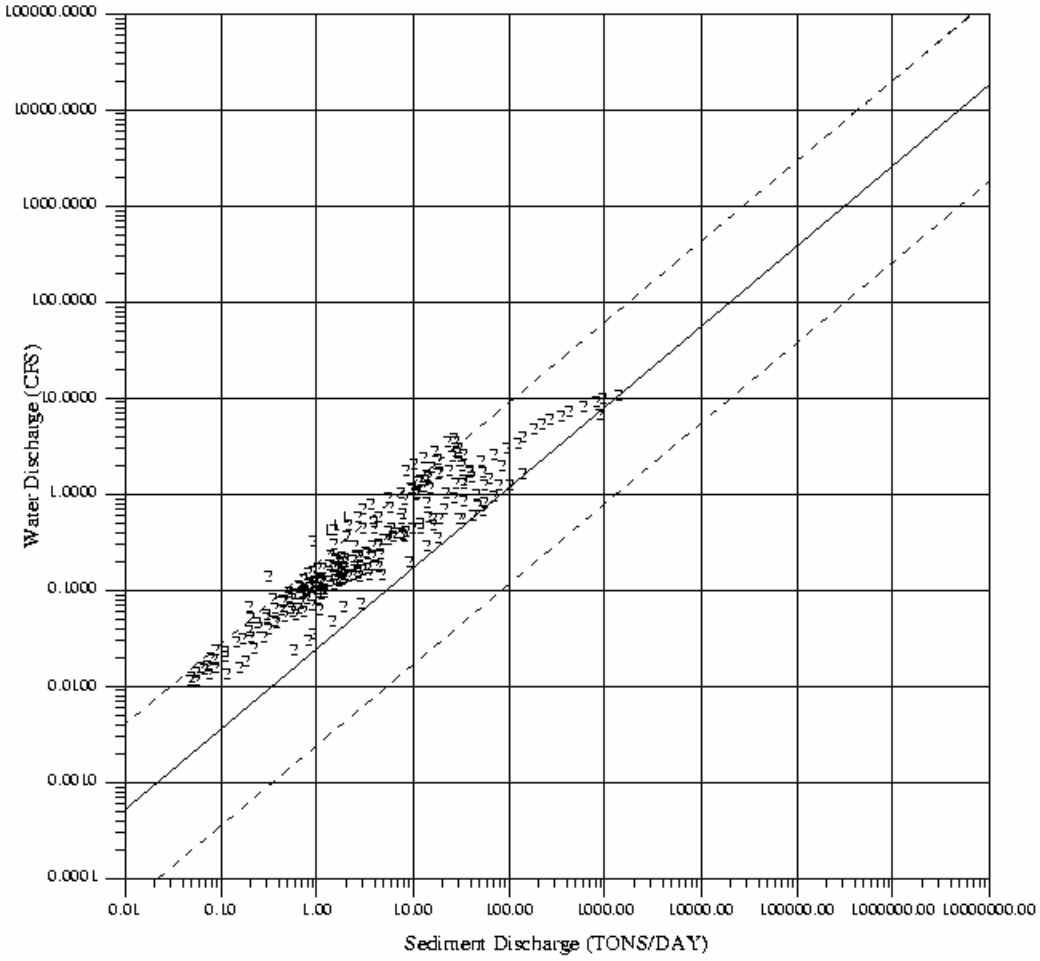


L = PTL-228 (lowest)

Site FLUM267

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SW16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha

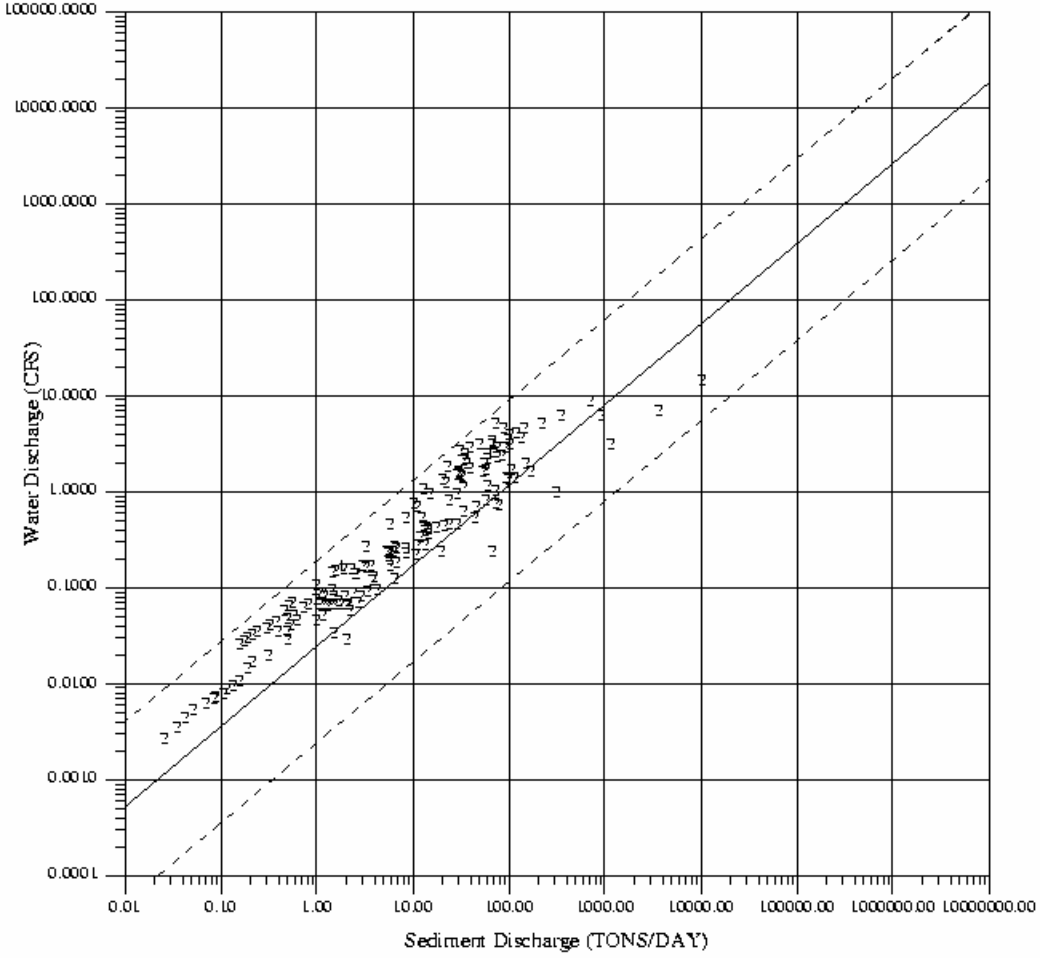


1 = D1267 (lowest), 2 = PTL-267

Site FLUM268

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SW16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha

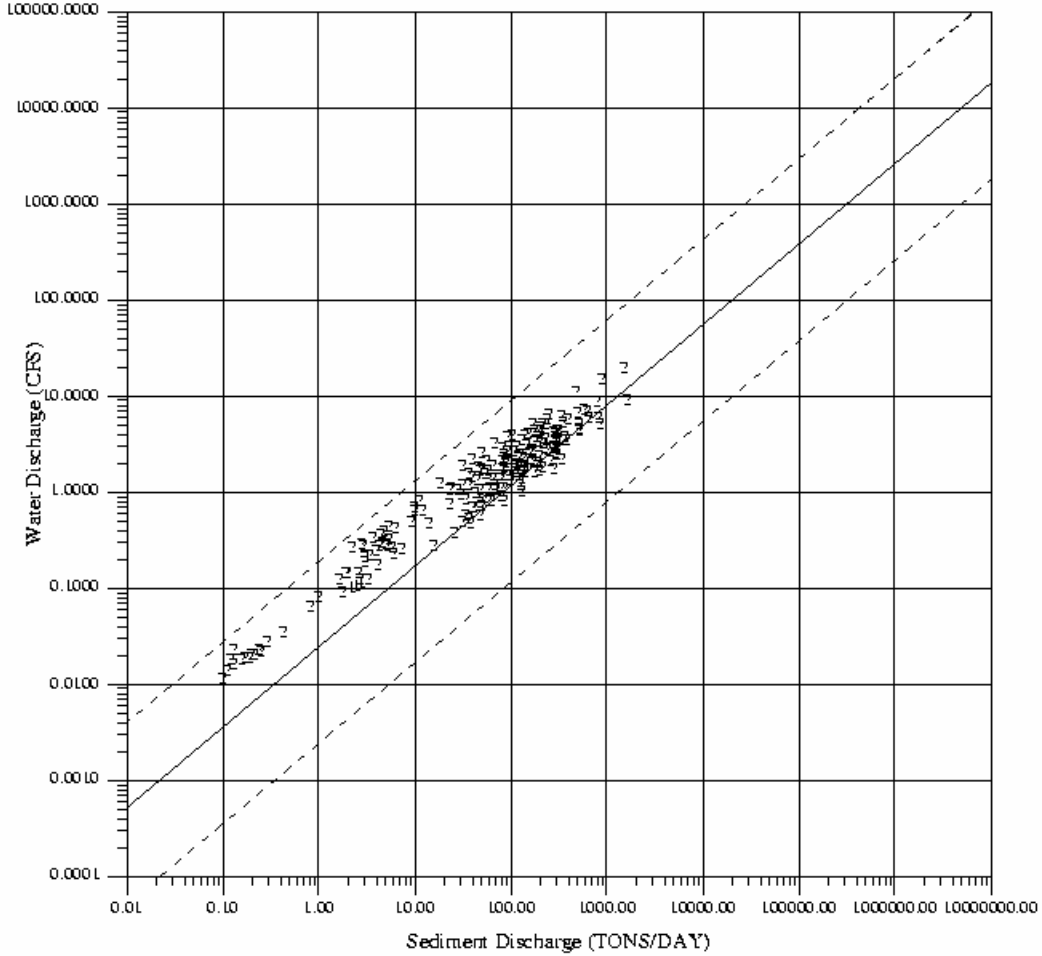


1 = D1268 (lowest), 2 = PTL-268

Site FLUM277

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SW16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha

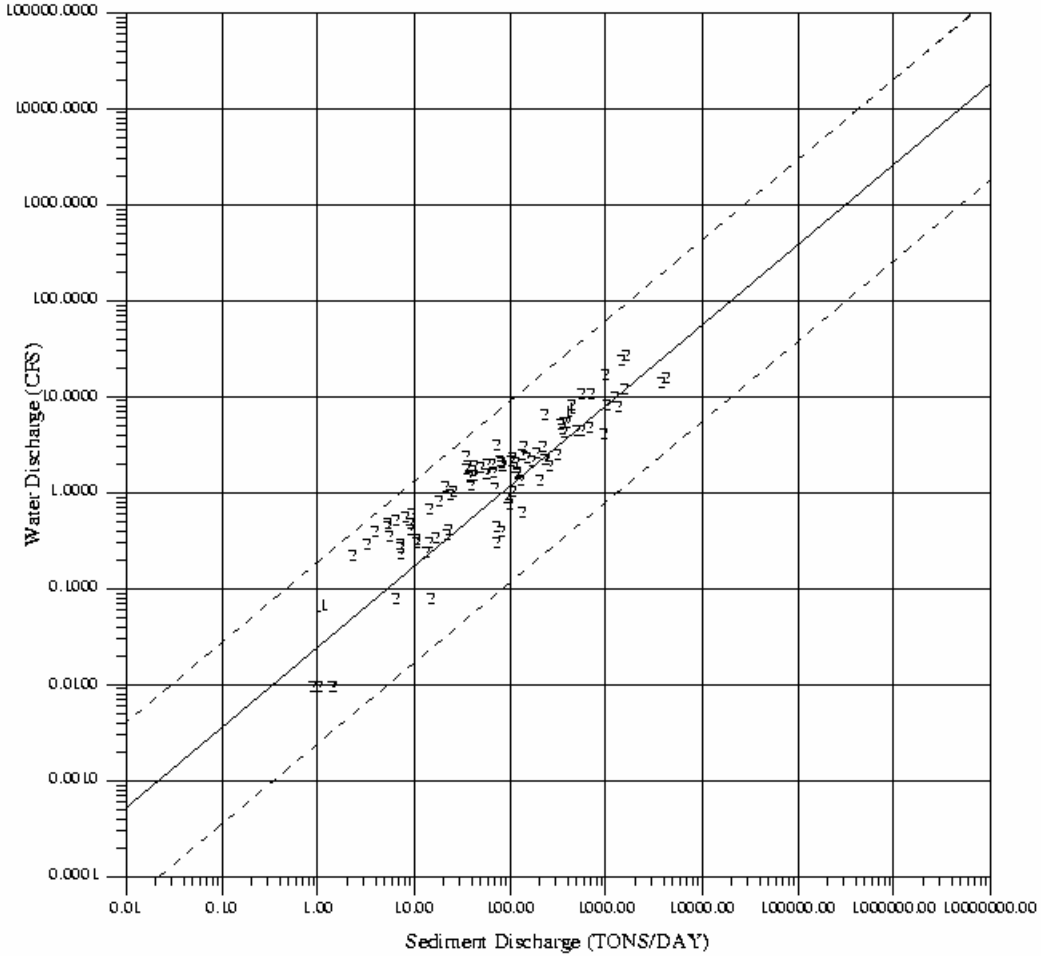


1 = DL277 (lowest), 2 = PTL-277

Site FLUM309

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SW16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha

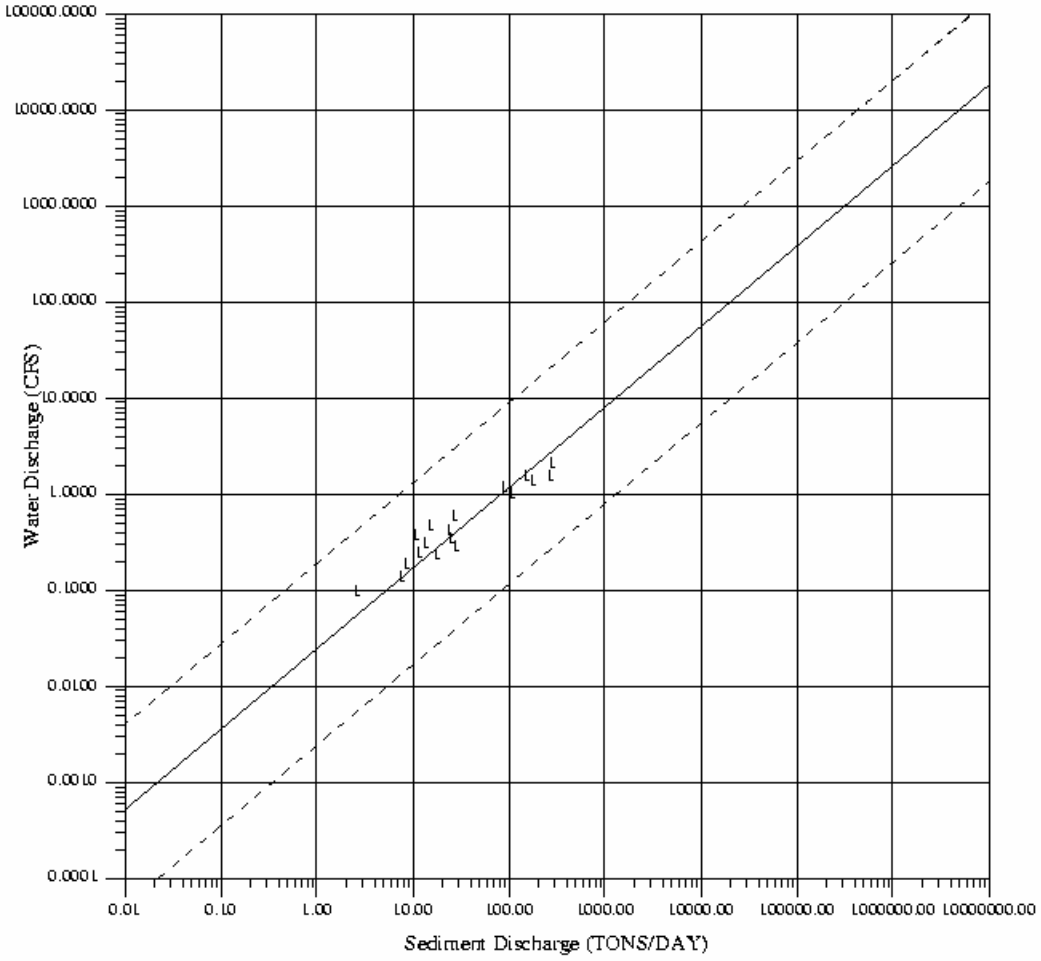


1 = DL309 (lowest), 2 = PTL-309

Site FLUM310

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SW16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha

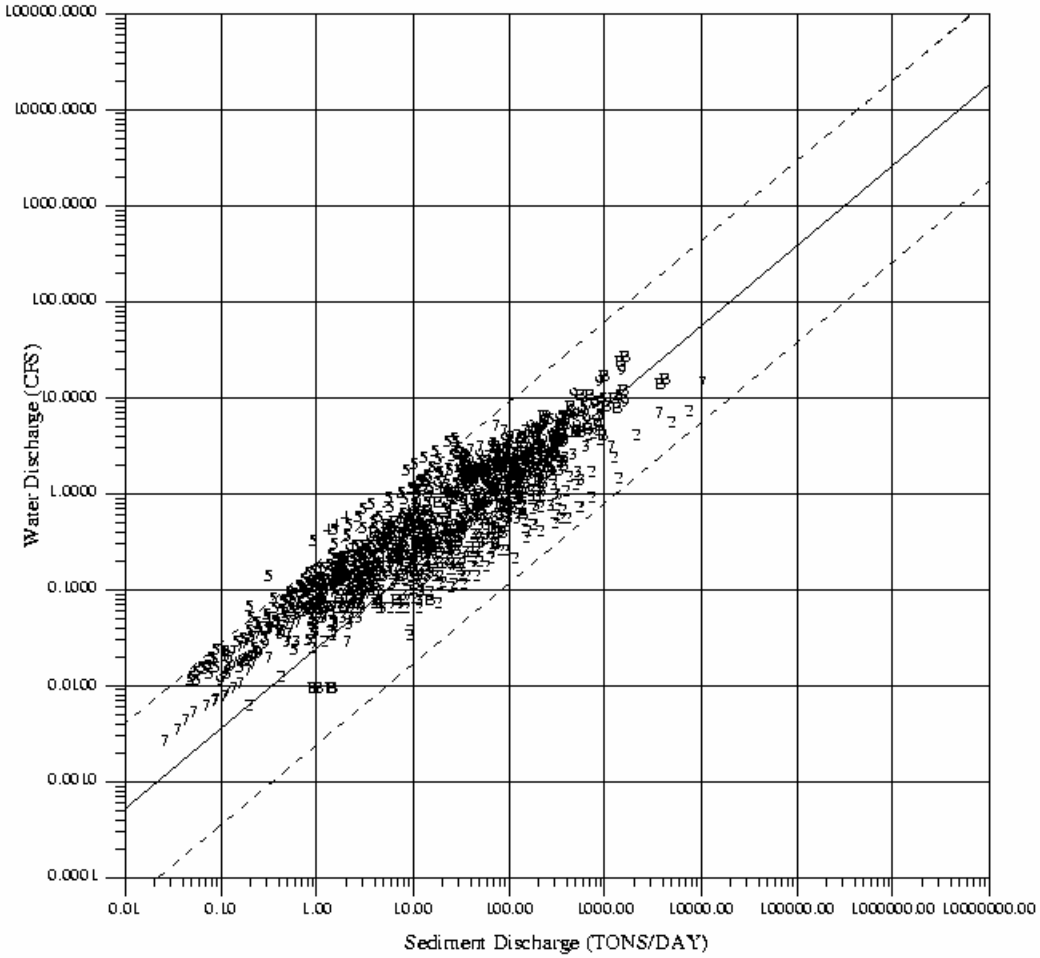


L = PTL-310 (lowest)

Sites FLUM227, FLUM228, FLUM267, FLUM268, FLUM277, FLUM309, FLUM310

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SW16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha

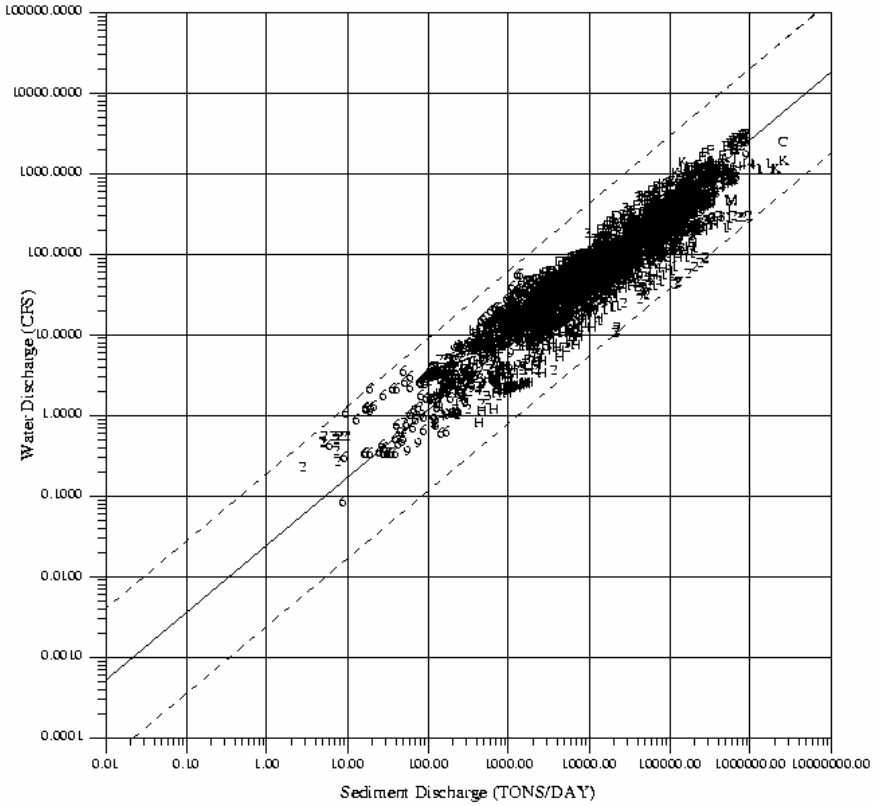


1 = DL227, 2 = PTL-227, 3 = PTL-228, 4 = DL267, 5 = PTL-267, 6 = DL268, 7 = PTL-268, 8 = DL277, 9 = PTL-277
A = DL309, B = PTL-309, C = PTL-310

Sites FLUM15, FLUM18, SW16, SW35, SW50

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SWS16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha

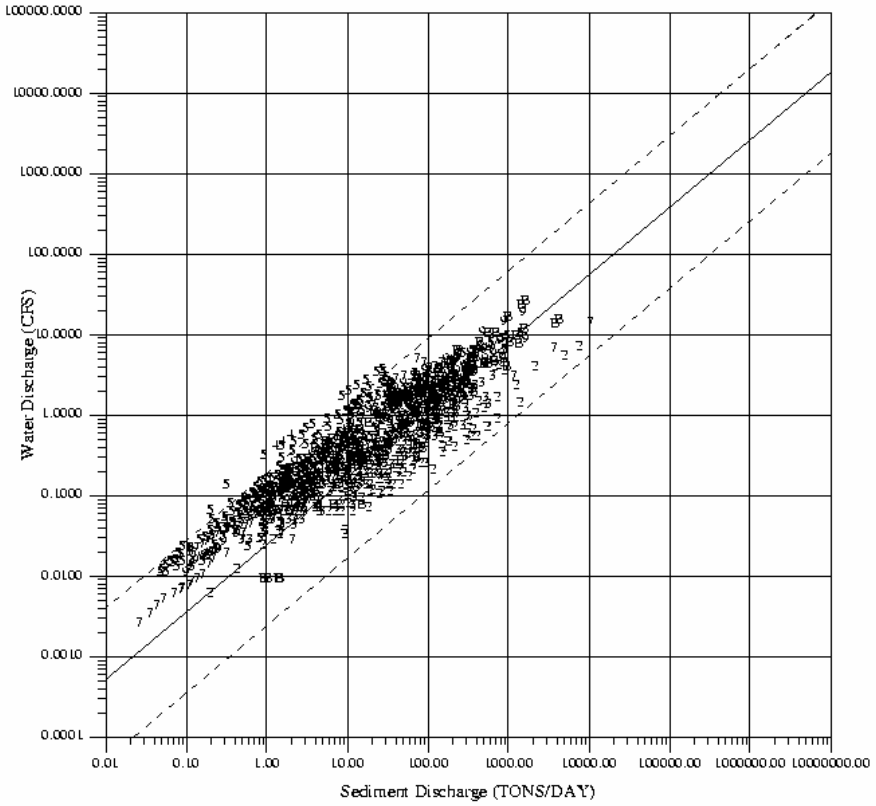


1 = FLUM15, 2 = PT1-15, 3 = PT2-15, 4 = PT3-15, 5 = FLUM18, 6 = PT1-18, 7 = PT2-18, 8 = PT3-18, 9 = PT1-16
A = PT2-16, B = PT3-16, C = PT+16, D = PT1-35, E = PT2-35, F = PT3-35, G = PT+35, H = PT1-50, I = PT2-50
J = PT3-50, K = PT+50, L = PT5-50, M = PTA-50

Sites FLUM227, FLUM228, FLUM267, FLUM268, FLUM277, FLUM309, FLUM310

Water Discharge Versus Sediment Discharge
FLUM15, FLUM18, SW16, SW35, SW50 Line

Sen Line: log(sediment) = 4.4230 + 1.1933 log(discharge), 0.000 Alpha



1 = D1227, 2 = PT1-227, 3 = PT1-228, 4 = D1267, 5 = PT1-267, 6 = D1268, 7 = PT1-268, 8 = D1277, 9 = PT1-277
A = D1309, B = PT1-309, C = PT1-310

Study Results

Regardless of watershed size, percentage slopes, drainage density, soil composition, vegetative cover, etc., the Sen slope lines are very similar and show a constant linear increase in sediment yield with increasing flow.

By examining the Sen estimations of the individual site slopes with their associated confidence intervals and by examining the individual site discharge and tons/day medians in relation to the individual site regression prediction intervals, we concluded that the site samples could be combined to derive a single representative line of regression with an associated prediction interval.

The Sen slope line for the combined data set for the five stream monitoring sites and its associated prediction limits can be compared to sediment-yield data collected on any reclamation anywhere on a leasehold to determine if the reclaimed area runoff is contributng additional sediment to the streamflows.

Conclusions

A. Based on the statistical analysis, data from the five main stream-monitoring sites can be combined and used for further comparisons with other runoff sediment-yield data.

B. Data sets did not have to be combined to prove that there is an excess of available sediment everywhere on the watersheds and in the channels.

C. The length of the main stream sediment v.flow-discharge data plots--each exhibiting a strong, constant linear relationship of increasing sediment yield with increasing flow--verifies that there is an unlimited source of available sediment.

D. That sediment data collected in five principal watersheds of differing size and other morphological features could plot so closely could only happen if each watershed had an excess of available sediment in the size ranges that are easily transportable.

Conclusions--continued

E. The implications for bond release and pond removal are enormous:

1. The sediment loads already being transported in the main channels are as high as they can be for a given range of flows. There is nothing PWCC can do in the reclaimed watersheds that will increase these sediment loads. Even our earliest efforts under interim-program lands that employed reclamation techniques since abandoned are not contributing additional suspended solids to streamflows.

2. The problem of controlling topsoil loss from reclaimed hillslopes in the Southwest is greater because the soils are not cohesive. Soil particles are easily entrained, especially when rainfall is intense.

3. Bond-release criteria for the Southwest mines need to be revisited with OSM. Permit revisions allowing significant reclaimed land-form deviations from approximate original contour and a different approach to field evaluations of upland slopes for stability are justified and needed.

Bibliography

Helsel, D. R., and Hirsch, R. M., 1992. Statistical Methods in Water Resources. New York: Elsevier Publishers. 490p.

Gibbons, R. D., 1994. Statistical Methods for Groundwater Monitoring. New York: John Wiley and Sons. 286p.

Gilbert, R. O., 1987. Statistical Methods for Environmental Pollution Monitoring. New York: Van Nostrand Reinhold. 320p.

Mann, H. B., 1945. *Nonparametric tests against trends.* Econometrica 13, p. 245-59.

Sen, P. K., 1968. *Estimates of the regression coefficient based on Kendall's Tau.* J. American Stat. Assoc., 63, p. 1379-89.

PROBABLE HYDROLOGIC CONSEQUENCES

Martin Stearns, Kennecott Energy Company
Doyl Fritz, WWC Engineering

WHY DO WE DO A PROBABLE HYDROLOGIC CONSEQUENCES (PHC) ANALYSIS?

- It’s the law!
- To set the bar; to establish a baseline
- To identify potential impacts
- To establish a position
- To form the basis for the hydrologic restoration plan

It’s the law

- 30 CFR 784.14 (e)
- OSM’s “Estimating Hydrologic Impacts – The Probable Hydrologic Consequences (PHC) Process,” found at www.osmre.gov/hyphc.htm (note that this publication is also reproduced as appendix C to these proceedings)

It's the law--continued

- OSM's "Sample Report Outline for PHC Determination," found at www.osmre.gov/phcol.txt (note that this sample outline is also reproduced as appendix D to these proceedings)

To set the bar

- Opportunity for the applicant to make its case
- Opportunity to present and sell data and interpretations
- Opportunity to set the grounds for bond release

To identify potential impacts

- Opportunity to find potential problems
- Opportunity to identify severity
- Opportunity to propose mitigation methods

To form the basis for the hydrologic restoration plan

- Gives a target for which to shoot
- Most important part of application for justifying ability to mine and reclaim with minimum impact to the hydrologic balance

HYDROLOGIC RESTORATION PLANNING: A DESIGN CONSULTANT'S PERSPECTIVE

Martin Stearns, Kennecott Energy Corporation
Doyl Fritz, WWC Engineering

Focus: Surface-Water Systems

- Other than alluvial valley floors (AVF's), ground-water restoration does not receive a great deal of planning
- Data show ground-water levels are recovering and water quality generally meets premining use suitability
- Full recovery of a ground-water system will take so long it is not a condition of bond release
- Design and construction of a stable surface-water system is key to reclamation success

Purpose of Hydrologic Restoration Plans (HRP's)

- **Provide for a postmining hydrologic system that is at least as good as the premining system:**
  - **Is erosionally as stable**
  - **Supports the postmining land uses**

- **Meet the Surface Mining Control and Reclamation Act of 1977 (SMCRA) requirement that land must be reclaimed to a condition equivalent to its premining condition**

Goals and Objectives of an HRP

- **Operator Goals**
  - HRP that can be permitted
  - HRP that can be economically constructed
  - HRP that if implemented will lead to bond release
- **Regulatory Agency Goals**
  - HRP that complies with all applicable rules and regulations
- **Design Consultant's Goal**
  - Develop a design that will be approved by the regulatory agency on the first round of review and can be built without costing the operator any money

Conflicts among HRP Goals

- Easiest HRP to permit is one that proposes a postmining system that looks just like the premining system
  - Probably not economical
  - May not be possible given stripping ratio, etc.
  - If design is judged on how easy the permit is to obtain, this is the easy route to take
- Easiest HRP proposal to build is one that requires least amount of earthwork in addition to what is required to remove the mineral

Conflicts Often Result from Personal Interpretation

- HRP may not propose copying the premining situation (meaning of “equal to” subject to interpretation)
- Copying the original system may mean lost opportunity to create something better
- Copying original system may not be possible given the stripping ratio at some mines (thin overburden)

How Did We Get Here?

- Most practices and all regulations are based on SMCRA and related State programs
- Interpretation has varied over the past 23 years
  - Designers come and go
  - Regulators come and go
  - "Current thinking" is a transient thing (emphasis on geomorphology, hydraulics, use of particular models or approaches, etc.)

Current Practices in HRP

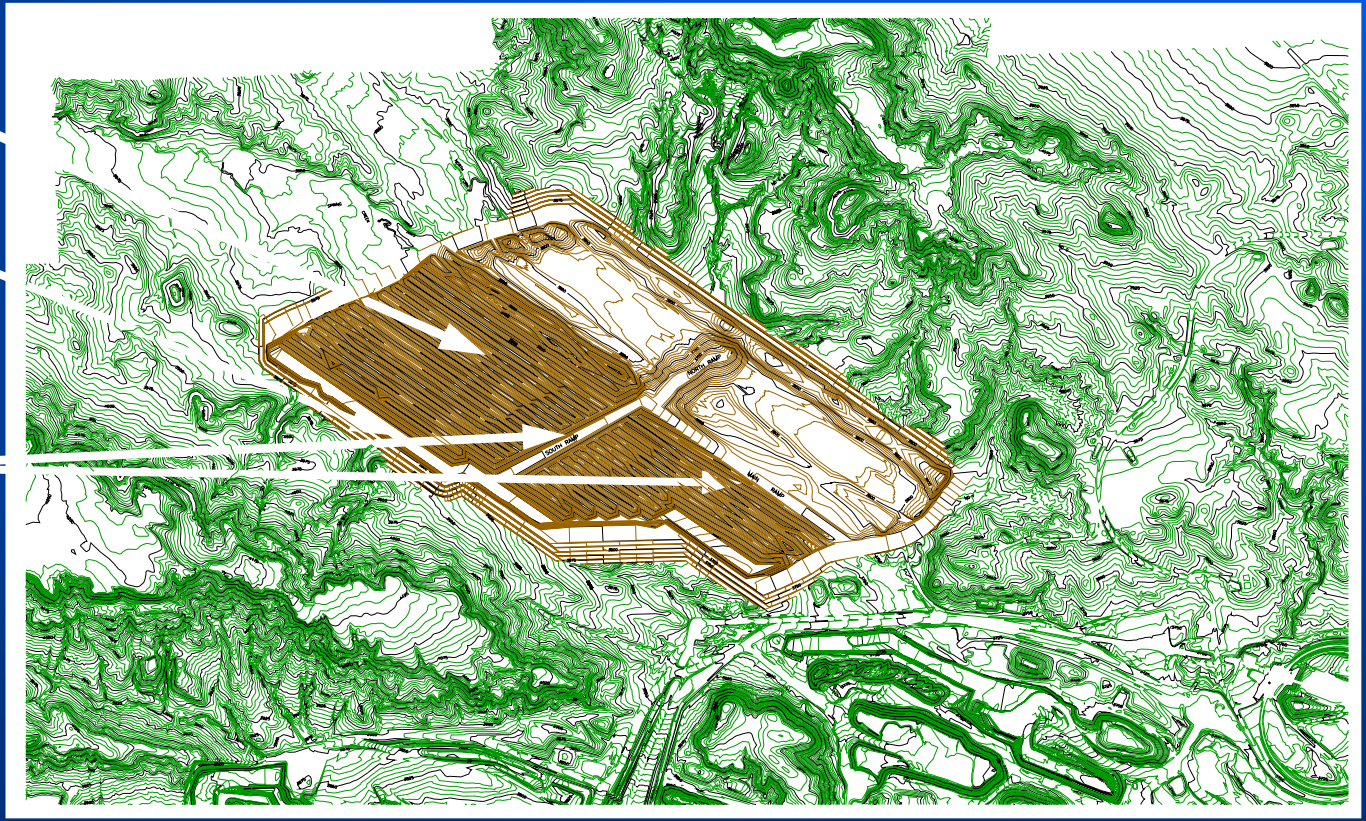
- Prepare computer simulation of mining operation
- Dragline dirt relatively fixed (use truck/shovel dirt to fill final voids, transport suitable materials, etc.)
- Create a “shifted spoil” surface as the first approximation of the postmining topography
- Develop a grading plan that creates a drainage system that approximates the premining system (drainage density, channel slopes, hydraulics, etc.)
- Provide quantitative analysis of the preceding parameters to justify the design

Example of computer-simulated spoil surface

Dragline Spoils

Final Pit

Ramps



Steps in design of drainage system

- Prepare mine model (coal, overburden, ground surface)
- Simulate mining
- Model graded spoil surface
- Tie to undisturbed ground
- Rough in successively lower order drainages
- Adjust topography for channel profiles, drainage basins
- Provide channel/floodplain designs
- Compare to premining system
- Repeat as necessary

Available Options

- Range between most economical to build and most similar to premining system
  - Both have advantages and disadvantages
    - Ease of permitting v. economy of construction
    - Sometimes “copy” of premining system not possible
- Sometimes the permits do not reflect reality of what will be built (operators agree to a permit in the interest of time and cost, and permit is revised as mining proceeds)

Need to Incorporate Flexibility into Plan

- **Mine Plans Change**
  - Increase/decrease in production rate
  - Need to blend coal
  - Incorporate new technologies
  - Add new areas
- **Reclamation Plans Change**
  - Technological advances
  - Learn more about previous unknowns (swell, rainfall-runoff, etc.)
  - Adapt to changing trends (wetlands, AVF's, channel design concepts, etc.)

Issues To Be Resolved

- Better definition of approximate original contour (AOC)
  - Too subjective (depends on reviewer's opinion)
  - Changes with time and with regulatory staff changes
  - Does every hill and every drainage channel have to be put back in its original location, aspect, etc.?
- Approach to dealing with final pits, ramps, etc.
  - Are impoundments a bane or a boon?
- Flexibility to deal with varying production, swell factors, etc.
  - What areas are critical and what areas can be used to absorb uncertainties?
- Can permit revisions be streamlined?

Keys to Success

- Primary streams (e.g., those which have both entry and exit points on the permit boundary) must control the drainage design
- Successively lower order tributaries can have much more flexibility in design provided certain criteria are met (concave profiles, conveyance, etc.)
- Uplands and first-order drainages can be used to “adjust” for unknowns (e.g., swell factor, production rates, etc.)

There are many success stories

Little Youngs Creek, Ash Creek Mine

September 98

September 99

Caballo Creek, Belle Ayr Mine

- ~ 200-square-mile drainage area
- Being put into use as soon as built (part of diversion)
- Receiving perennial flow from coal-bed methane
- Controls grading plan for entire permit area

Caballo Creek, Belle Ayr Mine--continued

Belle Fourche River, Cordero-Rojo Complex

- Typical primary streams have low-flow channel and floodplain
- Most natural channels have variety (riffle-pool sequences, bedrock contacts, profile irregularities, etc.)
- Erosional stability depends on conveyance, which is a function of discharge, slope, cross section, roughness, etc.

Belle Fourche River--continued

Restored riffles/pools

- Simulate nature
- “Safety valve”
- Provide variety

Lower Order Tributaries

- Function is to collect runoff and sediment and deliver them to the primary channel
- Drainage density is a function of relief, slope, cover, and soil type
  - Considerable flexibility in design, can be creative
- Variety can be added with impoundments or playas, both of which will affect channel design

Lower Order Tributaries (Examples)

West Fork Kicken Draw,
Cordero-Rojo Complex
Seeded 1991

Channel close-up

Lower-Order Tributaries--continued

Clabaugh Draw, Cordero-Rojo (seeded 1995)

Bagleys Bog, Cordero-Rojo (seeded 1987)

Lower-Order Tributaries--continued

SF6 Tributary to South Fork Spring Creek, Spring Creek Mine

Postmining Impoundments

Advantages:

- Support postmining land uses
- Capture sporadic runoff and make it available
- Help retain sediment and control erosion

Issues:

- Only good impoundment is as a replacement
- Perceived by operators only as a way to save money

Conclusions

- Fix the definition of AOC
- Be receptive to new concepts
- Acknowledge that change will occur and plan for it
- Although conflicts will continue, be aware that successful reclamation is proceeding, the system is working, and we can all feel good to be a part of it

Proposed Effluent-Limitation Guidelines

for the Coal-Mining Point-Source Category

(65 Federal Register 19440; April 11, 2000)

William A. Telliard and John Tinger

U.S. Environmental Protection Agency,

Office of Water,

Engineering and Analysis Division

U.S. Environmental Protection Agency's (EPA's) Proposed Rule *65 Federal Register 19440*

- On April 11, 2000, the EPA's Office of Water proposed an amendment to the existing effluent-limitation guidelines and standards at 40 CFR 434.
- The proposed amendment was for the addition of two new subcategories to the existing regulations for the coal-mining industrial category.
- The proposal did not otherwise change any of the existing regulations.

Acknowledgements

- This proposed rule was developed as a combined effort.
- EPA gratefully acknowledges the extensive support and efforts of the U.S. Department of Interior, Office of Surface Mining (OSM), the Western Interstate Energy Board (WIEB), and the National Mining Association (NMA).

Proposed Subcategories

- The “coal-remining” subcategory addresses pollutant levels in preexisting discharges located in remining areas of abandoned mine land (AML).

- The “Western alkaline coal-mining” subcategory addresses sediment control in runoff located in those portions of Western arid and semiarid alkaline coal mines that are reclaimed or under reclamation.

Current Subcategories at 40 CFR 434

- The “acid or ferruginous mine drainage” subcategory refers to these types of mine drainage from active mining areas (total suspended solids [TSS], pH, Fe, and Mn).
- The “alkaline mine drainage” subcategory refers to this type of mine drainage from active mining areas (TSS, pH, and Fe).
- The “coal-preparation plants and associated areas” subcategory refers to all discharges from processing areas (TSS, pH, Fe, and Mn).
- The “postmining areas” subcategory refers to discharges from reclamation areas (suspended solids and pH), acid drainage from underground mines (TSS, pH, Fe, and Mn), and alkaline drainage from underground mines (TSS, pH, and Fe).

Rulemaking Schedule

- Federal Register notice of proposed rule — April 11, 2000
- Public comment period — April 11-July 10, 2000
- Public meetings — June 2000

  Remining
  - June 13 - Nitro, West Virginia
  - June 14 - Frankfort, Kentucky
  - June 15 - Zanesville, Ohio

  Western
  - June 22 - Flagstaff, Arizona
  - June 28 - Denver, Colorado
  - June 29 - Gillette, Wyoming
- Final rulemaking — December 2001

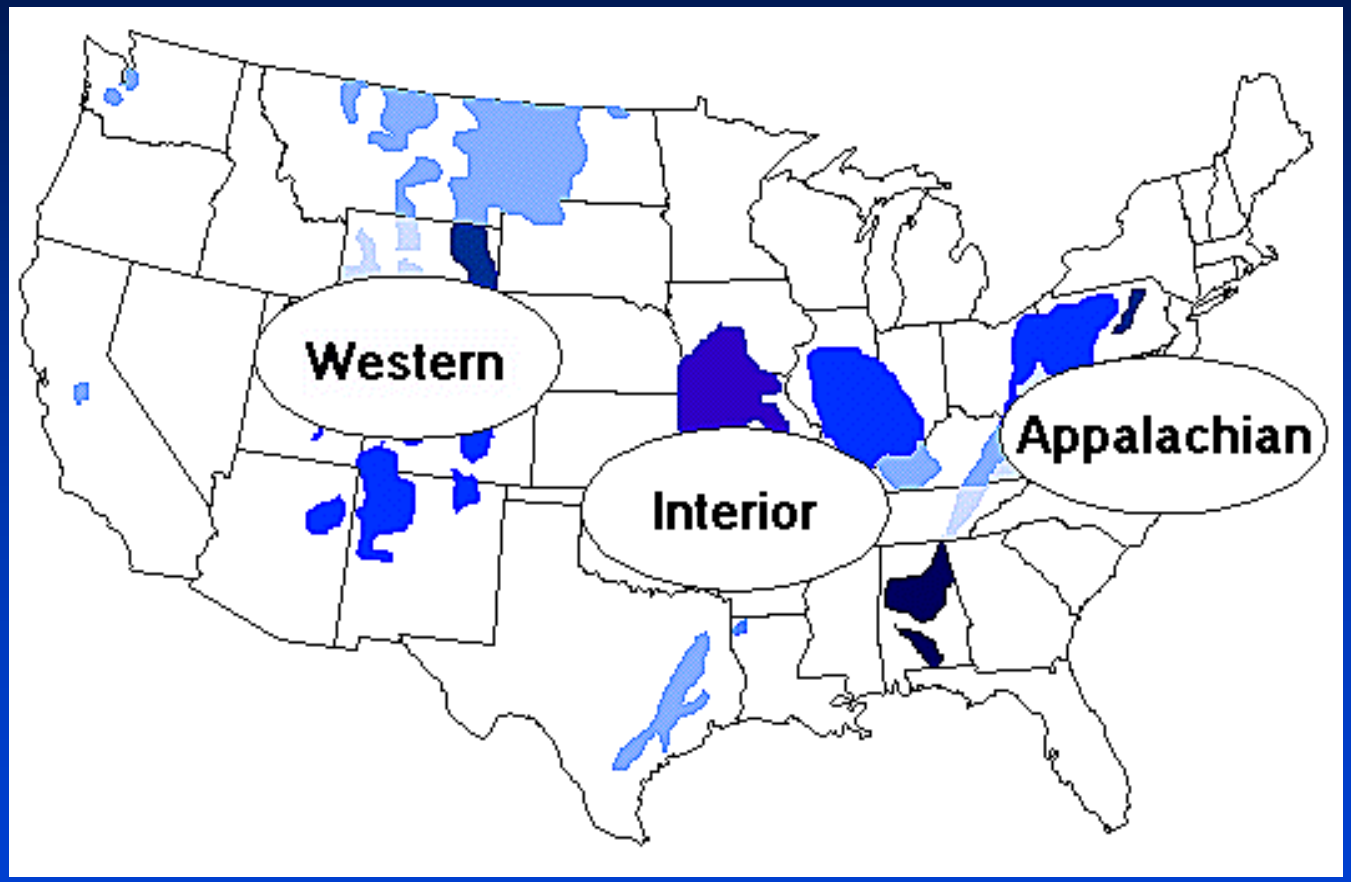
Proposed Western Alkaline Coal-Mining Subcategory

(this is the second of the two new proposed subcategories)

40 CFR 434,

Coal-Mining Point-Source Category

U.S. Coal-Producing Regions



What portion of the coal-mining industry will be affected by the adoption of this new subcategory?

- EPA has identified 47 surface mines, of 77 mines operating in the Western region, that could be affected by the proposed rule (2 percent of the total U.S. coal mines).
- These 47 mines produce approximately 497 million tons of coal annually (approximately 1/3 of the total U.S. production).
- The 47 mines are located in:

  Arizona (2 minesites)
  Colorado (5 minesites)
  Montana (6 minesites)
  New Mexico (6 minesites)
  Wyoming (28 minesites)

Why address arid and semiarid Western coal regions?

- Environmental conditions in the arid and semiarid Western coal regions are significantly different from conditions in the Interior and Appalachian coal regions. Western regions have:
  - Severely limited and highly valuable water resources;
  - Annual precipitation averages of 26 inches or less;
  - Short-duration, high-intensity storms with flash flooding;
  - Runoff from undisturbed land that typically contains several hundred thousand mg/L TSS;
  - Naturally unstable and highly eroded landscapes; and
  - Discontinuous and sparsely distributed vegetation.

What environmental issue would implementing the proposed Western alkaline coal-mining subcategory mitigate?

- To meet the existing requirements of subcategories at 40 CFR 434, operators for the most part use sedimentation ponds to control effluent in the arid and semiarid Western coal regions. Impacts caused by the predominant use of these ponds are:
  - Loss of critical water through evaporation;
  - Disruption of natural hydrologic balance;
  - Reduction or elimination of downstream channel flows;
  - Reduction or elimination of vegetation;
  - Severe and unnatural channel reconfiguration; and
  - Increased land instability.

Why propose a new subcategory?

- To encourage the use of erosion- and sediment-control best management practices (BMP's) in reclamation areas of coal mines in the arid and semiarid Western coal region.
- To reduce adverse environmental impacts and improve water management.
- To provide consistency with requirements under the Surface Mining Control and Reclamation Act of 1977 (SMCRA).

What are the environmental benefits of adopting this new subcategory?

Implementing requirements under the proposed Western alkaline coal-mining subcategory will help:

- Maintain natural hydrologic processes;
- Control erosion and sedimentation at the source;
- Reduce water loss from evaporation;
- Improve channel and land-surface stability ;
- Improve soil moisture;
- Promote vegetative success; and
- Improve water-resource management.

What are the regulatory and enforcement benefits of the adoption?

Implementing requirements under the proposed Western alkaline coal-mining subcategory will help:

- Resolve discrepancies between EPA sediment limitations and OSM requirements for maintaining hydrologic balance in arid and semiarid regions;
- Provide regulatory flexibility needed for appropriate site-specific erosion and sediment control;
- Provide an improved mechanism for inspection and enforcement; and
- Expedite bond release and return of lands to postmining uses and original owners.

Are there similar requirements in existing State programs?

- New Mexico's ASC Windows Program (19 NMAC 8.2) requires that operators demonstrate that:
  - The quality of area runoff is as good as, or better than, that of water entering the permit area and
  - There will be no increase in the sediment load to receiving streams.
- Wyoming's Coal Rules and Regulations (chapter IV) require that operators:
  - Demonstrate that drainage either will meet effluent-limitation standards or will not degrade receiving waters and
  - Use best technology currently available to prevent additional contributions of sediment to streams or runoff.

How did EPA develop this proposed rule?

EPA implemented recommendations of an EPA task force for streamlining the development and promulgation of regulations. This task force:

- Took as its presumptive rule that existing information and data should be used;
- Based the rule it developed on well-established technologies and practices; and
- Represented a combined effort of Federal agencies, State regulatory authorities, interstate agencies, and industry groups.

What existing information and data were used?

The Western Coal-Mining Work Group (representing OSM, WIEB, and NMA) provided:

- Performance-evaluation studies demonstrating the effectiveness of sediment-control BMP's;
- Site-specific, sediment-control plans targeting arid and semiarid regions;
- Cost evaluations;
- Case studies;
- A mine-modeling study; and
- Predictive soil-loss models.

What are the established technologies?

- BMP's have been used and demonstrated to be effective in surface reclamation for decades.
- Among others, BMP's that can be selected and implemented on a site-specific basis exist for vegetation, regrading, diversion channels, straw bales, mulch, terraces, contour berms, sediment traps, geotextiles, minimization of land disturbance, and contemporaneous reclamation.

Types of BMP's: Sediment-Control Measures

- Site-specific structures, methods, practices, and products that minimize and control sedimentation and erosion from disturbed areas are:
  - **Topographic practices:**
    - Grading and backfilling to original contours
    - Slope terracing
  - **Surface-protection measures:**
    - Soil compaction
    - Contour furrowing
    - Land imprinting
    - Mulching
    - Surface netting
    - Geotextile matting

Types of BMP's: Sediment-Control Measures--continued

- **Drainage diversion and conveyance systems:**
  - Dikes, curbs, and berms
  - Channels and culverts
  - Diversion ditches
  - Terrace drains
- **Flow-dispersion techniques:**
  - Check dams
  - Drop structures
  - Rock-outlet protection
  - Level spreaders
- **Filtering and detention structures:**
  - Silt fences
  - Straw-bale barriers
  - Brush barriers
  - Filter berms
  - Vegetative filters
  - Ponds

Types of BMP's: Sediment-Control Measures--continued

- **Vegetation methods:**
  - Topsoiling
  - Seedbed preparation
  - Broadcast seeding
  - Drill seeding
  - Diversity of plant species
  - Cover crops for postmining land use

Subcategory Definitions

- **Western coal-mining operation:** a mining operation west of the 100th meridian, in an arid or semiarid environment with an average annual precipitation of 26.0 inches or less
- **Sediment:** undissolved organic and inorganic material transported or deposited by water
- **Reclamation area:** surface area of a coal mine that has been returned to required contour and on which revegetation work has been commenced

Subcategory Applicability

- Proposed requirements apply to alkaline mine drainage from reclamation areas associated with Western coal-mining operations.
- Waste-water discharges produced or generated by active coal-mining operations will remain subject to existing effluent limitations.
- Waste streams that are commingled will continue to meet the most stringent limitations applicable to any component of the combined waste stream.

Subcategory Requirements

Technology-Based Rule = Sediment-Control Plan

- **Sediment-control plan:**
  - Must identify BMP's, design specifications, construction specifications, maintenance schedules, criteria of inspection, and expected performance;
  - Must submit results of a watershed model demonstrating that sediment yields will not be greater than background levels from undisturbed conditions; and
  - Must be consistent with SMCRA requirements.

Development Document for the Western Alkaline Coal Mining Subcategory (EPA 821-R-00-008)

- Provides a profile of the segment of the coal-mining industry potentially affected by the proposed subcategory;
- Describes environmental conditions unique to the arid and semi-arid Western coal regions;
- Discusses appropriate sediment-control plans and BMP's; and
- Presents case studies of sediment control in arid and semi-arid environments.

Economic and Environment Impact Assessment (EPA 821-B-00-002)

- Provides a profile of the affected industry portion;
- Discusses sources of data used to assess economic and financial impacts;
- Presents anticipated compliance costs to industry and regulators;
- Presents anticipated environmental impacts and benefits;
- Presents anticipated economic and financial impacts; and
- Presents cost-benefit analyses.

Where is additional relevant information available?

- Proposed rule and preamble:

  http://www.epa.gov/OST/guide

- Supporting documents:

  National Service Center for Environmental Publications: (800) 490-9198; or
  http://www.epa.gov/ncepi

- Technical information:

  John Tinger: U.S. Environmental Protection Agency
  1200 Pennsylvania Avenue
  Washington, D.C. 20460
  (202) 260-4992
  Tinger.John@epa.gov

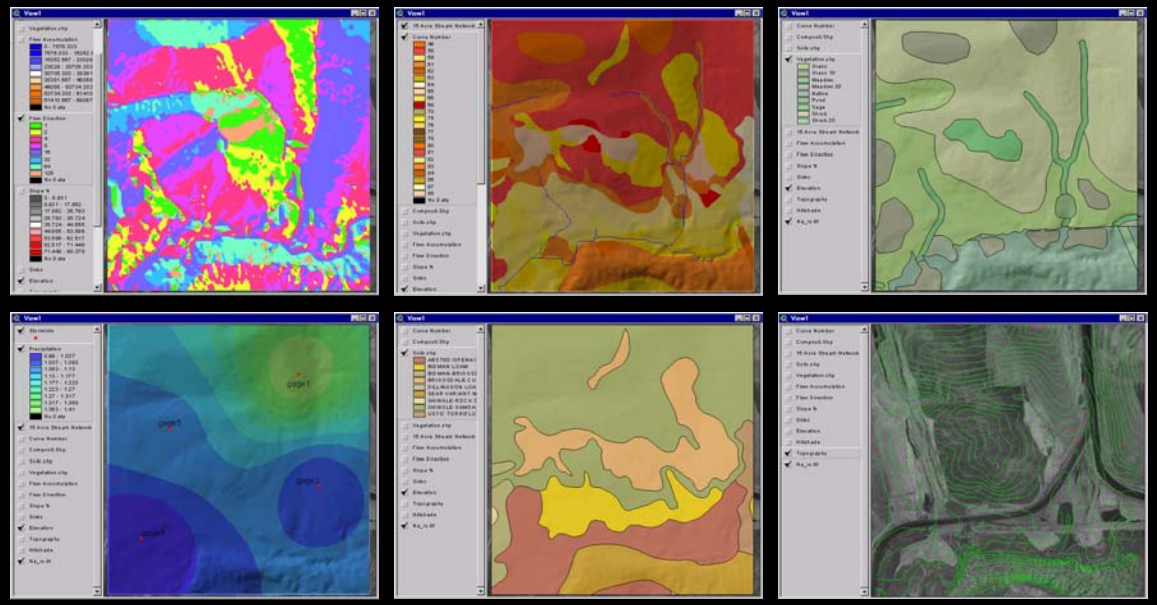
- Economic information:

  Kristen Strellec: (202) 260-6036

Comments

- The EPA solicited specific comments, information, and data regarding the proposed new subcategories in a Federal Register notice of proposed rule. In particular, EPA asked for comments regarding:
  - Consistency among the proposed subcategories and existing regulations;
  - Performance and site-specific selection of BMP's;
  - Recommendations for compliance determination;
  - Potentials for improving hydrologic balance; and
  - Sediment-yield modeling.
- Comments, data, and information on additional issues were also requested.

Spatial Data for Hydrology Monitoring Emphasizing New Developments in SEDCAD+ and GIS



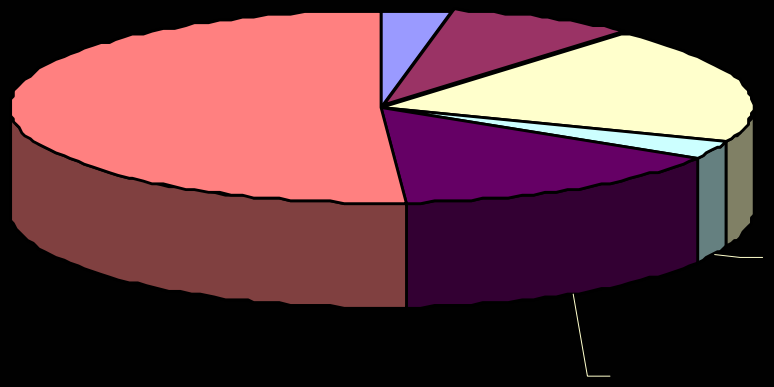
Richard C. Warner, Ph.D., and

Michael Anderson, University of Kentucky

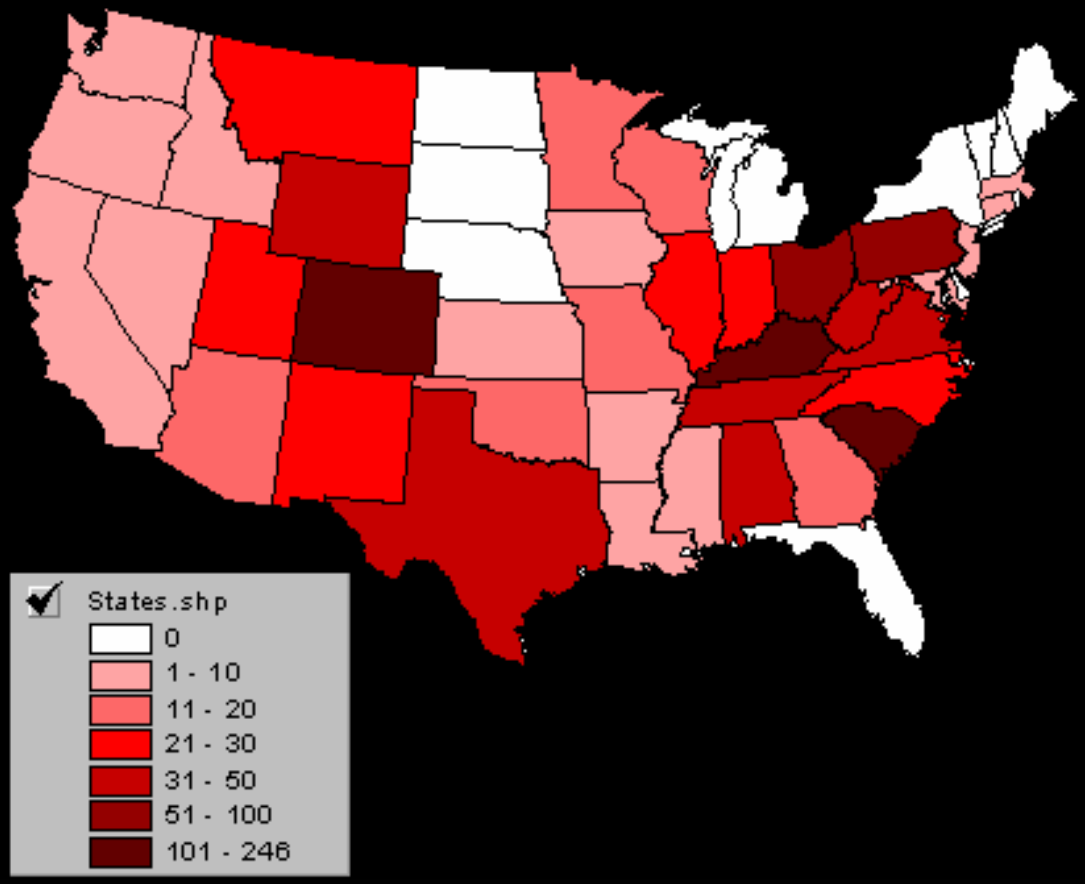
SEDCAD Overview/SedPrePro: Where We Are Headed

The New SEDCAD

SEDCAD Uses



SEDCAD Installations



Application Overview

- Hydrology:
  - Spatially distributed
- Erosion:
  - USLE (updated)
  - Eroded particle-size distribution
- Sediment controls
- Permit and design drawings

SEDCAD4 Hydrology

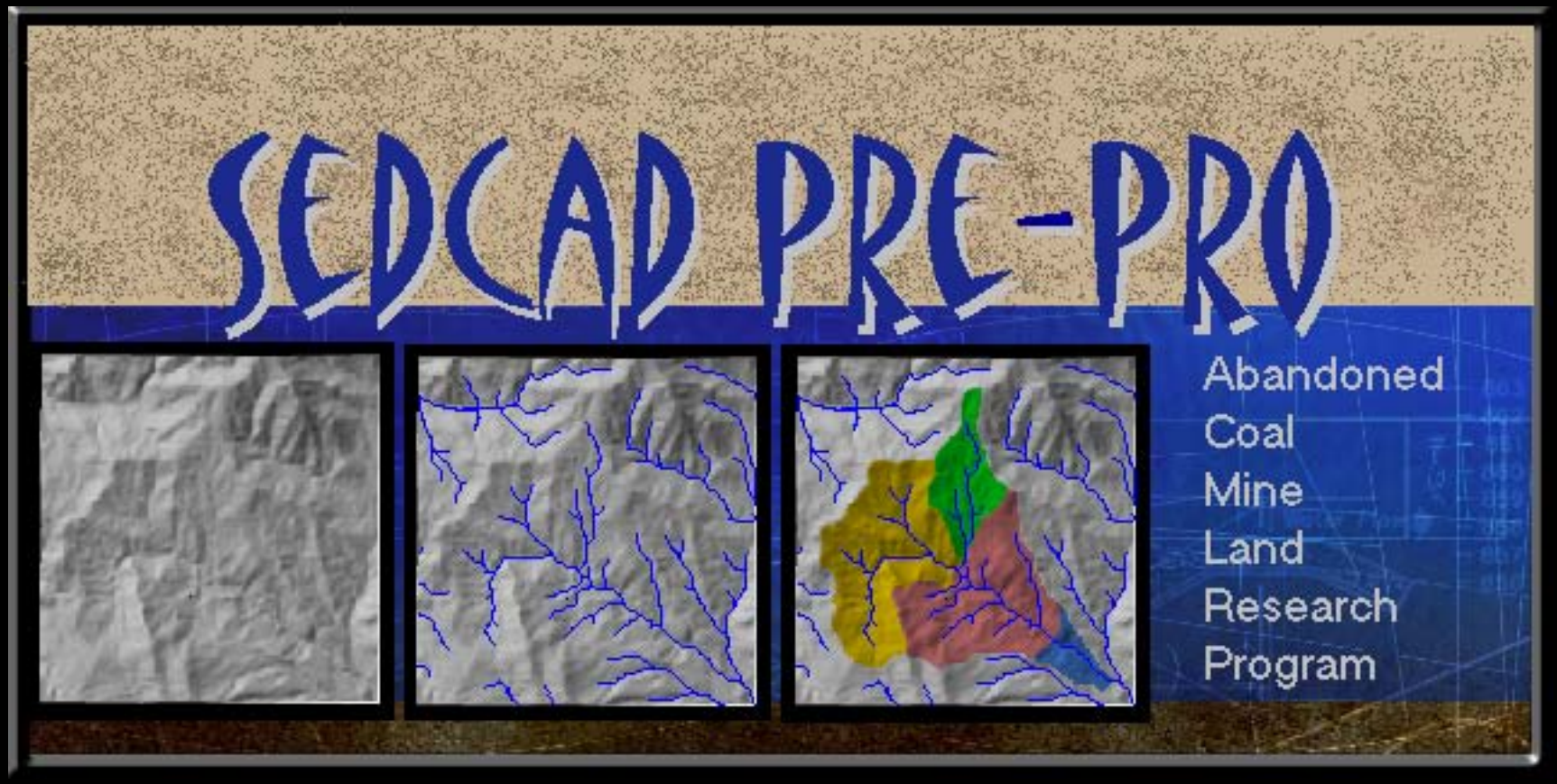
- Unit-hydrograph methodology:
  - Double triangle response function
  - TR-55 emulator
- Design storm (user-defined storm event)
- Spatially distributed subwatersheds

SEDCAD4
Erosion and Sediment Transport

- Erosion:
  - RUSLE (steep-slope)
  - Inputs through RUSLE
- Eroded particle sizes
- Subwatershed basis

- Sediment transport:
  - Exponential decay
  - Transport time
  - Particle-size distribution

SEDCAD and GIS



SedPrePro

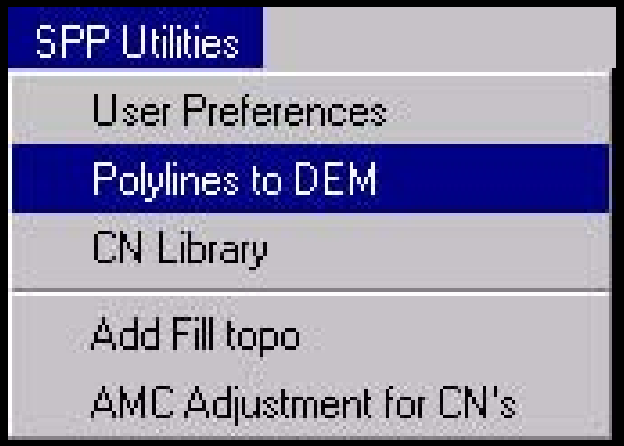
- ArcView preprocessor for SEDCAD:
  - Develops the majority of SEDCAD model parameters and inputs
- ArcView postprocessor for SEDCAD:
  - Displays SEDCAD results in the forms of hydrographs and postmodel output designs

Components of Preprocessing

- Developing a digital elevation surface
- Defining stream networks
- Generating curve numbers
- Considering precipitation
- Defining structure locations
- Generating automatic subwatershed delineations
- Exporting to SEDCAD

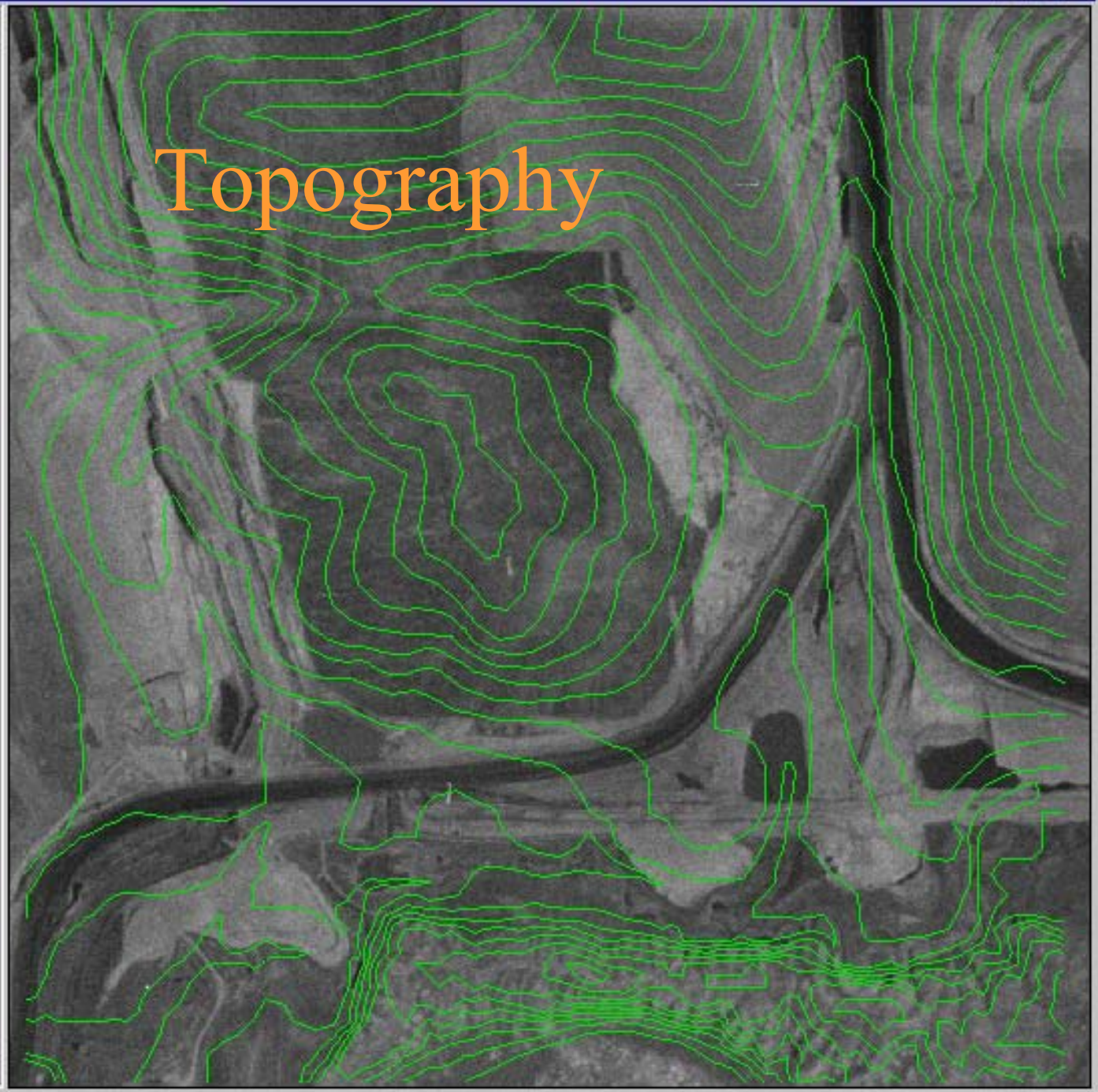
Topography Lines to a Digital Elevation Surface

- We take:
  - Any form of topography lines (from AutoCAD, ArcView, or ArcInfo)
- Topography lines must have elevation as an attribute
- We create:
  - A continuous-raster elevation surface



View1

- Curve Number
- Composit.Shp
- 15 Acre Stream Network
- Soils.shp
- Vegetation.shp
- Flow Accumulation
- Flow Direction
- Slope %
- Sinks
- Elevation
- Hillshade
- ✔ Topography
- ✔ Na_ro.tif



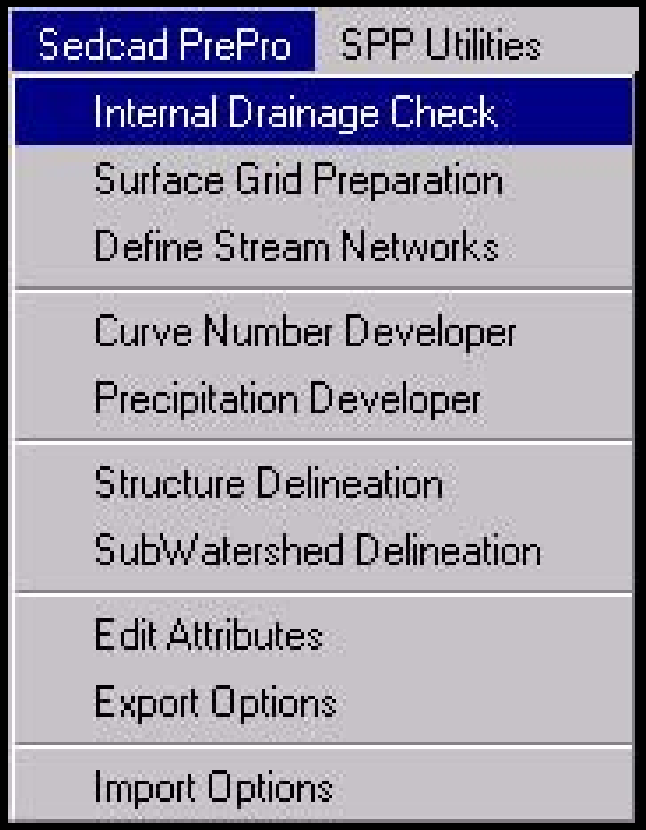
View1

- Curve Number
- Composit.Shp
- 15 Acre Stream Network
- Soils.shp
- Vegetation.shp
- Flow Accumulation
- Flow Direction
- Slope %
- Sinks
- ✓ Elevation
  - 4555.463 - 4583.16
  - 4583.167 - 4610.87
  - 4610.871 - 4638.57
  - 4638.574 - 4666.27
  - 4666.278 - 4693.98
  - 4693.982 - 4721.68
  - 4721.685 - 4749.38
  - 4749.389 - 4777.09
  - 4777.093 - 4804.79
  - No Data
- ✓ Topography
- ✓ Hillshade
- ✓ Na_ro.tif

Interpolated Surface Using Spline Method

Internal Drainage Check

- Why do this?
- ArcView smoothes the elevation grid to keep water moving downhill
- This is good and bad
- We accommodate for both outcomes



View1

- Curve Number
- Composit.Shp
- 15 Acre Stream Network
- Soils.shp
- Vegetation.shp
- Flow Accumulation
- Flow Direction
- Slope %
- ✔ Sinks
- ✔ Elevation
- ✔ Topography
- ✔ Hillshade
- ✔ Na_ro.tif

Identify Results

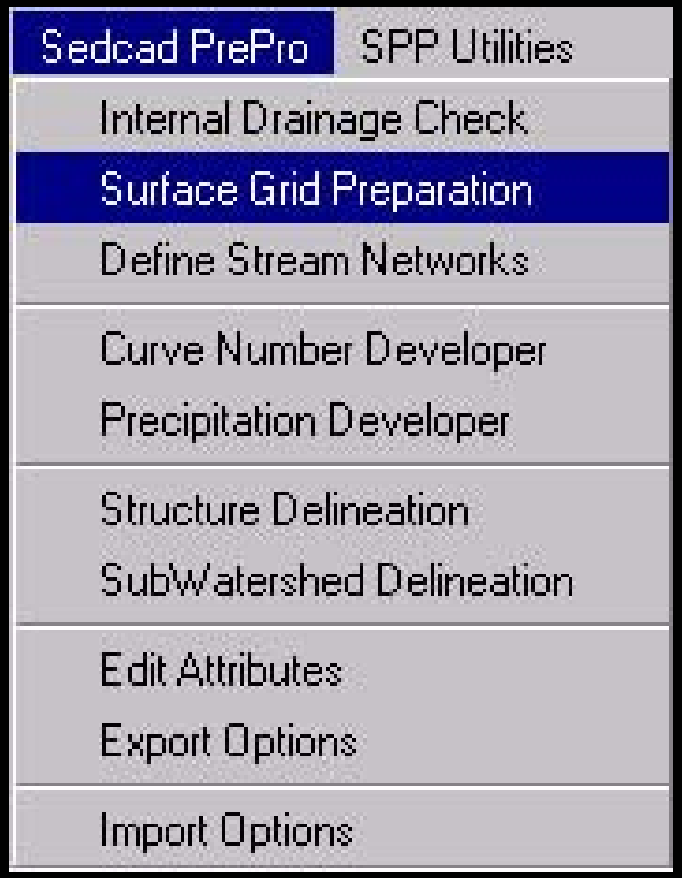
1: Sinks - 26

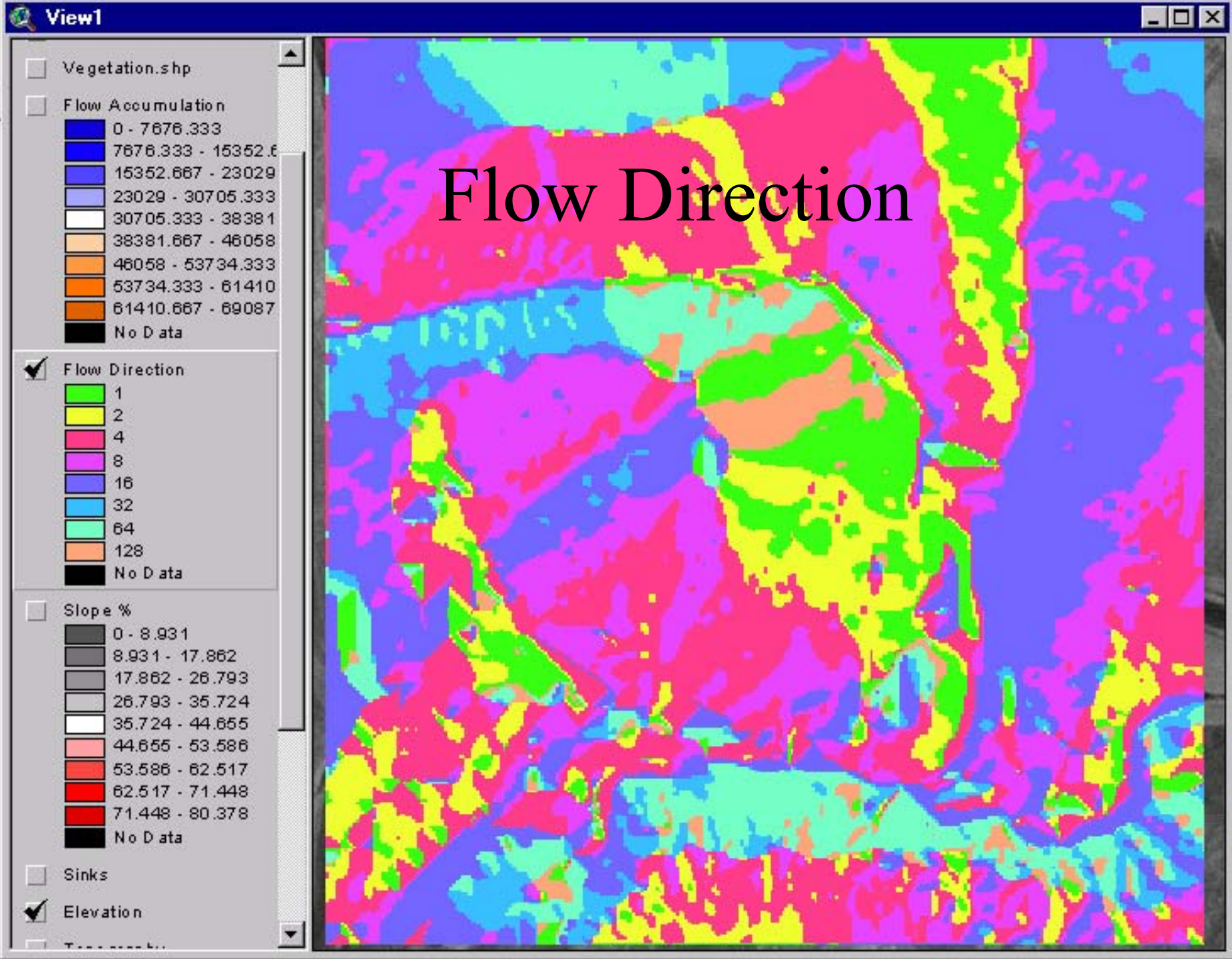
Shape	Polygon
Id	27
Gridcode	28
Area-Acres	0.010

Clear | Clear All

Surface-Grid Preparation

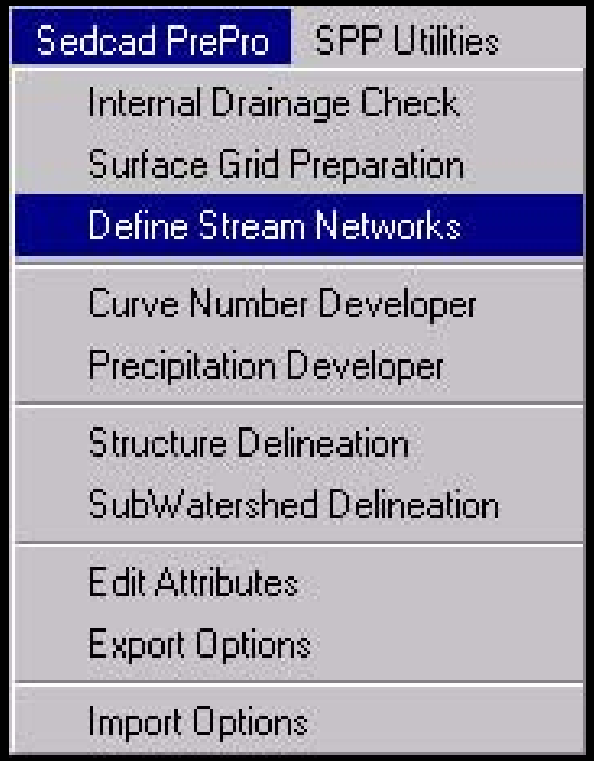
- Slope gradient (in percent):
  - Based on cell-to-cell elevation/distance
- Flow direction:
  - Based on cell-to-cell elevation changes
- Flow accumulation:
  - Based on cell-to-cell flow directions



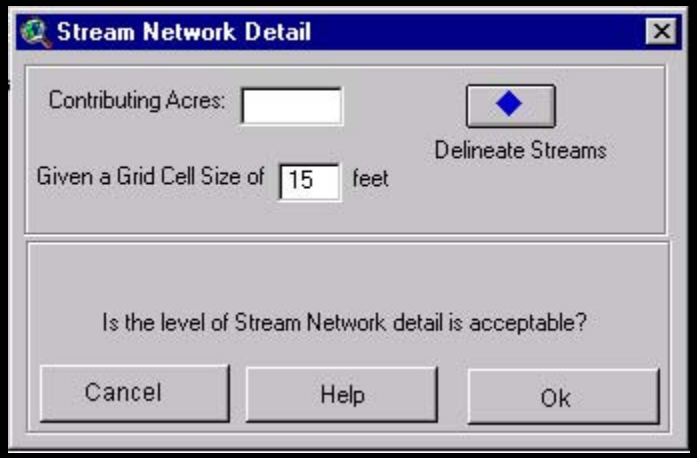

View1
Vegetation.shp
Flow Accumulation
0 - 7676.333
7676.333 - 15352.6
15352.667 - 23029
23029 - 30705.333
30705.333 - 38381
38381.667 - 46058
46058 - 53734.333
53734.333 - 61410
61410.667 - 69087
No Data
Flow Direction
1
2
4
8
16
32
64
128
No Data
Slope %
0 - 8.931
8.931 - 17.862
17.862 - 26.793
26.793 - 35.724
35.724 - 44.655
44.655 - 53.586
53.586 - 62.517
62.517 - 71.448
71.448 - 80.378
No Data
Sinks
Elevation
Flow Direction

Stream-Network Delineation

- Vector networks
- Based on size of contributing area
- How many acres of contribution before you have a stream channel? As many as you like!



Predicted at 15 Acres



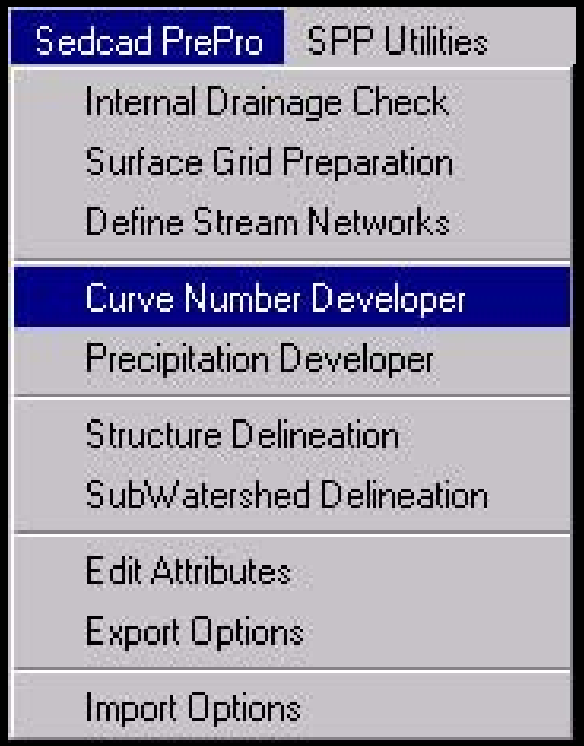
Curve-Number Development

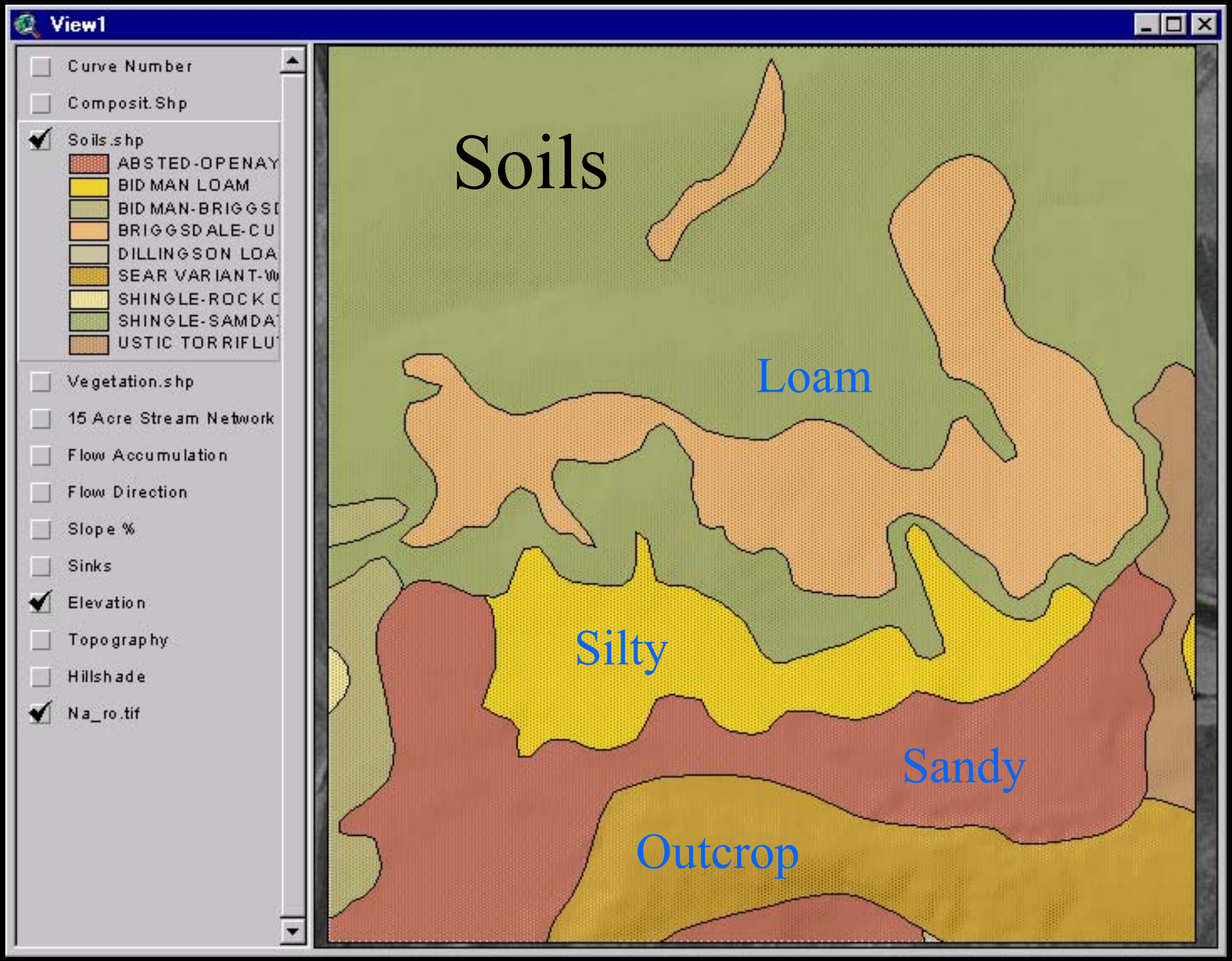
Soils Layer

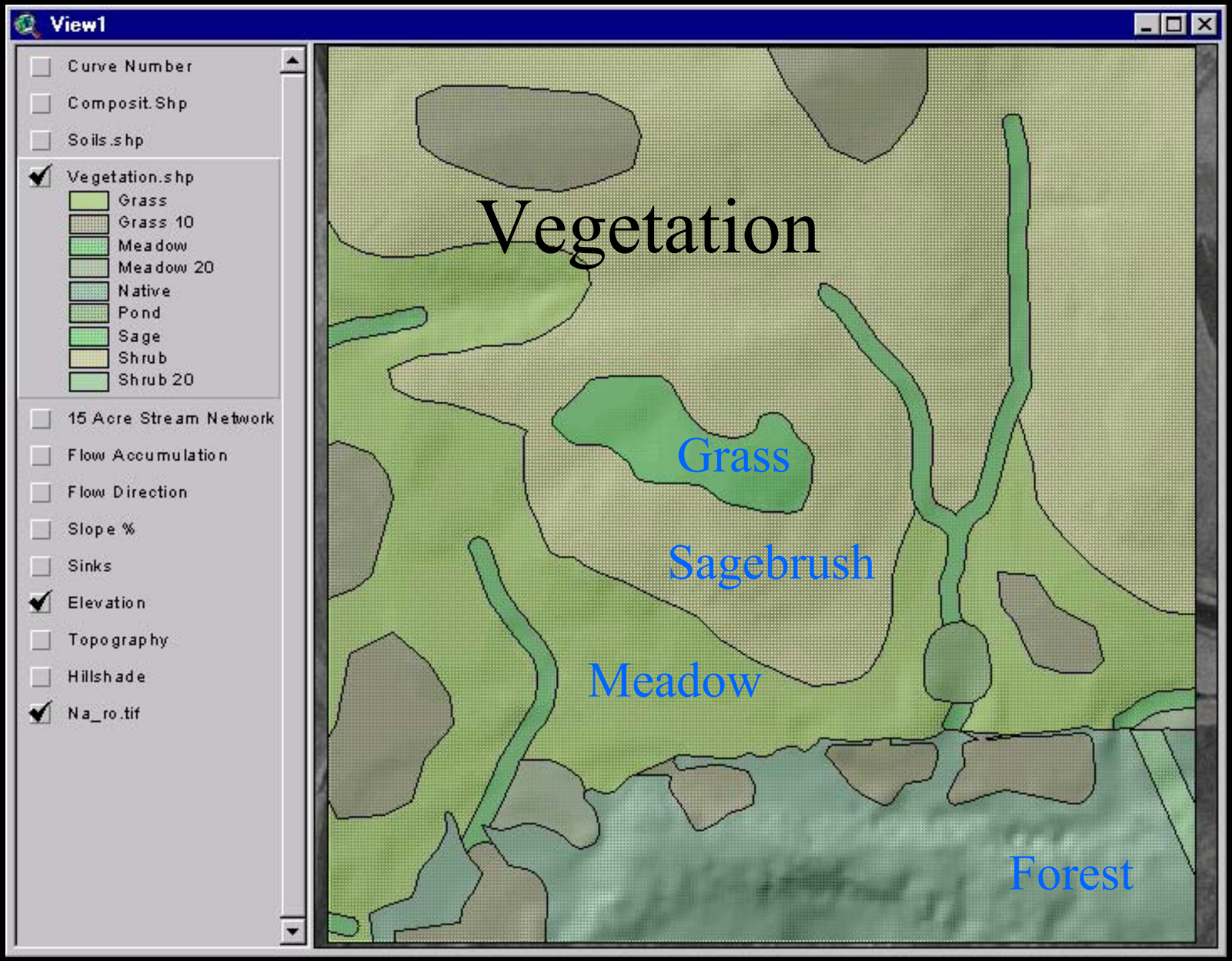
+ Vegetation/Land-Use Layer

+ Curve-Number Library

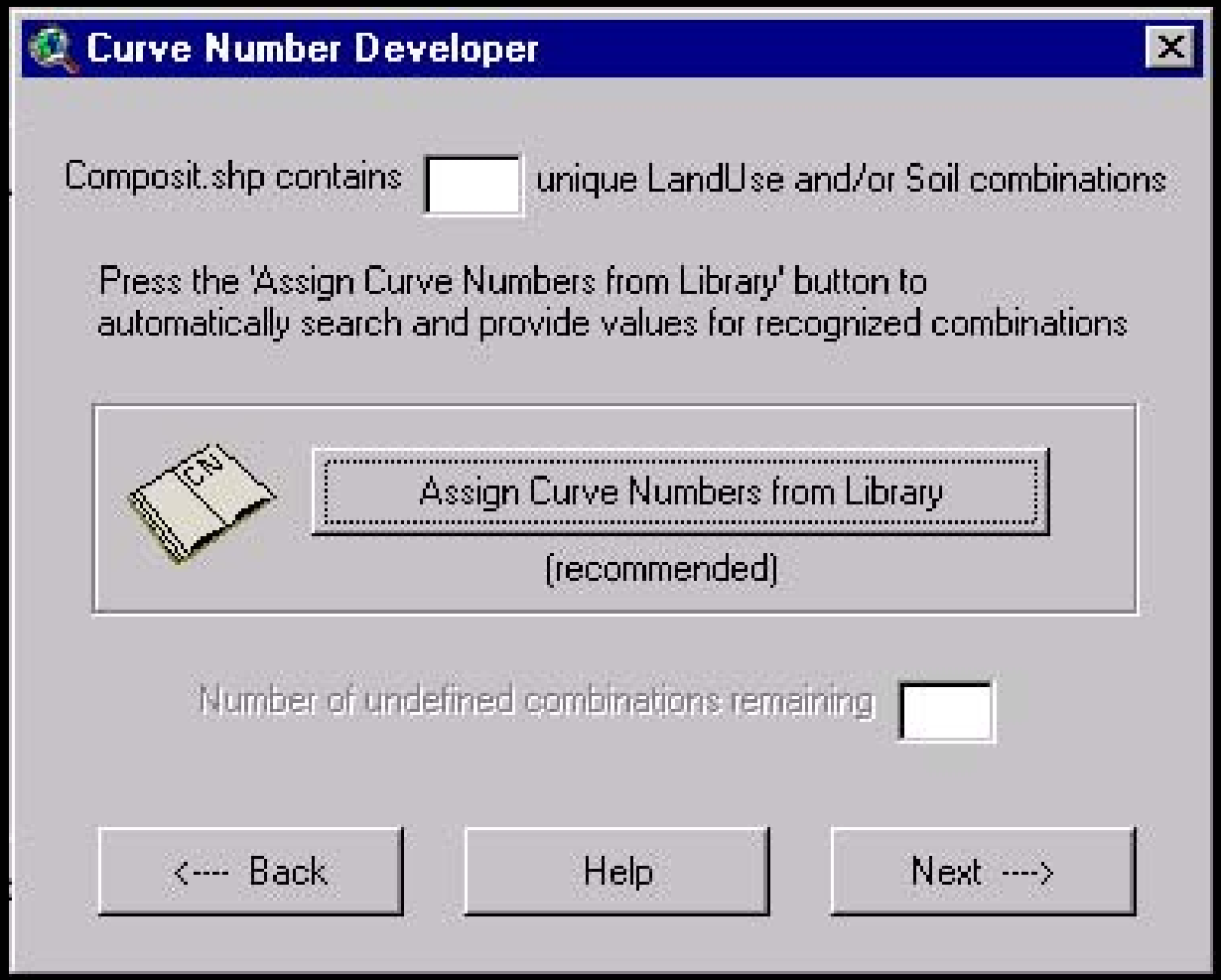
= Curve-Number Coverage




View1
Curve Number
Composit.Shp
Soils.shp
ABSTED-OPENAY
BID MAN LOAM
BID MAN-BRIGGSD
BRIGGSDALE-CU
DILLINGSON LOA
SEAR VARIANT-W
SHINGLE-ROCK C
SHINGLE-SAMDA
USTIC TORRIFLU
Vegetation.shp
15 Acre Stream Network
Flow Accumulation
Flow Direction
Slope %
Sinks
Elevation
Topography
Hillshade
Na_ro.tif
Soils
Loam
Silty
Sandy
Outcrop


View1
Curve Number
Composit.Shp
Soils.shp
Vegetation.shp
Grass
Grass 10
Meadow
Meadow 20
Native
Pond
Sage
Shrub
Shrub 20
15 Acre Stream Network
Flow Accumulation
Flow Direction
Slope %
Sinks
Elevation
Topography
Hillshade
Na_ro.tif
Vegetation
Grass
Sagebrush
Meadow
Forest

The Curve-Number Library

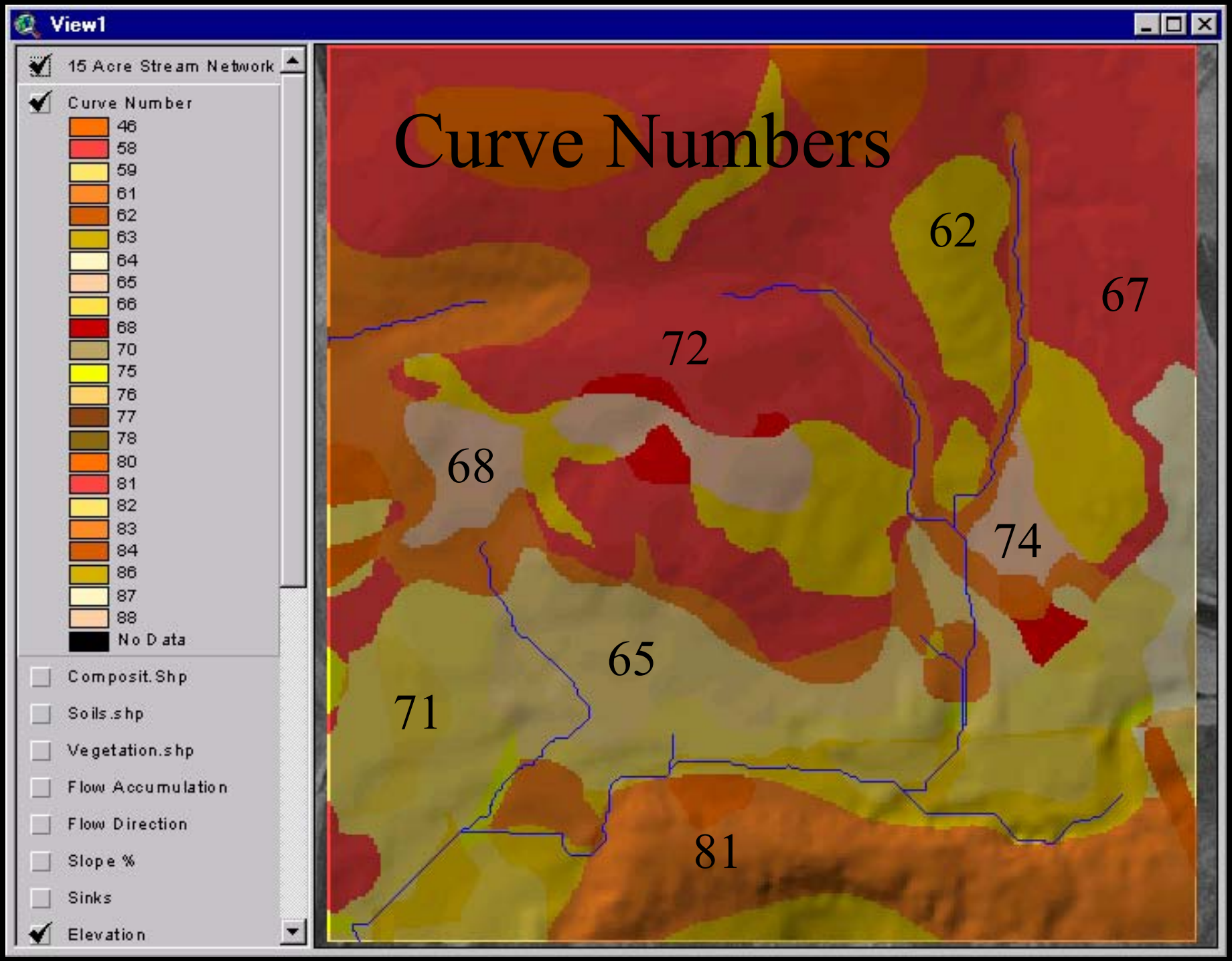


The Curve-Number Library

- A collection of user-generated associations
- The more you use it, the less it uses you
- Very generic
- Easily editable
- Extremely fast

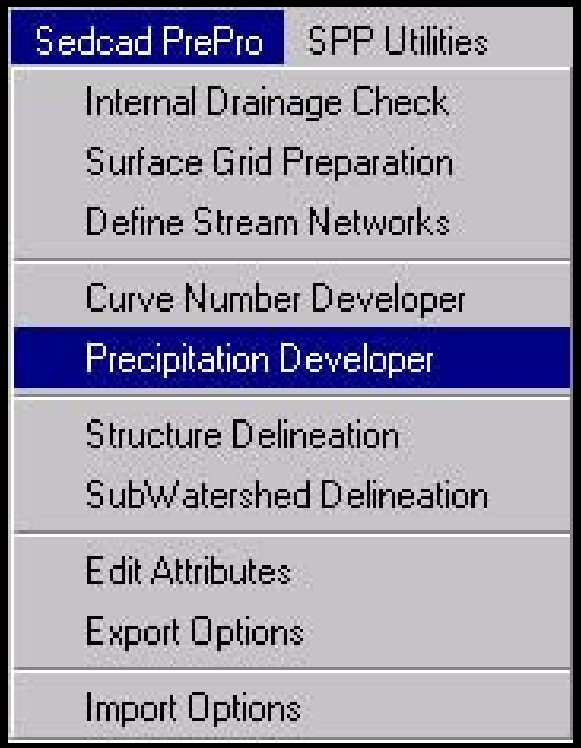
CN_library

Soil_id	Landuse_id	Cn
BRIGGSDALE-CUSHMAN C	Meadow 20	76
SHINGLE CLAY LOAM	Shrub	69
SHINGLE CLAY LOAM	Sage	58
SHINGLE CLAY LOAM	Grass 20	59
SHINGLE CLAY LOAM	Meadow	39
BOWBAC SANDY LOAM	Shrub	77
BOWBAC SANDY LOAM	Shrub 20	88
BOWBAC SANDY LOAM	Sage	75
ABSTED LOAM	Grass	75
ABSTED LOAM	Shrub	77
SHINGLE CLAY LOAM	Shrub 20	74
KISHONA CLAY LOAM	Sage	61
KISHONA CLAY LOAM	Shrub	63
KISHONA CLAY LOAM	Grass 20	63
DISTURBED	Shrub	65
TALUCE SANDY LOAM	Shrub	65
TALUCE SANDY LOAM	Sage	67
TALUCE SANDY LOAM	Shrub 20	87
HILAND SANDY LOAM	Grass	69

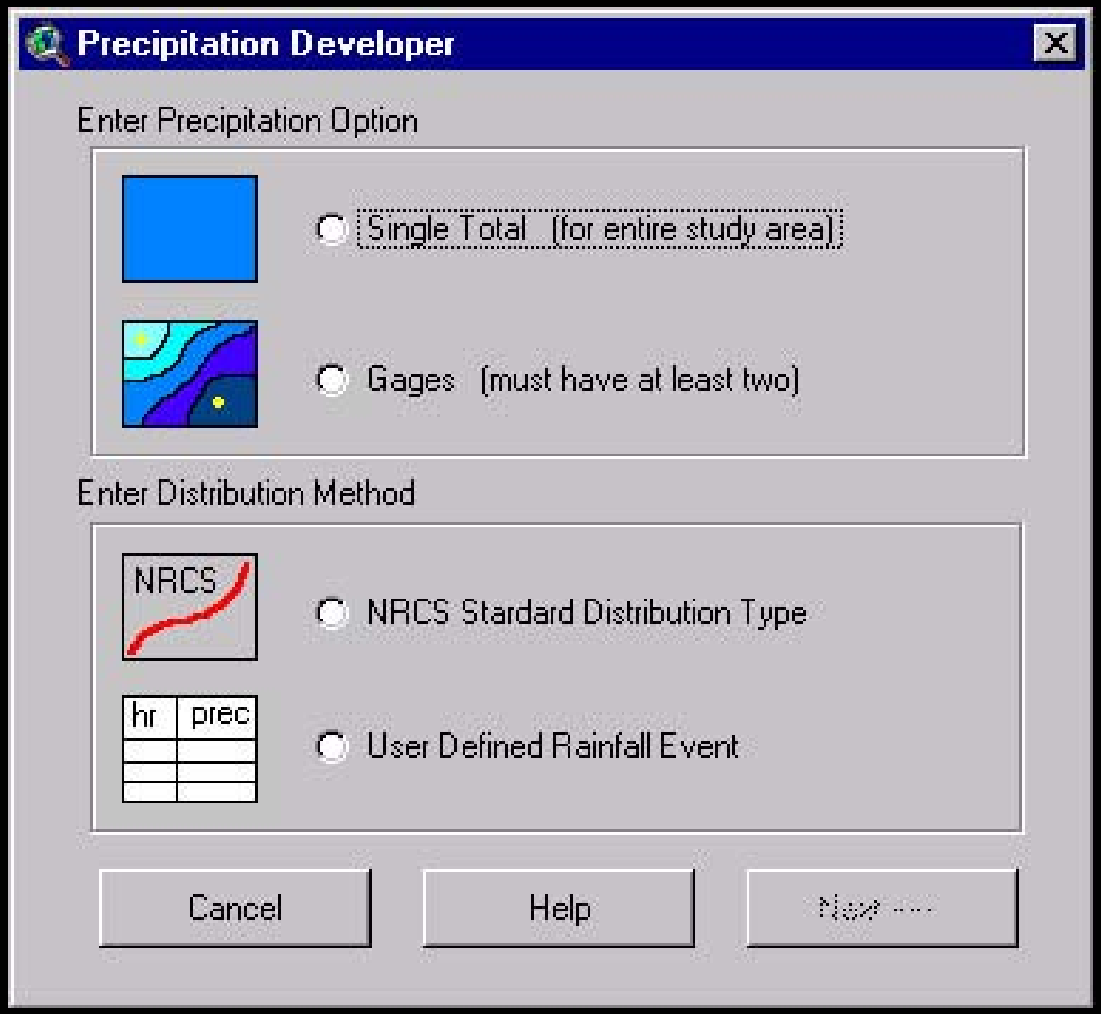

View1
15 Acre Stream Network
Curve Number
46
58
59
61
62
63
64
65
66
68
70
75
76
77
78
80
81
82
83
84
86
87
88
No Data
Composit.Shp
Soils.shp
Vegetation.shp
Flow Accumulation
Flow Direction
Slope %
Sinks
Elevation
Curve Numbers
62
67
72
68
74
65
71
81

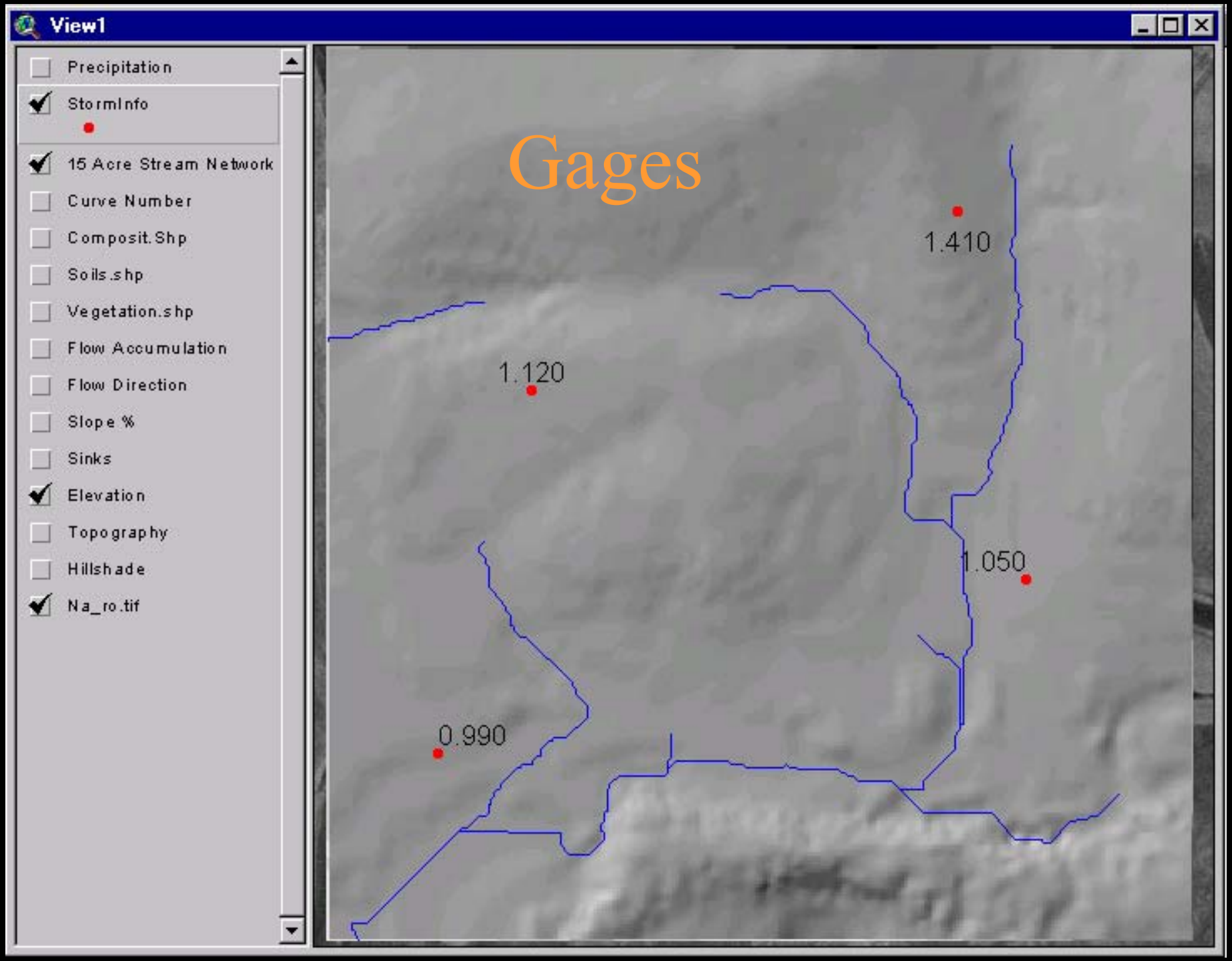
Precipitation Considerations

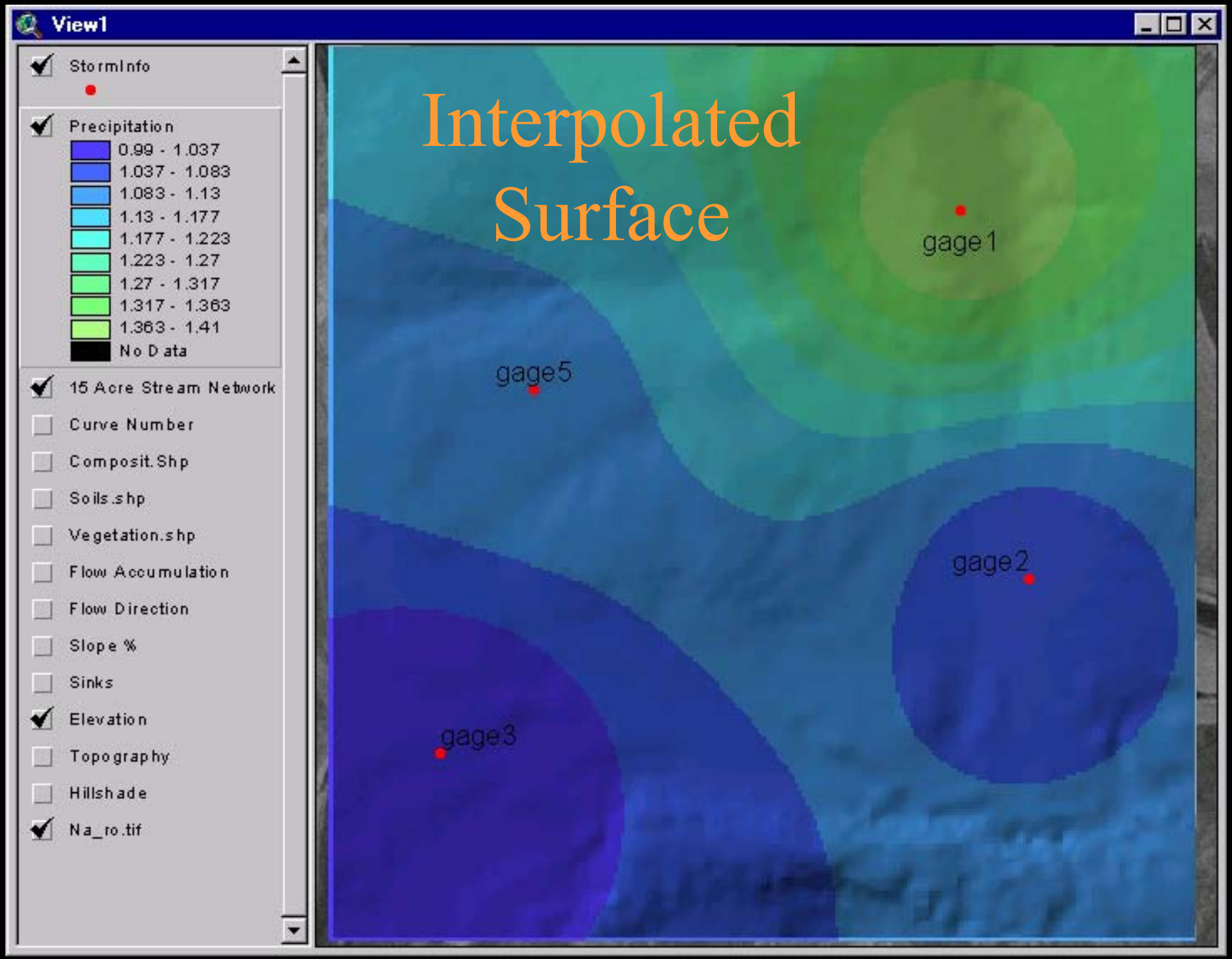
- Precipitation developer:
  - Single-storm total with NRCS distribution
  - Single-storm total with user-defined event distributions
  - User-placed gages with NRCS distribution
  - User-placed gages with user-defined event distributions



Options Options Options

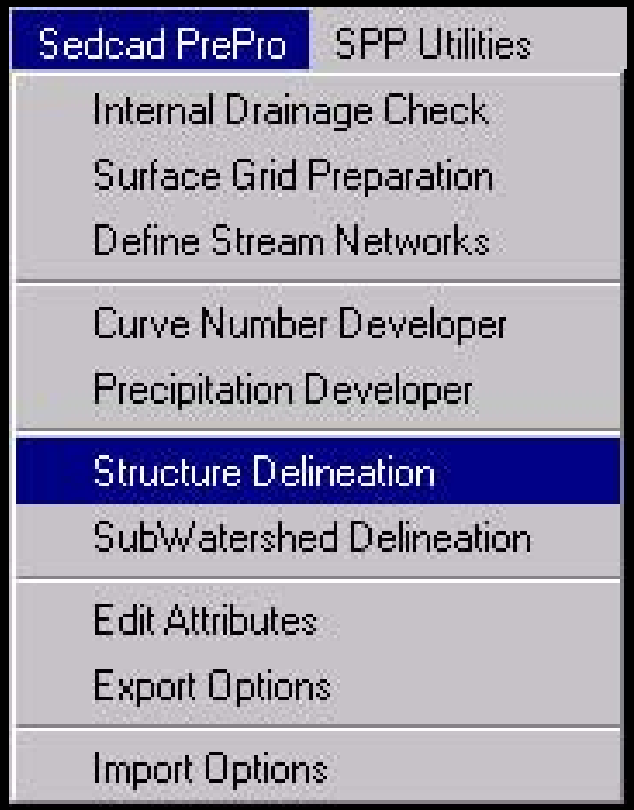



View1
Precipitation
StormInfo
15 Acre Stream Network
Curve Number
Composit.Shp
Soils.shp
Vegetation.shp
Flow Accumulation
Flow Direction
Slope %
Sinks
Elevation
Topography
Hillshade
Na_ro.tif
Gages
1.410
1.120
1.050
0.990


View1
StormInfo
Precipitation
0.99 - 1.037
1.037 - 1.083
1.083 - 1.13
1.13 - 1.177
1.177 - 1.223
1.223 - 1.27
1.27 - 1.317
1.317 - 1.363
1.363 - 1.41
No Data
15 Acre Stream Network
Curve Number
Composit.Shp
Soils.shp
Vegetation.shp
Flow Accumulation
Flow Direction
Slope %
Sinks
Elevation
Topography
Hillshade
Na_ro.tif
Interpolated Surface
gage1
gage5
gage2
gage3

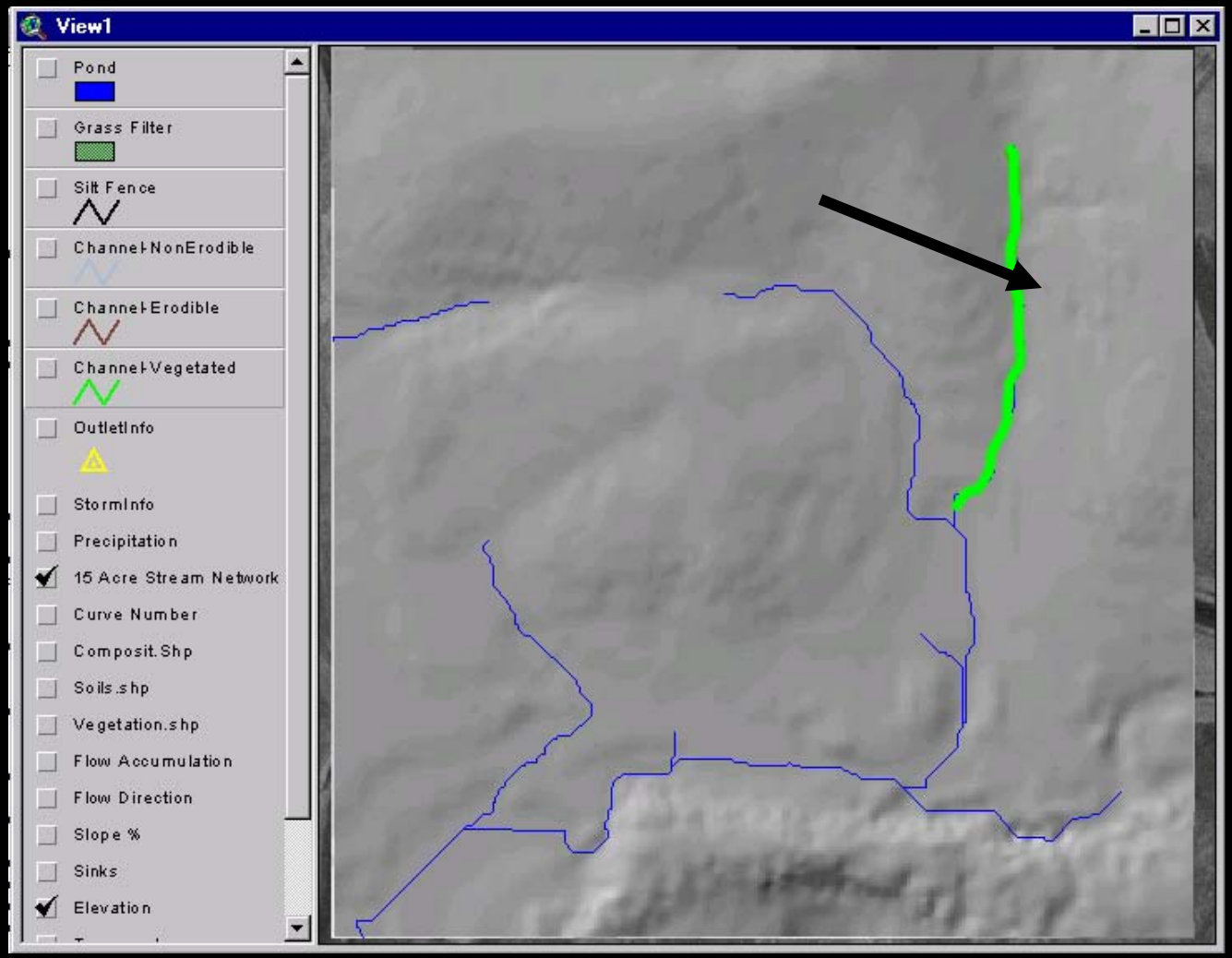
Structure Delineation

- Channels
- Ponds
- Silt fences
- Grass filters
- Culverts
- Check dams

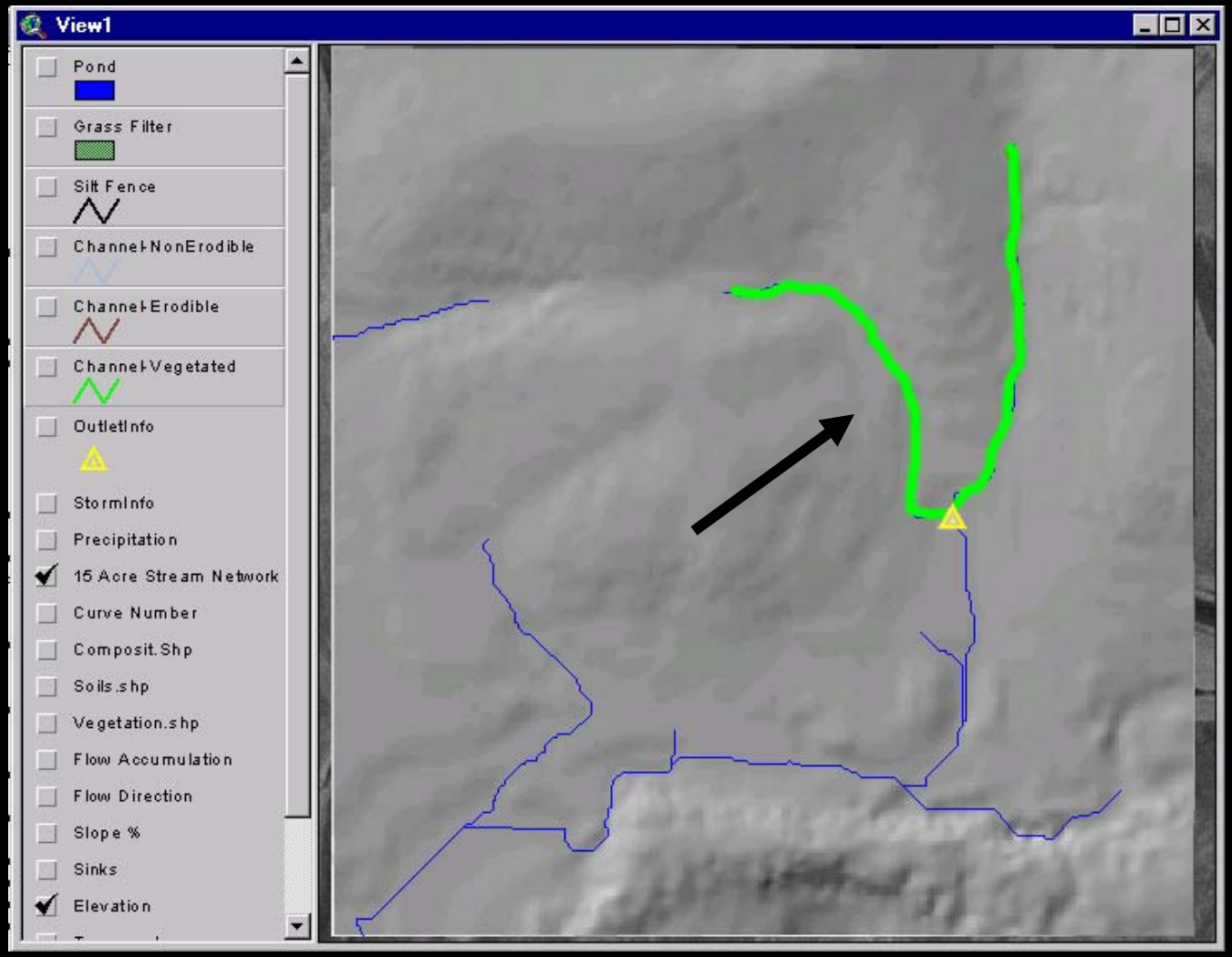


Structure Example

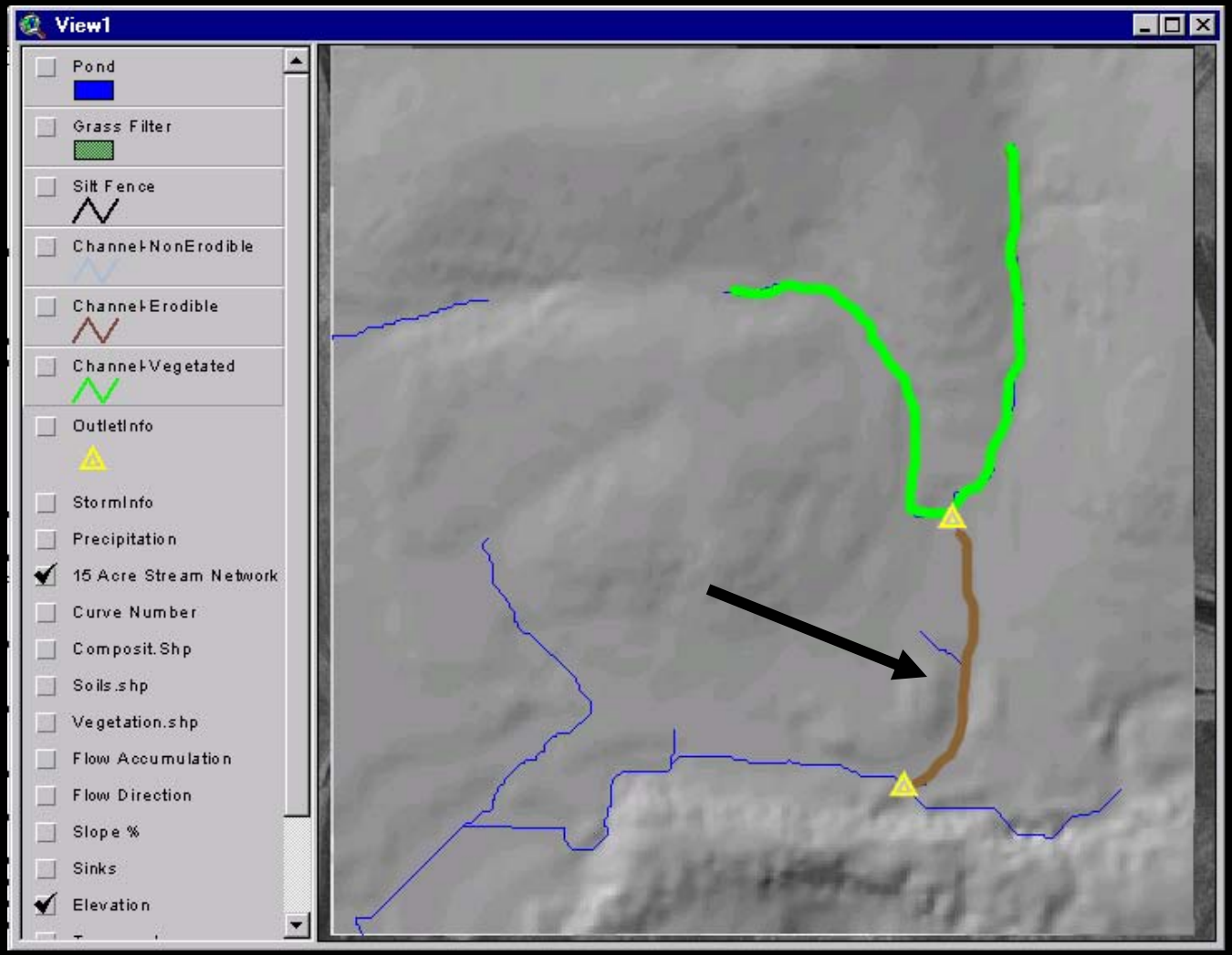
Add a Vegetated Channel



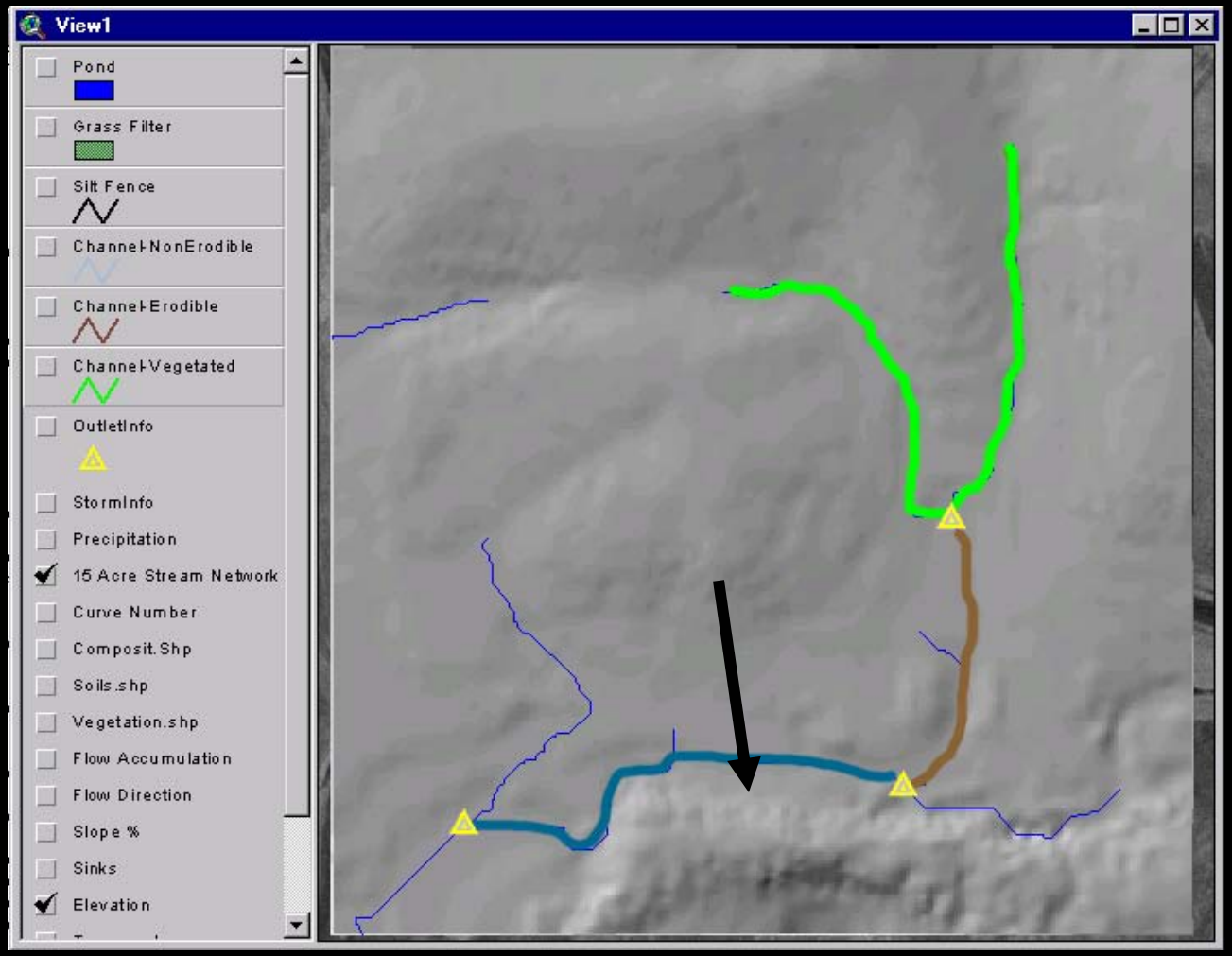
Add Another Vegetated Channel



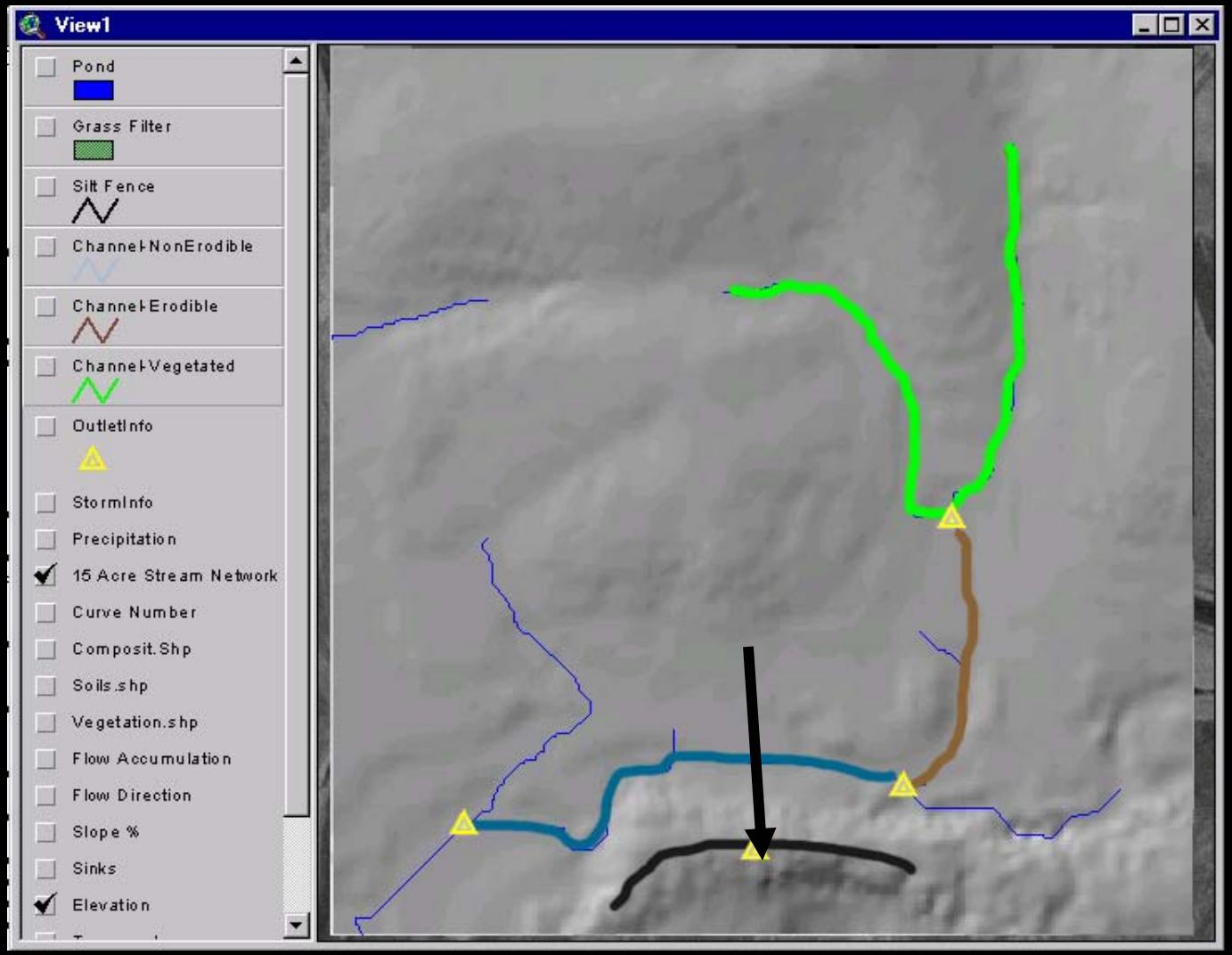
Add an Erodible Channel



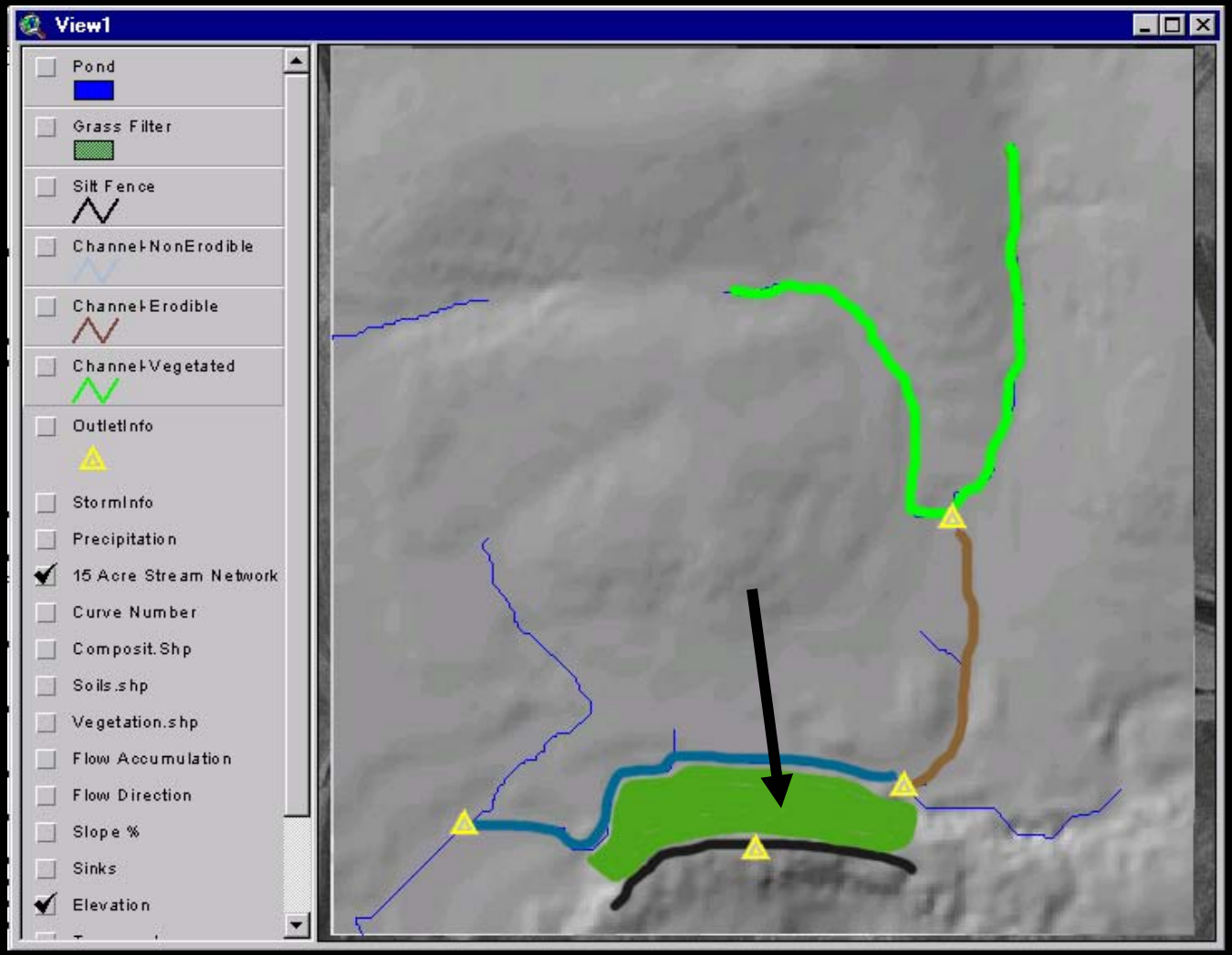
Add a Nonerodible Channel



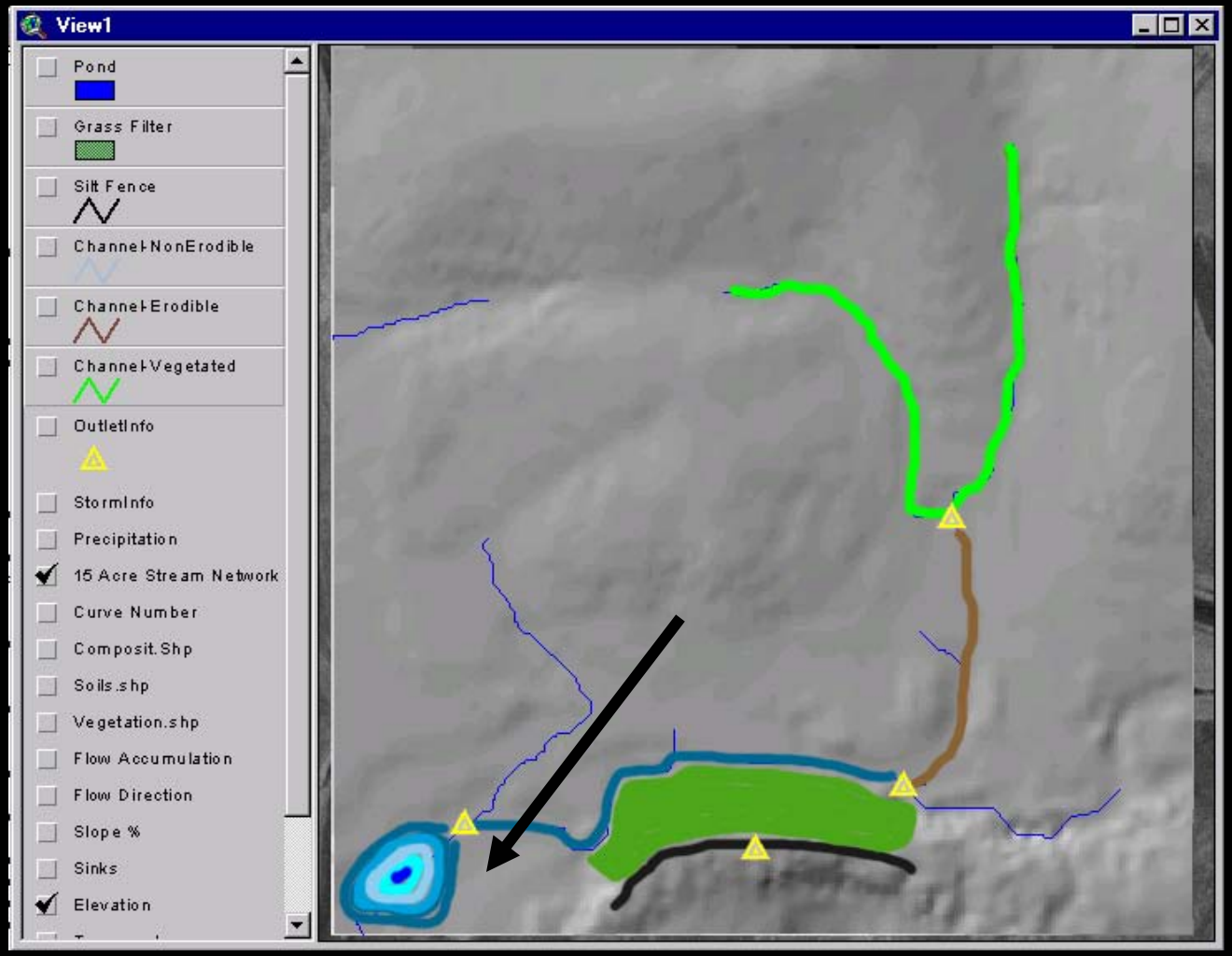
Add a Silt Fence



Add a Grass Filter

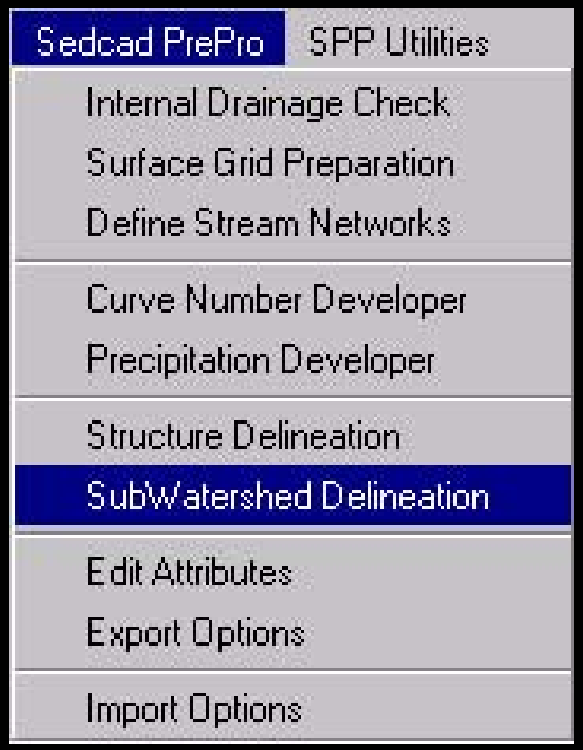


Add a Pond

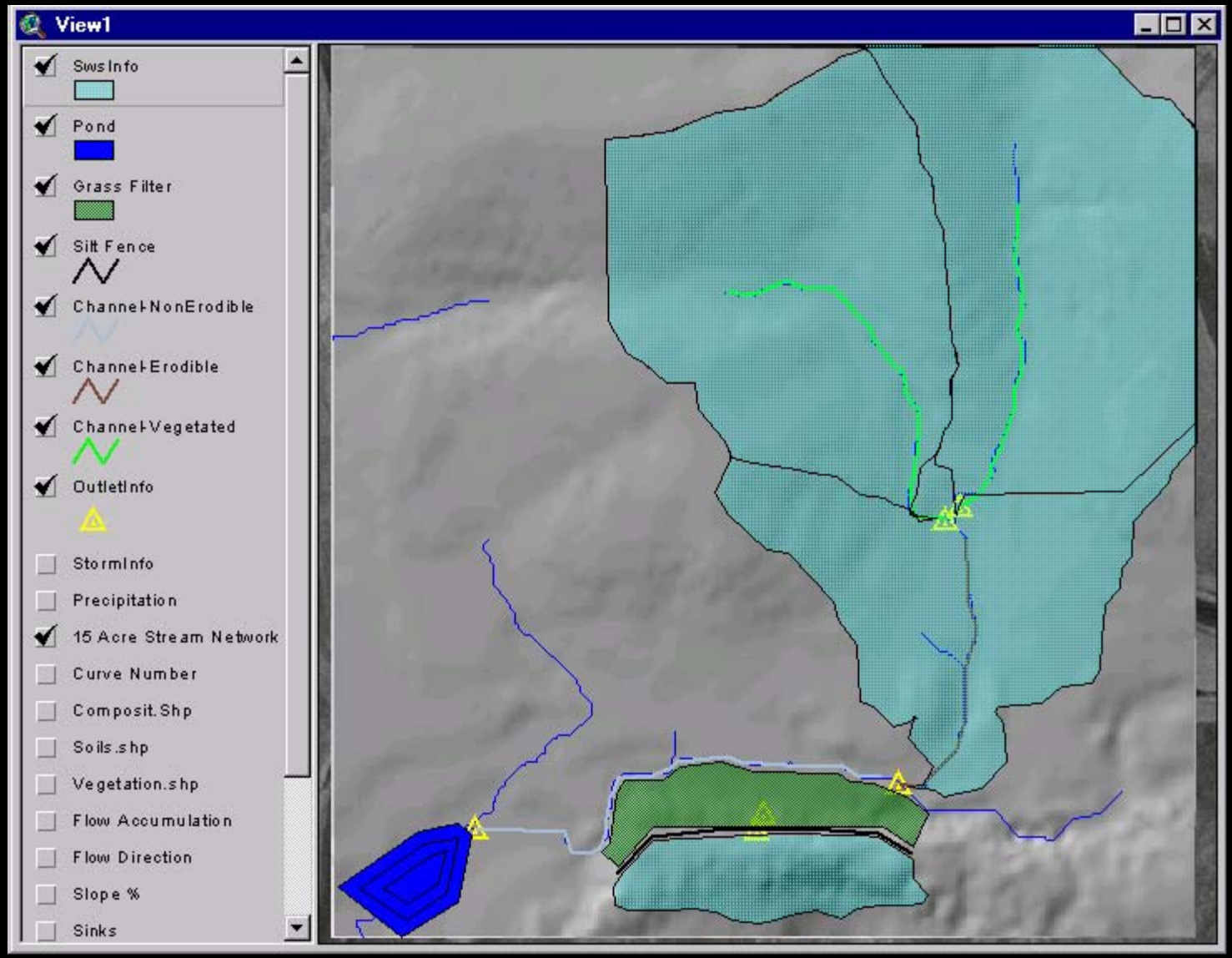

View1
Pond
Grass Filter
Silt Fence
Channel-NonErodible
Channel-Erodible
Channel-Vegetated
OutletInfo
StormInfo
Precipitation
15 Acre Stream Network
Curve Number
Composit.Shp
Soils.shp
Vegetation.shp
Flow Accumulation
Flow Direction
Slope %
Sinks
Elevation

Subwatershed Delineation

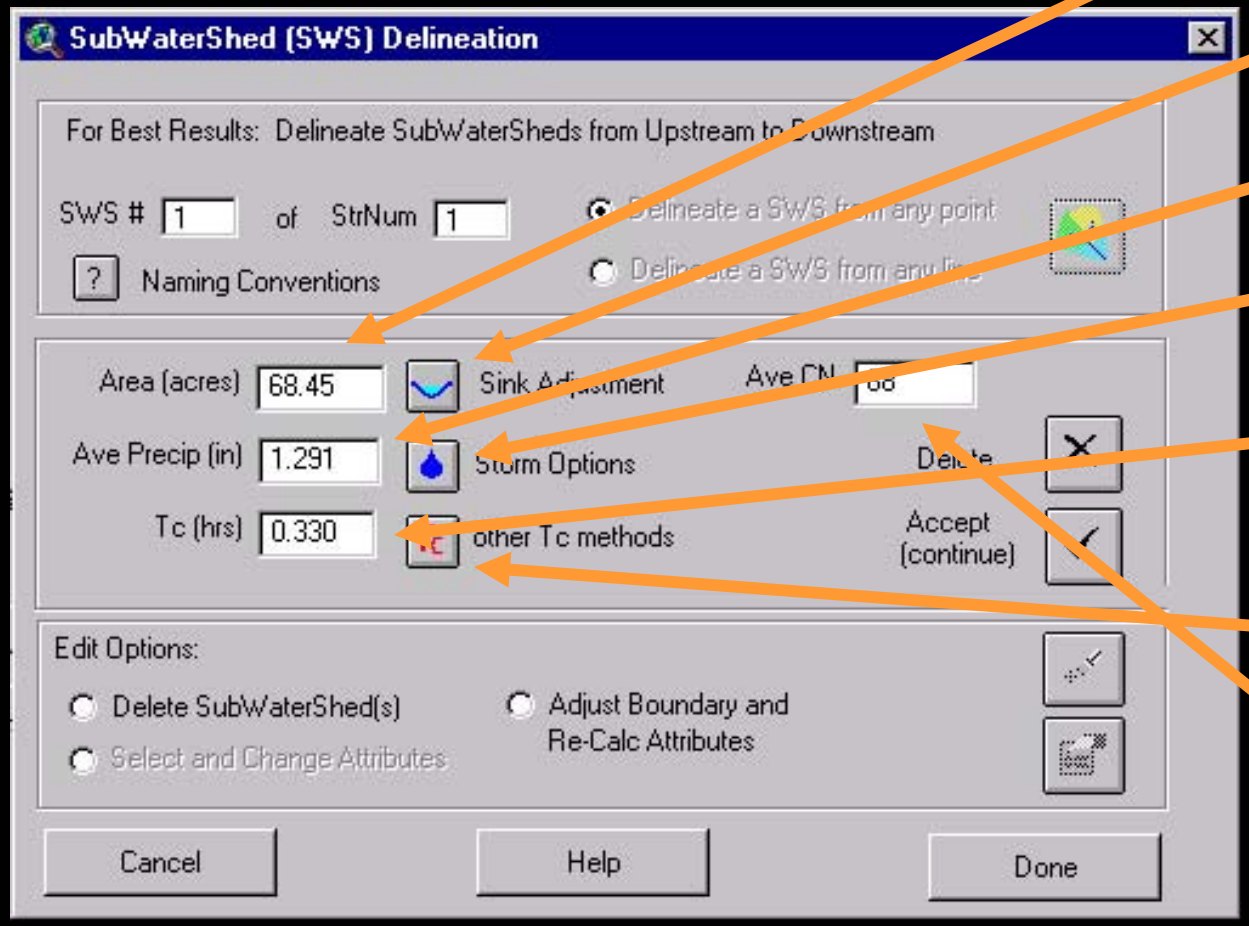
- Autodelineate the contributing subwatershed from any point
- Autodelineate the contributing subwatershed from any line (i.e., a silt fence)



Subwatershed Delineation



Averages and Options



Area (acres)

Sink adjustments

Average precipitation (inches)

Storm options

Time of concentration

Time-of-concentration options

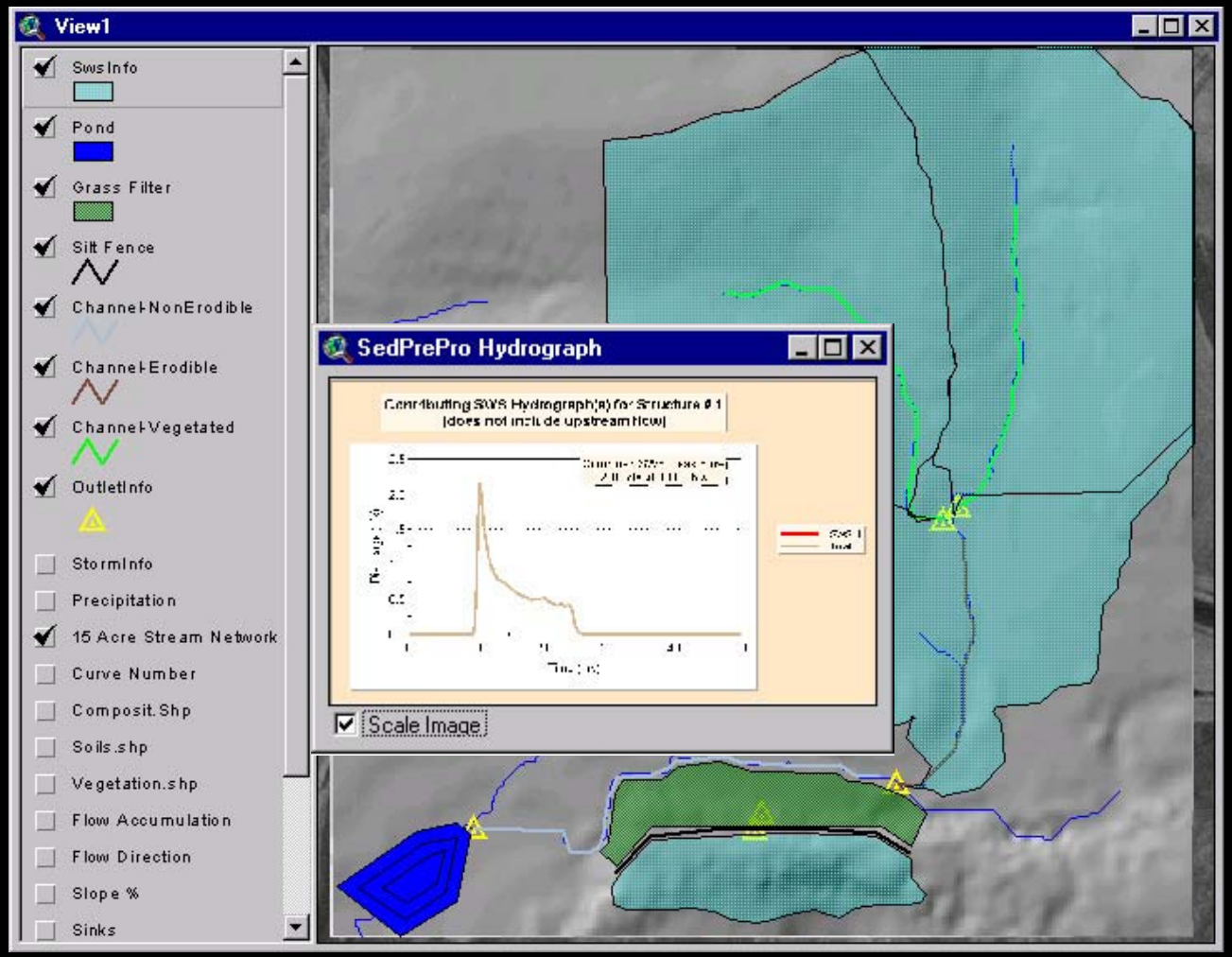
Average NRCS curve number

Editing and Reviewing

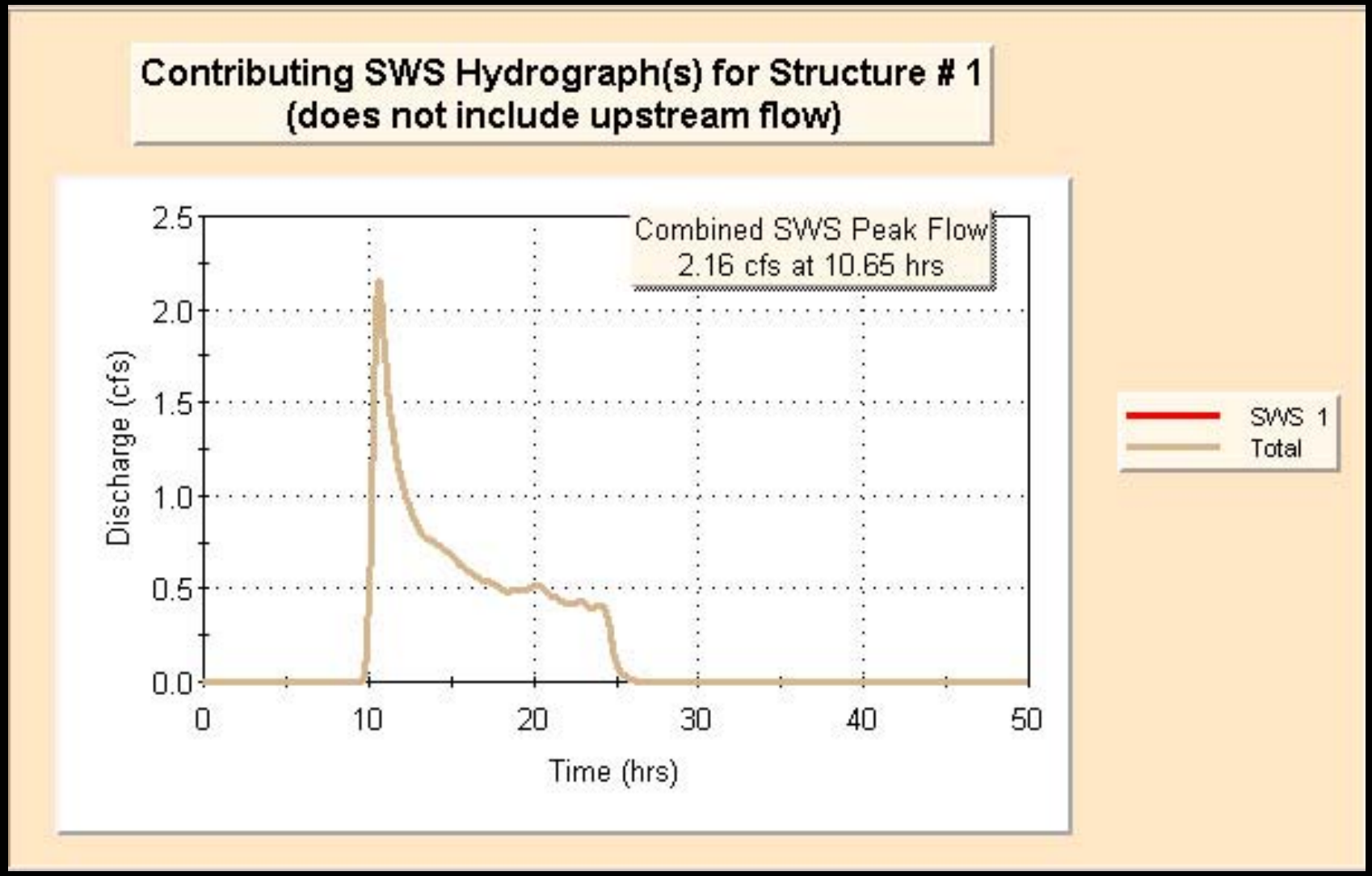
- View and adjust as necessary structure and subwatershed attributes:
  - Change values to test different hydrologic scenarios
  - Change size or shape of structures and watersheds to accommodate phased operations
- Point and click on any model component to instantly display all attributes

Display Hydrographs

Click and view

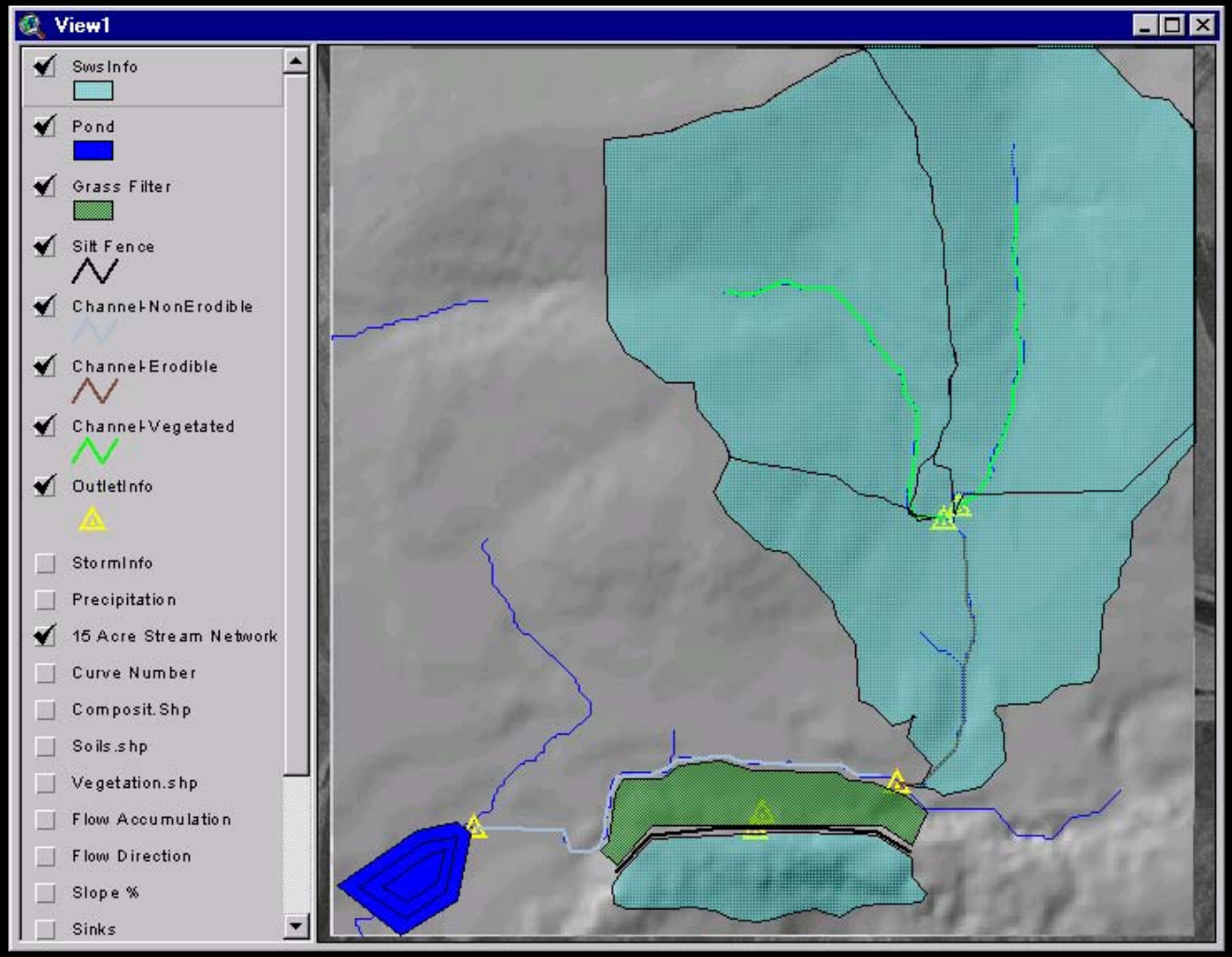


A Closer Look

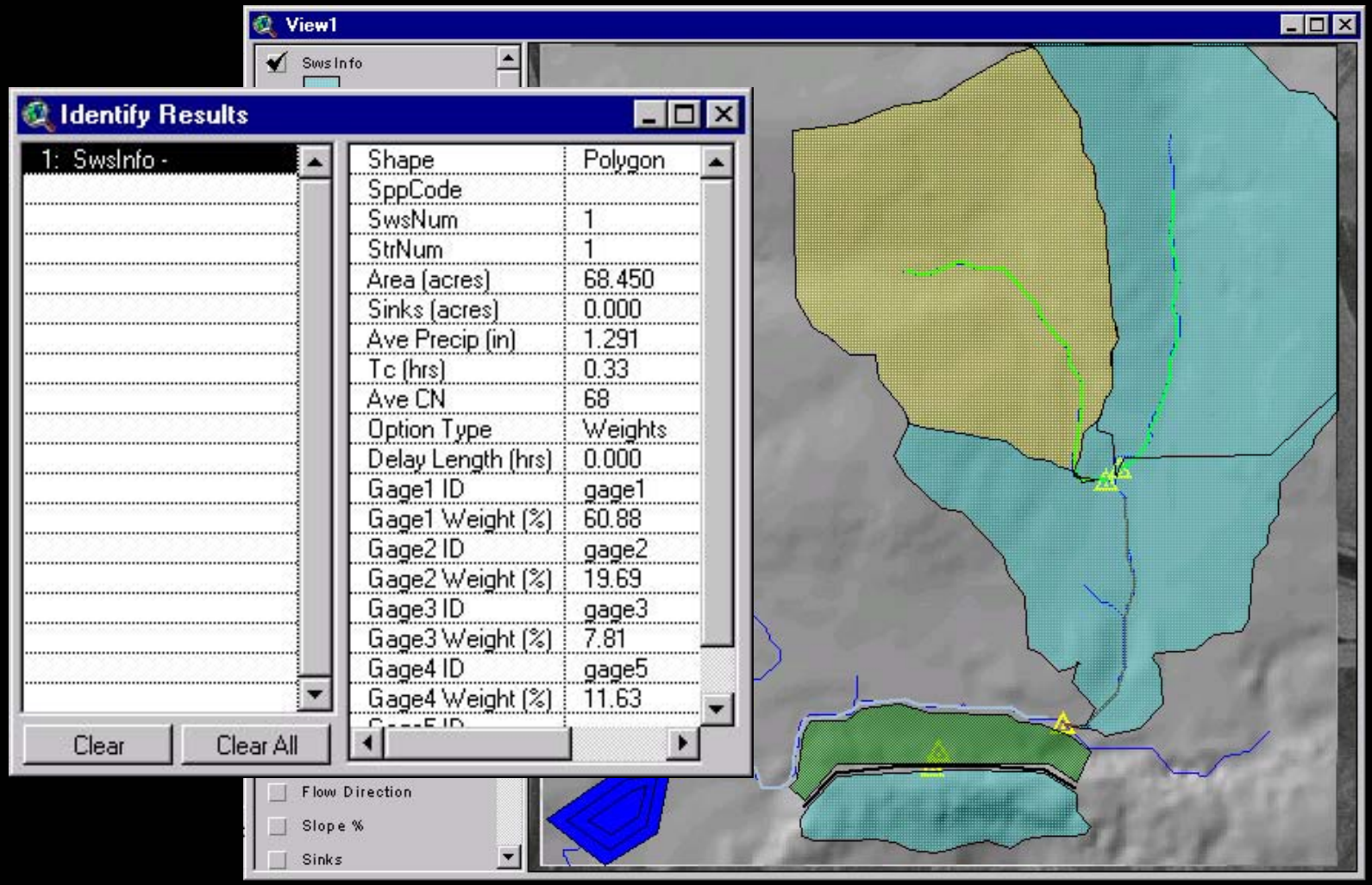


Attributes for Review

Click and view



Attributes for Review



SedPrePro Potential

- Design complete hydrologic models
- Visualize each and every step of the modeling process
- Easy adjustments allow for optimization of structure design and storm-water predictions
- Produce presentation-quality maps
- Potential for electronic permitting

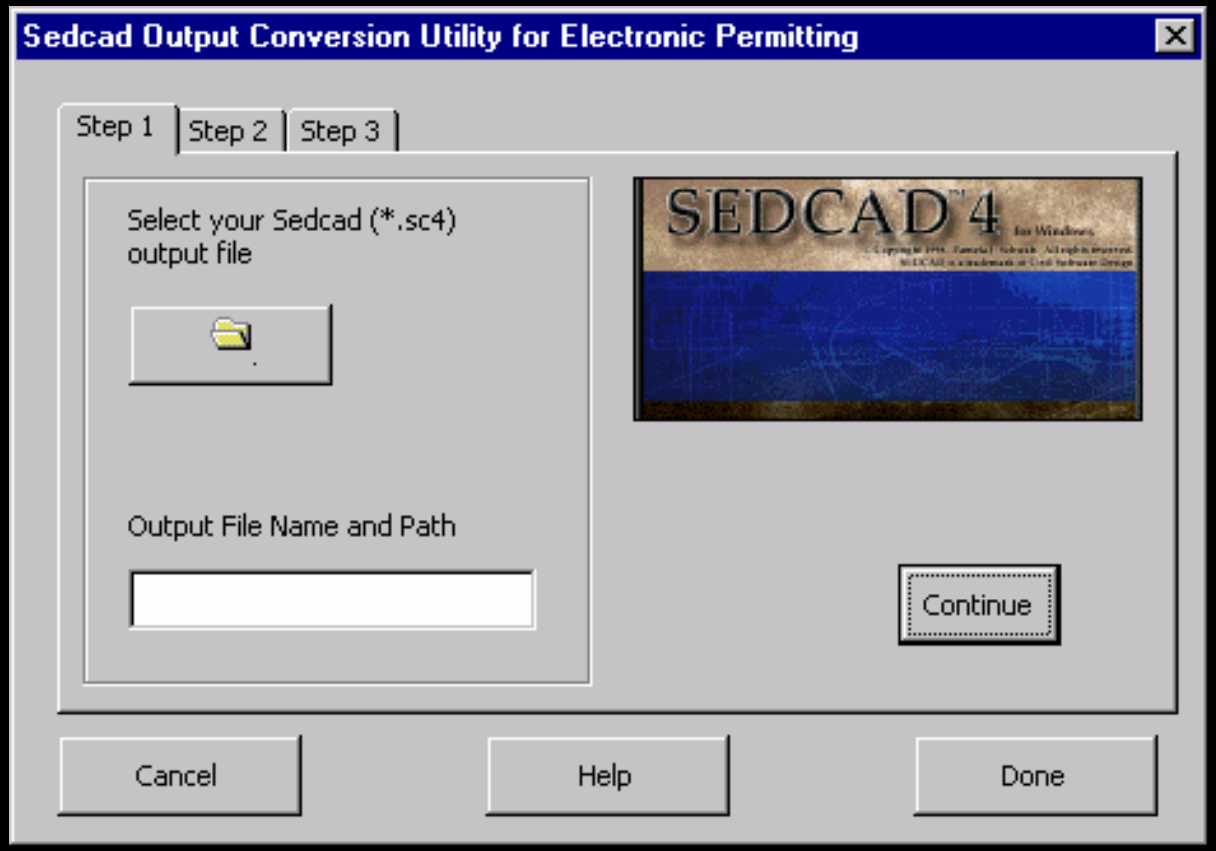
Current and Future Developments

- Automating SEDCAD outputs for Kentucky electronic mine-permit applications:
  - Working closely with the Kentucky Department for Surface Mining Reclamation and Enforcement

SEDCAD Output Conversion

Step 1.

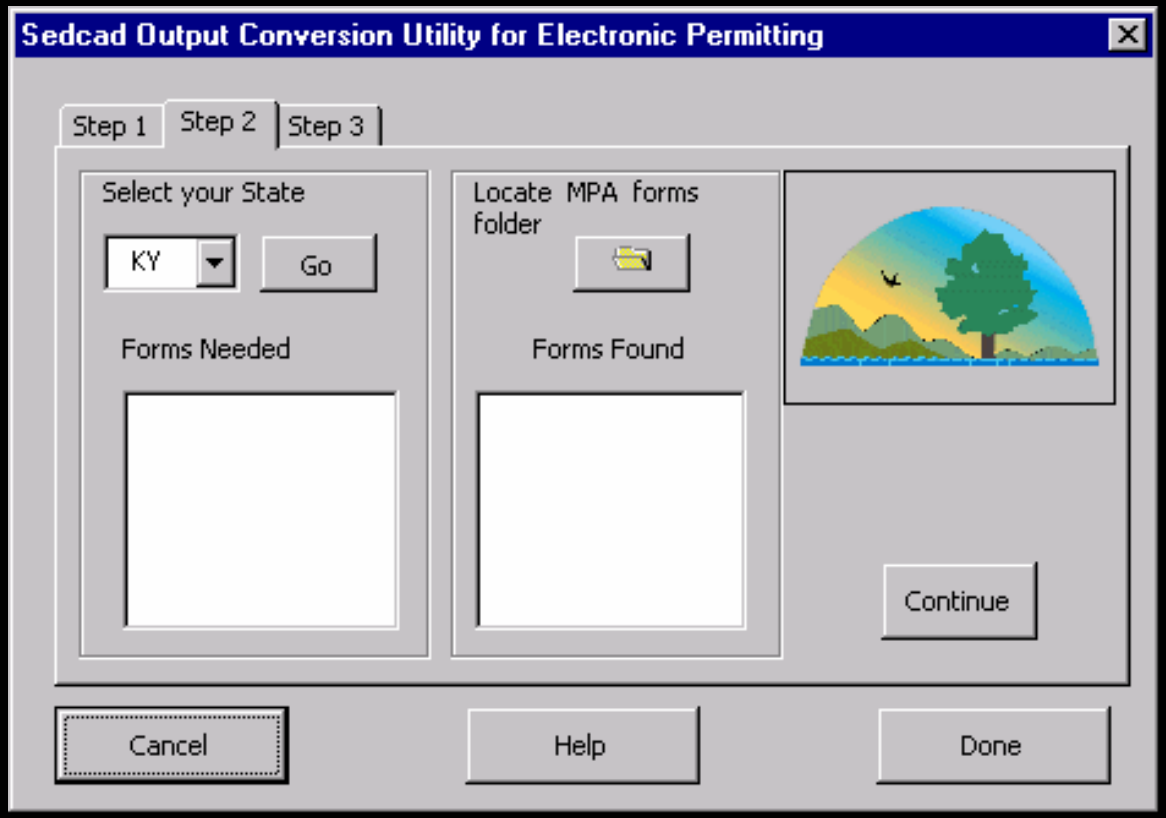
Load your SEDCAD output file



SEDCAD Output Conversion

Step 2.

Choose your State and the location of the permit area for your mine-permit application



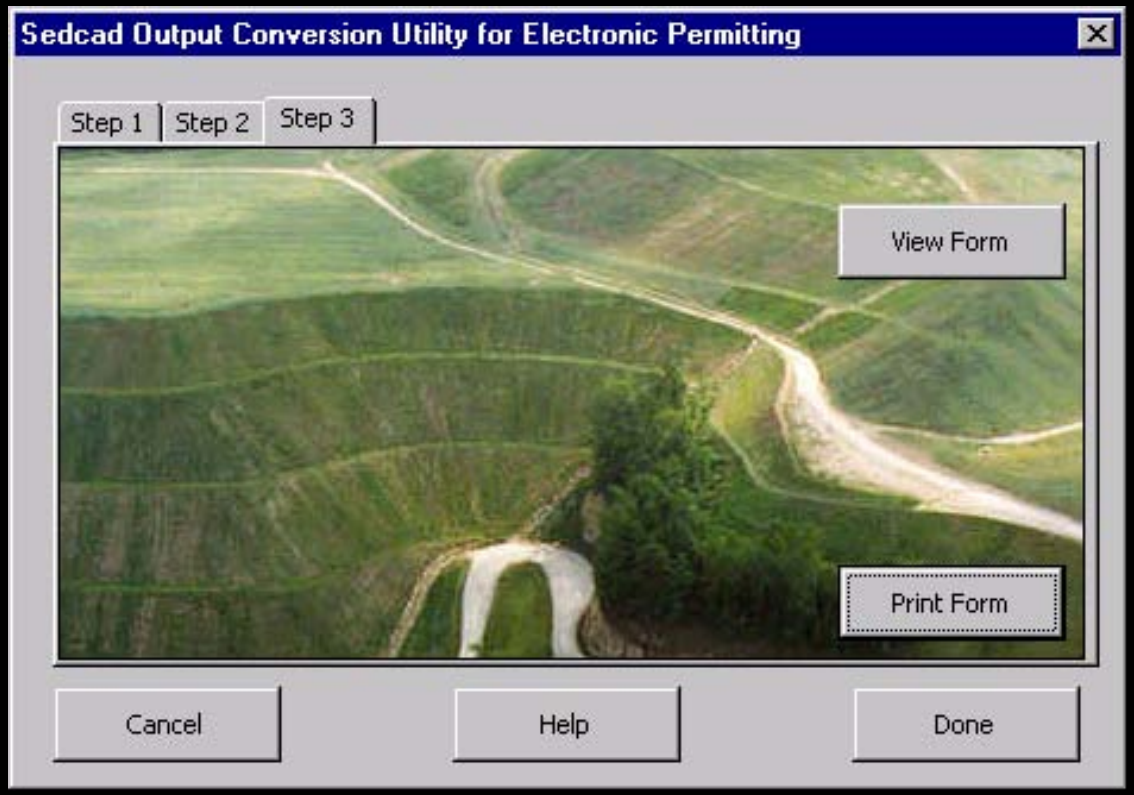
(NOTE: “MPA” denotes “mine permit application”)

SEDCAD Output Conversion

Step 3.

You're done!

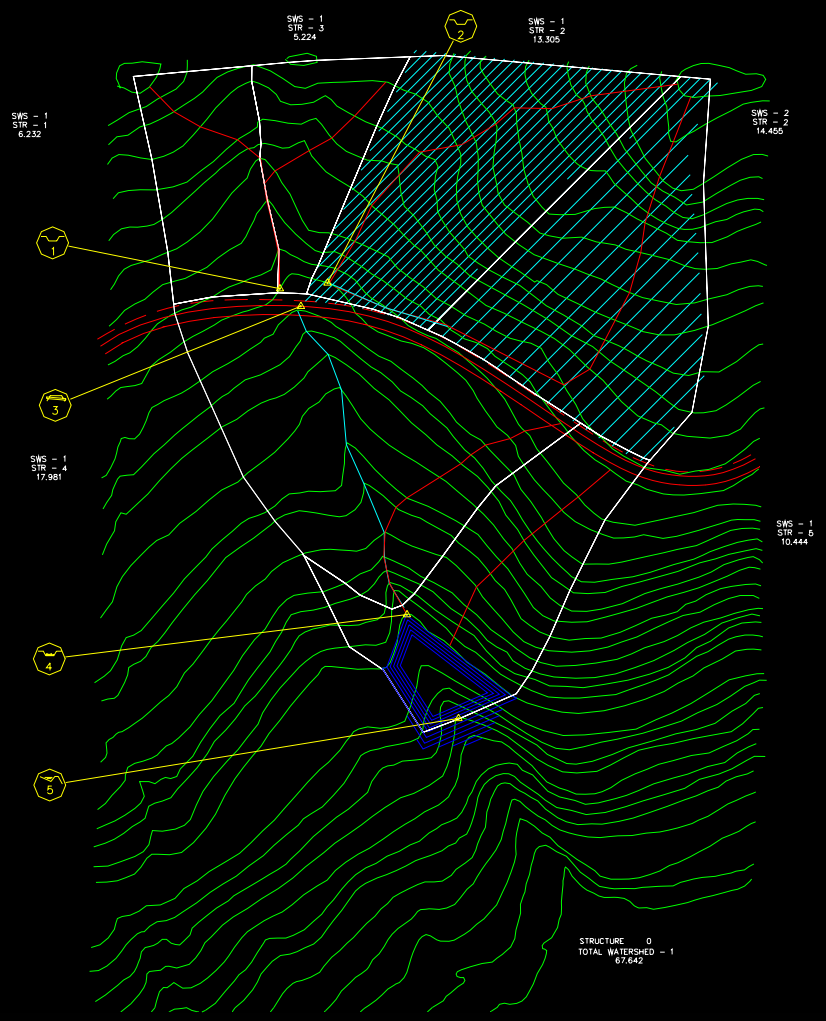
Would you like to print?



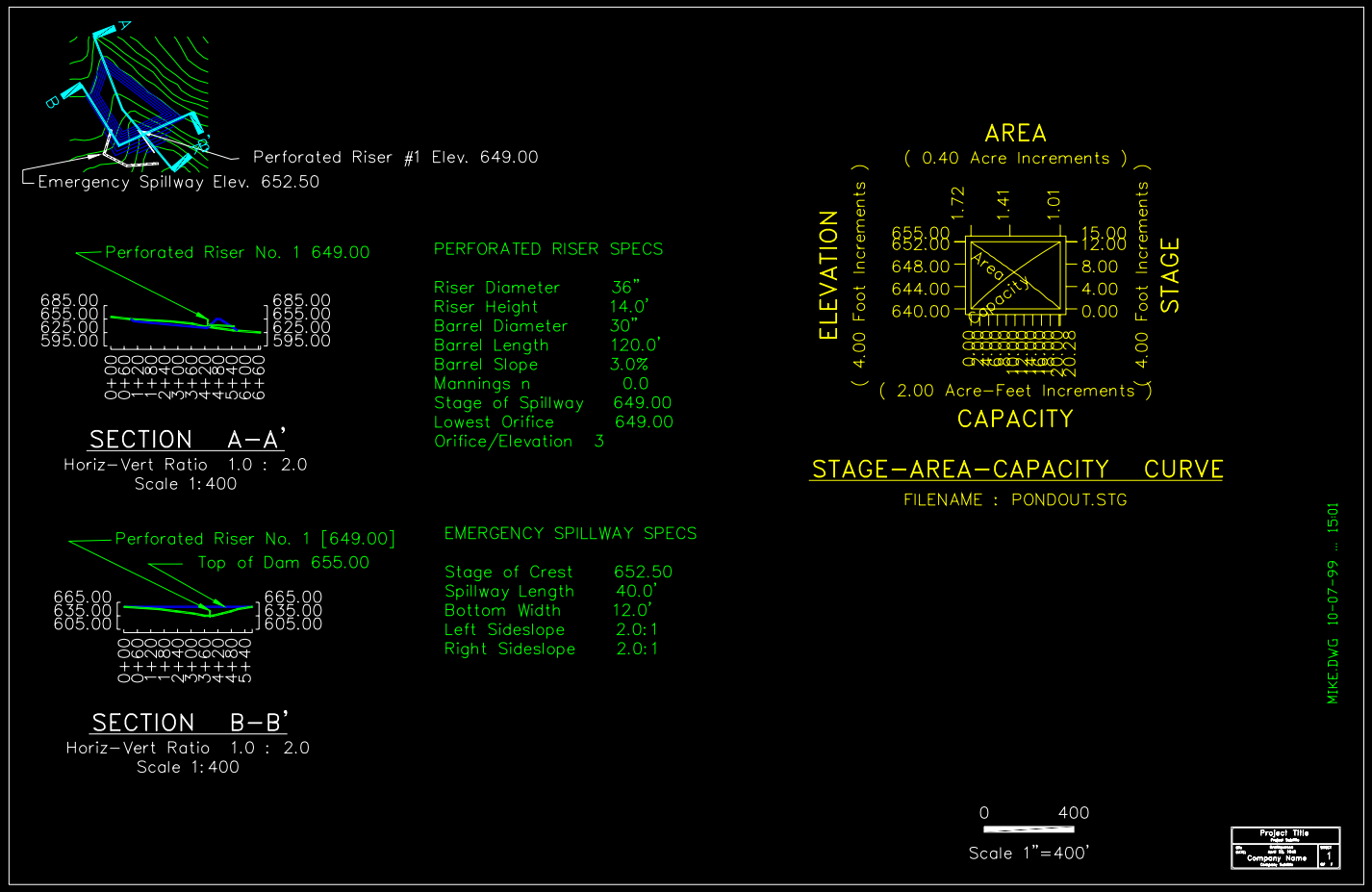
Current and Future Developments--continued

- SED-ACAD:
  - Similar to SedPrePro, but operates strictly within the AutoCAD environment
- AutoCAD Map:
  - Will parallel the look and feel of SedPrePro, but will make use of AutoCAD's GIS functionality

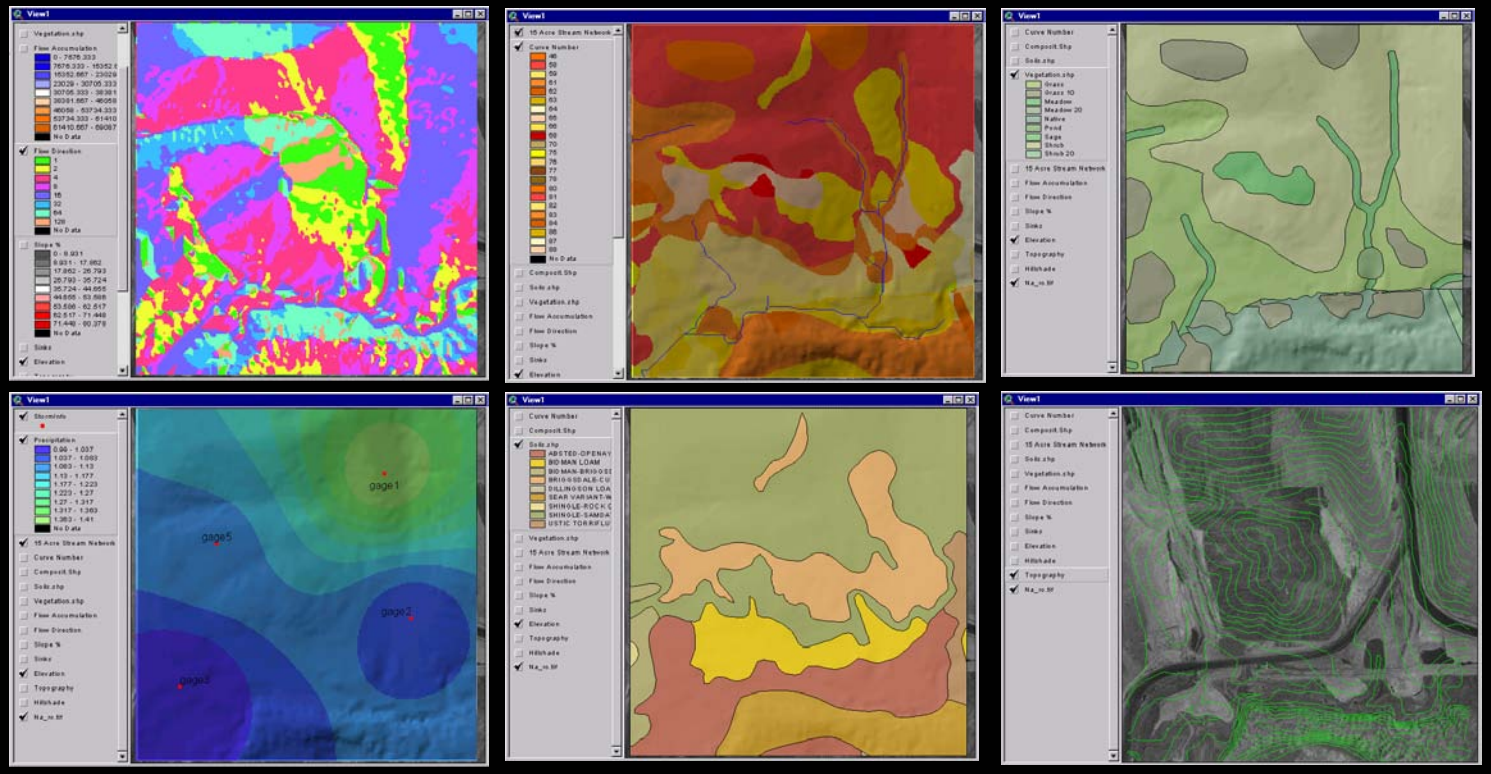
SED-ACAD


SWS - 1
STR - 3
5.224
SWS - 1
STR - 2
13.305
SWS - 1
STR - 1
6.232
SWS - 2
STR - 2
14.455
SWS - 1
STR - 4
17.981
SWS - 1
STR - 5
10.444
STRUCTURE 0
TOTAL WATERSHED - 1
67.642

SED-ACAD Output Drawings



For More Information



For more information, contact Richard C. Warner at rwarner@bae.uky.edu or go to http://www.wrcc.osmre.gov > Office of Technology Transfer > Publications

Automatic Monitoring Systems for Reclamation Design

Richard C. Warner, Ph.D.,
Michael Anderson, and Frank Camargo
University of Kentucky

Overview

- Why monitor?
- Parameters
- Data acquisition
- Costs of equipment
- Locations of sensors
- Sampling frequency
- Data transmission
- Using the data

Why Monitor?

- Bond release
- Follow prescribed regulatory guidelines
- Assess, calibrate, and verify reclamation-design model
- Ascertain best-management-practices effectiveness
- Verify compliance with effluent-concentration standards

Parameters (What To Monitor)

For purposes of this presentation, parameters are limited to:

- Rainfall
- Runoff
- Sediment

Precipitation Gages

- Weighing gages
  - Weigh amounts of rainfall collected
- Tipping bucket gages
  - Record tips of every 0.01 inch of precipitation
- Floating gages
  - Record vertical movements of floats

Digital Weather Monitoring

- HOBO™ weather stations
- Davis™ weather stations
- Campbell Scientific Weather, Inc. (CSI™), stations

HOBO™ Stations

- Inexpensive
- Easy to install
- Require manual data collection

www.benmedows.com

HOBO™ Stations

- Minimum requirements:
  - Tipping bucket
  - Data logger
  - HOBO™ shuttle
  - Software

www.benmedows.com

HOBO™ Stations

- Tipping bucket
  - Records rainfall in 0.01-inch increments
- Data logger
  - Records and stores detailed rainfall history, including information regarding quantity, duration, time, and intensity of rainfall
- Shuttle (optional)
  - Downloads data from up to 60 loggers (leaving the loggers in the field and the laptops in the office!)
- Boxcar software
  - Plots and interprets data, as well as exports them to usable spreadsheets

www.benmedows.com

HOBO™ Stations

Tipping bucket with event-data logger = $379

HOBO™ shuttle (optional) = $159

Total cost = $538

www.benmedows.com

Davis™ Stations

- Moderately inexpensive
- Require additional installation
- Multiple sensor options
- Wireless sensor logging
- Wireless data transmission
- Extensive software options

www.davisnet.com

Davis™ Stations

- Minimum requirements:
  - Tipping bucket
  - Weather monitor
  - Collection device
    - Manual
    - Wireless
  - Software for interpretation

www.davisnet.com

Davis™ Stations

- Rain collector:
  - Tipping bucket
  - Measures 0.01-inch increments

www.davisnet.com

Davis™ Stations

- Weather monitor:
  - Wind speed, chill, and direction
  - Barometric pressure, trend, and time
  - Humidity
  - Dew point
  - Temperature

www.davisnet.com

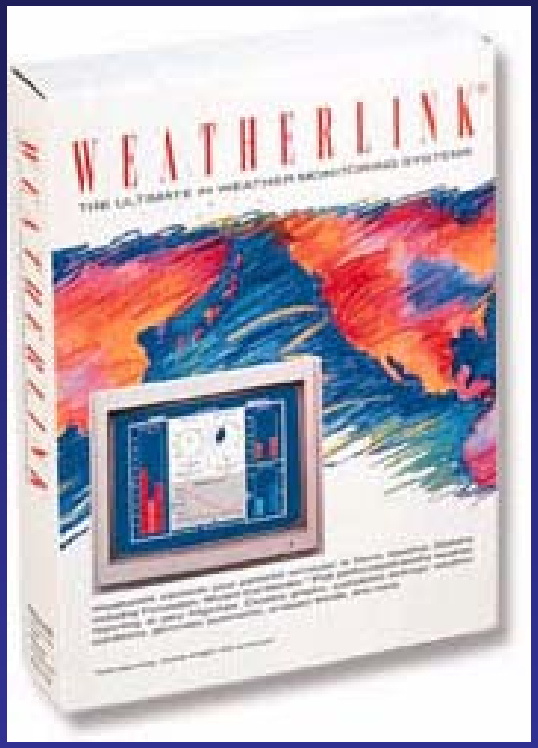
Davis™ Stations

- Sensor options (place wireless sensors up to 400 feet from a station):
  - Anemometer: measures wind speed, direction
  - Leaf wetness: surface moisture on foliage
  - Rain collector: self-emptying tipping bucket
  - Solar radiation: sun's radiant energy
  - Thermometer: measures air, soil, and/or water temperature
  - Humidity meter: measures humidity and dew point
  - Ultraviolet (UV) sensor: measures sun-burning portion of the UV spectrum

www.davisnet.com

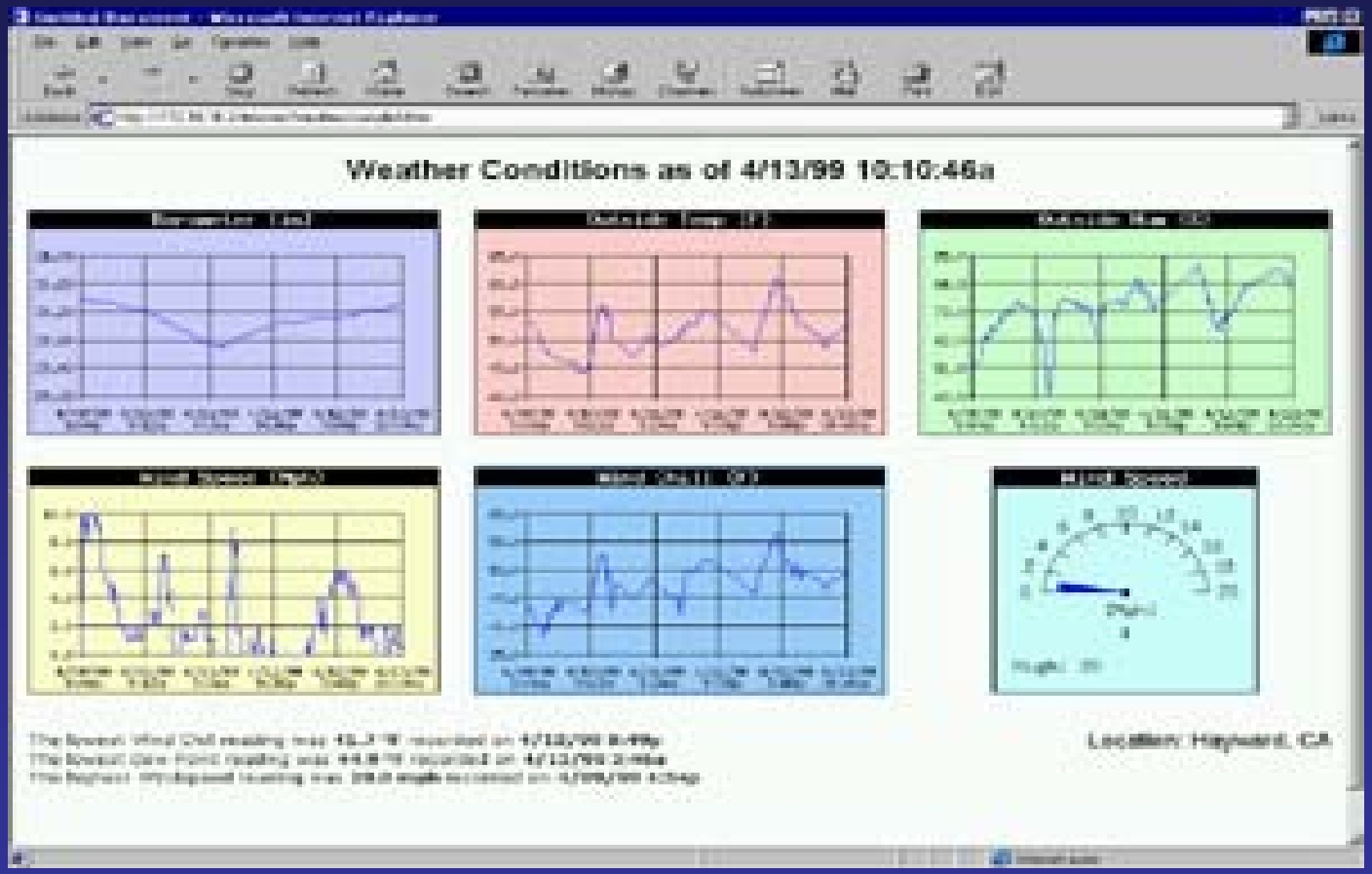
Davis™ Stations

- Weather link (similar to the HOBO™ shuttle)
  - Stores data until they are transferred to a user's personal computer
  - Uses included software to generate plots and spreadsheets



www.davisnet.com

Davis™ Stations



www.davisnet.com

Davis™ Stations

Tipping bucket with weather station = $485

Sensors (optional) = ?

Data collection (minimum cost, including weather link) = $165

- Weather link ($165)
- Weather Talker™ (optional, $395)
- Cellular telephone (optional, $850)
- UHF technology (optional, $1,750)
- Spread-spectrum technology (optional, $1,600)

Total minimum cost = $650

www.davisnet.com

CSI™ Stations

- Relatively expensive
- Require extensive installation
- Multiple sensor options
- Wireless sensor logging
- Wireless data transmission
- Networking options
- Fully automated and nearly self-regulating

www.campbellsci.com

CSI™ Stations

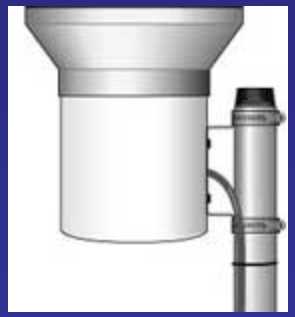
- Air temperature
- Relative humidity
- Barometric pressure
- Conductivity
- Dissolved oxygen
- Distance
- Fuel moisture and temperature
- Leaf wetness
- Ph/ORP
- Precipitation

- Soil heat flux
- Soil temperature
- Soil-water potential
- Soil volumetric (?) water content
- Solar radiation
- Turbidity
- Water level, stage, and flow
- Water temperature
- Wind speed/ direction

www.campbellsci.com

CSI™ Stations

- Precipitation collection options



www.campbellsci.com

CSI™ Stations

- Data loggers

www.campbellsci.com

CSI™ Stations

- Cost varies tremendously, based upon a nearly unlimited number of options
- Average cost is about $7,000

www.campbellsci.com

Runoff

- Stream
- Flume
- Pipe

Stream-Selection Criteria

- Straight for +/- 200 feet
- Confined to one channel
- Bed contains scour and fill
- Banks are stable and high
- Upstream pool
- Confluence of streams
- Accessibility

Stream Flow

- Measure water level
- In stilling wells:
  - Floats
  - Pressure transducers (cost = $200 to $400)
  - Data loggers (cost = $350 to $450)
    - +/- 0.01 to 1 percent full-scale
- Above water surface:
  - Ultrasonic

Flumes

- Supercritical flow trapezoidal:
  - Nine different configurations
  - Flow = 0.01 to 50 cubic feet/second
  - Constructed from Plexiglas™, sheet metal, and galvanized and stainless steel
- Parshall™, H-Type™, Palmer-Bowlus™, and Leopold-Lagco™
- Costs are from $200 to $3,000

Flumes

Stream-Sediment Sampling

- “Horizontal” samples are located in significant flow regimes
- “Vertical” samples are in single or multiple locations
- Data collected are used to assess storm size and runoff volume
- Begin sampling within about the first 60 percent of depth to be sampled (note that sampling equipment should not interfere with normal flow characteristics)
- Connect by intake pipes

Sample Frequency

- Initiate sampling with a liquid-level actuator
- Use non-uniform sampling intervals to capture peak-flow data (the rising and falling limb of the hydrograph)
- Base on modeled or monitored storms
- Give an example of a sampling sequence
- Take 6 samples at 3-minute intervals each, then 8 at 5-minute intervals each, and finally 10 in 100 to 200 minutes

Sediment Sampling

- Automatic samplers:
  - ISCO™
  - American Sigma™
- Programmable pump samplers:
  - Extensive capabilities
- Sampler, solar panel, lead-acid battery, and liquid-level actuator
- Costs are from $3,000 to $4,000

Automatic Samplers

- 24 1-liter bottles
- Capable of uniform, non-uniform, and/or intermittent sampling
- Can take individual or multiple samples at one time
- Are composed of multiple bottles
- Provide detailed sampling information

Automatic Samplers

Stream Velocity

- Mechanical:
  - Price AA™ or Price Pygmy™ meters (cost = $1,200)
- Electromagnetic (cost = $3,000):
  - Temporary or permanent and continuous
  - Electrode-fouling
- Ultrasonic (cost = ?):
  - Are not affected by sediment concentration, unstable beds, or air entrapment

Data Transmission

- Recover by shuttle or laptop
- Telephone land lines (modem required)
- Cellular telephone (modem required)
- VHF/UHF (line-of-site, repeaters)
- Satellites
  - Polar-orbiting
  - Geostationary
  - Meteor-burst telemetry

Communications

Radio repeater

Communications

Radio repeater
with tower

Communications

- Radio telemetry
- Spread-spectrum radios
- Short-haul modems
- Satellite
- Multi-drop interface
- Several combination options made up of all the above

Communications Options

- Land line:
  - Weather Talker™ (cost = $395):
    - Connects a weather station to a phone line so that a user can dial the station and hear the weather conditions at any time
    - Will contact its user any time one of its station's alarms has been activated

Communications Options

- Cellular telephone (cost = $750 to $960):
  - Optimal for rugged terrain or distant field sites, or when multiple users need access to the same field station
  - Allows unlimited access within cellular service area
  - Does not require an Federal Communication Commission (FCC) license
  - Requires an ongoing expenditure, in the form of monthly charges from cellular service provider

Communications Options

- Telephone modem:
  - Enables a personal computer with a Hayes™-compatible modem to contact a data logger at any time
- Cellular telephone package:
  - Supports telecommunications in areas served by cellular telephone companies

Communications Options

- Voice synthesizer:
  - Allows a data logger to vocally transmit real-time or historical data
  - Enables a caller to access voice-synthesized information using a touch-tone (including cellular) telephone
  - Supports bypassing the voice synthesizer to allow a COM 300™ to function as a data modem

Communications Options

- Communication option:
  - UHF radio (cost ranges from $1,700 to $2,000)
  - Radio range is up to 25 miles
  - FCC license required
  - Often requires a FCC license fee
  - Requires antenna installation
- Spread-spectrum option:
  - Spread-spectrum radio modem (cost ranges from $1,500 to $2,000)
  - Modem range is within 7 miles of line-of-sight

Consultants

- Determine monitoring objectives (what is going to be accomplished)
- Take account of stream/site considerations
- Select sensor
- Select (recommend) data loggers' data-transmission options
- Analyze data

GEOCHEMICAL MODELING AND CHEMICAL MASS BALANCE FOR A COAL-MINE PIT LAKE IN SOUTHEASTERN MONTANA

John Wheaton
Warren Phillips

Rosebud Conservation District
Montana Bureau of Mines and Geology
Department of Natural Resources and Conservation

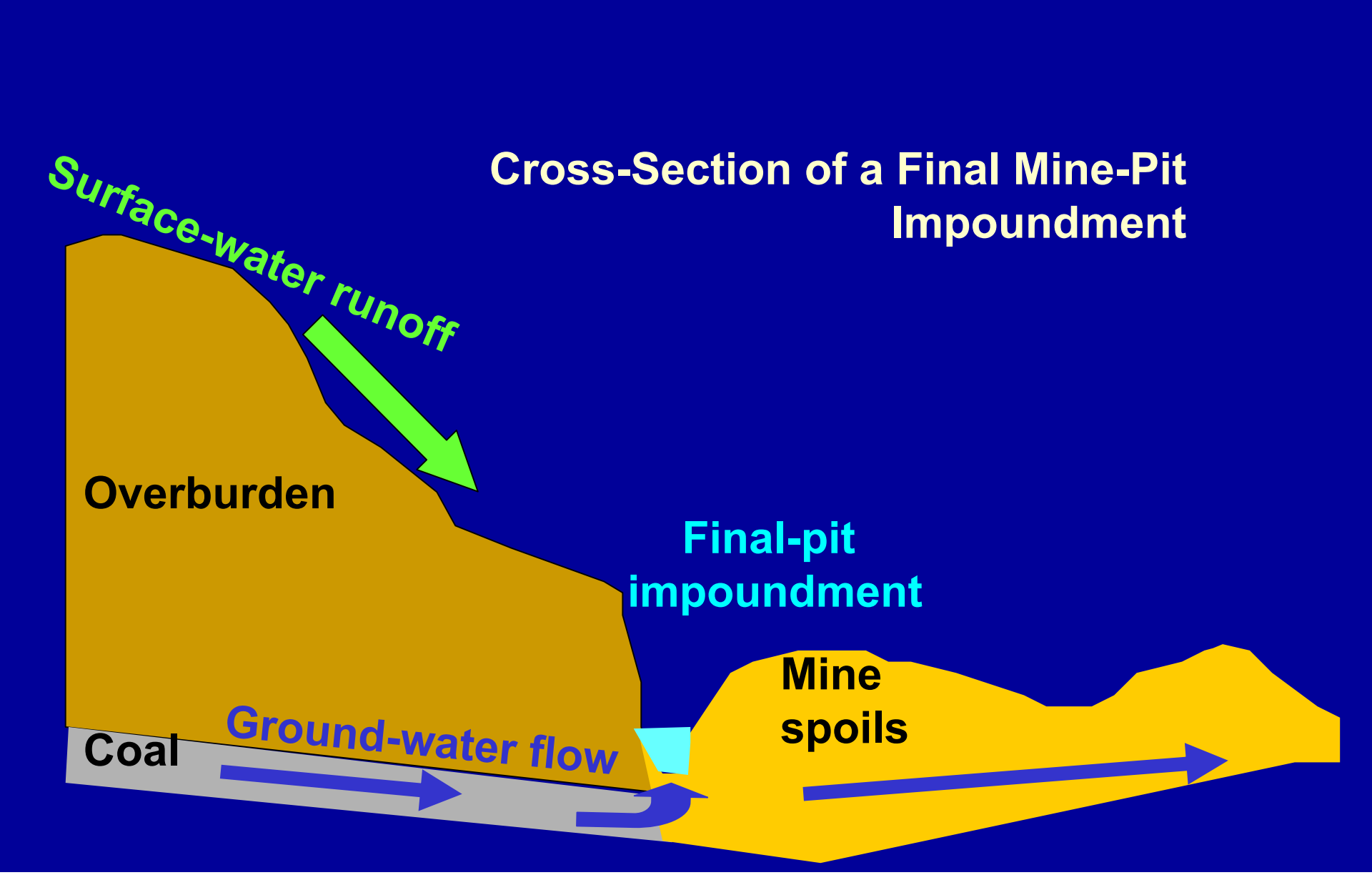


Figure 1.—Final mine-pit impoundments are created by allowing surface and ground water to fill a portion of a mine pit that is not backfilled during mine reclamation. A successful final-pit impoundment should be designed based on data available prior to mining, such as ground-water quality, aquifer transmissivity, and regional precipitation and evaporation rates.

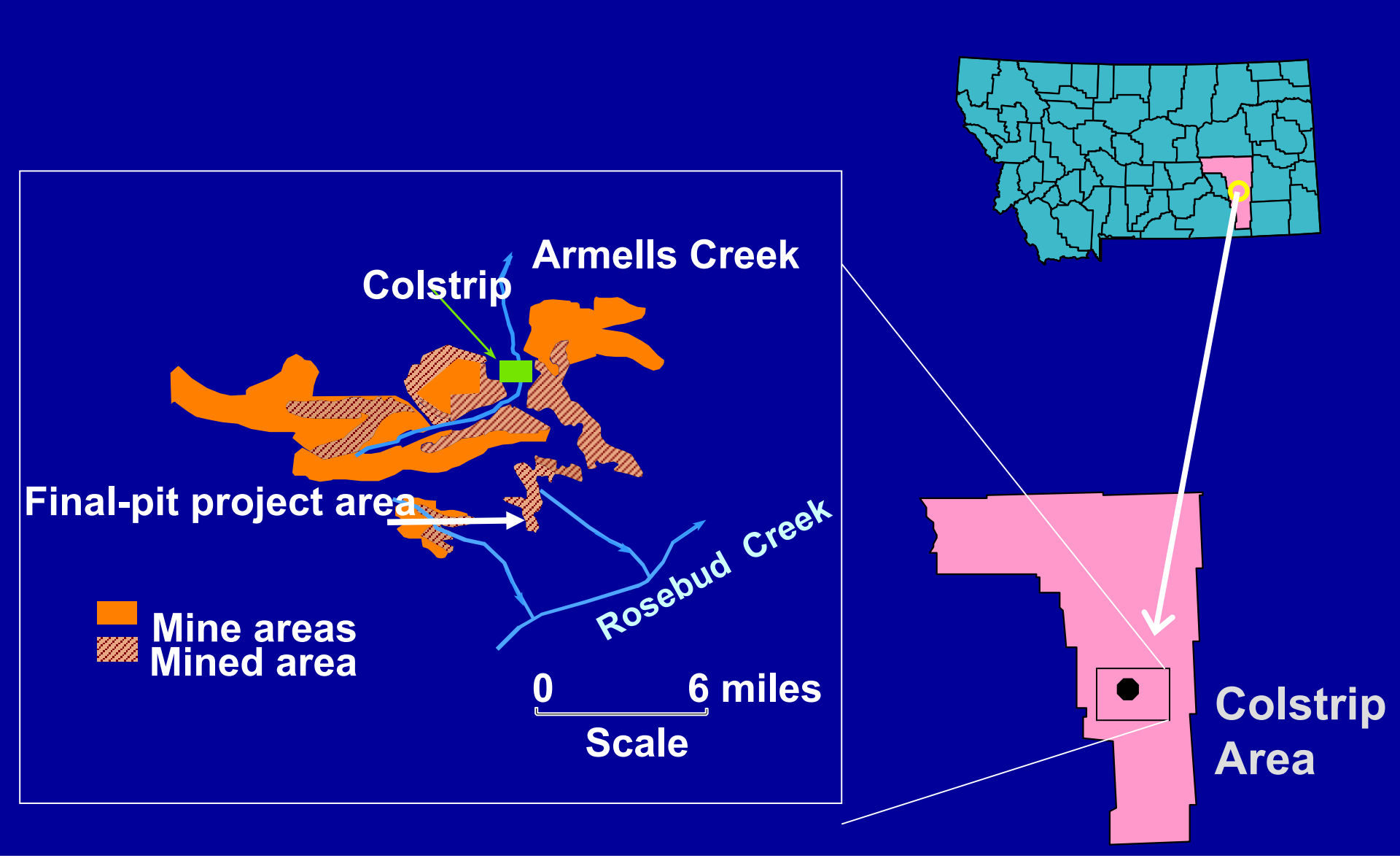


Figure 2.—To identify methods that will successfully model a mine-pit impoundment during the design phase, a detailed study of an existing impoundment was undertaken. The primary site for this study was a portion of Area A at Big Sky mine in southeastern. In addition, data were collected from other mine-pit impoundments and from traditional stock ponds that are not shown on this map.

Water-Budget Components: Inflow Components

	Possible sources of data
Precipitation	Onsite rain gage Local National Weather Service (NWS) data
Surface runoff	Contributing watershed proportion
Ground-water inflow	Ground-water data

Figure 3.—To calculate the anticipated water levels and quantity of water flowing through the system, a water budget for pond A was calculated, using data collected at the site. Inflow to pond A is from direct precipitation, surface-water runoff, and ground-water inflow.

Water-Budget Components: "Outflow" Components

	Possible sources of data
Evaporation	Floating pan Net radiation/temperature Local NWS data
Transpiration	Literature Bowen ratio: Net radiation/ temperature
Ground-water outflow	Ground-water data

Figure 4.—Loss from pond A is to evaporation, transpiration, and ground-water seepage.

Water-Budget Components: Change in Storage Capacity

	Possible sources of data
Storage	Pond stage Water budget and ground-water data

Figure 5.—The difference between inflow and outflow equals the change in storage, reflected in change in the water level of the pond.

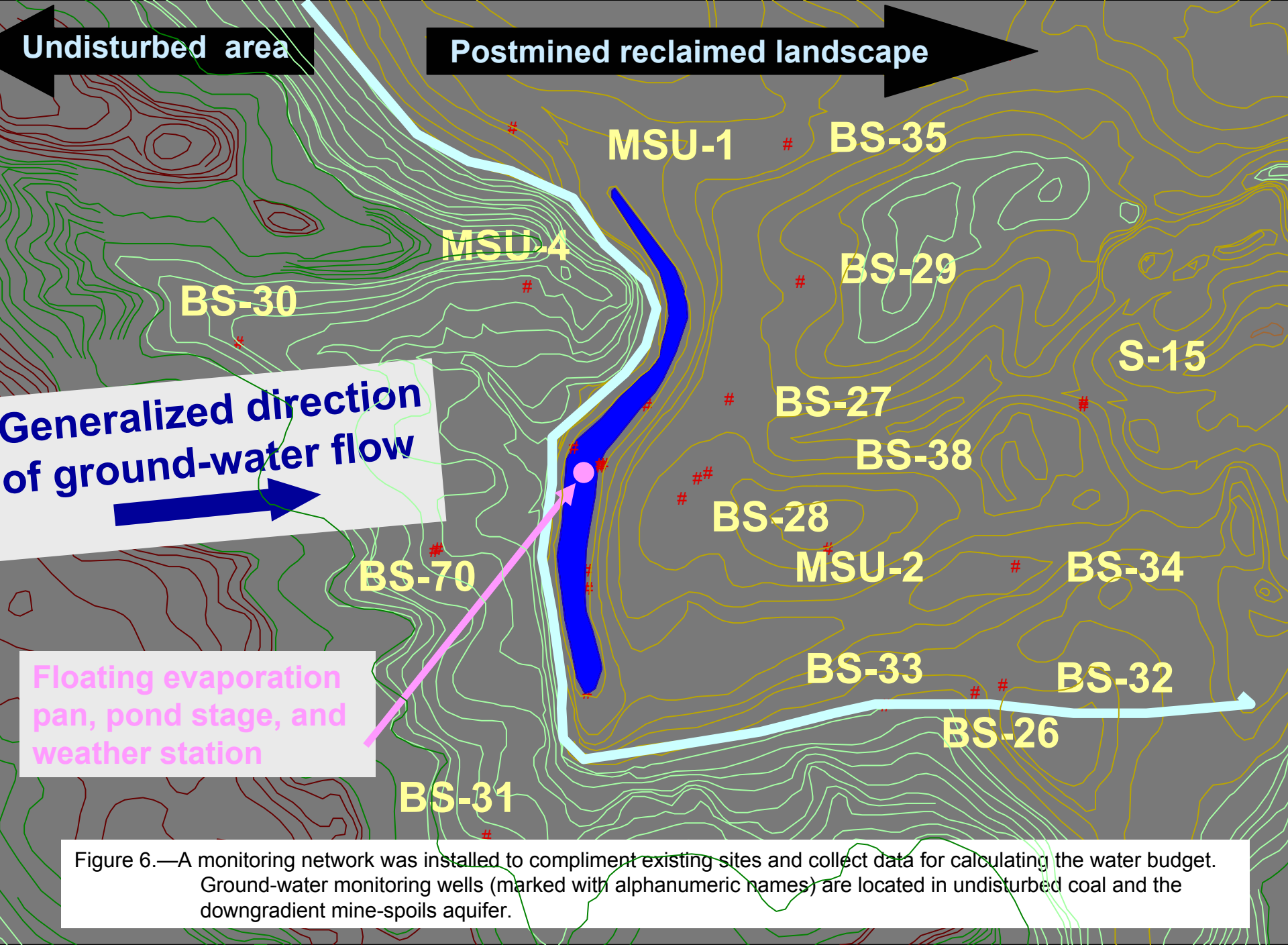


Figure 6.—A monitoring network was installed to compliment existing sites and collect data for calculating the water budget. Ground-water monitoring wells (marked with alphanumeric names) are located in undisturbed coal and the downgradient mine-spoils aquifer.

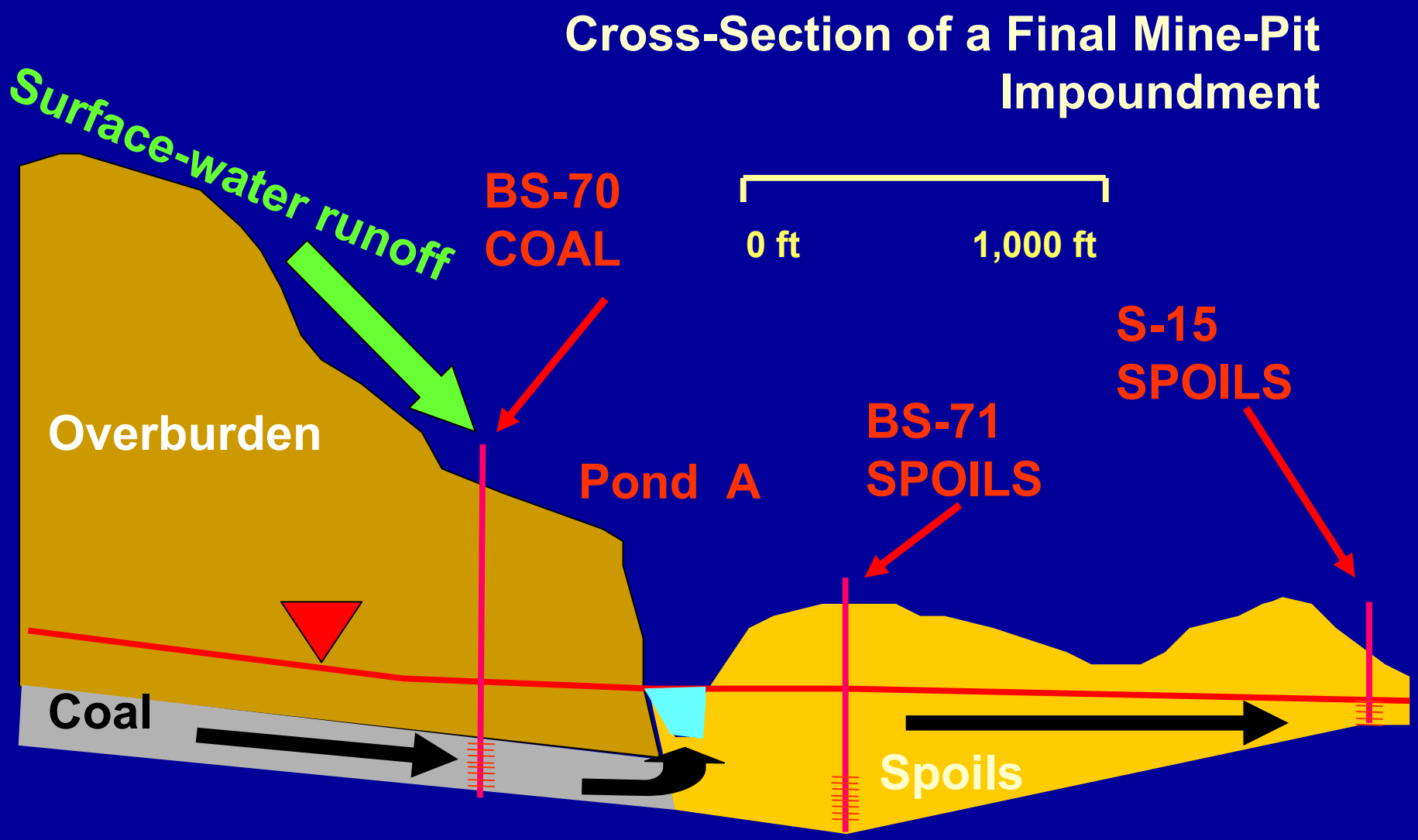
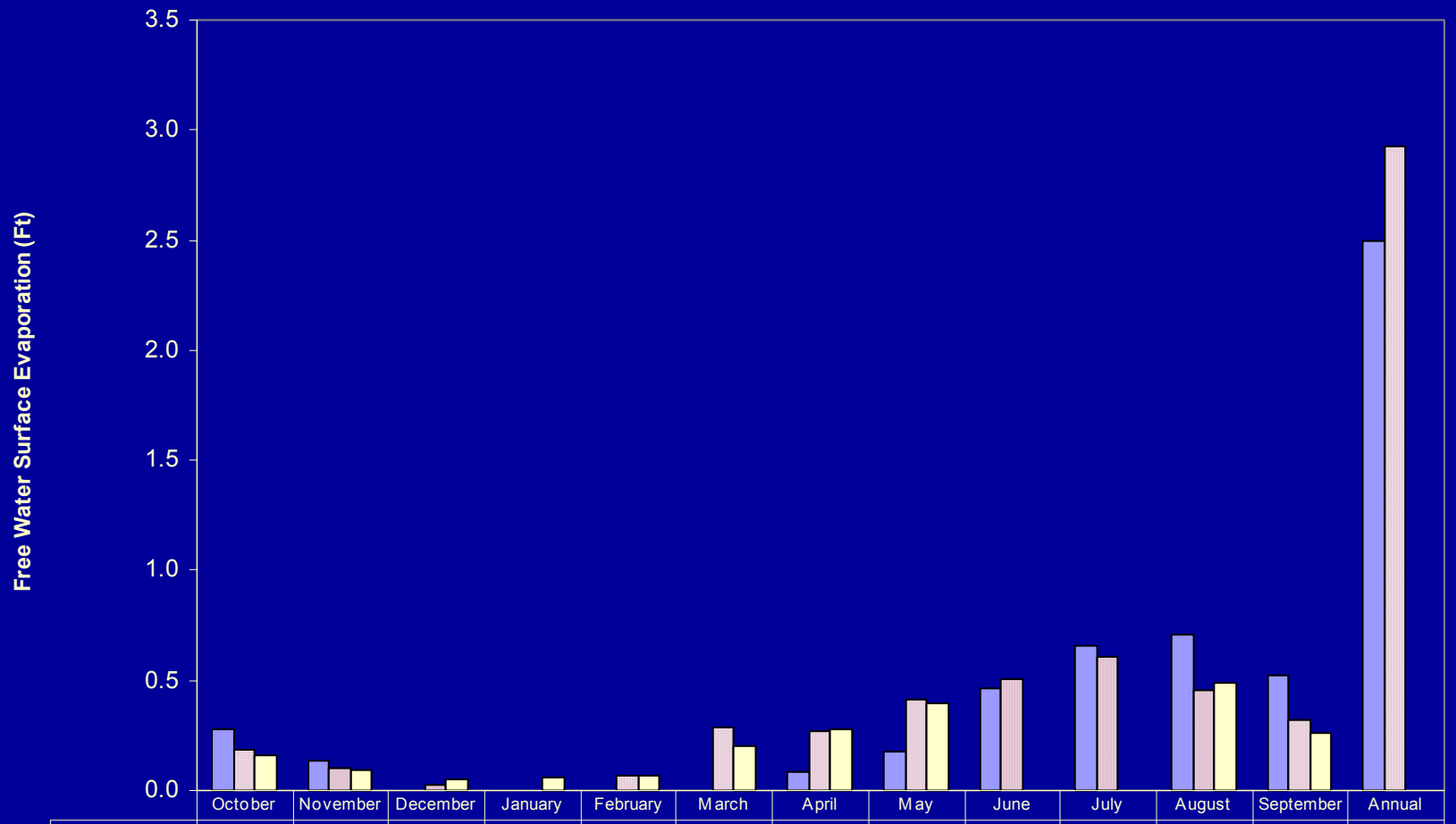


Figure 7.—Data were collected at monitoring wells completed in the coal and spoils aquifers, as well as from surface-water runoff stations. Hydrographs for wells and the pond stage are presented in the figures immediately following this one.



	October	November	December	January	February	March	April	May	June	July	August	September	Annual
Pan	0.28	0.14	0.00	0.00	0.00	0.00	0.08	0.17	0.47	0.65	0.71	0.52	2.50
BSM Net Rad	0.18	0.10	0.03	0.00	0.07	0.29	0.27	0.41	0.51	0.61	0.46	0.32	2.93
WECo Net Rad	0.16	0.09	0.05	0.06	0.07	0.20	0.28	0.40			0.49	0.26	

Figure 8.—Free-water surface evaporation rates for pond A were determined using a floating pan and calculated from net radiation data.

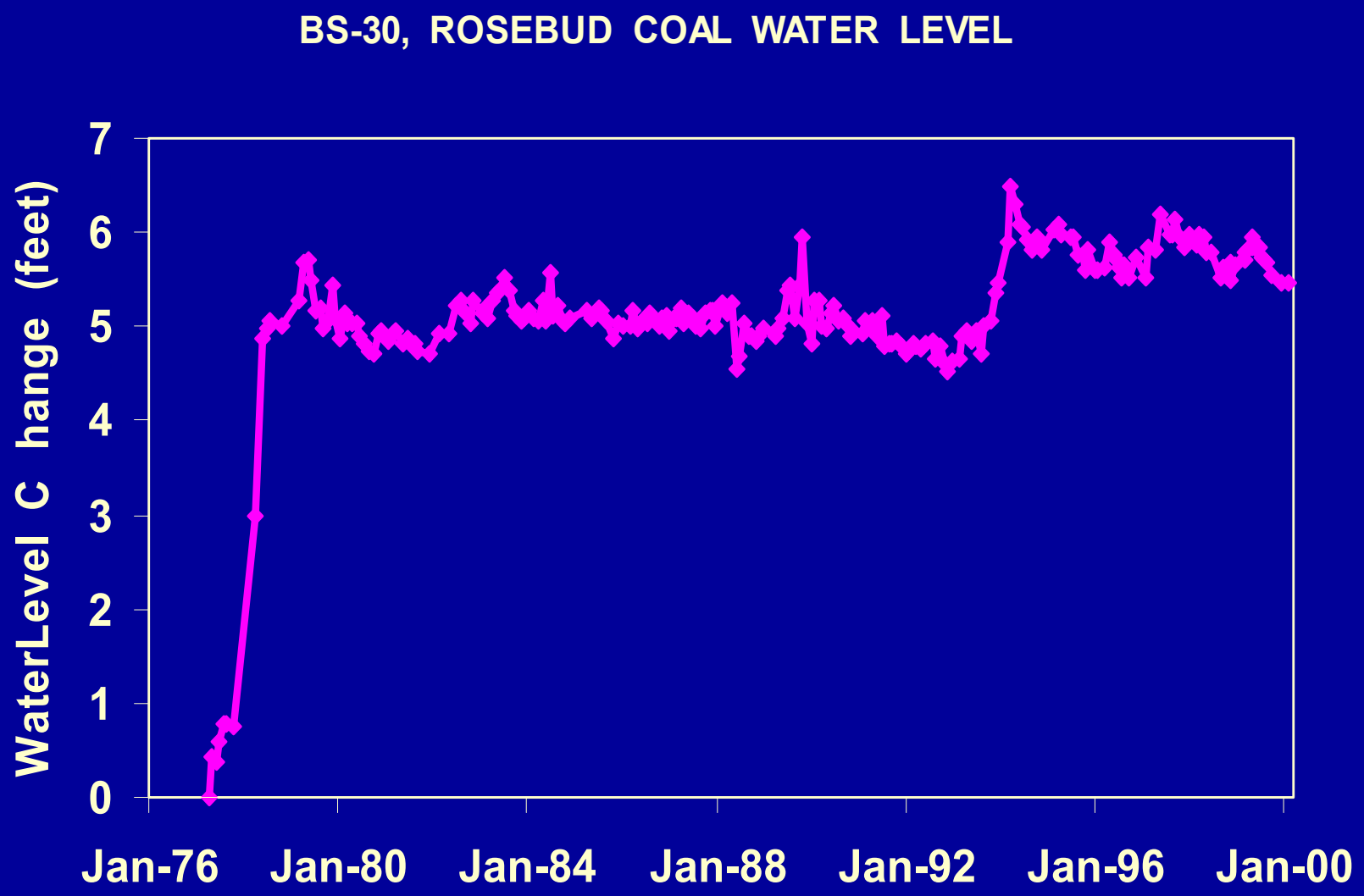


Figure 9. —For the 25-year period of record, ground-water level trends in the upgradient coal aquifer reflect natural seasonal variations since the end of reclamation in the 1970's.

Figure 10.—During the same period, ground-water level trends in the downgradient spoils aquifer have been similar to those measured in the upgradient aquifers.

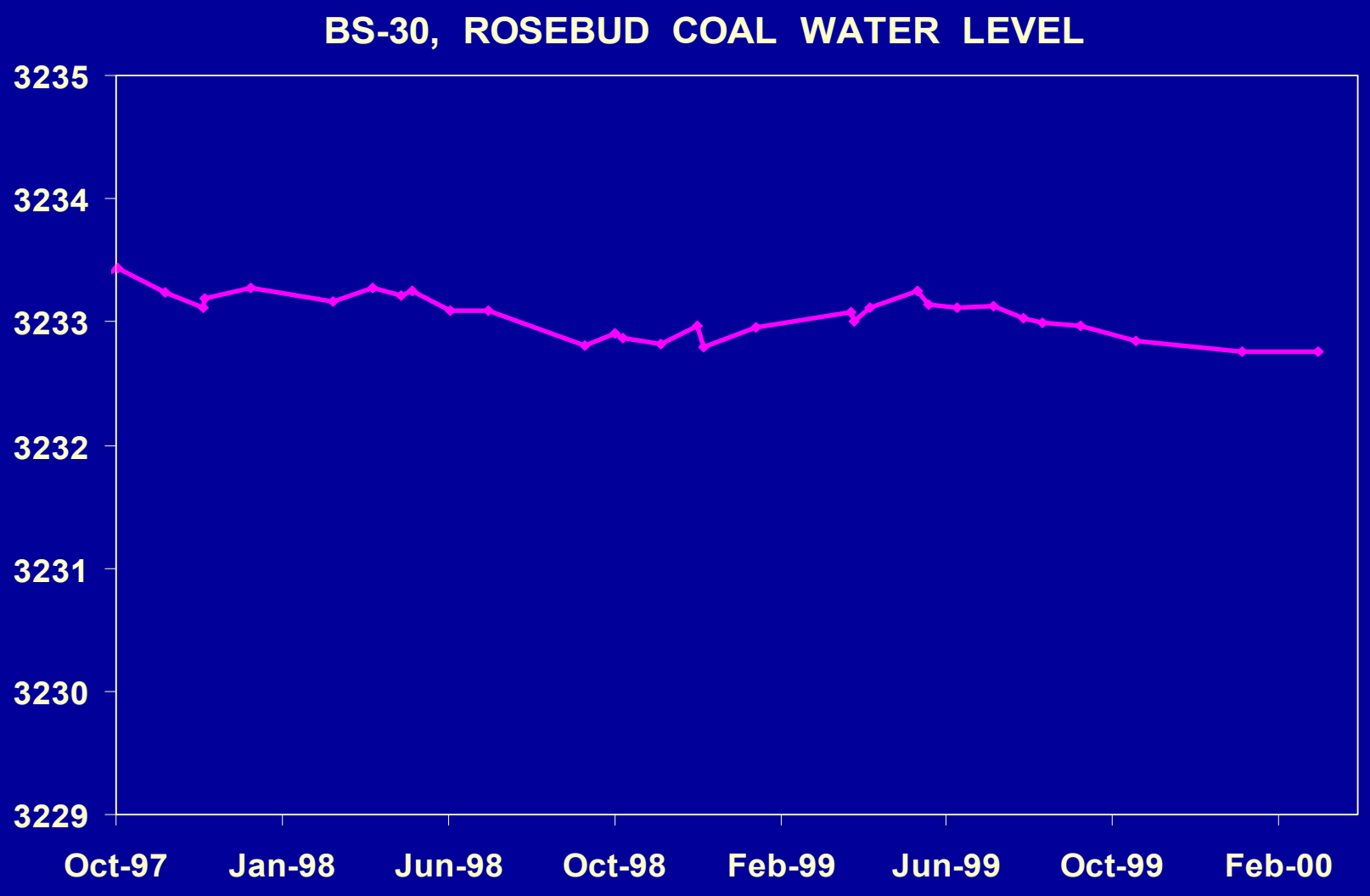


Figure 11.—During the duration of this study, seasonal variations were apparent in the water-level trend in the upgradient bedrock coal aquifer.

Figure 12.—Seasonal variations in the stage of pond A are greater in magnitude, but mimic those measured in the upgradient bedrock coal aquifer over the course of this study.

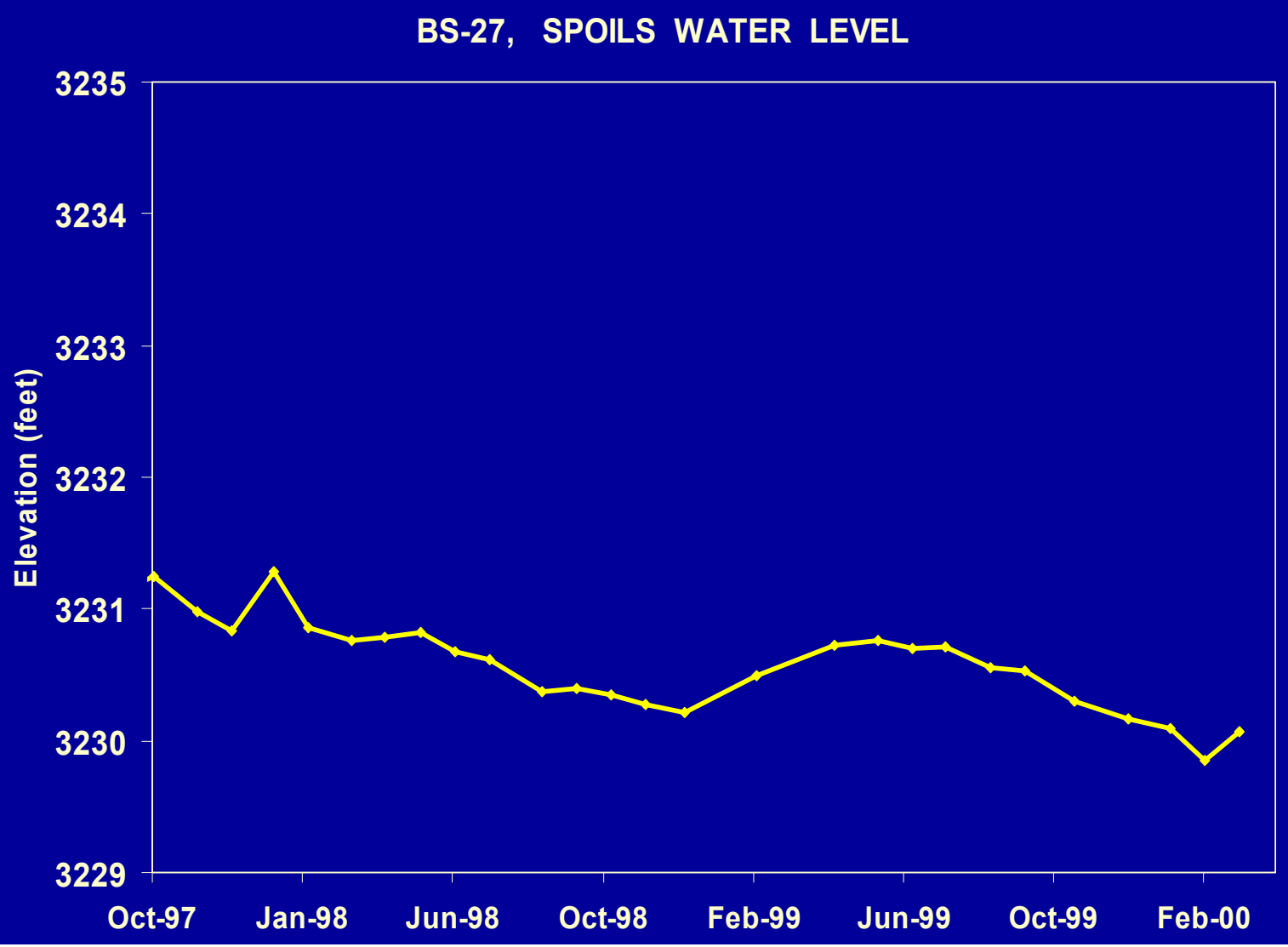


Figure 13.—Seasonal variations in the spoils aquifer are similar to those measured in the upgradient bedrock coal aquifer over the course of the study.

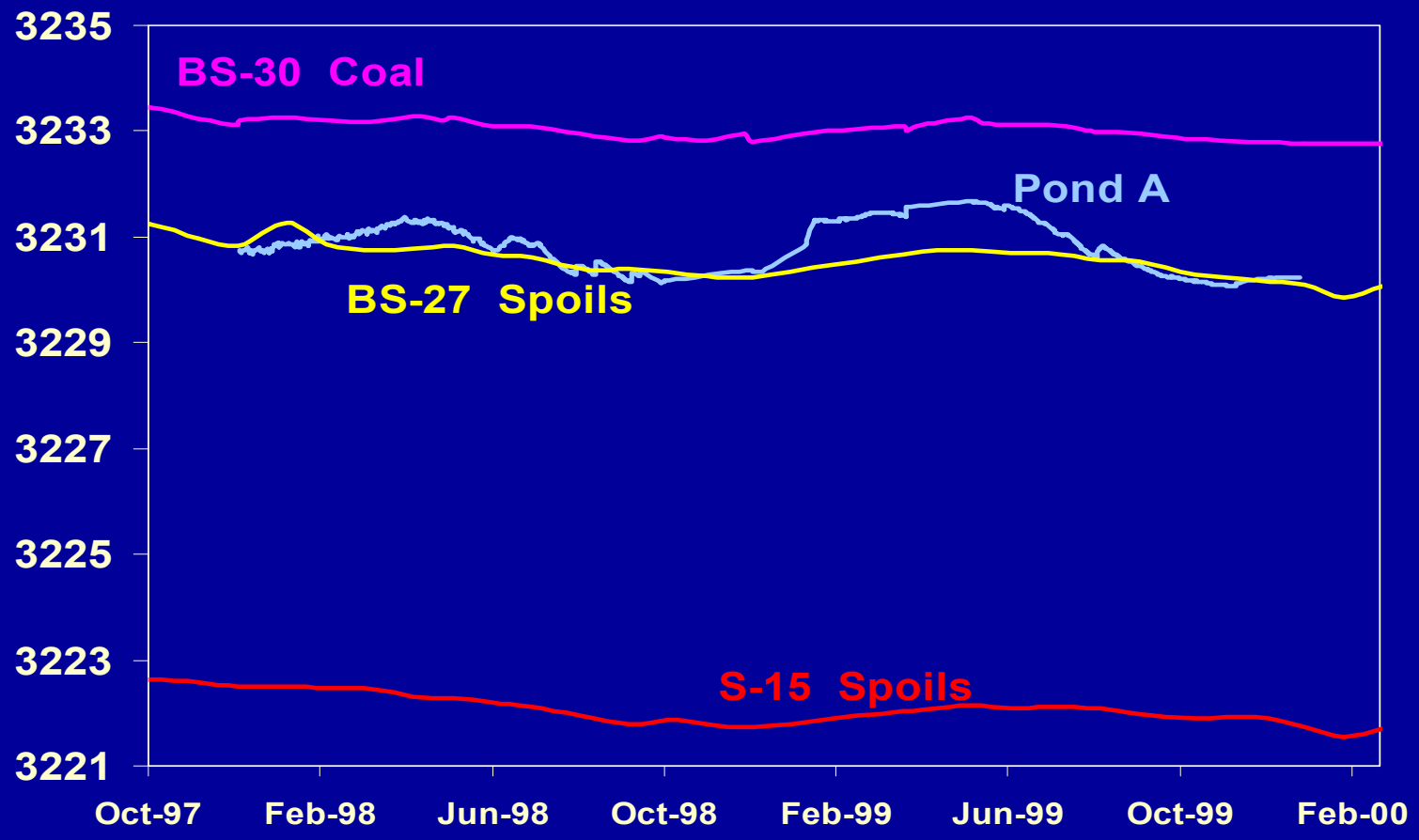


Figure 14.—Data from these wells, shown together, make apparent the similarity in seasonal trends. An additional spoils well, located further downgradient, has been added to this chart showing water-level altitude. All components of the hydrologic systems at pond A are closely related.

Cross-Section of Pond A, Water-Budget Components

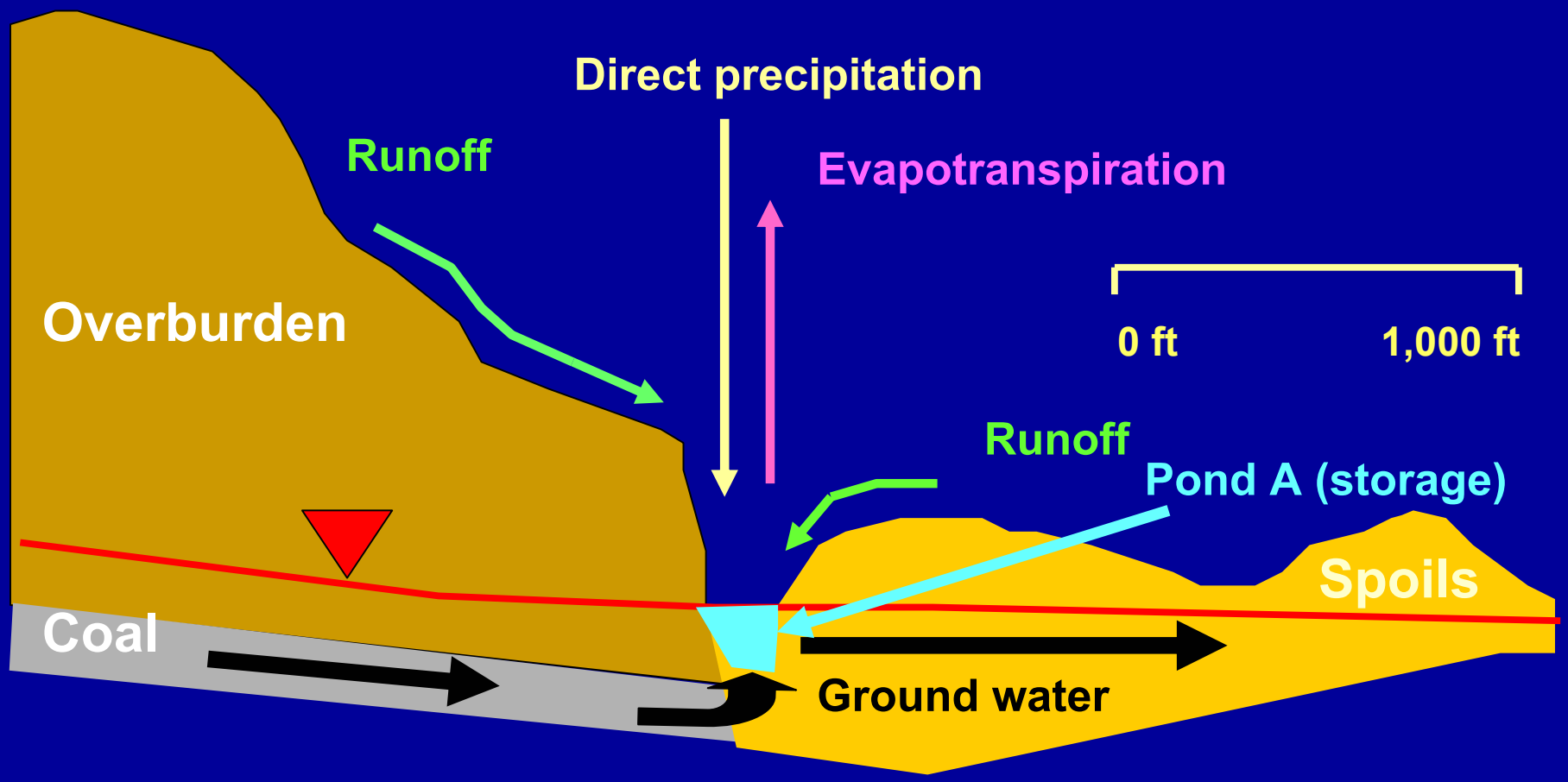


Figure 15.—The water budget components for pond A consist of surface water, ground water, and storage.

Water-Budget Equation

$$I_p + I_{sw} + I_{gw} = O_e + O_{gw} + S_d$$

I_{sw}	=	Runoff of surface water from native rangeland and reclaimed mine areas
I_{gw}	=	Ground-water inflow from bedrock aquifer
I_p	=	Precipitation falling on impoundment
O_e	=	Evaporation from impoundment surface
O_{gw}	=	Ground-water outflow to spoils aquifer
S_d	=	Change in storage

Figure 16.—The sum of inflows to the pond are equal to the sum of losses from the pond, plus or minus the change in the pond's storage capacity.

Table 1.--*Water-year 1999, water budget for pond A, Big Sky mine*

Inflow = "Outflow" +- Storage capacity

Precip + Runoff + Ground-water inflow = Evap + Ground-water outflow +- Storage

Month	Precipitation	Runoff	Ground-water inflow	Evaporation	Ground-water outflow	Storage	Total inflow	Total "outflow"
Oct-98	26,800	0	5,313	37,700	89	9,800	32,113	47,589
Nov-98	15,900	0	4,371	16,700	739	18,200	20,271	35,639
Dec-98	4,600	0	3,965	4,000	998	36,400	8,565	41,398
Jan-99	19,300	320,700	3,564	0	1,262	106,800	343,564	108,062
Feb-99	10,300	34,900	3,166	8,500	1,528	23,200	48,366	33,228
Mar-99	4,800	1,100	2,767	27,300	1,794	20,100	8,667	49,194
Apr-99	11,600	9,100	2,369	14,900	2,061	6,100	23,069	23,061
May-99	28,000	23,200	1,970	31,700	2,327	-10900	53,170	23,127
Jun-99	17,700	2,300	2,528	78,800	1,954	-41800	22,528	38,954
Jul-99	14,300	0	3,086	92,100	1,582	-82100	17,386	11,582
Aug-99	27,200	600	3,644	117,000	1,209	-31000	31,444	87,209
Sep-99	5,700	0	4,202	83,000	842	-46400	9,902	37,442
Annual total	186,200	391,900	40,945	511,700	16,385	8,400	619,045	536,485
Annual percentage of total budget	30%	63%	7%	95%	3%	2%	100%	100%
Percent of average pond volume	13%	27%	3%	36%	1%	1%	43%	37%

All units are cubic feet/month, except unit for "annual total," which is cubic-feet/year.

Figure 17.—Results of water-budget data indicate that surface runoff is the primary water input to the pond, and evaporation is the primary loss of water from the pond.

The Process for Determining Water Quality in Mine Pit Lakes

- Develop a simple geochemical mixing model that can be used to explain pit-lake chemistry

- Determine the physical and biogeochemical factors controlling pit-lake chemistry

- Prior to constructing further mine-pit impoundments, use information gained to develop tools that assist in the prediction of pit-lake chemistry

Figure 18.—Developing an understanding of the water quality in pond A, and using that understanding to identify the best methods to predict water quality in future mine-pit impoundments, was a three-step process.

Geochemical Model Development

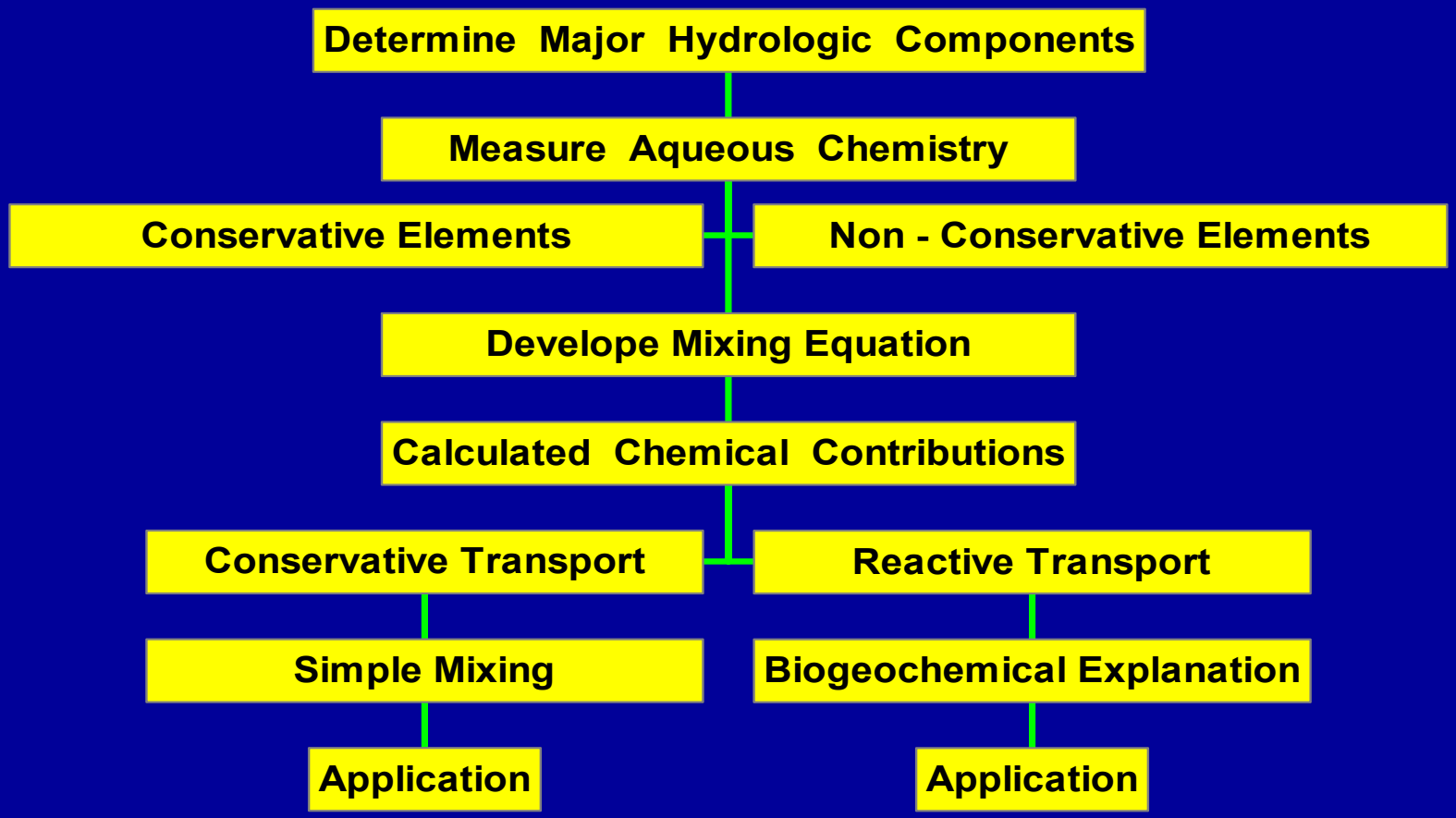


Figure 19.—The chemical model for pond A is based on data collected at the site.

Chemical Overview of Dissolved Metals In the Area-A Water System at Big Sky Mine

(concentrations are in mg/L)

	pH	SO_4	Mg	Ca	Na
Ground water	**6.9**	**1,900**	**370**	**370**	**160**
Surface runoff	**7.9**	**120**	**15**	**50**	**2.5**
Pond A	**8.0**	**1,400**	**300**	**125**	**100**

Figure 20.—Water quality in pond A is intermediate between that of upgradient ground water and that of surface water flowing into the pond, but is more similar to the former than to the latter.

Identifying Conservative Constituents

The correlations among concentrations of all measured components were tested using Pearson correlation coefficients and bivariate regression plots to help identify which constituents were probably not affected by chemical reactions along the flow paths.

The components found likely to be acting most conservatively were SO_4, Mg, and specific conductance. Each of these components correlated strongly with Cl^- and among each other.

Figure 21.—Chemical constituents that are least likely to be involved in reactions along the flow paths are termed "conservative" and were identified by comparing concentrations in samples.

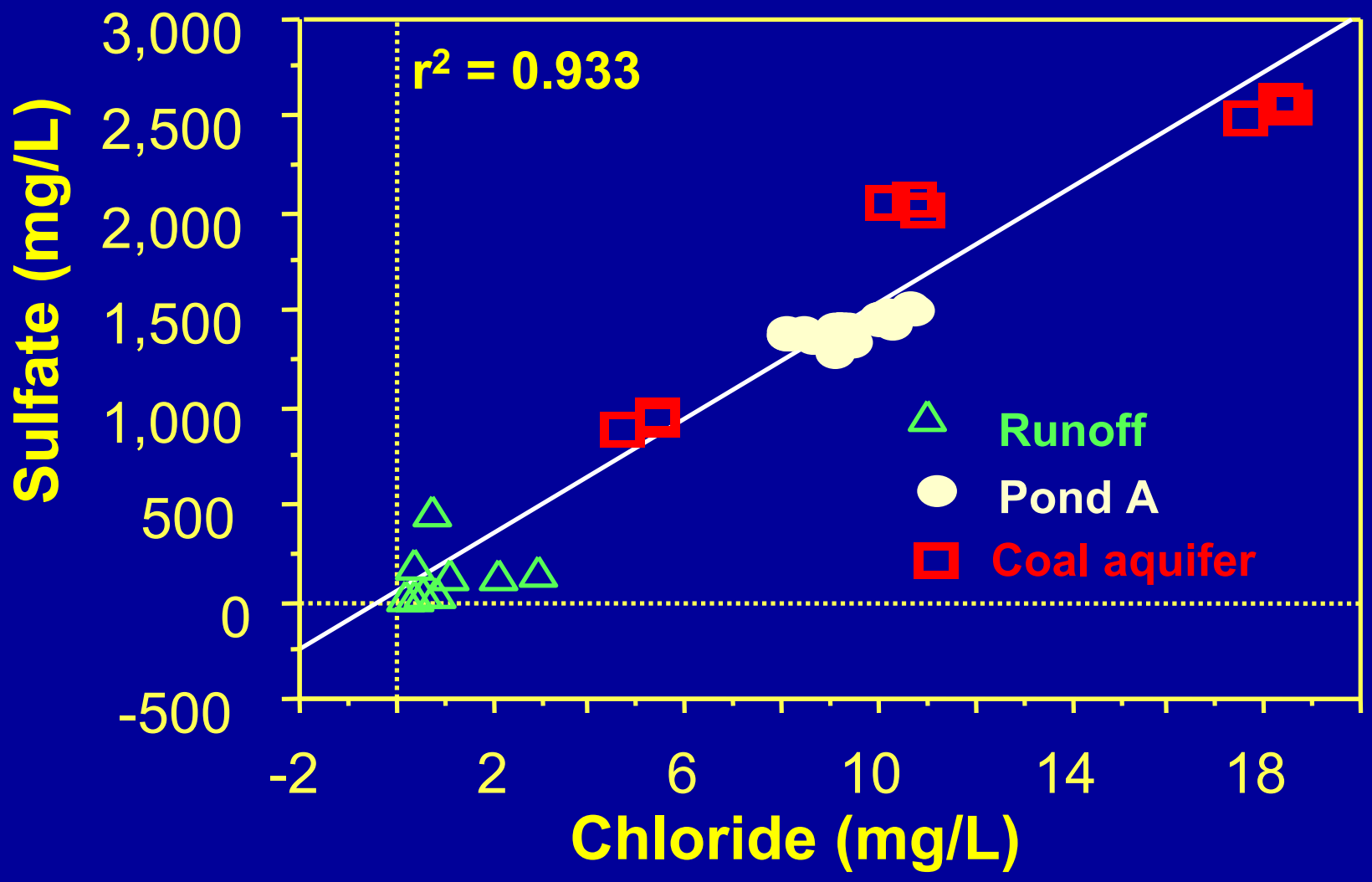


Figure 22.—A strong correlation exists between sulfate and chloride concentrations.

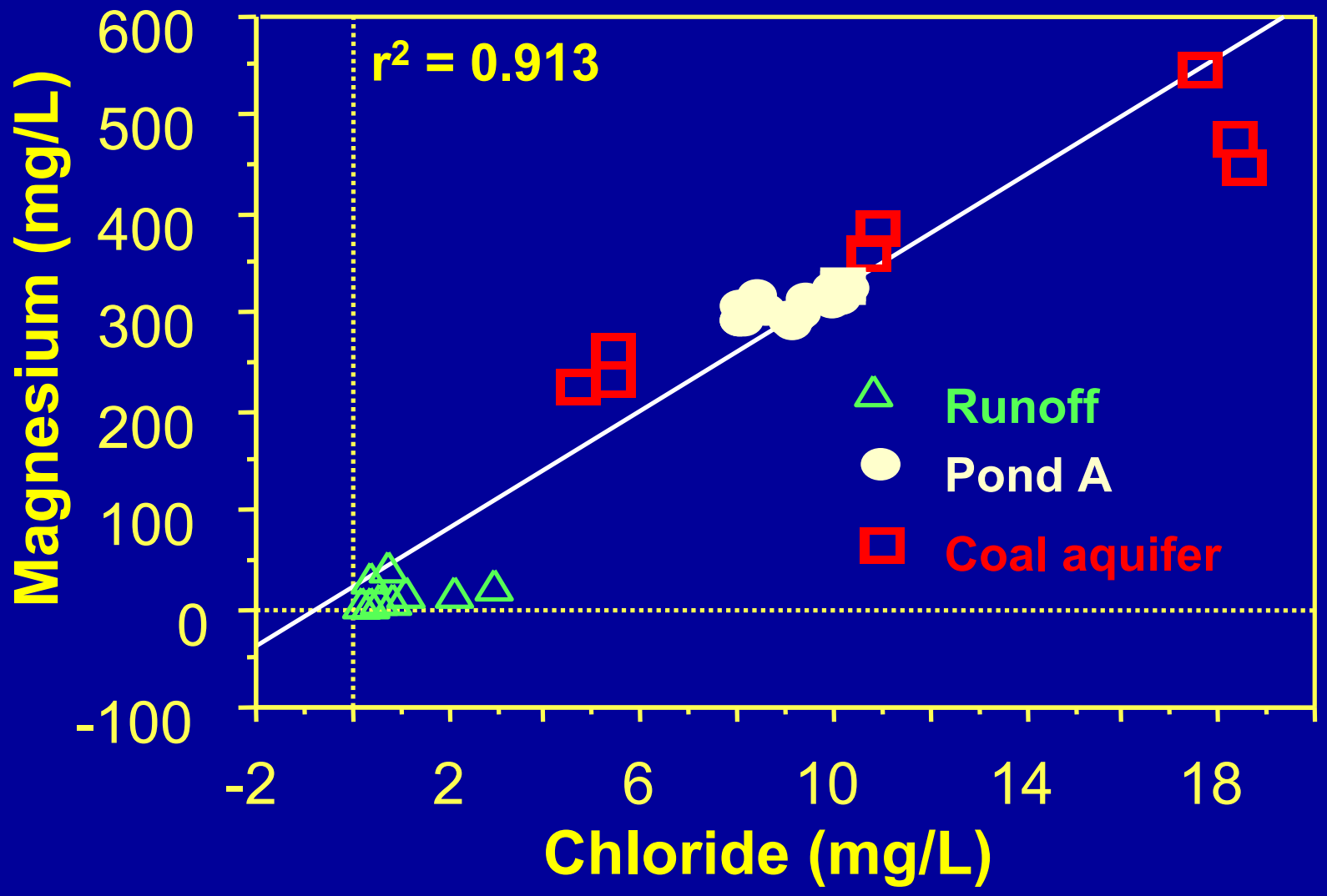


Figure 23.—A strong correlation also exists between magnesium and chloride concentrations.

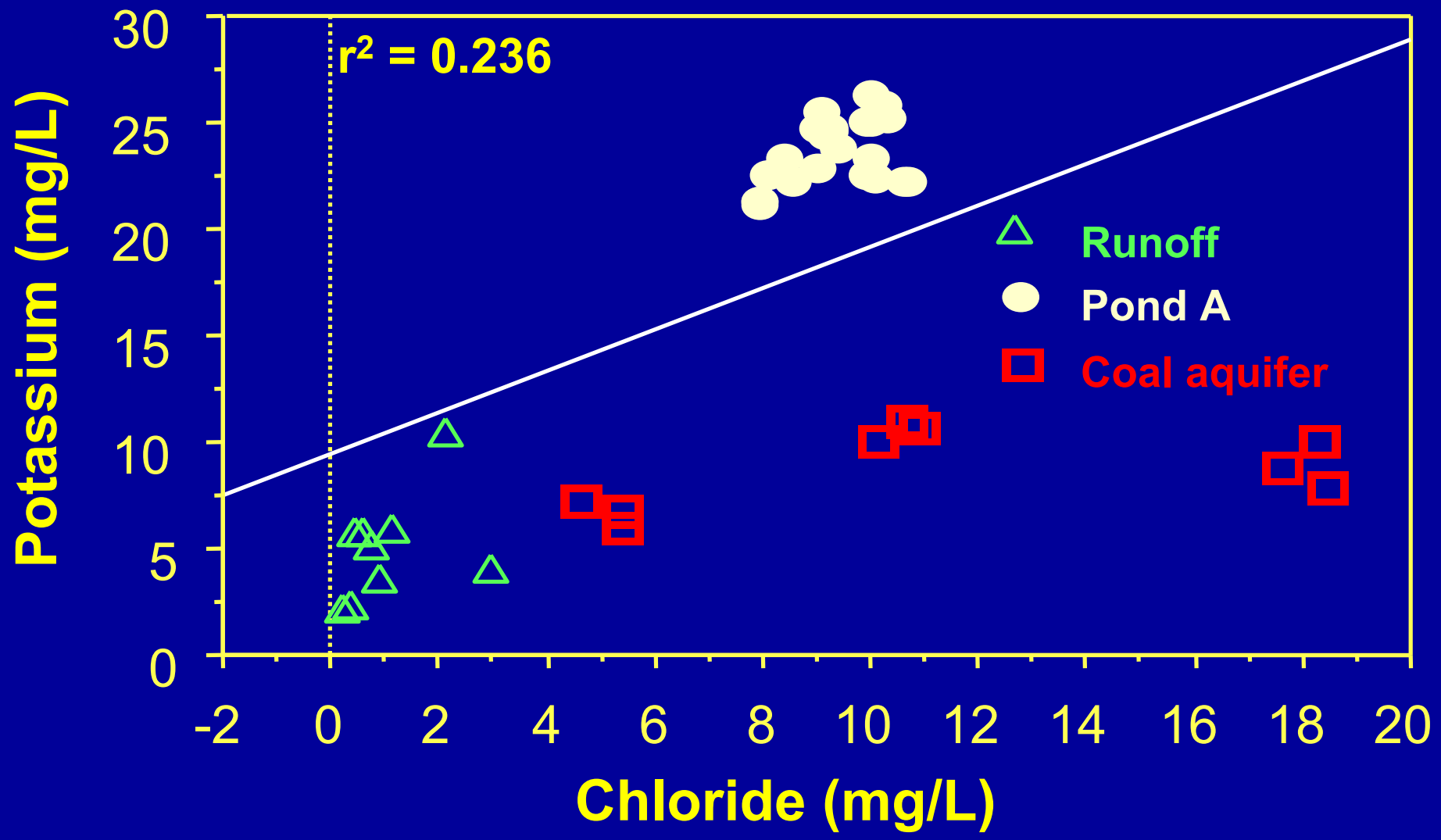


Figure 24.—No correlation exists between potassium and chloride concentrations.

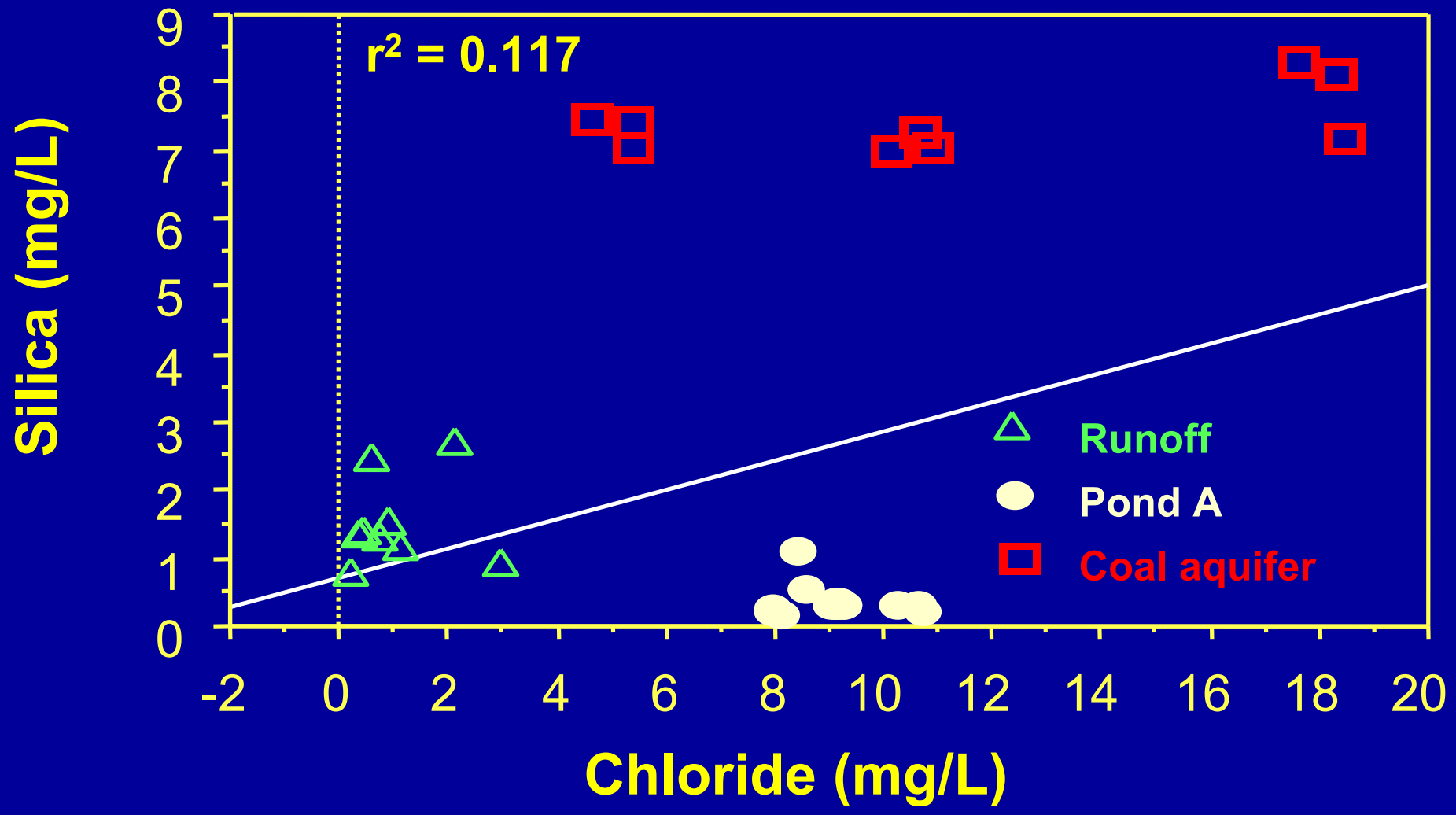


Figure 25.—No correlation exists between silica and chloride concentrations.

Mass-Balance Components at Pond A

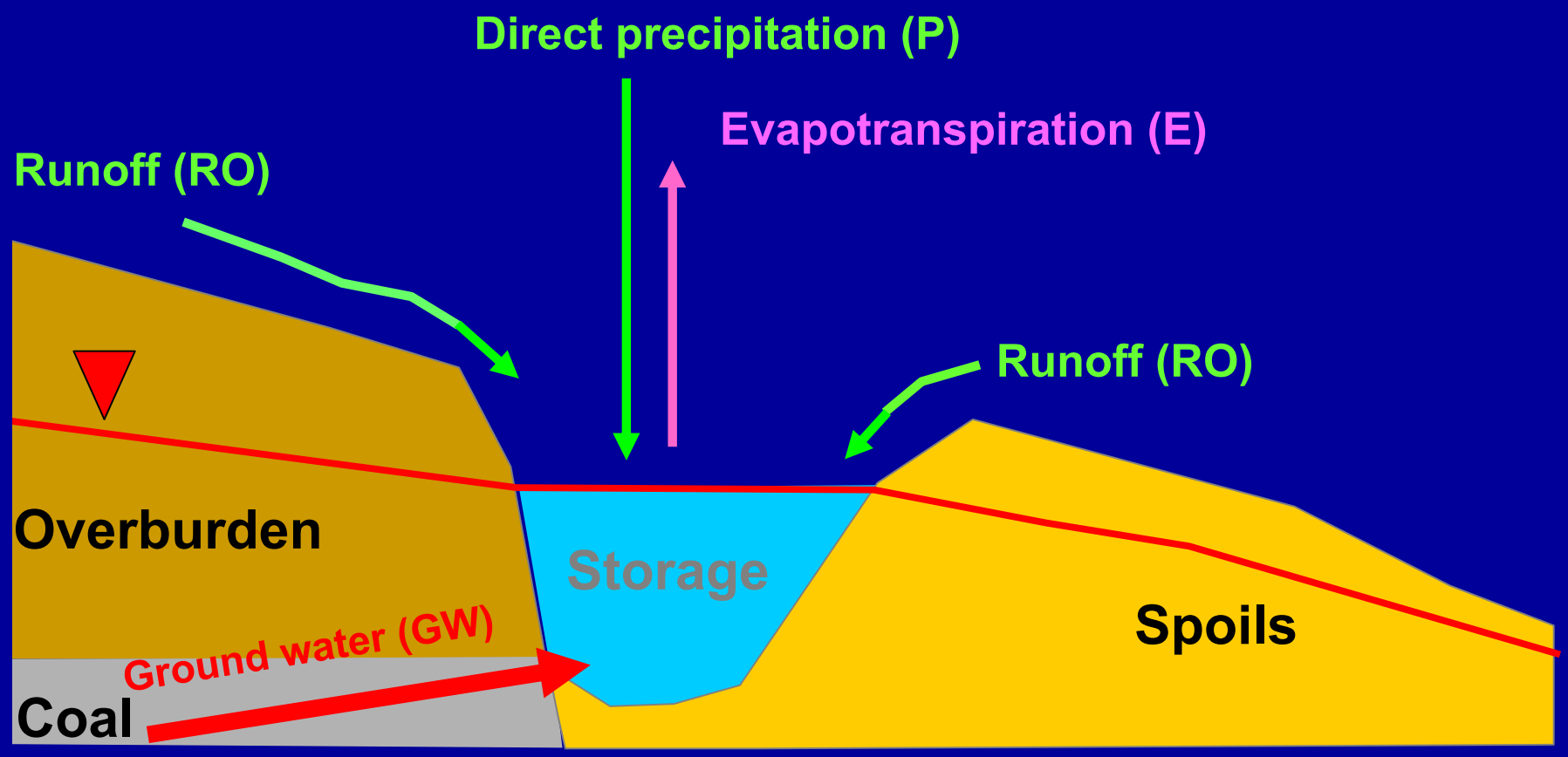


Figure 26.—For a simple mixing model, the quantity of water from each component of a flow system is determined from its water budget. The chemical concentrations are then mathematically mixed at a ratio equal to the ratio of inflow from each component. The water quality of the pond is dominated by inputs from ground water and surface-water runoff.

Simple Mixing Equation (Adjusted Inputs from Calculated Water Budget)

Inflow volumes for mixing equation are (all values are annual average):

GW + RO - Ee = PA, as follows:

GW = Ground-water inflow
RO = Runoff inflow, surface water
Ee = Effective evaporation (evaporation – precipitation)
PA = Total inflow to pond A

Figure 27.—In a simple mixing model, the concentration of a specific constituent in a pond (in our case, PA) is calculated by summing the concentrations from ground water (GW) and surface runoff (RO) in proportion to their respective input percentages from the water budget. The concentrations are increased by reducing the total water inflow by the amount lost to evaporation. For an existing pond, the equation can be rearranged to calculate the water-budget input percentages from water-quality concentrations, if the water quantity (but not the water quality) is known.

Simple Mixing Equation, Calculated Using Annual Averages of GW, RO, and Pond-A Chemistry

$[GW_E]\ X\ \% + [RO_E]\ Y\ \% = [PA_E]$

Mixing-model equation, calculating pond-A concentrations by mixing inflow concentrations using the inflow percentage contributions

Inflow percentages:

$X\% = (GW / [GW + RO - Ee])$

Percentage contribution from ground water, adjusted for evaporation loss from the pond

$Y\% = (RO / [GW + RO - Ee])$

Percentage contribution from runoff, adjusted for evaporation loss from the pond

$Y\ \% + X\ \% = 100\ \%$

Figure 28.—In a simple mixing model, the concentration of a specific constituent in a pond (in our case, PA) is calculated by summing the concentrations from GW and RO in proportion to their respective input percentages from the water budget (X and Y = percentages for GW and RO, respectively). The equation can be rearranged to calculate the water-budget input percentages, from water-quality concentrations, by inputting constituent concentrations and solving for X and Y.

Mixing-Model Results

Inflow source	Inflow (%)	Adjusted Ca (meq/L)	Adjusted Mg (meq/L)	Adjusted Na (meq/L)	Adjusted SO4 (meq/L)	Adjusted HCO3 (meq/L)	Adjusted SC (umhos/cm)	Adjusted CDS (mg/L)	Adjusted Cl (meq/L)
Precipitation	30%	0.0	0.0	0.0	0.0	0.1	4.9	3.2	0.0
Surface runoff	63%	1.7	0.7	0.1	1.6	1.0	220.9	141.4	0.0
Coal aquifer	6.5%	1.2	2.0	0.4	2.5	1.0	252.2	238.2	0.0
Spoils aquifer	0.1%	0.0	0.0	0.0	0.0	0.0	3.3	3.9	0.0
Total inflow concentration	100%	2.9	2.7	0.5	4.2	2.0	481	387	0.1
Total inflow concentration, corrected for 82-percent evapo-concentration		16.2	15.2	2.9	23.2	11.2	2674	2148	0.3
Pond A, average measured values		6.2	25.1	4.3	29.4	6.2	2184	2363	0.3

gure 29.—Results of the mixing model, corrected for evapo-concentration, indicate that it is a useful tool for estimating final pit-impoundmen water quality. Adjusted values for concentrations of constituents in water flowing into this pond are derived from actual laborator data, multiplied by the percentage inflow for each parameter as calculated from the water budget. For example, the adjusted calcium concentration contributed from the coal aquifer is the average from all coal water-quality samples, multiplied by 6.5 percent (the proportion of total inflow that is estimated to come from the coal aquifer). The constituent contributions are summe to calculate the concentration of total inflow to the pond; the concentration is then increased to adjust for evapo-concentration b reducing the volume of water by 82 percent (divided by 12 percent). For comparison, the average measured concentrations of these constituents are listed for pond A.

	Major Biogeochemical Controls		
Element	Simple Mixing (Dilution)	Simple Mixing (Concentration)	Mixing and Chem. Rxn's
Cl^-, SC, Mg, SO_4, Na, Li	X		
Calcium, TIC, Alkalinity			Calcite Precipitation
Barium			Barite Precipitation
Strontium			Coprecipitation
Boron			Coprecipitation
Manganese	X		Redox
Silica			Removal by Diatoms
Potassium			Cation Exchange
Zinc and Iron			Metal Sulfide Precipitation

Figure 30.—Simple mixing of inflow water is not the only control on pond-water quality. Several reactions are apparent, based on measured water quality in the pond.

Likely Fate of Fe^{2+} and Zn^{2+} at Pond A

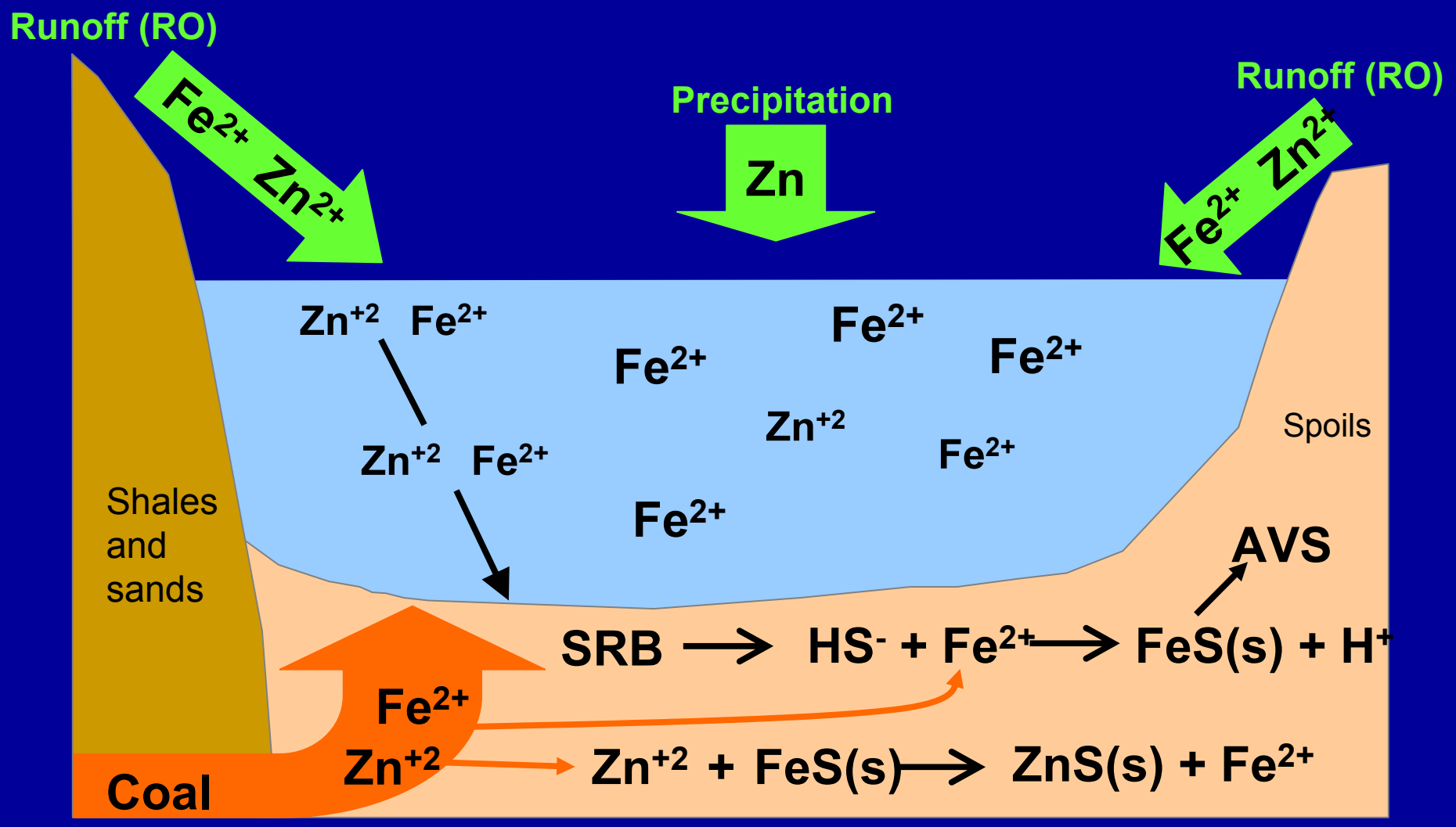


Figure 31.—Metal sulfides precipitate in the sediments of pond A, reducing the concentrations of these metals in the water column (AVS = acid-volatile sulfur; SRB = sulfate-reducing bacteria).

Likely Fate of Silica as Silicon (H_4SiO_4)

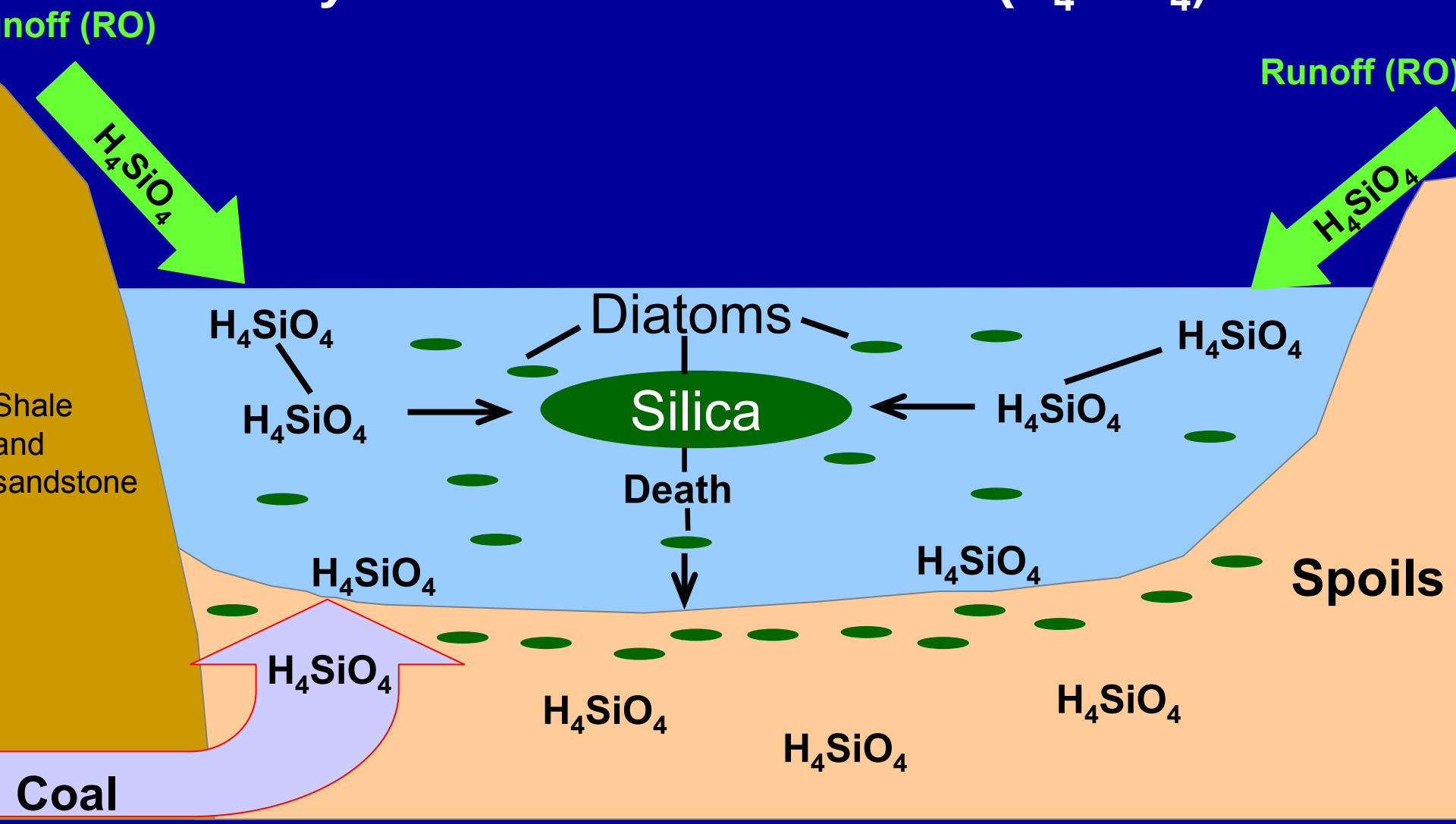


Figure 32.—The concentration of silica in pond water is reduced by diatoms. The diatoms take up the silica and, upon death, fall to the pond floor, depositing it in the sediments.

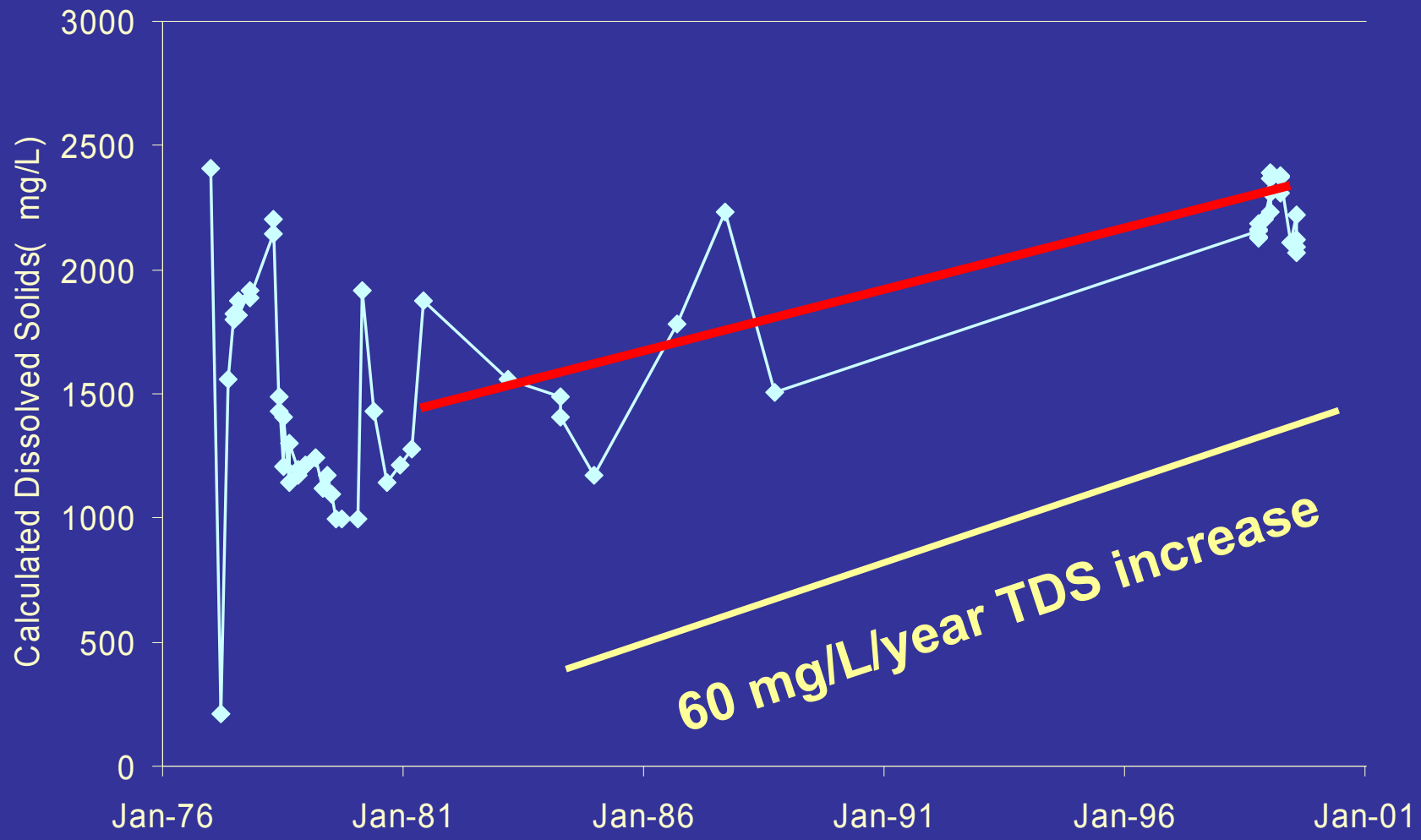


Figure 33.—The total dissolved solids (TDS) concentration in water samples from pond A show a slow increase over time since reclamation was completed in the 1980's (this linear regression is shown by the red line). An annual 60 mg/L increase in TDS concentrations was calculated on the basis of the simple concentrating effects of evaporation, using a loss of 500,000 ft^3 or about 36 percent of the total pond volume. The slope of this increase is indicated by the yellow line. These data support the need for including evapoconcentration in the mixing model.

Mine Pits and Stock Ponds in Southeastern Montana

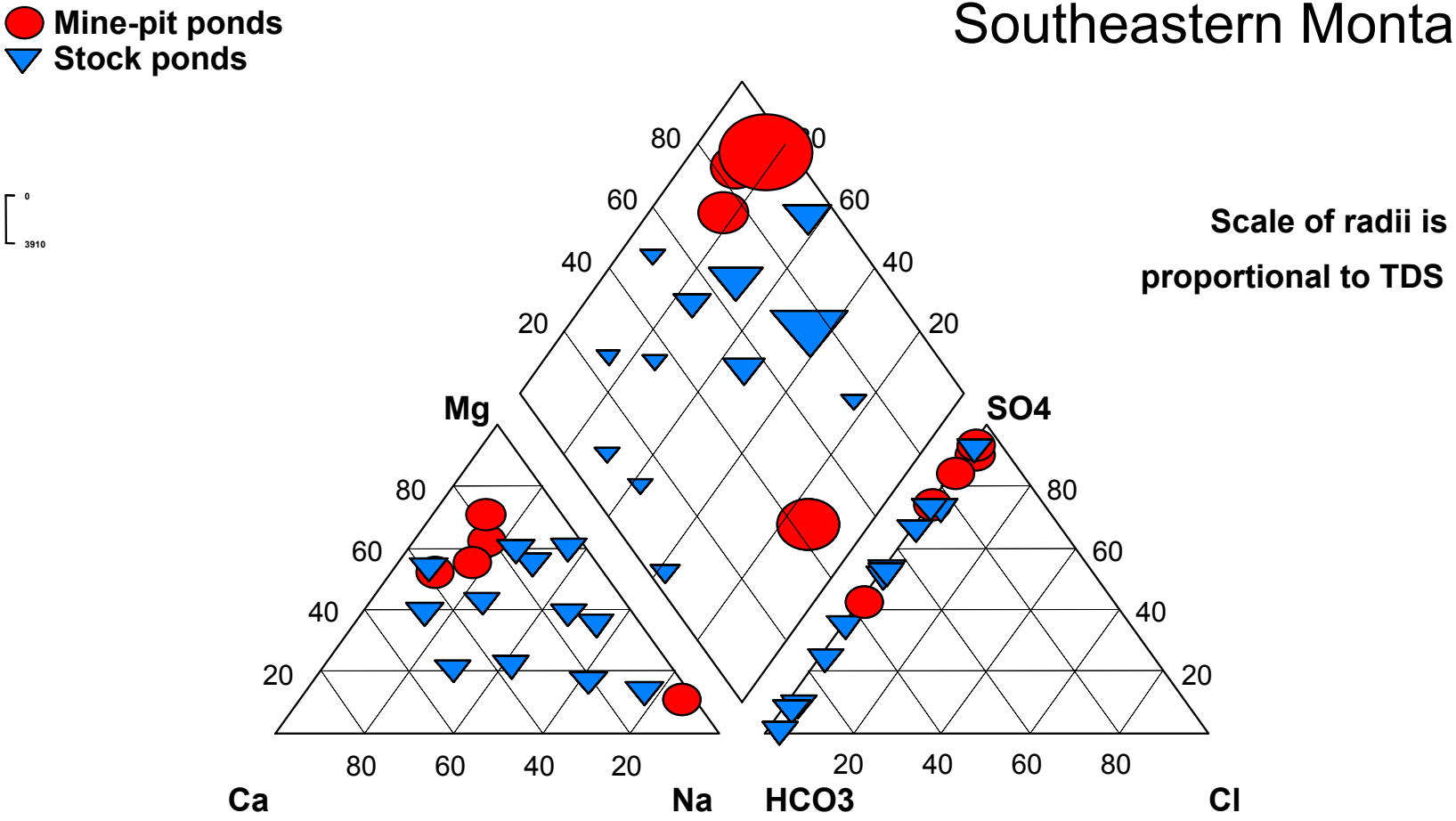


Figure 34.—TDS concentrations are generally somewhat greater in mine pits in Montana than in traditional stock ponds, even though water quality in these pits compares favorably with stock-pond quality.

Conclusions

Specific conclusions relative to pond A:

- The water budget for pond A is controlled primarily by surface runoff and evaporation
- Evaporation loss is a large percentage of the total volume of the pond
- Inflow from the coal aquifer provides stability to the water level in pond A
- The chemical composition of the pond reflects that both runoff and ground water affect pond chemistry through simple mixing
- Biogeochemical reactions alter pond-A chemistry by removing dissolved elements from the water column

Conclusions—continued

Specific conclusions relative to pond A—continued:

- Water quality can be estimated using a mixing model
- More complex chemical reactions need to be considered, but can be included by using more complex modeling or calculations
- Final-pit impoundment designs must be based on a watershed approach

General conclusion:

- Successful final-pit impoundments can be designed and constructed and will provide valuable water resources in postmined reclaimed landscape