CHAPTER 18

PROBABLE HYDROLOGIC CONSEQUENCES

CHAPTER 18

INDEX

Revised 09/10/04

INDEX (Cont.)

LIST OF FIGURES

LIST OF TABLES

Revised 09/10/04

LIST OF TABLES (Cont.)

LIST OF ATTACHMENTS

CHAPTER 18

PROBABLE HYDROLOGIC CONSEQUENCES

Introduction

This chapter contains a discussion of the probable hydrologic consequences of the life-of-mine mining plan upon the quality and quantity of surface and ground water for the proposed permit and adjacent areas. The significance of each impact or potential impact is determined. The determination of significance has been made considering the impact of any probable hydrologic consequence on: (1) the quality of the human environment; (2) any critical habitats or important plant species; or (3) any threatened and endangered wildlife species within the proposed life-of-mine permit and adjacent areas.

Ground Water

Interruption of Ground-Water Flow and Drawdown. A comparison of five year average Wepo water level contours and isopach maps which show pit bottom contour elevations for all areas to be mined, along with review of historic and recent records, indicates that portions of the J-1/N-6, N-2, N-7, N-10, N-11, J-16, J-19/20 and J-21 pits have already or will intercept the upper part of the Wepo aquifer for some period during the life of the mining areas. Review of Wepo water level contours developed from recent data (1995-2003) and actual field observations during mining indicate that pits in the J-7, J-23, N-9, and N-14 mining areas will not intercept the Wepo aquifer. Flow in the portions of the Wepo aquifer truncated by overburden and coal removal will be intercepted since the ground-water gradient will rapidly orient itself in the direction of the sinks (pits).

Previously developed estimates of Wepo ground-water inflow to the above-identified pits are presented in Tables 1 through 7, respectively. These estimates were prepared assuming that the total inflow would be derived from two principal sources: (1) the interception of pre-mining flow rates under a natural hydraulic gradient; and (2) the drainage of ground water from storage in the aquifers. It is assumed that the major portion of the Wepo ground-water inflow would be derived from lateral flow along bedding planes and fractures. Upward leakage from underlying aquifers was assumed to be negligible.

Two different techniques have been used to estimate the rates of groundwater inflow into the pits, depending on the technology available at the time the estimates were developed. Approach A was used for pits J-1/N-6, N-10, N-11, N-14, and J-16. This approach,

TABLE 1

Pit Inflows by Year for N-10

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (L_W) (Ft)	Days in Water (t) (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted T_F-Transmissivity (Gal/Day/Ft)	Weighted $T_{L,R}$ (Ft^2/Day)	I-Gradient (Ft/Ft)	Weighted Q_F (Gal/Yr)	Weighted Q_L (Gal/Yr)	Weighted Q_R (Gal/Yr)	Q_T (Gal/Yr)
2002*	8913	-	-	24.4	-	-	.018	-	-	-	-
2003*	8913	-	-	24.4	-	-	.018	-	-	-	-
2004*	8913	-	-	24.4	-	-	.018	-	-	-	-
2005	8913	1081	44	24.4	16.1	2.2	.018	20,833.0	12,541.0	832.0	34,206.0
2006	9566	2810	107	26.2	14.43	1.93	.018	123,834.2	34,176.8	271.0	158,282.0
2007	9566	2810	107	26.2	14.43	1.93	.018	243,574.7	67,223.8	533.1	311,331.6
2008	9566	2810	107	26.2	14.43	1.93	.018	331,589.0	91,514.8	725.8	423,829.6
2009	9566	2810	107	26.2	14.43	1.93	.018	324,425.1	89,537.6	710.1	414,672.8

*No mined area in water

TABLE 2

Pit Inflows by Year for N-11

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (Ft)	Days in Water (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted Transmissivity (Sq Ft/Day)	Saturated Depth of Pit (Ft)	I-Gradient (Ft/Ft)	QNatural Q_F (Gal/Yr)	QDrainage Q_L (Gal/Yr)	QTotal Q_T (Gal/Yr)
1995	3000.0	3000.0	182	16.5	0.556	[illegible]	.025	85309.0	5216.1	90525.2
1996	10500.0	3115.4	54	57.7	0.404	10.1	.025	79434.4	2875.9	82310.2
1997	4300.0	2150.0	91	23.6	0.244	6.1	.025	31294.0	725.6	32019.6
1998	8400.0	1110.7	16	69.4	0.146	3.6	.025	10780.7	179.5	10960.2
1999	13600.0	409.9	11	37.3	0.100	2.5	.025	2759.2	15.6	2774.8
2000	14700.0	483.3	12	40.3	0.100	2.5	.025	3249.0	18.4	3267.3
2001	6050.0	864.3	26	33.2	0.167	4.2	.025	9475.9	136.6	9612.5
2002	6400.0	1441.8	41	35.2	0.180	4.5	.025	16694.2	265.3	16959.4
2003	6000.0	3000.0	91	33.0	0.200	5.0	.025	35791.8	681.0	36472.8
2004	4950.0	1251.1	46	27.2	0.100	2.5	.025	7989.6	71.3	8060.9

TABLE 3

Pit Inflows by Year for J-1/N-6

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (L_W) (Ft)	Days in Water (t) (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted T_F-Transmissivity (Gal/Day/Ft)	Weighted $T_{L,R}$ (Ft^2/Day)	I-Gradient (Ft/Ft)	Weighted Q_F (Gal/Yr)	Weighted Q_L (Gal/Yr)	Weighted Q_R (Gal/Yr)	Q_T (Gal/Yr)
1972	922.9	19022	230	82.8	15.62	2.09	.013	44,688.4	5,028.1	5.0	49,721.5
1973	8231.0	19022	230	82.8	15.62	2.09	.013	625,638.3	70,393.9	69.5	696,101.7
1976	6248.1	-	230	82.8	15.62	2.09	.013	-	-	-	-
1977	26884.5	19022	230	82.8	15.62	2.09	.013	357,507.6	40,225.1	39.7	397,772.4
1978	35861.7	19022	230	82.8	15.62	2.09	.013	312,819.2	35,197.0	34.7	348,050.9
1979	39728.3	19022	230	82.8	15.62	2.09	.013	89,376.9	10,056.3	9.9	99,443.1
1980	29750.0	19022	230	82.8	15.62	2.09	.013	580,950.0	65,365.8	64.5	646,380.3
1981	34894.6	19022	230	82.8	15.62	2.09	.013	1,251,276.6	140,787.8	138.9	1,392,203.3
1982	29099.1	19022	230	82.8	15.62	2.09	.013	1,161,899.7	130,731.5	129.0	1,292,760.2
1983	24919.2	19022	230	82.8	15.62	2.09	.013	759,703.7	85,478.3	84.3	845,266.3
1984	30432.7	19022	230	82.8	15.62	2.09	.013	357,507.6	40,225.1	39.7	397,772.4
1985	26086.4	19022	230	82.8	15.62	2.09	.013	625,638.3	70,393.9	69.5	696,101.7
1986	28823.9	19022	230	82.8	15.62	2.09	.013	1,027,834.4	115,647.1	114.1	1,143,595.6
1987	36682.7	19022	230	82.8	15.62	2.09	.013	670,326.8	75,422.0	74.4	745,823.2

TABLE 3 (Cont.)

Pit Inflows by Year for J-1/N-6

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (L_W) (Ft)	Days in Water (t) (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted T_F-Transmissivity (Gal/Day/Ft)	Weighted $T_{L,R}$ (Ft^2/Day)	I-Gradient (Ft/Ft)	Weighted Q_F (Gal/Yr)	Weighted Q_L (Gal/Yr)	Weighted Q_R (Gal/Yr)	Q_T (Gal/Yr)
1988	29419.0	19022	230	82.8	15.62	2.09	.013	1,027,834.4	115,647.1	114.1	1,143,595.6
1989	31053.9	19022	230	82.8	15.62	2.09	.013	1,161,899.7	130,731.5	129.0	1,292,760.2
1990	32628.5	19022	230	82.8	15.62	2.09	.013	1,251,276.6	140,787.8	138.9	1,392,203.3
1991	30389.0	19022	230	82.8	15.62	2.09	.013	1,340,653.5	150,844.1	148.8	1,491,646.4
1992	27524.8	19022	230	82.8	15.62	2.09	.013	1,072,522.8	120,675.3	119.0	1,193,317.1
1993	26580.3	19022	230	82.8	15.62	2.09	.013	1,519,407.3	170,956.6	168.6	1,690,532.5
1994	25946.6	19022	230	82.8	15.62	2.09	.013	1,430,030.4	160,900.4	158.7	1,591,089.5
1995	25453.2	19022	230	82.8	15.62	2.09	.013	1,698,161.1	191,069.2	188.5	1,889,418.8
1996	29076.9	19022	230	82.8	15.62	2.09	.013	1,698,161.1	191,069.2	188.5	1,889,418.8
1997	29076.9	19022	230	82.8	15.62	2.09	.013	1,698,161.1	191,069.2	188.5	1,889,418.8
1998	29076.9	19022	230	82.8	15.62	2.09	.013	1,742,849.6	196,097.3	193.4	1,939,140.3
1999	29076.9	19022	230	82.8	15.62	2.09	.013	1,876,914.9	211,181.7	208.3	2,088,304.9
2000	29076.9	19022	230	82.8	15.62	2.09	.013	2,145,045.6	241,350.5	238.1	2,386,634.2
2001	39153.8	19022	230	82.8	15.62	2.09	.013	2,860,060.9	321,800.7	317.4	3,182,179.0

TABLE 3 (Cont.)

Pit Inflows by Year for J-1/N-6

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (L_W) (Ft)	Days in Water (t) (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted T_F-Transmissivity (Gal/Day/Ft)	Weighted $T_{L,R}$ (Ft^2/Day)	I-Gradient (Ft/Ft)	Weighted Q_F (Gal/Yr)	Weighted Q_L (Gal/Yr)	Weighted Q_R (Gal/Yr)	Q_T (Gal/Yr)
2002	39153.8	19022	230	82.8	15.62	2.09	.013	2,860,060.9	321,800.7	317.4	3,182,179.0
2003	39153.8	19022	230	82.8	15.62	2.09	.013	2,860,060.9	321,800.7	317.4	3,182,179.0
2004	39153.8	19022	230	82.8	15.62	2.09	.013	2,860,060.9	321,800.7	317.4	3,182,179.0
2005	39153.8	19022	230	82.8	15.62	2.09	.013	2,860,060.9	321,800.7	817.4	3,182,179.0
2006	39153.8	19022	230	82.8	15.62	2.09	.013	2,860,060.9	321,800.7	317.4	3,182,179.0

*No mined area in water

TABLE 4

Pit Inflows by Year for N-14

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (L_W) (Ft)	Days in Water (t) (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted T_F-Transmissivity (Gal/Day/Ft)	Weighted $T_{L,R}$ (Ft^2/Day)	I-Gradient (Ft/Ft)	Weighted Q_F (Gal/Yr)	Weighted Q_L (Gal/Yr)	Weighted Q_R (Gal/Yr)	Q_T (Gal/Yr)
N-14 Main Pit:											
1982	47614	18552	273	68.0	40.28	5.39	.029	1,834,230.2	49,554.8	73.4	1,883,858.4
1983	42445	18552	273	68.0	40.28	5.39	.029	9,262,862.7	250,251.5	370.9	9,513,485.1
1984	33709	18552	273	68.0	40.28	5.39	.029	9,904,843.3	267,595.7	396.6	10,172,835.6
1985	31025	18552	273	68.0	40.28	5.39	.029	11,830,785.1	319,628.2	473.7	12,150,887.0
1986	24923	18552	273	68.0	40.28	5.39	.029	10,271,689.3	277,506.7	411.3	10,549,607.3
1987	25231	18552	273	68.0	40.28	5.39	.029	10,363,400.9	279,984.4	414.9	10,643,800.2
1988	26538	18552	273	68.0	40.28	5.39	.029	10,913,669.9	294,850.8	437.0	11,208,957.7
1989	18077	18552	273	68.0	40.28	5.39	.029	7,428,632.5	200,696.8	297.4	7,629,626.7
1990	19308	18552	273	68.0	40.28	5.39	.029	7,978,901.5	215,563.2	319.5	8,194,784.2
1991	9385	18552	273	68.0	40.28	5.39	.029	3,851,883.5	104,065.0	154.2	3,956,102.7
1992	8769	18552	273	68.0	40.28	5.39	.029	3,668,460.5	99,109.5	146.9	3,767,716.9
1993	10769	18552	273	68.0	40.28	5.39	.029	4,402,152.6	118,931.4	176.2	4,521,260.2

TABLE 4 (Cont.)

Pit Inflows by Year for N-14

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (L_W) (Ft)	Days in Water (t) (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted T_F-Transmissivity (Gal/Day/Ft)	Weighted $T_{L,R}$ (Ft^2/Day)	I-Gradient (Ft/Ft)	Weighted Q_F (Gal/Yr)	Weighted Q_L (Gal/Yr)	Weighted Q_R (Gal/Yr)	Q_T (Gal/Yr)
N-14 Eastern Pit:											
1989	10538	7970	277	28.8	30.3	4.05	.035	3,200,037.8	75,721.8	208.3	3,275,967.9
1990	6963	7970	277	28.8	30.3	4.05	.035	2,042,881.2	48,340.3	133.0	2,091,354.5
1991	13848	7970	277	28.8	30.3	4.05	.035	3,471,469.6	82,144.7	226.0	3,553,840.3
1992	14331	7970	277	28.8	30.3	4.05	.035	4,028,619.0	95,328.4	262.3	4,124,209.7
1993	6853	7970	277	28.8	30.3	4.05	.035	1,542,875.4	36,508.8	100.4	1,579,484.6

TABLE 5

Pit Inflows by Year for J-16

Pit Year	Total Length of Pit (Ft)	Constant Length of Water (L_W) (Ft)	Days in Water (t) (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted T_F-Transmissivity (Gal/Day/Ft)	Weighted $T_{L,R}$ (Ft^2/Day)	I-Gradient (Ft/Ft)	Weighted Q_F (Gal/Yr)	Weighted Q_L (Gal/Yr)	Weighted Q_R (Gal/Yr)	Q_T (Gal/Yr)
1982	8025.1	12671	255	49.7	46.99	6.28	.03	3,997,316.8	66,484.1	155.0	4,063,955.9
1983	19457.8	12671	255	49.7	46.99	6.28	.03	8,882,926.2	147,742.5	344.4	9,031,013.1
1984	21463.2	12671	255	49.7	46.99	6.28	.03	6,395,706.9	106,374.6	247.9	6,502,329.4
1985	21041.5	12671	255	49.7	46.99	6.28	.03	4,885,609.4	81,258.4	189.4	4,967,057.2
1986	17514.9	12671	255	49.7	46.99	6.28	.03	5,773,902.0	96,032.6	223.9	5,870,158.5
1987	18019.3	12671	255	49.7	46.99	6.28	.03	5,063,267.9	84,213.2	196.3	5,147,677.4
1988	19613.6	12671	255	49.7	46.99	6.28	.03	7,461,658.0	124,103.7	289.3	7,586,051.0
1989	17523.7	12671	255	49.7	46.99	6.28	.03	4,707,950.9	78,303.5	182.5	4,786,436.9
1990	20874.2	12671	255	49.7	46.99	6.28	.03	9,238,243.2	153,652.2	358.2	9,392,253.6
1991	15936.0	12671	255	49.7	46.99	6.28	.03	7,106,341.0	118,194.0	275.5	7,224,810.5
1992	16162.8	12671	255	49.7	46.99	6.28	.03	7,994,633.6	132,968.3	310.0	8,127,911.9
1993	15615.0	12671	255	49.7	46.99	6.28	.03	7,816,975.1	130,013.4	303.1	7,947,291.6
1994	14308.0	12671	255	49.7	46.99	6.28	.03	7,195,170.2	119,671.4	279.0	7,315,120.6
1995	4615.0	12671	255	49.7	46.99	6.28	.03	2,309,560.8	38,413.1	89.5	2,348,063.4

TABLE 6

Pit Inflows by Year for J-19/J-20

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (Ft)	Days in Water (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted Transmissivity (Sq Ft/Day)	Saturated Depth of Pit (Ft)	I-Gradient (Ft/Ft)	QNatural Q_F (Gal/Yr)	QDrainage Q_L (Gal/Yr)	QTotal Q_T (Gal/Yr)
1994	9260.0	5961.9	47	126.8	2.288	57.2	.026	907283.6	330428.4	1237712.0
1995	10100.0	7056.2	51	138.4	2.424	60.6	.026	1130980.6	402844.1	1533824.7
1996	9100.0	7746.3	103	75.2	2.696	67.4	.026	1267192.7	314757.8	1581950.5
1997	10724.6	8603.3	73	117.9	4.400	110.0	.026	2414708.2	587682.7	3002391.0
1998	12700.0	8921.5	85	105.0	4.616	115.4	.026	2570887.4	505601.0	3076488.4
1999	14650.0	9051.4	112	80.5	4.172	104.3	.026	2256621.3	359062.6	2615683.9
2000	11500.0	6318.7	100	63.2	4.600	115.0	.026	1777787.6	268407.3	2046194.9
2001	11600.0	6118.7	96	63.7	3.504	87.6	.025	1266648.5	226660.6	1493309.1
2002	19400.0	13606.6	256	53.2	2.620	65.5	.025	1583271.3	285222.3	1868493.6
2003	11200.0	8184.6	133	61.5	2.704	67.6	.025	1233283.3	261317.5	1494600.7
2004	11250.0	8221.2	133	61.8	2.312	57.8	.025	1059201.2	241672.6	1300873.8
2005	10200.0	7341.8	131	56.0	2.548	63.7	.025	1045953.3	227050.5	1273003.8
2006	9000.0	6082.4	123	49.5	3.192	79.8	.025	1100077.7	213444.3	1313522.0
2007	7900.0	5816.5	134	43.4	3.144	78.6	.025	1017352.9	202194.6	1219547.4

TABLE 6 (Cont.)

Pit Inflows by Year for J-19/J-20

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (Ft)	Days in Water (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted Transmissivity (Sq Ft/Day)	Saturated Depth of Pit (Ft)	I-Gradient (Ft/Ft)	QNatural Q_F (Gal/Yr)	QDrainage Q_L (Gal/Yr)	QTotal Q_T (Gal/Yr)
2008	8050.0	7121.2	161	44.2	2.848	71.2	.025	1077085.8	233004.2	1310090.0
2009	7450.0	4912.1	120	40.9	3.640	91.0	.025	1018114.0	186559.8	1204673.8
2010	12000.0	7002.7	213	32.9	4.124	103.1	.025	1398711.1	191947.9	1590659.0
2011	12200.0	8590.1	257	33.4	3.532	88.3	.025	1344654.6	213652.6	1558307.2
2012	6250.0	5666.2	165	34.3	3.060	76.5	.025	914333.7	192921.0	1107254.7
2013	13300.0	8307.9	228	36.4	4.052	101.3	.025	1583225.1	225159.4	1808384.5
2014	6850.0	5457.4	145	37.6	3.344	83.6	.025	996501.4	196560.4	1193061.8
2015	14300.0	11714.2	299	39.2	3.712	92.8	.025	1756376.8	300230.5	2056607.3
2016	15600.0	7992.3	187	42.7	3.828	95.7	.016	995945.9	325509.8	1321455.7
2017	16300.0	5805.5	130	44.7	3.592	89.8	.016	749964.1	227498.2	977462.3
2018	16600.0	9095.9	200	45.5	3.752	93.8	.016	1084411.6	365670.0	1450081.6
2019	13100.0	9116.2	254	35.9	4.464	111.6	.016	1161572.4	408826.0	1570398.4
2020	12700.0	8931.9	128	69.8	2.724	68.1	.016	875014.9	437039.9	1312054.8

TABLE 6 (Cont.)

Pit Inflows by Year for J-19/J-20

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (Ft)	Days in Water (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted Transmissivity (Sq Ft/Day)	Saturated Depth of Pit (Ft)	I-Gradient (Ft/Ft)	QNatural Q_F (Gal/Yr)	QDrainage Q_L (Gal/Yr)	QTotal Q_T (Gal/Yr)
2021	12500.0	9710.7	94	103.3	2.740	68.5	.016	1007855.7	615183.6	1623039.3
2022	15833.1	7851.1	60	130.9	2.010	50.2	.016	629234.2	422313.3	1051547.5
2023	16100.0	6652.9	50	133.1	2.240	56.0	.016	603724.5	371867.0	975591.5
2024	6812.5	2270.8	15	151.4	1.948	48.7	.016	186882.2	187930.3	374812.6
2025	10780.0	4282.5	29	147.7	1.880	47.0	.016	338205.3	242843.6	581048.9
2026	18033.1	5663.3	38	149.0	2.068	51.7	.016	482869.1	272664.1	755533.2
2027	6966.7	2878.8	50	57.6	2.010	50.2	.016	234182.9	130768.6	364951.6

TABLE 7

Pit Inflows by Year for J-21

Pit Year	Total Length of Pit (Ft)	Constant Length to Face (Ft)	Days in Water (Day)	Constant Pit Adv./Day (Ft/Day)	Weighted Transmissivity (Sq Ft/Day)	Saturated Depth of Pit (Ft)	I-Gradient (Ft/Ft)	QNatural Q_F (Gal/Yr)	QDrainage Q_L (Gal/Yr)	QTotal Q_T (Gal/Yr)
1990	13000.0	571.4	8	71.4	0.350	2.5	.017	9168.2	48.1	9216.4
1991	21300.0	1521.4	13	117.0	0.812	5.8	.017	56239.5	684.8	56924.3
1992	21800.0	2275.8	19	119.8	1.008	7.2	.017	103556.7	1576.5	105133.1
1993	20350.0	2683.5	24	111.8	1.316	9.4	.017	158295.9	3163.6	161459.6
1994	17000.0	2335.2	25	93.4	1.092	7.8	.017	114138.8	1897.5	116036.3
1995	19750.0	3364.0	31	108.5	1.498	10.7	.017	223637.8	5135.2	228773.0
1996	17250.0	2938.2	31	94.8	1.379	9.8	.017	179812.4	3802.5	183614.9
1997	18300.0	4265.3	46	100.5	1.512	10.8	.017	303690.0	7192.8	310882.8
1998	14800.0	5611.0	69	81.3	1.470	10.5	.017	346115.6	8248.8	354364.5
1999	15200.0	5345.1	64	83.5	1.512	10.8	.017	341700.9	8312.1	350013.0
2000	18100.0	2983.5	30	99.5	1.526	10.9	.017	202339.5	4725.8	207065.3
2001	34500.0	9546.6	101	94.5	1.456	10.4	.017	556762.6	9179.5	565942.1
2002	35000.0	9013.7	94	95.9	1.680	12.0	.017	613299.0	11531.0	624830.0
2003	34900.0	764.9	8	95.6	1.512	10.8	.017	53165.9	793.0	53958.9

TABLE 7 (Cont.)

Pit Inflows by Year for J-21

Pit Year	Total Length of Pit (Ft)	Constant Length in Water (Ft)	Days in Water (Day)	Constant Pit Adv./Day (Ft/Day)	Weithted Transmissivity (Sq Ft/Day)	Saturated Depth of Pit (Ft)	I-Gradient (Ft/Ft)	QNatural Q_F (Gal/Yr)	QDrainage Q_L (Gal/Yr)	QTotal Q_T (Gal/Yr)
2004	30000.0	6164.4	75	82.2	1.596	11.4	.017	410342.9	7118.8	417461.7
2005	31500.0	11909.6	138	86.3	2.002	14.3	.017	898951.1	21618.4	920569.5
2006	32400.0	11983.6	135	88.8	2.212	15.8	.017	1004472.0	26544.4	1031016.4
2007	29400.0	9021.4	112	80.5	2.324	16.6	.017	825125.1	22053.3	847178.4
2008	29500.0	8001.4	99	80.8	1.862	13.3	.017	598661.9	12567.9	611229.8
2009	29000.0	6117.8	77	79.5	1.750	12.5	.017	445176.4	8490.5	453666.9
2010	30100.0	5112.9	62	82.5	1.148	8.2	.017	249662.8	3060.2	252723.0
2011	32000.0	3506.8	40	87.7	0.966	6.9	.017	148830.8	1487.7	150318.5
2012	33900.0	1578.9	17	92.9	0.588	4.2	.017	42145.6	249.0	42394.6

described in more detail below, sums flow rates calculated from equations for steady flow under a hydraulic gradient, and transient, confined flow toward a linear drain (representing the sides of an approximately linear cut) and toward a well (representing the ends of the cut). The second approach (Approach B) was developed later, and applied to J-16, J-19/J-20, and J-21 in previous versions of this chapter, and to N-99 in the current version. This approach can be used to calculate inflow under unconfined and/or confined conditions.

Approach A - Aquifer and pit characteristics and the definitions of terms used in pit inflow calculations may be found in Attachment 1. Pre-mining flow calculations are based on the following form of Darcy's law:

Q = TIL

Where:

Q = Quantity of water flowing through the aquifer at the proposed highwall locations in gal./day.

T = Transmissivity of the exposed aquifer in gal./day/ft.

I = Natural hydraulic gradient in ft./ft.

L = Length of aquifer exposed in the highwall normal to the natural hydraulic gradient in ft.

Aquifer testing at Wepo monitoring wells indicates that water in the Wepo aquifer is under some confining pressure. Some of the coal seams have very low hydraulic conductivities and act as aquitards. Water in the alluvium is believed to be in both unconfined and confined conditions depending on depth and location. Those units in the Wepo aquifer believed to transmit water are most of the coal seams and sandstone units below the prevailing water level. Alluvial ground water is assumed to flow from the entire saturated thickness of the alluvium.

In Approach A, the removal of ground water from aquifer storage was calculated using two equations; one to compute the radial component of inflow to the ends of a pit and the other to compute the linear component of inflow to the longitudinal sections of the pit. Radial inflow to each end of the pit was calculated using the following constant drawdown-variable discharge equation (Jacob and Lohman 1952 and Lohman 1972, pp. 23-24).

$$Q = 2\pi T G(\alpha) s$$

$$\alpha = \frac{Tt}{Sr_w^2}$$

Where:

Q = Radial discharge into one end of the pit in ft^3/day

T = Transmissivity of the exposed aquifer in ft^2/day

S = Storage coefficient

s = Drawdown in the aquifer at the pit face in ft.

r_w = Radius of the pit opening in ft.; equal to ½ the width of the initial box cut

$G(\alpha)$ = The G function of α (see Lohman, 1972, p. 23)

t = Time since discharge began in days

The linear portion of inflow from aquifer storage was calculated using the constant drawdown-variable discharge drain equation derived by Stallman (Lohman, 1972, pp. 41-43):

$$q = \frac{2s\sqrt{ST}}{\sqrt{\pi t}}$$

Where:

q = Discharge from an aquifer to both sides of a drain per unit length of drain in ft^2/day

S = Storage coefficient

s = Drawdown in water level at drain in ft.

T = Transmissivity of exposed aquifer in ft^2/day

t = Time since drain began discharging in days

With confined aquifer conditions, lowering of the water level occurs with the lowering of hydrostatic head. The release of water from aquifer storage under confined conditions is small per unit area, because it is only a function of the secondary effects of water expansion and aquifer compaction. After some length of exposure, the hydrostatic head may decline far enough that the aquifer becomes unconfined. Further declines in the water level would then be accompanied by significantly greater quantities of ground water discharge per unit area. It is assumed that during the life of the pits, ground water flow in the affected portions of the Wepo aquifer will remain under confined conditions or that the unconfined area would only extend a short distance from the pit.

The equation for radial inflow assumes that a constant concentric head surrounds each end of the pit. The actual situation representing radial flow to the ends of the pit can be described as an arc of a circle whose center coincides with the center of the pit. If "x" is the arc of the circle intersected by the pit ends, then:

$$Q_R = \frac{xQ}{360}$$

should approximate the actual radial discharge into the ends of the pit.

The variables used in the above-mentioned equations were determined as follows:

1. Transmissivity and storage coefficients were determined from aquifer tests and the thickness of the portion of the aquifer being intercepted.
2. Gradients were determined from water level contours of the Wepo aquifer (Drawing No. 85610).
3. Drawdowns at the pit face ranged from 3.9 to 13.4 ft./day using the calculation technique derived by McWhorter (1982, p. 28).
4. Pit lengths, lengths below water level and the number of days when ground water discharges into the pit were determined by overlaying pit bottom isopachs, annual pit disturbance maps, and Wepo water level contour maps.

To date, no mining pits have directly intercepted the alluvial aquifer. Should this ever occur, the previously described pit discharge equations require the following modifications. Ground water through flow in the alluvial aquifer will be calculated from:

Q = PIA

Where:

Q = Quantity of water flowing through the aquifer into the ends of the pit in gal./day

P = Permeability of the exposed aquifer in gal./day/ft^2

I = Natural hydraulic gradient in ft./ft.

A = Average cross sectional aquifer area through which the flow occurs in ft^2

Ground-water contribution from storage was calculated using the linear and radial flow equations with the following modifications:

$$s_o = s_o - \frac{s_o^2}{2b}$$

Where:

s_o = Observed change in water level in the mine pit

b = Saturated thickness of the exposed aquifer prior to pit development and dewatering

A possible additional source of ground-water inflow is induced recharge from the alluvial aquifer where the water level in the alluvial aquifer is at a higher elevation than the pit bottom. Trial computations were performed using the average flow velocity equation described by Lohman (1972, pp. 10-11):

$$v = \frac{K\left(\frac{\Delta h}{\Delta l}\right)}{\theta}$$

Where:

v = Average flow velocity in the aquifer in ft./day

K = Hydraulic conductivity of the permeable units in the segment of the Wepo Formation that the induced recharge would have to flow through before reaching the pit in ft./day.

$\Delta h / \Delta l$ = Ground water gradient between a chosen elevation in the aquifer at the highwall and the recharge boundary in ft./ft.

θ = Porosity of the permeable units of the Wepo aquifer.

Pit inflow estimates were determined for that portion of the total pit length and associated time intervals that each pit was assumed to be below water level. Calculations for each component of inflow were based on the sum of daily values, which incorporated a continually increasing pit length. Each component of inflow from the Wepo aquifer as well as the totals of all inflow components for each year are presented in Tables 1 through 4.

Trial computations suggest that the hydraulic conductivity of the Wepo Formation is so low that induced recharge cannot reach the pit before one or two rows of spoil have been placed back in thus precluding the induced recharge from ever reaching the active pit.

Approach B - This approach was developed to be able to calculate inflow rates under confined or unconfined conditions. If the confined option is selected, it is assumed that conditions are initially confined, but can become unconfined as water levels decline. The flow equations for confined and unconfined conditions are solved by numerical integration. The algorithm uses information on the rate of pit advance to calculate the daily inflow, and reports the inflow on an annual basis. However, it does not consider the effects of antecedent dewatering, and therefore tends to conservatively overestimate the inflow rate. This approach is described in detail in Appendix 2. This method was used to predict inflow rates for J-16, J-19/J-20, and J-21 (Tables 5 through 7).

The following procedures were used and assumptions made in estimating inflow to the N99 pit for calendar years 2005-2013:

- Wepo wells in the area surrounding the N99 pit were selected, and recent water level data were evaluated to determine whether water table elevations had changed significantly from those used in the calculation of the 1985 water-table map. The Wepo wells evaluated include: 38, 39, 40, 41, 42, 43, 44, 49, 52, 53, 54, 159, 178. Data available through May of 2003 were used in this evaluation.

  Although there were obvious trends in the data for the majority of the 13 wells, the most recent data point was used in this evaluation, since this should be most representative of the water table at start of mining in N99. These data were compared to the 1985 water table map, and revisions made as necessary. As a result of these comparisons, Drawing No. 85611, 2003 Wepo Water Level Contour Map, has been constructed (see Volume 23, PAP).

- The May 2003 water-table map was then compared with the anticipated elevations for the bottom of the N99 pit, and a 'difference' contour map was constructed that identified those areas where the 2003 water table was above the bottom of N99. The difference map indicates that the water table will be above base of pit along the majority of the eastern boundary, and in the northwestern section of N99 (in the area between pits N11 and N6). The difference map was then overlaid on the projected cuts for Calendar Years (CY) 2005-2013, which indicated that only those cuts in the northwestern section of the pit will encounter water within this time period. Cuts to be completed in CY2005-2007 are all located within the southwestern section of N99, and will therefore encounter minimal water. In Calendar Years 2008-2013, cuts will be made both within the southwestern section of N99, and in the northwestern section where water inflow to the cuts is expected.

- The analytical code Minel-2_3 was used to estimate the amount of flux entering the cuts in the northwestern section of N99 for CY2008-2013. [Minel-2_3 is a modification of Mine1-2 allowing pit geometry information to be input yearly, rather than using a single set of values for the entire mining period.] General parameters, and the selected values used as input to the code include:

- o The Wepo was simulated as confined, based on the lithology of the formation, and the low values of storage coefficient determined from aquifer tests.
- o The hydraulic conductivity was set to 0.03432 ft/day, which is the geometric mean of the 24 hydraulic conductivity values for Wepo wells listed in Table 32 (Chapter 15, Hydrologic Description, PAP). The arithmetic average conductivity value was not used, since this weighted the calculated value towards the fewer, significantly higher values of conductivity, and would have overestimated this parameter.
- o The regional hydraulic Gradient (0.014) was estimated from the May 2003 water-table map.
- o A conservative value for the storage coefficient ($1x10^{-4}$) was estimated from the larger of the two values presented in Table 32. Use of a lower value would result in lower values of inflow.

The remaining parameters are specific to the cuts within each calendar year, and include: saturated area; average width of cut; average saturated thickness, days open, and whether this was the first cut in the pit (inflow is assumed through both sides of the initial cut only).

There are two components that contribute to inflow into the cuts: flux controlled by the regional hydraulic gradient (termed $Q_{natural}$ in the code), and flux from water in storage (termed $Q_{drainage}$ in the code). The code assumes that the regional hydraulic gradient, and therefore the regional flux component, is perpendicular to the long axis of each cut. This assumption is generally valid for the southern two-thirds of the cuts located within the northwestern section of N99; however, the gradient is not perpendicular in the northern one-third of the cuts. In this area, groundwater discharge into the cuts will be less than if the gradient was perpendicular, and a correction factor must be applied to decrease the inflow appropriately (this is done outside of the code). Therefore, an approximate *dividing line* was identified between these two areas, separating Area A representing the northern one-third of the cuts, from Area B representing the southern two-thirds of the cuts, and the *area*, *saturated thickness*, and *days open* parameters were calculated separately for the sections of the cuts located within areas A and B. The correction used to calculate the regional component of inflow to the cuts in Area A is:

Corrected $Q_{natural}$ = $Q_{natural}$*([width of cut]*sin(alpha) + [length of cut]*cos(alpha))

Alpha is the angle between a line perpendicular to the length of the cut, and the regional hydraulic gradient. The first component within the parentheses represents flux across the end of the cut, and the second component represents flux across the length of the cut. Maximum inflow to the cuts occurs when the regional hydraulic gradient is perpendicular to the length of the cut (angle alpha is 0 degrees in the above equation), and minimum inflow occurs when the gradient is parallel to the length of the cut (angle alpha is 90 degrees - this results in flux across the end of the cut only).

The regional hydraulic gradient is approximately parallel to the cuts in CY10-13, indicating that the regional flux component is minimal and is simulated as occurring across the end of the cuts only. The cut within CY08 does not extend north of the *dividing line*. For the cuts in CY09, an angle of 45 degrees was used to calculate the regional flux component.

Total lengths for all cuts within the northeastern section of N99 for each calendar year were measured and summed in ArcView, and total areas were calculated. These were used to calculate average widths for each of the cuts as input to Mine1-2_3.

- Output from Mine1-2_3 includes values for $Q_{natural}$, $Q_{drainage}$, and Q_{total} for Areas A and B. For each of the cuts in Area A, a corrected $Q_{natural}$ value was calculated using the equation above, this value was added to $Q_{drainage}$, and a corrected Q_{total} determined. The corrected Q_{total} values were summed for each calendar year, and added to the corresponding Q_{total} values for that calendar year from Area B to derive a total flux per calendar year.

Results for N-99 are presented in Table 7a. [This nomenclature was adopted to avoid changes in table number throughout the remainder of this Chapter.] The predicted inflow varies from year to year because of changes in the length of the pits beneath the water table, and the estimated depth below the water table. In addition, drainage from two directions is assumed for the first year (2008), but from only one side in later years. The maximum estimated rate, which occurs in 2008, is approximately 10 gallons per minute (gpm); the lowest rate is predicted to be approximately 2.5 gpm, in 2010.

Table 7a. Estimated annual inflow for pit N-99 and length of time the base of the pit is below the pre-mining water table.

Year	**Inflow (gallons)**	**Total No. of Days in Water**
2008	1170710	84
2009	2105469	226
2010	485396	135
2011	607995	106
2012	1050225	264
2013	783849	241

For all pits including N99, the drawdown in the Wepo aquifer was estimated by using the predicted inflow rates and the analytical-element simulation program TWODAN (Fitts Geosolutions, 2000). This program solves the groundwater flow equations in two dimensions based on spatial and temporal superposition. Time-varying withdrawals can be simulated using wells. TWODAN solves a transient flow equation and can produce maps of drawdown. Although TWODAN can address cases where the aquifer is not continuous or infinite in extent, the limited drawdown that has been observed in Wepo wells in the vicinity of the pits indicated that it was not necessary to develop a more complex model incorporating the finite extent of the Wepo formation. The permeable units within the Wepo formation that have been mined or will be disturbed by mining are perched aquifers in some locations (e.g., J16 mining area near Wepo well 62R, J19 mining area near Wepo well 65), pinch out and/or are vertically displaced owing to some minor structure within the Peabody leasehold.

The estimated pit inflow rates change each year, because both the depth of the pit below the pre-mining water table and the length of time the pit is below the water table vary yearly. For each pit, the estimated inflow estimates were examined to determine if there was significant, systematic variation in the estimated inflow rate. If not, the average inflow rate was used in the model for each year that the pit was predicted to intercept the water table. If there was systematic variation, the time period was split into 2 or 3 periods of similar inflow, and the average inflow rate within each period was used. Thus, when a significant change in the estimated influx rate occurred, the change was incorporated in the model. When mining of a pit ceased, water production stopped, and inflow rate was set to zero. TWODAN simulates temporal changes in water budget by simulating discharge through wells. Two to five wells distributed around the perimeter and in the interior were used to represent each pit. The temporal changes in the location of the mining cuts within a pit are ignored.

The geometric mean of the hydraulic conductivities determined from aquifer tests of Wepo monitoring wells (Table 32, Chapter 15, Hydrologic Description, PAP), 0.03432 ft/d was used for the horizontal hydraulic conductivity of the Wepo, and the storage coefficient was set to 0.0001. The Wepo was assumed to be 200 feet thick uniformly through out the leasehold because of the limited depth of the pits, even though it is over 300 feet thick in the vicinity of these pits. This value was chosen to approximate the effect of partial penetration of the pits into the saturated Wepo, and to subtract the thickness of the Wepo above the water table. No recharge was assumed, which will cause drawdown to be over-predicted.

Figure 1 shows the locations of the 5-, 20-, 30-, 40-, 50-, 60-, and 65-foot drawdown contours, simulated using the TWODAN model, at the end of 2013. 2013 is the year when mining of N-99 below the water table and south of the beltline is scheduled for completion, and incorporates most of the mining currently underway or projected for the other pits such as J21. Thus, the drawdown contours shown on Figure 1 are cumulative of all past and proposed mining through 2013. A 5-foot drawdown cutoff was selected because natural water level fluctuations measured in the Wepo and alluvial monitoring wells on the PWCC leasehold are of that magnitude. Figure 1a shows the locations of the 5-, 20-, and 35-foot drawdown contours at the end of 2030. Both Figures 1 and 1a depict the locations of pre-existing shallow private wells and springs within and adjacent to the leasehold.

Table 8

Projected Pit Inflow Drawdowns at Well Locations Versus Measured Water Level Ranges at Alluvial and Wepo Monitoring Wells and Static Water Levels at Local Wells

PWCC Well Id	Pit Inflow Analysis Maximum Projected Drawdown (Feet)	Background Water Level Range Max	Background Water Level Range Min	Historic Water Level Range (1/88-1/95) Max	Historic Water Level Range (1/88-1/95) Min	Current Water Level Range (1998) Max	Current Water Level Range (1998) Min	Current Maximum Versus Background/ Historic Maximum
ALUV17	4	7.4	5.0	8.1	5.4	8.9	6.3	1.5 Ft deeper
ALUV23	30	18.6	15.6	18.1	16.0	17.6	16.6	No change
ALUV27R	42	-	-	26.7	21.5	28.3	26.7	1.6 Ft deeper
ALUV32R	30	-	-	Dry	1.1	Dry	Dry	No change
ALUV33R	10	5.3	3.1	5.0	2.9	5.0	3.3	No change
ALUV80R	4	11.7	8.9	12.9	10.6	10.8	10.5	No change
ALUV87	12	22.5	14.2	23.1	17.8	22.2	21.5	No change
ALUV88	50	4.3	1.3	3.6	1.2	3.7	1.6	No change
ALUV89R	50	-	-	5.0	2.5	5.0	3.0	No change
ALUV98R	42	-	-	14.3	9.6	13.0	11.6	No change
ALUV99R	23	-	-	13.8	9.8	15.0	13.0	1.2 Ft deeper
ALUV101R	30	Dry	Dry	Dry	Dry	Dry	Dry	No change
ALUV102	12	12.7	11.1	13.8	11.0	13.6	13.5	1.1 Ft deeper
ALUV108R	13	-	-	10.9	7.1	10.3	10.1	No change

Because the approach used to estimate the pit inflow rates does not take into consideration the decline in water levels caused by inflow into the pit in previous years, it will tend to over-estimate the pit inflow rate in the later years. In addition, the predicted inflow rates have tended to be considerably higher than observed during mining. For example, Western Water & Land (Water Waste and Land, 2003) noted

> The total [annual] inflows for pit J-1/N-6 were projected to range from approximately 50,000 gallons in 1972 to 3,182,179 gallons in 2003. As mining has progressed over the last several decades, it has generally been observed that pit inflows were overestimated, and in some cases no inflow has occurred at all. For example, initial mining of the southern portion of the N-6 Pit saw enough inflow to require pumping, but subsequent mining of this pit to the north has not resulted in any observed pit inflows.

In general, the drawdown estimates shown on Figure 1 are much larger and extend outward to distances much greater than has been observed in monitoring wells. No attempt was made to match these observations with the analytical model, as differences between the observed and estimated drawdown values would be expected. Most Wepo and many alluvial wells exhibit only a few feet of change during their period of record.

Table 8 presents a comparison of water-level changes predicted to occur because of dewatering of all the pits through 2013 with historical variability in currently active monitoring wells. Projected drawdowns, and water level ranges measured as background, during two historical periods of record (1988-1995, and 1995-2000), and during the most recent five-year period (2000-2004) are presented for both alluvial and Wepo monitoring wells. Table 8 also includes projected drawdown, historic completion and water level information, and an estimate of the percentage of available water height that may be lost due to pit inflows for two local wells (4K-389 and 8T-506) that were partially completed in the Wepo aquifer.

Table 8 shows current maximum water levels at six of the twenty-five Wepo monitoring wells are greater than background or historic maximum water levels. At WEPO62R, current maximum water levels are 72.4 feet deeper than background maximum water levels for WEPO62. This deepening exceeds the theoretical maximum projected drawdown for WEPO62R by

Table

Projected Pit Inflow Drawdowns at Well Locations Versus Measured Water Level Ranges at Alluvial and Wepo Monitoring Wells and Static Water Levels at Local Wells

PWCC Well Id	Pit Inflow Analysis Maximum Projected Drawdown (feet)	Background Water Level Range		Historic Water Level Range 1988-1995		Historic Water Level Range 1995-2000		Current Water Level Range 2000-2004		Current Maximum Versus Background/ Historic Maximum	Well Depth (dry wells) (only)
		Min	Max	Min	Max	Min	Max	Min	Max		
ALUV13R(a)	36.0	-	-	22.5	28.9	25.7	29.4	28.2	29.4	0.5 ft deeper	
ALUV17	53.0	5.0	7.4	5.4	8.0	5.1	8.9	5.9	7.9	0.5 Ft deeper	
ALUV19	32.0	5.6	9.4	6.2	9.6	7.0	14.9	14.7	Dry	> 7.5 ft deeper	16.9
ALUV23R	53.0	-	-	19.2	Dry	Dry	Dry	Dry	Dry	No change	19.7
ALUV27R(a)	36.0	-	-	21.5	26.7	26.3	28.6	27.6	29.5	2.8 Ft deeper	
ALUV29	25.0	0.4	5.3	0.4	7.2	0.2	6.7	0.5	7.9	2.6 ft deeper	
ALUV31R(a)	39.0	7.3	15.8	6.2	17.9	18.1	26.0	23.2	Dry	20.1 ft deeper	35.9
ALUV69(a)	43.0	4.6	10.0	6.0	10.8	8.3	11.6	11.6	12.2	2.2 ft deeper	
ALUV71(a)	28.0	14.6	16.6	15.6	16.9	15.7	16.6	16.4	16.8	0.2 ft deeper	
ALUV72(a)	54.0	11.6	13.3	9.2	13.5	10.8	13.4	12.1	13.2	No change	
ALUV77(a)	32.0	26.6	30.3	28.9	30.2	29.4	30.8	29.6	30.3	No change	
ALUV80R	54.0	-	-	8.9	11.7	10.5	12.9	11.4	12.0	0.3 Ft deeper	
ALUV83	40.0	0.9	3.3	1.0	3.4	0.8	3.5	-1.3	3.5	0.2 Ft deeper	
ALUV87	45.0	14.2	22.5	17.8	23.1	19.1	23.4	21.4	24.1	1.6 Ft deeper	
ALUV89R	61.0	-	-	2.5	5.0	2.8	6.3	1.2	6.0	1.0 Ft deeper	
ALUV93	23.0	25.2	29.1	25.9	29.8	26.0	32.8	33.4	37.4	8.3 ft deeper	
ALUV95	20.0	3.0	4.9	3.1	5.3	3.7	5.6	5.4	7.5	2.6 Ft deeper	
ALUV98R	57.0	-	-	9.6	14.3	11.6	14.7	12.4	16.2	1.9 Ft deeper	
ALUV99R	46.0	-	-	9.8	13.8	11.9	16.0	13.2	18.4	4.6 Ft deeper	
ALUV101R	65.0	-	-	Dry	Dry	Dry	Dry	Dry	Dry	No change	11.4
ALUV104R	15.0	-	-	15.6	20.3	19.4	20.3	18.9	20.4	0.1 ft deeper	
ALUV105R	19.0	-	-	8.1	Dry	9.5	10.2	9.7	Dry	No change	10.3
ALUV106R	22.0	-	-	4.6	Dry	6.7	8.2	7.8	Dry	No change	8.3
ALUV108R	33.0	-	-	7.1	11.0	8.8	11.6	11.2	13.6	2.6 Ft deeper	
ALUV165	65.0	-	-	20.3	28.7	27.2	30.2	29.2	31.9	3.2 Ft deeper	
ALUV168	34.0	-	-	- 0.4	1.4	0.6	1.9	1.3	2.6	1.2 Ft deeper	
ALUV169	36.0	-	-	7.2	9.0	7.2	9.2	7.9	9.7	0.7 Ft deeper	
ALUV170	34.0	-	-	4.5	5.8	4.2	6.3	4.7	7.0	1.2 Ft deeper	
ALUV172	19.0	-	-	13.1	14.1	14.5	18.7	17.8	21.4	7.3 ft deeper	
ALUV180(a)	47.0	-	-	6.1	10.3	9.4	12.4	11.6	12.6	2.3 ft deeper	
ALUV181(a)	32.0	-	-	11.8	16.8	15.0	20.1	19.7	20.6	3.8 ft deeper	
ALUV182	32.0	-	-	13.6	17.8	16.8	19.4	17.2	19.3	1.5 ft deeper	
ALUV193	46.0	-	-	10.9	12.4	9.8	13.0	10.6	12.6	0.2 Ft deeper	
ALUV197	32.0	-	-	10.2	13.2	11.8	19.9	19.7	24.9	11.7 ft deeper	
ALUV199	62.0	-	-	13.5	17.2	12.5	18.3	13.7	18.8	1.6 Ft deeper	
ALUV200	53.0	-	-	4.1	5.9	3.8	6.4	4.4	5.8	No change	

Notes:
(a) Discontinued monitoring at these wells in 2002 (idled).

Revised 09/10/04

Table (Cont.)

Projected Pit Inflow Drawdowns at Well Locations Versus Measured Water Level Ranges at Alluvial and Wepo Monitoring Wells and Static Water Levels at Local Wells

PWCC Well Id	Pit Inflow Analysis Maximum Projected Drawdown (feet)	Background Water Level Range		Historic Water Level Range 1988-1995		Historic Water Level Range 1995-2000		Current Water Level Range 2000-2004		Current Maximum Versus Background/ Historic Maximum
		Min	Max	Min	Max	Min	Max	Min	Max	
WEPO40	47.0	71.5	81.0	66.0	74.4	67.1	71.9	72.0	76.8	No change
WEPO41(a)	26.0	86.9	93.4	81.3	94.4	86.6	92.9	87.9	91.9	No change
WEPO42	54.0	-2.1	-1.5	-1.8	-1.3	-1.7	-1.0	-1.4	-1.0	No change
WEPO43R(b)	43.0	138.6	150.6	138.9	144.4	135.3	138.1	138.3	142.2	No change
WEPO44	49.0	183.5	187.8	177.7	187.3	175.2	180.9	172.0	175.9	No change
WEPO45	37.0	83.4	88.2	80.0	86.4	80.8	82.8	82.7	83.1	No change
WEPO46	38.0	117.9	157.2	149.8	155.4	151.2	155.0	154.2	155.5	No change
WEPO47R(c)	15.0	-	-	-	-	31.4	32.6	30.7	32.4	No change
WEPO49	55.0	4.3	9.6	1.8	4.8	1.1	3.0	0.4	1.4	No change
WEPO51(a)	26.0	43.0	52.0	48.9	52.1	51.2	52.5	52.3	53.2	1.2 ft deeper
WEPO52(a)	35.0	16.3	24.3	18.0	23.8	17.8	19.0	17.9	18.0	No change
WEPO53	65.0	36.7	55.4	46.4	54.7	54.8	66.0	66.9	73.2	17.8 ft deeper
WEPO54	60.0	47.4	55.7	49.5	51.4	50.3	51.8	50.8	52.1	No change
WEPO55	27.0	159.4	162.2	159.8	161.3	159.8	161.8	161.4	161.7	No change
WEPO56	35.0	30.9	40.4	32.8	38.4	35.0	37.6	36.6	38.0	No change
WEPO57	40.0	150.1	158.3	155.9	158.8	157.9	161.4	161.4	163.8	5.0 ft deeper
WEPO58	24.0	130.3	140.1	137.5	141.2	140.0	140.9	140.5	141.2	No change
WEPO59	20.0	142.7	144.6	142.7	144.3	143.1	145.1	144.7	145.8	1.2 ft deeper
WEPO60	19.0	81.2	87.3	88.2	95.7	90.8	93.7	90.3	91.6	No change
WEPO61	10.0	154.3	155.4	153.4	155.9	152.8	154.8	154.3	154.8	No change
WEPO62R(d)	63.0	114.1	139.7	133.1	197.7	213.1	227.7	207.9	212.1	72.4 ft deeper
WEPO65	50.0	71.9	164.5	113.8	128.7	125.0	143.5	143.6	146.6	No change
WEPO66	35.0	75.4	89.1	82.0	87.6	86.1	88.0	87.5	89.4	0.3 ft deeper
WEPO67	25.0	129.5	204.5	182.4	187.7	181.4	184.0	175.9	181.2	No change
WEPO68 (e)	37.0	-	-	-	-	107.9	110.8	107.7	109.9	No change

Local Well Id	Pit Inflow Analysis Maximum Projected Drawdown (feet)	Total Well Depth (feet)	Static Water Level (feet)	Percent of Potential Water Height in Well Bore Lost to Pit Pumpage
4K-389	30.0	417	356	49.2
8T-506	49.0	552	34	9.5

Notes:

(a) Discontinued monitoring at these wells in 2002 (idled).

(b) Background and historic water levels through 2/97 are from WEPO43, corrected for ground surface elevation. WEPO43 was removed ahead of gravel-pit expansion in 1997 and WEPO43R was installed that same year.

(c) Background and historic water levels through 3/98 are from WEPO47, and from 4/98 to present are from WEPO47R; both uncorrected for ground surface elevation differences. WEPO47 was removed ahead of pond construction and WEPO47R was installed in 1998.

(d) Background and historic water levels through 3/98 (including 1995-2000 maximum) are from WEPO62, corrected for ground surface elevation. WEPO62 was removed in 1998 and WEPO62R was installed in 1997.

(d) WEPO68 was installed in 1997.

9.4 feet. WEPO62 appears to have been open to one or more perched zones, which were gradually dewatered as the adjacent J-16 pit was mined. These perched zones are usually of limited aerial extent and can influence large well bore water level changes, which are not indicative of true aquifer water level changes. At WEPO53, current maximum water levels are 17.8 feet deeper than background and historic maximum water levels, yet are still less than the theoretical projected maximum drawdown at 2013 for this well which is 65 feet. The 17.8 feet deepening at WEPO53 has likely been influenced by pit dewatering in both the N-6 and N-11 pits. The maximum current water levels that are deeper than historical values in the remaining four Wepo monitoring wells range from 0.3 feet to 5.0 feet, which are comparable to natural water fluctuations in the Wepo formation. Nineteen of the Wepo monitoring wells show no change in current maximum water levels compared with historic values. Wepo monitoring wells WEPO40, WEPO43R, and WEPO44, situated adjacent to the J1/N6 pit, show no change in current maximum water levels compared to their historical records. Out of a total of twenty-five Wepo monitoring wells, there are only two wells adjacent to wet pits that have exhibited drawdowns in excess of natural fluctuations (greater than five feet), and that were most likely affected by dewatering of an adjacent pit. The remaining twenty-three wells have not shown drawdown impacts from pit dewatering even though many are within one-mile of the nearby pit, suggesting that the projected drawdowns depicted in both Figures 1 and 1a are extremely conservative.

Table 8 shows current maximum water levels at 5 of the 36 alluvial wells are deeper than 5 feet of their historical record. The five wells, ALUV19, ALUV31R, ALUV93, ALUV172, and ALUV197 are shallow monitoring wells constructed in the alluvium along the lower reaches of the major washes, several miles downstream of any of the wet pits. These deeper water levels are a result of recent trends in lower precipitation and subsequent recharge from runoff and discharge from the Wepo formation. Many of the remaining 31 alluvial wells exhibit deeper current maximum water levels compared to their historical record, but they are generally comparable to or less than the several-feet natural fluctuation of water levels in the alluvium, and all have been influenced to some degree by recent trends in lower precipitation. Projected drawdowns at each alluvial monitoring well location using the TWODAN analytical method are generally an order of magnitude greater than the drawdowns measured to date.

Figure 1 shows drawdowns in the Wepo formation in the vicinity of the N-99 pit are projected to be 60 feet or greater by 2013. In addition, drawdowns beneath the adjacent portion of Coal Mine Wash are projected to range between 40 feet at ALUV83 and 54 feet at ALUV80R. The Wepo is believed to be the source of discharge into the wash downstream from where Coal Mine Wash passes beneath the overland conveyor. Peabody does not believe that there will be significant impacts on this discharge for several reasons. First, observations of pit discharge suggest that the technique overestimates the inflow rate, as noted above. Second, the mining of N-6 has not caused a noticeable impact on the locations of discharge into Coal Mine Wash. Although the baseflow of Coal Mine Wash is not measured, a reduction in discharge caused by declining water levels beneath the wash would be also manifested by downstream movement of the location of the uppermost area of discharge. This has not been observed over many years of mining. Third, the water levels in WEPO40, a well close to both N-6 and Coal Mine Wash, appear to be affected more by changes in local recharge than by dewatering.

Based on the theoretical pit inflow drawdown contours, local well 4K-389 is projected to have its water level deepened by 30 feet, or 49.2 percent of its total available water height of 61 feet. Local well 8T-506 is projected to have its water level deepened by 49 feet, or 9.5 percent of its available water height of 518 feet. Both wells were selected for comparison purpose due to their proximity to wet pits; however, local well 8T-506 was removed in advance of the mining operations in the N-6 mining area. From the historic and current water levels at Wepo and alluvial monitoring wells in the vicinity of the two local wells, it appears likely that the projected water level declines at the two local wells will be significantly less than that theoretically calculated. The drawdown that will eventually occur in the Wepo formation in the vicinity of local well 8T-506 and at local well 4K-389 from pit inflows will not be significant.

As mentioned previously, Figures 1 and 1a depict the locations of numerous pre-existing wells, springs, and ponds within and adjacent to the leasehold. Chapter 17, Protection of the Hydrologic Balance, provides a thorough discussion of the nature and status of the pre-existing water sources shown on Figures 1 and 1a. Many of the wells are inoperable, or are completed in different formations or multiple formations in addition to the Wepo. Many of the springs are undeveloped, have little to no measurable discharge, or emanate from a formation other than the Wepo. Chapter 17 provides a discussion of plans to provide replacement sources of water for those wells and springs that have been or will be removed by mining. All of the pre-existing wells and springs that are operable and have measureable output within the leasehold are monitored, and none of the recent measurements indicate a significant reduction in output as a result of pit dewatering.

In summary, water from the Wepo formation is expected to enter N99 (and other) pits. Based on operational experience, the inflow rates have generally been lower than predicted by the techniques described here. Similarly, the simulated drawdowns caused by dewatering are no doubt much higher than will be encountered. Only two monitoring wells in the immediate vicinity of pits that have already been mined exhibit declines in water levels attributed to pit inflows, and drawdowns in other wells adjacent to previously mined pits are not evident. Inflow in the N99 and other wet pits is likely to be less than indicated in Tables 1 through 7a. Drawdowns expected to occur in the Wepo formation as a result of pit dewatering should not extend as far nor be as high as depicted on Figures 1 and 1a, and will not be significant.

<u>Removal of Local Wells and Springs</u>. One local well (4T-404), completed in the Toreva aquifer, is located within the proposed life-of-mine mining plan area. In addition,another local well (4T-403), completed in the Toreva aquifer, was removed in advance of the mining operation in the J-7 mining area. One local spring (Site #97) was removed in advance of mining at N-14. The impacts have been mitigated during mining by providing alternative water sources (N-aquifer public water standpipes). The two wells will be replaced with ones of comparable quality and yield following the completion of mining and reclamation in the respective mining areas. The spring will be mitigated by retention of a permanent impoundment (see Chapter 19).

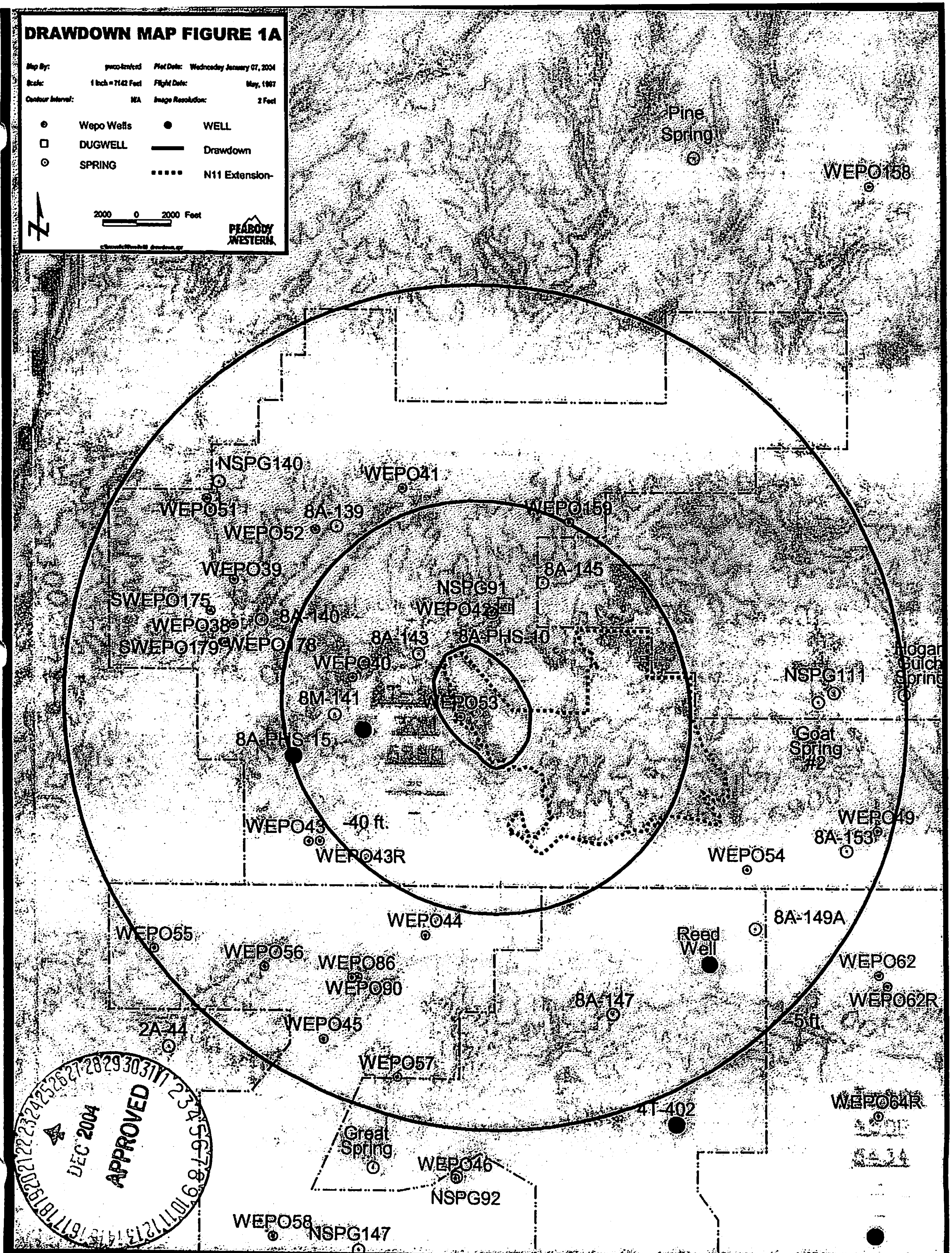
<u>Containment of Pit Inflow Pumpage</u>. It is sometimes necessary to pump ground water which seeps into pits to allow work to continue and to prevent slumping of spoil piles resulting from saturation near the bottom of the pit. Several sediment ponds and large dams (see Table 9) exist or will exist around the pits to contain all pit pumpage as well as storm water runoff and sediment from the disturbed areas up-watershed from the ponds.

Referring to Tables 1 through 7a, it can be seen that the maximum pit pumpage in any one year will be 19 to 37 acre-feet and will occur in the J-19/20 pit. Typical quantities of pit pumpage will be on the order of 2 or less acre-feet per year. The larger dams are designed to contain this additional volume of water with adequate freeboard. Reed Valley Dam has been designed to impound 475 acre-feet of water and J-7JR dam will hold an estimated 700 acre-feet of water. The capacity of smaller sediment ponds to contain storm runoff will be maintained by pumpage from the ponds. The current NPDES Permit (Chapter 16, Attachment 3) allows for pond dewatering or pond to pond pumpage.

Impact of Replaced Spoil Material on Ground-Water Flow and Recharge Capacity. Pits remain open only until the coal has been removed. Following the short-term impacts on the ground-water system associated with open pits, a longer term impact is experienced due to the placement of spoil material in the mined-out pits. A wide range in permeabilities for spoil material can occur depending on how it is placed.

Rahn (1976) reported that spoil material replaced using a dragline in one instance and a scraper in another, yielded hydraulic conductivities of 35.3 ft./day and 0.4 ft./day, respectively. Van Voast and Hedges (1975) concluded that greater porosities and hydraulic conductivities will result from volume changes (approximately one-fourth greater) between the spoil material in its original compacted, stratified state, and in its rearranged state following replacement, regardless of the method of replacement used.

Spoil material will be regraded by dozers and scrapers and final contouring will be accomplished with dozers. Based on the conclusions of the above studies, the spoil material should have higher porosities and permeabilities than it did in its original state. The topsoil surface will be disked as part of the reclamation activity; this procedure should further enhance the rainfall and overland flow infiltration rates.


DRAWDOWN MAP FIGURE 1A
Wepo Wells
WELL
DUGWELL
Drawdown
SPRING
N11 Extension-
2000 0 2000 Feet
PEABODY WESTERN
Pine Spring
WEPO158
NSPG140
WEPO41
WEPO51
8A-139
WEPO159
WEPO52
WEPO39
8A-145
NSPG91
SWEPO175
WEPO42
WEPO38
8A-140
8A-143
8A-PHS-10
SWEPO179
WEPO178
WEPO40
Hogan Gulch Spring
NSPG111
8M-141
WEPO53
8A-PHS-15
Goat Spring #2
WEPO49
WEPO43
-40 ft.
8A-153
WEPO43R
WEPO54
WEPO44
8A-149A
WEPO55
Reed Well
WEPO56
WEPO86
WEPO62
WEPO90
WEPO62R
8A-147
2A-44
WEPO45
-5 ft
WEPO57
WEPO64R
4T-402
Great Spring
WEPO46
NSPG92
WEPO58
NSPG147
DEC 2004
APPROVED

conveyor. Peabody does not believe that there will be significant impacts on this discharge for several reasons. First, observations of pit discharge suggest that the technique overestimates the inflow rate, as noted above. Second, the mining of N-6 has not caused a noticeable impact on the locations of discharge into Coal Mine Wash. Although the baseflow of Coal Mine Wash is not measured, a reduction in discharge caused by declining water levels beneath the wash would be also manifested by downstream movement of the location of the uppermost area of discharge. This has not been observed over many years of mining. Third, the water levels in Wepo 40, a well close to both N-6 and Coal Mine Wash, appear to be affected more by changes in local recharge than by dewatering.

In summary, Wepo water is expected to enter N99 (and other) pits. Based on operational experience, the inflow rates have generally been lower than predicted by the techniques described here. Similarly, the simulated drawdowns caused by dewatering are probably higher than will be encountered. Monitoring wells in the immediate vicinity of pits exhibit declines in water levels, but the drawdowns in other areas are likely to be low. Thus, inflow in the N99 pit is likely to be less than indicated in Table 7a, and the drawdowns are similarly to be less than portrayed in Figure 1a.

<u>Removal of Local Wells and Springs</u>. One local well (4T-404), completed in the Toreva aquifer, is located within the proposed life-of-mine mining plan area. In addition,another local well (4T-403), completed in the Toreva aquifer, was removed in advance of the mining operation in the J-7 mining area. One local spring (Site #97) was removed in advance of mining at N-14. The impacts have been mitigated during mining by providing alternative

water sources (N-aquifer public water standpipes). The two wells will be replaced with ones of comparable quality and yield following the completion of mining and reclamation in the respective mining areas. The spring will be mitigated by retention of a permanent impoundment (see Chapter 19).

<u>Containment of Pit Inflow Pumpage</u>. It is sometimes necessary to pump ground water which seeps into pits to allow work to continue and to prevent slumping of spoil piles resulting from saturation near the bottom of the pit. Several sediment ponds and large dams (see Table 9) exist or will exist around the pits to contain all pit pumpage as well as storm water runoff and sediment from the disturbed areas up-watershed from the ponds.

Referring to Tables 1 through 7a, it can be seen that the maximum pit pumpage in any one year will be 19 to 37 acre-feet and will occur in the J-19/20 pit. Typical quantities of pit pumpage will be on the order of 2 or less acre-feet per year. The larger dams are designed to contain this additional volume of water with adequate freeboard. Reed Valley Dam has been designed to impound 475 acre-feet of water and J-7JR dam will hold an estimated 700 acre-feet of water. The capacity of smaller sediment ponds to contain storm runoff will be maintained by pumpage from the ponds. The current NPDES Permit (Chapter 16, Attachment 3) allows for pond dewatering or pond to pond pumpage.

Impact of Replaced Spoil Material on Ground-Water Flow and Recharge Capacity. Pits remain open only until the coal has been removed. Following the short-term impacts on the ground-water system associated with open pits, a longer term impact is experienced due to the placement of spoil material in the mined-out pits. A wide range in permeabilities for spoil material can occur depending on how it is placed.

Rahn (1976) reported that spoil material replaced using a dragline in one instance and a scraper in another, yielded hydraulic conductivities of 35.3 ft./day and 0.4 ft./day, respectively. Van Voast and Hedges (1975) concluded that greater porosities and hydraulic conductivities will result from volume changes (approximately one-fourth greater) between the spoil material in its original compacted, stratified state, and in its rearranged state following replacement, regardless of the method of replacement used.

Spoil material will be regraded by dozers and scrapers and final contouring will be accomplished with dozers. Based on the conclusions of the above studies, the spoil material should have higher porosities and permeabilities than it did in its original state. The topsoil surface will be disked as part of the reclamation activity; this procedure should further enhance the rainfall and overland flow infiltration rates.

TABLE 9

Sediment Ponds and Dams to be Used to

Contain Pit Pumpage

Mining Area	Sediment Ponds and Dams Containing Pit Pumpage
N-10	N-10G Series Ponds
N-11	N-11A Series Ponds
N-14	N-14-D, E, F and G Dams
J-1/N-6	Wild Ram Valley Dam
J-16	Reed Valley and J-16-A Dams
J-19/20	Reed Valley and J-7 Jr. Dams
J-21	Reed Valley and J21 Dams

However, regardless of the infiltration rates of regraded spoil, infiltration in reclaimed areas will provide little or no recharge to the Wepo aquifer. The distance from the reshaped land surface to the saturated portions of the Wepo aquifer and the limited annual precipitation preclude rainfall and snowmelt recharge other than in burn and clinker or highly fractured areas. These areas are found adjacent to rather than in the reclaimed coal fields.

The time necessary for the replaced spoil material to become resaturated and for flow patterns to be reestablished will depend on the porosity and permeability of the replaced spoil material. Recharge of previously saturated areas may take from a few years to 100 years; but, the impact will be of little significance to the local well users. There are no local wells completed in the Wepo aquifer in the areas to be mined and local wells which do exist in the vicinity will not be significantly impacted (See Table 8 and Figure 1). The only exceptions to this are the two Toreva wells (4T-403 and 4T-404) which are discussed in the previous section "Removal of Local Wells". The maximum drawdowns will be at specific points within individual pits in a particular year and are estimated to range from 14 feet to 115 feet with the greatest drawdown in the J-16 and J-19 pits. Following the resaturation period, ground-water levels will recover to near premining levels.

Impact of Replaced Spoil on Ground-Water Quality. The replacement of spoil material in the areas of the pits where portions of the Wepo aquifer and in one case, the alluvial aquifer, are to be removed will have a long-term, localized impact on the ground-water quality in these areas. Two types of chemical reactions will probably occur as the spoil resaturates resulting in a change in the local ground-water quality - dissolution and oxidation and reduction of sulfides and organic sulfur.

The first chemical reaction will be an increase in the major ions as a result of dissolution of readily soluble materials in the spoil. Various leaching processes acting over geologic time remove most of the readily soluble constituents from the permeable unsaturated and saturated units in the undisturbed overburden. In contrast, a considerable quantity of soluble constituents may still remain in the relatively impermeable strata, such as the finer grained clay, siltstones and shales. Fracturing and mixing of materials during pit excavation and reclamation exposes many new chemically reactive surfaces and mineral constituents that may readily release ions to the ground water during resaturation.

Studies performed by Van Voast et al. (1978) and McWhorter et al. (1979) in western mine spoils suggest that increases in TDS from 50 to 130 percent could be expected in the disturbed portions of the Wepo aquifer following resaturation of the spoil material. Based on the Wepo aquifer water quality types, the more soluble salts (principal ions) that would account for these increases in TDS are Ca, Mg, Na, SO_4 and HCO_3.

On a related matter, Montana Department of State Lands personnel have noticed in their review of mine overburden data that materials with high salinity are generally quite shallow (less than 15 meters). Normal dragline operation would generally place some of the near surface overburden in the lower portions of the pit. This mining practice could cause the placement of some of the more saline materials in the resaturated zone and result in a greater degree of ground-water degradation. A review of overburden core data for portions of the pits which will intercept the Wepo aquifer (N-6, N-10, N-11, N-14, J-16, J-19/20 and J-21) indicates that there are no significantly high conductivity zones in the overburden material. Therefore, significant salinity increases are not expected in resaturated graded spoil on the Black Mesa leasehold.

The second principal chemical reaction that occurs in spoil material and could affect ground-water quality is the oxidation and reduction of sulfides and organic sulfur. In the west, waters which contact spoil are rarely acidic. Acid zones will probably form in the spoil; however, sufficient carbonate materials and alkaline salts are available to neutralize acid production resulting from the oxidation of sulfides.

Cores from within or immediately adjacent to the wet portions of the pits have been analyzed to determine the acid potential of the overburden (see Appendix 2). The overall acid-forming potential of core material involves a comparison of the acid potential and the neutralization potential expressed in terms of tons of $CaCO_3$ required per 1000 tons of material for neutralization (acid potential) and tons of $CaCO_3$ excess per 1000 tons of material (neutralization potential). Table 10 is a summary for the previously referenced cores: (1) the percent of the total core that is comprised of material with acid potential; (2) the mean weighted acid potential; and (3) the mean weighted neutralization potential. Only 1 core; Core #21099C in the N-10 mining area had a higher mean weighted acid potential. All other cores indicate excess ($CaCO_3$) neutralization potential. The neutralization of the acid produced from the oxidation of sulfides and sulfates does have an adverse water quality related side effect. In the process of the carbonate minerals reacting to achieve neutralization, there is increased dissolution of alkaline salts and consequently elevated TDS levels.

Considerable controversy surrounds the potential activity of the different forms of sulfur

TABLE 10

Summary of Acid and Neutralization Potential for

Cores in Mining Areas Projected to Intercept the Wepo Aquifer

Overburden Core No.	% of Core With Negative Potential	Mean Weighted Acid Potential (Tons $CaCO_3$ Needed for Neutrality per 1000 Tons Material)	Mean Weighted Neutralization Potential (Tons $CaCO_3$ Excess per 1000 Tons Material)
N-10 Mining Area			
21099-C	54.7	15.2	12.3
21100-C	44.1	18.1	19.8
21101-C	36.6	14.4	17.2
N-11 Mining Area			
26272-C	33.9	6.2	29.9
26364-C	30.9	9.1	38.7
26367-C	24.2	7.2	58.1
26463-C	44.4	12.6	52.3
N-14 Mining Area			
26269-C	34.6	10.7	21.6
26271-C	37.1	10.9	12.4
J-16 Mining Area			
23146-C	51.2	15.3	19.0
23147-C	31.0	14.1	20.3
23148-C	46.5	16.6	23.1
23149-C	3.5	7.4	21.8
23325-C	34.9	5.3	24.1
23326-C	22.3	4.6	49.6
23327-C	48.7	21.3	37.8
23328-C	36.7	16.1	28.0
26462-C	1.6	0.1	29.0
J-19,20,21 Mining Areas			
24403-C	13.0	3.0	79.2
24404-C	5.0	0.1	70.3
24405-C	10.3	0.9	50.9

TABLE 10 (Cont.)

Summary of Acid and Neutralization Potential for

Cores in Mining Areas Projected to Intercept the Wepo Aquifer

Overburden Core No.	% of Core With Negative Potential	Mean Weighted Acid Potential (Tons $CaCO_3$ Needed for Neutrality per 1000 Tons Material)	Mean Weighted Neutralization Potential (Tons $CaCO_3$ Excess per 1000 Tons Material)
<u>J-19,20,21 Mining Areas (Cont.)</u>			
24406-C	30.1	1.5	26.7
24407-C	30.9	5.4	23.7
24408-C	13.6	1.0	30.6
24418-C	24.7	4.0	23.4
<u>N-6 Mining Area</u>			
21104-C	10.6	2.7	36.9
23163-C	7.4	0.8	44.4
23164-C	13.3	0.4	30.7
23165-C	22.9	2.0	30.0
23166-C	6.2	0.8	58.4
24093-C	7.1	1.1	42.9
24094-C	22.7	1.8	53.1
24095-C	8.4	1.2	45.9
24096-C	7.4	0.5	51.0
24097-C	16.0	0.3	37.9
24098-C	22.6	3.7	36.4
24099-C	15.6	1.0	19.0
24400-C	5.6	4.1	56.8
24401-C	17.8	1.6	15.4
24402-C	27.7	4.8	21.6

and the significance of organic sulfur. In western mine settings as much as 70% of the total sulfur analyzed has been found to be organic sulfur. According to Dollhopf (1984), organic sulfur when oxidized produces approximately one-third less acid than the sulfide forms of sulfur in a low (<4) pH environment. A comparison of total sulfur versus pyritic sulfur in cores taken on Black Mesa suggests that organic sulfur is approximately 20 percent of the total sulfur. In this comparison it was assumed that only the above two forms comprised the total amount of sulfur. Whether it is pyritic or organic sulfur, not all the forms of either will react to form acid. Considerable research remains to be done in this area.

Oxidation of sulfides primarily occurs above the water table in the zone of water level fluctuations or in zones of significant infiltration of precipitation. As was explained previously, significant recharge will not occur to the aquifer through the spoil material, so the potential of this as a mechanism for additional leachate movement and acid production on the leasehold is minimal. Also, the typical Wepo water level fluctuations range from 2 to 3 feet or less. This does not constitute a significant zone in which alternate weathering and leaching of ions could occur.

Below the water table, less oxygen may be available than in the overlying unsaturated vadose zone resulting in less sulfide oxidation-reduction increases in salinity or acidity of the water. Pionke and Rogowski (1979) state that water has an oxygen diffusion coefficient four magnitudes less than for sulfides in air. The opportunity exists during the mining process to minimize the oxidation of pyrites and the production of sulfates by burying localized pyritic zones in the postmining saturated zone. Sulfide reduction may be the dominant process occurring below the water table if substantial populations of sulfate reducing bacteria are present. No information exists regarding the possibility of the presence of these bacteria on the leasehold.

A final concern associated with the oxidation and reduction of sulfides and sulfates is the mobilization of trace metals in the ground-water system. Dollhopf et al. (1979, 1981) compared column leach extracts with spoil water quality. They found that the statistical means and ranges for the comparisons between column leachates and water from spoil wells often differed by as much as a factor of ten. Though they did state that column leachates were comparable to well water concentrations to a degree, they allowed that these correlations would have to be made at many mines with contrasting chemical conditions in order to verify the usefulness of this method for judging which overburden materials would be most suitable for aquifer reestablishment.

Evaluation of cores taken in the N-11, N-14, J-16, J-19/20 and J-21 mining areas for B, As, Se, Mo, Hg, Cu, Cd, Cr and Zn indicates that there are not high concentrations of any of these chemical constituents in the overburden material. During the oxidation and reduction stages of the sulfide zones in the saturated portions of the pits, trace metals will be alternately taken into solution as the pH drops and precipitated out as the acid is neutralized and additional alkali salts go into solution. Total metal analyses on Wepo ground-water samples also supports the core chemistry. Wepo ground-water trace metal analyses presented in the annual "Hydrological Data Reports" and summarized in Table 11 indicate that concentrations of trace constituents are well below the livestock drinking water limits.

The above discussion has addressed the sources of potential ground-water quality degradation. In order to assess the significance of this potential degradation, the historic and potential uses of the Wepo and alluvial ground water is considered. Table 12 is a summary of the principal constituents in both aquifers which render the water sources unsuitable for livestock drinking water. Those monitoring sites chosen for Table 12 are either at or in the immediate vicinity (downgradient) of a pit which will intersect the Wepo and or alluvial aquifer. Livestock drinking water limits were taken from three well known and documented sources (listed in Table 12). All chemical parameter values listed are five-year average values based on water quality sampling at each site from 1980 to 1985.

The principal constituents rendering Wepo aquifer water unsuitable for use as livestock drinking water are alkalinity and fluoride. McKee and Wolf (1963) report that when alkalinity levels reach 50 mg/l, trouble with diarrhea in chickens begins and at a total alkalinity of 170 mg/l, animals are reported to develop diarrhea. Fluoride levels above 2 mg/l have been shown to cause mottling of teeth and skeletal damage in dogs, sheep and cattle. Principal constituents in the alluvial aquifer which preclude livestock use are alkalinity, lead, sulfates and total dissolved solids (TDS). Consumption of lead in concentrations above 0.1 mg/l by animals can result in deleterious affects on the central nervous system and to the animal's principal organs, as heavy metals tend to concentrate in these parts of the animals. Ingestion of sulfate concentrations above 3000 mg/l and TDS concentrations above 5000 mg/l in livestock drinking water tends to cause similar effects. McKee and Wolf (1963) state that ingestion of these concentrations by animals can cause diarrhea, rundown ragged appearances, weakening and eventually even death. Those portions of the Wepo and alluvial aquifers to be affected by pit interception will not be changed as far as water use potential, because the predisturbance water quality is already marginal to unsuitable for livestock use.

TABLE 11

Summary of Dissolved and Total Trace Metal

Concentrations in Wepo Aquifer Water

Black Mesa Leasehold

(1980 - 1985)

Chemical Constituent	Maximum Value (mg/l)	Minimum Value (mg/l)
Arsenic dissolved	.20	.005
Arsenic total	.10	.005
Boron dissolved	.90	.001
Boron total	1.60	.001
Copper dissolved	.15	.020
Copper total	.54	.020
Cadmium dissolved	.03	.001
Cadmium total	.01	.005
Chromium dissolved	.05	.01
Chromium total	.14	.02
Mercury dissolved	.01	.001
Mercury total	.01	.001
Molybdenum dissolved	1.00	.020
Molybdenum total	.50	.020
Selenium dissolved	.10	.005
Selenium total	.04	.005
Zinc dissolved	2.30	.01
Zinc total	5.20	.020

TABLE 12
Summary of The Principal Constituents In Wepo and Alluvial
Ground Water Which Render Both Water Sources Unsuitable for Livestock Drinking Water

Wepo Well	Alk HCO_3 (limit 170)	F (limit 2.0)	SO_4 (limit 3000)	TDS (limit 5000)
38	456*	3.16*	1,070	2,048
40	543*	8.33*	277	1,175
41	537*	2.49*	1,396	2,829
42	276*	2.02*	584	1,242
43	438*	1.22	226	965
44	958*	7.32*	107	1,962
49	270*	0.24	776	1,288
51	330*	1.07	851	2,171
53	549*	2.22*	1,208	2,636
54	372*	0.28	565	1,380
62	663*	0.80	2,863	5,503*
64	1135*	5.68*	36	1,521
65	1356*	2.15*	28	1,810
66	1094*	1.04	1,687	3,564

*Values exceed recommended livestock drinking water limits (McKee and Wolf, 1963; Botz and Pedersen, 1976; and National Academy of Sciences, 1974)

Alluvial Well	Alk	Pb	SO_4	TDS
17	270*	.023	470	1,233
19	306*	.026	2,437	4,574
23	239*	.029	594	1,320
27	269*	.024	748	1,856
32	993*	.030	1,187	3,023
33R	463*	.020	3,310*	5,625*
73	335*	.020	3,229*	5,452*
74	[illegible]	.020	2,899	5,986*
75	336	.11*	2,282	4,318
79	309*	.053	638	1,335

TABLE 12 (Cont.)

Summary of The Principal Constituents In Wepo and Alluvial

Ground Water Which Render Both Water Sources Unsuitable for Livestock Drinking Water

Alluvial Well	Alk	Pb	SO_4	TDS
80	331*	.026	2,309	4,155
88	294*	.11*	2,477	4,240
89	296*	.023	972	2,450
98	1724*	.033	33,314*	62,264*
99	79*	.070	5,364*	8,834*
100	489*	.080	12,230*	18,827*
101	520*	.130	5,009*	8,379*
102	416*	.040	935	2,569
107	396*	.11*	3,418*	5,921*
108	290*	.026	2,035	3,804
110R	659*	.020	3,060*	5,800*

*Values exceed recommended livestock drinking water limits (McKee and Wolf, 1963; Botz and Pedersen, 1976; and National Academy of Sciences, 1974).

In summary, increases in concentrations of Ca, Mg, Na, SO_4 and HCO_3 (TDS) will occur regardless of the nature of the spoil material placed in the saturated zone. The potential for acid formation and acid and trace metal migration is minimal, because of the overall buffering capacity of the overburden material. There will be some amount of additional TDS increases as a result of the neutralization of acid forming material placed in the saturated zones. Acid formation will occur primarily in response to oxidation of sulfides in advance of the wetting front during spoil resaturation. Reduction of sulfates will primarily occur following resaturation. Based on climatic conditions and the transmissivities of the material, resaturation and reestablishment of premining ground water flow gradients could take up to 100 years. The magnitude of the impact to either aquifer should be limited to the immediate pit areas, because gradients and transmissivities are very low. A comparison of the approximate aquifer volume to be impacted versus the total estimated Wepo volume beneath the leasehold suggests that the spatial magnitude of the impact is small - less than .003 percent.

The overall significance of this impact is minor. There are no present water users of the Wepo aquifer within the leasehold. In fact, only two wells (4K-389 and 4T-405) in the region are reported to be completed only in the Wepo aquifer (see Chapter 17). An inspection of the lithologic log for one of the wells suggests that it is actually completed in the upper member of the Toreva (155 feet of sandstone at the bottom of the well). No log could be found for the other well. Local wells are not completed in the Wepo aquifer for two reasons; (1) the yields are too low, and (2) the quality of the water is unsuitable for domestic or livestock purposes. Increases in TDS in the resaturated areas of the N-10, N-11, N-14, N-6, J-16, J-19/20 and J-21 pits will in no way impact local water users, the potential water use of the Wepo aquifer, and the future postmining land use in the area.

<u>Interception of Wepo Recharge to the Alluvial Aquifer by Pits</u>. Based on Drawing No. 85610, Wepo Water Level Contour Map, ground-water flow is from the Wepo aquifer to the alluvial aquifer system. Pit interception of portions of the Wepo aquifer in the N-10, N-14, N-6, J-16, J-19/20 and J-21 pits can potentially cause local decline in the alluvial aquifer system. Distance drawdown projections for the combined pit pumpage (Figure 1 and Table 8) suggest portions of the alluvial aquifer system (Reed Valley, Red Peak Valley, Upper Moenkopi and Dinnebito alluvial aquifers) could potentially be affected to the extent that drawdowns exceed natural water level fluctuations.

It is difficult to predict the magnitude of the drawdowns as the alluvial aquifers have a large range of transmissivities and storage coefficients. Comparing this situation to the

N-7/8 pit pumpage effects on the Yellow Water Canyon alluvial aquifer (Alluvial Well 74 and 75), it is estimated that drawdowns in the alluvial aquifer near the N-14, J-16 and J-19/20 pit areas could range from 8 to 20 feet during the period of maximum combined pit interception (1980 to 1983). Also, drawing on what was experienced at the N-7/8 pit, the alluvial aquifer drawdowns should be quite localized and limited in extent (less than one mile downgradient). These impacts should be partially offset by recharge to the aquifers from water impounded in Reed Valley, N-14D, N-14E, N-14F and J-16A dams. The significance of this impact is minimal because of the limited portions of the alluvial aquifer system affected and the absence of local use of the alluvial aquifer. As with the Wepo aquifer, the alluvial aquifer is low yielding throughout most of the leasehold and the quality is not suitable for domestic purposes and is marginal to unsuitable for livestock use. Therefore, water from the alluvium does not support the pre- or postming land use nor does it support any critical habitats or plant species (see Chapters 9 and 10).

Interception of Channel Runoff Recharge to Alluvial Aquifers by Dams and Sediment Ponds. Dams, sediment ponds and internal permanent impoundments will intercept the runoff from 27 and 9 percent, respectively, of the Moenkopi and Dinnebito watersheds to the down drainage lease boundaries. These structures will remove some potential channel bottom transmission loss recharge to the alluvial aquifers downstream from the structures. Downstream aquifer recharge impacts associated with the dams should be offset by the impounded water recharge to the alluvial aquifer. The alluvial aquifer water level monitoring program indicates that the impact of the structures on alluvial water levels is insignificant. There is no evidence suggesting gradual water level declines in the alluvial aquifer system over time (see Chapter 15).

Truncation of Portions of the Alluvial Aquifers by Dams. Eight large dams have been constructed such that the embankments cut through the entire thickness of alluvium to bedrock. The embankments are designed and constructed to be impervious. These structures impact the alluvial aquifer system by disrupting the ground-water flow. A review of the five-year alluvial ground-water level hydrographs (Chapter 15) indicates that these impacts are of no significance probably owing to the following reasons. All dams, with the exception of J-7 Dam are on small tributaries which only contribute minimal amounts of water to the alluvial ground-water system. Seepage occurs around J-7 Dam along sandstone bedding planes. The Wepo aquifer discharges to the alluvial aquifer all along the channel reaches. Any localized ground-water flow disruptions would be offset within short distance below the dams.

Effects of Altered Wepo Aquifer Water Quality on Alluvial Aquifer Water Quality. The effects of higher TDS water from resaturated spoil in the Wepo aquifer recharging the alluvial aquifer are expected to be minimal. The pits will require anywhere from several years to 100 years to resaturate and reestablish ground-water flow gradients because of limited precipitation recharge and very low Wepo ground-water flow rates. These same low transmissivities will continue to limit the Wepo feed and contaminant transport into the alluvial aquifer. In contrast, responses to snowmelt and rainfall runoff recharge are rapid and greater than Wepo feed during three seasons of the year. The potential for rapid dilution of elevated TDS inputs from the Wepo would be quite high during these significant recharge periods.

The significance will be minimal because, the alluvial aquifer water within the leasehold is unsuitable for domestic purposes and marginal to unsuitable for livestock drinking water. Water from the alluvial aquifer is not essential to support the postmining land use or critical habitats or plant species.

<u>Mining Interruption of Spring Flow</u>. To date, only eight natural and one artificial spring of any significance (more than just a damp spot along the side of a channel) have been identified and monitored within and immediately adjacent to the leasehold. Of these, one spring (Monitoring Site #97) at the northwest edge of N-14 has been removed by mining activities (N-14 channel realignment). Reference to the statistical water quality summary for springs in Chapter 15, Hydrologic Description, indicates that the water quality of the spring was unsuitable for livestock use. Those parameters and parameter concentrations above the livestock drinking water limits are presented in Table 13. Peabody has provided two alternate water supplies for this spring: (1) water impounded in the N-14D dam; and (2) three public water outlets around the leasehold. The alternate water supplied is greater in quantity and better in quality than the spring water. The water supplied at the public water outlets meets domestic drinking water requirements. No other springs are expected to be impacted by the proposed mining.

<u>Impact of Peabody Wellfield Pumpage on Regional Water Levels and Stream and Spring Flows</u>. Peabody operates a wellfield consisting of eight wells completed in the D and N-aquifers (Entrada Sandstone, Navajo Sandstone and Wingate Sandstone) to provide water for the coal slurry pipeline serving the Mohave Generating Station and for other operational uses. Pumpage was initiated in 1969 and has averaged 3,860 acre-feet per year (1972 - 1998). Being a confined aquifer (N-aquifer), most of the water pumped comes from storage and the cone of depression spread over a considerable distance. Because Tribal community pumpage has occurred from the same aquifer during the same time period, drawdowns from these pumpage locations are additive to those being caused by the Peabody pumpage. The U.S. Geological Survey (Eychaner 1983) has modeled the effects of the pumping in a fashion which permits the distinction of the two separate drawdown amounts at common locations.

TABLE 13

Chemical Parameters and Concentrations at Spring 97

Which Exceed Livestock Drinking Water Limits

Parameter	Mean Concentration (mg/l)	Recommended Livestock Limits (mg/l)
Alkalinity	405	170
Fluoride	2.1	2.0
Lead	0.167	0.1
Sulfate	4077	3000
Total Dissolved Solids	6846	5000

Table 14 presents the drawdowns caused by Peabody and municipal pumpage at various communities. As can be seen, by the year 2001, the magnitude of the Peabody pumpage impact, in terms of the areal extent of drawdowns, is substantial. However, when comparing the magnitude of the Peabody drawdowns in terms of total drawdown at a location, the impact takes on less significance. At only eight of the nineteen communities listed in Table 14 are drawdowns associated with Peabody pumpage greater than 50 percent of the total drawdown.

To further assess the significance of Peabody caused drawdowns in Tribal community wells, the drawdowns were compared against the total height of water available in Tribal wells. To determine the percent of the total water height lost in Tribal wells due to Peabody pumpage, Figures 2, 3 and 4 from USGS Water Supply Paper 2201 were used. Table 15 presents a summary of available water heights in Tribal community wells lost due to Peabody pumpage. The maximum percent of available water height lost because of Peabody pumpage is only 5.4 percent. Communities presented in Table 15 represent most of the major population centers in the vicinity of Black Mesa, a range of distances from the leasehold and all directions around the leasehold. The significance of Peabody caused drawdowns on total available community well water heights is not significant.

The USGS model assumed a PWCC pumping rate of 3700 AF/yr (average rate from 1971 through 1979) and that PWCC pumpage would cease in 2001; whereas, the current coal supply agreements run through 2007 and 2011 for the Black Mesa and Kayenta Mines, respectively. Even considering this difference, it is not anticipated that the Peabody induced drawdowns would increase much. Extending the drawdown plot trend in Figure 2.a. (top plot of Figure 2) to 2007, suggests that the amount of additional drawdown from the longer pumpage would only be on the order of 10 to 20 feet <u>near the leasehold</u>. This would cause negligible increases in the percent of available water height losses. The pumpage projections used in the USGS model and shown as labels to the simulated water levels in Figure 2 are defined and presented graphically on Page 44 and Figure 2A, respectively.

Finally, Peabody pumpage will not cause structural damage to the Navajo aquifer. Drawdowns beneath the leasehold are not projected to go below the top of the Navajo aquifer, so no compression of the aquifer is anticipated. Water level recovery times are predicted to be fairly rapid following the cessation of pumpage. Referring to Figure 2.a. (top plot of Figure 2), the USGS model projections indicate that within six years following the cessation of Peabody pumpage, water levels in the N-aquifer should recover to within 20 percent of their original levels in 1964. Eychaner (1983) concludes that despite the seemingly large drawdowns over the model simulation period, only about 0.1 percent of the water in the N-aquifer would be withdrawn.

TABLE 14

Drawdowns Projected at Year 2001 From

Tribal and Peabody Wellfield Pumpage

Community	Combined Tribal-Peabody Pumpage Drawdowns (ft)	Drawdown Attributable to Tribal Pumpage (ft)	Drawdown % of Total	Drawdown Attributable to Peabody Pumpage (ft)	Drawdown % of Total
Forest Lake	130.0	8.1	6.2	121.9	93.8
Cottonwood	4.0	1.6	40.0	2.4	60.0
Keams Canyon	100.0	80.6	81.0	19.4	19.0
Polacca	55.0	36.1	66.0	18.9	34.0
Mishongovi	35.0	20.3	58.0	14.7	42.0
Second Mesa	30.0	19.2	64.0	10.8	36.0
Shongopovi	30.0	20.3	68.0	9.7	32.0
Oraibi	50.0	42.0	84.0	8.0	16.0
Hotevilla	30.0	16.1	54.0	13.9	46.0
Tuba City	115.0	115.0	100.0	-	-
Red Lake	2.0	.2	10.0	1.8	90.0
Shonto	.1	-	-	-	-
Kayenta	110.0	60.0	54.5	50.0	45.5
Rough Rock	20.0	9.7	49.0	10.3	51.0
Kitsille	65.0	6.9	11.0	58.1	89.0
Chilchinbito	60.0	12.7	21.0	47.3	79.0
Dennehotso	-	-	-	-	-
Low Mountain	60.0	25.3	42.0	34.7	58.0
Pinon	79.0	22.8	29.0	56.2	71.0

TABLE 15

Percent of Available Water Height in Tribal Wells

Lost Because of Peabody Pumpage Through 2001

Community	Elevation of Top of N-Aquifer	Saturated Thickness of N-Aquifer (ft)	Elevation of Bottom of N-Aquifer	Water Level Elevations in Wells In N-Aquifer, 1964	Total Initial Height of Water In Wells in 1964 (ft)	% of Total Available Water Height Lost to Peabody Pumpage as of 2001
Forest Lake	4,250	800	3,450	5,700	2,250	5.4%
Cottonwood	5,600	300	5,300	5,680	380	0.6%
Keams Canyon	5,000	15	4,985	5,540	555	3.5%
Polacca	4,820	280	4,540	5,460	920	2.1%
Mishongovi	5,000	260	4,740	5,415	675	2.2%
Second Mesa	5,080	240	4,840	5,400	560	1.9%
Shongopovi	5,040	270	4,770	5,404	634	1.5%
Oraibi	4,930	350	4,580	5,409	829	1.0%
Hotevilla	4,950	410	4,540	5,400	860	1.6%
Tuba City	5,000	300	4,700	5,000	300	0%
Red Lake	5,250	930	4,320	5,445	1,125	.2%
Shonto	6,625	580	6,045	6,320	275	0%

TABLE 15 (Cont.)

Percent of Available Water Height in Tribal Wells

Lost Because of Peabody Pumpage Through 2001

Community	Elevation of Top of N-Aquifer	Saturated Thickness of N-Aquifer (ft)	Elevation of Bottom of N-Aquifer	Water Level Elevations in Wells In N-Aquifer, 1964	Total Initial Height of Water In Wells in 1964 (ft)	% of Total Available Water Height Lost to Peabody Pumpage as of 2001
Kayenta	5,500	850	4,650	5,570	920	5.4%
Rough Rock	5,230	610	4,620	5,525	905	1.1%
Kitsillie	4,740	700	4,040	5,584	1,544	3.8%
Chilchinbito	4,960	800	4,160	5,490	1,330	3.6%
Dennehotso	5,465	700	4,765	5,025	260	0%
Low Mountain	4,960	180	4,780	5,620	840	4.1%
Pinon	4,500	500	4,000	5,653	1,653	2.8%

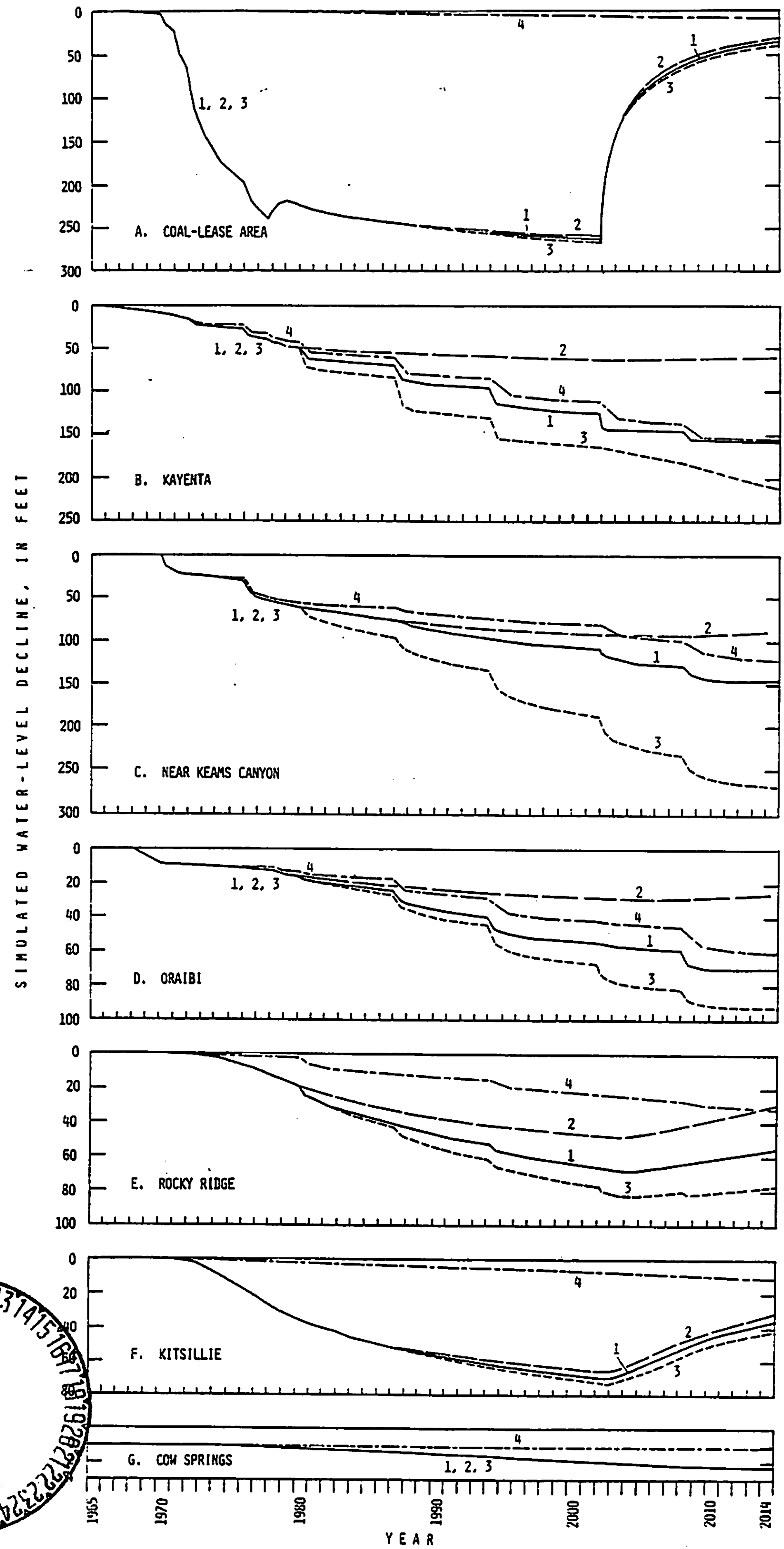


Figure 2. --Simulated water-level changes, 1965-2014, for projections 1, 2, 3, and 4.

Legend For Figure 2 Pumpage Drawdown Projections

Projection 1. PWCC pumpage is to continue at 3,700 AF/yr through 2001 and then reduces to 0 through 2014. Community pumpage is extended through 2014 using recent rates of increase. The community pumpage in 2001 is greater than 5,100 AF/yr.

Projection 2. PWCC pumpage is 3,700 AF/yr from 1980 through 2001 and 0 from 2001 through 2014. Community pumpage is held at 1,870 AF/yr from 1980 through 2014.

Projection 3. PWCC pumpage is 3,700 AF/yr from 1980 through 2001 and 0 from 2001 through 2014. All other pumpage in the confined portion of the N-aquifer is projected to increase at twice the 1980 rate. Total community pumpage is 6,370 AF/yr in 2001 and 9,580 AF/yr in 2014.

Projection 4. All PWCC pumpage is excluded and community pumpage is the same as in Projection 1.

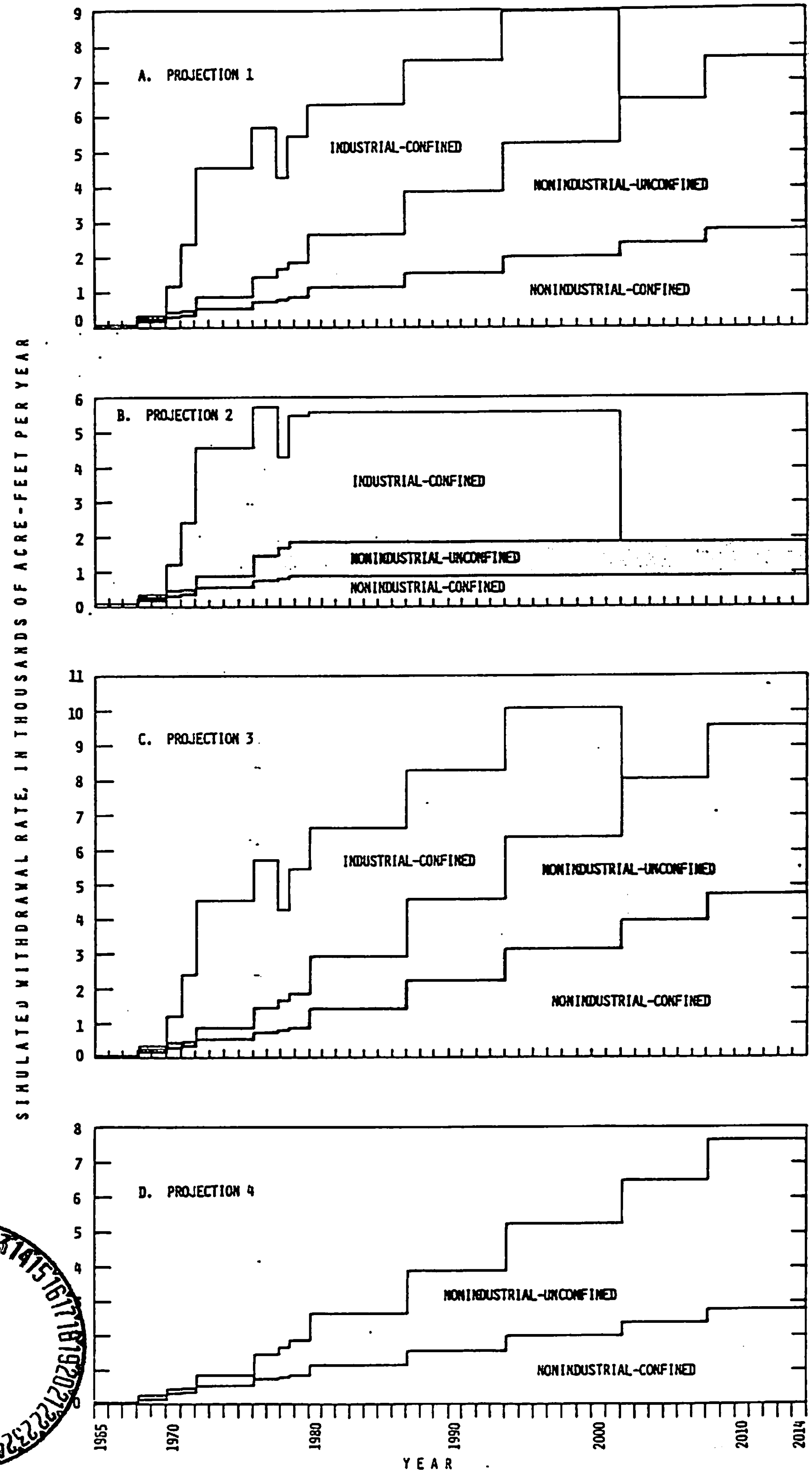


Figure 2A. Simulated Withdrawal Rate, 1965-2014, for Projections 1, 2, 3 and 4

Outflows to springs and streams from the N-aquifer are projected by the USGS model to decline 150 acre-feet due to Peabody pumpage and 330 acre-feet because of Tribal community pumpage. Overall, this will amount to about a six percent reduction in stream and spring flow. Although the projected declines are small, it is unlikely that they will ever return to pre-1965 flow levels following cessation of the Peabody pumpage because Tribal community pumpage will continue and is presently causing a majority of the flow reductions. Most of the reduction is expected to occur along Laguna Creek near Kayenta.

The significance of Tribal community pumpage on N-aquifer drawdowns should not be understressed. Eychaner states that in areas of large community pumpage, little of the simulated decline is caused by mining. At Kayenta, over 85 percent of the total water level declines will be caused by community pumpage. Two-thirds of the simulated decrease in N-aquifer outflow to springs, streams and alluvium and one-third of the evapotranspiration loss and leakage increase from the D-aquifer system would be caused by community pumpage.

<u>Effects of Induced Leakage of Poorer Quality Water from the Overlying D-Aquifer System on N-Aquifer Water Quality</u>. The water quality from Peabody and Tribal wells completed in the N-aquifer has been periodically monitored by the USGS since 1967. The thrust of the N-aquifer water quality monitoring effort has been towards assessing if vertical leakage from the overlying D-aquifer system is significant. The concentrations of dissolved solids, chloride and sulfate ions in the D-aquifer is 7 times, 11 times and 30 times greater, respectively, than in the N-aquifer. If the N-aquifer water level declines are inducing large amounts of vertical leakage from the D-aquifer system, there should be marked changes with time in these parameter concentrations.

It can be argued that, because Peabody production wells are completed in the lower aquifer of the D-aquifer system (Entrada Sandstone), the effects of induced leakage of poorer quality water would be masked. This does not appear to be the case for the following reasons: (1) the Entrada Sandstone is of better quality than the Dakota or Morrison aquifers; (2) the percentage of the total well yield from the Entrada Sandstone is minimal in comparison to the N-aquifer units, and the perforations opposite the Entrada tend to become scaled over rapidly; and (3) comparison of Peabody N-aquifer well chemical parameter concentration levels (Table 16) with those in Tribal N-aquifer wells (Table 17). The comparison indicates that the masking effect of the Entrada Sandstone water chemistry must be minimal because Peabody well water chemical concentrations are typically well below those in Tribal wells.

Comparisons of the concentration levels for certain chemical parameters over a period of several years are presented for the Peabody wells in Table 16 and for the Tribal wells in Table 17. There is no evidence to suggest that significant vertical leakage is occurring from the D-aquifer system into the N-aquifer system.

Surface Water

Effects of Dams, Sediment Ponds and Permanent Internal Impoundments on Runoff and Channel Characteristics. Ten major dams have or will be constructed on principal tributaries confluent to Moenkopi Wash during the life of the mining operation. Portions of the drainages above as well as below the dams will be affected. The reach immediately above a dam will gradually aggrade headward as more and more water is impounded until a pool level is reached that is in equilibrium with water gains and losses. Channel reaches below the dams will become incised by smaller active meandering channels whose widths are a function of drastically reduced runoff potential, channel gradients and sediment load particle size ranges. Vegetation will begin encroaching on the edges of the new active channels as there will be insufficient runoff to remove it.

The effects of sediment ponds and permanent internal impoundments on runoff and channel characteristics will be minimal on an individual basis, but comparable to the effects of dams when considered in total. It is estimated that more than 175 sediment ponds and several permanent internal impoundments have been or will be constructed during the life of the mining operation. The internal impoundments are typically small, excepting PIIs like N2-RA, N7-D and the two impoundments proposed for the J-19 coal resource area, and occur primarily on pre-law lands. Channel effects will be similar to those described for dams. Since most of the sediment ponds are on very small side tributaries, there will not be any updrainage impacts of any significance. Because of the number of ponds and their wide range of locations, the downstream effects (active channel narrowing and vegetative encroachment) will be manifested over longer channel distances.

In addition to the permanent internal impoundments, 34 sediment control structures (see Chapter 6, Table 9) are proposed for consideration as permanent impoundments that will remain as permanent features of the postmining landscape. The total drainage area that these permanent impoundments will encompass amounts to only 2.4 percent of the entire Moenkopi watershed (down to its confluence with the Little Colorado River).

The impacts of the sediment ponds and dams will be of little significance as there are no local users of water for flood irrigation (see Alluvial Valley Floor section of Chapter

TABLE 16

Selected Parameters from Chemical Analysis of Water From Wells of the Peabody Coal Company, Black Mesa Area, 1967-74 and 1980-84

Well Number	Year	Specific Conductance (Uumhos)	Dissolved Solids Residue at 180oC (mg/L)	Chloride, Dissolved (mg/L as Cl)	Sulfate, Dissolved (mg/L as SO_4)
2	1967	221	144[1]	5.0	21
	1980	225	144	11	20
3	1968	236	154[1]	4.0	17
	1980	230	151	3.5	14
4	1974	200	140	3.8	13
	1980	230	139	4.3	13
5	1968	224	149[1]	3.5	16
	1980	210	134	2.9	9.5
6	1968	201	333[1]	3.0	13
	1980	260	160	3.5	15
7	1972	222	141[1]	2.5	20
	1980	210	136	3.7	11
8	1980	420	283	4.8	100
	1983	440	278	4.8	100
	1984	436	264	4.7	100

[1]Dissolved-solids data from 1974.

TABLE 17

Selected Paramenters From Chemical Analysis of Water From Nonindustrial Wells

That Tap the N-aquifer, Black Mesa Area, 1982-84

Site Name	Year	Specific Conductance (umhos)	Dissolved Solids Residue at 180oC (mg/L)	Chloride, Dissolved (mg/L as Cl)	Sulfate, Dissolved (mg/L as SO_4)
Keams Canyon	1982	1,010	592	94	35
	1983	1,120	636	120	42
	1984	1,040	578	96	36
Rough Rock	1983	1,090	628	130	110
PM 5	1984	1,090	613	130	99
Rocky Ridge	1982	255	---	1.4	6.0
PM 3					
New Oraibi	1982	385	228	4.0	10
PM 4					
New Oraibi	1983	400	235	4.1	9.8
PM 3	1984	395	216	4.0	10
Kayenta	1982	360	228	4.5	58
PM 2	1983	375	230	---	60
	1984	365	209	4.2	51
Forest Lake	1982	470	281	11	67
Kitsillie	1982	580	365	5.4	84
	1983	505	291	5.2	20
	1984	460	258	5.2	20
Pinon	1982	485	---	3.7	5.0
PM 6	1983	505	293	3.6	5.3
	1984	495	273	3.7	5.4

17). Following removal of the dams and sediment ponds, there will be certain short term impacts to the channel reaches immediately below these structures. Sediment loads will temporarily increase as the active channel widens in response to the increased runoff potential. The increased channel bank vegetation should provide some stability during this active channel readjustment period. The potential for flood flows overtopping the channels will be negligible as the typical channel banks are 15 to 20 plus feet high above the active channel. The frequency of the larger runoff events will dictate how fast the channels reestablish themselves in quasi-equilibrium with the environmental conditions.

<u>Effects of Dams, Sediment Ponds and Permanent Internal Impoundments on Downstream Users</u>. An alluvial farm plot and phreatophyte survey performed by Intermountain Soils, Inc. in June, 1985 documented that there is no evidence that flood irrigation was ever practiced in the past or that it is presently being practiced along the major washes and tributaries within the leasehold. All agricultural plots inspected were located on high terraces and were planted with shallow rooting cultivars which are solely reliant on rainfall infiltration. Inspection of regional reservation land use maps indicates that flood irrigation is not practiced along lower Dinnebito and Moenkopi Washes other than some 70 miles below the leasehold at the town of Moenkopi where channel geomorphic conditions and flood flows are more amenable to these practices.

The total Dinnebito and Moenkopi watershed areas to the leasehold boundary draining to dams, ponds and impoundments are 4.84 and 68.18 square miles, respectively. There are a lot of significant tributaries to both washes between the leasehold and the Little Colorado River. Comparing the above drainage areas impounded to the total drainage areas for these washes suggests that this loss of runoff is of little significance at the points where the runoff water is being used. The impounded drainage areas on the leasehold amount to only 0.6 percent and 2.7 percent of the total Dinnebito and Moenkopi watersheds, respectively.

Peabody has monitored the 24 most probable ponds to hold water for monthly water levels since the latter half of 1985. The monitoring has been conducted to determine when impounded water levels exceeded surveyed elevation markers indicating the stage height at which the 10-year, 24-hour available storage volume remained. In addition to the above, Peabody has monitored annual water levels and volumes in the MSHA size dams since August, 1978. Based on the pond and dam monitoring information, the following analysis was performed to assess the potential impact of the dams and ponds on the town of Moenkopi using flow volumes.

Revised 12/01/86

Table 17a is a compilation of the results of the above-referenced monitoring. The values listed in each column are the volumes of water in acre feet measured in the ponds and MSHA dams in August (middle of the summer monsoon season) of each year. An average new inflow volume of 60 acre feet per year was assumed as the combined total of all the ponds, because: 1) most of their upgradient watersheds were small; 2) monthly water level monitoring indicated only 1 or 2 ponds during an entire year would have water levels above the 10-year, 24-hour available storage volume level; and 3) the total storage volume for ponds CW-A and CW-B is only 30 acre feet and most of this volume was filled by pit pumpage of ground water rather than surface water runoff.

A review of Table 17a indicates that the year with the greatest increase in water impounded from the previous year was 1983-1984. Six hundred forty-seven acre feet of additional water was impounded from overland runoff, Navajo well pumpage and pit pumpage. The latter two water sources were not considered to be a significant part of the total and were thus ignored. Annually, 60 new acre feet of water was assumed to be impounded by all the non-MSHA sized sediment ponds combined. This 60 acre feet has been included in the maximum total of 647 acre feet.

The analysis approach employed moving a flow volume equal to 645 acre feet down a 70 mile length of Moenkopi Wash in a channel with a constant 80 foot flat bottom width (based on a cross section of Moenkopi Wash that is being measured and monitored within the leasehold for indirect flow calculations) as shown in Figure 2B. Although flow loss to the channel banks is significant, infiltration loss through the channel bottom was the only one considered. An hourly loss rate of 1 inch per hour was used and is the lowest loss rate determined from particle size analyses of bed material from the principal channels transgressing the leasehold (see Table 12, Chapter 15).

A storm runoff flow with a total flow volume of approximately 644 acre feet was computed using SEDIMOT II for a portion of Moenkopi Wash within the leasehold. Trial and error 24-hour precipitation inputs were tried until a total flow volume as close to 647 acre feet as possible was achieved. The duration of this flow hydrograph (18.4 hours, refer to Table 17b) was used to determine the minimum amount of time that an infiltration loss of 1 inch per hour would occur over each square foot of the channel bottom between Moenkopi Wash on the leasehold and Moenkopi Wash at the town of Moenkopi (a distance of at least 70 miles). Table 17c shows the infiltration loss in acre feet (14.5) for each mile that a flow with an 18.4 hour duration moves towards the town of Moenkopi. At a rate of 14.5 acre feet per mile, the entire 644 acre foot flow generated on the leasehold would be lost to channel bed infiltration before the flow had moved 45 of the 70 miles towards the town of Moenkopi.

TABLE 17a

Summary of Impounded Surface Runoff in

MSHA Dams and Sediment Ponds by Year

(acre feet)

Year	J2-A	J-7	J16-A	J16-L	N14-D	N14-E	N14-F	N14-G	N14-H	All Ponds[1]
8/78-8/79		137								
8/79-8/80		117								
8/80-8/81		37								
8/81-8/82		182	**		8	**	0.5	5		60
8/82-8/83		180	**		80	**	2	6		60
8/83-8/84		425	13	220	153	**	4	40		60
8/84-8/85		305	4	***	150	**	4	26		60
8/85-8/86	*	335	10	65	153	**	4	13	2	60
1989-1990	42	300	50	69	107	0.1	6	35	38	60
1998	21	208	27	44	75	0	5	24	30	60

* Under construction

** Negligible amount of water impounded

*** Drained for repair

[1] Assumed 60 additional acre feet impounded each year

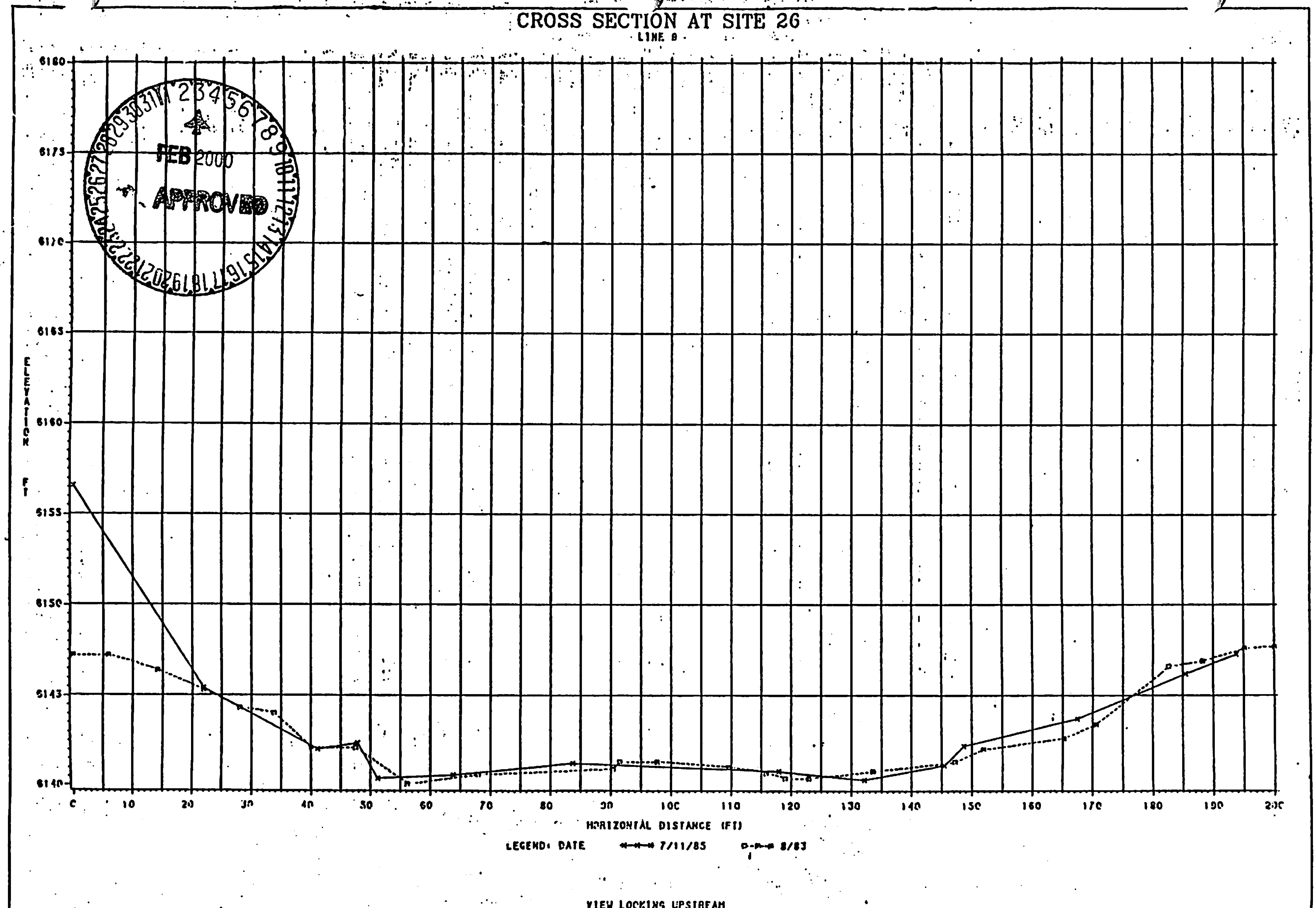


FIGURE 2B. CHANNEL CROSS SECTION FOR MOENKOPI WASH ON LEASEHOLD USED FOR FLOW LOSS COMPUTATIONS DOWN TO THE TOWN OF MOENKOPI

TABLE 17b

Discharge Hydrograph Output From SEDIMOT II Run

for 644 Acre Foot Flow Volume on Moenkopi Wash

Time (hrs)	Discharge (cfs)	Time (hrs)	Discharge (cfs)	Time (hrs)	Discharge (cfs)	Time (hrs)	Discharge (cfs)	Time (hrs)	Discharge (cfs)
1170	0.134	1460	1302.409	1750	605.403	2040	374.685	2330	279.027
1180	1.615	1470	1287.579	1760	589.178	2050	373.363	2340	277.233
1190	6.186	1480	1263.996	1770	573.179	2060	371.934	2350	275.672
1200	15.553	1490	1232.567	1780	557.571	2070	370.334	2360	274.297
1210	31.760	1500	1195.552	1790	542.437	2080	368.501	2370	273.069
1220	54.974	1510	1155.723	1800	527.854	2090	366.421	2380	271.960
1230	88.993	1520	1115.680	1810	513.939	2100	364.215	2390	270.949
1240	138.810	1530	1077.302	1820	500.777	2110	361.935	2400	270.021
1250	205.400	1540	1041.274	1830	488.194	2120	359.478	2410	269.148
1260	281.526	1550	1007.689	1840	476.169	2130	356.731	2420	268.192
1270	361.065	1560	976.513	1850	464.747	2140	353.617	2430	267.129
1280	438.975	1570	947.754	1860	453.973	2150	350.093	2440	265.948
1290	515.344	1580	921.268	1870	443.887	2160	346.190	2450	264.557
1300	600.635	1590	896.752	1880	434.526	2170	342.010	2460	262.719
1310	701.142	1600	873.816	1890	425.950	2180	337.645	2470	260.319
1320	810.924	1610	852.136	1900	418.221	2190	333.144	2480	257.228
1330	920.040	1620	831.417	1910	411.375	2200	328.525	2490	253.426
1340	1018.324	1630	811.516	1920	405.418	2210	323.828	2500	249.172
1350	1098.921	1640	792.390	1930	400.316	2220	319.122	2510	244.594
1360	1160.101	1650	773.931	1940	395.991	2230	314.440	2520	239.480
1370	1205.486	1660	755.867	1950	392.336	2240	309.839	2530	233.614
1380	1239.773	1670	738.026	1960	389.232	2250	305.361	2540	226.834
1390	1265.835	1680	720.297	1970	386.572	2260	301.042	2550	219.062
1400	1284.288	1690	702.753	1980	384.264	2270	296.924	2560	210.368
1410	1296.2[illegible]0	1700	685.754	1990	382.244	2280	293.063	2570	200.974
1420	1304.311	1710	669.443	2000	380.466	2290	289.519	2580	191.094
1430	1308.[illegible]56	1720	653.512	2010	378.884	2300	286.337	2590	180.841
1440	1310.[illegible]5	1730	637.632	2020	377.411	2310	283.536	2600	170.265
1450	1309.468	1740	621.607	2030	376.016	2320	281.111	2610	159.467

TABLE 17b (Cont.)

Discharge Hydrograph Output From SEDIMOT II Run

for 644 Acre Foot Flow Volume on Moenkopi Wash

Time (hrs)	Discharge (cfs)	Time (hrs)	Discharge (cfs)
2620	148.600	2840	18.492
2630	137.759	2850	16.234
2640	127.075	2860	14.264
2650	116.645	2870	12.497
2660	106.548	2880	10.924
2670	96.878	2890	9.513
2680	87.759	2900	8.230
2690	79.320	2910	7.067
2700	71.659	2920	6.037
2710	64.817	2930	5.050
2720	58.777	2940	4.199
2730	53.468	2950	3.483
2740	48.778	2960	2.899
2750	44.591	2970	2.404
2760	40.804	2980	2.024
2770	37.338	2990	1.717
2780	34.134	3000	1.456
2790	31.145	3010	1.228
2800	28.343		
2810	25.708		
2820	23.231		
2830	20.935		

TABLE 17c

Channel Bed Infiltration Loss for Each Hour of
Flow Over the Channel Bed Area Between
the Leasehold and the Town of Moenkopi

Channel Bottom Area for Each Lineal Foot in Acres	Infiltration Rate in feet/hour	Acre Feet of Flow Loss for Each Mile of Flow with an 18.4 Hour Duration
.0018	.083	14.5

The above analysis was performed using very conservative numbers. Average channel bottom widths from the leasehold to the town of Moenkopi are considerably larger than 80 feet and would account for larger infiltration losses per mile than were used. Channel bed infiltration rates are considerably higher than the 1 inch per hour rate that was used. This rate is probably more indicative of saturated flow infiltration rates. The flow duration would increase as the flow hydrograph peak lowers and the flow rate slows in the downstream direction. The 18.4 hours is the shortest time span during which flow losses over each square foot of the channel would occur. Finally the total flow volume used (644 acre feet) is extreme and is an accumulation of runoff from many storms. Individual storm volume totals would be considerably smaller and totally lost as channel bed infiltration in shorter distances from the leasehold. Considering watershed areas and runoff volumes impounded, the sediment ponds and dams on the leasehold do not have any measurable impact on surface water use at the town of Moenkopi.

With the current NPDES Permit, Peabody is able to pump from ponds and/or dams following significant runoff events. Considering the significant channel transmission losses, this water would only be of benefit in the immediate vicinity of the leasehold. The quantity of water made available from this pumpage would most probably be used for livestock drinking water purposes if used at all.

<u>Effects of Dams, Sediment Ponds and Permanent Internal Impoundments on Stream-Water Quality</u>. The effects of pond and dam discharges on stream-water quality will be negligible, because all sediment ponds and dams are designed to contain the 10-year, 24-hour runoff volumes plus sediment. Pond and dam discharges resulting from storm runoff have and should continue to be infrequent. In the event of their occurrence, the NPDES permit requirements for sampling, effluent limits and reporting will be complied with.

The disposal of sediment removed from sediment ponds is conducted in a manner that protects stream water quality and is described in Chapter 6, Page 22, 3rd paragraph (12/04/97 version) of Permit AZ0001D.

The current NPDES Permit (Chapter 16, Attachment 3) allows pond dewatering and pond to pond pumpage as a means of providing sufficient detention time and storage to help ensure discharge effluent limits are met and there are no significant water quality impacts to the streams. Seepage from dam embankments or around the sides of embankments is also presently being monitored to document this form of pond discharge poses no significant threat to the receiving stream water quality.

Runoff discharges from the permanent internal impoundments are extremely unlikely. Should they occur, impacts to the stream-water quality are highly unlikely. Tables 18 and 19 shows a comparison of average concentrations for certain chemical constituents in permanent internal impoundment water and streamflows. As can be seen, the permanent internal impoundment water quality is suitable for use as livestock drinking water, excepting the alkalinity values at Impoundments 113 and 123. Alkalinities at 50 percent of the stream sites are above the recommended limit for livestock. Though some of the other chemical concentrations in impoundment water are higher, discharges would not significantly affect stream-water quality, and they would not change the potential stream water use.

<u>Effects of Stream Channel Diversions on Channel Characteristics and Runoff Water Quality</u>. Six channel diversions affecting approximately 6.0 miles of channel in tributaries to Moenkopi Wash have or will be constructed during the life of the mining operations. The effects of channel diversions on channel characteristics and stability will be minor for the following reasons. All diversion channels will be at least as wide as the existing channel which should eliminate the potential for flow constrictions and excessive lateral erosion. All diversion channel slopes will approximate original channel slopes so that comparable flow velocity ranges will be maintained. Energy dissipators will be constructed at the entrance and exit points of each diversion to provide an additional control on flow velocities and erosion potential at these points. The only anticipated channel effects from the diversions would be the channel's natural tendency to reestablish meanders. This will cause some minor erosion on alternating sides of the diversion where the meandering thalweg intersects side slopes. The stability of the channel diversions will be no less than the stability of the natural channels.

The diversion channel construction activity and the natural meandering tendency of the active channel thalweg will expose fresh alluvial surfaces to weathering and erosion.

TABLE 18

Mean Concentrations of Selected Chemical Parameters Measured In

Permanent Internal Impoundments on Reclaimed Areas on Black Mesa

Monitoring Site

Parameter	11[illegible]	117*	118*	121	122*	123*	112*	113*	119*	120*	206	212
pH	7.8	7.3	7.4	7.2	7.6	8.0	8.5	7.7	7.5	7.8	8.1	8.1
TDS	2085	279	239	490	308	549	2628	4816	411	724	915	4403
Alk	158	136	121	78	117	229	157	242	91	122	77	133
SO_4	1320	46	19	210	48	175	1213	2590	187	337	523	2973
Ca	119	31	26	66	27	69	52	155	37	80	123	278
Mg	148	16	13	21	11	24	39	189	17	35	66	258
Na	214	11	6	19	8	47	462	854	43	54	22	640

*Pre-law area ponds

TABLE 19

Mean Concentrations of Selected Chemical Parameters

Measured at Stream Station Sites on Black Mesa

(1980 - 1985)

Monitoring Site

	DN		RE	YC	YW			CM			RP		MK	
Parameter	34	78	37	85	50	15	157	16	18	25	14	155	35	26
pH	7.7	7.4	7.4	7.7	7.7	7.7	7.7	7.5	7.6	7.6	7.7	7.8	7.4	7.7
TDS	1998	1823	1205	289	1869	1396	229	449	1623	1853	783	470	1312	1987
Alk	192	168	303	141	198	189	83	117	194	199	144	122	170	308
SO_4	1187	1063	648	118	582	827	55	170	1157	1061	350	161	766	1170
Ca	234	207	150	52	175	178	38	71	149	187	67	62	158	224
Mg	131	105	61	9	66	88	9	20	139	119	46	18	89	126
Na	144	97	95	13	29	52	6	12	124	126	61	35	65	124

DN Dinnebito Wash

RE Reed Valley Wash

YC Yucca Flat Wash

YW Yellow Water Canyon Wash

CM Coal Mine Wash

RP Red Peak Valley Wash

MK Moenkopi Wash

This will result in additional amounts of sediment and dissolved chemicals being contributed to the streamflows. Several years of monitoring downstream from the Coal Mine Wash and Yazzie Wash channel changes indicates that natural background levels of sediment are so high that these minor additions are negligible (Chapter 15). Dissolved chemical loads have been historically quite variable. Stream water chemistry appears to be significantly affected by the portion of the watershed the flow originates in and the magnitude of the sediment load being transported by the flow. The cation exchange capacity of the sediment is high, and this does affect the flow chemistry. It is concluded that the water chemistry effects of channel diversions are minimal as they cannot be distinguished from natural fluctuations.

Effects of Culverts at Road Crossings on Stream Runoff and Water Quality. The effects of culverts on stream runoff and water quality will be minimal for the following reasons. All culverts or combinations of culverts are designed to pass the 10-year 6-hour flow with at least 1 foot of freeboard. If culvert exit velocities exceed six feet per second, riprapped energy dissipators will be employed to reduce the velocities. If exit velocities are between four to six feet per second, culverts will be inspected periodically for evidence of accelerated erosion immediately below their outfalls. If accelerated erosion is occurring, riprapped energy dissipators will be constructed at these points. Finally, these structures involve such minor areas of disturbance that chemical and sediment changes in the flows will be undetectable.

Removal of Pre-existing Surface Water Structures. One pre-existing surface water structure (DM-1) will be removed as a result of constructing the Reed Valley Wash channel diversion. One pre-existing structure (DM-7) was disturbed as a result of upgrading the original embankment for sediment control (K-P pond). The K-P pond will be reclaimed after permit approval. It is a redundant pond as a result of the completion of Wild Ram Valley Dam (J2-A pond) downstream. One pre-existing structure (DM-9) was impacted by construction of the main J-1/N-6 haul road. A portion of the pre-existing watershed was truncated as a result of the haul road alignment. The pre-existing watershed will not be restored because the haul road will most probably be retained as part of the postmining land use plan.

The probable hydrologic consequences of mining and related activities on 22 actual or suspected pre-existing surface water structures will be nill or inconsequential. This conclusion is reached for one or more of the following reasons: 1) minimal or no direct or indirect physical disturbance will occur at several of the pond sites or in impounding watersheds during the life-of-mine activities; 2) several sites do not actually exist; 3) several structures are non-functional due to structural failure; and 4) several structures are not applicable to this permitting action.

Interim impacts caused by the loss of the three structures previously discussed have been or will be mitigated by providing alternate water sources (N-aquifer public water standpipes and existing and proposed sediment control structures). The three structures will be replaced with one of vastly superior structural design following the completion of mining and reclamation in the affected areas.

The loss of structure DM-7 will be mitigated by the retention of the J2-A pond as a permanent impoundment. The loss of DM-9 will be mitigated by the retention of several pre-law internally draining ponds in reclaimed portions of the J-1/N-6 or J-3 coal resource areas, or the retention of Ponds J3-D or J3-E as permanent impoundments. The loss of structure DM-1 will be mitigated by the retention of the J16-L sediment control structure (Reed Valley Dam) as a permanent impoundment. All the proposed permanent impoundments currently meet, or will be upgraded to meet the permanent performance standards (see Chapter 6 for design information). All proposed permanent impoundments and pre-law internally draining ponds have been demonstrated to have superior persistence capabilities and water quality (see Chapters 6 and 15 and Appendix E to Permit AZ-0001D and the 1/17/94 cover letter response, including Appendices 1 and 2, to technical Deficiency Number 3 to Chapter 16, Permit AZ-0001D.

<u>Effects of Runoff From Reclaimed Areas on the Quantity and Quality of Streamflow</u>. Considering the natural physiographic region in which Peabody is reclaiming lands disturbed by mining, and criteria imposed by regulatory authorities for evaluating reclamation efforts with regard to bond release, probable hydrologic consequences of runoff from post-law reclaimed areas is addressed in the following sections. Bond release criteria include the successful establishment of vegetative cover, topsoil stabilization, and the effects of runoff from reclaimed areas on the quantity and quality of waters in the receiving streams. Runoff from reclaimed areas will flow into receiving streams following the removal of sediment structures at the time of bond release.

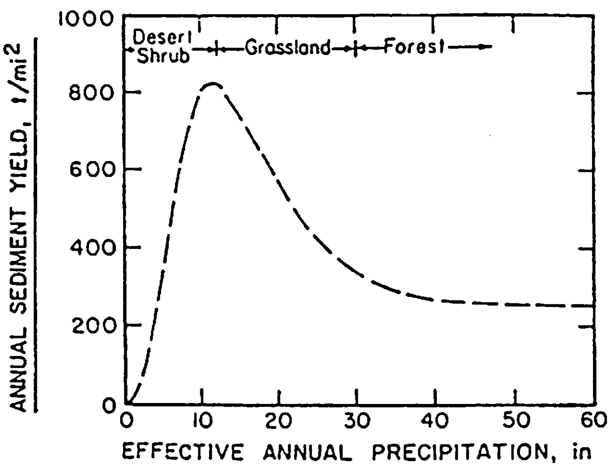
Reclamation efforts undertaken by Peabody in post-law coal resource areas on the leasehold occur in a physiographic region typified by a mild mean annual temperature (48°F) and a low mean annual precipitation (10 inches). Mean annual precipitation is based on nonheated recording rain gauges. Including the contributions from snow, the mean effective precipitation on the leasehold is about twelve inches. Typical basin morphologies in the region include highly eroded landscapes of moderate to high relief, with entrenched sandbed channels and headward-cutting arroyos.

In this arid climate, intense summer thunderstorms produce flash-flooding in ephemeral channels resulting in high concentrations of sediment loads (10^5 mg/l). The highly erodible natural soils provide a significant contribution to the sediment yields produced in this climate. The limited vegetative cover in this region due to climatic and grazing conditions contributes to the flashy response of ephemeral channels from intense storms. Figure 3.a. shows a relationship among effective annual precipitation (EAP), climate and annual sediment yield (Langbein and Schumm 1958). Considering this diagram, EAP and climate on Black Mesa correlate to the highest annual sediment yields. Figure 3.b. shows the same relationship as Figure 3.a., including the effect of mean annual temperature (MAT) (Schumm 1977). MAT on Black Mesa, in combination with EAP and climate, correlate to extreme annual sediment yields. Estimates of annual sediment yields (tons/mi^2) on the leasehold, incorporating site-specific parameters into the USLE, range between 4,666 tons/mi^2 and 14,477 tons/mi^2. These estimates were made taking into account the factors that affect erosion in the region, including the typical sparse cover and highly erodable soils (see Annual Sediment Yield Estimates, Chapter 15).

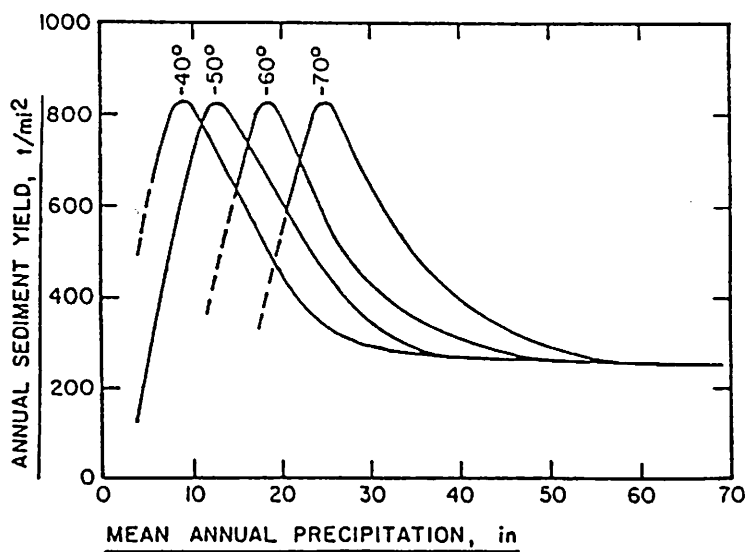
Reclaimed areas created by Peabody on Black Mesa will have topography characterized by long slopes no greater than 3:1 (h:v). Topsoil material used to cover regraded spoil material will be spread to a minimum depth of twelve inches. Spoil material will be compacted to some degree during regrading, as it contains higher clay contents than topsoil material. The only suitable topsoil materials available are highly erosive due to their overall fine-sandy texture and lack of organic material, and are typical of those forming regionally under arid conditions. The "K" value assigned to topsoil material used for reclaimed areas by Intermountain Soils, Inc. personnel is .43 (Chapter 8), which confirms the high erosion potential of the topsoil.

Topsoiled reclaimed areas will feature vegetation established sufficiently to support the stabilization of topsoil material and the postmining land use of livestock grazing. Vegetative ground cover in the reclaimed areas will be similar to the native vegetation. For a discussion of vegetative ground cover and success standards for cover see Chapters 23 and 26, Permit AZ-0001D.

Discharge. The effects of runoff from reclaimed areas on the quantity and quality of waters in receiving streams will be minimal. Receiving streams on Black Mesa (Moenkopi, Coal Mine, Yellow Water, Dinnebito, Yucca Flat and Red Peak Washes) commonly yield



a. *Variation of sediment yield with climate in the United States (from Langbein and Schumm, 1958).*



b. *The effect of mean annual temperature (°F) on the sediment yield--climate relationship (after Schumm, 1977, p. 44).*

FIGURE 3. Climate and Sediment Yield

discharges characterized by hydrographs with sharp peaks, short time to peaks, and short durations. These hydrograph characteristics become somewhat dampened downstream, as channel slopes lessen and cross section geometries increase.

Runoff from reclaimed areas should largely occur as overland flow, typified by hydrographs of gentle peaks and longer durations. With the controlled topography in reclaimed areas (slopes less than 3:1) and the modified drainage system, runoff times of concentration will be longer, resulting in reduced flow peaks and longer hydrograph durations than typical hydrographs of runoff from natural undisturbed basins on Black Mesa. External drainages will be established as part of the final reclamation, along with networks.

Runoff volumes and discharges from reclaimed areas should result in localized decreases in runoff to receiving streams. Reclaimed coal resource areas will contribute less runoff to receiving streams for similar storms than those same areas did prior to mining. Computations using SEDIMOT II to predict runoff and sediment differences from areas in the Coal Mine Wash drainage before mining and following reclamation show reductions in peak discharges and runoff volumes for an identical storm input (see Coal Mine Wash Pre- and Postmining Sediment Yield Estimates, Chapter 15, PAP). In watersheds with large portions of mined and reclaimed areas, magnitudes of the predicted decreases in peak flows range between 2 and 24 percent. Reductions in predicted runoff volumes range between 5 and 21 percent.

Topography, soils and vegetation modeled in the Coal Mine Wash drainage are typical of final reclamation that will be established in all mined coal resource areas on the Black Mesa leasehold. Based on SEDIMOT II predictions, watersheds established in reclaimed coal resource areas will typically yield reduced peak flows and runoff volumes compared to runoff from the areas before mining activities commenced. The impact of these reductions in runoff from reclaimed areas to receiving streams will be local. SEDIMOT II predictions of peak discharge and runoff volume from the entire Coal Mine Wash watershed under postmining conditions at Site 18 (includes junctions I-XIV) were only slightly less than the runoff generated under premining conditions. Predicted peak discharge and runoff volumes were reduced by only 2 percent and 3 percent respectively. Considering the order of magnitude of flows for which predicted runoff parameters were determined by SEDIMOT II up to junction XIV (10^3), these reductions are not significant. Also, junction XIV was established only a short distance downstream from these largely reclaimed watersheds in which runoff reductions were estimated at more than 20 percent.

The prediction results for modeling Coal Mine Wash drainage under pre- and postmining conditions suggest that, for a 24-hour duration storm of uniform distribution over the entire watershed, runoff reductions from reclaimed areas will be local and will result in insignificant reductions of runoff in the main channels. As runoff in the main channel systems progresses downstream, encountering additional lateral inflow from undisturbed basins, localized runoff reductions will become less pronounced and unmeasurable.

Generally, an increase in total drainage area is accompanied by an increase in watershed discharge. Reclaimed areas on Black Mesa that will drain into the Moenkopi watershed comprise only two percent of the total Moenkopi watershed above its confluence with the Little Colorado River. Slight reductions in runoff from reclaimed areas will not affect the overall runoff from this watershed area; however, runoff from the large drainage areas above the village of Moenkopi near Tuba City has been utilized for flood irrigation purposes. Reductions in runoff discharge in Moenkopi Wash from reclaimed areas on the leasehold will not be detected some 70 miles downstream in the vicinity of Moenkopi.

Busby (1966) mentions that approximately 50 percent of the runoff produced in tributaries of the Little Colorado River is lost in transmission before reaching this major channel. Channel transmission and evapotranspiration losses of this magnitude would completely mask any runoff reductions from the small reclaimed areas on the leasehold to receiving streams.

Sediment. Sediment concentrations measured in receiving streams as part of monitoring efforts by Peabody personnel commonly range from 10^4 to 10^5 mg/l (see Peabody Sediment Monitoring, Chapter 15). Sediment yields (tons/day) have been determined on a storm basis from measured discharges and sediment concentrations made at automated stream station sites on the leasehold. Measured sediment yields range from 10^2 to 10^3 tons per day for low discharges, and up to 10^5 tons per day in higher discharges (Automated Site Sediment Yield Analyses, Chapter 15, PAP).

Channel contributions to measured sediment yields were estimated using SEDIMOT II computations (see Coal Mine Wash Pre- and Postmining Sediment Yield Estimates, Chapter 15, PAP). Using a range of storms, peak discharge and sediment concentrations were predicted for the entire Coal Mine Wash drainage above the location of Stream Station 16. These predicted values were converted to tons per day and plotted on the sediment rating curve developed from data collected at Site 16 (Figure 4). Regression lines defining the

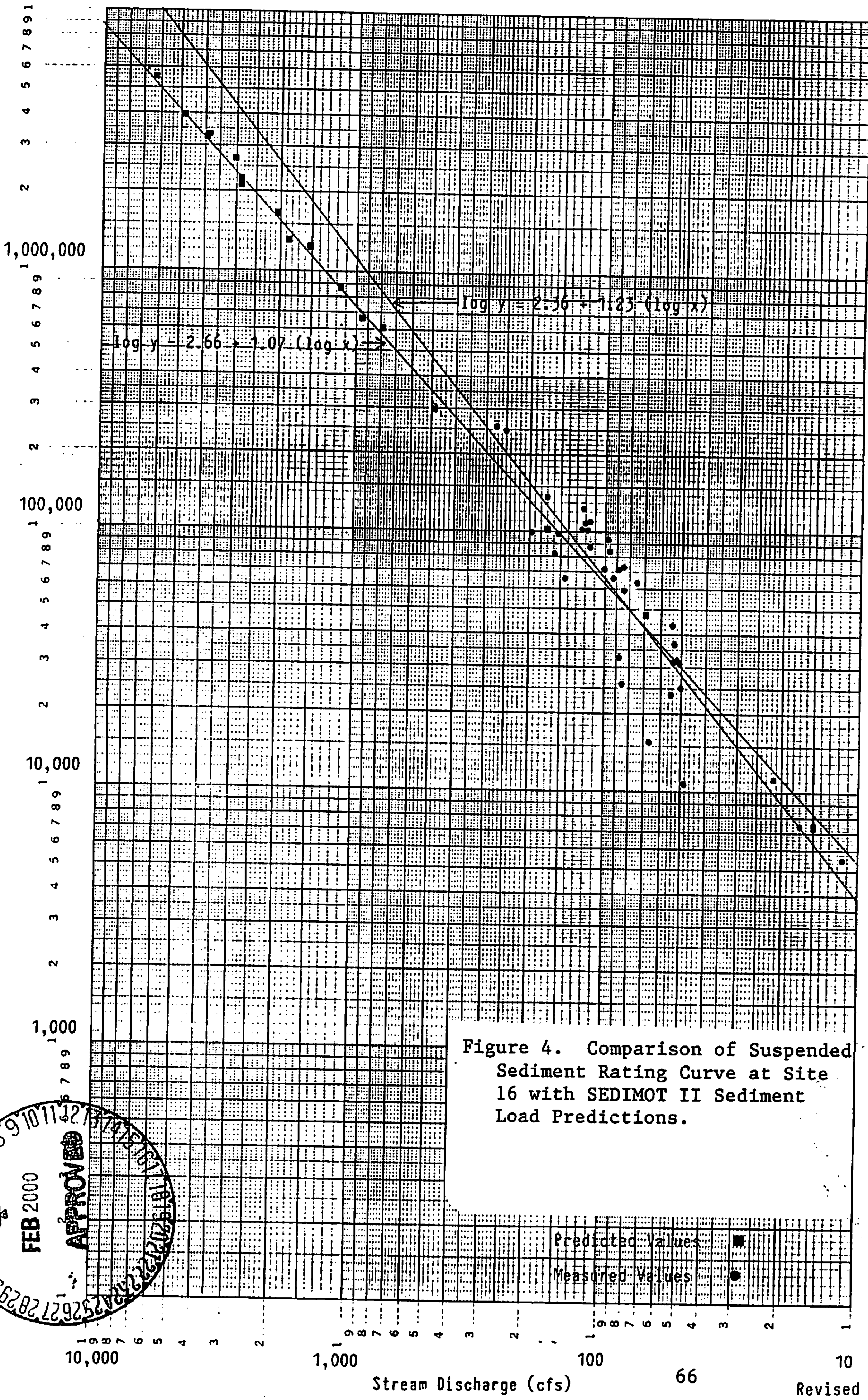


Figure 4. Comparison of Suspended Sediment Rating Curve at Site 16 with SEDIMOT II Sediment Load Predictions.

Revised 12/01/88

relationships among both the measured and predicted values were determined and are labeled on Figure 4. Comparisons of the regression lines at various discharges suggest that sediment contributions from the channel sides and bed to the main channel sediment load could be as high as 45 percent at discharges in the range of 3,000 cfs. It can be concluded that the main channels of the principal drainages that disect the Black Mesa leasehold could contribute up to 45 percent of the total sediment load discharge during large flow events.

Due to the likelihood of intense summer thunderstorms occurring on reclaimed areas, and the highly erosive nature of topsoil material, sediment concentrations of runoff from reclaimed areas could approach concentrations comparable to receiving streams. For purposes of comparing premining conditions (undisturbed) with postmining conditions (reclaimed coal resource areas), sedimentation estimates in runoff from Coal Mine Wash have been made using SEDIMOT II (see Coal Mine Wash Pre- and Postmining Sediment Yield Estimates, Chapter 15, PAP). The drainage area above the location at which these estimates were made comprised almost 43 square miles. Sediment yield calculations were made assuming that the outlet of this drainage area is located about one mile downstream from the N-1 reclaimed area at Stream Station 18. Results (Chapter 15) show decreased sediment concentrations (1 to 23 percent) and sediment yields (4 to 34 percent) in streamflow due to discharge from modeled watersheds within the Coal Mine Wash watershed largely comprised of reclaimed areas.

Again, reclaimed topography, soils and vegetation modeled in the Coal Mine Wash drainage are typical of final reclamation to be established in all mined coal resource areas. Watersheds established in reclaimed coal resource areas will typically yield reduced peak sediment concentrations and sediment yields compared to premining conditions.

The effect of decreased sediment concentrations and yields in receiving stream runoff resulting from reclaimed area runoff will be local. Generally, as discharges increase in receiving streams, reduced sediment contributions from watersheds largely composed of reclaimed areas become less pronounced. Model predictions for the entire Coal Mine Wash watershed at Site 18 show a reduction in sediment yield (5 percent) and a 1 percent increase in peak sediment concentration for postmining conditions. The order of magnitude of both predicted parameters is 10^5, which diminishes the significance of the difference in these parameters between premining and postmining conditions.

As flow in receiving streams proceeds downstream, lateral inflow from undisturbed watersheds will contribute to sediment loads in the main channels. These additional contributions will tend to mask the localized decreases in sediment loads resulting from watersheds comprised mainly of reclaimed areas. Finally, sediment yield contributions from channel beds and sides may be as high as 40 percent, which will offset the predicted reductions in sediment loads from reclaimed areas. Channel contributions to sediment loads are predicted to completely mask the localized effects of reclaimed area contributions in the downstream direction.

Water Quality. Receiving stream-water quality has been monitored since 1981 at stream station sites on the leasehold (see Stream Water Quality Section, Chapter 15). Permanent internal impoundments (PII) established in both pre-law and post-law reclaimed areas on Peabody's leasehold have also been sampled for water quality. Tables 18 and 19 are summaries of sample means for selected major chemical parameters. Table 19 presents mean parameter values measured at stream station sites, and Table 18 presents mean parameter values measured in PII's in both pre-law and post-law areas.

Generally, PII's created in pre-law areas have water quality similar to post-law areas. Runoff flowing into PII's in pre-law areas occurs on regraded spoil material. Although post-law areas were topsoiled, comparisons using mean parameter values from post-law and pre-law PII's indicate no significant differences in the quality of water flowing over spoil material versus topsoil material.

Mean parameter values of PII's compare favorably with stream values, showing only slight increases in ranges. PH means measured in PII's range between 7.2 and 8.5, while stream values range between 7.4 and 7.8. TDS means in PII's (239 to 4816 mg/l) range higher than streams (229 to 1998 mg/l). An exception to the slight increases in mean parameters is the higher maximum alkalinities measured in streams (308 mg/l for Site 26) compared to PII's (242 mg/l for PII 113). Maximum mean values for sulphate, dissolved Ca, Mg and Na are slightly higher in PII's than in receiving streams.

Both sets of data show that water quality in streams and ponds fall within the livestock drinking water limits presented in McKee and Wolf 1963, Botz and Pedersen 1976, and National Academy of Sciences 1974, except for values of total alkalinity. Two PII's and 50 percent of the stream monitoring sites show average alkalinity values higher than 170 mg/l.

Runoff water quality from reclaimed areas (including pre-law areas not topsoiled) will not significantly alter receiving stream water quality. Increased levels of total and dissolved chemical constituents in runoff from reclaimed areas will be slight. For small discharge events, these slight increases will affect stream water quality locally. The significance of these slight increases in the larger flows will be negligible as TDS values tend to somewhat lower in larger flows. Thus, the diluting effect of the larger streamflows should be greater.

<u>The Impact of the Reclamation Plan on the Stability of Reclaimed Areas</u>. Reclamation of coal resource areas on PCC's Black Mesa leasehold occurs in a semi-arid climate. Common products of this climatic regime include flash floods in ephemeral channels resulting from very intense summer thunderstorms. Drainages exhibit high degrees of drainage densities, severly eroded landscapes of moderate to high relief, entrenched sandbed channels and the continual evolution of rills and gullies in the upslope portions of drainage basins.

No physical measurement guidelines have been found that provide distinctions between rills and gullies. Generally, gullies are classified as large rills. Quantification of the processes that form rills and gullies has not yielded conclusive results. Gullies have been classified as continuous or discontinuous (Leopold and Miller, 1956). Continuous gullies begin their downstream course with many small rills, while discontinuous gullies start with an abrupt head cut (Heede, 1975). Most rills and gullies that form naturally on Black Mesa are continuous, as abrupt head cuts in these systems are not commonplace, occurring only where lithologic controls predominate.

Several key factors contribute to the formation of rills and gullies in the semi-arid southwest. Intense thunderstorms commonly generate large raindrops that impact soil surfaces with high degrees of kinetic energy. The raindrop impacts detach soil particles which are then entrained by overland flow. The kinetic energy imparted by very intense rainfall tends to seal some soil surfaces rapidly, concentrating overland runoff. The disruption of the soil surface and concentration of overland flow during a storm event creates an opportunity for the establishment of small rills.

Another major influence is the vegetative canopy covering the soil surface. The vegetative canopy intercepts a portion of the total rainfall volume reducing the potential for rapid runoff. The vegetative cover tends to reduce the energy of the raindrop impacts, thereby lessening the degree to which the soil surface is impacted and the quantity of detached soil particles.

The tendency of a soil to erode (detachment) also affects the degree to which rilling occurs. Sandy textured soils have a higher susceptibility for detachment than soils high in clay content. The presence of organic matter tends to provide soil cohesiveness, reducing the possibility of soil detachment. Topsoil material present on the leasehold tends to have a sandy texture and be low in organic matter and clay content.

Morphologic factors such as slope steepness, length, shape and drainage density affect the rilling process. The tractive force, a measure of detachment potential of flow, increases with slope steepness (Meyer, Foster and Romkens, 1975). Runoff increases with distance from the tops of slopes, as the contributing drainage area above increases. As the length of slopes increase so does the potential for rill and gully development. The shape of an irregular slope will affect the development of rills depending on the interrelationships of slopes and slope lengths. Natural basins will establish drainage networks of a sufficient density to carry excess runoff to the basin outlet. Although rills and gullies are small in comparison to main channels, they are an integral part of a basin's drainage network.

Many theories and concepts have been developed in the literature that explain the development of rills in gullies in semi-arid environments. Schumm and Hadley (1957) proposed a model of semi-arid erosion in which channels (including rills and gullies) adjust, by either aggrading or downcutting, to variations in sediment loads and discharge. Bergstrom and Schumm (1981) discuss a model based on the episodic behavior of a drainage basin, in which distinct zones of a watershed adjust channel characteristics in response to episodic changes in flow and sediment with time. The concept of equilibrium is discussed at length by Schumm (1977), and involves the complex process-response concept of a fluvial system.

Regardless of whether the drainage systems on Black Mesa are in quasi-equilibrium, or whether their development over time may be explained by a model, several factors influencing the development of rills and gullies in these drainages and in reclaimed areas remain constant. Intense summer thunderstorms occurring on Black Mesa generate high-energy raindrops that result in considerable soil detachment. Also, the vegetation canopy cover to be successfully established in coal resource areas will be similar to canopy covers found in the natural surrounding landscape. Topsoil material used as plant-growth media on reclaimed areas has the same erosive texture as soils found in the surrounding highly eroded landscape. Natural drainages on Black Mesa exhibit a high degree of density, naturally forming rills and entrenched gullies in the upland areas. Regardless of the extent of vegetal cover or the flatness of the regraded slopes, rills are going to form in the reclaimed areas as the basins adjust drainage to convey excess runoff. Summer thunderstorms are intense and localized resulting in overland flow that rapidly concentrates and scours in relatively short distances.

Peabody has developed a plan for insuring the stability of reclaimed areas (see Chapter 26). The key to the plan is to control those components of the surface runoff process to the extent that the potential for erosion is greatly minimized. By controlling the erosive nature of the surface runoff the degree of rilling and gullying will be minimized such that sufficient landform stability can be achieved and a successful vegetative cover can be developed that will promote the postmining land use of livestock grazing and wildlife habitat.

An important component of the plan (see Chapter 26) is to construct gradient terraces with slight positive drainage (no greater than 2 percent) on reclaimed slopes (greater than 10 percent) that have high potentials for excessive erosion and uncontrolled drainage development (rills and gullies). These terraces will break up slope lengths, limiting the upslope area contributions to overland flow. Distances over which tractive forces increase will be controlled, which will limit the scouring action of concentrated runoff in the downstream direction. By establishing limited drainage areas between the contour terraces, the size and density of rills that occur will be minimized.

Primary surface manipulations include: 1) deep ripping on all slopes ; and 2) contour furrowing using an offset disk unit that will promote infiltration and reduce excess runoff. The retopsoiled areas, including contour terraces, will be mulched with a cover crop or anchored straw or hay mulch, and then revegetated with the permanent seed mixes (see Chapter 26). Revegetation and mulching will promote soil cohesiveness as vegetation becomes established, providing further resistance to rilling.

In addition to the creation of gradient terraces and the surface treatments, a network of downdrains and main channels will be constructed. Downdrains will be established at specific intervals across the slopes for connecting the contour terraces to the main channel. Downdrains will enhance the stability and integrity of the contour terraces, as they will convey runoff from the inter-terrace areas to the main channel without promoting failure of the terraces. An important feature of the plan is the sizing and lengths of the terraces between the downdrains. Terrace embankment heights and lengths will be maximized to insure the containment of concentrated overland runoff and to increase the time of concentration of flow to the downdrains, respectively. This should greatly reduce the potential for extreme downcutting in the downdrains.

The downdrain systems will be constructed in some instances after topsoil has been replaced. Under these circumstances, topsoil will be removed at a minimum width of 45 feet to prevent topsoil loss. Ripping and disking will be implemented across the downdrain system creating a surface roughness perpendicular to flow. This will provide some resistance to scour in the downdrain. In addition, the non-topsoiled drains will contain a significant percentage of rock fragments further increasing the surface roughness.

The main channels will be engineered to convey the appropriate discharge contributed by the watershed areas drained. The main channels will range in width from approximately 45 to 135 feet which includes a fifteen foot apron on each side of the channel. The main channels and aprons will not be topsoiled to prevent topsoil loss. Application of the seed mixes will be used to revegetate and further stabilize the non-topsoiled areas.

The establishment of the drainage network outlined above will increase the overall time of concentration of flows and reduce peak flows from the reclaimed area basins. Flow velocities will be controlled, as surface manipulations, including those performed in downdrains and the main channels, provide roughness and resistance to scour. Thus, drainage development in reclaimed areas will be planned and controlled, thereby minimizing the number and size of rills. Landform stability and vegetative development supportive of the post-mining land use can be achieved, because the reclaimed area drainage development will have been controlled and reasonably stabilized rather than in a state of quasi-equilibrium between storms of large return periods as in the natural drainage system.

Summary

This chapter has presented a discussion of probable hydrologic consequences of the proposed life-of-mine mining plan. Table 20 summarizes the discussion by listing the probable hydrologic consequences and the results of the analysis of each. As can be seen, all the probable impacts have been determined to have either no impact or no short or long term significant impacts.

TABLE 20

Summary of Probable Hydrologic Consequences of the Life-of-Mine Mining Plan for Black Mesa and Kayenta Mines

Probable Hydrologic Consequences	Analysis Results	Significance
Ground Water		
1. Interruptions of ground-water flow and drawdown in the Wepo aquifer	Maximum 10% reduction in water levels in 2 wells partially completed in Wepo Formation	No short or long term significant impacts
2. Removal or elimination of local wells and springs	Two local wells completed in the Toreva aquifer and one spring will be removed by mining. Alternate water supply is being provided until the wells and spring are replaced	Impact during the life of the pit. Following reclamation, Peabody will replace the wells and spring. No short or long term significant impacts
3. Containment and discharge of pit inflow pumpage	Pumpage can be treated with settling basins so that discharge meets applicable standards	No short or long term significant impacts

TABLE 20 (Cont.)

Summary of Probable Hydrologic Consequences of the Life-of-Mine Mining Plan for Black Mesa and Kayenta Mines

Probable Hydrologic Consequences	Analysis Results	Significance
Ground Water		
4. Impact of replaced spoil material on ground-water flow and recharge	Resaturation will take from a few to as many as 100 years. Water levels will recover to near premining levels. Water is not currently used to support land use activities due to quality and yield. Alternate water supply is available.	No short or long term significant impacts
5. Impact of replaced spoil on ground-water quality	Increased TDS levels in resaturated portions of Wepo aquifer within mining areas only. Little, if any, salinity increases expected. Potential for acid formation and trace control migration is minimal. Water not currently used to support land use activities due to quality and yield. Alternative water supply available. Water use category will remain unchanged.	No short or long term significant impacts

TABLE 20 (Cont.)

Summary of Probable Hydrologic Consequences of the Life-of-Mine Mining Plan for Black Mesa and Kayenta Mines

Probable Hydrologic Consequences	Analysis Results	Significance
Ground Water		
6. Interruptions of Wepo recharge to the alluvial aquifer	0-20 foot localized (time and space) declines in portions of the alluvial aquifer near N-14, J-16 and J-19/20. No local use of alluvial aquifer on leasehold and water does not support critical habitat or species. Impact is transient.	No short or long term significant impact
7. Truncation of alluvial aquifers by dams	No observed impact on existing alluvial water levels since dams are mainly in small tributaries and Wepo discharges to alluvium.	No short or long term significant impact
8. Recharge of alluvial aquifer from resaturated spoil in Wepo formation	Low transmissivity in Wepo so this source has less impact than other sources of recharge (rainfall and snowmelt).	No short or long term significant impact

TABLE 20 (Cont.)

Summary of Probable Hydrologic Consequences of the Life-of-Mine

Mining Plan for Black Mesa and Kayenta Mines

Probable Hydrologic Consequences	Analysis Results	Significance
Ground Water		
8. (Cont.)	No local use of alluvial aquifer on leasehold and water does not support critical habitats or plant species. Impact is transient.	
9. Interruptions of spring flows (Wepo or alluvial)	No Wepo or alluvial springs expected to be impacted by remaining mining operations. One spring at N-14 removed by mining has been mitigated by alternative water sources.	No short or long term significant impacts
10. Peabody wellfield pumpage reducing regional water levels and stream and spring flows	Substantial areal extent of drawdowns contributed to by wellfield pumpage. Greater than 50 percent of drawdowns at 8 of 19 communities examined, due to Peabody pumpage. Maximum reduction in available water height at 19 communities due to Peabody pumpage only 5.4 percent-average is 2.1 percent. Minimal additional declines expected. No structural	No short or long term significant impact

TABLE 20 (Cont.)

Summary of Probable Hydrologic Consequences of the Life-of-Mine Mining Plan for Black Mesa and Kayenta Mines

Probable Hydrologic Consequences	Analysis Results	Significance
Ground Water		
10. (Cont.)	damage to aquifer. Approximately 0.1 percent of water in N-aquifer to be withdrawn. Rapid recovery of water levels after pumping. Less than 2 percent reduction in stream and spring flows due to wellfield pumpage.	
11. Impact of induced leakage from D-aquifer system to N-aquifer system	No evidence suggesting impacts to N-aquifer due to leakage from D-aquifer.	No short or long term significant impact
Surface Water		
1. Impact of dams, ponds or impoundments on runoff and channel characteristics	Minor headward aggradation above embankments in stream. Minor incising of streams below dams. Vegetation encroachment on new channels. All ponds and dams temporary structures. Small	No short or long term significant impact

TABLE 20 (Cont.)

Summary of Probable Hydrologic Consequences of the Life-of-Mine Mining Plan for Black Mesa and Kayenta Mines

Probable Hydrologic Consequences	Analysis Results	Significance
Surface Water		
1. (Cont.)	percentage of drainage impounded and structure to be dewatered. Following removal sediment loads will temporarily increase. Channels will reestablish.	
2. Impact of dams, ponds or impoundments on downstream water users	No flood irrigation practice on or close to leasehold. Only 0.6 percent and 2.7 percent of total Dinnebito and Moenkopi watersheds to be dammed. Dewatering of structure anticipated.	No short or long term significant impacts
3. Impact of dams, ponds or impoundments on stream water quality	Infrequent discharges meeting applicable effluent limits. No discharge from permanent impoundments.	No short or long term significant impacts

TABLE 20 (Cont.)

Summary of Probable Hydrologic Consequences of the Life-of-Mine Mining Plan for Black Mesa and Kayenta Mines

Probable Hydrologic Consequences	Analysis Results	Significance
Surface Water		
4. Impact of stream channel diversion on channel characteristics and water quality	Diversion as wide as actual channels. Slopes approximate natural slopes. Energy dissipation when needed. Construction and reclamation will temporarily increase sediment loads. Downstream monitoring shows no effect.	No short or long term significant impacts
5. Effects of culverts at road crossings on stream runoff and water quality	Proper engineering design and use of energy dissipators minimize erosion and allow adequate discharge.	No short or long term significant impacts
6. Removal of pre-existing surface water structures	Three pre-existing surface water structures will be removed by mining. Alternate water supply is being provided until the structures are replaced by permanent impoundments	No short or long term significant impacts
7. Runoff from reclaimed areas to streams	Reshaping of regraded spoils, revegetation and soil reconstruction activities result in localized decreases in peak discharge, runoff volumes, peak sediment concentrations, sediment yield and chemical	No short or long term significant impacts

TABLE 20 (Cont.)

Summary of Probable Hydrologic Consequences of the Life-of-Mine Mining Plan for Black Mesa and Kayenta Mines

Probable Hydrologic Consequences	Analysis Results	Significance
Surface Water 7. (Cont.)	constituents. However, effects will be minor compared to total flow and quality of receiving streams. Original premining conditions will likely be approximated with time following reclamation. Total disturbed area small in comparison to total watersheds.	No short or long term significant impacts
8. Impact of the Reclamation Plan on the Stability of Reclaimed Areas	Development of contour terraces, downdrains and main channels in reclaimed areas with engineering design to insure a controlled drainage development. Sediment yields and flow rates and volumes from reclaimed areas should be lower. Some maintenance may be required, particularly in pre-plan reclaimed areas.	No short or long term significant impacts

Literature Cited

Bergstrom, F.W. and Schumm, S.A. "Episodic Behavior in Badlands." International Association of Hydrological Science, Pub. 132, (1981): p. 478-489.

Botz, M.K. and Pedersen, D. "Summary of Water Quality Criteria". Water Quality Bureau, Montana Department of Health and Environmental Sciences. Helena, Montana. 1976.

Busby, M.W. "Annual Runoff in the Conterminous United States." USGS Hydrologic Inventory Atlas. HA-212. 1966.

Dollhopf, D.J.; Goering, J.D.; Levine, C.J.; Bauman, B.J.; Hedberg, D.W.; and R.L. Hodder. "Selective Placement of Strip Mine Overburden in Montana, V Summary Report." Final Report: July 1976 to June 1981. Contract No. H0262032. Montana Agric. Exp. Sta. June, 1981.

Dollhopf, D.J.; Goering, J.D.; Levine, C.J.; Bauman, B.J.; and R.L. Hodder. "Selective Placement of Coal Strip Mine Overburden in Montana, IV Hydrogeologic Studies." Interim Report: July 1978 to June 1979. Contract No. H0262032. Montana Agric. Exp. Sta. 1979.

Dollhopf, D.J. and Russell, L.J. "Assessment of Acid Producing Materials in the Northern Plains." Third Biennial Symposium on Surface Coal Mine Reclamation on The Great Plains. Billings, Montana. pp. 201-208. 1984.

Eychaner, J.H. "Geohydrology and Effects of Water Use in the Black Mesa Area, Navajo and Hopi Indian Reservations, Arizona." U.S. Geological Survey Water Supply Paper 2201. p. (1983): 26.

Fitts Geosolutions, 2000, TWODAN - Two-Dimensional Analytic Groundwater Flow Model.

Heede, B.H. "Stages of Development of Gullies in the West." In Present and Prospective Technology for Predicting Sediment Yields and Sources, ARS-S-40, June 1975: p. 155-161.

Jacob, C.E. and Lohman, S.W. "Nonsteady Flow to a Well of Constant Drawdown in an Extensive Aquifer." American Geophys. Union Trans. Vol. 33, pp. 559 - 569. 1952.

Langbein, W.B. and Schumm, S.A. "Yield of Sediment in Relation to Mean Annual Precipitation". American Geophysical Union Transactions. Vol. 39. (1958): 1076-1084.

Leopold, L.B., and Miller, J.P. "Ephemeral Streams-Hydraulic Factors and Their Relation to the Drainge Net." U.S. Geological Survey Professional Paper 282-A. (1956): 37.

Lohman, S.W. "Ground-Water Hydraulics." U.S. Geological Survey Professional Paper 708. (1972): 70.

McKee, J.E. and Wolf, H.W. "Water Quality Criteria." The Resources Agency of California, State Water Resources Control Board Publication NO. 3-A. (1963): 548.

McWhorter, D.B. "Procedures for Predictive Analysis of Selected Hydrologic Impacts of Surface Mining." E.P.A. Cincinnati, Ohio. (1982): 28.

McWhorter, D.B.; Rowe, J.W.; VanLiew, M.W.; Chandler, R.L.; Skogerboe, R.K.; Sunada, D.K.; and Skogerboe, G.V. "Surface and Subsurface Water Quality Hydrology in Surface Mined Watersheds, Part 1: Text." U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory. Cincinnati, Ohio. EPA-600/7-79-193a, August, 1979.

Meyer, L.D., Foster, G.R., and Romkens, M.J.M. "Sources of Soil Eroded by Water From Upland Slopes." in Present and Prospective Technology for Predicting Sediment Yields and Sources. U.S. Department of Agriculture, Agricultural Research Service, ARS-S-40, (1975): 177-189.

National Academy of Sciences, National Academy of Engineering. Water Quality Criteria, 1972. Washington, D.C.: U.S. Government Printing Office. 1974.

Pionke, H.B. and Rogowski, A.S. "How Effective Is the Deep Placement of Acid Spoil Materials?" Proc., 4th Annual Meeting Canadian Land Reclamation Assoc. Regina, Saskatchewan. August, 1979.

Rahn, P. "Potential of Coal Strip Mine Spoils as Aquifers in the Powder River Basin." Project No. 10470025; Old West Regional Council. 1976.

Schumm, S.A. The Fluvial System. New York: John Wiley and Sons. (1977): 338.

Schumm, S.A. and Hadley, R.F. "Arroyos and the Semiarid Cycle of Erosion." American Journal of Science V. 256. (1957).

Van Voast, W.A. and Hedges, R.B. "Hydrologic Aspects of Strip Coal Mining in Southwestern Montana - Emphasis One Year of Mining Near Decker, Montana." Montana Bureau of Mines and Geology Bulletin 93. 1975.

Van Voast, W.A.; Hedges, R.B.; and J.J. McDermott. "Strip Coal Mining and Mined-Land Reclamation in the Hydrologic System, Southeastern Montana." Old West Regional Commission. Billings, Montana. 1978.

ATTACHMENT 1

Values Used in Calculating Pit Inflows

Pit	Avg Transmissivity For West Side Of Lease (Gal/Day/Ft)	Avg Transmissivity For East Side Of Lease (Gal/Day/Ft)	Avg Saturated Thickness Of Wepo Aquifer For West Side of Lease (Ft)	Avg Saturated Thickness Of Wepo Aquifer For East Side of Lease (Ft)	r_w (ft)	Drawdown $s_o = W \tan\Theta$ (Ft)	(Degrees)	Storage Coefficient-S
N-10	126.3		235.9		65	13.4	5.9	$8*10^{-5}$
N-11	126.3		235.9		65	8.2	3.6	$8*10^{-5}$
J-1/N-6	126.3		235.9		65	6.6	2.9	$8*10^{-5}$
N-14 Main Pit		196.2		201.0	65	5.7	2.5	$8*10^{-5}$
N-14 Eastern Pit		196.2		201.0	65	4.5	2.0	$8*10^{-5}$
J-16		196.2		201.0	65	3.9	1.7	$8*10^{-5}$
J-19/J-20		196.2		201.0	65	4.5	2.0	$8*10^{-5}$
J-21		196.2		201.0	65	5.7	2.5	$8*10^{-5}$

Terminology Used in Pit Inflow Discussion

1. Total length of pit is the length in feet that the pit will be open for that specific year.

2. Length in water (feet) was computed two different ways depending on the proportion of the pit that was projected to intercept the Wepo aquifer. For those pits that were projected to be predominantly in water, a constant length in water was calculated by summing the total lengths in water each year and dividing by the total number of years in water. For those pits with smaller areal extents in water, a constant length in water was calculated by taking the average lengths in water for individual pit cuts for the total period in water.

3. Pit advancement is the constant length in feet per day that the pit will advance for all years in a given mining area.

4. Time in water is the constant number of days the pit will be open and subject to pit inflow each year.

5. Weighted T_F is the weighted transmissivity of the exposed aquifer expressed in gal/day/ft for the entire pit. It was calculated by taking the average depth in water for a specific year and dividing it by the average saturated thickness for the Wepo aquifer for the respective side of the leasehold. This saturated thickness ratio was multiplied by the average transmissivity value* for the respective side of the leasehold to adjust the transmissivity value for the pit saturated thickness. The adjusted transmissivity value for each year was multiplied by a wet area weighting factor (wet area for a given year divided by the total wet area in the entire mining area). The annual weighted transmissivity values were then summated to yield the constant weighted transmissivity value for the entire mining area.

   *In computing the average transmissivity value for each side of the leasehold, five wells were not included (42, 44, 49, 59, and 62). These values were not included because they were extremely low or atypically high as a result of being partially completed in the Toreva aquifer.

6. Weighted $T_{L,R}$ is the weighted T_F divided by 7.48 gal/ft^3 to convert values for the entire pit to ft^2/day.

7. I is the Wepo or alluvial aquifer's natural hydraulic gradient for the specific pit to be evaluated. It is expressed in ft/ft.

8. Weighted Q_F is the amount of water which will be intercepted from the aquifer through flow and is calculated by the formula q_{F1}, q_{F2} = TIL. The initial pit cut in water (q_{F1}) was incremented by day to account for the gradually increasing pit length. The

q_{F2} values for subsequent pit cuts were calculated using a constant length in water (calculated as described in Statement 2). The number of days remaining after the initial cut was multiplied to q_{F2} to calculate the total q_{F2} for the entire mining area. The q_{F1} and q_{F2} values were added to give a total Q_F for the entire mining area. The total Q_F was weighted by a wet area weighting factor (wet area for a given year divided by the total wet area in the entire mining area) to compute the Q_F totals for each specific year. The units are gal/yr. For the unconfined alluvial aquifer, the formula Q = PIA was used. The variables for this equation are defined in Chapter 18.

9. Weighted Q_L is the linear portion of inflow from aquifer storage and is calculated using the formulas $Q_L = \frac{2s\ ST}{\pi t}$

and $Q_L = q_L * Lw* 7.48\ gal/ft^3$. The initial pit cut in water (Q_{L1}) was incremented by day to account for the gradually increasing pit length. Subsequent pit cuts for Q_{L2} were calculated using a constant length in water. The q_{L2} was divided by 2 to account for the spoil piles intercepting inflows from one side of the pit. The number of days remaining for the life of the mining area after the initial pit cut was multiplied to Q_{L2} to calculate the total Q_{L2} for the entire mining area. The Q_{L1} and Q_{L2} values were added to give a total Q_L for the entire mining area. The total Q_L was weighted by a wet area factor as described above to compute Q_L totals for each year. The units are gal/yr. For the unconfined alluvial aquifer

$$s = (s_0 - \frac{s_0^2}{2b})$$

was used. The equation accounts for inflows from both sides of the pit. The variables for the unconfined conversion of s are defined in Chapter 18.

10. Q_R, the radial inflow to each end of the pit, is calculated by the formula

$$Q_R = 2\pi T\ G\ (\alpha)s$$

where,

$$\alpha = \frac{Tt}{Sr_w^2}$$

The Q_R is multiplied to a constant factor for a given mining area which was calculated by taking the wet width for the entire pit and dividing it by 130' (pit width). The constant factor is the total number of 130' pit widths for the total wet width in the mining area. Once the Q_R for the entire pit was calculated, it was multiplied by a weighting factor to compute total Q_R values for each year. The units are in gal/yr. For the unconfined alluvial aquifer $s = (s_0 - \frac{s_0^2}{2b})$

Attachment 2

Attachment 2
Documentation of Program MINE 1-2

The program entitled "MINE 1-2", calculates the volume of flow into an open pit resulting from natural-gradient flow and pit dewatering (Figure 1). The program can be used to simulate a confined, unconfined, or a combination of unconfined/confined aquifer conditions. In the case of the unconfined/confined solution, the program accurately accounts for the unconfined zone that develops adjacent to an open pit wall for an initially confined aquifer. The program simulates an advancing pit by incrementing and summing fluxes on a daily basis.

Theory

The derivation of the equations used to calculate pit inflows follows the same procedure developed by McWhorter (1981), which is based upon the concept of a succession of steady states. Equations describing one-dimensional unconfined and confined flow are the following:

$$K \frac{\partial}{\partial x}\left(h \frac{\partial h}{\partial x} \right) = S_{ya} \frac{\partial h}{\partial t} \qquad 0 \le x \le L_u \qquad (1)$$

$$T \frac{\partial^2 h}{\partial x^2} = S \frac{\partial h}{\partial t} \qquad L_u \le x \le L_c + L_u \quad (2)$$

where K is the hydraulic conductivity L/t;
T is the transmissivity, L^2/t;
S_{ya} is the specific yield, dimensionless;
S is the confined storage coefficient, dimensionless;
h is the head in the unconfined zone, L;
H is the pressure head above the confining unit in the confined zone, L;
x is the location in cartesian coordinate space, L;
t is time, t;
L_u is the distance to the unconfined-confined zone interface, L; and
L_c is the distance from the unconfined-confined interface to the undisturbed zone, L.

Intergrating equations 1 and 2 with respect to x over the intervals in which they are applicable, applying Leibnitz's rule, and summing the two solutions results in the following equation:

$$q_r - q_o = S_{ya}\frac{d}{dt}\left(\int_0^{L_u} h\,dx - bL_u\right) + S\frac{d}{dt}\left(\int_{L_u}^{L_u+L_c} H\,dx - H_o\left(L_{u+L_c}\right)\right) \quad (3)$$

where q_r is the regional flux, L^2/t;
q_o is the flux into the pit, L^2/t;
b is the confined aquifer thickness, L; and
H_o is the pressure head above the confining unit in the undisturbed zone.

Substituting for h, Lu, H, and Lc and carrying out the integration results in the following equation:

$$q_r - q_o = -\frac{d}{dt}\left(\frac{E}{q_o}\right) \quad (4)$$

where

$$E = \left(\frac{S_{ya}Tb^2}{6} + \frac{STH_o^2}{2} + \frac{STH_ob}{2}\right) \quad (5)$$

Taking the differential of the right-hand side of equation 4 and rearranging, results in the following equation:

$$dt = \frac{-E}{q_o^3 - q_r q_o^2}dq_o \quad (6)$$

Intergrating both sides of equation 6 results in the following:

$$\int_0^t dt = \int_{q_o(0)=\infty}^{q_o(t)} \frac{-E}{q_o^3 - q_r q_o^2}dq_o \quad (7)$$

$$t = -E\left[\frac{1}{q_r q_o} + \frac{1}{q_r^2}\ln\left(\frac{q_o - q_r}{q_o}\right)\right] \quad (8)$$

The total flux of water into the open pit as a function of time is represented by the qo term in equation 8. Therefore, the flux of water as a function of time can be determined by solving for the roots of equation 8. The program MINE1-2 numerically solves for the roots through the use of a Newton-S iteration method.

The total volume of flow into the pit is determined by integrating the flux as a function of time. This is performed numerically in the program by subdividing each day into 100 equal time increments, calculating the flux at the fixed time increments, and using Simpson's rule to numerically integrate the area under the flux versus time curve. The daily rate of flow into an open pit decreases at an exponential rate. The program automatically reduces the number of time increments each day is subdivided into when the change in daily flow rates is less than one percent. This reduction in the number of time increments accelerates the amount of time required to run the program, with virtually no loss of accuracy.

If the regional gradient is zero (i.e. $q_r = 0$), equation 7 reduces to the following:

$$\int_0^t dt = \int_{q_o(0)=\infty}^{q_o(t)} \frac{-E}{q_o^3}\, dq_o \qquad (9)$$

and

$$q_o = \left(\frac{E}{2}\right)^{1/2} t^{-1/2} \qquad (10)$$

The total flow into the pit is calculated by analytically integrating equation 9 with respect to time,

$$Q = 2\left(\frac{ET}{2}\right)^{1/2} \qquad (11)$$

Hence, an analytical integration of equation 10 has eliminated the need to perform a numerical integration, as was the case for equation 8.

The definition of 'E" in equation 5 is for the combined case of an unconfined/confined aquifer system. In order to obtain solutions for the strictly unconfined and confined cases, the definition of "E" (eq. 5) has to be modified. For the case of an unconfined aquifer, the second and third terms in equation 5 are set to zero and for a confined aquifer, the first term in equation 5 is set to zero. Equations 8 and 11, which are used to calculate the total flow into a pit, remain unchanged for all solutions.

Assumptions

The assumptions made in deriving the flow equations and in writing program MIME 1-2 are the following:

1. Mining intercepts the saturated portion of the pit at the start of each year.
2. The length of pit opened on a daily basis is equivalent to the total pit length divided by the number of days required to open the pit.
3. Each daily pit increment is instantaneously opened.
4. Total pit inflow per year is equal to the sum of incremental daily inflows for that year.
5. Pit infows for each year are independent of residual effects from preceding years. The method therefore tends to overestimate the amount of water coming into the pit.
6. Hydraulic conductivity, storage coefficient, and depth of saturation are constant for each mime pit for each year.
7. Pit inflow is from two sides for the first year and from one side for all remaining years. (i.e. there is no additional flow from the reclaimed spoils).
8. Natural-gradient flow is over the entire saturated length of the pit; no corrections are made for the orientation of the pit in relation to the gradient direction; hence, the saturated pit length is assumed to be perpendicular to the gradient direction.
9. Natural-gradient flux is unaffected by reclaimed spoils from the preceding year.
10. Fluxes through the ends and bottom of the pit are insignificant and not accounted for in the program.
11. The aquifer is homogeneous, isotropic, and infinite in extent.
12. The transmissivity value for a pit is set equal to the product of the saturated depth of pit and the average hydraulic conductivity.
13. The number of pits mined per year must be a whole number, with the number of days all pits are open for a year being less than or equal to 365 days. (i.e. 1 pit open for 365 days, 2 pits open 182 days each, 3 pits open 121 days each, etc.).
14. The aquifer is either initially confined or unconfined. The combined option is only valid for the development of a small unconfined zone near the pit opening for an initially confined aquifer.
15. If the confined head is not explicitly entered the program substitutes the depth in water for the confined head.
16. If the confined aquifer thickness is not entered the program defaults to the depth in water for the confined aquifer thickness.

*Note assumptions 7 and 9 are contradictory if the mining direction is in the direction of decreasing water-table gradient.