

DP-1840 Copper Flats Project Hearing Testimony

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Short Bio: Kenneth C. Carroll

Education:

- Ph.D., University of Arizona (UA)
 - Major: Hydrology and Water Resources
 - Minor: Soil, Water, and Environmental Science (SWES)
- M.S., Ohio University
 - Major: Aqueous/Environmental Geochemistry
- B.S., Ohio University (OU)
 - Major: Geological Sciences

Experience:

- 2017 – Present: Associate Professor: Plant & Environmental Sciences Department NMSU
- 2013 – 2017: Assistant Professor: Plant & Environmental Sciences Department NMSU
- 2010 – 2013: Research Scientist: Environmental Systems Group at Pacific Northwest National Laboratory (PNNL)
- 2007 – 2010: Postdoctoral Researcher/Laboratory Manager: UA SWES Department
- 2003 – 2007: Hydrogeologist and Geochemist: Water Management Consultants and Hydro Geo Chem, Inc.

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Selected and Relevant Publications:

- Tian-Chyi J. Yeh, Raz Khaleel, and K.C. Carroll (2015) Flow Through Heterogeneous Geologic Media, Cambridge University Press. ISBN: 9781107076136.
- Miao, Z., C. Carreon-Diazconti, K.C. Carroll, and M.L. Brusseau (2014) The Impact of Biostimulation on the Fate of Sulfate and Associated Sulfur Dynamics in Groundwater. *Journal of Contaminant Hydrology*, 164(August): 240–250.
- Miao, Z., K.C. Carroll, and M.L. Brusseau (2013) Characterization and Quantification of Groundwater Sulfate Sources at a Mining Site in an Arid Climate: The Monument Valley Site in Arizona, USA. *Journal of Hydrology*, 504: 207–215.
- Miao, Z., M.L. Brusseau, K.C. Carroll, C. Carreón Diazconti, and B. Johnson (2012) Sulfate Reduction in Groundwater: Characterization and Applications for Remediation. *Environmental Geochemistry and Health*, 34(4): 539-550.
- Borden, A.K., M.L. Brusseau, K.C. Carroll, N.H. Akyol, A. McMillan, J. Berkompas, Z. Miao, F. Jordan, G. Tick, W.J. Waugh, and E.P. Glenn (2012) Ethanol Addition for Enhancing Denitrification at the Uranium Mill Tailing Site in Monument Valley, Arizona. *Water, Air, & Soil Pollution*, 223: 755–763.
- Carroll, K.C., F.L. Jordan, E.P. Glenn, J. Waugh, and M.L. Brusseau (2009) Comparison of Nitrate Attenuation Characterization Methods at the Uranium Mill Tailings Site in Monument Valley, Arizona. *Journal of Hydrology*, 378: 72–81.
- Johnson, B., and K.C. Carroll (2007) Waste Rock Backfill of Open Pits: Design, Optimization, and Modeling Considerations. In *Mine Closure 2007, Conference Proceedings*, Santiago, Chile, October 16-19.
- Carroll, K.C., D.L. López, and M.W. Stoertz (2003) Solute Transport at Low Flow in an Acid Stream in Appalachian Ohio. *Water, Air, & Soil Pollution*, 144: 195-222.
- López, D.L., B. Overly, E.I. Robbins, and K.C. Carroll (1999) The Role of Flow Regime on the Chemical Evolution of Acidic Waters Discharged from an Abandoned Underground Coal Mine. In *Sudbury 99 Mining and the Environment II, Conference Proceedings*, Sudbury, Ontario, Canada, Sept. 12-16, 1, pp. 89-98.

DP-1840 Opinions:

- Current pit lake has been proven to be impacted by ARD (i.e., acid rock drainage and/or mine impacted water) generated from pit walls from 3 months of mining in 1980s. This type of material will also be in the future pit lake and in the waste rock stockpiles (WRSP).
- *Proposed permit condition:* Underlining liners and overlying covers (both low permeability materials) for WRSPs outside of open pit hydraulic sink should be installed as part of closure/reclamation.
- Current groundwater has been proven to be impacted by ARD or mine impacted discharge from 3 months of mining in 1980s. Discharge of ARD or mine impacted discharge from mine facilities outside of open pit hydraulic sink occurred in the past, and is likely to occur during proposed mining.
- *Proposed permit condition:* Underlining liners and overlying covers (both low permeability materials) for tailings storage facility (TSF) outside of open pit hydraulic sink should be installed as part of closure/reclamation.
- Current reclamation plan will remove all mine impacted water collection impoundments, and will not include contaminated groundwater interceptor system. However, existing groundwater has been contaminated, and has not been abated.
- *Proposed permit condition:* Include groundwater interceptor system to abate current and future migration of groundwater contamination, and include mine impacted water collection impoundments for any discharge from WRSPs and TSF. Add monitoring wells to assess nature/extent of plume.
- Aquifer assessment did not consider uncertainty in either hydrogeologic or geochemical modeling input data, which limits groundwater impact predictive capability.
- *Proposed permit condition:* Include full range of geochemical and hydrogeologic data in aquifer assessment predictions.
- Appropriate financial considerations should include long-term closure and contamination cleanup.

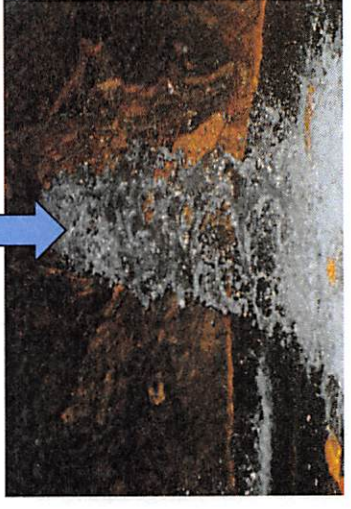
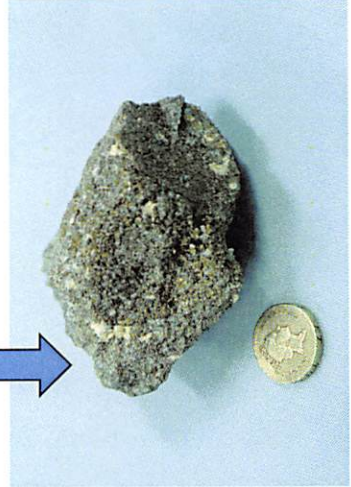
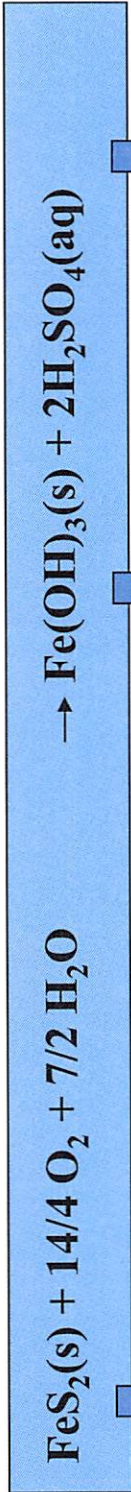
ARD: Acid Rock Discharge

- The generation of H+ involves mainly sulfide minerals (FeS₂), *pyrrhotite* (Fe_(1-x)S_x), and *marcasite* (FeS₂) e.g. pyrite

GENERAL CONCEPT

The process of pyrite oxidation involves 3 components:

- Sulfide Mineral
- O₂
- H₂O



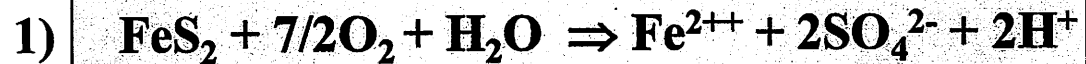
Oxidation of Pyrite

In reality, the reactions between FeS_2 and O_2 will involve the oxidation of 2 discrete components:

1) Fe^{2+}

2) S-sulfide

Fe^{2+} dissolves from pyrite in acid environments, and maintains a reduced form (aqueous) due to the kinetic controls oxidation. A more realistic preliminary phase in the pyrite oxidation is:

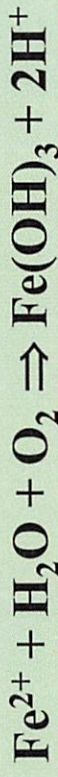


This process produces acidity, but the SO_4 and Fe^{2+} production is more important in the context of the final pH of water.

ARD and Iron Oxidation

The production of Fe^{2+} facilitates a chain of reactions that produces protons:

2) Hydrolysis of Fe^{2+}



3) Oxidation of Fe^{2+}



4) Hydrolysis of Fe^{3+}



5) Oxidation by Fe^{3+}



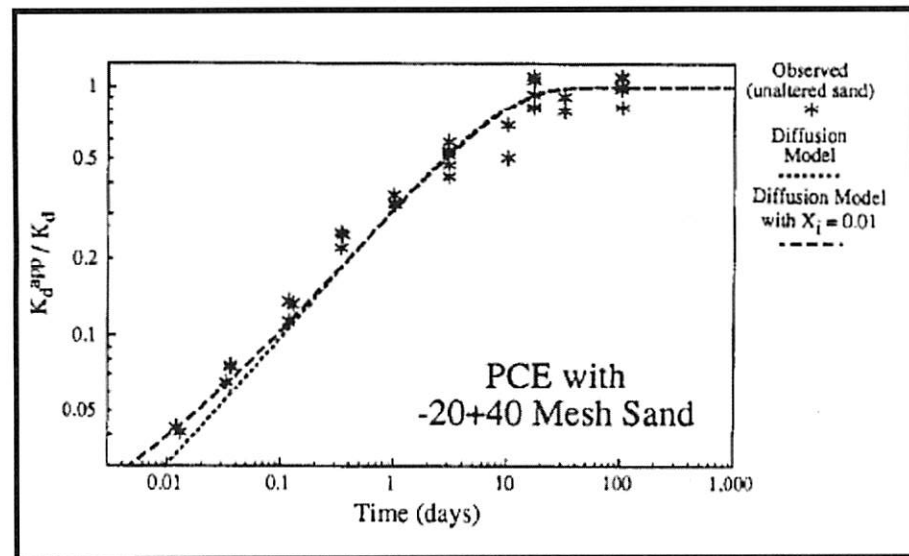
Rates (2) and (3) are controlled by (1)

Rates (4) and (5) are controlled by (3)

Rate-Limited Processes

- Many chemical and mass-transfer processes in natural systems do not obtain equilibrium instantaneously, but are **rate-limited**.
- Therefore, equilibrium can be used to predict long-term contaminant concentrations (assumes reactions have enough time to complete).
- However, *kinetics* can be used to predict the time-dependence of the chemical reaction as it proceeds toward equilibrium.

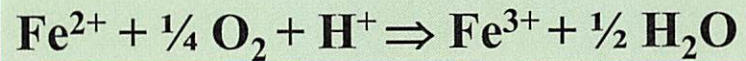
Example: Rate-limited sorption of PCE to soil may take 10 to 100 days to reach equilibrium



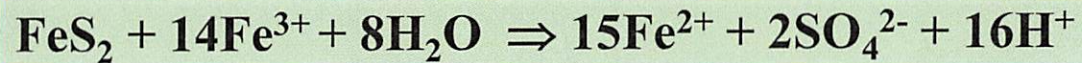
K_d (sorption equilibrium coeff.) as a function of time for PCE and a Canadian soil. From Ball and Roberts (1991).

Main Kinetic Constraints

- Based on kinetics of reaction: the oxidation rates (abiotic) of Fe^{2+} , and of FeS_2 oxidation by Fe^{3+} are the following:



$$3 \times 10^{-12} \text{ mol kg}^{-1} \text{ s}^{-1}$$



$$2 \times 10^{-8} \text{ mol kg}^{-1} \text{ s}^{-1}$$

- The first reaction is the source of Fe^{3+} for the second reaction.
- Bacterially mediated pyrite oxidation by Fe^{3+} is faster than abiotic oxidation by oxygen (*Nordrom & Alpers, 1999*)

Role of Secondary Sulfates

The formation of sulfate minerals from ARD produces a deposit of stored acidity. For example:



Sulfate minerals may form after pyrite is oxidized. Part of the sulfate is immobilized as a non-hydrolyzed sulfate, which is only partially oxidized.

The dissolution of minerals like *Jarosite* produce a secondary source of ARD.



Carbonate Mineral Reactions and Acid Neutralization

General concept



Calcite dissolution by sulfuric acid



Calcite dissolution by sulfuric acid combined
with the oxidation of pyrite



Acid Neutralization

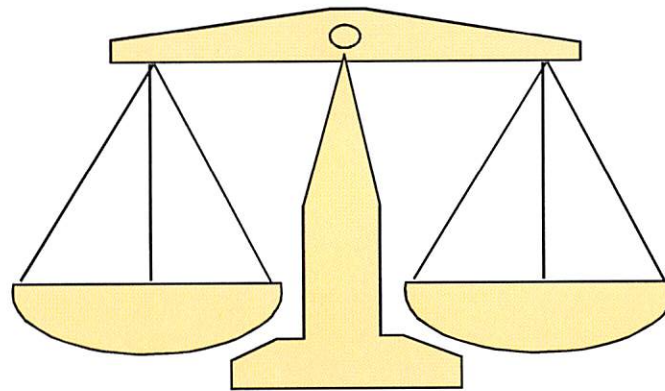
Sulfides generating ARD typically co-exist with minerals that can consume acid through dissolution reactions.

Therefore, the final pH of ARD is a balance between:



Acid producers:

Sulfides
Sulfates



Acid consumers

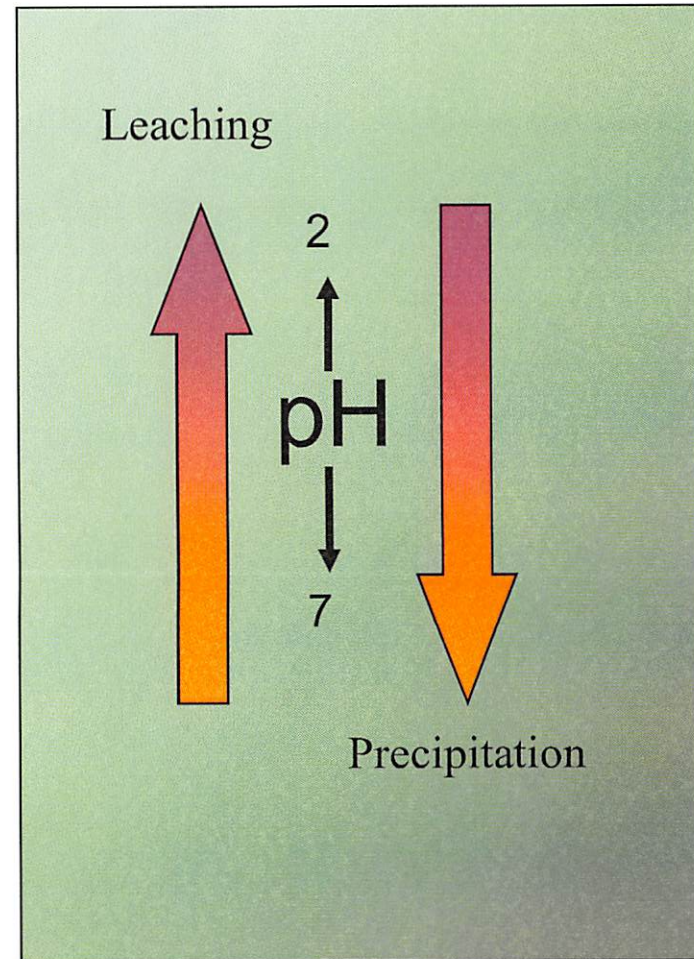
Carbonates
Some Silicates
Hydroxides

**Final Water
Chemistry**

Mobilization of Metals

Other metals, in addition to iron, mobilize through the oxidation of sulfur (ZnS or PbS). Also, the solubility of many metals increases at low pH values.

ARD is a solution of high reactivity. It can leach metals from many primary and secondary minerals, which increases the total dissolved solids.



However, some contaminants leached with acid remain soluble and potentially mobile even after neutralization (i.e., mine impacted water).

Gold King Mine

On August 5, 2015, an EPA team investigating the Gold King Mine as a source of metals inadvertently triggered a release of 3 million gallons of acidic, mine-influenced waters into the Animas River (EPA, 2016). EPA dedicated >\$29 million by 2016 for cleanup including areas in Colorado and New Mexico.



Exhibit 16—EPA, 2016. One Year After the Gold King Mine Incident A Retrospective of EPA’s Efforts To Restore and Protect Impacted Communities, 23 pg.

<https://lastrealindians.com/gold-king-mine-spill-investigators-were-ordered-to-stay-clear-of-the-u-s-epas-negligence-navajo-nation-responds/>

A Few Other NM Mines

- Chino: ~14000 acre groundwater plume
- Cobre: ~528 acre groundwater plume
- Tyrone: ~6280 acre groundwater plume

- Report notes that concentrations at some groundwater well locations have not decreased in over 20 years, and report suggests groundwater contamination will last for at least 100 years.

Table 1-2: Existing Pit Lake Chemistry (1989 – 2017)

Parameter	Units	n	Average	Minimum	Maximum
pH	s.u.	47	6.5	3.6	8.3
TDS	mg/L	56	7,538	2,711	14,800
Bicarbonate	mg/L	37	40.4	<3	122
Sulfate	mg/L	55	4,803	1,566	8,690
Chloride	mg/L	55	332	47.3	730
Fluoride	mg/L	33	19.2	4.8	34
Calcium	mg/L	37	550	455	684
Magnesium	mg/L	37	698	43	1,120
Sodium	mg/L	37	888	165	1,400
Potassium	mg/L	37	32.1	11	60.6
Aluminum	mg/L	33	10.4	<0.02	82.6
Antimony	mg/L	7		<0.001*	
Arsenic	mg/L	10	0.004	<0.001	0.006
Boron	mg/L	9	0.14	<0.1	0.2
Cadmium	mg/L	35	0.05	<0.005	0.1
Chromium	mg/L	11	0.03	<0.006	0.1
Cobalt	mg/L	32	0.29	<0.05	0.49
Copper	mg/L	22	4.44	0.001	26.5
Iron	mg/L	11	0.2	<0.02	1.3
Lead	mg/L	11	0.02	<0.005	0.1
Manganese	mg/L	35	34.8	0.02	59
Mercury	mg/L	10	0.0005	<0.0002	0.001
Molybdenum	mg/L	9	0.04	0.015	0.1
Nickel	mg/L	9	0.06	0.039	0.1
Selenium	mg/L	34	0.028	<0.001	0.25
Silver	mg/L	12	0.026	<0.005	0.1
Thallium	mg/L	8	0.0045	<0.001	0.005
Uranium	mg/L	4	0.11	0.11	0.12
Vanadium	mg/L	4	0.1	<0.05	0.25
Zinc	mg/L	33	5.4	0.01	9
Total Dissolved Solids	mg/L	56	7,538	2,711	14,800

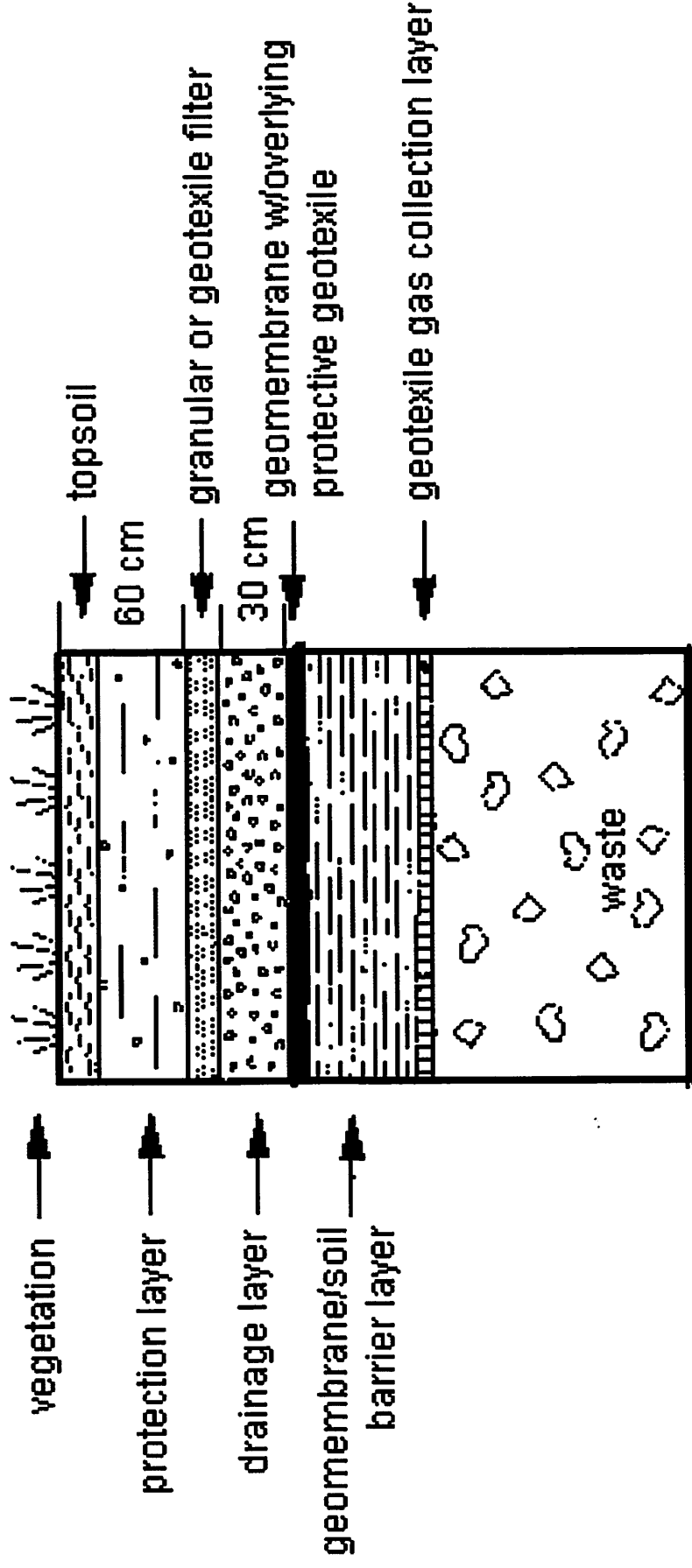
SRK (2018, Table 1-2,
Bates 18410)

Compared to Water
Quality Standards

NMAC 20.6.2.3103 Water Quality Standards	(mg/L)
pH (standard unit not mg/L)	6-9
TDS	1000
Sulfate	600
Cadmium	0.01
Chromium	0.05
Cobalt	0.05
Copper	1
Iron	1
Lead	0.05
Manganese	0.2
Selenium	0.05
Silver	0.05
Uranium	0.03

Drained prior to mining? Outside of
hydraulic sink? Potential for release?

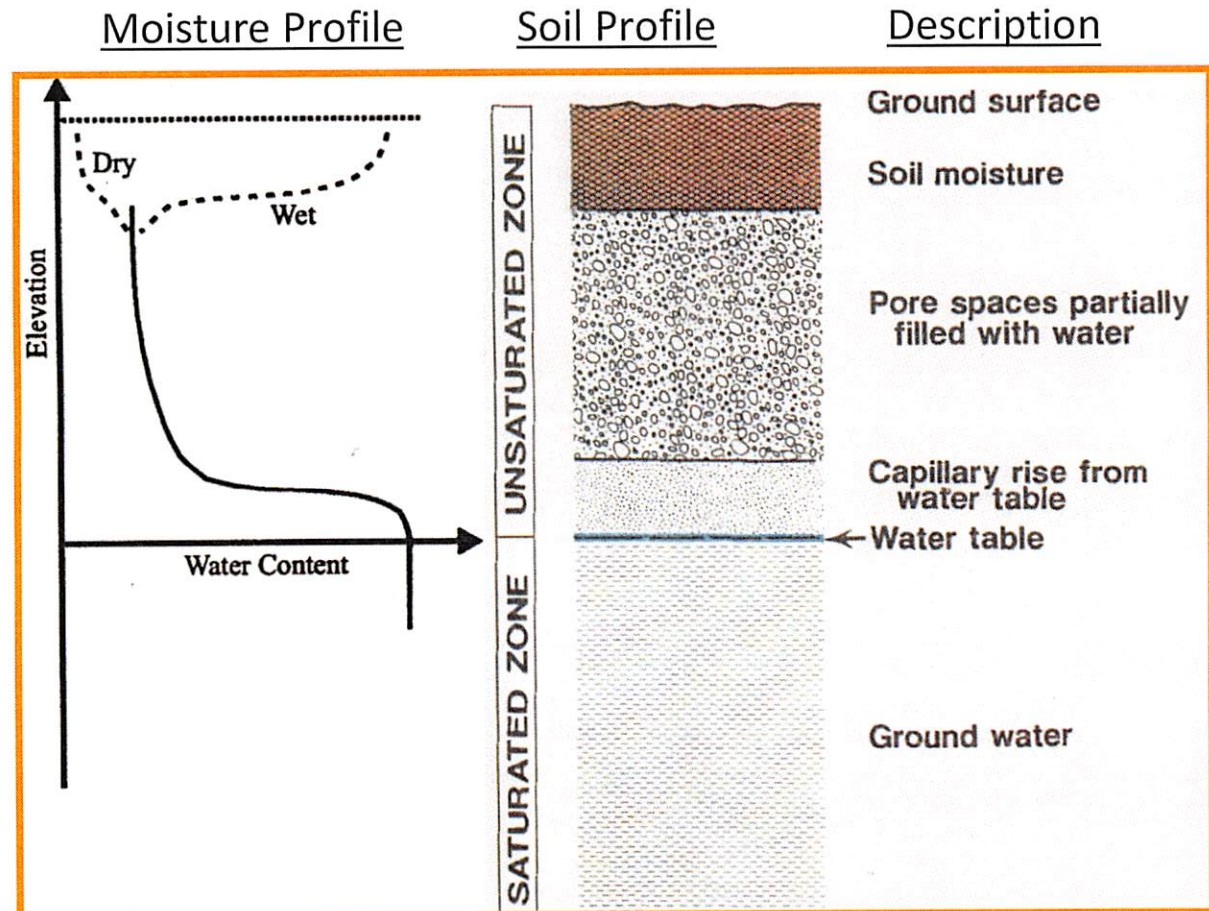
A Typical Constructed "Cover"



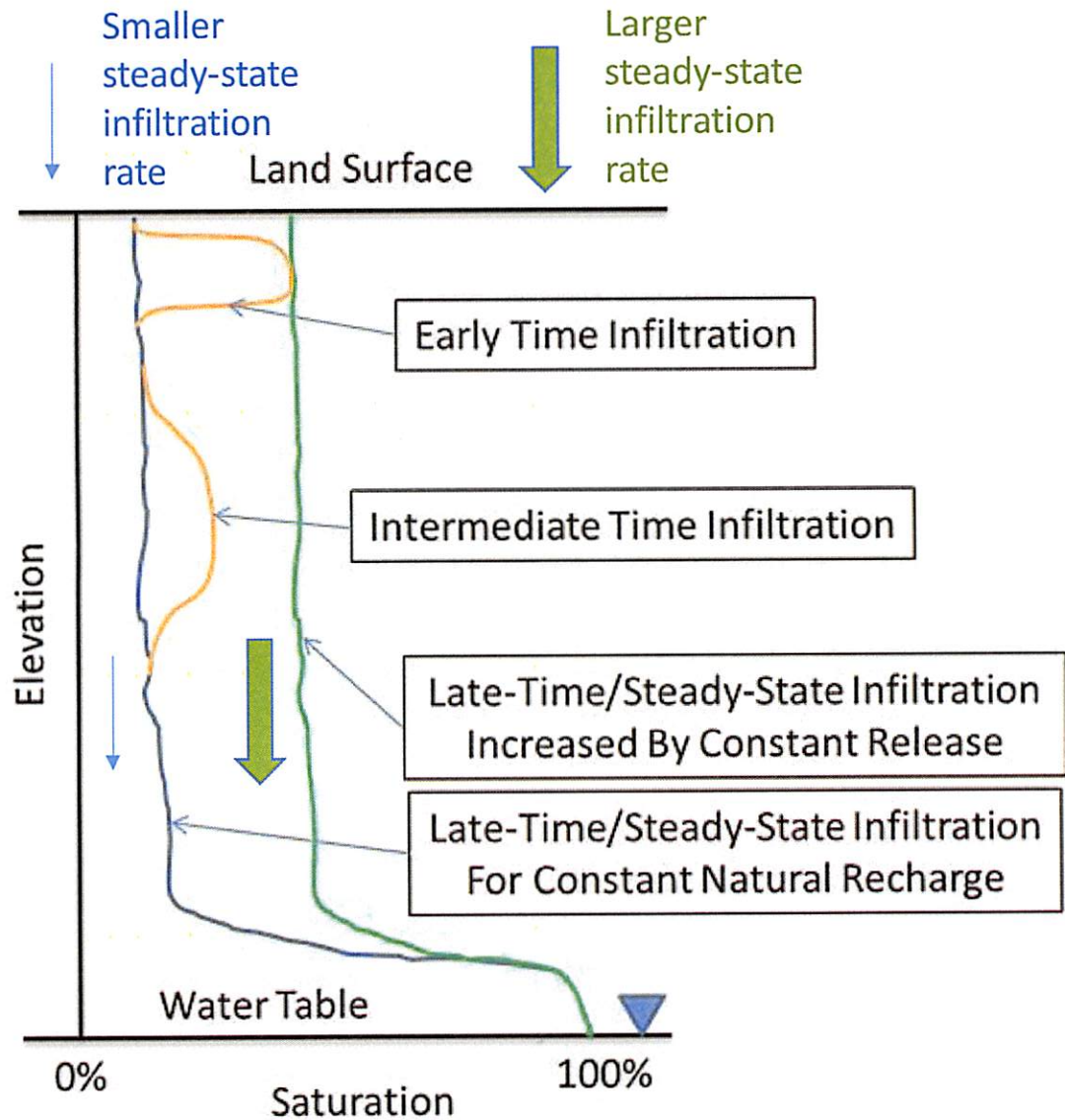
Federal Remediation and Technologies Roundtable, February 12, 2003. 4.30 Landfill Cap (Soil Containment Remediation Technology).

Distribution of Water for Cover System

- **Unsaturated Zone**
 - Water held by capillary forces, water content near field capacity (residual storage S_r) except during infiltration
- **Capillary fringe**
 - Saturated at base
 - Field capacity at top
- **Saturated Zone**
 - Fully saturated pores



Water Infiltration Behavior



Inflow =
Outflow
+/- Storage
Change

Steady state, long-term flow through waste rock and tailings facilities will likely occur as the cover system is not required to eliminate infiltration.

JSAI (2018, Fig. 3-18, Bates 18347)

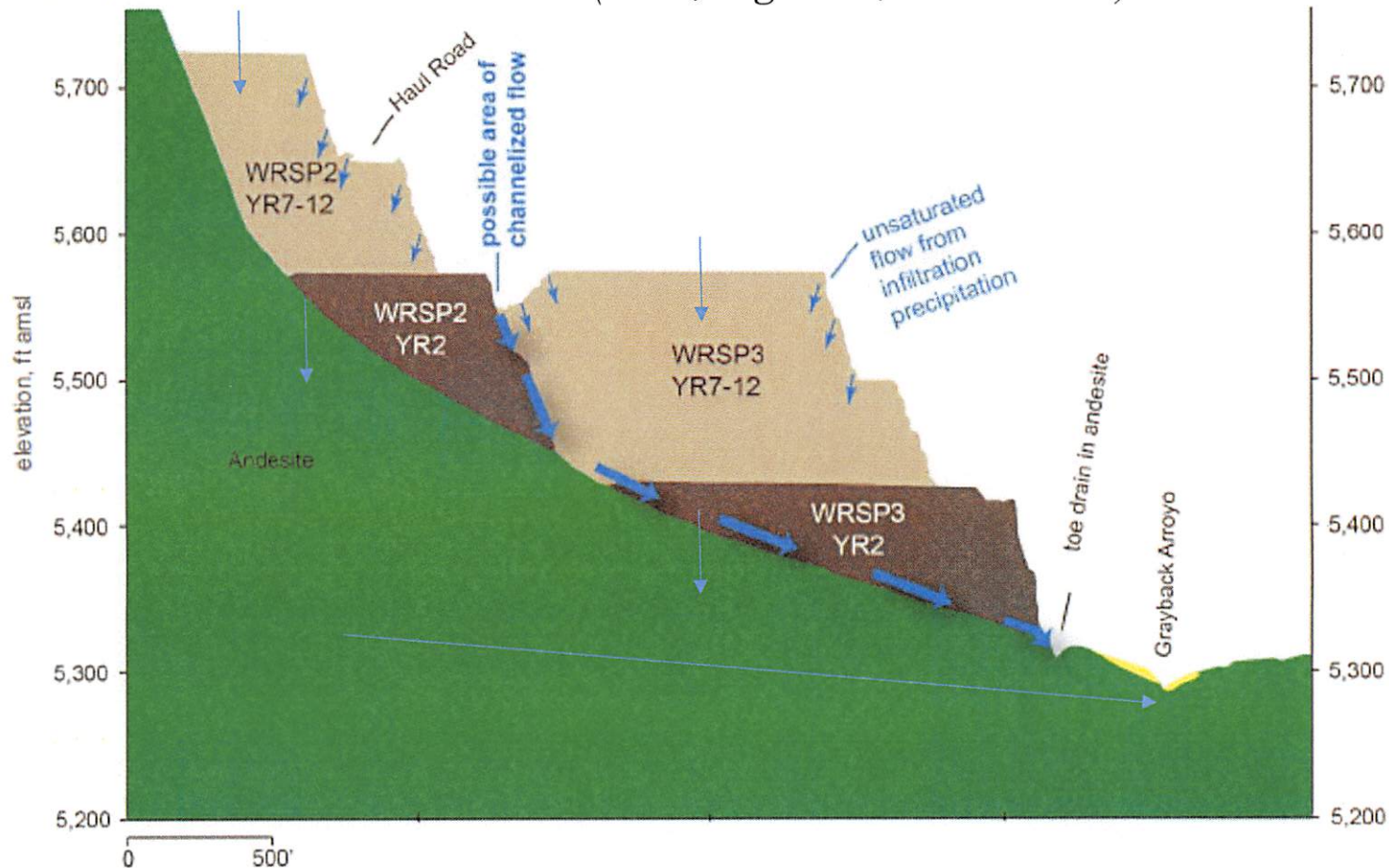


Figure 3.19. Waste rock stockpiles conceptual model.

Infiltration clean water through sandy-loam soil “cover” on WRSF and TSF will have a potential to react with ARD generating materials, and at steady state a similar flow rate of mine impacted water would likely discharge from these facilities, which will continue after closure and reclamation.

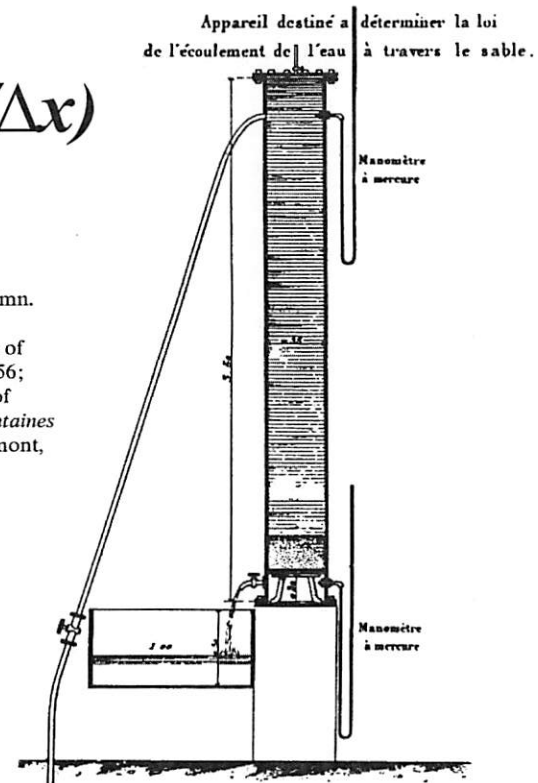
Darcy's Law, 1856



Henry Darcy

$$Q = KA(\Delta H/\Delta x)$$

Figure 1.2
Darcy's experimental sand column.
(From Hubbert, 1969. © 1956,
Society of Petroleum Engineers of
AIME, published *JPT*, Oct. 1956;
Trans. AIME, 1956. Facsimile of
Fig. 3 in Darcy, Henry, *Les Fontaines
de la Ville de Dijon*, Victor Dalmont,
Paris, 1856.)



Darcy's experiment and hydraulic conductivity

$$Q = KA \frac{h_1 - h_2}{L}$$

$$\text{or } Q = -KA \frac{h_2 - h_1}{L}$$

Q : volumetric flow rate [$L^3 T^{-1}$]

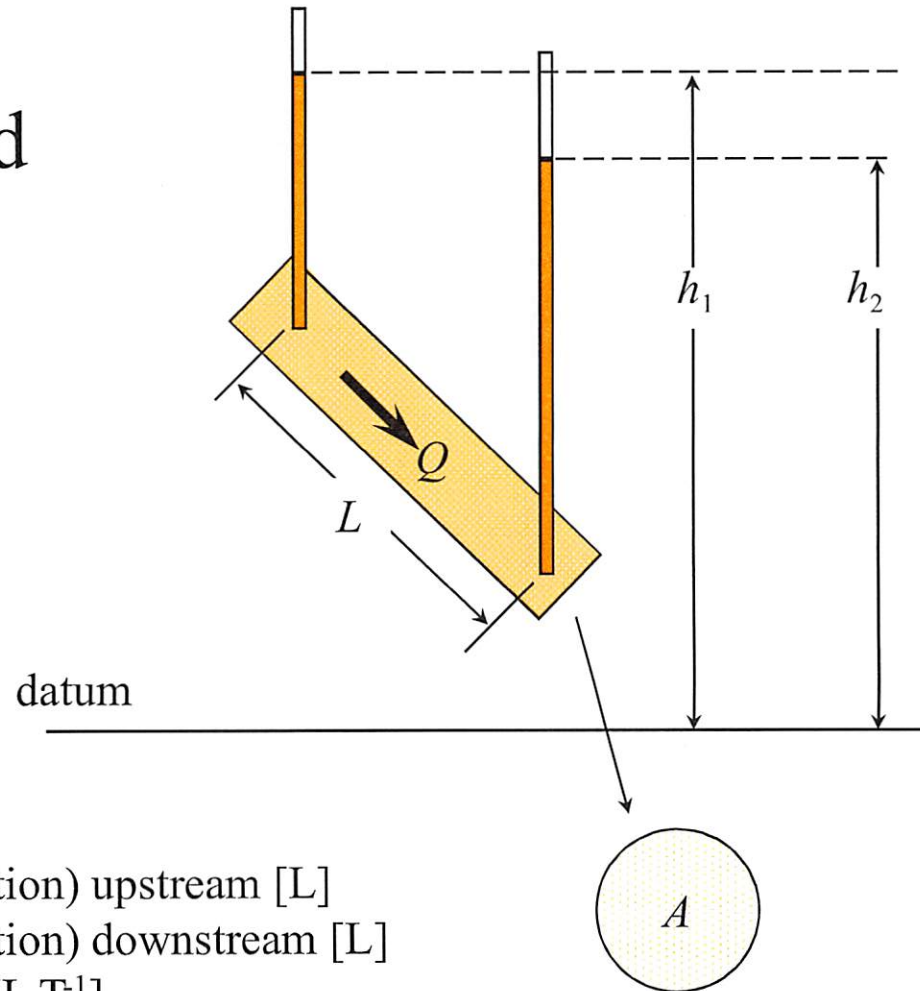
h_1 : hydraulic head (groundwater elevation) upstream [L]

h_2 : hydraulic head (groundwater elevation) downstream [L]

K : **HYDRAULIC CONDUCTIVITY** [$L T^{-1}$]

A : cross sectional area normal to flow direction [L^2]

L : distance between locations (length or change in location)
where h_1 and h_2 are measured [L]



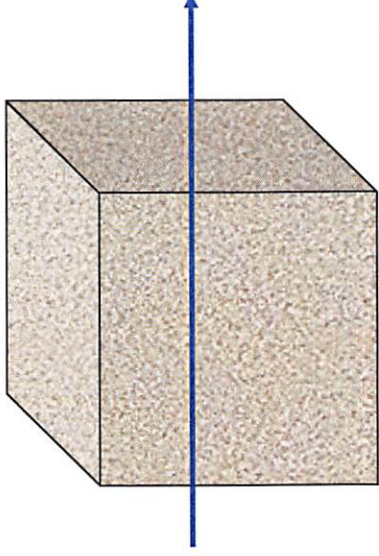
Forms of Darcy's Law

- Volumetric discharge (Q)

$$Q = -KA \left(\frac{dh}{dL} \right)$$

- Specific discharge (q)

$$q = \frac{Q}{A} = -K \left(\frac{dh}{dL} \right)$$



$$q = Q/A$$

Where:

q : specific discharge [L/t]

dh/dL : hydraulic gradient [-]

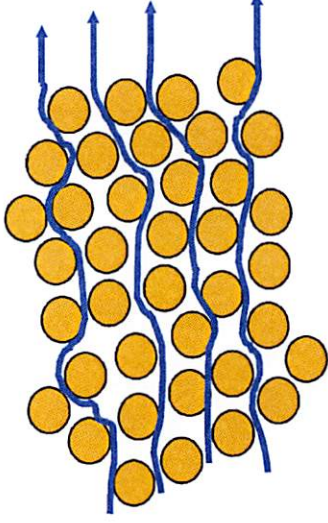
- Linear velocity (v)

$$v = \frac{q}{n} = - \left(\frac{K}{n} \right) \left(\frac{dh}{dL} \right)$$

Where:

v : linear velocity [L/t]

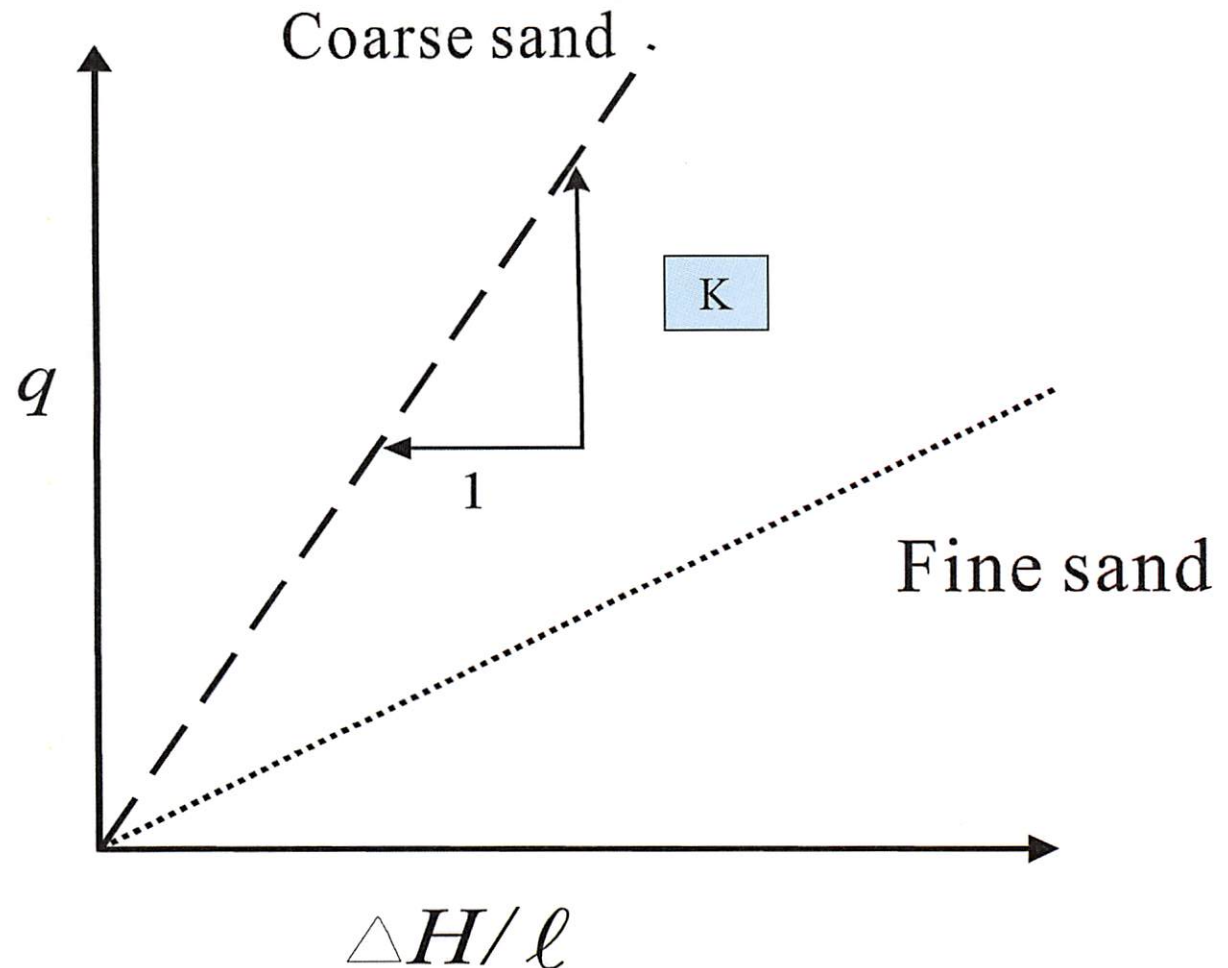
n : porosity [-]



$$v = Q/(An)$$

Parameterization of Darcy's Law

- Hydraulic conductivity is the slope of discharge vs. gradient, and significant changes in the slope may be observed for different media.



Hydraulic Conductivity (K)

- The coefficient of proportionality of Darcy's Law describing the ability of medium to transmit water
- Property of both the porous medium and fluid

$$K = \frac{k\rho g}{\mu}$$

Where:

K : hydraulic conductivity [L/t]

k : intrinsic permeability [L²]

ρ : density of fluid [M/L³]

g : gravitational acceleration [L/t²]

μ : fluid viscosity [M/Lt]

- Intrinsic permeability (k)
 - Relative ease with which a porous medium can transmit a liquid (e.g., water or other)
 - Independent of fluid

Terminology associated with Hydraulic Conductivity

Heterogeneity vs Homogeneity

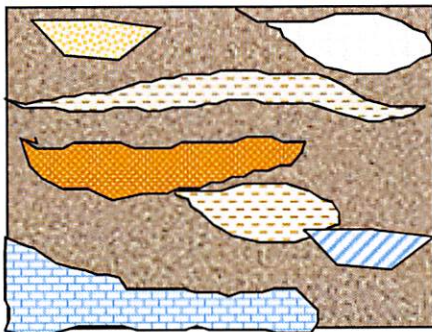
These terms describe spatial variations in the properties of aquifers.

Heterogeneous: a formation in which K varies from one location to another location (i.e., spatially variable).

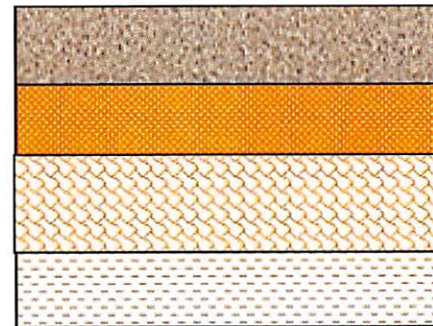
Homogeneous: a formation in which K remains relatively constant (i.e., spatially constant or invariant).

Two types of heterogeneity:

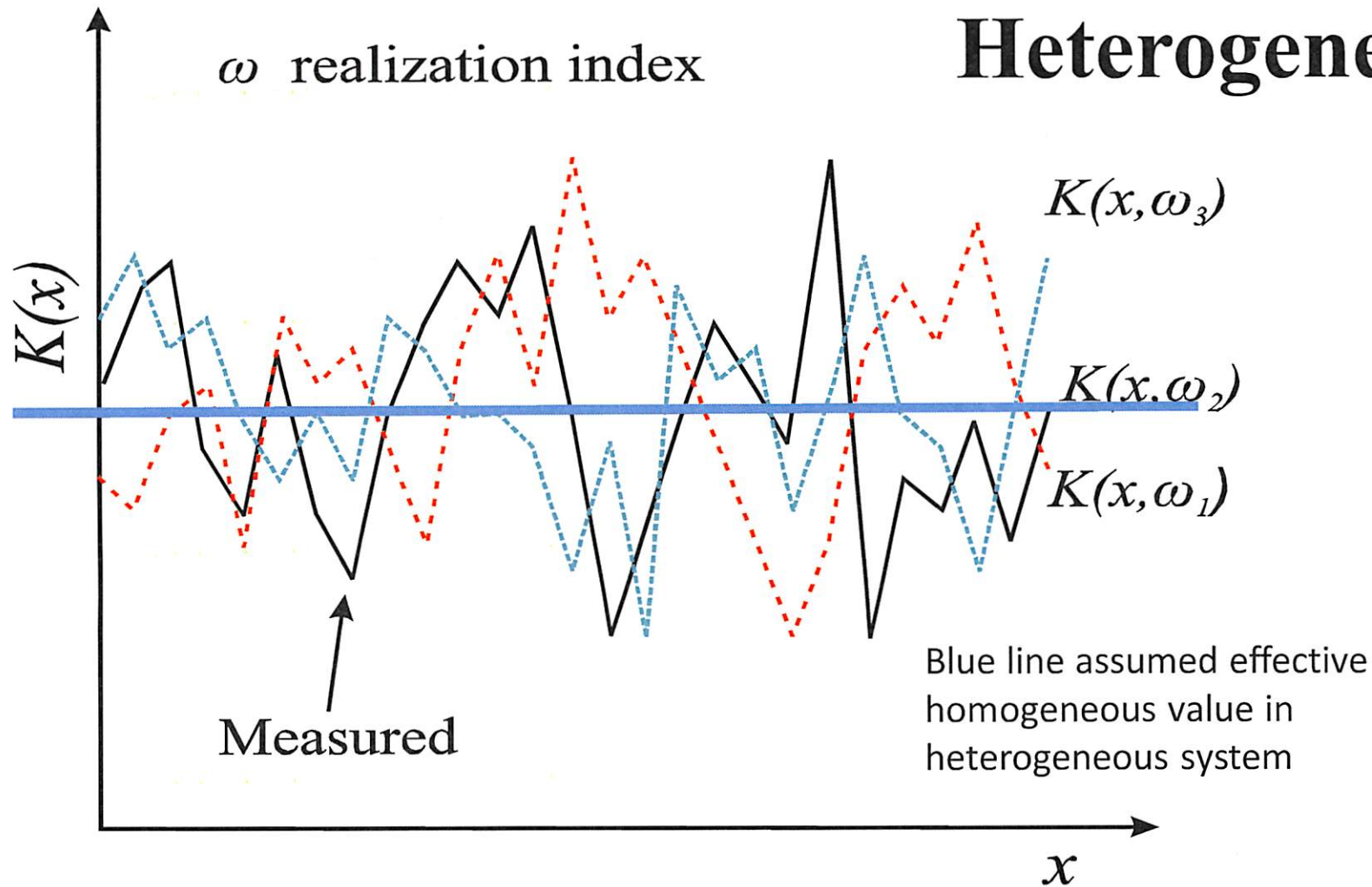
a) variations within the same unit



b) variation from one unit to another unit



Heterogeneity



Schematic illustration of the stochastic process of the hydraulic conductivity distribution along a transect line. The solid line represents the measured hydraulic conductivity values; the dashed lines denote some possible values (different realizations) along the transect.

K range/comparison
 (Heath, R.C., 1983.
 Basic ground-water
 hydrology, U.S.
 Geological Survey
 Water-Supply Paper
 2220, 86p.)

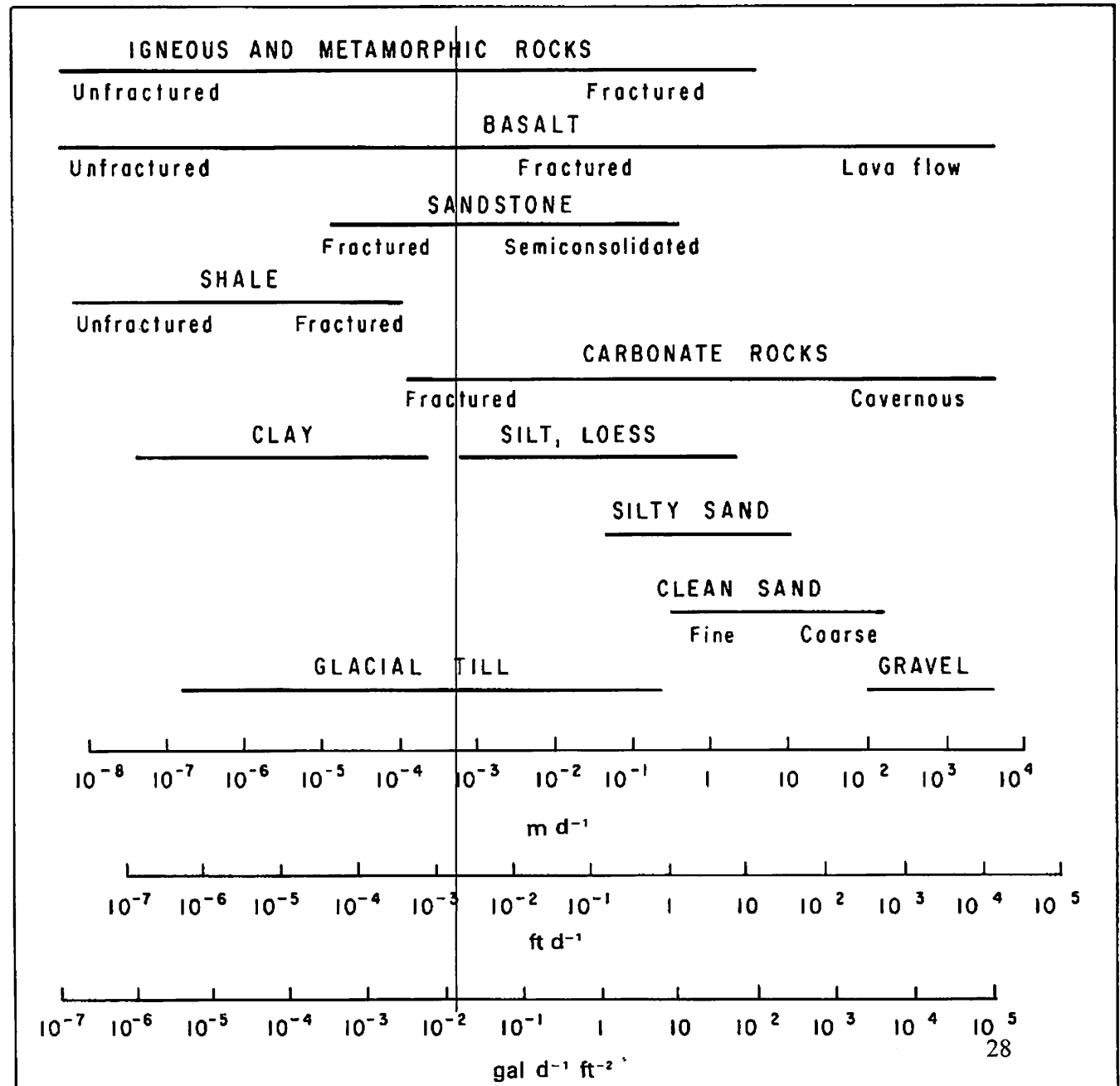
Basalt is a rock type
 that can be called an
 aquifer and not an
 aquifer. It can span the
 known 12 orders of
 magnitude of K.

$K=1 \times 10^{-6}$ cm/sec
 Is equal to
 8.6×10^{-4} m/d

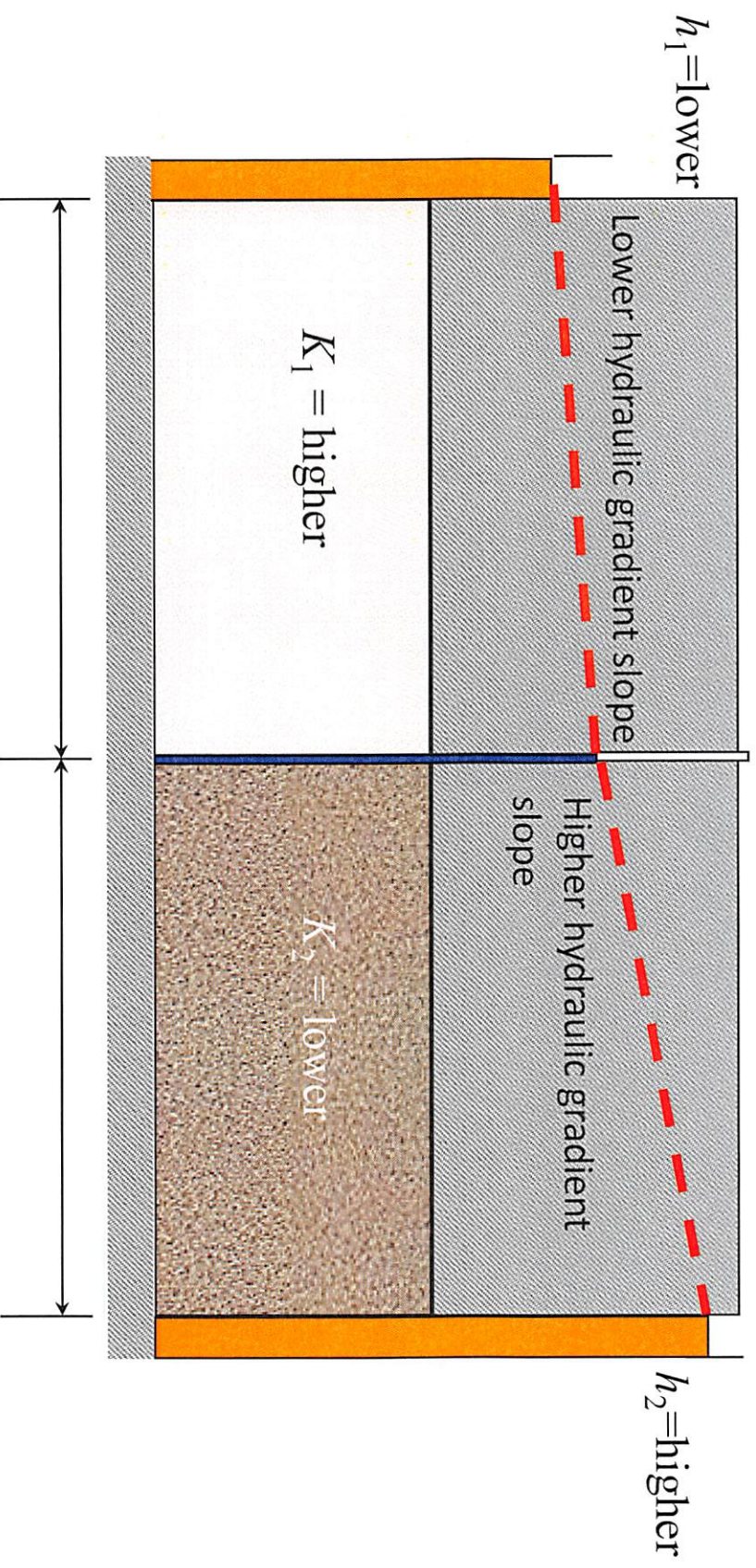
NRCS sandy loam
 "cover" could be 10x to
 >100x higher

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr10/tr/?cid=nrcs144p2_0748
 46

Hydraulic Conductivity of Selected Rocks

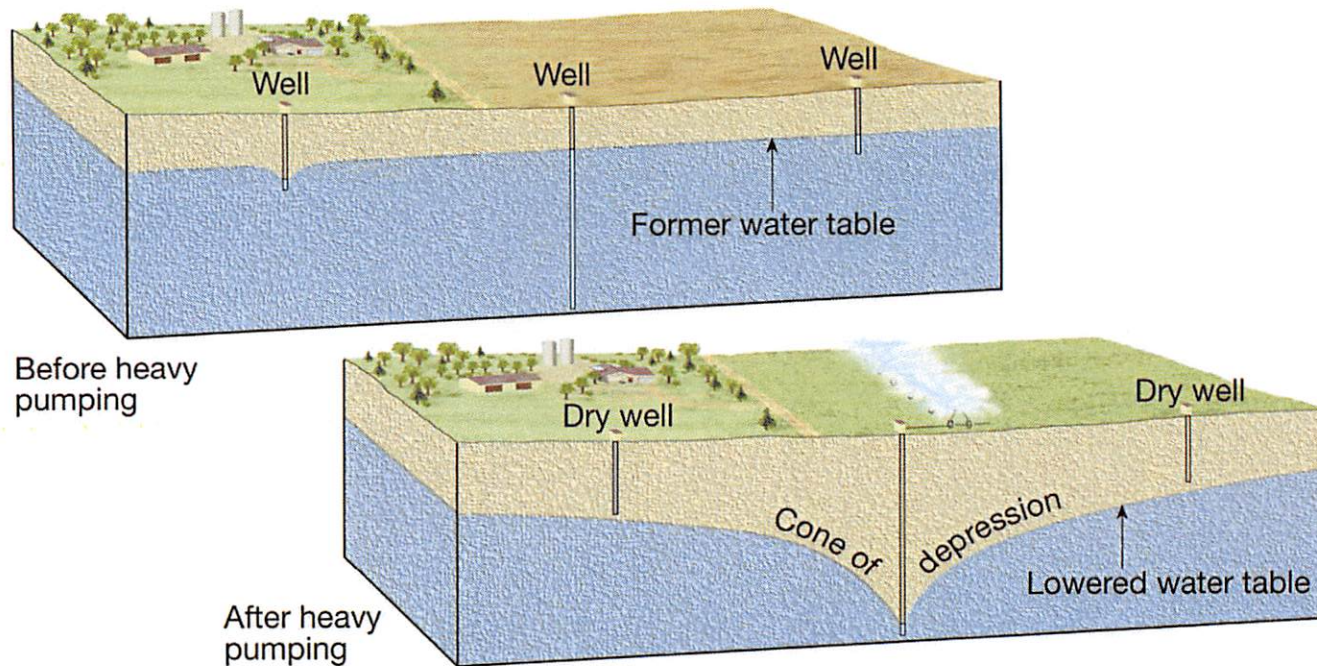


Different gradients of potentiometric surface reflecting Darcy's Law $Q = K A (dh/dx)$
At steady state, if flow is constant in both aquifers with no change in flow area, then
hydraulic gradient would differ for each aquifer with a different hydraulic conductivity
(steeper gradient for lower K or hydraulic conductivity).



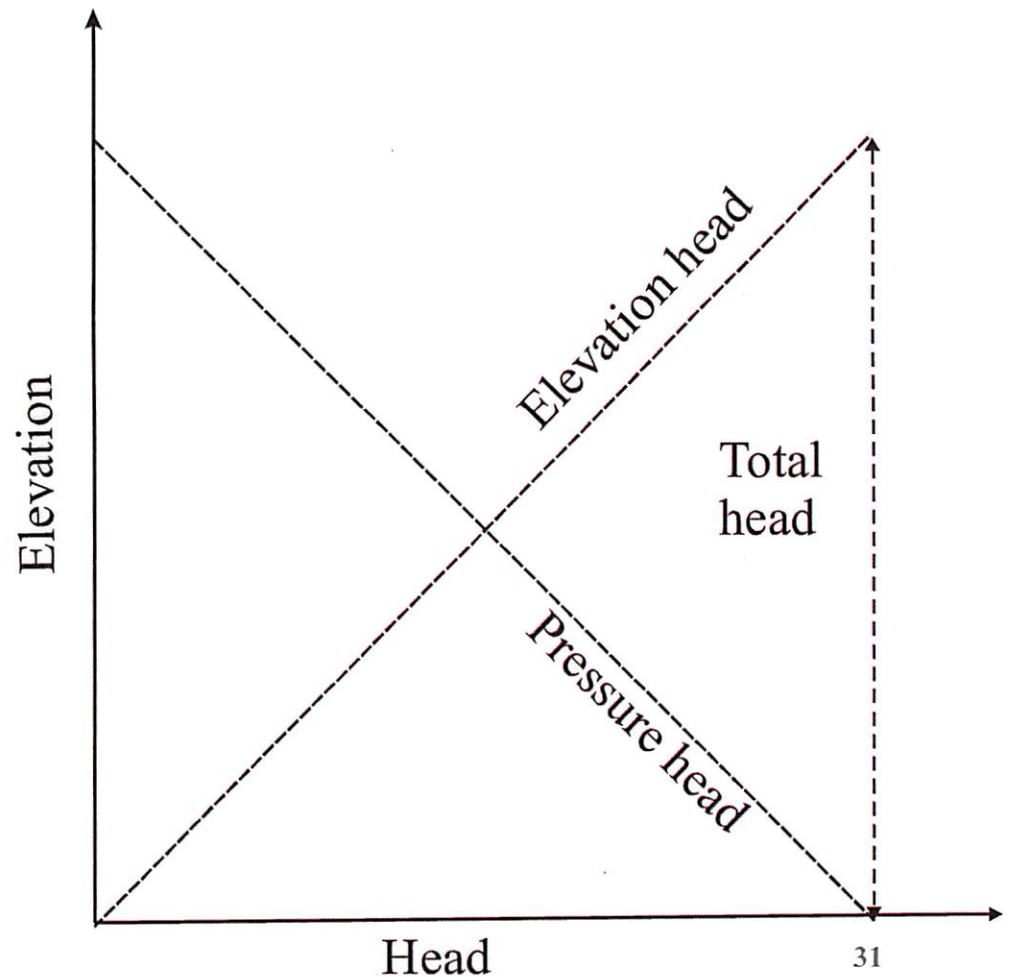
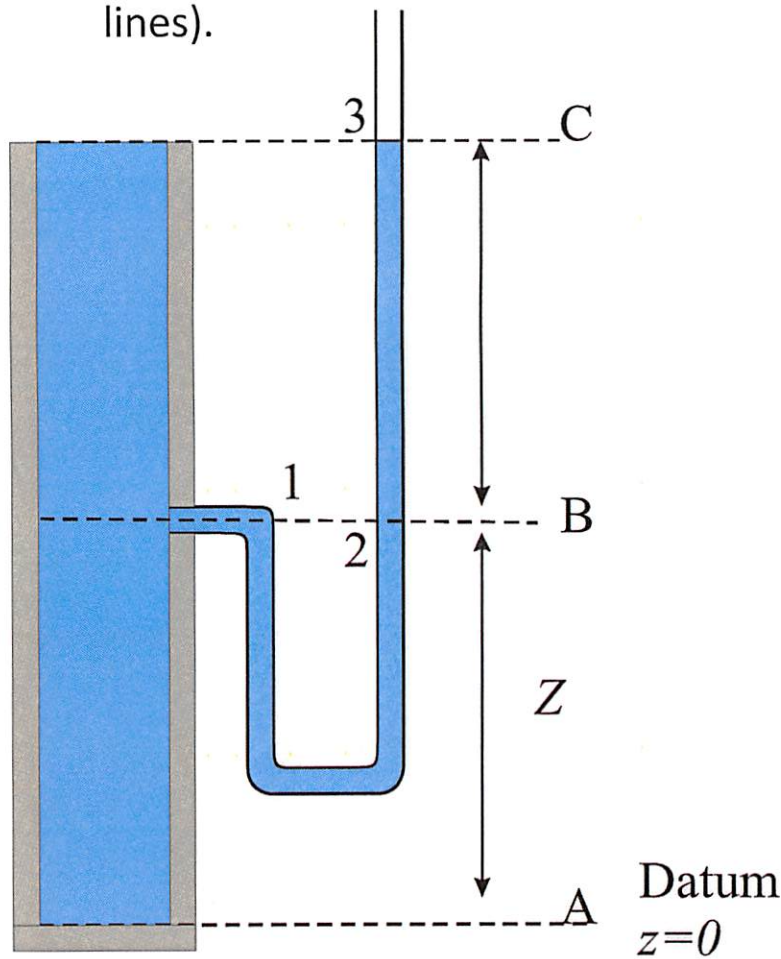
Groundwater Extraction Can Change Hydraulic Gradient without Changing Hydraulic Conductivity

- **Pumping of wells can cause cone of depression in groundwater elevation:**
 - **Lowering of water table around a well, and these changes in groundwater elevation are changes in hydraulic gradient**



Hydrostatics – This a no flow system

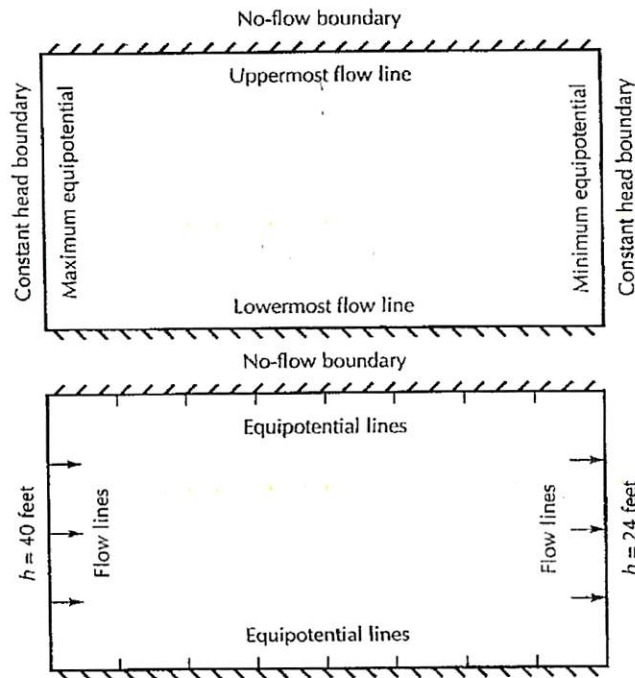
- When you have no change in hydraulic head or groundwater elevation spatially, then the hydraulic gradient and the flow rate become negligible.
- The locations along groundwater elevation contour lines have constant head and there is no flow (negligible gradient) along each contour line (flow is perpendicular to those lines).



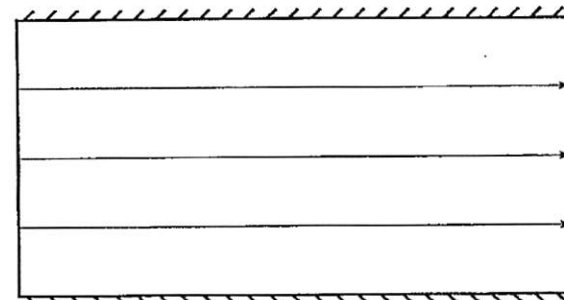
Procedure for constructing a flow net in **homogeneous, isotropic** media
 (Applied Hydrogeology, Edition 4, By C.W. Fetter. 2000; Prentice Hall)

Assumptions: Homogeneous, saturated, isotropic, steady state, incompressible soil and water, darcy flow, boundary conditions are known

- (1) Identify the boundary conditions
- (2) Sketch the boundaries to scale without vertical exaggeration
- (3) Draw the flow lines (there is always a flow line adjacent and parallel to boundary)
- (4) Draw the equipotential lines (hydraulic head or groundwater elevation contours)
- (5) Erase and redraw until the orthogonal equipotential and flow lines are obtained

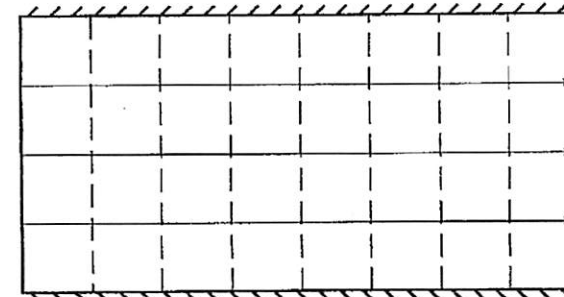


Step 1—Sketch the flow and identify prefixed lines and equipotenti:



Step 3—Draw trial set of flow lines.

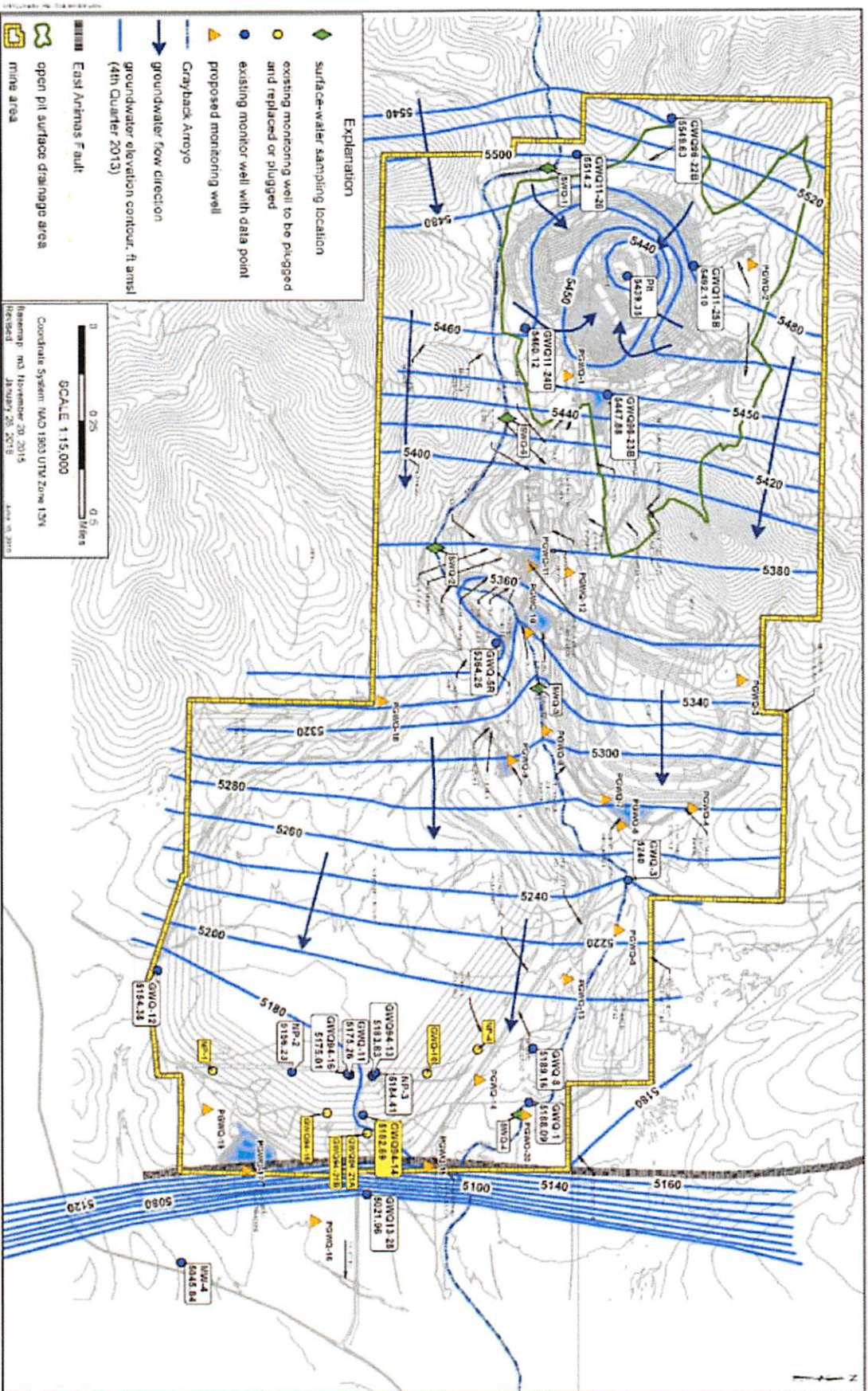
Step 2—Identify prefix positions of flow line: equipotential lines.



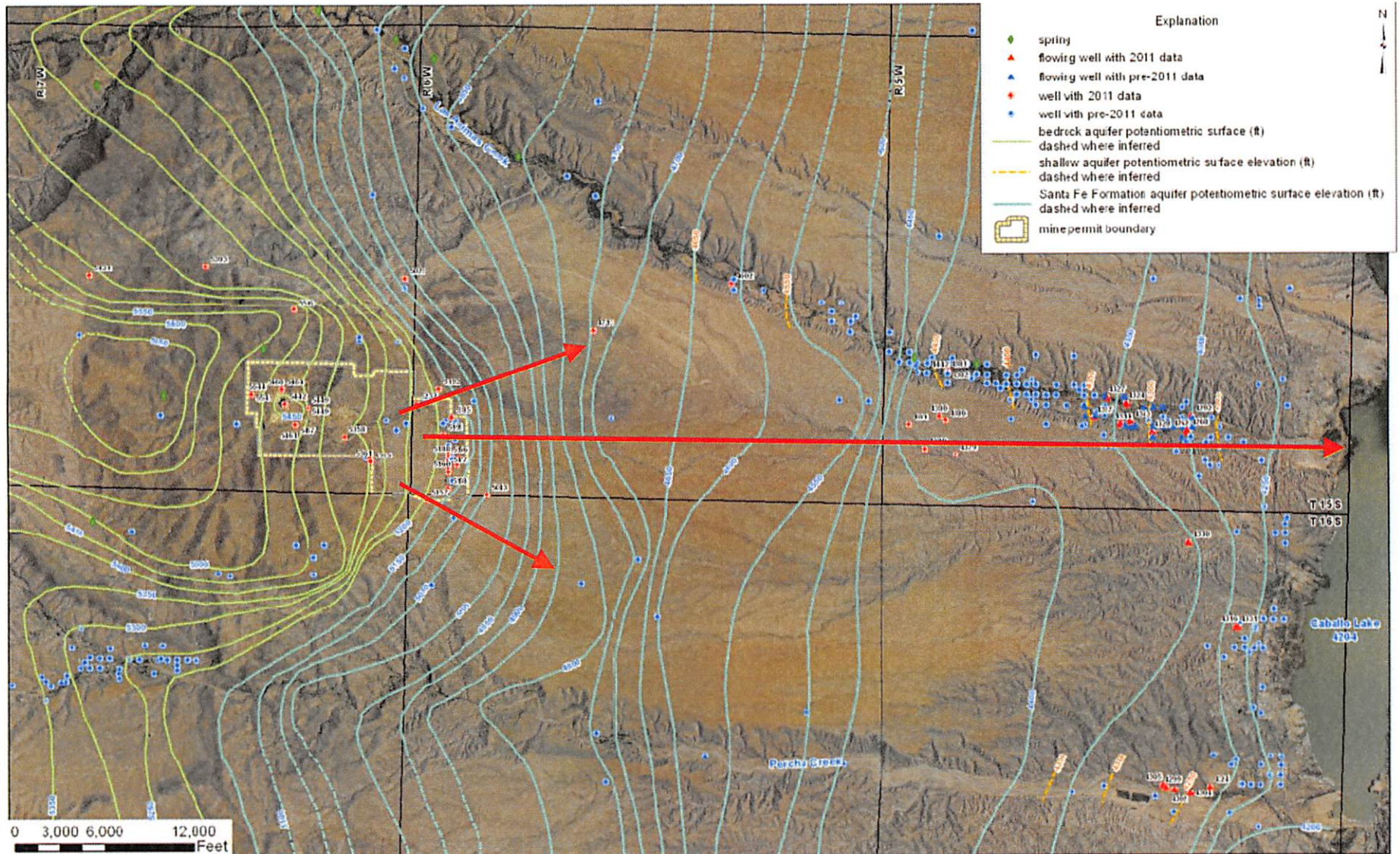
Step 4—Draw trial set of equipotential lines orthogonal to flow lines.

Suggested Barrier Boundary to Groundwater Flow (Fig. 2 of DP-1840)

Figure 2 – Ground and Surface Water Sampling Locations



Groundwater Flow (Fig. 5.1 of Jones et al. 2014)



JSAI (2013, Table 5, Bates 07458)

Table 5. Summary of 1st and 2nd Quarter water-quality data for pit area

sample ID	date	pH	total dissolved solids (TDS)	total alkalinity	bicarbonate	carbonate	sulfate	chloride	fluoride	calcium	magnesium	sodium	potassium	aluminum	cadmium	cobalt	copper	manganese	selenium	zinc
		standard units	mg/L	mg/L as CaCO ₃	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
NMWOCC standard*		6 to 9	1,000				600	250	1.6					5.00	0.01	0.05	1.0	0.2	0.05	10
pit wall seepage	8/19/2010	2.00	13,900	<20	<20	<2	11,000	21	\$1.00	470	190	<50	<50	\$40.00	0.140	1.500	\$0.000	24.00	0.086	12.00
pit	1/9/2013	7.73	11,100	112	112	<2	6,800	577	18.70	500	958	1,170	44,400	0.08	0.037	0.086	0.059		0.008	0.78
pit	4/12/2013	7.07	11,700	122	122	<2	6,750	670	22.10	494	929	1,320	49.1	0.11	0.039	0.069	0.058	31.90	0.013	0.86
pit lake 1A**	4/12/2013	7.07	10,500	123	133	<2	7,130	\$99	20.40	455	859	1,230	40.2	0.11	0.039	0.070	0.061	\$3.10	0.015	0.88
GWQ96-21A	1/9/2013	7.85	521	301	301	<2	39	61	3.07	41	3	147	2.34	0.02	<0.002	<0.006	<0.001		<0.001	<0.01
GWQ96-22B	1/9/2013	7.52	722	477	477	<2	6	101	3.32	70	6	193	3.66	0.04	<0.002	<0.006	0.003		<0.001	0.05
GWQ96-23A	1/11/2013	8.07	693	627	627	<2	6	12	2.00	129	38	71	1.37	0.03	<0.002	<0.006	0.001		<0.001	<0.01
GWQ96-23B	1/11/2013	8.03	571	502	502	<2	<5.0	15	2.05	77	21	98	1.57	<0.02	<0.002	<0.006	<0.001		<0.001	0.01
GWQ11-24A	1/8/2013	4.53	4,180	<20	<20	<2	2,550	30	17.40	464	108	129	6.98	38.00	0.181	0.256	104.000		0.029	5.72
GWQ11-24A	4/12/2013	4.48	4,320	<20	<20	<2	2,730	30	22.90	468	110	126	<10	46.00	0.206	0.290	126.000	11.40	0.035	6.32
GWQ11-24B	1/9/2013	7.07	2,280	219	219	<2	1,280	27	3.39	417	76	96	6.23	<0.02	<0.002	0.011	<0.001		<0.001	0.05
GWQ11-24B	4/12/2013	6.18	2,440	189	189	<2	1,510	28	3.99	469	78	91	5.81	<0.02	<0.002	0.019	<0.006	3.54	<0.005	0.23
GWQ11-25A	1/9/2013	3.98	11,300	<20	<20	<2	7,900	21	12.100	419	149	647	<100	414.00	0.385	1.720	12.600		0.087	14.90
GWQ11-25A	4/12/2013	3.30	23,800	<20	<20	<2	17,400	11	\$24.00	556	<500	<500	<500	17,700.00	0.656	3.910	63,900	77.50	<0.500	42.10
GWQ11-25B	1/9/2013	6.94	2,540	343	343	<2	1,400	27	8.03	493	76	139	3.9	0.34	<0.002	<0.006	0.002		0.002	0.02
GWQ11-25B	4/12/2013	6.54	2,530	339	339	<3	1,470	27	8.10	465	81	128	4.35	0.38	<0.002	<0.006	<0.006	3.30	0.002	0.02
GWQ11-26	1/8/2013	7.76	654	361	361	<2	97	14	<1.00	96	22	72	1.34	0.03	<0.002	<0.006	0.003		0.001	<0.01
GWQ11-26	4/12/2013	7.05	582	354	354	<2	98	16	0.39	93	23	68	1.73	<0.02	<0.002	<0.006	<0.006	0.02	0.002	<0.01

* may not apply to pit and pit capture area
 ** confirmation sample

NMWOCC - New Mexico Water Quality Control Commission
 mg/L - milligrams per liter

GWQ11-24 and GWQ11-25 inside pit surface water drainage area, but outside of groundwater hydraulic sink?

JSAI (2013, Table 6, Bates 07460)

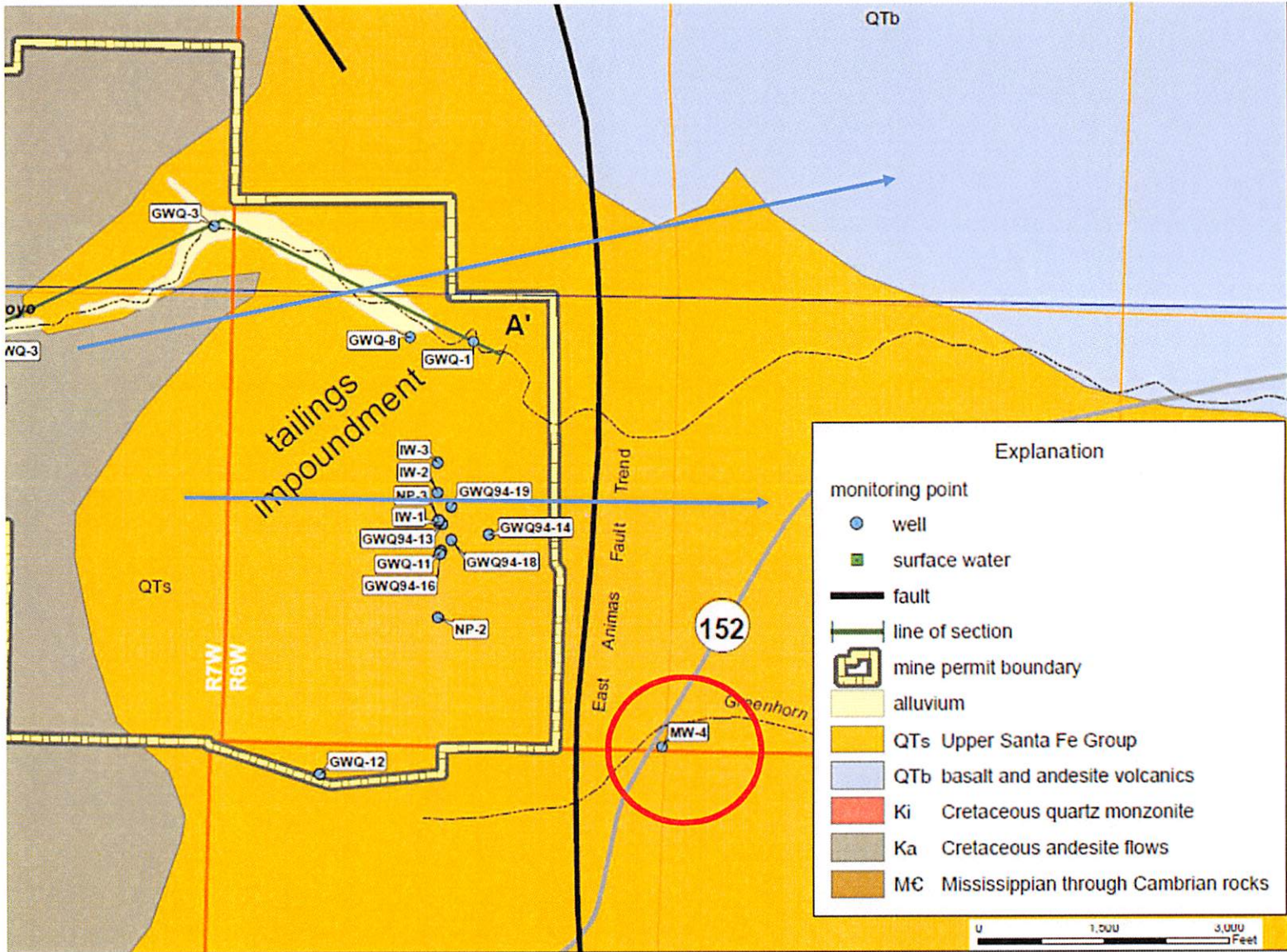
Table 6. Summary of 1st and 2nd Quarter water-quality data for monitoring points in the waste rock/mill site and TSF areas

sample location	analysis date	pH	total dissolved solids (TDS)	total alkalinity	bicarbonate	carbonate	sulfate	chloride	fluoride	calcium	magnesium	sodium	potassium	aluminum	cadmium	cobalt	copper	selenium	zinc
		standard units	mg/L	mg/L as CaCO ₃	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
NMWQCC standard		6 to 9	1,000				600	250	1.6					5.0	0.01	0.05	1.0	0.05	10.0
waste rock and mill site area																			
GWQ-1	1/10/2013	7.87	487	164	164	< 2	152	38	0.38	63.2	17.7	65.1	2.11	< 0.02	< 0.002	< 0.006	< 0.001	< 0.001	< 0.01
GWQ-1	4/12/2013		465	195	195	< 2	120	30		57.0	13.5	60.0	2.00						
GWQ-3	4/12/2013	7.50	3,060	188	188	< 2.0	1,750	75		477.0	111.0	253.0	3.99						
GWQ-5R	1/10/2013	7.79	504	293	293	< 2	97	17	1.25	96.9	22.7	34.0	5.15	< 0.02	< 0.002	< 0.006	< 0.001	< 0.001	0.01
GWQ-5R	4/12/2013	7.12	500	285	285	< 2	101	17		87.1	20.3	30.6	4.63						
GWQ-8	1/10/2013	7.60	1,200	213	213	< 2	498	89	< 0.50	202.0	33.8	107.0	2.43	< 0.02	< 0.002	< 0.006	< 0.001	0.002	0.01
GWQ-8	4/12/2013	7.16	1,190	214	214	< 2.0	447	85		214.0	35.6	113.0	2.73						
tailings storage facility (TSF) area																			
GWQ-11	4/12/2013	6.73	952	163	163	< 2	359	142		155.0	43.0	68.6	3.34						
GWQ-12	4/12/2013	7.19	360	179	179	< 2	47	27		50.0	16.1	26.9	2.66						
GWQ94-13	1/10/2013	7.63	1,460	126	126	< 2	543	184	< 0.50	246.0	49.9	106.0	3.22	< 0.02	< 0.002	< 0.006	< 0.001	0.017	< 0.01
GWQ94-13	4/10/2013	7.16	1,410	124	124	< 2	517	177		231.0	44.2	90.7	2.73						
GWQ94-14	1/11/2013	7.78	583	218	218	< 2	140	44	0.42	90.2	24.5	45.8	1.62	< 0.02	< 0.002	< 0.006	< 0.001	0.003	< 0.01
GWQ94-14	4/10/2013	7.36	553	213	213	< 2	141	44		94.8	25.8	48.7	1.71						
GWQ94-16	1/10/2013	7.76	1,170	173	173	< 2	407	192	0.59	188.0	47.7	75.7	3.33	0.04	< 0.002	< 0.006	< 0.001	0.002	< 0.01
GWQ94-16	4/12/2013		1,070	171	171	< 2	421	191		281.0	50.7	65.0	4.78						
NP-2	4/12/2013	7.38	872	167	167	< 2	299	170		147.0	40.7	68.9	4.24						
NP-3	1/10/2013	7.24	1,390	54.2	54.2	< 2	557	190	< 0.10	218.0	49.5	107.0	3.23	< 0.02	< 0.002	< 0.006	0.001	0.006	1.85
NP-3	4/12/2013	6.95	1,340	71.4	71.4		561	191		219.0	47.5	97.9	3.41						
MW-4	4/12/2013	8.29	267	87	87	< 2.0	92	21		23.2	7.3	48.1	2.27						

NMWQCC - New Mexico Water Quality Control Commission
 mg/L - milligrams per liter

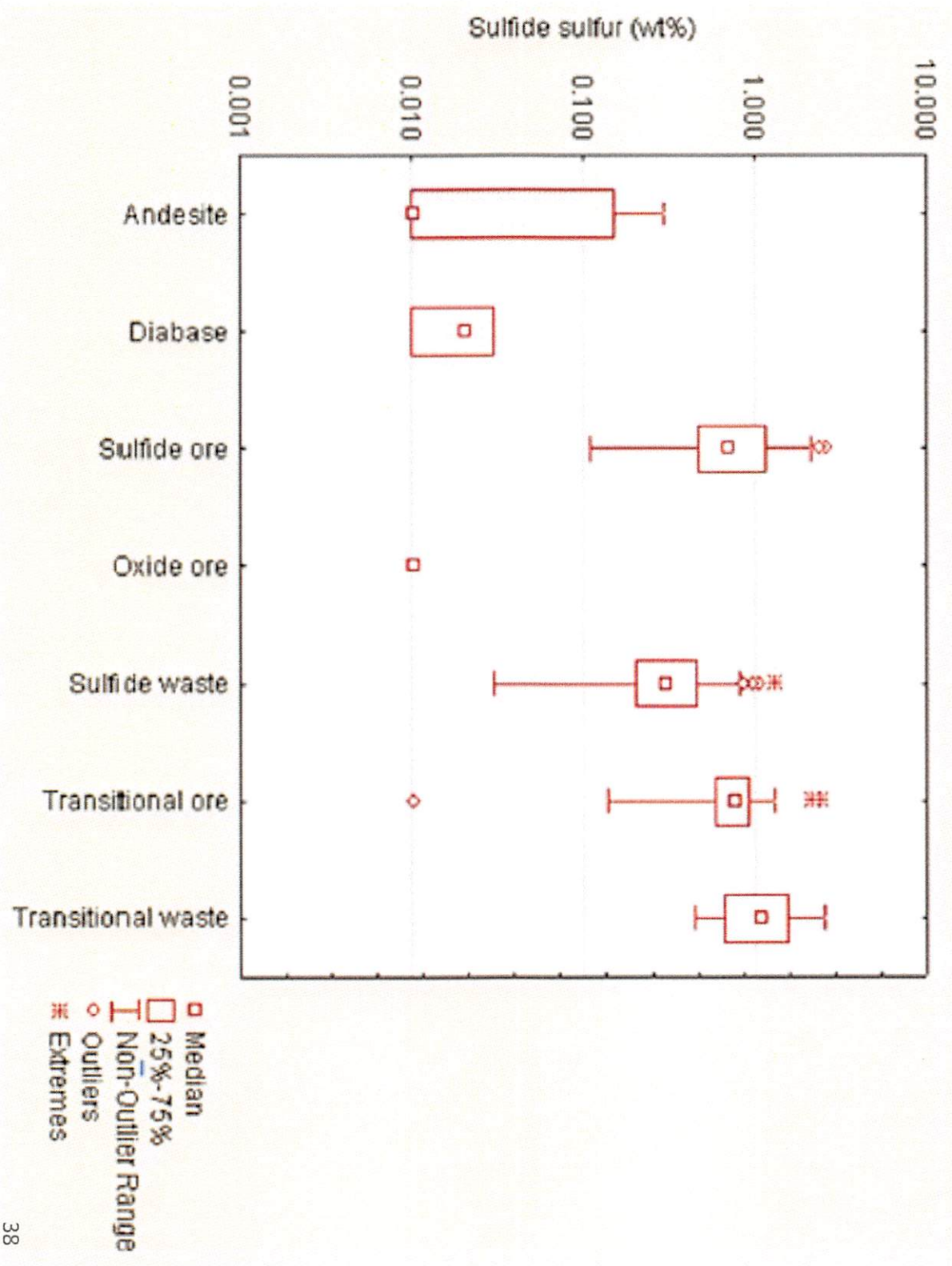
Dr. Myers rebuttal testimony shows Fig. 7 (Bates 07471) JSAI (2013) with sulfate concentrations at GWQ-3 and GWQ-8 increasing over time from 1980 to 2014. 36

JSAI (2013, Fig. 3, Bates 07467)

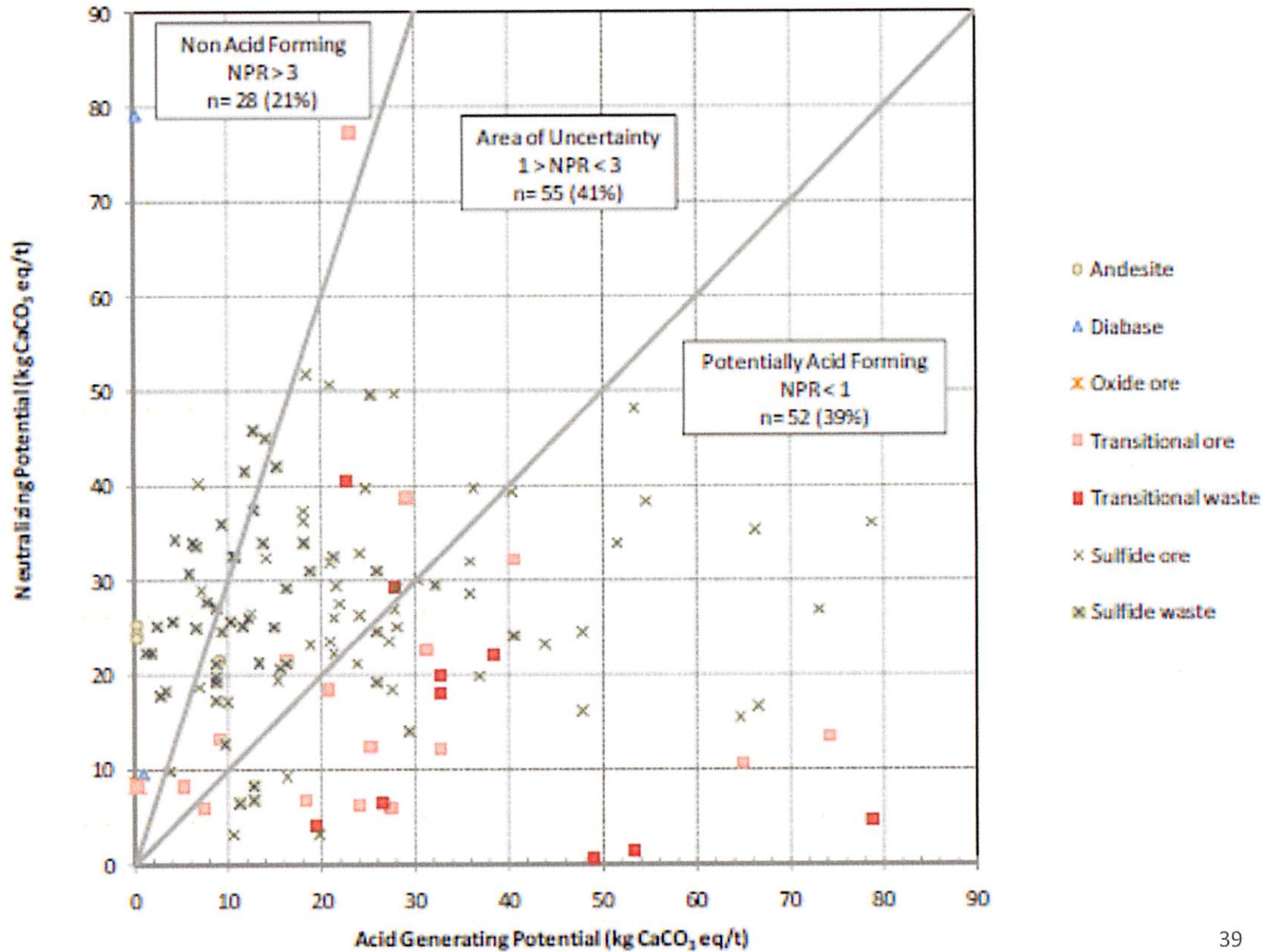


Need more monitoring wells to characterize nature and extent of off site migration of groundwater contaminant plume.

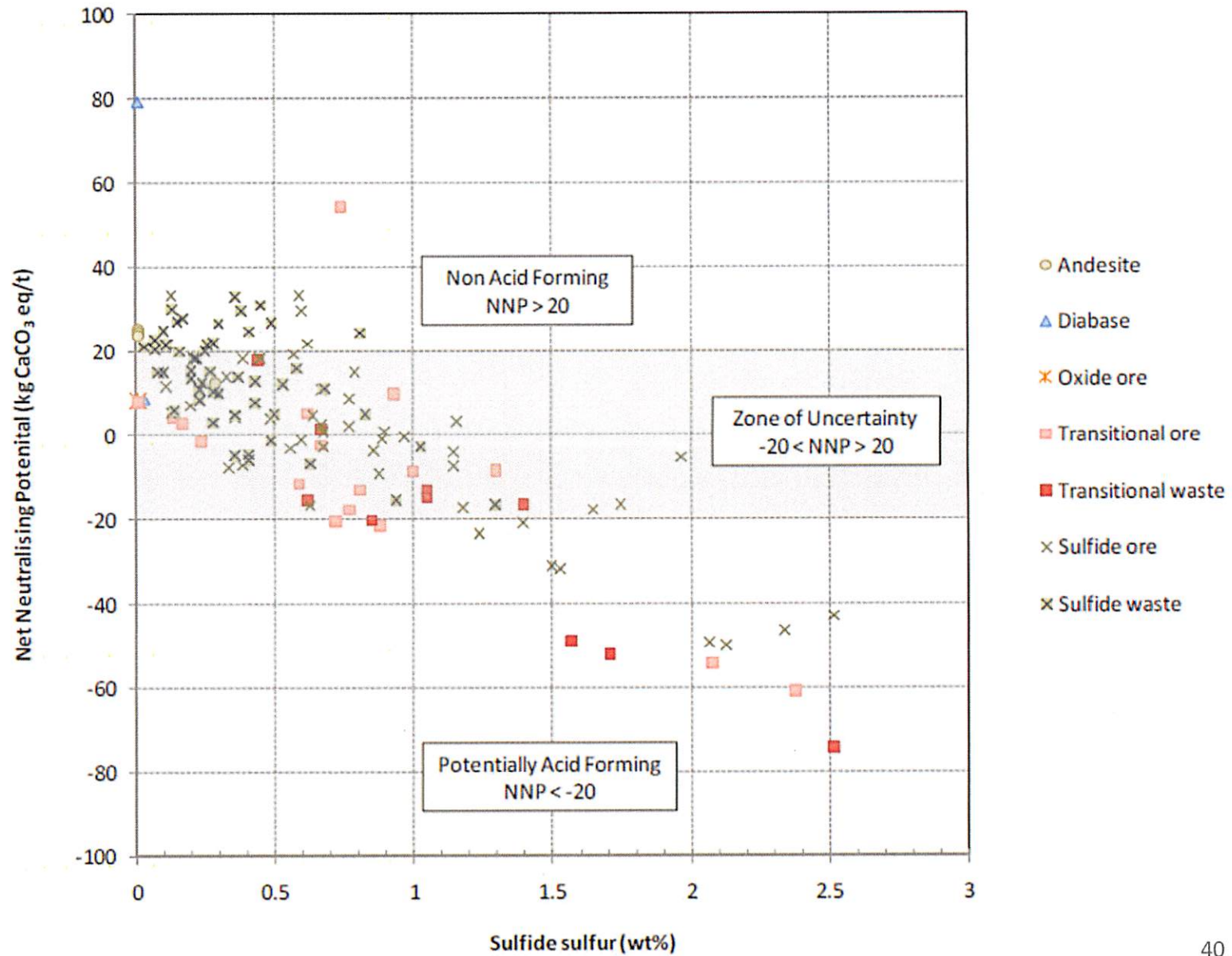
SRK (2013, Fig. 5-1, Bates 05578)



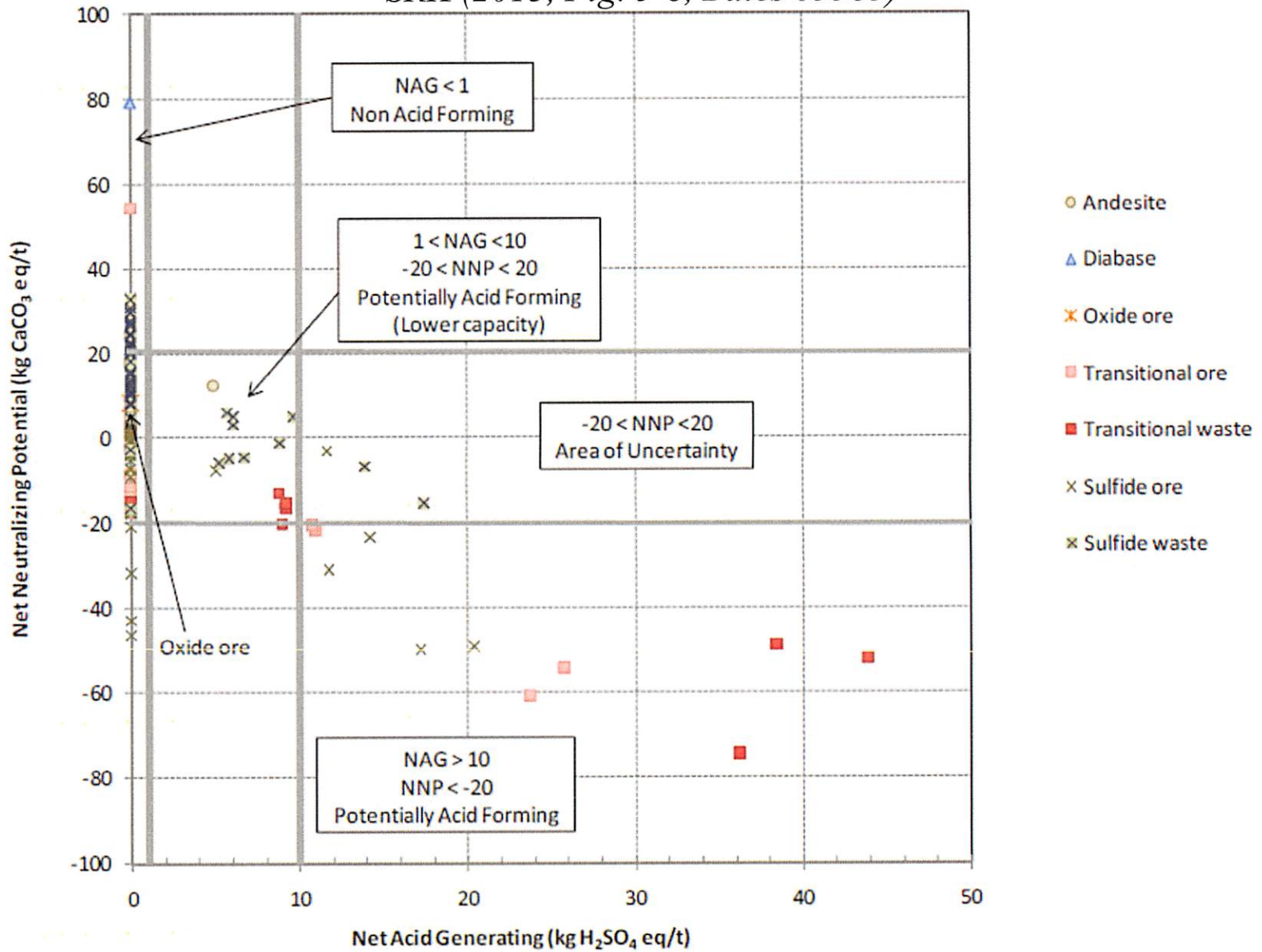
SRK (2013, Fig. 5-2, Bates 05578)



SRK (2013, Fig. 5-4, Bates 05579)



SRK (2013, Fig. 5-8, Bates 05583)



SRK (2013, Table 5-5, Bates 05582)

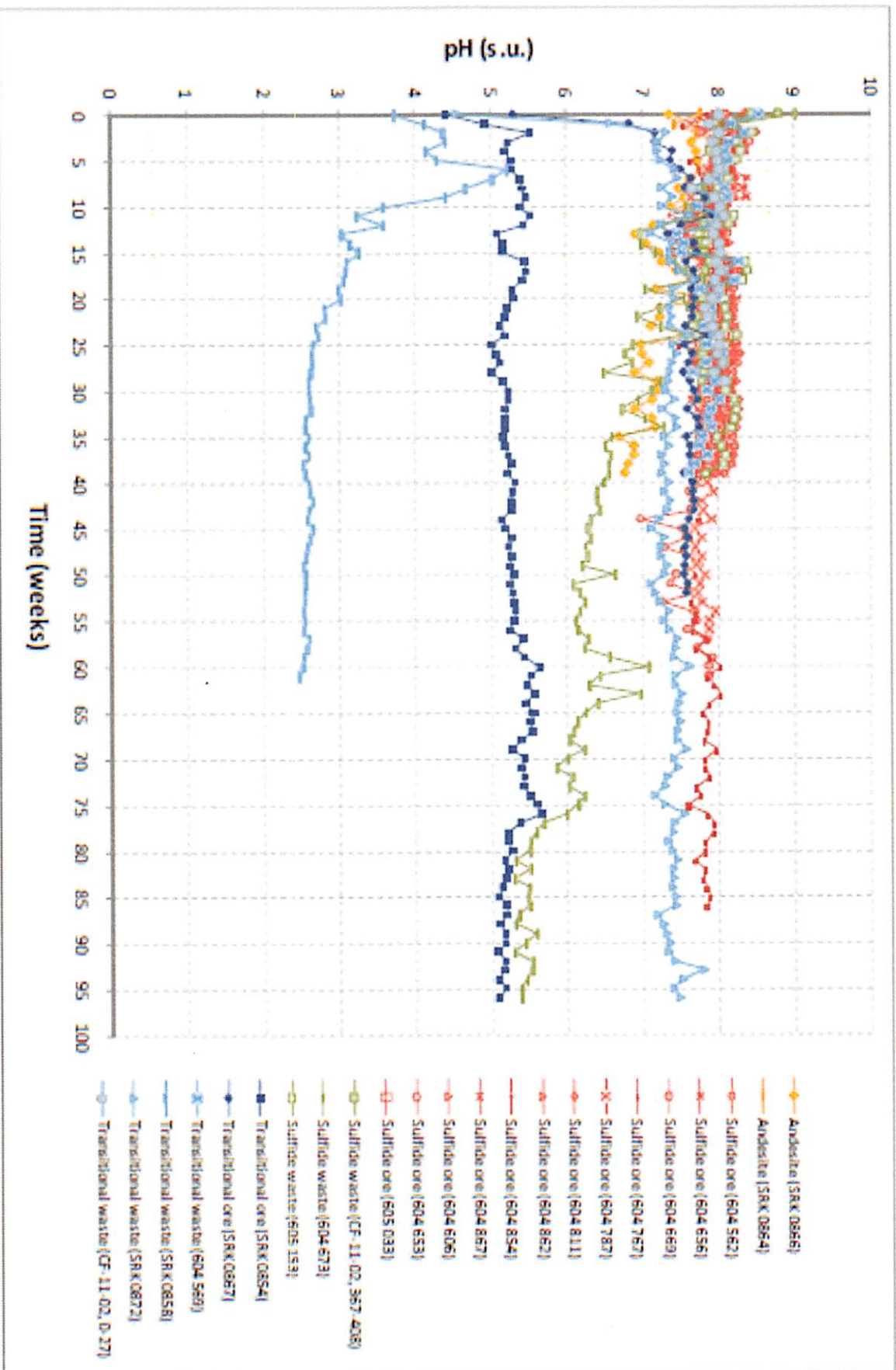
Table 5-5: Summary of Waste Rock Net Acid Generation Results

Material Type	#	NAG pH (s.u.)		NAG (kg H ₂ SO ₄ eq/t)	
		Mean	S.D.	Mean	S.D.
Andesite	4	6.50	2.23	1.23	2.45
Diabase	2	8.69	1.94	0	0
Sulfide waste	50	7.33	2.12	1.71	3.88
Transitional waste	10	4.34	2.57	15.5	17.1
Sulfide ore	48	7.38	2.02	1.68	4.81
Transitional ore	17	6.17	2.34	4.20	8.54
Oxide ore	1	8.88	-	0	-

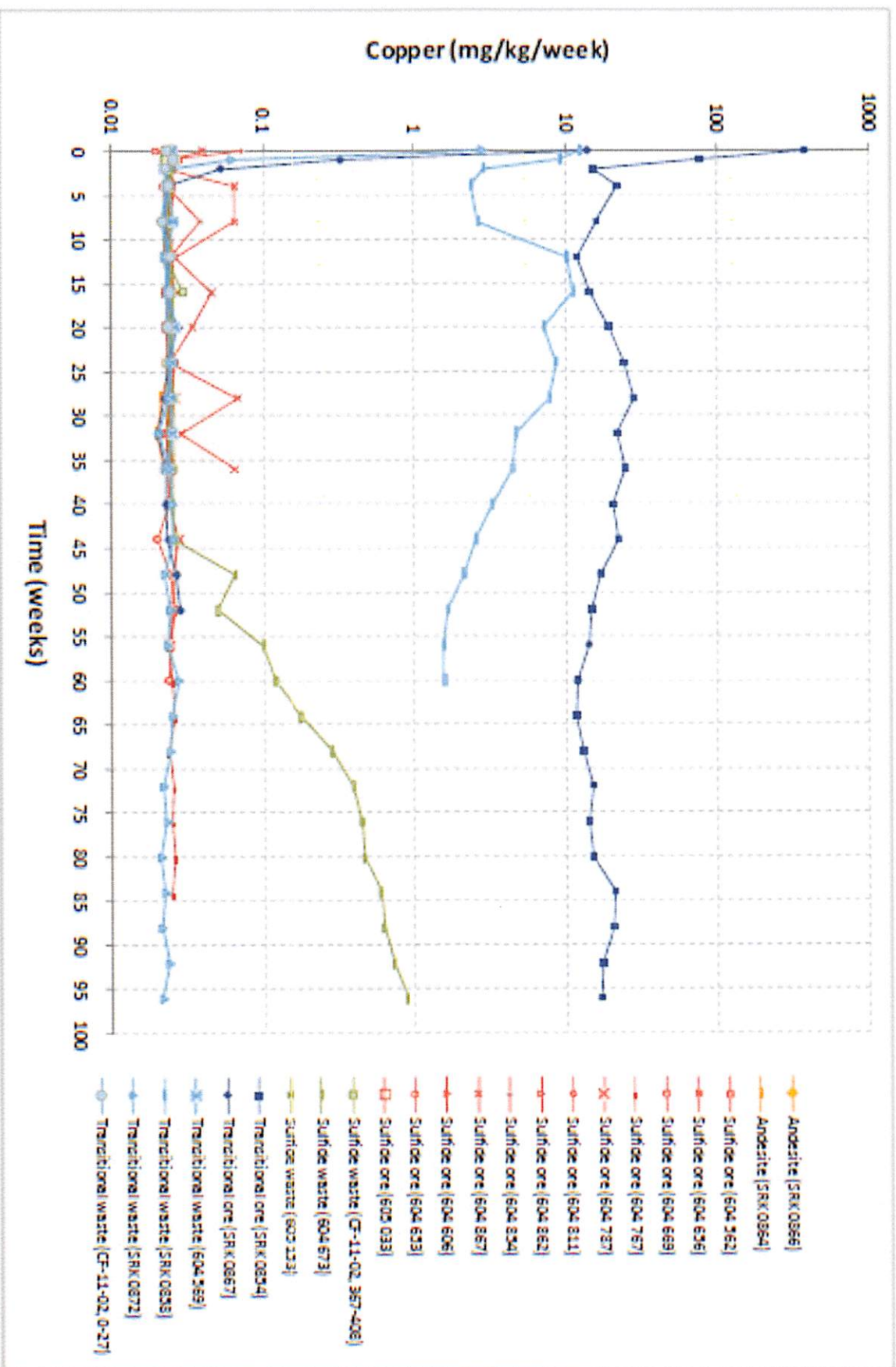
Number of samples representing material type

	Potentially acid forming (PAF)
	Potentially acid forming (PAF) lower capacity
	Non Acid Forming (NAF)

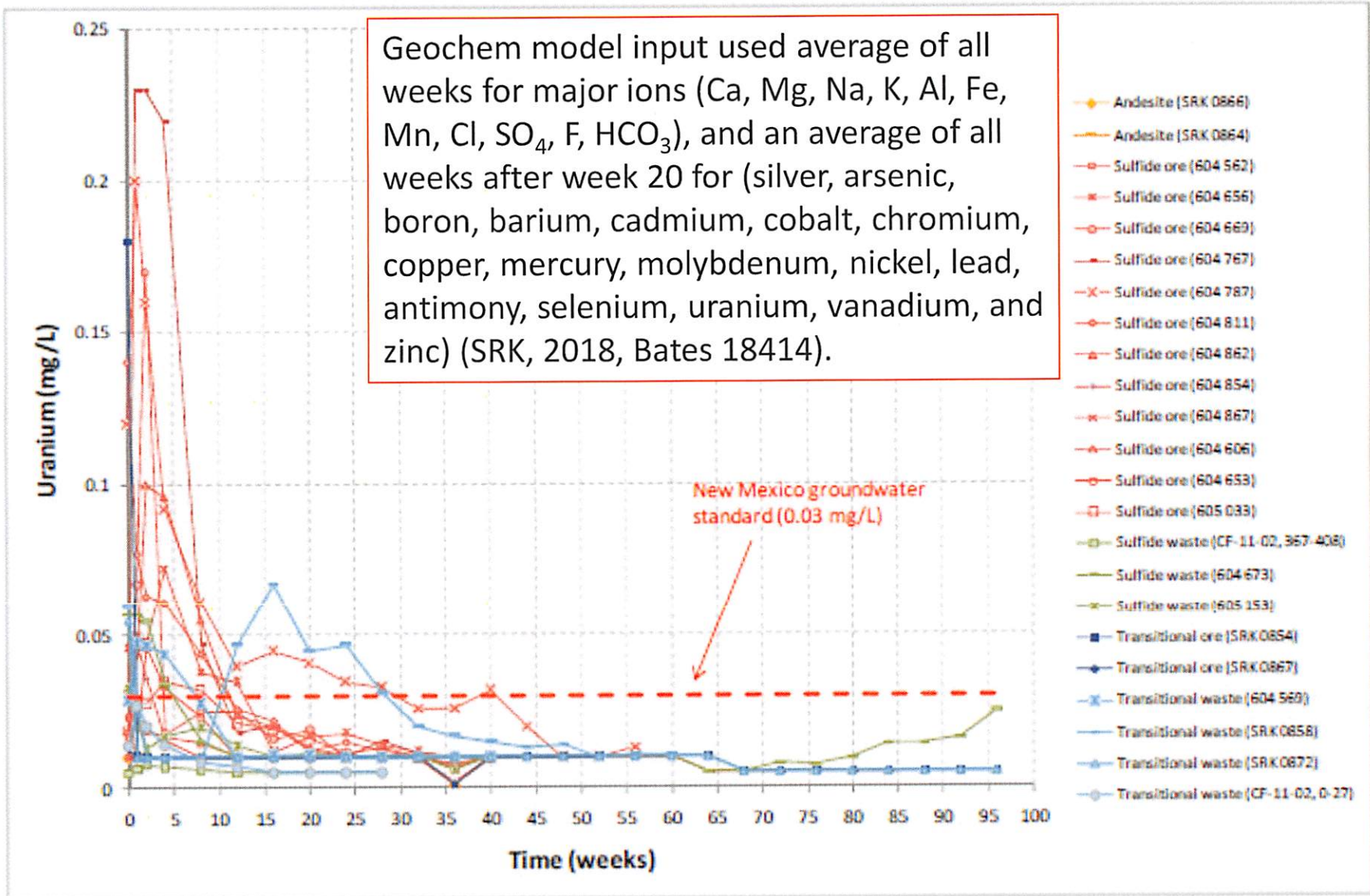
SRK (2013, Fig. 6-1, Bates 05601)



SRK (2013, Fig. 6-5, Bates 05603)



SRK (2013, Fig. 6-8, Bates 05605)



SRK (2013, Kinetic Testing Results)

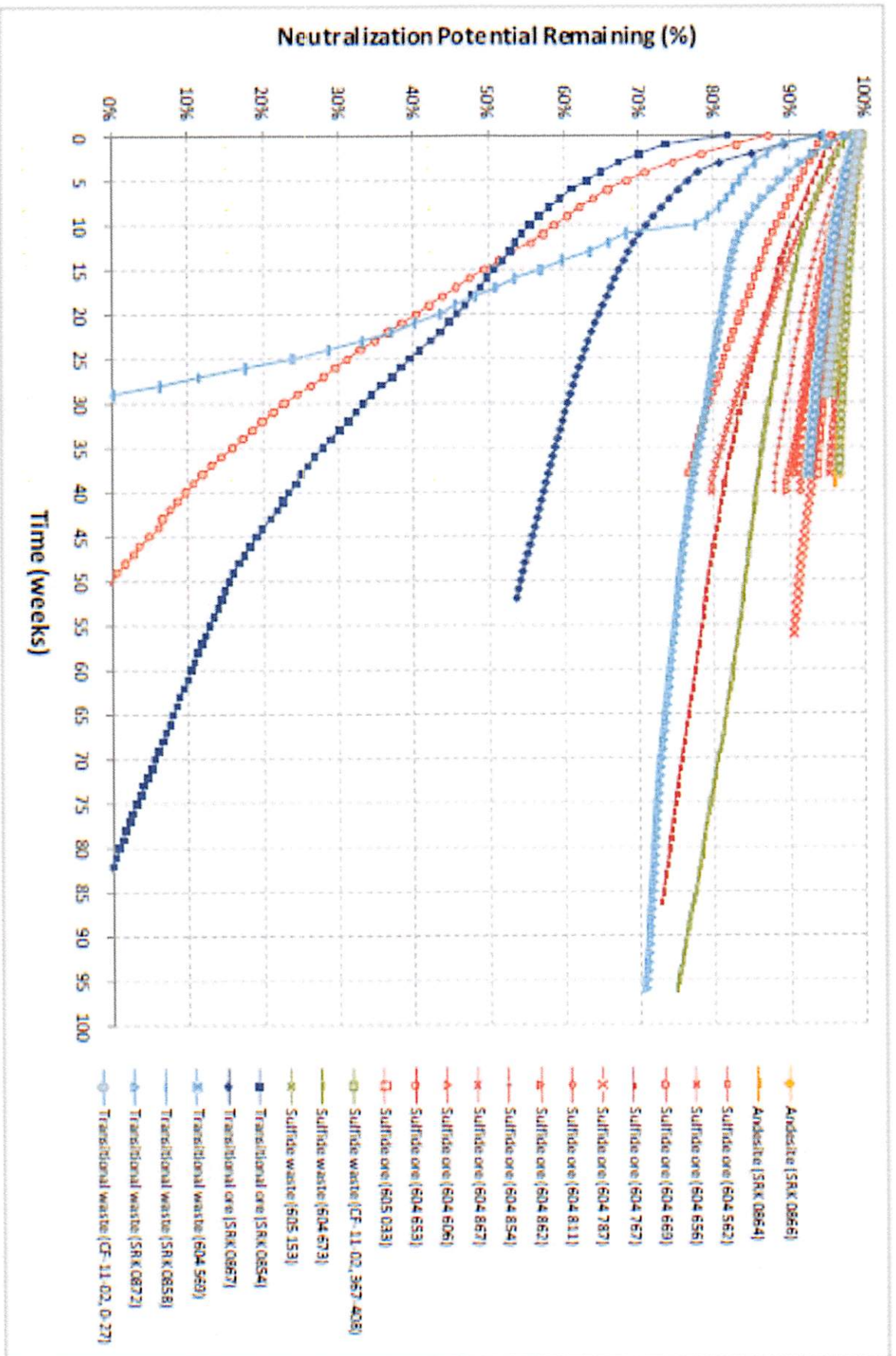
“How long? Data from 10 cells that operated from 3 to 7 years indicated there is roughly a 50% chance that a cell will geochemically stabilize after the first year and that this stability will persist for at least several years.

Geochemical stability is defined here as fluctuations in the last-five-week average of less than a factor of two above and below the long-term average. Thus, on average, 50% of cells can be terminated shortly after the first year of operation.

The remaining 50% must be operated for more than 3-5 years to obtain long-term stable rates.”

Morin, K.A., and N.M. Hutt. 1999. Humidity Cells: How Long? How Many? Proceedings of Sudbury '99, Mining and the Environment II, Volume 1, p.109-117, Sudbury, Canada, September 13-15.

SRK (2013, Fig. 6-10, Bates 05606)



SRK (2013, Fig. 6-11, Bates 05606)

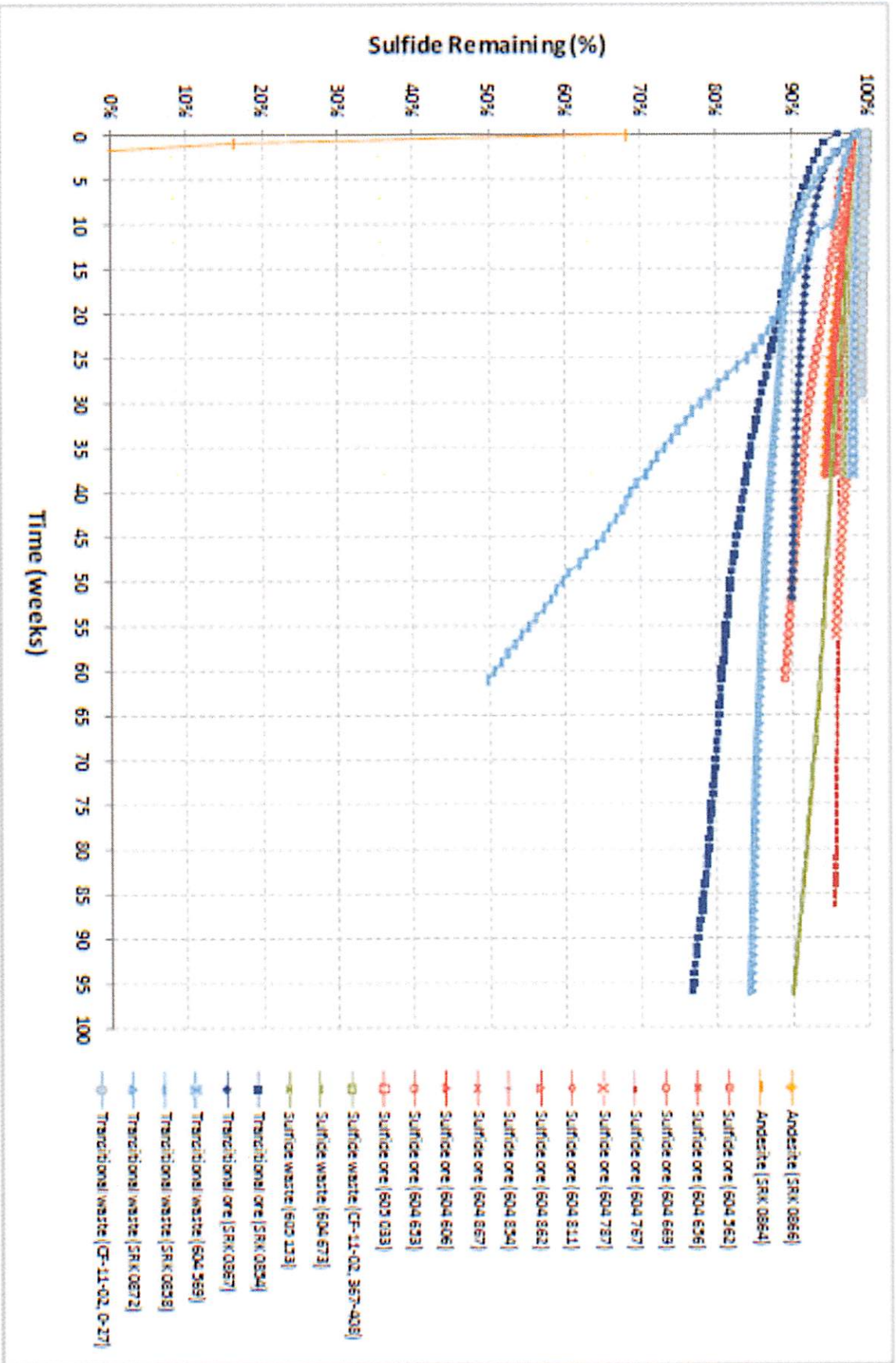


Table 6-2: Comparison of HCT results with static testwork results

Material type	Primary lithology	Cell ID	Acid Generation Prediction*		
			ABA	NAG	HCT
Andesite	Andesite	SRK 0864	NAF	NAF	NAF
	Andesite	SRK 0866	NAF	PAF	NAF
Sulfide waste	Biotite Breccia	605033	NAF	NAF	NAF
	Quartz Monzonite	604673	PAF	PAF	NAF
	Quartz Monzonite	605153	NAF	NAF	NAF
Sulfide ore	Biotite Breccia	604811	PAF	NAF	NAF
	Biotite Breccia	604862	NAF	NAF	NAF
	Biotite Breccia	604867	PAF	NAF	NAF
	Biotite Breccia	604854	PAF	NAF	NAF
	Quartz Feldspar Breccia	604767	PAF	PAF	NAF
	Quartz Feldspar Breccia	604787	PAF	NAF	NAF
	Quartz Monzonite	604562	PAF	NAF	NAF
	Quartz Monzonite	604606	NAF	NAF	NAF
	Quartz Monzonite	604669	PAF	NAF	NAF
	Quartz Monzonite	604653	NAF	NAF	NAF
	Quartz Monzonite	604656	NAF	NAF	NAF
Transitional waste	Biotite Breccia	SRK 0872	PAF	PAF	NAF
	Quartz Monzonite	604569	PAF	NAF	NAF
	Quartz Monzonite	SRK 0858	PAF	PAF	PAF
Transitional ore	Biotite Breccia	SRK 0854	PAF	PAF	PAF
	Quartz Monzonite	SRK 0867	PAF	NAF	NAF
Tailings	CF-11-02 (52-117) flotation tailings		NAF	-	NAF
	CF-11-02 (227-367) flotation tailings		NAF	-	NAF
	K-spar Breccia 0-5 comp. flotation tailings		NAF	-	NAF
	K-spar Breccia 5+ comp. flotation tailings		NAF	-	NAF
	Biotite Breccia 0-5 comp. flotation tailings		NAF	-	NAF
	Biotite Breccia 5+ comp. flotation tailings		NAF	-	NAF
	Quartz Monzonite 0-5 comp. flotation tailings		NAF	-	NAF
	Quartz Monzonite 5+ comp. flotation tailings		NAF	-	NAF
	Cu Ro. tailings		NAF	-	NAF

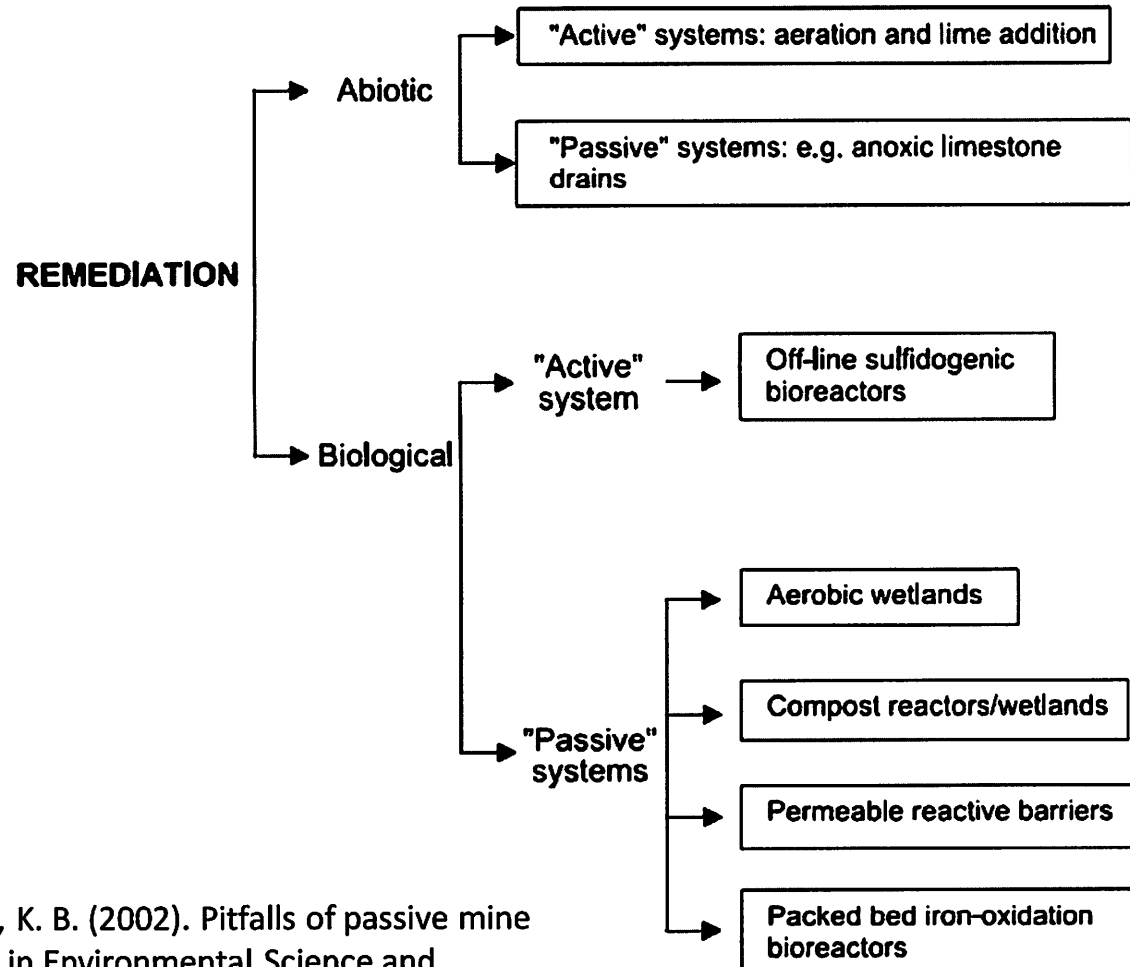
* PAF = Potentially Acid Forming; NAF = Non-Acid Forming

SRK (2013, Table 6-2, Bates 05612)

Because kinetic HCT data did not match static test results (i.e., geochemical data uncertainty), static data was interpreted as over-estimating ARD potential, and kinetic HCT mixed data approach was applied for geochemical model predictions of pit lake, WRSP discharge, and TSF discharge contaminant concentrations.

The full range of data was not considered, and an alternative conclusion is that the HCT data underestimated ARD potential.

Remediation options for ARD; figure reproduced from Johnson and Hallberg (2005)



Johnson, D. B., & Hallberg, K. B. (2002). Pitfalls of passive mine water treatment. *Reviews in Environmental Science and Biotechnology*, 1(4), 335–343.

Remediation options for sulfate groundwater contamination plumes

- Pump and treat is the standard method used for remediation of groundwater for which sulfate is the primary contaminant. This approach is effective at controlling the contaminant plume, but is generally cost and time intensive.
- In situ reduction methods are also possible (e.g., zero valent iron, electron-donor substrates)

Miao, Z., M.L. Brusseau, K.C. Carroll, C. Carreón Diazconti, and B. Johnson (2012) Sulfate Reduction in Groundwater: Characterization and Applications for Remediation. *Environmental Geochemistry and Health*, 34(4): 539-550.

JSAI (2018, Bates 18305)

“The sources of possible hydrologic consequences of the Project include:

1. Groundwater withdrawals from the SFG aquifer: The mine water supply will be withdrawn from pumping wells PW-1, PW-2, PW-3, and PW-4. Water level in the SFG aquifer will be lowered around the well field and then gradually recover after mining. Secondary effects evaluated include:

- a. Reduced groundwater discharge to Rio Grande and Caballo Reservoir.
- b. Reduced flow to artesian wells and other effects to local groundwater users.
- c. Potential reduced discharge to shallow aquifers along Animas Creek and Percha Creek, leading to lower alluvial water levels and reduced discharge to the perennial flow and riparian areas along Animas Creek.
- d. Potential ground subsidence.

2. Groundwater withdrawals from the crystalline bedrock associated with the open pit. Water levels in the bedrock around the pit will be permanently lowered, and groundwater will flow to the pit and evaporate. Groundwater flow rates to the pit and the future open pit water level and water balance area assessed. Secondary effects evaluated include:

- a. Potential groundwater discharge from the open pit.
- b. Potential effects on springs discharging from the crystalline bedrock and on the Percha Creek perennial (riparian) area.

3. Potential for groundwater discharge from the tailings storage facility (TSF) and waste rock stockpiles (WRSPs).”

DP-1840 Summary:

- Current pit lake has been proven to be impacted by ARD (i.e., acid rock drainage and/or mine impacted water) generated from pit walls from 3 months of mining in 1980s. This type of material will also be in the future pit lake and in the waste rock stockpiles (WRSP).
- *Proposed permit condition:* Underlining liners and overlying covers (both low permeability materials) for WRSPs outside of open pit hydraulic sink should be installed as part of closure/reclamation.
- Current groundwater has been proven to be impacted by ARD or mine impacted discharge from 3 months of mining in 1980s. Discharge of ARD or mine impacted discharge from mine facilities outside of open pit hydraulic sink occurred in the past, and is likely to occur during proposed mining.
- *Proposed permit condition:* Underlining liners and overlying covers (both low permeability materials) for tailings storage facility (TSF) outside of open pit hydraulic sink should be installed as part of closure/reclamation.
- Current reclamation plan will remove all mine impacted water collection impoundments and will not include contaminated groundwater interceptor system. However, existing groundwater has been contaminated, and has not been abated.
- *Proposed permit condition:* Include groundwater interceptor system to abate current and future migration of groundwater contamination, and include mine impacted water collection impoundments for any discharge from WRSPs and TSF. Add monitoring wells to assess nature/extent of plume.
- Aquifer assessment did not consider uncertainty in either hydrogeologic or geochemical modeling input data, which limits groundwater impact predictive capability.
- *Proposed permit condition:* Include full range of geochemical and hydrogeologic data in aquifer assessment predictions.
- Appropriate financial considerations should include long-term closure and contamination cleanup.