CHAPTER 18

PROBABLE HYDROLOGIC CONSEQUENCES

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CHAPTER 18

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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.

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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,

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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	13.9	.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

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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

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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

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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

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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

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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

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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

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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

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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

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TABLE 7

Pit Inflows by Year for J-21

Pit Year	Total Length of Pit (Ft)	Constant (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

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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.

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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).

$$Q = 2\pi TG(\alpha)s$$

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

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.

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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

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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

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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 Mine1-2_3 was used to estimate the amount of flux entering the cuts in the northwestern section of N99 for CY2008-2013. [Mine1-2_3 is a modification

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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

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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

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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.

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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.

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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		Historic Water Level Range (1/88-1/95)		Current Water Level Range (1998)		Current Maximum Versus Background/ Historic Maximum
		Max	Min	Max	Min	Max	Min	
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

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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 three historical periods of record (1988-1995, 1995-2000, and 2000-2004), and during the most recent five-year period (2004-2008) 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 nine of the twenty-five Wepo monitoring wells are greater than background or historic maximum water levels. At WEPO62R, current maximum water levels are 68.6 feet deeper than background maximum water levels for WEPO62. This deepening exceeds the theoretical maximum projected drawdown for WEPO62R by

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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		Historic Water Level Range 1988-1995		Historic Water Level Range 1995-2000		Historic Water Level Range 2000-2004		Current Water Level Range 2004-2008		Current Maximum Versus Background/ Historic Maximum
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
ALUV13R(a)	36.0	-	-	22.5	28.9	25.7	29.4	28.2	29.4	27.71	28.38	No change
ALUV17	53.0	5.0	7.4	5.4	8.0	5.1	8.9	5.9	7.9	5.1	7.3	No change
ALUV19	32.0	5.6	9.4	6.2	9.6	7.0	14.9	14.7	Dry	11.4	Dry	> 7.5 ft deeper
ALUV23R	53.0	-	-	19.2	Dry	Dry	Dry	Dry	Dry	Dry	Dry	No change
ALUV27R	36.0	-	-	21.5	26.7	26.3	28.6	27.6	29.5	-	-	(b)
ALUV29	25.0	0.4	5.3	0.4	7.2	0.2	6.7	0.5	7.9	0.0	1.3	No change
ALUV31R(c)	39.0	7.3	15.8	6.2	17.9	18.1	26.0	23.2	24.2	9.5	23.8	8.0 ft deeper
ALUV69(b)	43.0	4.6	10.0	6.0	10.8	8.3	11.6	11.6	12.2	10.1	11.9	1.9 ft deeper
ALUV71(b)	28.0	14.6	16.6	15.6	16.9	15.7	16.6	16.4	16.8	15.4	17.0	0.4 ft deeper
ALUV72(b)	54.0	11.6	13.3	9.2	13.5	10.8	13.4	12.1	13.2	9.6	12.7	No change
ALUV77(c)	32.0	26.6	30.3	28.9	30.2	29.4	30.8	29.6	30.3	29.1	29.7	No change
ALUV80R	54.0	-	-	8.9	11.7	10.5	12.9	11.4	12.0	10.2	12.4	0.7 Ft deeper
ALUV83	40.0	0.9	3.3	1.0	3.4	0.8	3.5	-1.3	3.5	-3.4	2.1	No change
ALUV87	45.0	14.2	22.5	17.8	23.1	19.1	23.4	21.4	24.1	17.3	21.7	No change
ALUV89R	61.0	-	-	2.5	5.0	2.8	6.3	1.2	6.0	0.5	4.3	No change
ALUV93	23.0	25.2	29.1	25.9	29.8	26.0	32.8	33.4	37.4	38.0	39.6	10.5 ft deeper
ALUV95	20.0	3.0	4.9	3.1	5.3	3.7	5.6	5.4	7.5	7.4	8.7	3.8 Ft deeper
ALUV98R	57.0	-	-	9.6	14.3	11.6	14.7	12.4	16.2	13.1	14.9	0.6 Ft deeper
ALUV99R	46.0	-	-	9.8	13.8	11.9	16.0	13.2	18.4	12.4	Dry	5.2 Ft deeper
ALUV101R	65.0	-	-	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	No change
ALUV104R	15.0	-	-	15.6	20.3	19.4	20.3	18.9	20.4	17.3	20.3	No change
ALUV105R	19.0	-	-	8.1	Dry	9.5	10.2	9.7	Dry	6.9	Dry	No change
ALUV106R	22.0	-	-	4.6	Dry	6.7	8.2	7.8	Dry	5.2	Dry	No change
ALUV108R	33.0	-	-	7.1	11.0	8.8	11.6	11.2	13.6	12.3	13.4	2.4 Ft deeper
ALUV165	65.0	-	-	20.3	28.7	27.2	30.2	29.2	31.9	31.4	33.0	4.3 Ft deeper
ALUV168	34.0	-	-	- 0.4	1.4	0.6	1.9	1.3	2.6	2.4	2.7	1.3 Ft deeper
ALUV169	36.0	-	-	7.2	9.0	7.2	9.2	7.9	9.7	7.5	8.7	No change
ALUV170	34.0	-	-	4.5	5.8	4.2	6.3	4.7	7.0	3.5	5.7	No change
ALUV172	19.0	-	-	13.1	14.1	14.5	18.7	17.8	21.4	11.0	19.0	4.9 ft deeper
ALUV180	47.0	-	-	6.1	10.3	9.4	12.4	11.6	12.6	-	-	(b)
ALUV181(a)	32.0	-	-	11.8	16.8	15.0	20.1	19.7	20.6	14.7	17.9	1.1 ft deeper
ALUV182	32.0	-	-	13.6	17.8	16.8	19.4	17.2	19.3	15.1	17.9	0.1 ft deeper
ALUV193	46.0	-	-	10.9	12.4	9.8	13.0	10.6	12.6	12.7	14.7	2.3 Ft deeper
ALUV197	32.0	-	-	10.2	13.2	11.8	19.9	19.7	24.9	16.2	22.8	9.6 ft deeper
ALUV199	62.0	-	-	13.5	17.2	12.5	18.3	13.7	18.8	13.7	16.8	No change
ALUV200	53.0	-	-	4.1	5.9	3.8	6.4	4.4	5.8	3.0	5.4	No change

Notes:

(a) Discontinued monitoring at these wells in 2002, but reinstated monitoring in 2005, due to opening of N9 mining area.

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

(c) Discontinued monitoring at these wells in 2002, but periodic measurement of water levels since then.

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Table 8 (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		Historic Water Level Range 2000-2004		Current Water Level Range 2004-2008		Current Maximum Versus Background/ Historic Maximum
		Min	Max	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	77.3	80.6	No change
WEPO41(a)	26.0	86.9	93.4	81.3	94.4	86.6	92.9	87.9	91.9	86.1	91.1	No change
WEPO42	54.0	-2.1	-1.5	-1.8	-1.3	-1.7	-1.0	-1.4	-1.0	-1.5	-1.2	0.3 ft deeper
WEPO43R(b)	43.0	138.6	150.6	138.9	144.4	135.3	138.1	138.3	142.2	134.3	142.1	No change
WEPO44	49.0	183.5	187.8	177.7	187.3	175.2	180.9	172.0	175.9	171.3	172.5	No change
WEPO45	37.0	83.4	88.2	80.0	86.4	80.8	82.8	82.7	83.1	82.9	83.2	No change
WEPO46	38.0	117.9	157.2	149.8	155.4	151.2	155.0	154.2	155.5	154.5	155.6	No change
WEPO47R(c)	15.0	-	-	-	-	31.4	32.6	30.7	32.4	27.7	30.6	No change
WEPO49	55.0	4.3	9.6	1.8	4.8	1.1	3.0	0.4	1.4	0.1	0.8	No change
WEPO51(a)	26.0	43.0	52.0	48.9	52.1	51.2	52.5	52.3	53.2	51.8	52.1	0.1 ft deeper
WEPO52(a)	35.0	16.3	24.3	18.0	23.8	17.8	19.0	17.9	18.0	17.9	24.5	0.2 ft deeper
WEPO53	65.0	36.7	55.4	46.4	54.7	54.8	66.0	66.9	73.2	70.6	71.5	16.1 ft deeper
WEPO54	60.0	47.4	55.7	49.5	51.4	50.3	51.8	50.8	52.1	50.4	51.5	No change
WEPO55	27.0	159.4	162.2	159.8	161.3	159.8	161.8	161.4	161.7	161.2	161.8	No change
WEPO56	35.0	30.9	40.4	32.8	38.4	35.0	37.6	36.6	38.0	38.1	39.5	No change
WEPO57	40.0	150.1	158.3	155.9	158.8	157.9	161.4	161.4	163.8	163.7	164.2	5.9 ft deeper
WEPO58	24.0	130.3	140.1	137.5	141.2	140.0	140.9	140.5	141.2	140.7	141.4	1.3 ft deeper
WEPO59	20.0	142.7	144.6	142.7	144.3	143.1	145.1	144.7	145.8	143.9	145.5	0.9 ft deeper
WEPO60	19.0	81.2	87.3	88.2	95.7	90.8	93.7	90.3	91.6	90.0	91.4	4.1 ft deeper
WEPO61	10.0	154.3	155.4	153.4	155.9	152.8	154.8	154.3	154.8	154.2	155.1	No change
WEPO62R(d)	63.0	114.1	139.7	133.1	197.7	213.1	227.7	207.9	212.1	206.1	208.3	68.6 ft deeper
WEPO65	50.0	71.9	164.5	113.8	128.7	125.0	143.5	143.6	146.6	141.7	145.9	No change
WEPO66	35.0	75.4	89.1	82.0	87.6	86.1	88.0	87.5	89.4	77.6	87.3	No change
WEPO67	25.0	129.5	204.5	182.4	187.7	181.4	184.0	175.9	181.2	184.9	185.8	No change
WEPO68 (e)	37.0	-	-	-	-	107.9	110.8	107.7	109.9	109.5	110.7	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.

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5.6 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 16.1 feet deeper than background and historic maximum water levels, yet are only 6.5 feet deeper than the theoretical projected maximum drawdown at 2013 for this well (65 feet). The 16.1 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 0.1 feet to 5.9 feet, which are comparable to natural water fluctuations in the Wepo formation. Sixteen 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 six 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 four wells, ALUV19, ALUV31R, ALUV93, 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 32 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.

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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

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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.

Removal of Local Wells and Springs. One existing local well (4T-404), completed in the Toreva aquifer, is located within the proposed life-of-mine mining plan area (J-19 mining area). In addition, two other local wells (4T-403 and 8T-506), both completed in the Toreva aquifer were removed in advance of the mining operations in the J-7 and N-6 mining areas, respectively. 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 three local 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).

Containment of Pit Inflow Pumpage. 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.

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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.

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TABLE 9

Sediment Ponds and Dams to be Used to

Contain Pit Pumpage

Mining Area	Sediment Ponds and Dams Containing Pit Pumpage
N10	N10-G Series Ponds
N11	N11-A Series Ponds
N14	N14-D, -E, -F and -G Dams
N99	N11-H, -I, and -J Ponds
J1/N6	Wild Ram Valley Dam
J16	Reed Valley and J16-A Dams
J19/20	Reed Valley and J7-Jr. Dams
J21	Reed Valley and J21 Dams

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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 clays, 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.

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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 that will intercept the Wepo aquifer (N-6, N-10, N-11, N-14, N99, 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 B). 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 of: (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. Cores from within or adjacent to wet pits, and new cores (2003) drilled in the J2, J4, J6, J9, J14, J15, J23, N9, N12, and N99 coal resource areas are also included. Only 1 core; Core #30356EO in the N-9 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 and the significance of organic sulfur. In western mine settings as much as 80% of the total sulfur analyzed has been found to be organic sulfur. According to Dollhopf

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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)
J2 Mining Area			
30362EO	13.67	7.77	33.11
J4 Mining Area			
30359EO	20.21	10.27	29.21
J6 Mining Area			
30366EO	22.31	5.25	19.16
30367EO	36.42	8.82	20.63
J9 Mining Area			
30364EO	7.61	3.00	30.34
J14 Mining Area			
30360EO	8.32	5.20	42.03
30361EO	21.88	3.51	25.68
J15 Mining Area			
30363EO	11.97	5.82	40.87
N6 Mining Area			
21104C	16.63	9.76	40.94
23163C	4.48	7.98	45.01
23164C	15.38	11.26	39.39
23165C	26.35	10.36	39.51
23166C	14.97	7.41	62.12
24093C	14.42	8.21	44.63
24094C	12.98	7.13	61.89
24095C	12.60	6.94	50.53
24096C	5.39	6.92	52.68
24097C	22.77	8.61	40.35
24098C	23.32	7.21	38.85
24099C	11.93	2.82	36.39
24400C	12.50	9.23	51.70
24401C	20.14	10.90	21.81
24402C	21.67	12.54	38.14
J16 Mining Area			
23146C	44.57	24.37	32.29
23147C	33.14	17.81	28.66
23148C	41.22	30.79	39.28
23149C	1.42	4.59	24.60
23325C	37.64	13.89	28.80
23326C	32.34	11.06	40.85
23327C	45.26	23.06	39.89
23328C	34.72	24.12	39.41
26462C	12.28	2.65	27.30
J19 Mining Area			
24406C	33.23	5.05	27.74
24407C	32.03	16.48	32.03
24408C	17.97	4.34	32.01
24418C	24.09	15.39	34.28
J21 Mining Area			
24403C	12.02	7.44	79.73
24404C	11.98	4.97	73.07
24405C	12.36	8.49	54.99
J23 Mining Area			
30365EO	13.04	7.71	48.83
N9 Mining Area			
30355EO	29.64	16.10	51.16
30356EO	54.64	21.25	20.63
30357EO	34.30	18.57	41.57
30358EO	32.14	17.42	72.61

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TABLE 10 (Continued)

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)
N10 Mining Area			
21099C	46.63	20.02	21.97
21100C	40.09	23.89	28.40
21101C	38.21	20.86	24.10
30354EO	12.32	15.81	43.99
N11 Mining Area			
26272C	29.61	18.73	42.57
26364C	25.91	18.50	49.32
26367C	20.76	14.00	69.67
26463C	37.84	17.98	58.24
N12 Mining Area			
30370EO	17.19	15.12	33.15
N14 Mining Area			
26269C	31.41	18.73	30.73
26271C	40.04	16.51	19.65
N99 Mining Area			
30351EO	11.06	10.09	34.62
30352EO	32.00	14.47	28.76
30353EO	18.88	14.12	33.72
30368EO	28.11	15.11	33.91
30369EO	32.48	16.34	24.77
30381EO	26.65	15.72	46.39

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(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

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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 recoverable metal analyses performed on Wepo and alluvial ground-water samples collected at below-mining monitors also support the core chemistry. Wepo and alluvial ground-water trace metal analyses presented in the annual "Hydrological Data Reports" and summarized in Table 11 indicate that both the dissolved and total recoverable concentrations of trace constituents at monitoring sites downgradient of wet pits are typically 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 use of the Wepo and alluvial ground water is considered. Table 12 is a summary of the principal constituents in both aquifers that render the water sources unsuitable for livestock drinking water. The monitoring sites chosen for Table 12 are either at or in the immediate vicinity (downgradient) of a pit that will intersect the Wepo and or alluvial aquifer. Recently promulgated Tribal water quality standards (NNEPA, 2008; Hopi, 2008).were principally used, as well as recommended standards for both TDS (NAS, 1974) and sulfate (Botz and Pederson, 1976). All chemical parameter values listed are for water quality sampling at each site from 1986 through 2008, and comparisons of standards for trace elements were limited to dissolved analyses.

The principal constituent rendering Wepo aquifer water unsuitable for use as livestock drinking water is pH (at four wells). The NO3, Se, TDS and sulfate standards were also exceeded at one site (WEPO46). Low pH levels appear to be isolated occurrences at two of the four wells, where only one or two low pH values appear in twenty or more measurements. Low pH values at these wells range from 6.2 to 6.5, which is only slightly below the livestock drinking water limit (lower limit is 6.5). A single high pH value (9.16) appears in 56 measurements taken at well 40 (higher limit is 9.0). Elevated NO3 levels can lead to methemoglobinemia and impaired liver function, whereas elevated Se can cause white muscle disease in livestock. Ingestion of sulfate levels greater than 3000 mg/l and TDS concentrations greater than 7000 mg/l in livestock drinking water tends to cause diarrhea, rundown ragged appearances, weakening, and death. Principal constituents in the alluvial aquifer that preclude livestock use are sulfate and TDS. Almost all occurrences of trace elements Cd, Pb and Se greater than the standards result from laboratory method detection limits greater than the standards. Alluvial well D99 consistently exhibits low pH values below the standard. Those portions of the Wepo aquifer potentially affected by pit interception do not appear to be significantly

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Table 11.

Summary of Dissolved and Total Recoverable Trace Metal Concentrations in Portions of the Wepo and Alluvial Aquifers Below Mining Black Mesa Leasehold (1986 – 2008)

Wepo Aquifer

Chemical Constituent	Range of Minimum Values (mg/l)	Range of Mean Values (mg/l)	Range of Maximum Values (mg/l)	Livestock Standards (mg/l)#
Arsenic (D)	<.001-.003	.001-.004	<.001-.004	0.2
Arsenic (TR)	.001-.003	.001-.004	<.001-.005	0.2
Boron (D)	.03-.79	.065-.88	.08-1.2	5.0
Cadmium (D)	<.003-.008	.003-.011	<.003-.02	0.05
Cadmium (TR)	<.003-.009	.005-.009	<.005-.009	0.05
Chromium (D)	<.01-.01	.01-.01	<.01-.01	1.0
Chromium (TR)	<.01-.01	.01-.01	<.01-.01	1.0
Copper (D)*	<.01-.01	.01-.023	<.01-.02	0.5
Copper (TR)	<.01-.02	.01-.037	<.01-.06	0.5
Lead (D)*	<.02-.02	.02-.02	<.02-.02	0.1
Lead (TR)	<.02-.08	.02-.08	<.02-.08	0.1
Mercury (D)*	<.0001-.0003	.0003 - .0003	<.0001-.0003	0.01
Mercury (TR)	<.0001-<.0001	-	<.0002-<.0002	0.01
Molybdenum (D)	<.001-.002	.001-.003	<.001-.003	N/A
Molybdenum (TR)	<.001-.002	.001-.003	.001-.005	N/A
Selenium (D)*	<.001-.011	.001-.09	<.001-.21	0.05
Selenium (TR)	<.001-.007	.001-.09	<.001-.21	0.05
Zinc (D)	<.01-.30	.01-.34	.01-.40	25
Zinc (TR)	.01-.03	.02-.20	<.01-.53	25

Alluvial Aquifer

Chemical Constituent	Range of Minimum Values (mg/l)	Range of Mean Values (mg/l)	Range of Maximum Values (mg/l)	Livestock Standards (mg/l)#
Arsenic (D)	<.001-.013	.001-.013	<.002-.015	0.2
Arsenic (TR)	<.001-.006	.001-.008	.001-.03	0.2
Boron (D)	<.02-.66	.088-.78	.07-.90	5.0
Cadmium (D)*	<.003-.02	.003-.02	<.01-.02	0.05
Cadmium (TR)	<.003-.02	.003-.02	<.01-.021	0.05
Chromium (D)*	<.01-.03	.01-.038	<.01-.07	1.0
Chromium (TR)	<.01-.03	.01-.11	<.01-.35	1.0
Copper (D)*	<.01-.04	.01-.043	<.01-<.08	0.5
Copper (TR)	<.01-.02	.01-.062	<.01-.22	0.5
Lead (D)*	<.02-.08	.02-.08	.02-.12	0.1
Lead (TR)	<.02-.04	.02-.14	<.02-.59	0.1
Mercury (D)*	<.0001-.0009	.0002-.002	<.0002-.003	0.01
Mercury (TR)*	<.0001-.0004	.0001-.0007	<.0001-.0013	0.01
Molybdenum (D)	<.001-.002	.001-.004	<.001-.01	N/A
Molybdenum (TR)	<.001-.002	.002-.008	<.001-.016	N/A
Selenium (D)	<.001-.017	.001-.014	<.002-.032	0.05
Selenium (TR)	<.001-.004	.001-.011	.002-.024	0.05
Zinc (D)*	<.01-.67	.02-.32	.02-.77	25
Zinc (TR)	<.01-.02	.02-.08	<.01-.47	25

* Range adjusted to exclude suspected outliers. Criteria used for identifying suspected outliers include: measureable dissolved concentrations yet the pH is alkaline; dissolved concentrations higher than total recoverable concentrations; and one or two abnormally high dissolved values mixed with 40 below detection limit values.
# Standards are taken from Navajo Nation Surface Water Quality Standards (NNEPA, 2008), and from Draft Hopi Water Quality Standards (Hopi, 2008 – mercury only).

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Table 12 - Downgradient Wepo and Alluvial Well Chemistry vs. Livestock Drinking Water Standards

Analyte	Standard	No. Sites	Sites	Frequency	Exceedence Date Range	Exceedence Value Range	Exceedence Median	
LIVESTOCK WATERING STANDARDS -- NNEPA (2008), Hopi (2008), NAS (1974), Botz and Pederson (1976)								
Aluminum, Dissolved	0.0000 - 5.0000	1	ALUV199	1/0/0/44	07/03/01-07/03/01	8.2000 -	8.2000	8.2000
Arsenic, Dissolved	0.0000 - 200.0000	0	none					
Boron, Dissolved	0.0000 - 5000.0000	0	none					
Cadmium, Dissolved	0.0000 - 50.0000	6	ALUV180	0/0/1/37	08/25/97-08/25/97(<)	200.0000 -	200.0000	200.0000
			ALUV181	0/0/1/41	08/25/97-08/25/97(<)	200.0000 -	200.0000	200.0000
			ALUV182	0/0/1/44	03/24/98-03/24/98(<)	60.0000 -	60.0000	60.0000
			ALUV19	0/0/1/61	01/27/98-01/27/98(<)	80.0000 -	80.0000	80.0000
			ALUV193	0/0/1/53	11/03/97-11/03/97(<)	400.0000 -	400.0000	400.0000
			ALUV197	0/0/2/53	11/03/97-01/27/98(<)	80.0000 -	400.0000	240.0000
Chromium, Dissolved	0.0000 - 1000.0000	0	none					
Copper, Dissolved	0.0000 - 500.0000	0	none					
Field Ph	6.5000 - 9.0000	5	ALUV199	21/0/0/44	05/31/94-07/13/09	5.8500 -	6.4800	6.3100
			WEPO40	1/0/0/56	10/25/95-10/25/95	9.1600 -	9.1600	9.1600
			WEPO42	2/0/0/58	02/16/94-03/09/95	6.3700 -	6.3700	6.3700
			WEPO46	5/0/0/49	03/11/93-06/03/09	6.2100 -	6.4900	6.2500
			WEPO49	2/0/0/54	06/29/92-03/09/95	6.2300 -	6.4700	6.3500
Lead, Dissolved	0.0000 - 100.0000	16	ALUV169	0/0/12/43	11/20/97-02/04/05(<)	200.0000 -	200.0000	200.0000
			ALUV170	0/1/29/53	04/21/97-07/28/09(B)	200.0000 -	200.0000	200.0000
					(<)	200.0000 -	200.0000	200.0000
			ALUV180	0/0/18/37	03/07/97-05/20/02(<)	200.0000 -	2000.0000	200.0000
			ALUV181	0/0/22/41	03/07/97-06/20/08(<)	200.0000 -	2000.0000	200.0000
			ALUV182	0/1/19/44	03/07/97-11/03/09(B)	300.0000 -	300.0000	300.0000
					(<)	200.0000 -	800.0000	200.0000
			ALUV19	0/0/16/60	02/04/97-02/25/09(<)	200.0000 -	200.0000	200.0000
			ALUV193	0/0/26/53	11/03/97-03/22/10(<)	200.0000 -	1000.0000	200.0000
			ALUV197	0/0/26/53	08/26/97-03/22/10(<)	200.0000 -	1000.0000	200.0000
			ALUV199	0/0/23/44	07/16/96-07/13/09(<)	200.0000 -	200.0000	200.0000
			ALUV27R	0/0/16/50	11/06/97-07/29/02(<)	200.0000 -	200.0000	200.0000
			ALUV80R	0/1/4/66	07/19/99-02/16/09(B)	200.0000 -	200.0000	200.0000
					(<)	200.0000 -	400.0000	200.0000
			ALUV83	0/0/33/69	07/16/96-03/22/10(<)	200.0000 -	200.0000	200.0000
			ALUV89R	0/0/23/66	03/02/98-02/04/09(<)	200.0000 -	200.0000	200.0000
			WEPO178	0/0/8/22	03/10/97-05/20/02(<)	200.0000 -	200.0000	200.0000
			WEPO46	0/0/4/28	09/18/97-05/19/06(<)	200.0000 -	200.0000	200.0000
			WEPO55	0/0/1/26	08/26/97-08/26/97(<)	200.0000 -	200.0000	200.0000
Mercury, Dissolved	0.0000 - 10.0000	0	none					
NO3_NO2 Nitrogen_N	0.0000 - 132.0000	2	ALUV200	1/0/0/54	03/25/08-03/25/08	323.0000 -	323.0000	323.0000
			WEPO46	2/0/0/24	09/18/97-11/06/97	202.0000 -	270.0000	236.0000
Nitrate Nitrogen_N	0.0000 - 132.0000	2	ALUV200	1/0/0/54	03/25/08-03/25/08	323.0000 -	323.0000	323.0000
			WEPO46	2/0/0/28	09/18/97-11/06/97	202.0000 -	269.0000	235.5000

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Table 8 (cont.) - Downgradient Wepo and Alluvial Well Chemistry vs. Livestock Drinking Water Standards

Analyte	Standard	No. Sites	Sites	Frequency	Exceedence Date Range	Exceedence Value Range	Exceedence Median	
Selenium, Dissolved	0.0000 - 50.0000	2	ALUV200	2/0/0/54	03/25/08-04/16/08	56.0000 -	300.0000	178.0000
			WEPO46	13/0/0/28	06/24/86-06/03/09	51.0000 -	560.0000	160.0000
Solids, Dissolved	0.0000 - 6999.0000	7	ALUV170	13/0/0/53	03/18/93-04/17/01	7010.0000 -	9540.0000	7470.0000
			ALUV19	1/0/0/63	04/28/06-04/28/06	7120.0000 -	7120.0000	7120.0000
			ALUV197	25/0/0/53	08/28/98-07/22/09	7040.0000 -	7730.0000	7330.0000
			ALUV199	38/0/0/44	12/17/92-07/09/08	7050.0000 -	9692.0000	8400.0000
			ALUV200	1/0/0/54	03/25/08-03/25/08	13900.0000 -	13900.0000	13900.0000
			ALUV83	30/0/0/70	10/23/87-03/22/10	7002.0000 -	7670.0000	7222.0000
			WEPO46	2/0/0/58	09/18/97-11/06/97	7840.0000 -	8010.0000	7925.0000
Sulfate	0.0000 - 3000.0000	14	ALUV170	53/0/0/53	10/01/92-07/28/09	3300.0000 -	5800.0000	3990.0000
			ALUV180	18/0/0/37	08/09/94-08/17/01	3010.0000 -	3380.0000	3100.0000
			ALUV181	1/0/0/41	04/23/97-04/23/97	3140.0000 -	3140.0000	3140.0000
			ALUV182	4/0/0/44	09/05/95-04/28/97	3050.0000 -	3160.0000	3080.0000
			ALUV19	21/0/0/62	02/04/97-03/22/10	3040.0000 -	4200.0000	3370.0000
			ALUV193	29/0/0/53	09/21/93-03/22/10	3020.0000 -	4000.0000	3180.0000
			ALUV197	53/0/0/53	10/30/92-03/22/10	3441.0000 -	4640.0000	4100.0000
			ALUV199	44/0/0/44	12/17/92-07/13/09	4000.0000 -	6610.0000	5380.0000
			ALUV200	1/0/0/54	03/25/08-03/25/08	7900.0000 -	7900.0000	7900.0000
			ALUV27R	49/0/0/50	06/02/89-07/29/02	3293.0000 -	4110.0000	3676.0000
			ALUV83	69/0/0/70	07/17/86-03/22/10	3239.0000 -	5038.0000	4116.0000
			ALUV89R	4/0/0/66	01/13/00-04/15/05	3020.0000 -	3120.0000	3075.0000
			WEPO178	1/0/0/22	07/21/97-07/21/97	3170.0000 -	3170.0000	3170.0000
			WEPO46	7/0/0/28	10/17/88-06/03/09	3130.0000 -	4290.0000	3457.0000
Vanadium, Dissolved	0.0000 - 100.0000	2	WEPO40	0/0/1/35	04/23/86-04/23/86(<)	500.0000 -	500.0000	500.0000
			WEPO55	0/0/1/26	04/16/86-04/16/86(<)	500.0000 -	500.0000	500.0000
Zinc, Dissolved	0.0000 - 25.0000	4	ALUV19	0/0/1/60	01/12/00-01/12/00(<)	50.0000 -	50.0000	50.0000
			ALUV199	0/0/1/44	01/12/00-01/12/00(<)	50.0000 -	50.0000	50.0000
			ALUV83	0/0/1/69	01/14/00-01/14/00(<)	50.0000 -	50.0000	50.0000
			ALUV89R	0/0/1/66	01/13/00-01/13/00(<)	50.0000 -	50.0000	50.0000

:equency = uncensored/between MDL&PQL/censored/no. samples, (B) = Between MDL&PQL range, (<) = Censored range

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affected as relatively few of the twelve Wepo wells exhibit unsuitable livestock water use potential. Also, those portions of the alluvial aquifer potentially affected by pit interception of the Wepo aquifer do not appear to be significantly affected because 4 of the 18 alluvial wells have typically had unsuitable livestock water use potential owing to TDS, and eight of the 18 wells have exhibited high levels of sulfate historically.

In summary, increases in concentrations of Ca, Mg, Na, SO_4 and HCO_3 and 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 10 years or more. The magnitude of the impact to either aquifer should be limited to the immediate pit areas, because gradients and transmissivities are very low.

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 may be unsuitable for domestic or livestock purposes

Interception of Wepo Recharge to the Alluvial Aquifer by Pits. 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-11, 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.

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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 about 29 and 12 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 distances below the dams.

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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.

Mining Interruption of Spring Flow. To date, ten natural and two artificial springs 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 (NSPG97) 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 N14-D dam; and (2) two public water outlets on 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.

Impact of Peabody Wellfield Pumpage on Regional Water Levels and Stream and Spring Flows. Peabody operates a wellfield consisting of eight wells completed in the D aquifer and N aquifer (Navajo Sandstone, Kayenta Sandstone, and Wingate Sandstone) that provided water for the coal slurry pipeline serving the Mohave Generating Station through the end of 2005, and for other continuing operational uses. Pumpage was initiated in 1969 and has averaged about 4,000 acre-feet per year (1969-2003).

The pumping of water from the N aquifer by Peabody since 1969 has produced one of the longest term pumping tests ever. Water-level changes have been measured in wells at

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TABLE 13

Chemical Parameters and Concentrations at Spring 97

Which Exceed Livestock Drinking Water Limits

Parameter	Mean Concentration (mg/l)	Recommended Livestock Limits[1] (mg/l)
Lead	0.167	0.1
Sulfate	4077	3000
Total Dissolved Solids	6846[2]	6999

(1) Limits are based on Navajo Nation (2008), Hopi Tribe (2008), National Academy of Science (1974), and Botz and Pederson (1976).

(2) One of four TDS values was greater than 6999 mg/l.

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considerable distances and in several directions from the PWCC wellfield. The rates of pumping at the well field have been measured throughout the period of pumping. The result is a data set which, if properly evaluated, provides considerable information about the aquifer, and about the response of the aquifer to pumping. These measurements also provide information with which to estimate the effects of future water use. It is important to use appropriate tools to interpret this information. The analytical models, such as the Theis, Cooper-Jacob, Hantush, or other solutions of the flow equations, while appropriate for short-term tests, are commonly not suitable for longer tests because many of their simplifications affect long-term results. Material properties can vary over reasonably short distances, and boundaries can affect aquifer responses to pumping. Therefore, numerical models are better tools with which to properly interpret these long-term pumping tests, and to predict the effects of future pumping. In short, monitoring the effects of past water use provides information with which to predict future effects. This approach was first applied in the Black Mesa area in 1985 and 1987 by the USGS, through the development of a ground water flow model of the N aquifer beneath and surrounding the Black Mesa basin, and use of the calibrated model to predict the effects of future pumping. In 1998, consultants for Peabody started development and calibration of a more realistic, three-dimensional model of the aquifer and incorporating more recently collected information; this improved model is used to predict the effects of N aquifer water use by Peabody.

The following analysis of the effects of Peabody's pumping of the N Aquifer is based on data measured before and during the period of pumping, and on models based on these data. It considers the effect of pumping on drawdown at existing locations of groundwater use, groundwater discharge at springs and to streams, the structural integrity of the N aquifer, and water quality of the N aquifer that might be affected by increased leakance of water through the overlying Carmel.

Numerical Modeling. Several numerical models have been developed to estimate the impacts of pumping by Peabody and the tribal communities on the N Aquifer, beginning in 1983 (Eychaner, 1983). Most recently, Peabody has developed a model that includes the overlying D Aquifer (PWCC, 1999). The D Aquifer is also used as a water resource, but to a much lesser extent than the N Aquifer; model simulation results indicate that over the calibration period, approximately 3% of Peabody pumping is from the D. These models are the best tools available for determining the individual contribution of each pumping stress on the observed or measured effects (i.e., water levels and stream flows). The models are not of sufficient resolution to simulate flow at individual springs, but can be used to make intelligent observations of regional spring flow. Each model includes:

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- Development of a basic description of the real system, including geologic controls on material properties (i.e., geometry of the rock layers, deformation of the rocks, etc.), areas and amounts of recharge and discharge, and distribution of water levels.
- Formulation of a mathematical description of the system to be modeled. This formulation is based on

  - o Darcy's Law - a mathematical expression that relates the rate of groundwater flow to observable differences in water levels.
  - o Mass balance - a mathematical expression of conservation of mass. For a groundwater-flow system, this means that flow into the system (recharge) must equal flow out of the system (pumping or discharge to streams or springs) plus the change in the amount of water held or released from storage as water levels change.
  - o Boundary conditions - mathematical statements of various conditions that exist on the boundaries of the modeled system. These require knowledge of the geometry of the rock formations and the processes and locations through which water enters and exits the system.
  - o Initial conditions - description of the water levels everywhere in the system at the beginning of the modeled time period.

- Development of a set of numerical values for all parameters appearing in the mathematical formulation. These include hydraulic conductivity, specific storage, and specific yield, all of which may be spatially variable.

- Application of a numerical algorithm that "solves" the mathematical formulation for different applied stresses. The algorithm calculates the spatial and temporal distribution of water levels and groundwater flow rates that satisfy the mathematical model for different pumping rates, recharge rates, etc.

Each model is put through a calibration process whereby model parameters are adjusted by either manual or automated methods until simulated results reasonably match measurements. This usually means matching historic water-level measurements at wells against model output. The model parameters adjusted towards calibration are typically flow and storage properties of the geologic material. They are adjusted within ranges reported in the scientific literature for the specific rock type. Boundary conditions such as recharge may also be adjusted if calibration can not be achieved with the independently derived estimates. The geometry of the flow system is typically held fixed during this process. Calibration can be performed for non-pumping (steady state) and pumping (transient) conditions whereby a single set of flow properties is derived to match water levels

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representing both conditions.

Each of the groundwater models developed for the Black Mesa area was based on the USGS's finite-difference computer codes, covered most or all of the Black Mesa Basin, included all known pumping stresses and was calibrated under non-pumping and pumping conditions using the USGS's six monitoring wells as key calibration targets.

The first model developed was by Eychaner of the USGS in 1983 using the computer code written by Trescott and others (1976) which simulates flow in one or two dimensions. The N Aquifer was simulated as a single flow unit (using one model layer) in two-dimensional space and the transient calibration period was from 1965 through 1977. Soon thereafter, the USGS (Brown and Eychaner, 1988) updated this model using a refined grid spacing and the USGS modeling code MODFLOW (McDonald and Harbaugh, 1988). After calibration, this model was used to predict the effects of pumpage on the flow system. Concurrently, an independent modeling effort was begun by Peabody. Both groups chose to simulate the flow system in two dimensions and to represent the N Aquifer as one flow unit. This was reasonable given the N Aquifer's large regional-scale, relatively uniform and continuous nature, and its predominantly horizontal groundwater flow. The USGS (Brown and Eychaner, 1988) kept their same model boundaries while Peabody's version (GeoTrans, 1987) extended the boundaries to cover more of Black Mesa basin (Figure 2), particularly to the southeast. This difference in extent reflects the fact that the USGS only includes the Navajo Sandstone in the southwestern part of the model, while the Peabody model also includes the Kayenta and Wingate. The USGS extended their calibration period from 1965 through 1984, whereas the Peabody model was calibrated from 1956 through 1985. The earlier time period (pre-1965) was chosen to simulate community pumping at Kayenta. The Peabody model also increased the number of transient calibration-target locations from six to nine. Although the two models were developed independently and differed from each other in details, their results were similar.

In 1993, under the auspices of the coal leases and authorized by the Secretary of Interior, the Hopi Tribe, the Navajo Nation, and Peabody funded a study by S. S. Papadopulos & Associates, Inc. (SSPA) that reviewed the USGS model (Brown and Eychaner, 1988) for appropriateness, application, calibration, and results. They concluded that:

> "A mathematical model, such as the one constructed by the USGS, is the only method available for separately determining impacts of Peabody's pumping on groundwater conditions in the N-Aquifer. This method insures consistency among the different facets of the hydrogeologic system such as recharge, discharge, ground-water levels, pumping, aquifer properties and

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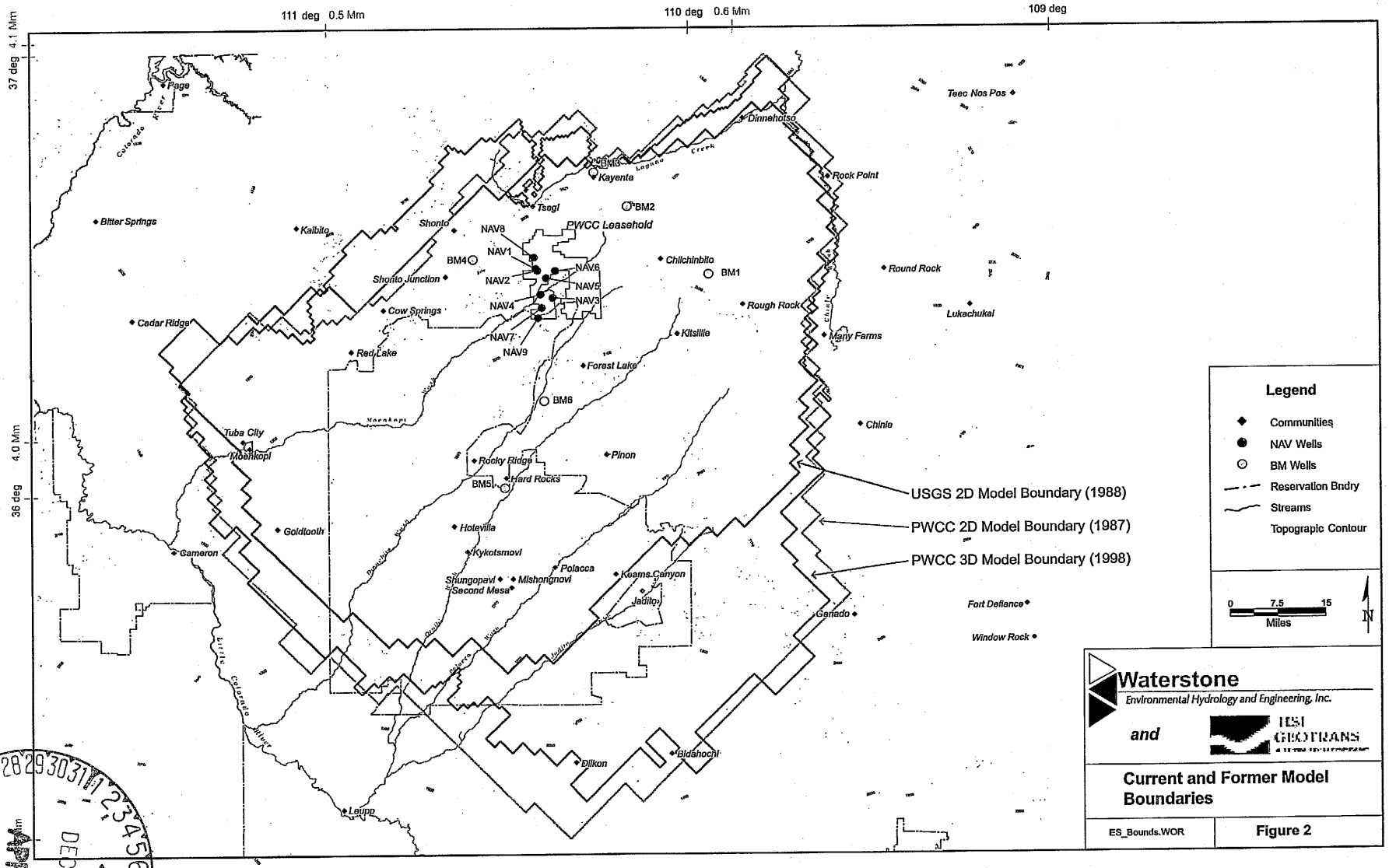

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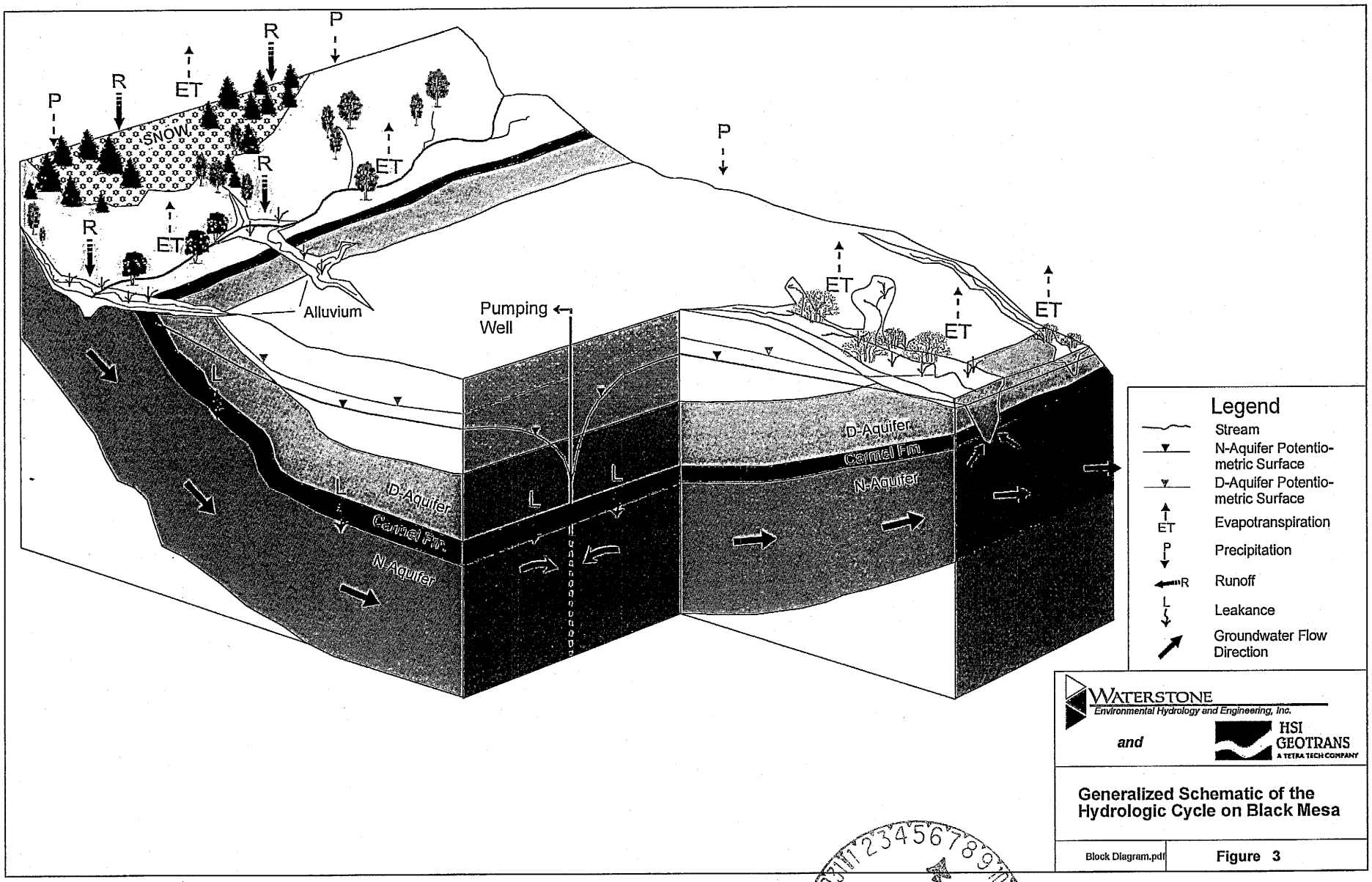
aquifer extent. Consequently, the method used in the USGS studies is a standard method and is clearly appropriate for the purpose of evaluating impacts due to pumping by Peabody."

They further concluded that application of the modeling method was appropriate, the calibration was reasonable, and that Peabody's impacts on surface-water features (such as streams and springs) was minimal because water was predominantly coming from aquifer storage. An important contribution of SSPA (1993) towards the understanding of the N Aquifer system was the development of a database for the N aquifer that was more comprehensive than the one used by Brown and Eychaner (1988).

Following the completion of the SSPA report and because of the concern expressed by some of the participants in the co-operative study, the Secretary of Interior requested that the USGS conduct a fresh review of the Brown and Eychaner report. The reviewer from the USGS believed that Brown and Eychaner did not sufficiently document the water budget estimates, and that the model was less credible as a result. To evaluate this concern, Peabody initiated a modeling study in which the sensitivity of modeling predictions to the estimated recharge rate was tested (Peabody, 1994). First, this study compared the USGS and Peabody models. Second, it documented the conversion of both the USGS and Peabody models to an automated calibration modeling code, MODFLOWP (Hill, 1991). The converted USGS model was then successfully re-calibrated for pre-pumping conditions using recharge values that were 0.5, 0.75, 1.5, and 2.0 times the base recharge value used by Brown and Eychaner (1988) of 13,380 ac-ft/yr. The best agreement with water-level data occurred with the base-case recharge value. Pumping simulations were then performed, and results indicated the importance of calibrating the model to both pre-pumping and pumping conditions. MODFLOWP did not have this capability. Similar tests were performed with the Peabody model (1987), with similar results.

In 1999, Peabody substantially revised the modeling of the flow system by developing a three-dimensional representation of the N and D Aquifers, separated by the intervening low-permeability Carmel Formation (Figure 3). The revised three-dimensional model, including detailed discussions on the model database, conceptual model, geology, hydrogeology, numerical modeling, and future pumping effects, are presented in the report entitled "A Three-Dimensional Flow Model of the D and N Aquifers, Black Mesa Basin, Arizona" (PWCC, 1999). Each of the seven rock units that comprise the D and N Aquifers are explicitly included in this 7-layer model. Moreover, the changes in material properties caused by different depositional environments within the rock units are incorporated, allowing their properties to be explicitly adjusted individually during the



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model-calibration process. In previous models, the model parameters represented a lumped average for the properties of several different formations. The calibration period was extended from 1956 through 1996 and the number of wells providing information on changes in water levels caused by pumping increased from nine to 47. This work was based on a database that included and went beyond the one compiled by SSPA (1993), in part, by adding information for the Carmel Formation and the D Aquifer, and including eleven additional years of pumping stresses, water-level measurements, and spring and streamflow measurements.

When the 3D model was developed, it was calibrated to both non-pumping (pre-1956) and pumping (1956 through 1996) conditions. Temporal changes in measured water levels were compared with changes in the simulated water levels. The calibration process relied more on data from wells BM-1, -2, -3, -4, -5 and -6 than from other wells, because (1) these wells were specifically chosen for monitoring the effects of pumping at the Peabody leasehold, (2) the higher quality and greater quantity of data from the BM-series, and (3) detailed information on pumping of community wells was not available. The calibrated model provides good agreement with the measured changes in water levels for the BM-series wells.

An automated calibration process that used both pre-pumping and pumping datasets was used. This facilitated the development of multiple calibrated models, each one calibrated to different estimates of recharge or other model parameters. In 1997, Lopes and Hoffmann (1997) used geochemical data to estimate the recharge rate near Shonto. Their estimated rate was approximately one-half that proposed by Brown and Eychaner for this area. Using a larger geochemical data set and a numerical transport model, Zhu and others (1998) and Zhu (2000) showed that the geochemical data are consistent with the higher, earlier estimates of recharge rates based on hydrologic data. Still, uncertainty in recharge rates remains. To address this uncertainty, the model was calibrated twice, first using a recharge value similar to Brown and Eychaner's and again, using a value similar to Lopes and Hoffmann's. In addition, two different approaches (full ET and low ET) to simulating discharge in non-wash settings were used, resulting in four calibrated models. These are termed FR/FET (full recharge and full ET), HR/FET (half recharge and full ET), FR/LET (full recharge and low ET), and HR/LET (half recharge, low ET). The use of different recharge estimates and different non-wash discharge approaches in the four calibrated models explicitly answers questions about the sensitivity of the models' predictions to uncertainty in these items.

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These four models were used to estimate impacts of Peabody and tribal pumping on the D and N Aquifers. Unless otherwise indicated, the term "base-case model" refers to Peabody's FR/FET 3D model of the D and N aquifers using a recharge rate similar to that used by Eychaner (1983) and Brown and Eychaner (1988), and using MODFLOW's ET package to simulate discharge in the non-wash settings.

The 3D model was developed to improve the confidence in predictions of future effects of Peabody's pumping. The fact that the new model matched water-level information better than older models, while reassuring, does not necessarily mean that the predictions will be accurate. Earlier models produced reasonably good agreement with water-level change information available at the time of their calibration, but the agreement of measured and simulated water-level changes degraded with increasing time.

Calibration of the 3D model benefited from the collection of approximately eleven additional years of data since development of the earlier 2D models. These data provided additional indirect information about the groundwater system through a model-development process. Groundwater models are widely acknowledged to be "non-unique". Different models (boundary conditions, geometries, material properties, solution techniques) can produce equally good agreement with available information. However, they may yield different results when used to make predictions. Thus, an important aspect of using models to guide resource management decisions is to evaluate whether the model results agree with data not used to calibrate the model, such as newly collected water-level data. If the agreement is good, confidence in the model's predictive ability is increased. However, if the agreement is poor, the need for additional calibration work is indicated.

The accuracy of the 3D model to simulate water-level changes beyond the calibration period was tested using pumping and water level data through 2009, which includes the period beginning in January 2006 when Peabody pumping was considerably less than in previous periods. Water-level data from the BM-series wells and annual community pumping data were obtained from the U.S. Geological Survey through the end of 2009. Monthly pumpage data from each of the PWCC production wells were used in the simulations.

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Simulations were performed using the four different models described in Peabody (1999). These four models, each individually calibrated, use a combination of two different recharge rates and two different upland (non-stream) discharge values simulated using different maximum ET rates. For the model validation tests, only the pumping rates for the period 1997 through 2009 were updated from the 1999 report; no other changes were made to the modeling data sets.

In the following temporal drawdown figures, the drawdown is calculated based on the time of the first available measurement in the indicated well. Errors in the first measurement would affect the calculation of the measured drawdown values. The effects of errors may be greatest at BM3, which displays considerable variation in water level because of local pumping.

Figures 4 through 9 provide comparisons of measured and simulated drawdown for the four models for the BM-series wells through 2009. At BM1, the agreements of the two models using the full recharge values are better than for the two models using half the full recharge values; the base case provides the best fit to the data. There is a measured long-term slow trend of declining water levels, with less than 1 foot of decline over more than 30 years. All four of the models simulated more drawdown for the calibration period than was observed. Thus, it is not a surprise that they continue to simulate more drawdown than has occurred.

At BM2, the simulated drawdowns for the four models approximate the same total drawdown as observed over the calibration period, although the simulated drawdowns occurred earlier than the measured values. The agreement between measured and simulated drawdown appears to have improved after about 1992, and all four models do a reasonably good job of approximating measured drawdown through the end of the calibration period. The base case and low upland discharge models provide the best fit to measured data. In recent years, measured drawdown has been occurring more rapidly than predicted drawdown. The simulations show a small response to the reduction in pumping by Peabody in 2006. The measured values show that the rate of drawdown has decreased but that water levels have not yet started to rise.

Comparison of simulated and measured values is more difficult at BM3 because of the impacts of variable, local pumping and the resultant high variability of water levels in the well. The four models track the measured changes approximately equally well. The low upland discharge model provides better simulation results to an increase in drawdown between approximately 1977 and 1984 than the other three models. Although variability in

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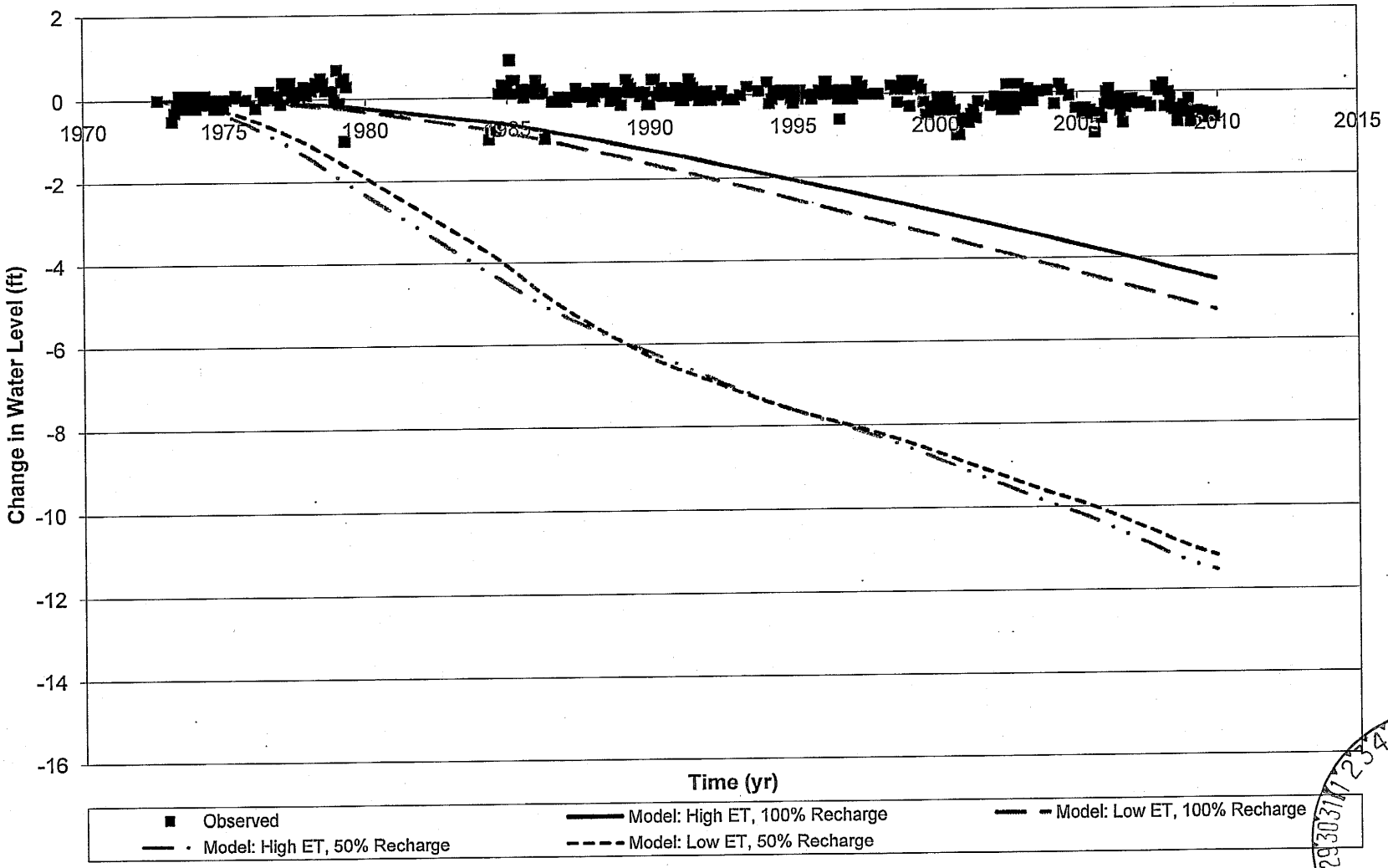

Figure 4. Simulated and Measured Drawdown at BM-1

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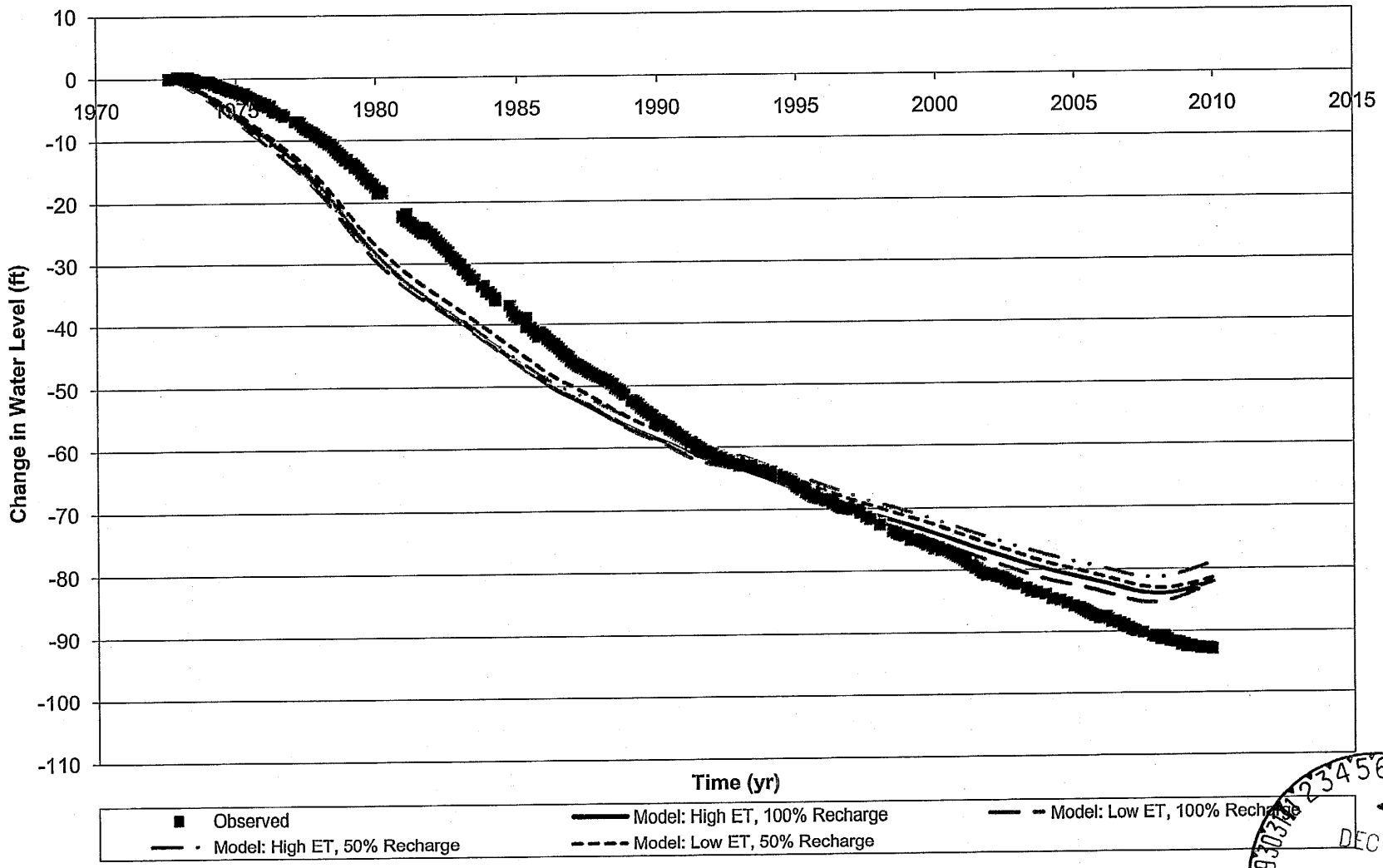

Figure 5. Simulated and Measured Drawdown at BM-2

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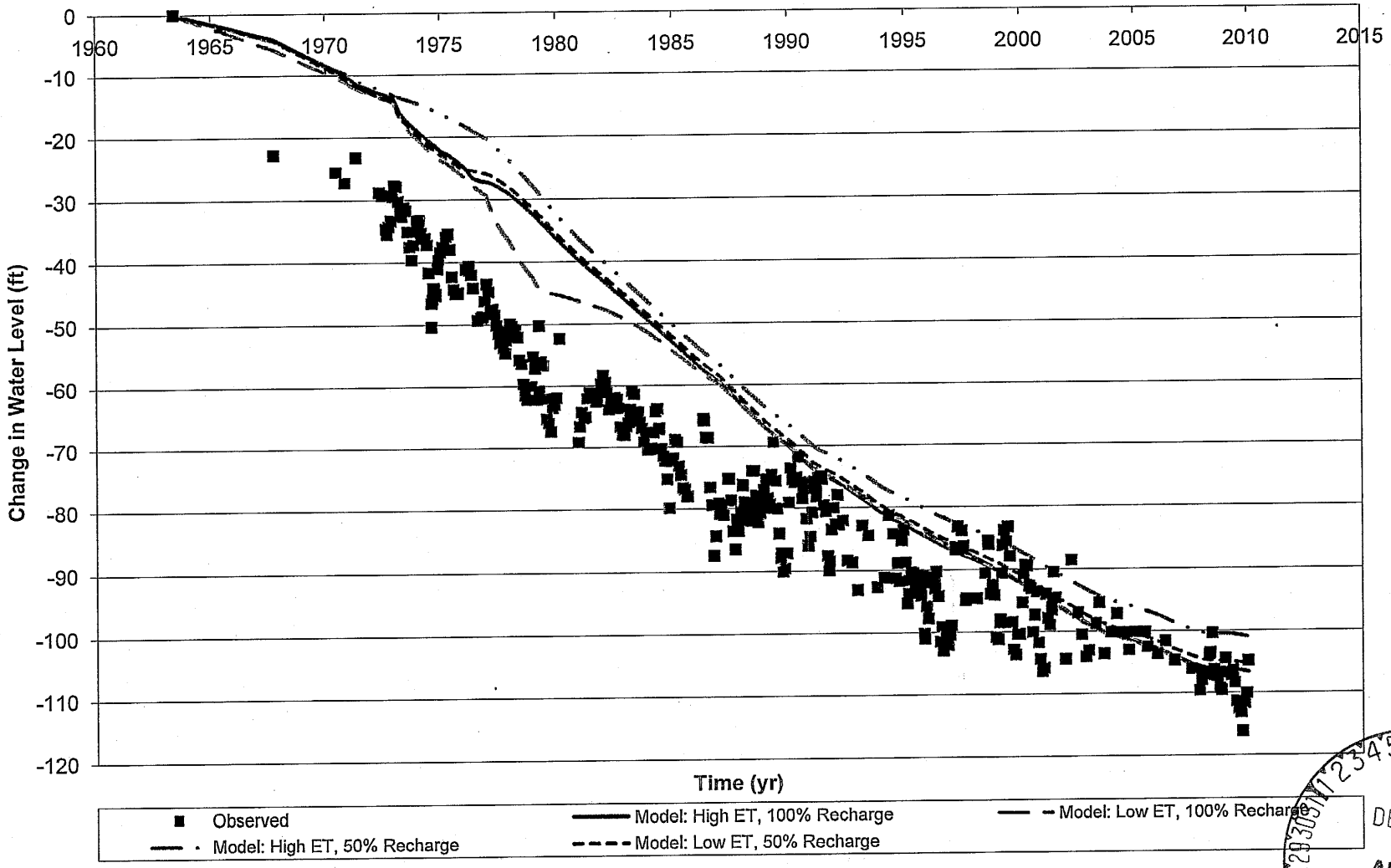

Figure 6. Simulated and Measured Drawdown at BM-3

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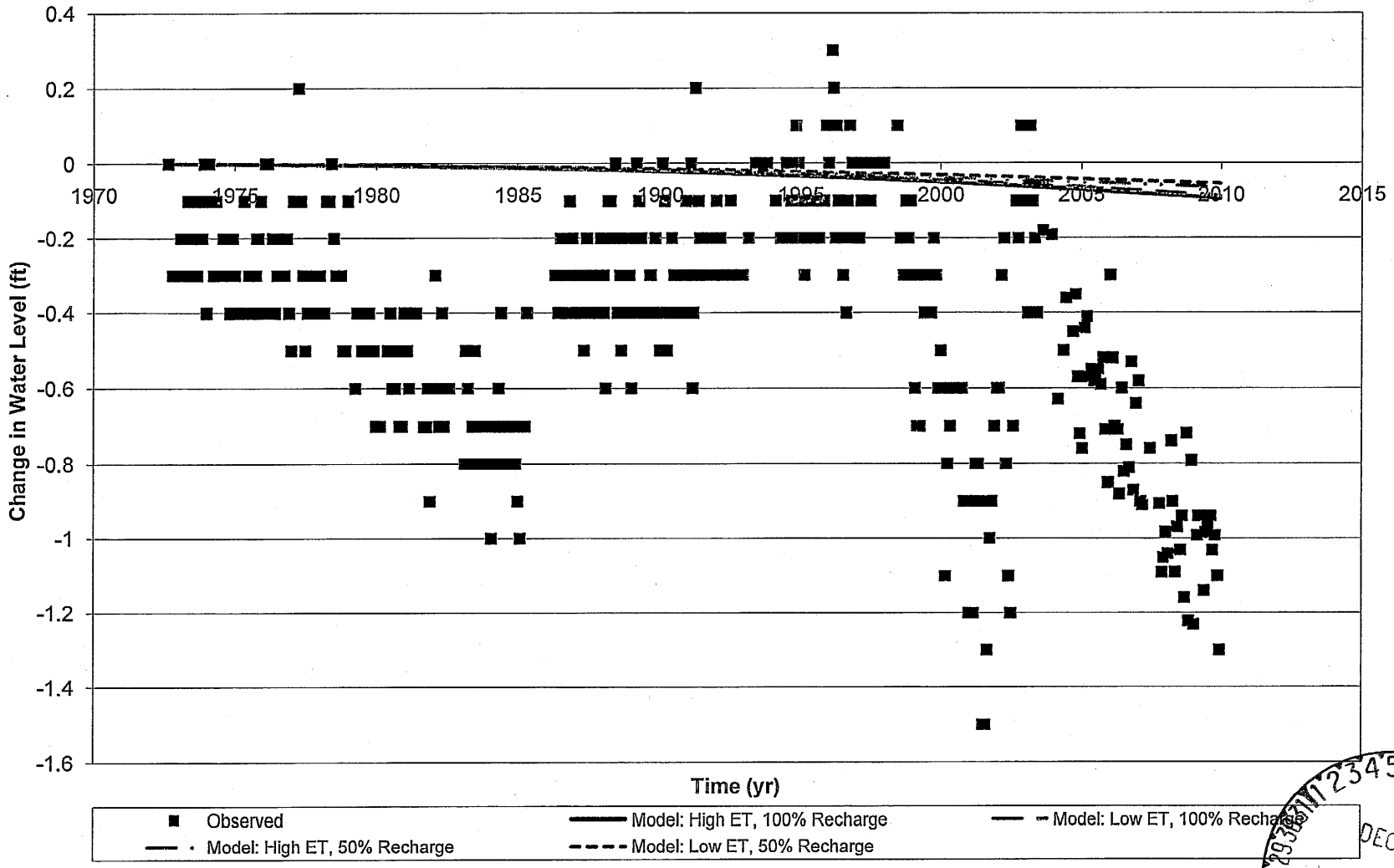

Figure 7. Simulated and Measured Drawdown at BM-4

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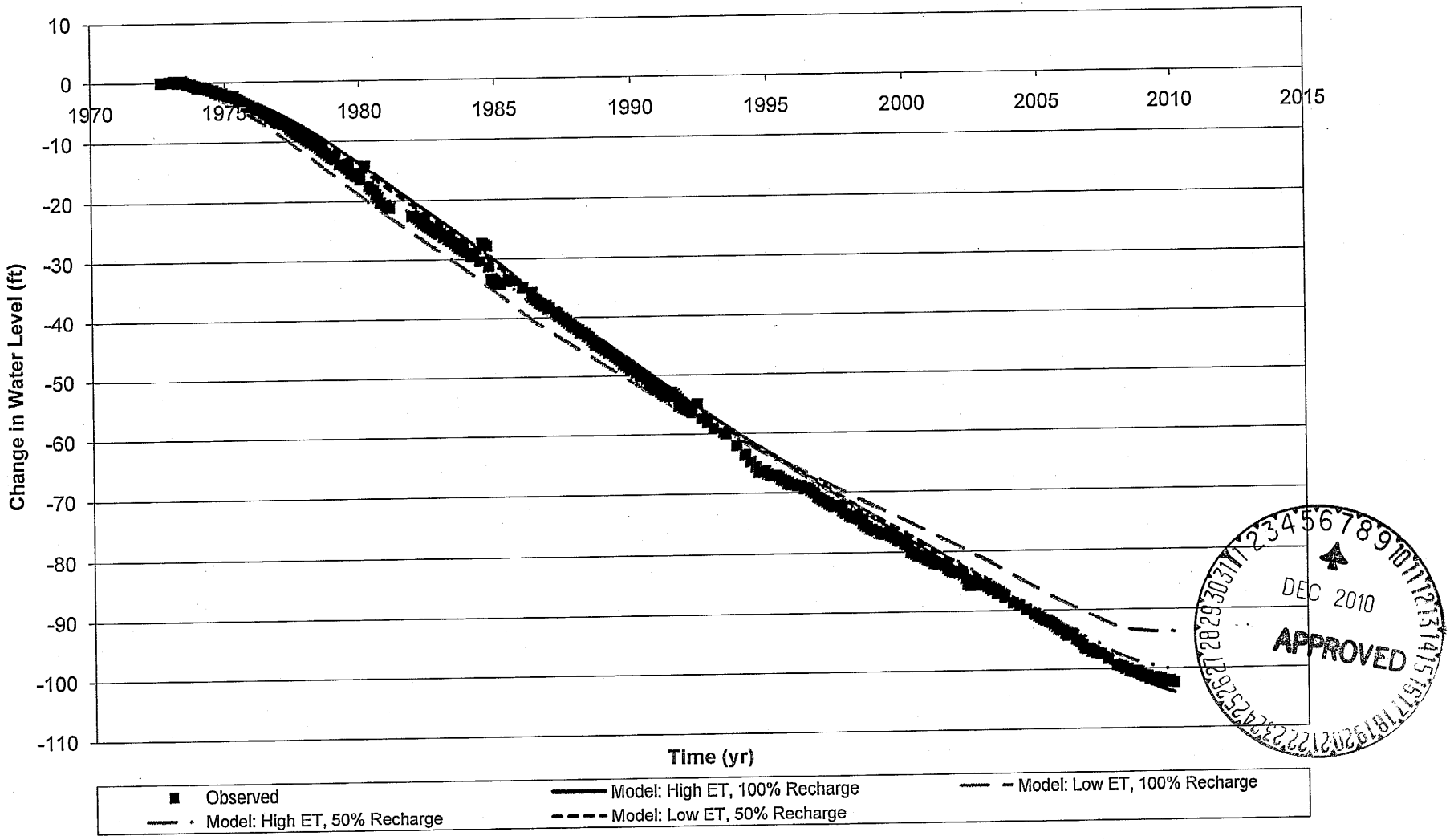

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Figure 8. Simulated and Measured Drawdown at BM-5

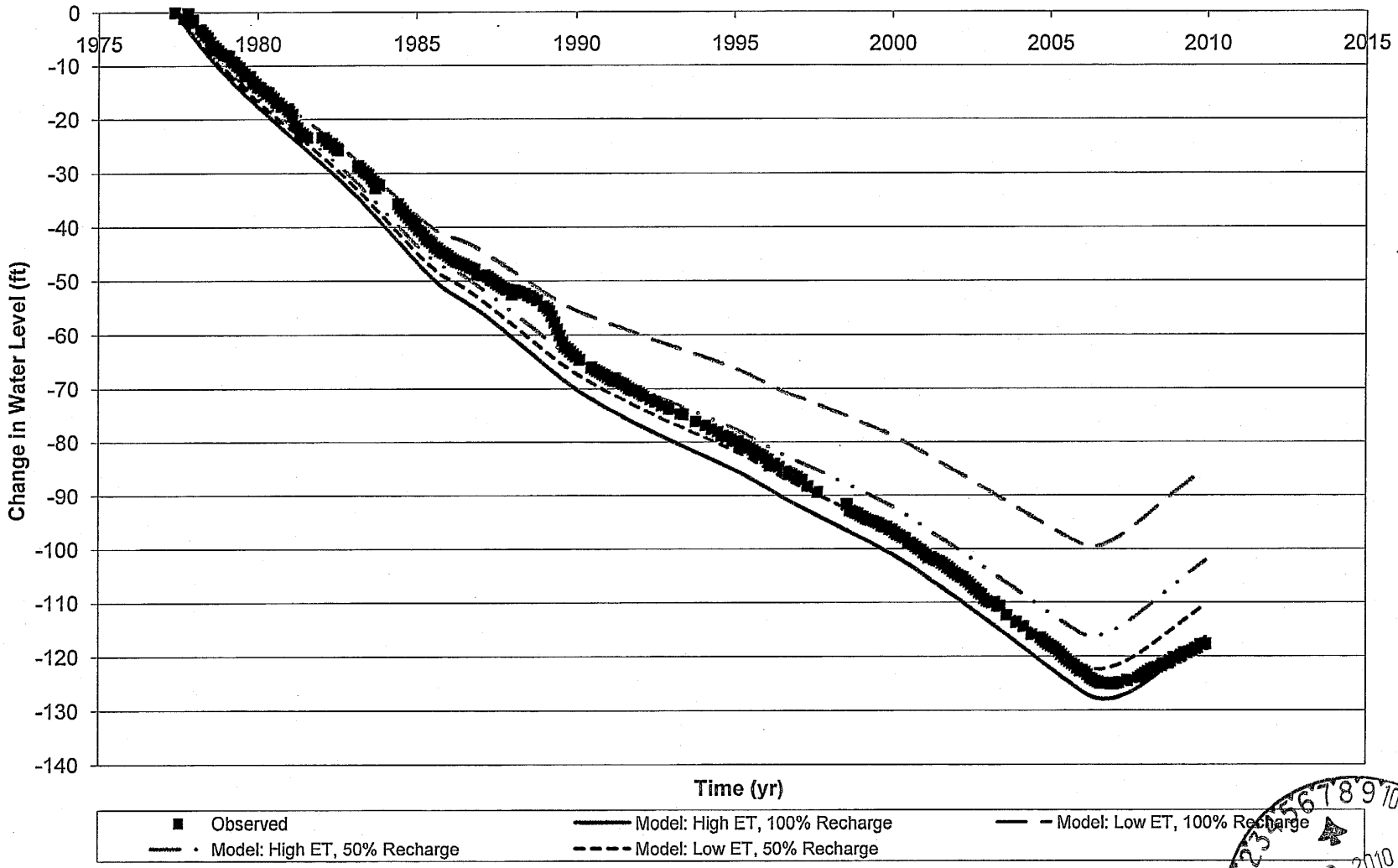

Figure 9. Simulated and Measured Drawdown at BM-6

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the measured values makes comparison with the simulated values uncertain, the four models appear to simulate a slighter greater rate of drawdown than the measured values from end of calibration through 2009. Effects of reduced pumpage by Peabody are not apparent in the data. The simulations show a slight decrease in the rate of drawdown.

Little change has occurred in water-level measurements in BM4. A decline in water levels of approximately 1 ft occurred between 1998 and the beginning of 2003, but levels increased back to pre-1998 levels, and then began to decline again. As with BM1, the cause for the short-term decrease is not known. The models are beginning to simulate a small (<0.1 ft) amount of drawdown at this well.

The most recent 13 years of data (since the end of the calibration dataset) at BM5 are tracked very well by the four models, although the agreement of the full recharge/low ET model is not quite as good as the other three. The rate of drawdown at the well has decreased slightly since PWCC pumping decreased at the end of 2005. The models are matching this change well.

At BM6, the full recharge/low ET model simulates about 20% less total drawdown than that measured over the calibration period, and less than the other three models. The rates of change calculated by the other three models agree quite well with the measured rate of change, although the base-case (full recharge/ET) and the half-recharge, low upland discharge models provide the best overall fit to the calibration data. The reduction in Peabody's pumping at the beginning of 2006 is apparent in the data and the simulation results, with the models having a slightly earlier and slightly faster recovery than the measurements. From the end of calibration through 2007, the base-case and half-recharge, low upland ET models continue to provide the best fits to measured drawdown. The agreement between measured drawdown and the predicted drawdowns calculated from these two models over this time period indicates that the two models should reliably predict drawdown for many years.

The four models match the observed water-level changes at the six BM monitoring wells quite well. The base-case model provides the best overall fit. The comparisons indicate that recalibration is not warranted at this time, and support the ability of the models to accurately predict the effects of pumping by Peabody within the groundwater basin. As with all models used to guide decisions, the models should be periodically evaluated as more data are collected, and updates made when appropriate. Near Kayenta, where pumping is more likely to affect stream flows, the models are conservative, in that they predict a faster rate of drawdown than is occurring.

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The base-case model is used in the predictive simulations presented below. Testing of the four models used longer pumping periods than evaluated in this PHC (Scenario A, PWCC, 1999), and indicated that all four models produce similar results. The predicted drawdowns are similar (because each model is calibrated to the same water-level and drawdown data), though not identical. Similarly, the predicted impacts on the discharge to streams are also quite similar. Obviously, for the half-recharge cases, the simulated discharge into the streams is less than for the full-recharge cases, and therefore the effects of pumping on stream discharge, expressed on a percentage basis, are slightly higher for the half-recharge cases. Because the effects of PWCC pumping on stream discharge are predicted to be low in Scenario A for all four cases, and because the pumping plan evaluated in the PHC envisions a decrease in both pumping rates and length of time of pumping, only the base-case model is evaluated below.

The effects of Peabody's withdrawals from the D and N aquifers have been simulated using conservative estimates of the annual pumping rate under the proposed mining scenario (Table 14). While PWCC has not and does not relinquish or restrict any right it has or may have to continue to utilize water from the N aquifer in accordance with the terms of its tribal lease agreements, the currently proposed mining plan does not include mining to supply coal to the power plant at Laughlin, NV, and therefore pumping at rates sufficient to provide water for the coal slurry pipeline is not considered in the computer simulations. The effects of actual pumping after the curtailed operation of the coal-slurry pipeline beginning in 2006 are not considered in these simulations. Rather, the projected future pumping after 2005 were used. The projected rate of 1,236 af/y for this period compares well with the averaged actual pumping rate of 1,244 af/y for the period 2006 through 2009.

Beginning in 2006 and continuing through 2025, the N-Aquifer wellfield is assumed to supply the needs of the Kayenta Mine (928 af/y). In addition, 247 af/y is pumped for maintenance of the Black Mesa wells not currently in operational use, and 61 af/y is pumped and provided to the public, for a total of 1,236 af/y. For the period from 2026 through 2028, the N-aquifer wellfield is assumed to supply 430 af/y for Kayenta Mine reclamation activities. The public supply pumping is assumed to increase to a rate of 75 af/y, for a total of 505 af/y. The Black Mesa wells continue to supply 247 af/y of the 505 af/y. For the remainder of the simulation (2029 through 2038), the combined pumping from wells in both mining areas is 444 af/y, including maintenance and public supply pumping.

Community pumping in the future is assumed to increase at a rate of 2.7% per year, described in Chapter 6 of the 3D modeling report (PWCC, 1999), and shown in Attachment 3.

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Table 14

Simulated Pumping Rates from the N Aquifer

Period	Simulated Pumping Rates
1956-2005	Actual
2006-2025	1236 af/y (928 Kayenta Mine, 247 well maintenance, 61 public supply)
2026-2028	505 af/y (430 Kayenta reclamation [247 well maintenance, 183 Kayenta mine], 75 public supply)
2029-2038	444 af/y (444 well maintenance, public water derived from the maintenance pumping)

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Impacts of Drawdown at Community Pumping Centers. Pumping of water from the D and N aquifers causes lowering of water levels or confined pressures within the aquifer. Drawdown is necessary in order for water to be withdrawn from the aquifer by wells and occurs due to pumping at the Peabody well field, as well as at the communities. However, excessive drawdown may cause wells to become unusable (e.g., if the water level during pumping of the well is lowered to the pump intake, and the pump cannot be lowered). Drawdown also increases pumping costs. The USGS has been monitoring water levels in communities throughout the basin for several years, and has estimated the drawdown caused by pumping of water from the N aquifer.

Figure 10 shows the simulated drawdown through 2005 for the top part of the N aquifer, using the base-case 3D model, for both combined Peabody and Tribal pumping (Figure 10A) and for Peabody pumping only (Figure 10B). Drawdown resulting from Peabody's pumping is greatest beneath the leasehold, and is very small within the unconfined area. The transition from confined to unconfined conditions greatly limits drawdown because of the much greater storage coefficient under unconfined conditions. Drawdown caused by pumping at the communities is also apparent. Community drawdown is most obvious at Shonto and Tuba City, because drawdown due to Peabody pumping is essentially non-existent there. However, it also has occurred at other communities, for example, Polacca, Kykotsmovi, and Kayenta. This is evident when comparing the drawdowns presented in figures A and B. The model-estimated drawdown caused by pumping at the end of 2005 is presented in Table 15a. These wells were chosen because of their use by the USGS in the annual monitoring reports. The percentage of drawdown attributable to Peabody pumping was calculated from the base-case 3D modeling results, based on pumping simulations with and without Peabody pumping. Data on the depth of the N aquifer or uppermost open interval were obtained from USGS monitoring reports. The drawdown estimated from the combined community and Peabody pumping is added to the initial depth to water to estimate the pumping water level near the well. The pumping water level is compared with the depth of the N aquifer or the top of the well's open interval to determine the remaining column of water above the N aquifer or production interval. This thickness represents the additional drawdown available before the water level would be lowered to the top of the N aquifer or the top of the production interval in the well.

The greatest effects on water levels in 2005 are for Forest Lake, Chilchinibito, Rough Ridge and Pinon, where the estimated drawdowns attributable to Peabody range from 68 to 198 feet. Elsewhere, the drawdown resulting from Peabody pumping is 35 feet or less. In all locations except Rough Rock, more than 439 feet of water remains above the top of the aquifer at of the end of 2005, based on simulations including both Peabody and community

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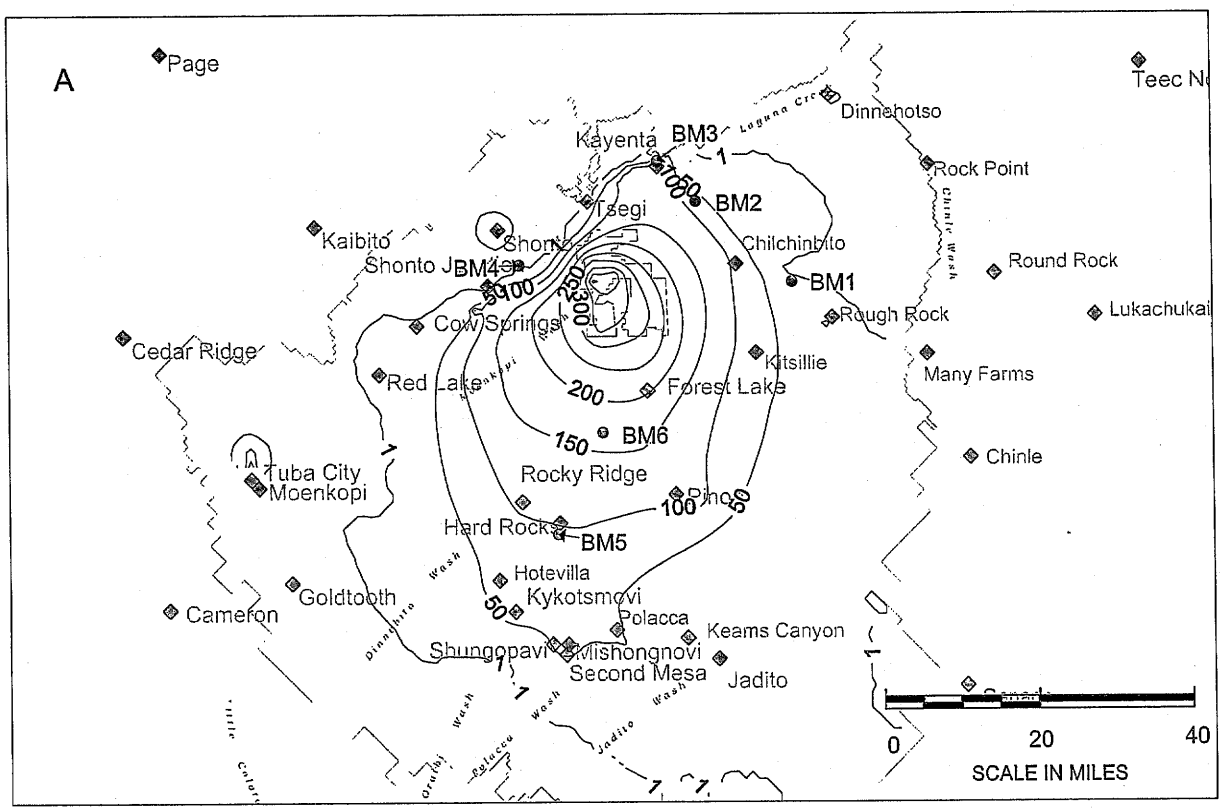

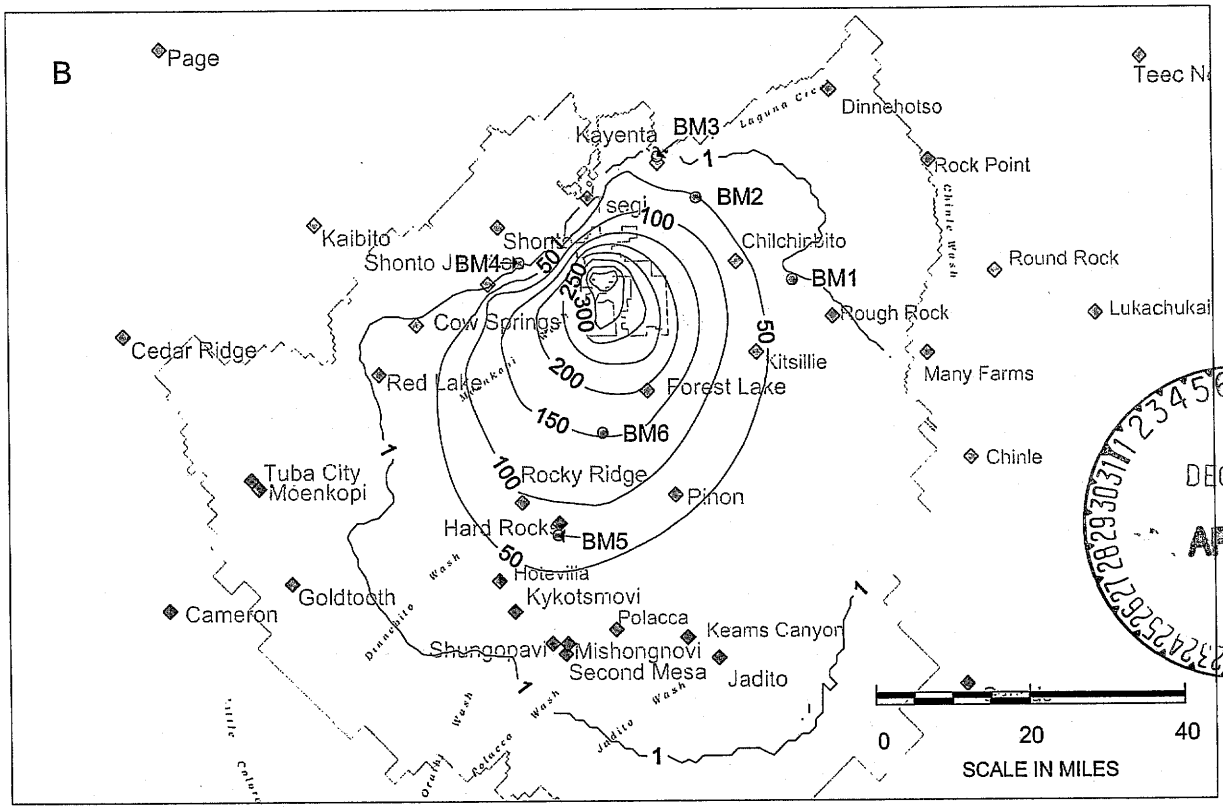

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Figure 10. Simulated drawdown in the N Aquifer in 2005. A: Peabody and community pumping. B: Peabody pumping only. The contour interval is 50 feet, with a supplemental contour for 1 foot.

Table 15

Simulated Drawdown at Selected Community Wells Caused by Combined Pumping and by Peabody's Pumping, and Remaining Water Column

a. 2005

Community	Well	Initial DTW (ft)	Simulated Drawdown (ft)	PWCC Allocation (%)	PWCC Allocation (ft)	Depth to N or Top of Open Interval	Remaining Excess Water Column (ft)
Chilchinibito	PM3	405.0	94	73%	68	1136	663
Forest Lake NTUA	4T-523	1096.0	217	92%	198	1870	576
Kayenta West	8T-541	227.0	125	27%	34	700	439
Keams Canyon	PM2	292.5	35	24%	8	900	599
Kykotsmovi	PM1	220.0	88	26%	23	880	637
Pinon	PM6	743.6	126	57%	72	1870	1054
Rocky Ridge	PM2	432.0	110	85%	93	1442	917
Rough Rock	10R-111	170.0	4	47%	2	210	38

b. 2025

Community	Well	Initial DTW (ft)	Simulated Drawdown (ft)	PWCC Allocation (%)	PWCC Allocation (ft)	Depth to N or Top of Open Interval	Remaining Excess Water Column (ft)
Chilchinibito	PM3	405.0	86	50%	43	1136	688
Forest Lake NTUA	4T-523	1096.0	139	77%	107	1870	667
Kayenta West	8T-541	227.0	165	14%	23	700	450
Keams Canyon	PM2	292.5	56	21%	12	900	596
Kykotsmovi	PM1	220.0	144	21%	30	880	630
Pinon	PM6	743.6	150	42%	64	1870	1063
Rocky Ridge	PM2	432.0	108	71%	77	1442	933
Rough Rock	10R-111	170.0	6	37%	2	210	38

c. 2038

Community	Well	Initial DTW (ft)	Simulated Drawdown (ft)	PWCC Allocation (%)	PWCC Allocation (ft)	Depth to N or Top of Open Interval	Remaining Excess Water Column (ft)
Chilchinibito	PM3	405.0	89	33%	30	1136	701
Forest Lake NTUA	4T-523	1096.0	121	62%	76	1870	698
Kayenta West	8T-541	227.0	196	10%	19	700	454
Keams Canyon	PM2	292.5	73	14%	10	900	597
Kykotsmovi	PM1	220.0	187	14%	26	880	634
Pinon	PM6	743.6	172	29%	49	1870	1077
Rocky Ridge	PM2	432.0	104	57%	59	1442	951
Rough Rock	10R-111	170.0	7	28%	2	210	38

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pumping. Pumping of the well itself will cause additional drawdown. Information on this local drawdown is not available, and it is assumed that the local drawdown is a few hundred feet or less. Thus these calculations indicate that the combined pumping, as of 2005, will not cause sufficient drawdown to reduce the production of the aquifer by dewatering. For Rough Rock (well 10R-111), the water column above the top of the aquifer was only 40 feet thick before any pumping, and Peabody's pumping reduces it by approximately 2 feet. At this location it is likely that the pump is already set below the top of the N aquifer, similar to wells in the unconfined area.

Figure 11 portrays the predicted drawdown in the N Aquifer at the end of 2025, due to combined Peabody and community pumping (Figure 11a), and Peabody pumping (Figure 11b). The drawdown beneath the leasehold has decreased, while that near the communities has typically increased. Figure 12 shows the change in simulated water drawdown between 2005 and 2025 for all pumping (Figure 12a) and Peabody pumping (Figure 12b). The recovery caused by the reduction in pumping is predicted to be greater than 200 feet beneath the Peabody leasehold. Drawdown due to pumping near the communities will increase, but generally by less than 50 feet. For example, at Kykotsmovi, the drawdown is predicted to increase by approximately 45 feet between 2005 and 2025. Near Second Mesa, the increase is predicted to be similar.

Table 15b presents information on the predicted drawdown at the end of 2025. With reduction in the amount of water pumped at the leasehold, there will be reductions in the drawdown attributable to Peabody at the communities that are located closest to the leasehold (Chilchinibito, Forest Lake, Kayenta, Pinon, and Rocky Ridge). Near the southern Hopi villages (for example, Keams Canyon and Kykotsmovi), Peabody's past pumping will result in small increases in drawdown compared to those in 2005. In all cases, the drawdown in community wells attributable to community pumping is predicted to increase between 2005 and 2025; actual water levels in Chilchinibito and Forest Lake are predicted to rise because of their close location to the leasehold and the greater relative impact of decreased Peabody pumping. Drawdown caused by pumping in the indicated community wells will further reduce the water column thickness in the wells while the local pumping is occurring. For nearly all of these wells, the remaining water column is hundreds of feet thick, indicating that the N aquifer will be able to continue to supply water at previous rates. The sole exception is possibly well 10R-111 near Rough Rock. As previously discussed, this well only had a water column of 40 feet above the top of the aquifer before pumping. Peabody's predicted reduction is approximately 2 feet, but local pumping from the well would be expected to have a greater impact. If the drawdown due to pumping from 10R-111 is more than 38 feet, dewatering of the aquifer in the vicinity of

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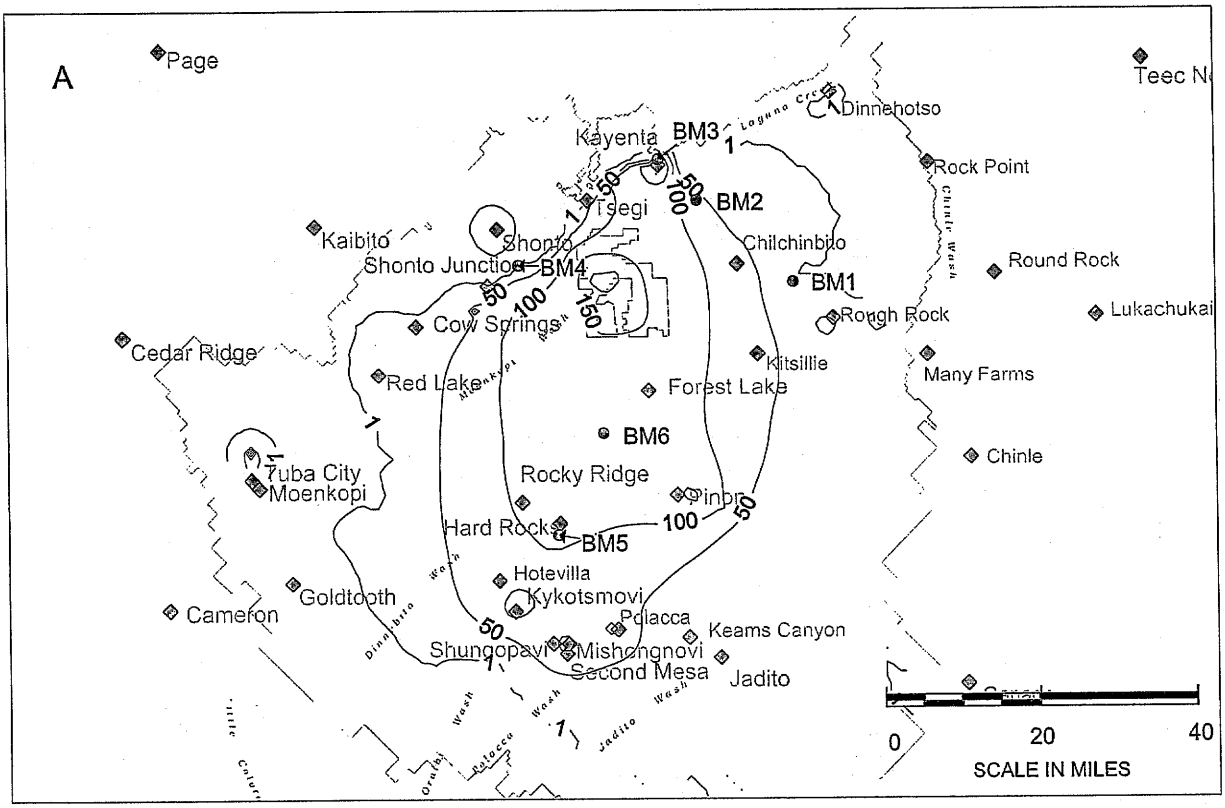

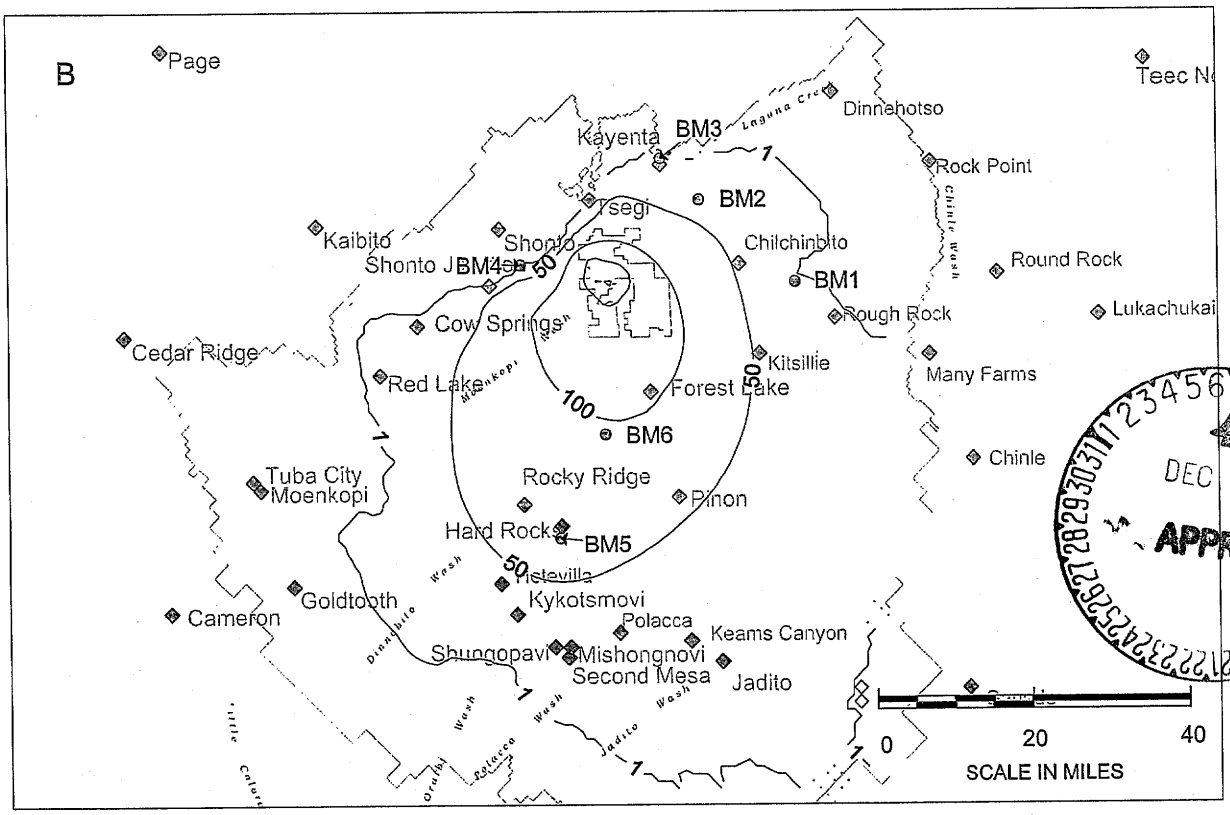

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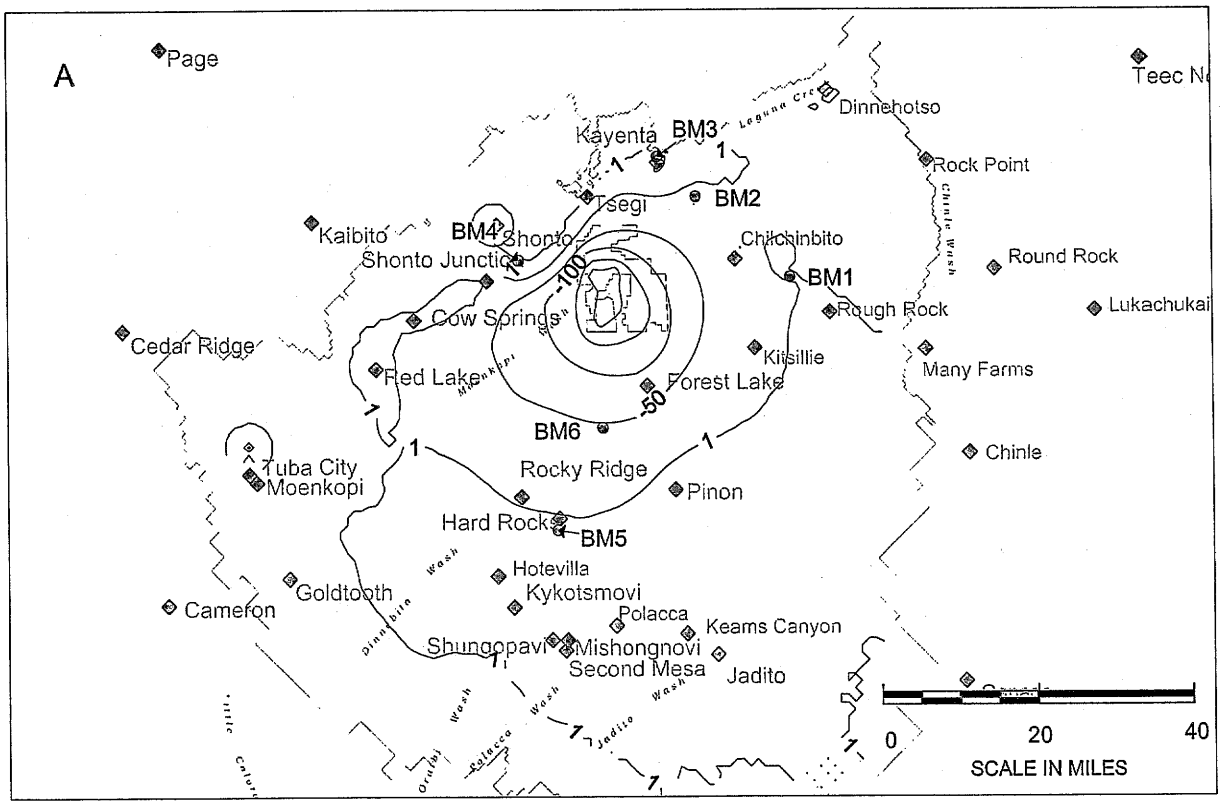
Figure 11. Simulated drawdown in the N Aquifer in 2025. A: Peabody and community pumping. B: Peabody pumping only. The contour interval is 50 feet, with a supplemental contour for 1 foot.



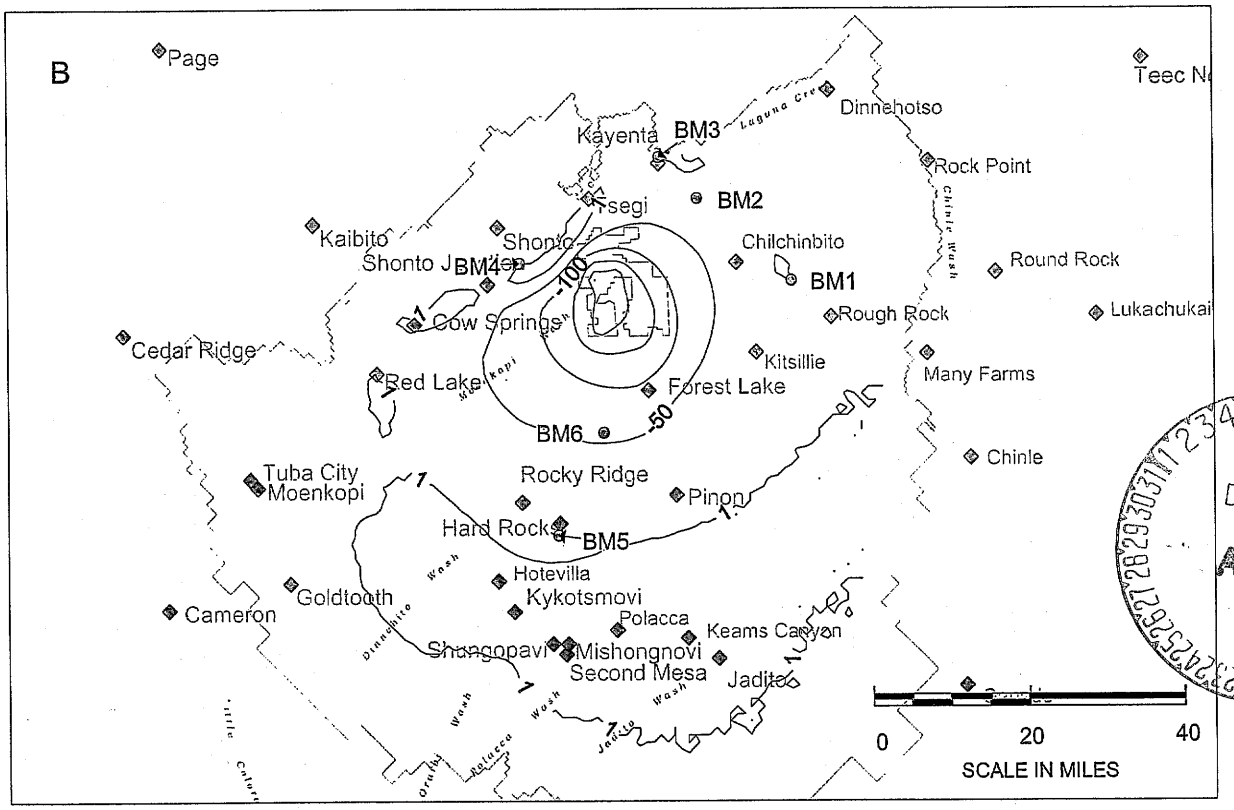


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Figure 12. Simulated drawdown in the N Aquifer in 2025, relative to 2005. A: Peabody and community pumping. B: Peabody pumping only. The contour interval is 50 feet, with a supplemental contour for 1 foot.

the well may occur. Here, the N aquifer is approximately 600 ft thick, so that local dewatering, if it occurs, will have only a minor impact on aquifer productivity.

Under the proposed mining plan, pumping from the N aquifer beneath the leasehold would be reduced from 1,236 af/y in 2025 to 505 af/y in 2026, and to 444 af/y in 2029. Because these latter two rates are approximately the same, simulation results are presented only for 2038, after which Peabody pumping would cease. The simulated drawdowns at the end of 2038 are presented in Figure 13a (all pumping) and 13b (only Peabody pumping). Recovery continues beneath the leasehold, and the maximum drawdown beneath the leasehold resulting from Peabody's pumping is predicted to be approximately 120 ft. The increasing drawdown around the communities is more apparent in Figure 13a than in 11a. Simulated changes in water levels since 2005 are shown in Figure 14a (all pumping) and 14b (Peabody pumping). Beneath the leasehold, water levels are predicted to rise more than 300 feet as a result of the reduction in pumping beneath the leasehold. Near the communities, drawdown is predicted to increase.

Table 15c provides more specific values for drawdown at communities for 2038. A notable change has occurred from the 2025 simulation results. At Keams Canyon and Kykotsmovi, the drawdown caused by Peabody's pumping is starting to decrease. The greater distance from the leasehold to these communities compared with Forest Lake, Rocky Ridge, and Pinon causes a delay in the response in water levels to changes at the leasehold. Thus, with the simulated reduction in pumping beginning in 2006, drawdown is predicted to continue to occur at the distant communities until after 2025, even though recovery begins sooner closer to the leasehold. By 2038, recovery is occurring at all the communities evaluated.

The next set of figures (15-19) show the simulated drawdowns for model layer 3, which represents the lower part of the D aquifer. The contour interval for these figures is 10 feet, with a supplemental contour of 1 foot. In 2005, there are two areas in which the model simulates drawdown in the D aquifer (Figure 15). Beneath the leasehold, a maximum drawdown of approximately 100 feet is simulated, as a result of several of the production wells being completed in part of the D aquifer in addition to the N aquifer. The extent of the drawdown cone for the D is considerably less than for the N aquifer. The second area of simulated drawdown for the D aquifer is near Polacca. Between 2005 and 2025, D-aquifer water levels beneath the leasehold are predicted to recover up to 30 feet (Figures 16 and 17). Drawdown is projected to increase near Polacca. By 2038, drawdown in the D aquifer beneath the leasehold is predicted to be less than 30 ft (Figure 18), a recovery of approximately 80 feet since 2005 (Figure 19). Although there may be

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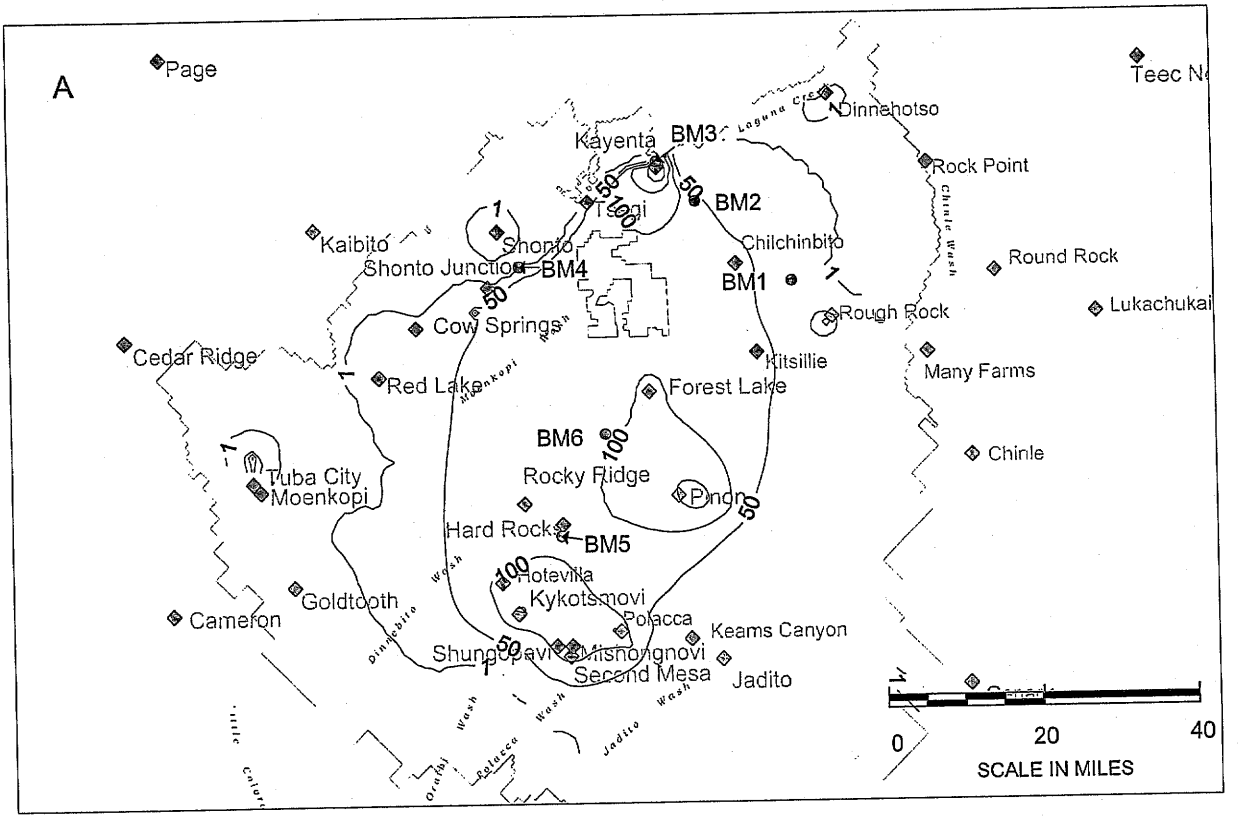

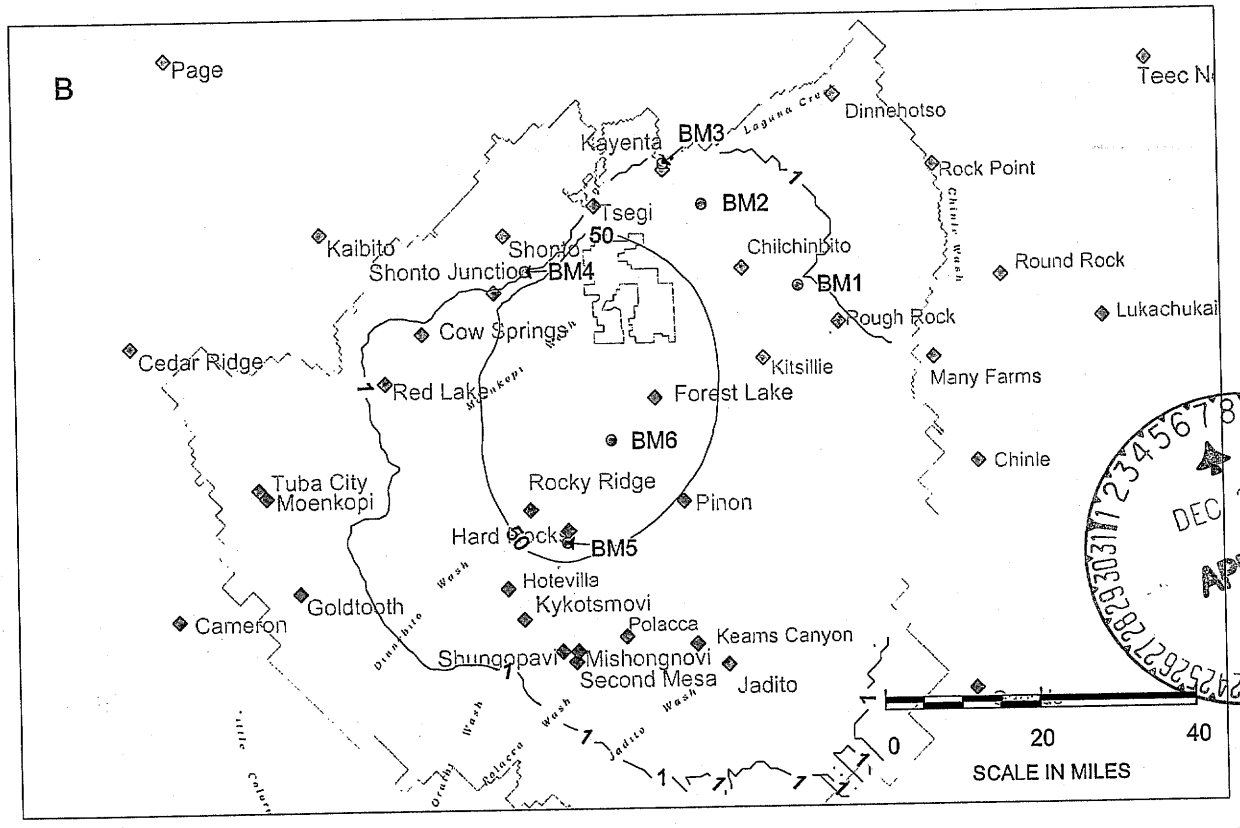

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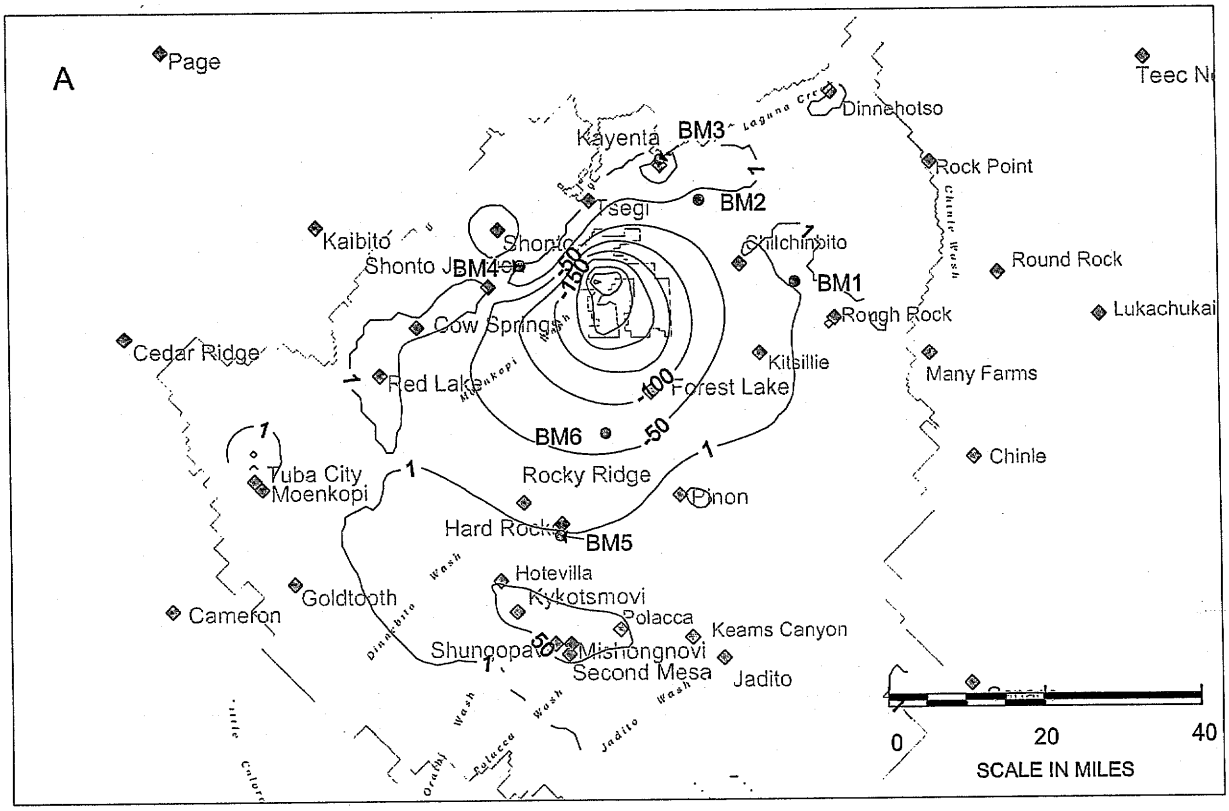
Figure 13. Simulated drawdown in the N Aquifer in 2038. A: Peabody and community pumping. B: Peabody pumping only. The contour interval is 50 feet, with a supplemental contour for 1 foot.



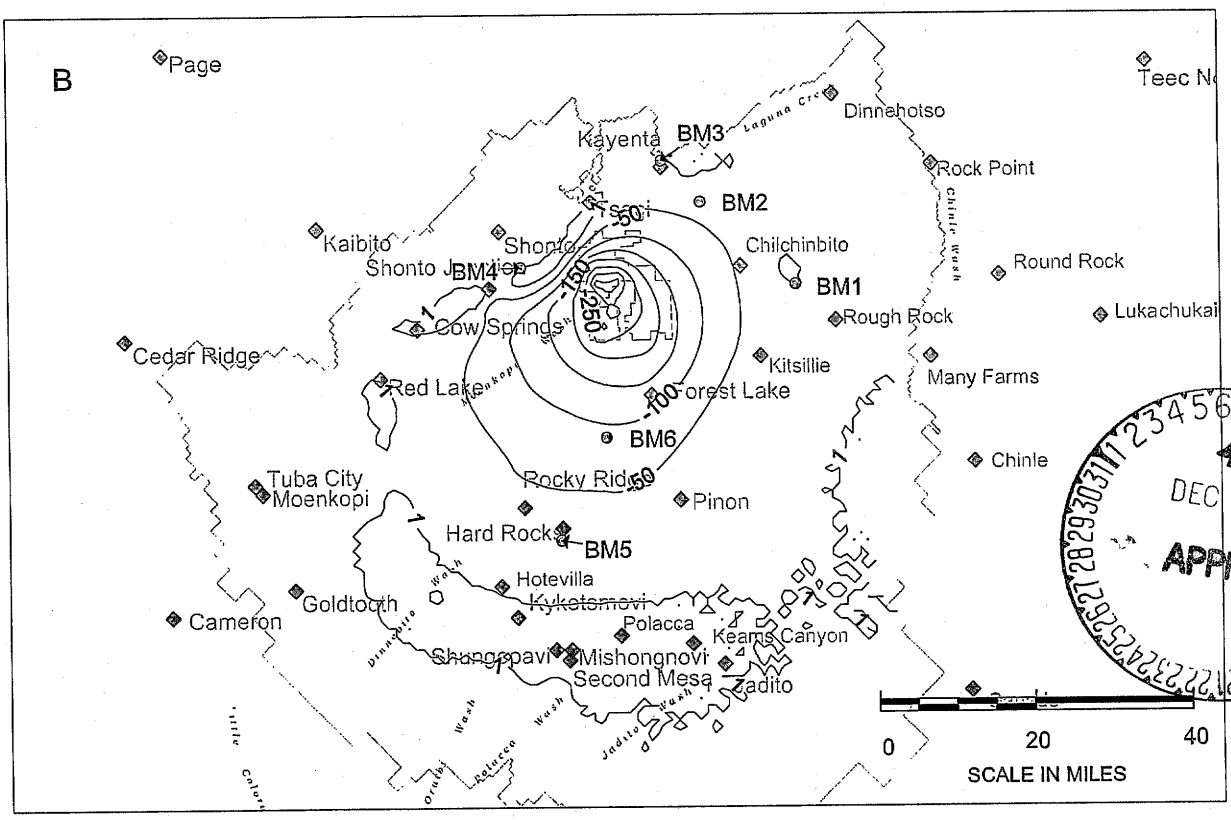


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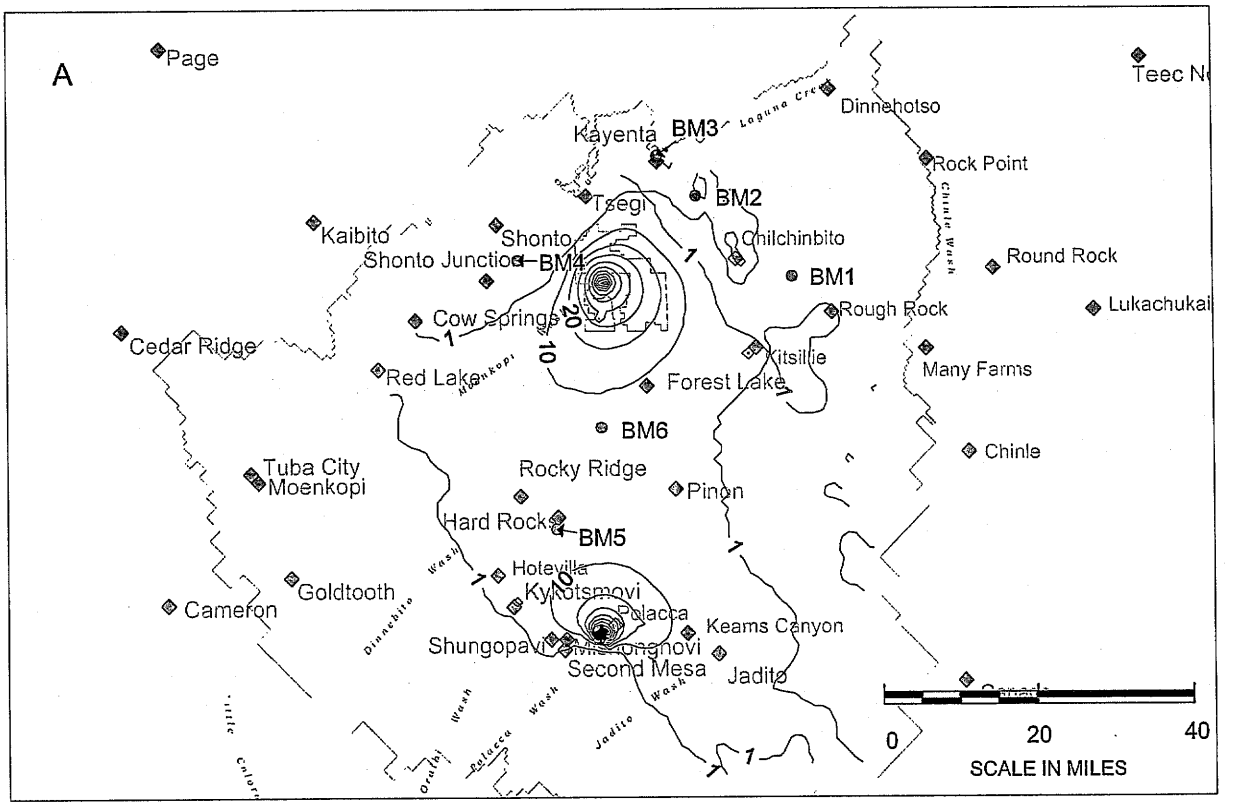
Figure 14. Simulated drawdown in the N Aquifer in 2038, relative to 2005. A: Peabody and community pumping. B: Peabody pumping only. The contour interval is 50 feet, with a supplemental contour for 1 foot.



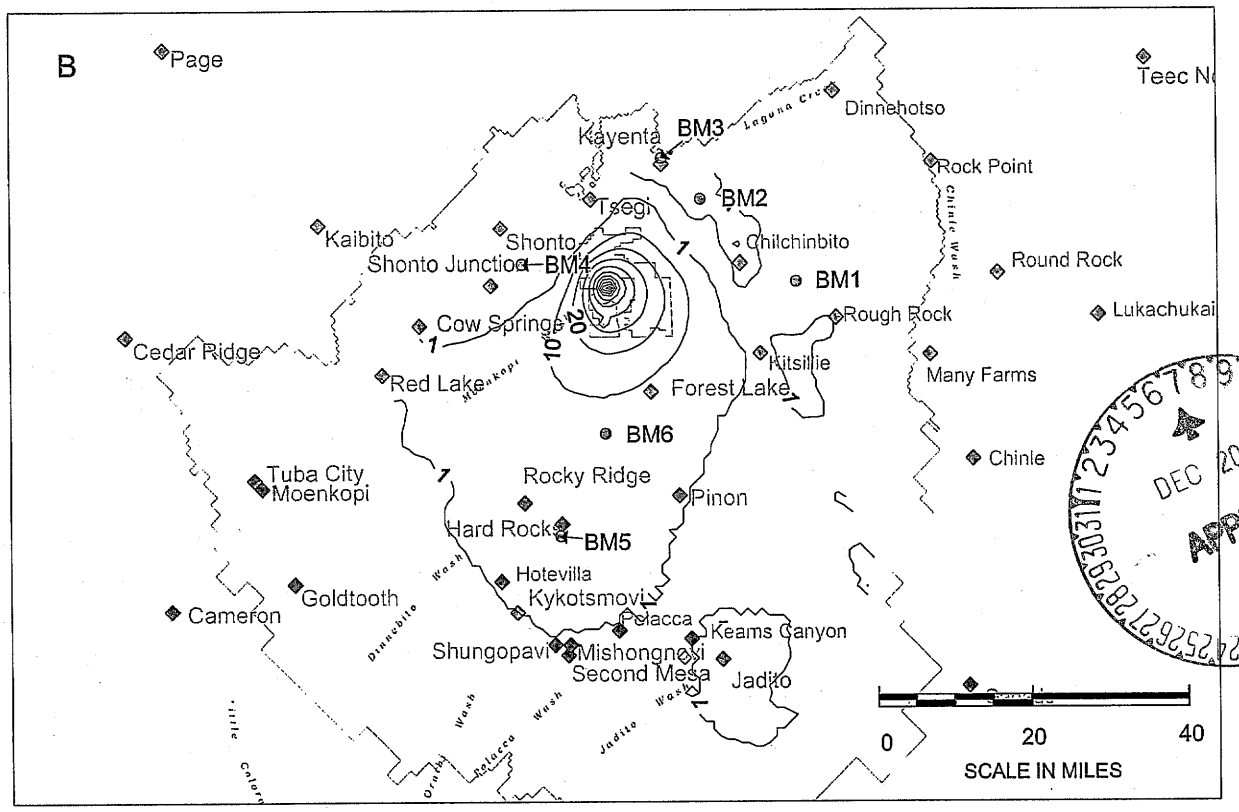


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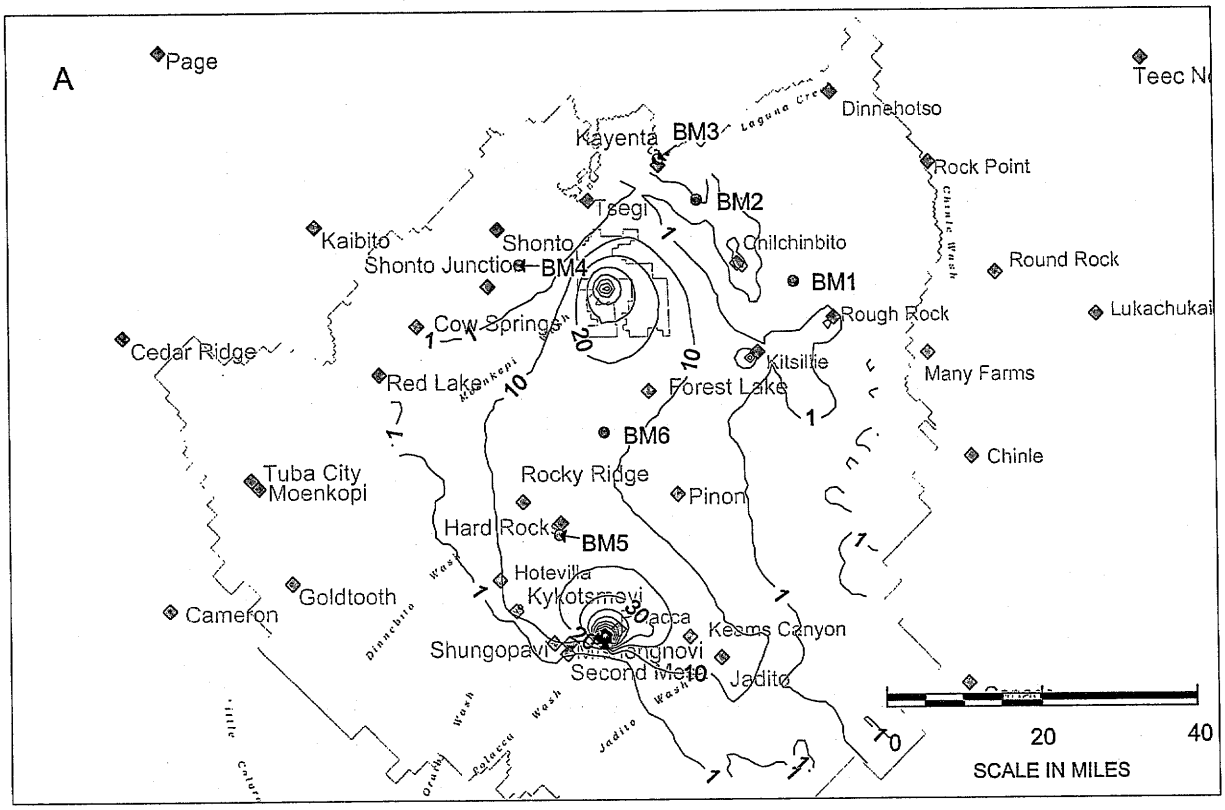
Figure 15. Simulated drawdown in the D Aquifer in 2005. A: Peabody and community pumping. B: Peabody pumping only. The contour interval is 10 feet, with a supplemental contour for 1 foot.



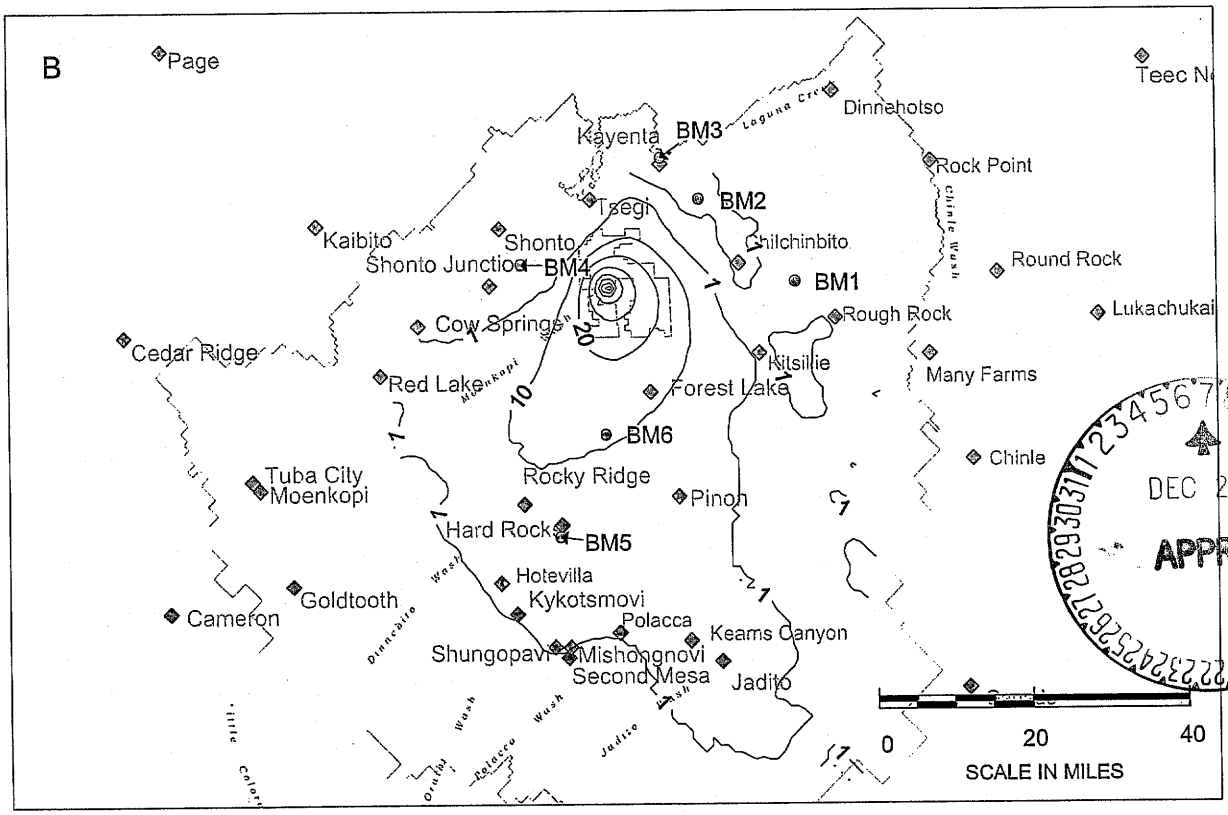


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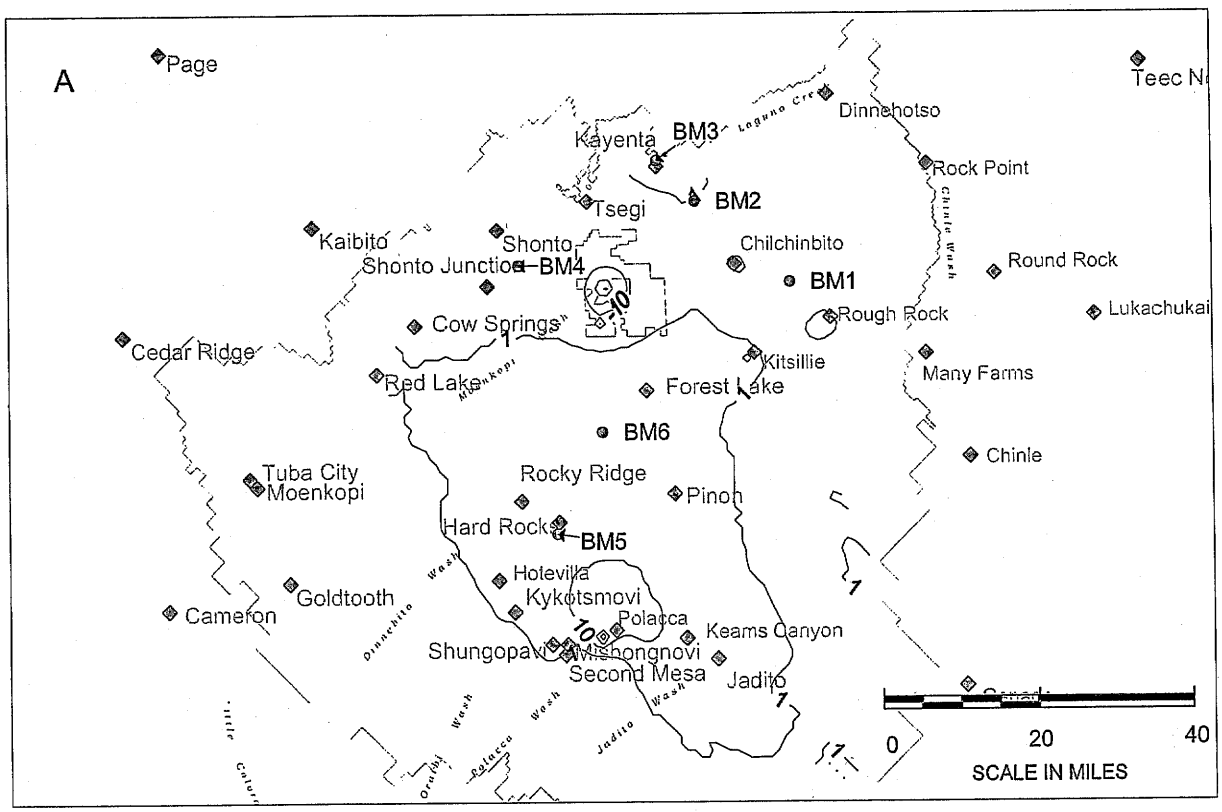
Figure 16. Simulated drawdown in the D Aquifer in 2025. A: Peabody and community pumping. B: Peabody pumping only. The contour interval is 10 feet, with a supplemental contour for 1 foot.



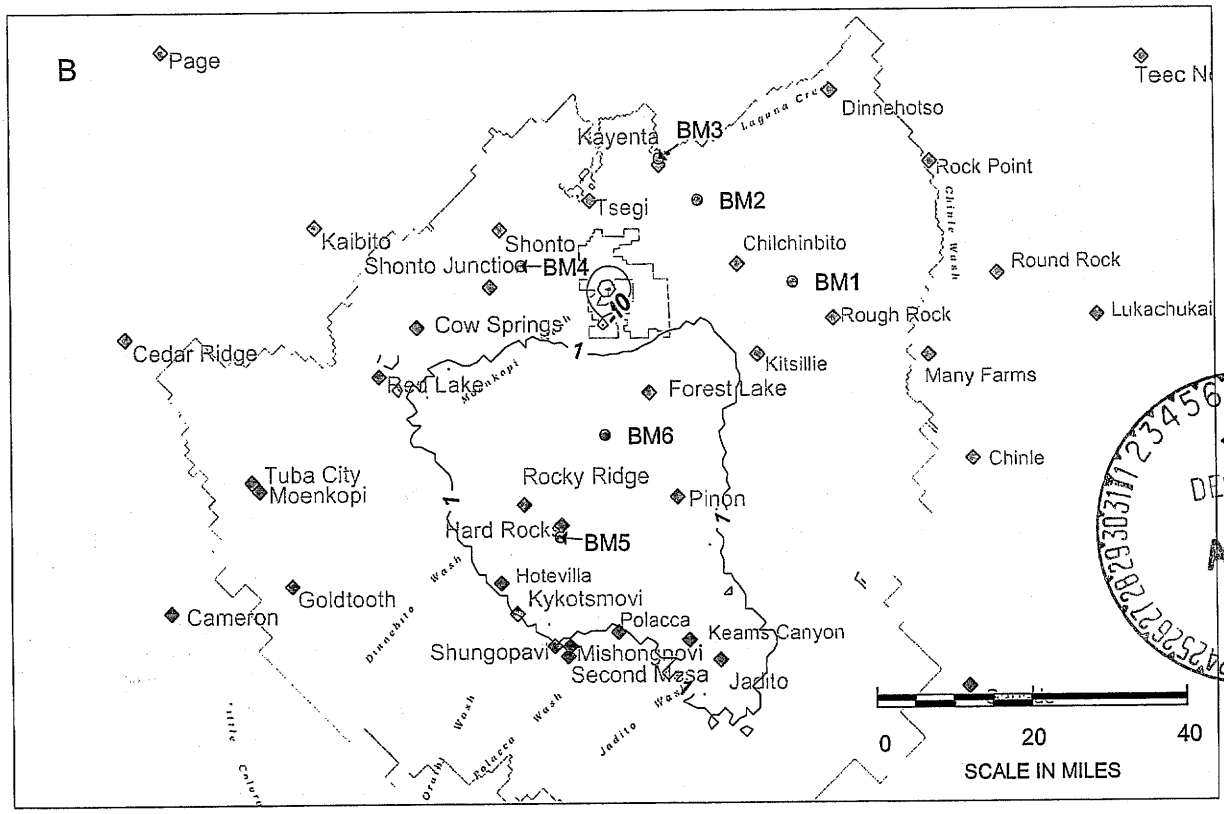


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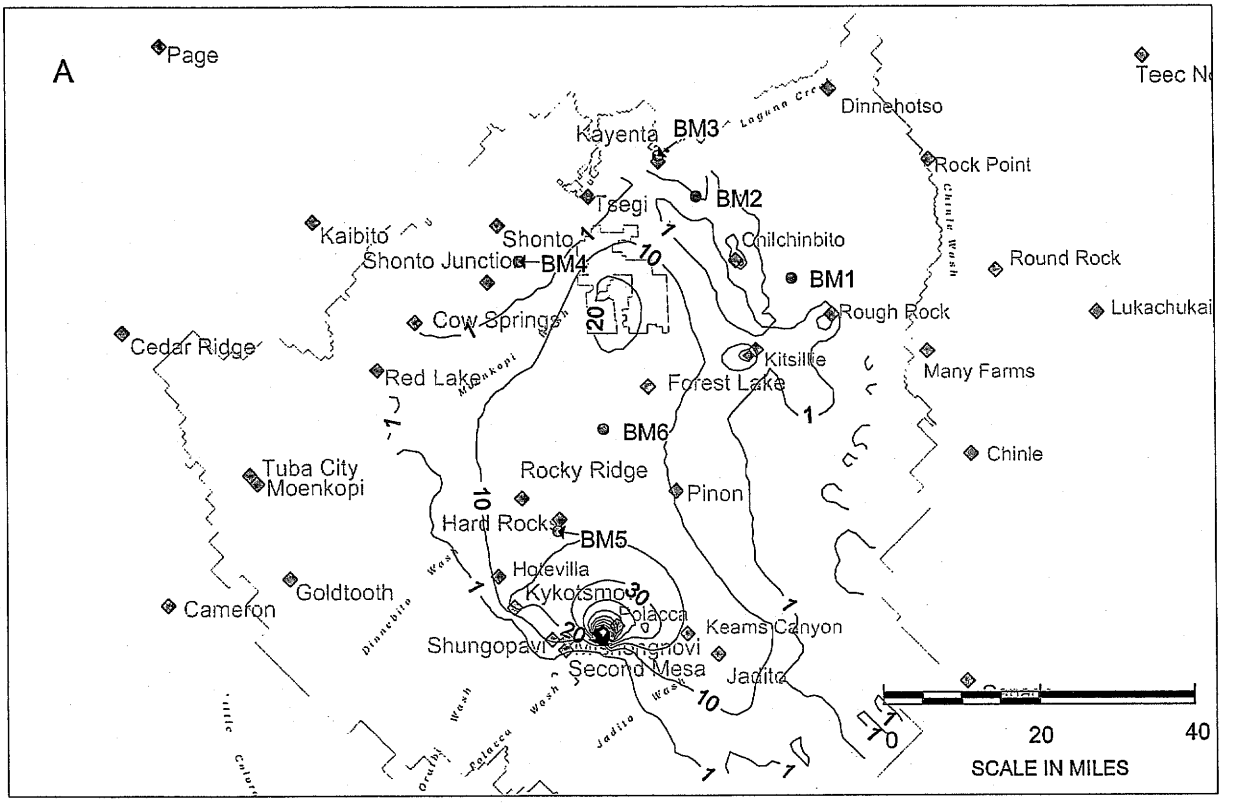
Figure 17. Simulated drawdown in the D Aquifer in 2025, relative to 2005. A: Peabody and community pumping. B: Peabody pumping only. The contour interval is 10 feet, with a supplemental contour for 1 foot.



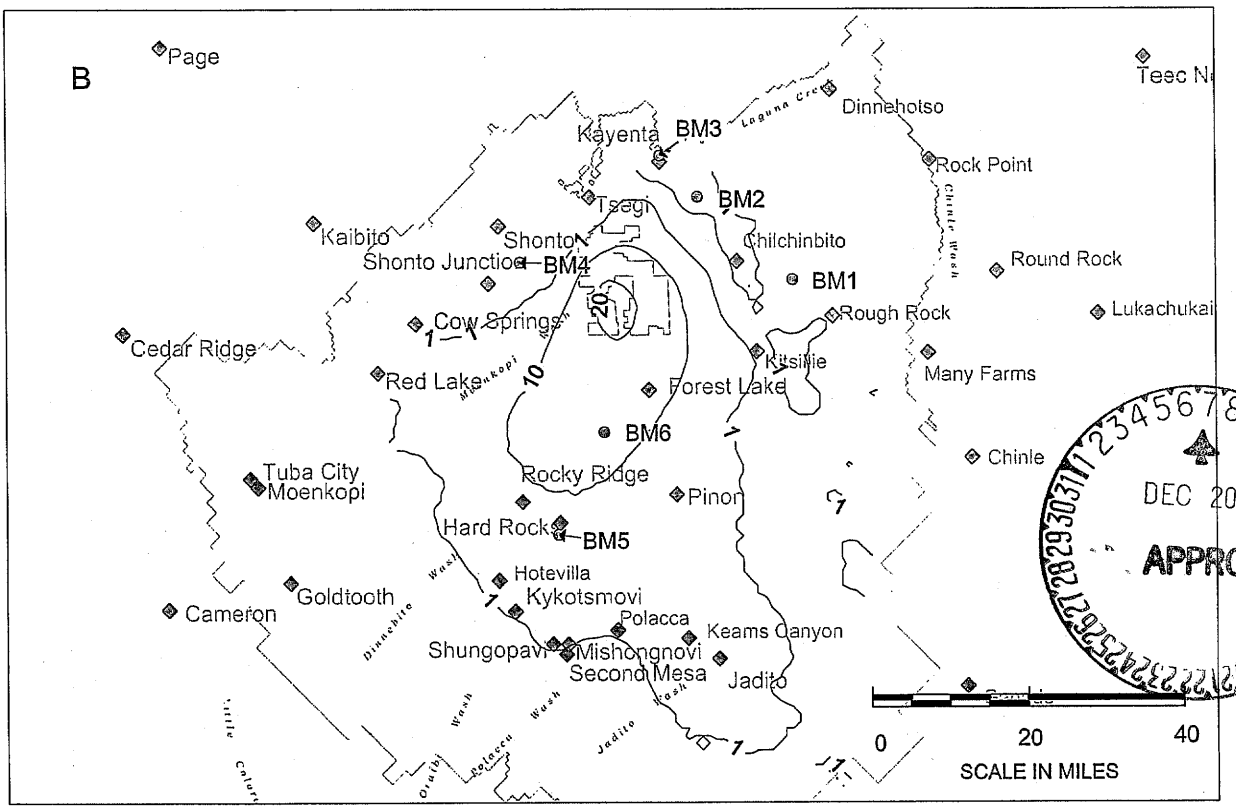


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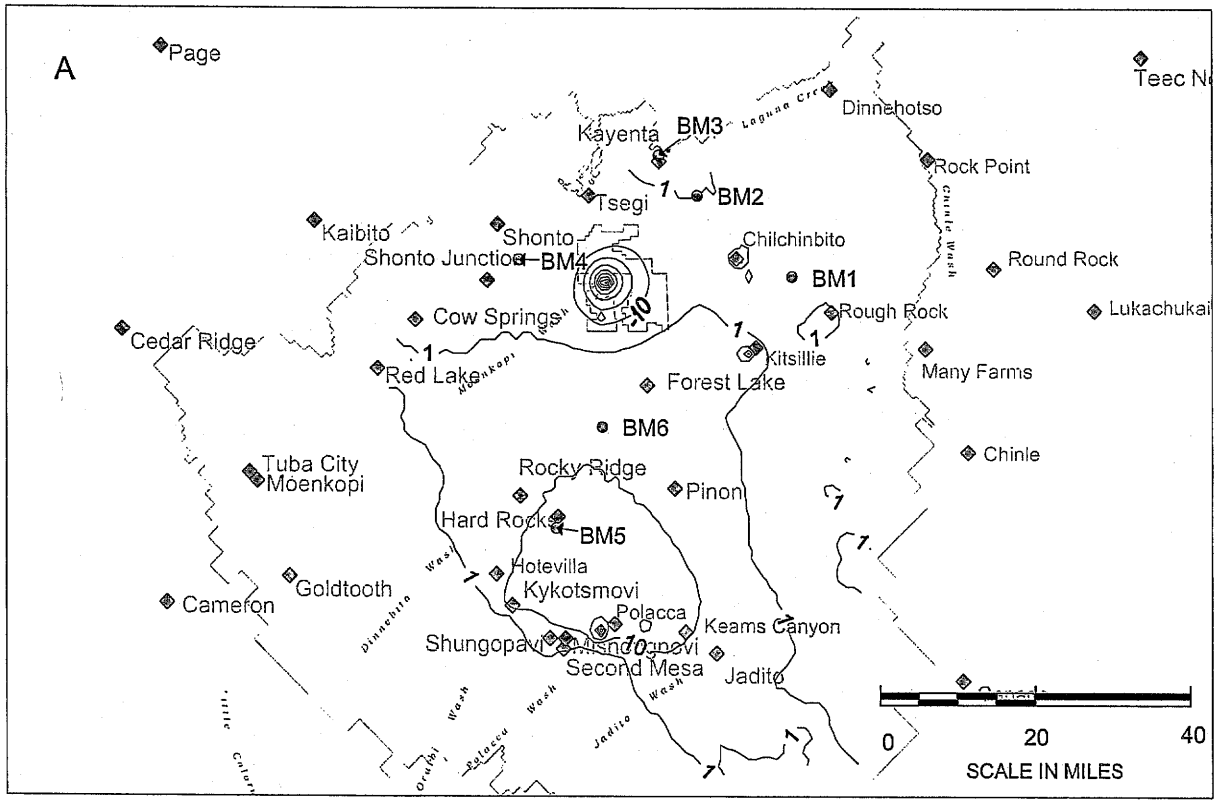
Figure 18. Simulated drawdown in the D Aquifer in 2038. A: Peabody and community pumping. B: Peabody pumping only. The contour interval is 10 feet, with a supplemental contour for 1 foot.



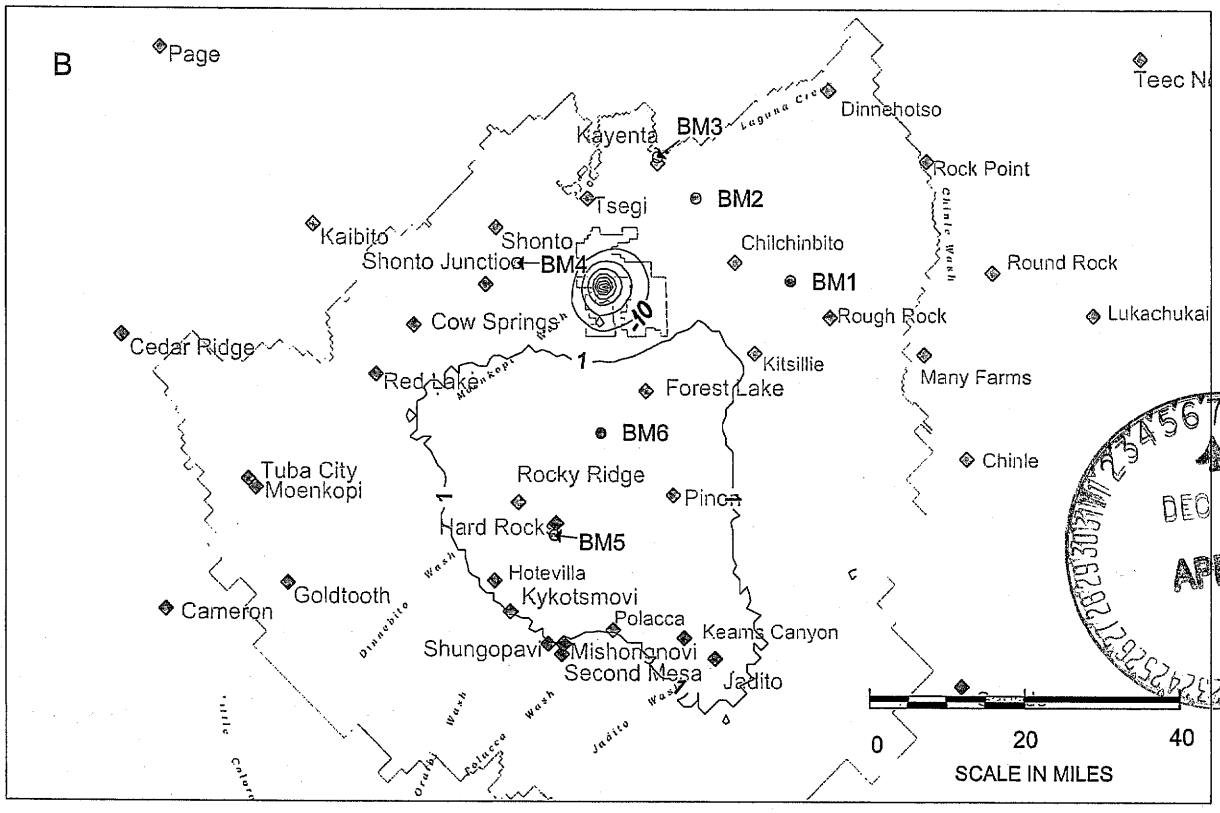


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Figure 19. Simulated drawdown in the D Aquifer in 2038, relative to 2005. A: Peabody and community pumping. B: Peabody pumping only. The contour interval is 10 feet, with a supplemental contour for 1 foot.

significant local drawdown around wells pumping from the D aquifer, the extent of drawdown throughout the region is limited.

Chapter 17, Protection of the Hydrologic Balance, presents information on local wells completed within or adjacent to the leasehold. Table 2 in Chapter 17 lists eight wells completed in the D Aquifer: 4T-516; 4K-387; 4K-407; 4T-399; 4T-402; 4T-503; 4T-504; and 4T-508. Figure 2 in Chapter 17 shows the locations of the eight wells. A comparison of the well locations with the drawdown contours shown on Figure 16b (2025) indicate wells 4T-516, 4K-407, 4T-399, and 4T-504 are outside of the 10-foot drawdown contour, and should not be measurably impacted by PWCC's withdrawals from the D Aquifer. Wells 4K-387, 4T-503, and 4T-508 are at or near the 10-foot drawdown contour. Information shown in Table 2 (Chapter 17) indicates the available water column in these wells ranges between about 340 to 550 feet. Drawdown in the range of ten feet due to PWCC's pumping from the wellfield should have only a minimal impact on these wells.

The database maintained by the USGS was queried (5/28/08) to find wells completed in the D aquifer to determine whether drawdown data in the D are available. All but two D aquifer wells had only a single depth-to-water measurement. Data for well 355924110485001, near Kykotsmovi, exhibit some variability (probably caused by local pumping or changes in local recharge rates) but no long-term trends. Only two measurements are available from well 363137110044701, located to the southeast of Kayenta. These measurements indicate a 2.5 foot increase in water levels between 1994 and 2001.

Well 4T-402 is the most proximate D aquifer well, situated in between the southern portions of the leasehold (Figure 2, Chapter 17). Drawdown contours in Figure 15 indicate approximately 40 feet of drawdown occurred at this well by 2005. Between 2005 and 2025, water levels are predicted to rise about 10 ft (Figure 17). Table 2 (Chapter 17) indicates there is about 380 feet of available water in the well. A review of available water level data from the USGS indicates no recent water levels are available from well 4T-402, where water is pumped periodically when the windmill is operational. PWCC has no information on water levels trends in well 4T-402; regardless, PWCC believes the potential impact on this well due to partial withdrawals from the D aquifer is minimal, has likely already occurred, and should lessen when water levels begin recover due to reduced pumpage from the wellfield (Figures 16 and 18).

Impacts on stream baseflow and spring discharge rates. The effects of Peabody's pumping on stream baseflow and spring discharge rates are expected to be small. Two-dimensional

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simulations previously performed by the USGS (Eychaner, 1983; Brown and Eychaner, 1988) and by GeoTrans (1987) provided results consistent with this expectation.

Tables 16 through 18 summarize the predicted effects of pumping on discharge into streams. The tables present results from two simulations: the first simulation included both PWCC and non-PWCC pumping (columns labeled "All"), while the second simulation included community-only pumping (labeled "Non-PWCC"). The simulated annual discharge rates to streams from the two simulations were then used to calculate the change in the discharge rates for "All", "Non-PWCC", and "PWCC" pumping. The table columns labeled "% Reduction All" and "% Reduction PWCC" are the percentage reductions in the discharge rates to streams for all pumping, and for Peabody pumping, respectively. The results are presented for two different starting times, 1955 and 2005; the two starting points were selected to meet data requirements specified in both the CHIA and the EIS, respectively.

Table 16 presents the predicted effects of pumping on discharge into streams for the time period 1955 through 2005. The largest percentage reduction over this time period due to Peabody pumping is estimated to occur at Moenkopi Wash. The simulated pre-pumping (1955) discharge into Moenkopi Wash was 4305.1 acre-feet per year (af/y). At the end of 2005, the simulated discharge is predicted to be reduced by 21.8 af/y, of which 2.4 af/y is caused by non-PWCC pumping, and 19.4 af/y by PWCC pumping. The percentage reduction due to Peabody's pumping is estimated to be 0.45%. The percentage reductions caused by Peabody's pumping for all discharge areas are estimated to range from 0.0 to 0.45%.

The predicted effects of pumping on discharge rates to streams in 2025 are provided in Table 17a and 17b. The largest percentage change due to Peabody pumping occurs at Cow Springs (1.00% decrease in pre-pumping discharge rates from 1955 through 2025, of which 0.63% of the decrease occurs from 2005 through 2025); the magnitude in this predicted reduction in discharge is too small to be measurable. By the end of 2038, the decline at Cow Springs since 1955 was 1.39% (Table 18a), of which 1.02% occurred since 2005 (Table 18b). Measurable declines in stream discharge rates are predicted at Pasture Canyon due entirely to local, not Peabody, pumping.

In contrast with the regionally significant discharge areas, the models did not specifically evaluate the effect of pumping on individual springs in non-wash settings (1) because of the difficulty of accurately simulating these impacts considering the topographic relief and constraints on grid spacing, and (2) because of the limited drawdown in unconfined areas caused by distant pumping. The locations of many of the

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Table 16.

Effects of Pumping on Simulated Discharge to Streams, through 2005

a. 1955 through 2005

Pumping	1955		2005		Change due to Pumping			% Reduction	
	All	Non-PWCC	All	Non-PWCC	All	Non-PWCC	PWCC	All	PWCC
Chinle Wash	498.9	498.9	498.8	498.8	0.0	0.0	0.0	0.01	0.00
Laguna Creek	2535.4	2535.4	2434.5	2443.2	100.9	92.2	8.7	3.98	0.34
Pasture Canyon	426.8	426.8	389.4	389.4	37.3	37.3	0.0	8.74	0.000
Moenkopi Wash	4305.1	4305.1	4283.3	4302.7	21.8	2.4	19.4	0.51	0.45
Dinebito Wash	515.6	515.6	515.0	515.3	0.6	0.3	0.3	0.12	0.06
Oraibi Wash	458.1	458.1	455.5	455.9	2.7	2.2	0.4	0.58	0.10
Polacca Wash	440.5	440.5	431.1	432.1	9.4	8.4	1.0	2.12	0.22
Jaidito Wash	2027.4	2027.4	2015.1	2018.2	12.3	9.2	3.1	0.61	0.15
Cow Spring	2178.0	2178.0	2169.1	2177.3	8.9	0.7	8.2	0.41	0.37

All discharge rates in af/y

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Table 17.

Effects of Pumping on Simulated Discharge to Streams, through 2025

a. 1955 through 2025

Pumping	1955 All	1955 Non-PWCC	2025 All	2025 Non-PWCC	Change due to Pumping All	Change due to Pumping Non-PWCC	Change due to Pumping PWCC	% Reduction All	% Reduction PWCC
Chinle Wash	498.9	498.9	498.8	498.8	0.1	0.1	0.0	0.02	0.00
Laguna Creek	2535.4	2535.4	2381.1	2390.4	154.3	145.0	9.3	6.09	0.37
Pasture Canyon	426.8	426.8	330.5	330.5	96.2	96.2	0.0	22.55	0.000
Moenkopi Wash	4305.1	4305.1	4274.7	4299.5	30.4	5.6	24.8	0.71	0.58
Dinebito Wash	515.6	515.6	514.1	514.9	1.5	0.7	0.8	0.28	0.15
Oraibi Wash	458.1	458.1	452.3	453.6	5.8	4.6	1.2	1.26	0.27
Polacca Wash	440.5	440.5	422.3	424.2	18.2	16.3	1.9	4.13	0.43
Jaidito Wash	2027.4	2027.4	1999.2	2007.8	28.2	19.6	8.6	1.39	0.42
Cow Spring	2178.0	2178.0	2153.4	2175.3	24.6	2.7	21.9	1.13	1.00

b. 2005 through 2025

Pumping	2005 All	2005 Non-PWCC	2025 All	2025 Non-PWCC	Change due to Pumping All	Change due to Pumping Non-PWCC	Change due to Pumping PWCC	% Reduction All	% Reduction PWCC
Chinle Wash	498.8	498.8	498.8	498.8	0.1	0.1	0.0	0.01	0.00
Laguna Creek	2434.5	2443.2	2381.1	2390.4	53.4	52.8	0.6	2.19	0.02
Pasture Canyon	389.4	389.4	330.5	330.5	58.9	58.9	0.0	15.13	0.000
Moenkopi Wash	4283.3	4302.7	4274.7	4299.5	8.6	3.2	5.4	0.20	0.13
Dinebito Wash	515.0	515.3	514.1	514.9	0.9	0.4	0.5	0.17	0.09
Oraibi Wash	455.5	455.9	452.3	453.6	3.1	2.3	0.8	0.69	0.17
Polacca Wash	431.1	432.1	422.3	424.2	8.8	7.9	0.9	2.05	0.22
Jaidito Wash	2015.1	2018.2	1999.2	2007.8	15.8	10.3	5.5	0.79	0.27
Cow Spring	2169.1	2177.3	2153.4	2175.3	15.7	2.0	13.7	0.72	0.63

All discharge rates in af/y

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Table 18.

Effects of Pumping on Simulated Discharge to Streams, through 2038

a. 1955 through 2038

Pumping	1955 All	1955 Non-PWCC	2038 All	2038 Non-PWCC	Change due to Pumping All	Change due to Pumping Non-PWCC	Change due to Pumping PWCC	% Reduction All	% Reduction PWCC
Chinle Wash	498.9	498.9	498.7	498.7	0.2	0.2	0.0	0.04	0.00
Laguna Creek	2535.4	2535.4	2333.0	2343.9	202.4	191.5	10.9	7.98	0.43
Pasture Canyon	426.8	426.8	292.7	292.7	134.1	134.1	0.0	31.42	0.000
Moenkopi Wash	4305.1	4305.1	4272.7	4296.7	32.3	8.4	23.9	0.75	0.56
Dinebito Wash	515.6	515.6	513.6	514.6	2.1	1.0	1.0	0.40	0.20
Oraibi Wash	458.1	458.1	449.8	451.4	8.3	6.8	1.6	1.82	0.34
Polacca Wash	440.5	440.5	417.5	418.9	23.0	21.6	1.4	5.21	0.31
Jaidito Wash	2027.4	2027.4	1987.2	1998.2	40.2	29.2	11.0	1.98	0.54
Cow Spring	2178.0	2178.0	2142.3	2172.7	35.7	5.3	30.4	1.64	1.39

b. 2005 through 2038

Pumping	2005 All	2005 Non-PWCC	2038 All	2038 Non-PWCC	Change due to Pumping All	Change due to Pumping Non-PWCC	Change due to Pumping PWCC	% Reduction All	% Reduction PWCC
Chinle Wash	498.8	498.8	498.7	498.7	0.1	0.1	0.0	0.03	0.00
Laguna Creek	2434.5	2443.2	2333.0	2343.9	101.5	99.3	2.2	4.17	0.09
Pasture Canyon	389.4	389.4	292.7	292.7	96.8	96.8	0.0	24.85	0.000
Moenkopi Wash	4283.3	4302.7	4272.7	4296.7	10.6	6.0	4.5	0.25	0.11
Dinebito Wash	515.0	515.3	513.6	514.6	1.4	0.8	0.7	0.28	0.13
Oraibi Wash	455.5	455.9	449.8	451.4	5.7	4.5	1.1	1.25	0.25
Polacca Wash	431.1	432.1	417.5	418.9	13.6	13.2	0.4	3.16	0.09
Jaidito Wash	2015.1	2018.2	1987.2	1998.2	27.9	20.0	7.9	1.39	0.39
Cow Spring	2169.1	2177.3	2142.3	2172.7	26.8	4.6	22.2	1.24	1.02

All discharge rates in af/y

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smaller springs are determined by the geometric relationships between beds of different hydraulic properties, and by locations of fracture zones. Many of the smaller springs discharge from formations, such as those in the D aquifer, that contain low hydraulic conductivity beds. These lower conductivity beds, which are responsible for the occurrence of the springs, will tend to isolate the springs from the effects of pumping in the N aquifer.

Further, the discharge rates of these springs are likely to be more sensitive to changes in local recharge than to drawdown caused by distant pumping. These springs are typically located near recharge areas, and temporal changes in their discharge rates caused by short-term changes in local recharge rates would be expected. Observations of springs discharging from the Wepo formation on the leasehold confirm the temporal variability of these smaller springs. Tree-ring studies performed throughout the southwestern U.S. document the variability of precipitation on the scale of decades (see, for example, Stahle and others, 2000). Even if good spring flow data were available, the variability in precipitation rates would make calibration to the spring discharge data difficult. Because of the character of these springs and of the groundwater system, the effects of Peabody's pumping are expected to be negligible. Measurement of pumping effects on these springs will be difficult because of the expected small magnitude of these effects, seasonal changes of precipitation and evapotranspiration rates, and longer term changes in local precipitation rates.

In summary, groundwater models are the best tools available for evaluating the contributions of different pumping stresses on water levels and stream flows. Models of the N Aquifer flow system have been developed by both the USGS and by Peabody since the 1980's, with each successive effort improving on the previous. As additional data have been collected and improved computational tools made available, the models have incorporated more knowledge of the groundwater system.

The models have varied in detail; however, they were each based on the data available at the time of the model's development and incorporate the major components of the N Aquifer flow system. Further, each model has been subjected to a calibration process whereby the ability of the model to simulate historical measurements is demonstrated. Peabody's 3D model has been used to evaluate the effects of uncertainty in the recharge rate. Importantly, the models are consistent with respect to their predictions of the impacts from pumping on the N Aquifer flow system. They predict that water levels in the confined part of the N aquifer will be reduced by pumping but that the water levels will

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remain well above the top of the N aquifer. The effect of Peabody's pumping on discharge to streams has been and will continue to be minimal.

Effect on the Structural Integrity of the N Aquifer. Lowering of water levels by pumping has resulted in compaction of unconsolidated sediments in some areas of the western U.S. (e.g., Las Vegas valley, Nevada; Antelope Valley, California; San Joquin Valley, California). The U.S. Geological Survey (Galloway and others, 1999) published a Circular documenting examples of aquifer compaction and related land subsidence associated with reduction of water pressures, oxidation of organic deposits, and formation of sinkholes in carbonate terranes. It states (p. 8-9):

> REVERSIBLE DEFORMATION OCCURS IN ALL AQUIFER SYSTEMS
>
> The relation between changes in ground-water levels and compression of the aquifer system is based on the principle of effective stress first proposed by Karl Terzaghi (Terzaghi, 1925). By this principle, when the support provided by fluid pressure is reduced, such as when ground-water levels are lowered, support previously provided by the pore-fluid pressure is transferred to the skeleton of the aquifer system, which compresses to a degree. Conversely, when the pore-fluid pressure is increased, such as when ground water recharges the aquifer system, support previously provided by the skeleton is transferred to the fluid and the skeleton expands. In this way, the skeleton alternately undergoes compression and expansion as the pore-fluid pressure fluctuates with aquifer-system discharge and recharge. *When the load on the skeleton remains less than any previous maximum load, the fluctuations create only a small elastic deformation of the aquifer system and small displacement of land surface.* [Emphasis added] This fully recoverable deformation occurs in all aquifer systems, commonly resulting in seasonal, reversible displacements in land surface of up to 1 inch or more in response to the seasonal changes in ground-water pumpage.

The USGS circular was primarily addressing basin fill materials of relatively young age. The rocks of the N aquifer are more than 135 million years old, have been buried to sufficient depth to cause pressure welding of the quartz grains, and exhumed. Thus, it is unlikely that production of water from the N aquifer will cause the load on the skeleton to exceed the previous maximum load or produce sufficient compaction to be of concern.

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To provide information with which to calculate the amounts of compaction that might occur, rock mechanics studies were performed (GeoTrans, 1993; Peabody, 1994). Because cores of the Navajo Sandstone beneath the Peabody leasehold were not available, samples were collected from outcrop areas. These samples had been subjected to near-surface weathering processes that would remove calcite cement, and thus the testing results are believed to overestimate the effect of drawdown on the material properties. Reduction of water pressure (by pumping, for example) removes some of the support that helps maintain the thickness of the aquifer, and thus allows the rock or aquifer to compact. The laboratory tests were designed to measure this compaction process and its effect on the porosity and hydraulic conductivity of the rock samples. These were performed by placing the samples in a test cell in which the pressure was increased to simulate the pressures at the depth of the aquifer in the deepest parts of the basin. The resulting changes in the samples' porosities and their hydraulic conductivity were measured.

Five samples were placed under effective stresses of up to 2,000 psi, which is approximately equivalent to a depth of burial of 3,000 feet and a depth to water of 600 feet. This is greater than the actual stress conditions near the deepest part of the basin. Measurements of the reduction in porosity of these outcrop samples as the effective stress was increased (water pressure decreased) indicate that the compressibility of the sandstone is about 4×10^{-6}/psi, which is higher than expected for many un-weathered sandstones. This value is consistent with the weathered nature of the samples. The data also indicate that the samples had previously been subjected to higher pressures than in the outcrop setting, consistent with the geologic history of the area and microscopic observations that the sand grains had been pressure welded. Derivation of compressibility from specific storage measurements for the aquifer (based on model-based interpretations of the observed drawdown caused by Peabody pumping of the aquifer) yield numbers approximately one-tenth of the laboratory compressibility measurements. This observation suggests that the compressibility of the weathered rock is approximately 10 times that of the un-weathered rock. Thus, the laboratory compressibility measurements should not be used to characterize the specific storage of the aquifer, but they do provide insight into the maximum changes in the porosity and hydraulic conductivity as water levels change as a result of pumping.

Calculations based on these laboratory compressibility measurements indicate that there could be as much as 1.5 feet reduction in the thickness of the aquifer by 2007. This is approximately a 0.12 percent decrease in thickness. Using compressibility values that are more representative of un-weathered sandstone, the decrease in thickness would be

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approximately one order of magnitude smaller, or 0.15 feet. The reduction in hydraulic conductivity as a result of the drawdown-induced compaction was also measured on the samples. These measurements indicate that the reduction would be approximately 5% in the immediate vicinity of the Peabody water-supply wells. If un-weathered samples had been tested, the measured reduction would have been considerably less.

Peabody has run video logs in its water-supply wells to evaluate the condition of well screens and the amount of scale that might clog the screen openings. If compaction of the N aquifer sufficient to cause concern were occurring, buckling of the screens would be expected. Many of the wells were logged in the early 1980's, after the majority of drawdown at the wells had occurred; no damage attributable to compaction has been observed. The most recent video log was run in June, 2001, in NAV 8, and no evidence of compaction effects was found. If compaction is not significant at these wells where drawdown and overburden stress are greatest, then compaction in other areas of the aquifer will also be negligible.

In summary, the data indicate that there is no risk of damage to the structural integrity of the aquifer resulting from projected drawdown. Similarly, compaction has been and will be insignificant, and any compaction is expected to be recoverable.

Effects of Induced Leakage of Poorer Quality Water from the Overlying D-Aquifer System on N-Aquifer Water Quality. In the vicinity of the leasehold, water levels in the D aquifer are 100 to 250 feet higher than in the N aquifer. Thus, there is natural downward movement of water from the D to the N aquifer. The large difference in water levels suggests that hydraulic conductivity of the Carmel is low, and therefore that the rate of downward movement is slow. Drawdown in the N aquifer caused by pumping of water from the N aquifer will increase the rate of water movement in proportion to the increase in water level change. Thus, several hundred feet of drawdown in the N aquifer could increase the leakage rate several fold. Whether this is important depends on the magnitude of leakage prior to any pumping. If the pre-pumping leakage rates were very small, increasing it several fold would still produce a small leakage rate.

The most direct means to evaluate the impact of leakage from the D aquifer on N aquifer water chemistry is to evaluate water-chemistry data. Water samples have been collected from well 4T-402, a windmill that is completed in the D aquifer near the center of the leasehold. Water from this well has a high TDS, with concentrations of major ions as shown in Table 19. The chemistry of this water is distinct from that of the N aquifer

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Table 19

Average Concentrations of Major Ions from D and N Aquifer Wells on or near the PWCC Leasehold, and Calculated Contribution from the D Aquifer Based on Chloride Concentrations

Well	Ca (mg/l)	Na (mg/l)	Alkalinity as CaCO3 (mg/l)	Cl (mg/l)	SO4 (mg/l)	%D Aquifer (Cl)
4T-402	7.1	540	401	200.	554	100.0
NAV 2	9.5	28.5	80.3	2.0	10.5	0.25
NAV 3	4.5	37.8	82.8	1.8	5.0	0.15
NAV 4	5.2	44.2	86.5	3.6	11.4	1.06
NAV 5	3.1	61.1	107.6	4.0	20.3	1.26
NAV 6	3.9	38.5	83.6	1.5	5.4	0.00
NAV 7	4.0	48.8	86.8	3.3	17.4	0.91
NAV 8	25.1	69.2	96.8	5.2	120.6	1.86
NAV 9	4.1	33.5	71.5	1.8	4.6	0.15

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Wells in the Peabody wellfield have been routinely sampled since approximately 1981; results have been provided to OSM in annual monitoring reports. Until the mid 1980's, laboratory problems produced data of uncertain quality. These problems have since been resolved, and the analytical results over the last fifteen years show only occasional "noise" and no clear temporal trends.

Four of the wells (NAV 4, NAV 5, NAV 7, and NAV 8) in the wellfield are completed in both the N and D aquifers. Based on the chemical data, the contribution to the wells' pumpage from the D aquifer is small. Table 19 presents average concentrations of major ions for D aquifer well 4T-402 and the Peabody production wells. The percentage of water derived from the D aquifer is also presented, based on the mixing equation for chloride:

$$X\ Cl_{Daq} + (1-X)\ Cl_{Naq} = Cl_{sample}$$

where X is the proportion of water from the D aquifer, Cl_{Daq}, Cl_{Naq}, and Cl_{sample} are the chloride concentrations in the D aquifer, N aquifer, and the water sample, respectively. Even in the wells that are partially completed in the D aquifer, the chloride-based values are less than 2% contribution from the D aquifer, even after more than 30 years of pumping. The chloride data indicate that the percent of D aquifer-derived water is approximately 0.2% or less. The lack of a significant trend of increasing concentrations suggests that these concentrations are largely determined by pre-pumping N aquifer chemistry. The sulfate values suggest a greater contribution from the D aquifer, but may be affected by gypsum particles deposited with the quartz and other mineral grains.

Beginning in 2006, pumping from Peabody's wellfield was significantly reduced due to the shutdown of Mohave Generating Station and the cessation of coal shipments via the coal slurry pipeline. As a result, pumping of wells 3, 4, 5, 7, and 9 has been significantly reduced, limited to incidental withdrawals of groundwater for mine related uses and for collecting water quality samples in accordance with procedures summarized in Chapter 16, Hydrologic Monitoring Program. Reductions in pumping at individual wells partially completed in the D-Aquifer (wells 4, 5, and 7) may slightly alter water quality within the bore hole and in the N-Aquifer for some distance adjacent to each well bore. However, a review of water quality data collected in these wells and reported in the 2009 Annual Hydrologic Data Report (PWCC, 2010) indicate no significant impacts have occurred through 2009. No trends in chloride concentration have been detected in any of the N aquifer wells through 2009, and the ranges of TDS, sulfate, and dissolved sodium measured in wells 4, 5, and 7 during 2009 are within the historical ranges for these parameters from 1986 through 2005 when pumping was significantly higher. Through 2009, the water use potential for all N aquifer wells is unchanged over previous years and remains suitable for domestic drinking water uses.

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The program ZONEBDGT (Harbaugh, 1990) was used to calculate flow within the N aquifer across a specified block that encompassed the Peabody wellfield, using fluxes calculated from a predictive run using the base-case 3D model and the pumping schedule described in Table 14. The ZONEBDGT results indicate that the leakage rate from the D to the N aquifer within this block increased by a factor of 1.8 between the pre-pumping period and 2005 (this factor will decrease in later years as N Aquifer pumping is reduced). They also indicate that lateral flow into the block from the N aquifer would increase by a factor of about 20. Thus, the chemistry of the water pumped from the wellfield would primarily be determined from chemistry of the water in the N aquifer in areas surrounding the wellfield. The small component of D aquifer water in the N aquifer water (Table 19), even if assumed to be entirely representative of pre-pumping conditions in the N aquifer, indicates that the effect of pumping on the water quality is insignificant. This results because of (1) the limited leakage rate under non-pumping conditions (evidenced by the present water chemistry), (2) the limited increase in leakage rate (factor of 1.8), and (3) the flow dynamics produced by pumping water primarily from the N aquifer.

Based on ZONEBDGT calculations and mixing equations, the change in sulfate concentrations in several different areas within the N aquifer basin was calculated. The results are shown in Table 20, respectively, and reflect the cumulative effect of pumping by PWCC between 1956 and 2038. Because of the small amount of leakage through the Carmel under natural conditions (indicated by the low TDS levels in the N aquifer even after leakage from the D aquifer for thousands of years), the increase in leakage due to pumping is predicted to cause very minor changes in the chemistry of the N Aquifer water. Where natural leakage is believed to be higher (in the eastern part of the basin) based on water chemistry data, approximately 70 years of pumping is predicted to cause an increase in sulfate concentrations of about 0.5%. In all other areas, the increase is predicted to be less than 0.1 percent.

Surface Water

Effects of Dams, Sediment Ponds and Permanent Internal Impoundments on Runoff and Channel Characteristics. Nine major dams (MSHA) have been 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

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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 320 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 one impoundment proposed for the J-19 coal resource area, and most have been built 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 up-drainage 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.

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Table 20

Maximum Predicted Sulfate Concentrations (mg/L)
Resulting from PWCC Pumping, 1955-2038

Subarea	Initial Concentration (mg/L)		Final Concentration (mg/L)	Change
	D Aquifer	Navajo sandstone	Navajo sandstone	
Northeast	250	70	70.053	0.0752%
East	850	100	100.455	0.4550%
Hopi Buttes	360	50	50.103	0.2059%
Forest Lake	1000	100	100.055	0.0548%
Kitsillie	75	30	30.002	0.0063%
Pinon	200	5	5.006	0.1136%
Rocky Ridge	250	10	10.011	0.1116%
Preston Mesa	400	10	10.000	0.0004%
Leasehold	400	30	30.016	0.0519%
Pinon to Kitsillie	1000	20	20.034	0.1687%
Surrounding leasehold	100	45	45.002	0.0034%
Red Lake to Tuba City	400	50	50.011	0.0227%
Hotevilla to Kabito	200	35	35.005	0.0148%
Pinon to Rocky Ridge	210	140	140.003	0.0021%

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In addition to the permanent internal impoundments, 31 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 31 permanent impoundments will encompass amounts to only 0.5 percent and 2.2 percent of the entire Dinnebito and Moenkopi watersheds, respectively (down to each 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 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.

Effects of Dams, Sediment Ponds and Permanent Internal Impoundments on Downstream Users. As of June 2008, the total Dinnebito and Moenkopi watershed areas to the leasehold boundary draining to PWCC dams, ponds and impoundments are 4.19 and 65.91 square miles, respectively. There are numerous large, significant tributaries to both washes between the leasehold and the Little Colorado River. Comparing the above impounded drainage areas to the total drainage areas for both washes (812.8 square miles for Dinnebito Wash and 2,605.3 square miles for Moenkopi Wash) suggests that this loss of runoff is of little significance at the points where the runoff water has any potential for being used for flood irrigation. As of June 2008, the impounded drainage areas on the leasehold amounted to only 0.5 percent and 2.5 percent of the total Dinnebito and Moenkopi watersheds, respectively.

Busby (1966) developed estimates of average annual runoff in the counterminous United States, including Northeastern Arizona. Based on these average annual estimates, runoff was calculated for the total watershed areas of both Dinnebito and Moenkopi washes to their respective confluences with the Little Colorado River. Average annual runoff for each basin was determined by summing the calculated runoff for partial areas defined as the watershed area lying between each pair of average annual runoff isopleths that transect the basin. The average annual runoff isopleths shown for the Black Mesa region

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on the Hydrologic Investigation Atlas HA-212 were used. Therefore, the lower portions of each basin were assigned an average annual runoff value of 0.1 inches, and the upper portions of each basin, including those portions in which PWCC's leasehold are situated, were assigned much higher average annual runoff numbers (1.25 to 1.75 inches). Based on Busby's empirical estimates, the average annual runoff for the entire Dinnebito basin was calculated to be 17,242 acre-feet, and 57,022 acre-feet of average annual runoff for the entire Moenkopi basin was determined.

Table 21 presents combined annual runoff measured from 1987 through 2008 at continuous flow monitoring sites SW155, SW25, and SW26, as well as annual runoff measured for the same period at the USGS Streamflow-gaging station (09401260) located on Moenkopi Wash at Moenkopi, Arizona. The runoff values are presented as acre-feet and inches of runoff. The inches of runoff for the PWCC sites were calculated by dividing the total runoff in acre-feet by the combined drainage area (in acres) above all three monitoring sites that was not controlled by PWCC dams, ponds and impoundments for each year shown (e.g., 188.65 square miles in 2000) and multiplied by 12. Similarly, the inches of runoff for the USGS Moenkopi gage was calculated by first subtracting baseflow contributions from ground water discharge from each year's total measured runoff, then dividing the adjusted total runoff (acre-feet) by the total drainage area (in acres) above the gage that was not controlled by PWCC impoundments (e.g., 1564.38 square miles in 2000). The inches of runoff presented for both locations represent runoff generated from precipitation events.

For the twenty-two year period presented in Table 21, the upper sites (SW155, SW25, and SW26) averaged 0.15 inches of runoff, and the USGS gage at Moenkopi averaged 0.07 inches of runoff. The average annual runoff in inches determined from the 22-year record at the USGS gage at Moenkopi (0.07 inches) was used to estimate the average annual runoff (in acre feet) for the entire watersheds of both the Dinnebito and Moenkopi basins, and are presented on Table 22. Comparing Table 22 values with the average annual runoff estimated for both basins using Busby's estimates (17,242 acre-feet for Dinnebito; 57,022 acre-feet for Moenkopi), it is obvious that Busby's empirical estimates of average annual runoff for the Black Mesa region are extremely high and unrealistic compared to average annual runoff calculations that are based on local stream flow measurements.

Table 22 also presents drainage areas and average annual runoff estimates for the watershed areas draining PWCC dams, ponds and impoundments (impounded areas) within both Dinnebito and Moenkopi washes as of June 2008 and for December 2013, the last month of Year 4 of the current approved five-year mining plan. Impounded areas are based on summing designed drainage areas for the existing impoundments (June 2008) and those proposed to

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Table 21

Measured Annual Runoff at PWCC's Continuous Flow Monitoring Sites and at the USGS Streamflow-Gaging Station 09401260, Moenkopi Wash at Moenkopi, Arizona

	PWCC Sites[1] Total		USGS Station 09401260[2]		
Calendar Year	Total Runoff (acre-ft)	Runoff[3] (in.)	Total Runoff (acre-ft)	Adjusted Total Runoff[4] (acre-ft)	Runoff[5] (in.)
1987	3,307.2	0.32	10,030	9,230	0.11
1988	3,387.7	0.32	8,970	7,990	0.10
1989	1,475.4	0.14	3,270	2,480	0.03
1990	1,899.0	0.19	7,610	6,680	0.08
1991	276.2	0.03	1,750	1,000	0.01
1992	1,864.2	0.18	3,820	3,110	0.04
1993	414.4	0.04	8,000	7,050	0.08
1994	124.1	0.01	1,370	410	0.005
1995	1,092.7	0.11	2,720	1,790	0.02
1996	374.9	0.04	1,610	730	0.01
1997	2,860.7	0.28	8,520	7,620	0.09
1998	548.8	0.05	1,650	610	0.01
1999	1,618.1	0.16	13,810	12,870	0.15
2000	210.9	0.02	3,430	2,370	0.03
2001	800.1	0.08	14,739	13,974	0.17
2002	920.4	0.09	9,026	8,215	0.10
2003	2,647.2	0.26	12,448	11,590	0.14
2004	909.8	0.09	7,327	6,433	0.08
2005	896.6	0.09	6,409	5,569	0.07
2006	4,105.8	0.41	13,650	12,812	0.15
2007	1,976.2	0.20	9,972	9,126	0.11
2008	1.036.7	0.10	4,135	3,384	0.04
	Avg.	0.15		Avg.	0.07

1 - Combined Measured Annual Runoff from Sites SW155, SW25, and SW26 (PWCC Annual Hydrology Reports, 1987 - 2008)

2 - USGS records (NWISWeb, 2003 and 2010)

3 - Based on the combined drainage area for all three sites (253.27 square miles) less total PWCC-impounded area during each calendar year

4 - Runoff numbers adjusted to remove groundwater baseflow component and reflect only snowmelt and rainfall runoff

5 - Based on the total drainage area for USGS Station 09401260 (1629 square miles) less total PWCC-impounded area during each calendar year

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Table 22

Drainage Areas and Estimates of Annual Runoff

	Moenkopi Wash Basin		Dinnebito Wash Basin	
	Total Area (mi^2)	Runoff (ac-ft)	Total Area (mi^2)	Runoff (ac-ft)
Totals without PWCC Ponds	2,605.3	9,726.5[1]	812.8	3,034.5[1]
PWCC Dams, Ponds, and PII's - June 2008	65.91	527.3[2]	4.19	33.6[2]
PWCC Dams, Ponds, and PII's - December 2013[3]	70.03	560.3[2]	5.47	43.7[2]
Post-mining Permanent Impoundments[4]	57.50	460.0[2]	3.84	30.7[2]

1 - Based on 22-year average annual runoff measured at USGS Station 09401260.

2 - Based on 22-year average annual runoff measured at PWCC gages SW155, SW25, and SW26.

3 - Year 4 of the 5-year approved mine plan from 2010 to 2014.

4 - See Table 9, Chapter 6, Facilities.

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be constructed from 2009 through 2013(see Drawing 85406, Volume 22). Table 22 shows the June 2008 impounded area is 0.5 percent and 2.5 percent respectively of the total drainage areas for the Dinnebito and Moenkopi basins, and in December 2013, the total impounded area increases slightly to 0.7 percent and 2.7 percent respectively of the total Dinnebito and Moenkopi drainage areas. The increased impounded area between June 2008 and December 2013 in both basins will result from the construction of 5 new temporary sediment ponds in the Dinnebito basin and 19 new temporary sediment ponds in the Moenkopi basin.

The 22-year average measured runoff at the three PWCC sites (0.15 inches, Table 21) was used to estimate average annual runoff for the June 2008 and December 2013 impounded areas. The estimates of average annual runoff for the June 2008 impounded area on the leasehold is 1.1 and 5.4 percent respectively of the average annual runoff calculated for the entire Dinnebito and Moenkopi basins. Table 22 shows average annual runoff for the December 2013 impounded area on the leasehold will increase slightly to 1.4 percent and 5.8 percent respectively of the average annual runoff calculated for the entire Dinnebito and Moenkopi basins. Additional impounding area for the life of mining will include construction of three proposed permanent impoundments in the J19, J21, and N10 reclaimed landscapes (see Chapter 6, Facilities). Additional temporary sediment structures may be constructed after 2013 to provide treatment of disturbed area runoff from future mining areas (e.g., J23); however, the dates for construction and reclamation of these facilities are unknown at this time.

Table 22 also presents the total impounded area of permanent impoundments proposed to remain in the post-mining landscape in both the Dinnebito and Moenkopi basins (see Chapter 6, Facilities, and Chapter 14, Land Use). Following final reclamation of all mining areas, the drainage area associated with PWCC's proposed permanent impoundments will comprise 0.5 percent of the total Dinnebito drainage area and 2.2 percent of the total Moenkopi drainage area. Using the annual average runoff of 0.15 inches determined from 16 years of stream flow measurements collected at the three PWCC gages, the permanent impoundments may impound about 1.0 and 4.7 percent of the average annual runoff at the lower ends of the Dinnebito and Moenkopi basins, respectively.

Based on percentages of impounded drainage areas presented in Table 21 for the June 2008, December 2013, and permanent impoundments with the total basin areas of Dinnebito and Moenkopi washes, loss of runoff in each basin is of little significance at downstream points where runoff water has any potential for being used. An alluvial farm plot and phreatophyte survey performed by Intermountain Soils, Inc. in June, 1985 documented that

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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 below the leasehold along lower Dinnebito and Moenkopi Washes other than some 70 miles below the leasehold at the town of Moenkopi. PWCC is not aware of any other diversions immediately downstream of, or further downstream for approximately 70 miles in either Dinnebito or Moenkopi Washes. Runoff from precipitation events in both washes typically occurs as flash floods, with rapidly rising water levels, high velocities, and very high concentrations of suspended solids. The channel beds and banks of both channels are subject to significant changes in width and depth as a result of runoff events, often changing appreciably during each event, which can create significant problems regarding the construction and maintenance of water diversion structures.

Comparisons of average annual runoff estimates indicate the impounded areas through December 2013 have the potential to, on average, reduce average annual runoff in the Dinnebito basin by no more than 1.4 percent, and in the Moenkopi basin by no more than 5.8 percent. Total runoff in the basins is greatly affected by depression storage, channel transmission losses and evapotranspiration. Channel transmission losses along the sand-bed channel bottoms within the leasehold have been estimated to be quite high, potentially resulting in more than a 50 percent reduction of flow volumes during runoff events that occur along the major channels within the leasehold (see Chapter 15, Hydrologic Description).

Review of historical daily records from both the three upper PWCC sites (PWCC Annual Hydrology Reports, 1997 through 2002, see Preface to Chapter 15, Hydrologic Description) and the USGS Moenkopi gage (NWISWeb, 2002) indicate significant loss of runoff from the upper basin area can occur. From August 7 through August 8, 1987, 1,328.7 acre-feet of runoff was measured at the three PWCC gages. One large event was measured at SW155 on August 8, featuring a peak discharge of 10,100 cfs and a total runoff volume of 638.7 acre-feet. Total runoff volume measured at the USGS gage from August 8 through 9, 1987 was 668.7 acre-feet, suggesting almost 50 percent of the total runoff (1,328.7 acre-feet) from the three upper sites was lost downstream if these were the sole source of runoff recorded at Moenkopi. On August 16, 1989, summer thunderstorms generated moderate-sized flash floods at all three gages at about 1600 hours, resulting in a total runoff volume of 524.8 acre-feet. No runoff had occurred at any of the three sites for at least 6 days prior. Runoff at the USGS Moenkopi gage was only 1.3 acre-feet on the same day, and only

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117 acre-feet was measured on August 17, 1998. The record comparison indicates about 77 percent of the 524.8 acre-feet of runoff generated from this portion of the basin was lost. On July 27, 1998, a flash flood passed by SW25 at a peak flow of 1,650 cfs resulting in a total runoff volume of 206.7 acre-feet. This one event was more than 37 percent of the total runoff measured at the three PWCC gages in 1998. The USGS gage measured only 14 acre-feet of runoff from July 27 through 29, 1998, indicating a loss of more than 93 percent of the 206.7 acre-feet. It is likely the 14 acre-feet measured at the USGS gage was comprised of return flow from bank storage from the upstream, 70-mile channel reach, and that the entire volume of the 200-plus acre-feet runoff event from the upper basin was lost in the channel. It should be pointed out that these comparisons assume no additional inflows to Moenkopi Wash below the leasehold occurred. This is an unlikely assumption considering that the entire basin above the USGS gage is large, and summer thunderstorms in the region often move great distances while maintaining high rainfall amounts and intensities, even though the areal extent of individual storm cells may be relatively small.

Table 21 indicates actual runoff is highly variable from year to year in both the upper and lower portions of the Moenkopi basin. Runoff variability is closely related to the highly variable climatic differences typical in this semi-arid environment, and the limited areal extent and varying intensities of the storms that do occur. From 1987 through 2008, measured annual runoff at the three PWCC gages has ranged from 124.1 acre-feet in 1994 to a high of 4,105.8 acre-feet in 2006. For the same 22-year period, measured runoff at the USGS Moenkopi gage was also lowest in 1994, but the highest annual runoff was 13,974 acre-feet in 2001. Total measured runoff at the three PWCC gages in 1988 was greatly influenced by one extremely large runoff event measured at SW25 on August 26, 1988. The peak discharge was estimated at 25,000 cfs for a total runoff volume of 1,836 acre-feet. This one event accounted for more than 50 percent of the total runoff measured at the three PWCC gages in 1988. The total runoff measured at the three PWCC gages from August 25 through August 27, 1988 was 2,624.5 acre-feet, about 69 percent of the annual total measured in 1988. For the same period, the USGS gage measured 2,945.5 acre-feet, indicating that this extreme event fell on other portions of the Moenkopi basin and contributed additional runoff to the gage some 70 miles downstream.

By contrast, the total runoff measured at the USGS Moenkopi gage in 1988 was only the seventh highest of the twenty-two years presented for this gage (see Table 21). Combined total measured runoff at the three PWCC gages as a percentage of the USGS Moenkopi gage

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ranged widely from 5.7 percent in 2001 to 90.0 percent in 1998, illustrating the considerable variability in runoff within the basin. In fact, total measured runoff from the upper part of the basin (PWCC gages) in 2001 was only 5.7 percent of the highest annual measured runoff at the USGS Moenkopi gage (13,974 acre-feet).

Review of the measured daily records at both the three PWCC gages and USGS Moenkopi gage and the annual measured runoff shown in Table 21 suggests that 1) considerable amounts of runoff generated in the upper basin can be lost before reaching downstream locations, ranging from 50 percent of runoff events in excess of 1,000 acre-feet upwards to 100 percent for smaller events (200 acre-feet); 2) areal and temporal variability of runoff within both Dinnebito and Moenkopi basins is high; 3) channel transmission losses can significantly reduce annual runoff contributed from the upper portions of both basins; and 4) the impact of PWCC impounded areas in the upper part of both the Dinnebito and Moenkopi basins is minimal.

Peabody has monitored annual water levels and volumes in the MSHA size dams since construction, beginning with J7-DAM in August 1978. Estimates of water volumes in all ponds based on quarterly and monthly inspections were compiled for the years 1989, 1990, and 1996 through 2008. Table 23a is a compilation of the results of the above-referenced monitoring and water volume estimates. The values listed in each column are the volumes of water in acre-feet measured or estimated in the ponds and MSHA dams for each year or period presented.

Table 23a shows a 722 acre-foot increase in the amount of water impounded from 1996 to 1997, a 465 acre-foot increase from 1998 to 1999, and a 566 acre-foot increase from 2002 to 2003. Assuming the increases shown for these three periods represent only surface water runoff, dividing the amounts by the total impounded area present during each period yields values of annual runoff in inches of 0.22 for 1997, 0.13 for 1999, and 0.17 for 2003. The values compare reasonably well with the inches of runoff measured at the three PWCC gages in 1997 (0.28) and 1999 (0.16) as shown on Table 21. The annual runoff measured at the PWCC gages in 1999 was only 12.6 percent of the annual runoff measured some 70 miles downstream at the USGS Moenkopi gage. The estimate of runoff based on the increase in the amount of water impounded for 2003 (0.17 inches) is lower than the 0.26 inches of runoff measured at the three PWCC gages in 2003 (PWCC, 2004), but likely resulted from the variability of storm events that occurred during 2003 in the upper portion of the Moenkopi basin. Considering the variability in measured annual runoff from year to year at the upper portion of the Moenkopi basin at PWCC's leasehold compared to measurements made further downstream at the USGS gage at Moenkopi, impounded runoff in

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TABLE 23a

Summary of Maximum Impounded Surface Runoff in

MSHA Dams and Sediment Ponds by Year

(Acre-feet)

Year	J2-A	J-7	J7-JR	J16-A	J16-L	N14-D	N14-E	N14-F	N14-G	N14-H	All Other Ponds[1]	Total
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	256
8/82-8/83		180		**		80	**	2	6		60	328
8/83-8/84		425		13	220	153	**	4	40		60	915
8/84-8/85		305		4	***	150	**	4	26		60	549
8/85-8/86	*	335		10	65	153	**	4	13	2	60	642
1989-1990	42	300		50	69	107	0.1	6	35	38	305	952
1996	24	100		3	36	29	2	1	2	29	88	314
1997	47	338		48	101	90	**	3	33	47	329	1036
1998	36	140		8	44	53	**	0.4	15	39	295	630
1999	23	293		63	235	123	1	6	43	73	235	1095
2000	17	184		15	137	70	**	3	33	59	158	676
2001	14	157	*	44	104	34	**	2	19	30	233	637
2002	30	96	4	34	115	24	**	1	21	21	172	518
2003	36	85	72	92	222	162	13	17	63	68	255	1084
2004	63	162	166	93	207	159	4	16	61	68	205	1205
2005	32	221	198	29	136	90	2	6	43	57	247	1061
2006	5	252	178	43	103	72	1	6	20	30	326	1036
2007	21	369	164	47	160	120	4	7	24	27	427	1370
2008[2]	131	424	156	103	286	146	2	26	65	48	395	1782

* Pond under construction

** Negligible amount of water impounded

*** Pond drained for repair

1 Assumed 60 acre-feet impounded each year between 8/81 and 8/86

2 Ponds J2-A and J16-L were dewatered 78 acre-feet and 242 acre-feet, respectively, during 2008

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PWCC's dams, ponds and impoundments appear to have had a minimal effect on downstream runoff.

Based on the pond and dam monitoring information presented in Table 23a, the following analysis was performed to further assess the potential impact of the dams and ponds on flow volumes at the town of Moenkopi. The analysis considers whether the amount of water captured by the impoundments in a year would reach the town of Moenkopi if the total amount was due to a single, large storm at the leasehold. Further review of Table 23a indicates that one of the years with significant increases in water impounded from the previous year was 1983-1984. Five hundred eighty-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. In Table 23a, 60 new acre-feet of water was assumed to be impounded by all the non-MSHA sized sediment ponds combined for each of the years 1978 through 1986. This 60 acre-feet added to the 1983-1984 increase in water impounded by MSHA structures yields a total of 647 acre feet of new water for that year.

The analysis approach employed moving a flow volume equal to 644 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 20. 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 23b) 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 23c 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.

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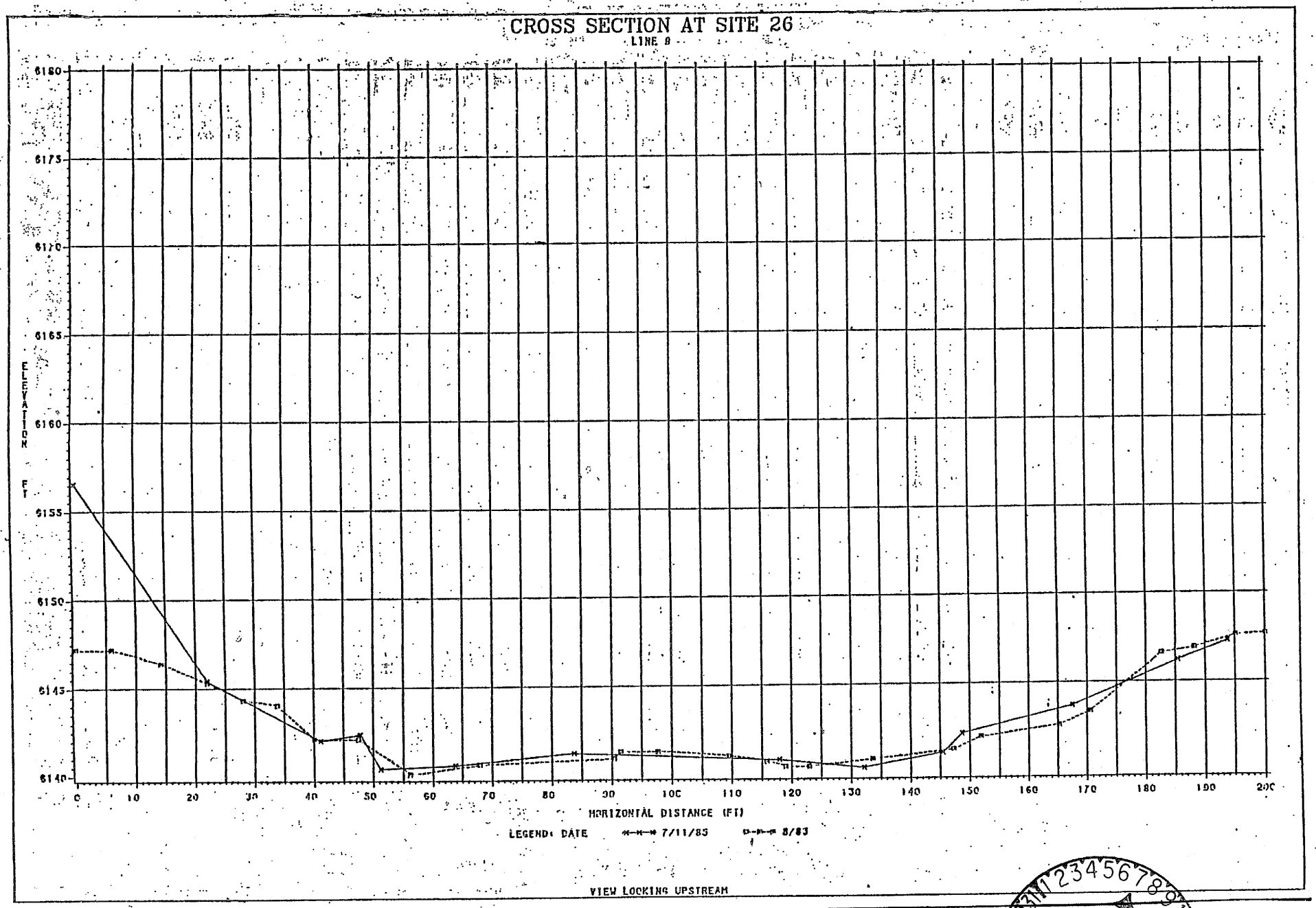

FIGURE 20 CHANNEL CROSS SECTION FOR MOENKOPI WASH ON LEASEHOLD USED FOR FLOW LOSS COMPUTATIONS DOWN TO THE TOWN OF MOENKOPI

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TABLE 23b

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	1296.290	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	1308.856	1720	653.512	2010	378.884	2300	286.337	2590	180.801
1440	1310.865	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

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TABLE 23b (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		

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TABLE 23c

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 lost due to the impoundments would be considerably smaller and totally lost as channel bed infiltration in shorter distances from the leasehold. Considering watershed areas, estimates of annual runoff, comparisons of daily stream flow measurements and measured annual runoff, 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.

Effects of Dams, Sediment Ponds and Permanent Internal Impoundments on Stream-Water Quality. 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, PWCC will make all efforts to comply with the effluent limits and monitoring requirements of the NPDES permit (No. AZ0022179, Attachment 3, Chapter 16, Hydrologic Monitoring Program). The disposal of sediment removed from sediment ponds is conducted in a manner that protects stream water quality and is described in the section entitled "Design Methodology" of Chapter 6, Facilities.

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The NPDES Permit allows pond dewatering 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. Pond to pond pumping is also periodically employed. Seepage from dam embankments or around the sides of embankments is also presently being monitored in accordance with the NPDES Permit 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 will be negligible. Table 24 shows average concentrations for select chemical constituents measured in permanent internal impoundments from 1986 through 2008. Almost all the impoundments selected contain surface water runoff and have no appreciable ground-water contribution from resaturated spoil, with the exception of Pond N2-RA. Table 25 shows average concentrations for the same chemical constituents measured in stream flows generated by rainfall runoff at stream monitoring sites for the same period. Excepting pond N2-RA, water quality documented in the permanent internal impoundments is similar to slightly lower in range and magnitude compared to stream flows.

Annual Hydrology Reports (AHR's) present comparisons of recent and historical pond and stream water quality data with existing numeric limits for livestock drinking water and other uses. Sources of the livestock drinking water limits used in the AHR's include the Navajo EPA (2008) and Hopi Tribe (2008). In the March 5, 2001 Hydrologic Monitoring Program Permit Revision package, PWCC attached the document entitled "Justification of Monitor and Monitoring Frequency Reductions at the Black Mesa and Kayenta Mines, Arizona" (PWCC, 2001). The document presents a thorough evaluation of summary statistics, water types, trend analyses, and comparisons of historical stream water quality with livestock and other use limits. Based on the livestock limit comparisons presented in the document that used total recoverable metal analyses, all stream flow generated by storm runoff is not suitable for livestock drinking water. The document also mentions, if only dissolved analyses are used for comparison purposes, most of the stream water quality is suitable for livestock drinking.

The Navajo Nation's surface water quality standards (NNEPA, 2008) establish livestock drinking water limits using both dissolved (B, Co, Cu & V) and total (As, Cd, Cr, Hg, Se & Zn) metal analyses. Using these standards, and those promulgated by the Hopi Tribe (Hopi, 2008), and recommended standards for TDS (NAS, 1974) and sulfate (Botz and Pedersen, 1976), comparisons were made between permanent internal impoundments and stream flow water quality collected from 1986 through 2008. Table 26 lists the

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TABLE 24

Mean Concentrations of Selected Chemical Parameters Measured In

Permanent Internal Impoundments on Reclaimed Areas on Black Mesa

(1986-2008)

Monitoring Site

Parameter	116	124	118*	N1-RA	122*	123*	112*	113*	119*	N7-D	N2-RA	N2-RB	N2-RC	N8-RA
pH	8.2	7.8	8.6	9.5	8.0	7.5	7.8	7.9	7.9	8.1	8.6	8.1	8.6	8.0
TDS	459	205	144	440	143	177	281	603	165	939	9509	566	227	133
Alk	84	100	105	142	96	102	109	205	116	74	261	113	97	56
SO_4	225	68	16	197	15	21	98	252	25	595	6557	297	79	34
Ca	63	44	24	35	25	26	24	46	29	155	359	108	44	26
Mg	25	13	11	24	9	9	12	21	12	56	432	34	12	4
Na	29	4	5	70	4	7	44	117	9	41	1934	12	6	2
Cl	10	3	5	7	5	6	4	8	2	20	45	7	4	4

*Pre-law area ponds

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TABLE 25

Mean Concentrations of Selected Chemical Parameters

Measured at Stream Station Sites on Black Mesa

During Rainfall Runoff Events

(1986 - 2008)

Stream Monitoring Site

Parameter	Dinnebito Wash		Reed Valley Wash	Yellow Water Wash			Coal Mine Wash			R.P. Valley Wash[1]		Moenkopi Wash	
	34	78	37*	50	15	157	16	18**	25	14	155	35	26
pH	8.0	8.0	8.0	8.0	8.0	8.1	8.1	8.0	8.0	8.2	8.3	8.1	8.1
TDS	1179	1462	1485	755	686	229	471	1335	1503	271	324	292	924
Alk	98	87	121	86	85	112	80	123	130	95	94	68	100
SO_4	671	919	694	437	398	112	242	809	913	106	135	118	525
Ca	160	191	162	125	127	48	87	165	165	46	44	52	128
Mg	62	95	105	44	34	8	19	80	92	12	12	11	53
Na	64	96	100	19	16	4	13	104	135	15	33	5	68
Cl	15	22	213	17	10	3	8	27	21	10	11	4	40

Notes:

1 Red Peak Valley Wash

* Excludes chemical data for two samples that were influenced by magnesium chloride spills, upgradient of this monitoring site.

** Includes chemical data from sub-sites FLUM18 and CG18.

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comparison results for the permanent internal impoundments, and Table 27 shows the comparison results for the stream monitoring sites. Table 26 shows that, excepting the high pH values measured in PIIs N1-RA and N2-RA, the high TDS and sulfate values at pond N2-RA, and only single excursions of these same standards at four other ponds historically, the permanent impoundment water quality is suitable for use as livestock drinking water. Table 27 also indicates most of the stream flow generated by rainfall runoff meets the pH, NO3_NO2, TDS and sulfate standards, as well as the trace element livestock drinking water standards expressed as dissolved. The high pH values documented in Pond N1-RA would likely be reduced by contact with soil and channel bed materials if a discharge occurs. An unlikely discharge from either Pond N1-RA or N2-RA would be diluted when mixing with the larger volumes of stream flow runoff. Due to the similarity in water quality between permanent internal impoundments and stream flows, discharges from permanent internal impoundments would not significantly affect stream-water quality, and would not change the potential stream water use.

Effects of Stream Channel Diversions on Channel Characteristics and Runoff Water Quality. 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. 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

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Table 26

Exceedances of Livestock Drinking Water Limits at Permanent Internal Impoundments (1986 - 2008)

Analyte	Standard	No. Sites	Sites	Frequency	Exceedence Date Range	Exceedence Value Range	Exceedence Median	
LIVESTOCK WATERING STANDARDS -- NNEPA (2008), Hopi (2008), NAS (1974), Botz and Pederson (1976)								
Aluminum, Dissolved	0.0000 - 5.0000	0	none					
Boron, Dissolved	0.0000 - 5000.0000	0	none					
Copper, Dissolved	0.0000 - 500.0000	0	none					
Field Ph	6.5000 - 9.0000	5	N1-RA-P	11/0/0/13	01/28/92-09/18/00	9.1200 -	10.6100	9.4600
			N2-RA-P	4/0/0/23	01/13/06-07/07/08	9.1500 -	9.6100	9.2900
			N2-RB-P	1/0/0/4	01/28/99-01/28/99	9.1000 -	9.1000	9.1000
			PII116-P	1/0/0/2	07/28/98-07/28/98	9.0200 -	9.0200	9.0200
			PII118-P	1/0/0/5	05/27/93-05/27/93	9.4200 -	9.4200	9.4200
NO3_NO2 Nitrogen_N	0.0000 - 132.0000	0	none					
Solids, Dissolved	0.0000 - 6999.0000	1	N2-RA-P	19/0/0/28	03/05/86-04/10/00	7832.0000 -	18100.0000	12708.0000
Sulfate	0.0000 - 3000.0000	2	N2-RA-P	21/0/0/28	03/05/86-07/07/05	3690.0000 -	12965.0000	8080.0000
			N7-D-P	1/0/0/10	12/09/92-12/09/92	3482.0000 -	3482.0000	3482.0000
Total Recoverable As	0.0000 - 200.0000	0	none					
Total Recoverable Cd	0.0000 - 50.0000	0	none					
Total Recoverable Cr	0.0000 - 1000.0000	0	none					
Total Recoverable Cu	0.0000 - 500.0000	0	none					
Total Recoverable Hg	0.0000 - 10.0000	0	none					
Total Recoverable Pb	0.0000 - 100.0000	2	N2-RA-P	1/0/4/22	09/20/90-07/07/05	200.0000 -	200.0000	200.0000
					(<)	200.0000 -	400.0000	300.0000
			N2-RC-P	0/0/1/5	07/21/99-07/21/99(<)	200.0000 -	200.0000	200.0000
Total Recoverable Se	0.0000 - 50.0000	0	none					
Total Recoverable V	0.0000 - 100.0000	0	none					
Total Recoverable Zn	0.0000 - 25.0000	0	none					
Vanadium, Dissolved	0.0000 - 100.0000	1	N2-RA-P	0/0/1/18	03/05/86-03/05/86(<)	500.0000 -	500.0000	500.0000

:equency = uncensored/between MDL&PQL/censored/no. samples, (B) = Between MDL&PQL range, (<) = Censored range

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Table 27

Exceedances of Livestock Drinking Water Limits at Stream Monitoring Sites During Rainfall Runoff Events (1986 - 2008)

Analyte	Standard	No. Sites	Sites	Frequency	Exceedence Date Range	Exceedence Value Range	Exceedence Median
LIVESTOCK WATERING STANDARDS -- NNEPA & HOPI (08/10/10) - PHC UPDATE							
Aluminum, Dissolved	0.0000 - 5.0000	0	none				
Arsenic, Dissolved	0.0000 - 200.0000	0	none				
Boron, Dissolved	0.0000 - 5000.0000	0	none				
Cadmium, Dissolved	0.0000 - 50.0000	0	none				
Chromium, Dissolved	0.0000 - 1000.0000	0	none				
Copper, Dissolved	0.0000 - 500.0000	0	none				
Field Ph	6.5000 - 9.0000	0	none				
Lead, Dissolved	0.0000 - 100.0000	0	none				
Mercury, Dissolved	0.0000 - 10.0000	0	none				
NO3_NO2 Nitrogen_N	0.0000 - 132.0000	0	none				
Selenium, Dissolved	0.0000 - 50.0000	1	CG37	0/0/1/10	05/07/92-05/07/92(<)	200.0000 - 200.0000	200.0000
Solids, Dissolved	0.0000 - 6999.0000	2	CG37	2/0/0/21	05/07/92-11/01/95	7600.0000 - 10170.0000	8885.0000
			SW25	1/0/0/39	07/21/98-07/21/98	7750.0000 - 7750.0000	7750.0000
Sulfate	0.0000 - 3000.0000	3	CG37	1/0/0/21	05/07/92-05/07/92	6660.0000 - 6660.0000	6660.0000
			FLUM18	1/0/0/10	07/24/91-07/24/91	3132.0000 - 3132.0000	3132.0000
			SW25	3/0/0/39	07/10/92-04/15/05	3460.0000 - 4880.0000	4116.0000
Total Recoverable Al	0.0000 - 5.0000	14	CG14	14/0/0/14	08/06/91-10/23/00	33.6000 - 1090.0000	273.5000
			CG157	10/0/0/10	07/23/91-08/22/00	14.0000 - 976.0000	273.0000
			CG18	9/0/0/9	07/23/97-07/10/01	70.4000 - 1950.0000	519.0000
			CG34	30/0/0/30	07/28/89-08/08/08	7.9100 - 2460.0000	400.5000
			CG37	17/0/0/17	07/28/89-10/23/00	15.1000 - 1440.0000	262.0000
			CG78	18/0/0/19	07/28/89-08/05/05	8.9100 - 1360.0000	223.5000
			FLUM15	12/0/0/12	07/05/90-05/19/01	15.4000 - 1480.0000	484.0000
			FLUM18	6/0/0/6	07/24/91-08/25/96	38.4000 - 507.0000	198.0000
			SW155	23/0/0/23	07/29/91-09/04/09	11.5000 - 2190.0000	358.0000
			SW16	14/0/0/15	09/05/90-07/10/01	99.4000 - 1270.0000	353.0000
			SW25	29/0/0/31	07/31/89-09/04/09	12.1000 - 1640.0000	241.0000
			SW26	29/0/0/32	07/24/91-09/04/09	12.4000 - 1650.0000	258.0000
			SW35	10/0/0/10	07/28/89-07/09/01	40.6000 - 586.0000	147.0000
			SW50	11/0/0/11	08/06/91-08/22/00	157.0000 - 1660.0000	421.0000
Total Recoverable As	0.0000 - 200.0000	11	CG157	1/0/0/10	07/23/91-07/23/91	400.0000 - 400.0000	400.0000
			CG34	5/0/0/30	07/17/90-08/03/07	210.0000 - 1550.0000	280.0000
			CG37	4/0/0/17	07/28/89-08/10/00	220.0000 - 310.0000	285.0000
			CG78	2/0/0/19	07/28/89-08/03/00	300.0000 - 540.0000	420.0000

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Table 27 (cont.)

Exceedances of Livestock Drinking Water Limits at Stream Monitoring Sites During Rainfall Runoff Events (1986 - 2008)

Analyte	Standard	No. Sites	Sites	Frequency	Exceedence Date Range	Exceedence Value Range	Exceedence Median
			FLUM15	1/0/0/12	07/23/91-07/23/91	500.0000 -	500.0000 500.0000
			FLUM18	1/0/0/6	07/24/91-07/24/91	800.0000 -	800.0000 800.0000
			SW155	1/0/0/23	07/29/91-07/29/91	220.0000 -	220.0000 220.0000
			SW16	3/0/0/15	09/05/90-07/24/91	350.0000 -	800.0000 400.0000
			SW25	2/0/0/31	07/31/89-07/22/08	280.0000 -	790.0000 535.0000
			SW26	2/0/0/32	07/24/91-07/23/97	370.0000 -	1200.0000 785.0000
			SW50	2/0/0/11	08/06/91-08/05/92	250.0000 -	300.0000 275.0000
Total Recoverable Cd	0.0000 - 50.0000	14	CG14	1/1/0/14	08/09/93-08/04/97	200.0000 -	200.0000 200.0000
					(B)	130.0000 -	130.0000 130.0000
			CG157	1/0/0/10	08/04/97-08/04/97	250.0000 -	250.0000 250.0000
			CG18	1/1/0/9	10/07/97-07/09/01	78.0000 -	78.0000 78.0000
					(B)	60.0000 -	60.0000 60.0000
			CG34	3/1/2/30	07/28/89-08/05/05	53.0000 -	440.0000 220.0000
					(B)	90.0000 -	90.0000 90.0000
					(<)	60.0000 -	200.0000 130.0000
			CG37	1/2/0/17	07/28/89-10/07/97	129.0000 -	129.0000 129.0000
					(B)	60.0000 -	100.0000 80.0000
			CG78	4/1/0/19	07/28/89-10/23/00	61.0000 -	120.0000 108.5000
					(B)	150.0000 -	150.0000 150.0000
			FLUM15	1/0/1/12	10/03/97-07/12/99	120.0000 -	120.0000 120.0000
					(<)	60.0000 -	60.0000 60.0000
			FLUM18	0/0/1/6	08/11/94-08/11/94(<)	500.0000 -	500.0000 500.0000
			SW155	0/2/2/23	08/28/96-07/24/08(B)	60.0000 -	130.0000 95.0000
					(<)	100.0000 -	100.0000 100.0000
			SW16	1/1/0/15	08/24/96-07/10/01	80.0000 -	80.0000 80.0000
					(B)	80.0000 -	80.0000 80.0000
			SW25	2/0/2/31	07/31/89-07/22/08	76.0000 -	250.0000 163.0000
					(<)	100.0000 -	100.0000 100.0000
			SW26	1/0/3/32	07/24/91-07/30/07	90.0000 -	90.0000 90.0000
					(<)	60.0000 -	100.0000 100.0000
			SW35	1/0/0/10	07/28/89-07/28/89	190.0000 -	190.0000 190.0000
			SW50	0/0/2/11	08/25/96-06/17/99(<)	60.0000 -	60.0000 60.0000
Total Recoverable Cr	0.0000 - 1000.0000	10	CG14	1/0/0/14	08/06/91-08/06/91	1200.0000 -	1200.0000 1200.0000
			CG18	0/1/0/9	06/17/99-06/17/99(B)	2200.0000 -	2200.0000 2200.0000
			CG34	8/0/0/30	07/28/89-08/08/08	1070.0000 -	2300.0000 1465.0000
			CG78	3/0/0/19	07/08/98-08/05/05	1160.0000 -	1300.0000 1300.0000
			FLUM15	2/0/0/12	07/23/91-06/17/99	1100.0000 -	1500.0000 1300.0000
			SW155	2/0/0/23	07/30/06-07/24/08	1220.0000 -	2300.0000 1760.0000
			SW16	1/0/0/15	07/21/98-07/21/98	1270.0000 -	1270.0000 1270.0000
			SW25	3/0/0/31	07/13/95-07/22/08	1050.0000 -	1700.0000 1590.0000
			SW26	2/0/0/32	07/24/91-07/23/97	1200.0000 -	1900.0000 1550.0000
			SW50	3/0/0/11	08/06/91-06/17/99	1100.0000 -	1700.0000 1500.0000
Total Recoverable Cu	0.0000 - 500.0000	14	CG14	7/0/0/14	08/06/91-07/14/99	520.0000 -	2200.0000 810.0000
			CG157	4/0/0/10	07/23/91-08/22/00	900.0000 -	1270.0000 1075.0000
			CG18	6/1/0/9	07/23/97-07/09/01	530.0000 -	1120.0000 770.0000
					(B)	2500.0000 -	2500.0000 2500.0000
			CG34	16/0/0/30	07/28/89-08/08/08	5[illegible].0000 -	1140.0000 1100.0000
			CG37	6/0/0/17	07/28/89-07/13/99	[illegible]10.0000	1600.0000 985.0000
			CG78	7/0/0/19	07/28/89-08/05/05	[illegible]00.0000 -	2400.0000 1620.0000

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Table 27 (Cont.)

Exceedances of Livestock Drinking Water Limits at Stream Monitoring Sites During Rainfall Runoff Events (1986 - 2008)

Analyte	Standard	No. Sites	Sites	Frequency	Exceedence Date Range		Exceedence Value Range	Exceedence Median
			FLUM15	6/0/0/12	07/23/91-07/12/99		640.0000 - 2100.0000	1255.0000
			FLUM18	1/0/0/6	07/24/91-07/24/91		900.0000 - 900.0000	900.0000
			SW155	12/0/0/23	07/29/91-07/24/08		560.0000 - 2300.0000	1000.0000
			SW16	7/0/0/15	09/05/90-07/10/01		650.0000 - 2010.0000	1000.0000
			SW25	11/1/0/31	07/31/89-07/22/08		560.0000 - 2920.0000	1130.0000
						(B)	900.0000 - 900.0000	900.0000
			SW26	12/0/0/32	07/24/91-09/04/09		560.0000 - 2800.0000	725.0000
			SW35	2/0/0/10	07/28/89-07/09/99		800.0000 - 900.0000	850.0000
			SW50	6/0/0/11	08/06/91-08/22/00		570.0000 - 3500.0000	1205.0000
Total Recoverable Hg	0.0000 - 10.0000	3	CG34	1/0/0/21	07/08/98-07/08/98		13.0000 - 13.0000	13.0000
			SW26	1/0/0/21	07/24/91-07/24/91		12.0000 - 12.0000	12.0000
			SW50	1/0/0/11	08/06/91-08/06/91		20.0000 - 20.0000	20.0000
Total Recoverable Pb	0.0000 - 100.0000	14	CG14	5/3/4/14	08/06/91-10/23/00		380.0000 - 1700.0000	700.0000
						(B)	230.0000 - 700.0000	400.0000
						(<)	200.0000 - 400.0000	300.0000
			CG157	4/2/1/10	07/23/91-08/22/00		190.0000 - 970.0000	745.0000
						(B)	900.0000 - 1000.0000	950.0000
						(<)	200.0000 - 200.0000	200.0000
			CG18	2/5/1/9	07/23/97-07/09/01		380.0000 - 650.0000	515.0000
						(B)	300.0000 - 3000.0000	700.0000
						(<)	400.0000 - 400.0000	400.0000
			CG34	11/9/2/30	07/28/89-08/08/08		130.0000 - 3600.0000	1480.0000
						(B)	140.0000 - 800.0000	500.0000
						(<)	200.0000 - 200.0000	200.0000
			CG37	9/4/1/17	07/28/89-10/23/00		130.0000 - 1400.0000	700.0000
						(B)	120.0000 - 500.0000	340.0000
						(<)	200.0000 - 200.0000	200.0000
			CG78	8/4/2/19	07/28/89-08/05/05		130.0000 - 2000.0000	580.0000
						(B)	200.0000 - 1500.0000	350.0000
						(<)	200.0000 - 400.0000	300.0000
			FLUM15	4/6/1/12	07/05/90-05/19/01		510.0000 - 1800.0000	895.0000
						(B)	140.0000 - 1900.0000	450.0000
						(<)	200.0000 - 200.0000	200.0000
			FLUM18	4/1/1/6	07/24/91-08/25/96		210.0000 - 700.0000	360.0000
						(B)	200.0000 - 200.0000	200.0000
						(<)	200.0000 - 200.0000	200.0000
			SW155	6/12/2/23	07/29/91-09/04/09		300.0000 - 870.0000	545.0000
						(B)	140.0000 - 2000.0000	450.0000
						(<)	400.0000 - 800.0000	600.0000
			SW16	8/5/2/15	07/28/89-07/10/01		300.0000 - 1500.0000	1000.0000
						(B)	110.0000 - 600.0000	200.0000
						(<)	200.0000 - 200.0000	200.0000
			SW25	11/8/5/31	07/31/89-07/22/08		120.0000 - 2500.0000	700.0000
						(B)	170.0000 - 900.0000	450.0000
						(<)	200.0000 - 1000.0000	200.0000
			SW26	10/13/4/32	07/24/91-09/04/09		140.0000 - 3000.0000	505.0000
						(B)	110.0000 - 900.0000	300.0000
						(<)	200.0000 - 800.0000	600.0000

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Table 27 (cont.)
Exceedances of Livestock Drinking Water Limits at Stream Monitoring Sites During Rainfall Runoff Events (1986 - 2008)

Analyte	Standard	No. Sites	Sites	Frequency	Exceedence Date Range	Exceedence Value Range	Exceedence Median	
			SW35	2/4/2/10	07/28/89-07/09/01	200.0000 -	400.0000	300.0000
					(B)	190.0000 -	700.0000	300.0000
					(<)	200.0000 -	200.0000	200.0000
			SW50	5/5/1/11	08/06/91-08/22/00	230.0000 -	3100.0000	450.0000
					(B)	300.0000 -	1600.0000	600.0000
					(<)	400.0000 -	400.0000	400.0000
Total Recoverable Se	0.0000 - 50.0000	1	CG34	2/0/0/30	07/08/98-08/05/05	60.0000 -	75.0000	67.5000
Total Recoverable V	0.0000 - 100.0000	14	CG14	13/0/0/14	08/06/91-10/23/00	130.0000 -	2400.0000	640.0000
			CG157	9/0/0/10	07/23/91-08/22/00	142.0000 -	2030.0000	810.0000
			CG18	9/0/0/9	07/23/97-07/10/01	143.0000 -	3800.0000	940.0000
			CG34	25/0/0/30	07/28/89-08/08/08	116.0000 -	4240.0000	1060.0000
			CG37	15/0/0/17	07/28/89-10/23/00	190.0000 -	2820.0000	760.0000
			CG78	15/0/0/19	07/28/89-08/05/05	120.0000 -	2650.0000	650.0000
			FLUM15	11/0/0/12	07/05/90-05/19/01	160.0000 -	2820.0000	990.0000
			FLUM18	5/0/0/6	07/24/91-08/25/96	400.0000 -	1500.0000	400.0000
			SW155	20/0/0/23	07/29/91-09/04/09	264.0000 -	4300.0000	825.0000
			SW16	14/0/0/15	09/05/90-07/10/01	200.0000 -	2700.0000	850.0000
			SW25	26/0/0/31	07/31/89-07/22/08	106.0000 -	3180.0000	635.0000
			SW26	26/0/0/32	07/24/91-09/04/09	109.0000 -	3180.0000	600.0000
			SW35	8/1/0/10	07/28/89-07/09/01	110.0000 -	1200.0000	380.0000
					(B)	290.0000 -	290.0000	290.0000
			SW50	11/0/0/11	08/06/91-08/22/00	340.0000 -	3100.0000	740.0000
Total Recoverable Zn	0.0000 - 25.0000	0	none					
Vanadium, Dissolved	0.0000 - 100.0000	0	none					
Zinc, Dissolved	0.0000 - 25.0000	0	none					

Frequency = uncensored/between MDL&PQL/censored/no. samples, (B) = Between MDL&PQL range, (<) = Censored range

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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.

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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).

Effects of Runoff From Reclaimed Areas on the Quantity and Quality of Streamflow. 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 (48F) and a low mean annual precipitation (10 inches). Mean annual precipitation is based on nonheated recording rain gauges. Including the contributions from snow, the

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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 21a 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 21b shows the same relationship as Figure 21a, 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.

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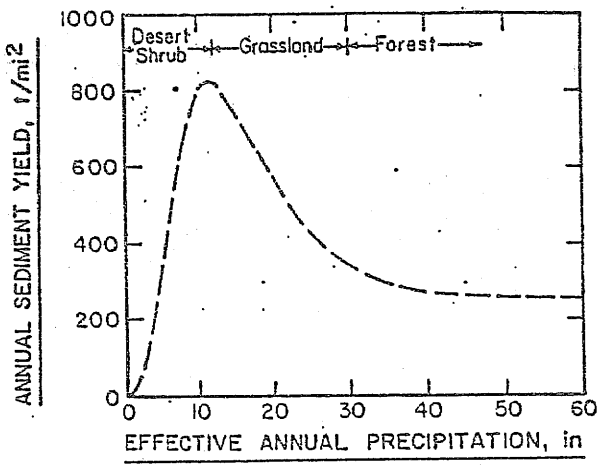
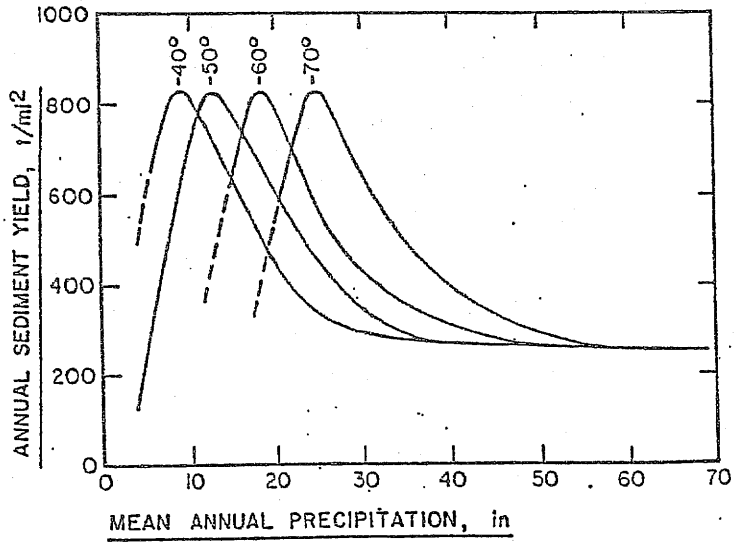


a. *Variation of sediment yield with climate in the United States (from Langbein and Schumm, 1958).*



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

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FIGURE 21 Climate and Sediment Yield

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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 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

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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).

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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 22). Regression lines defining the relationships among the measured and predicted values were determined and are labeled on Figure 22. 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

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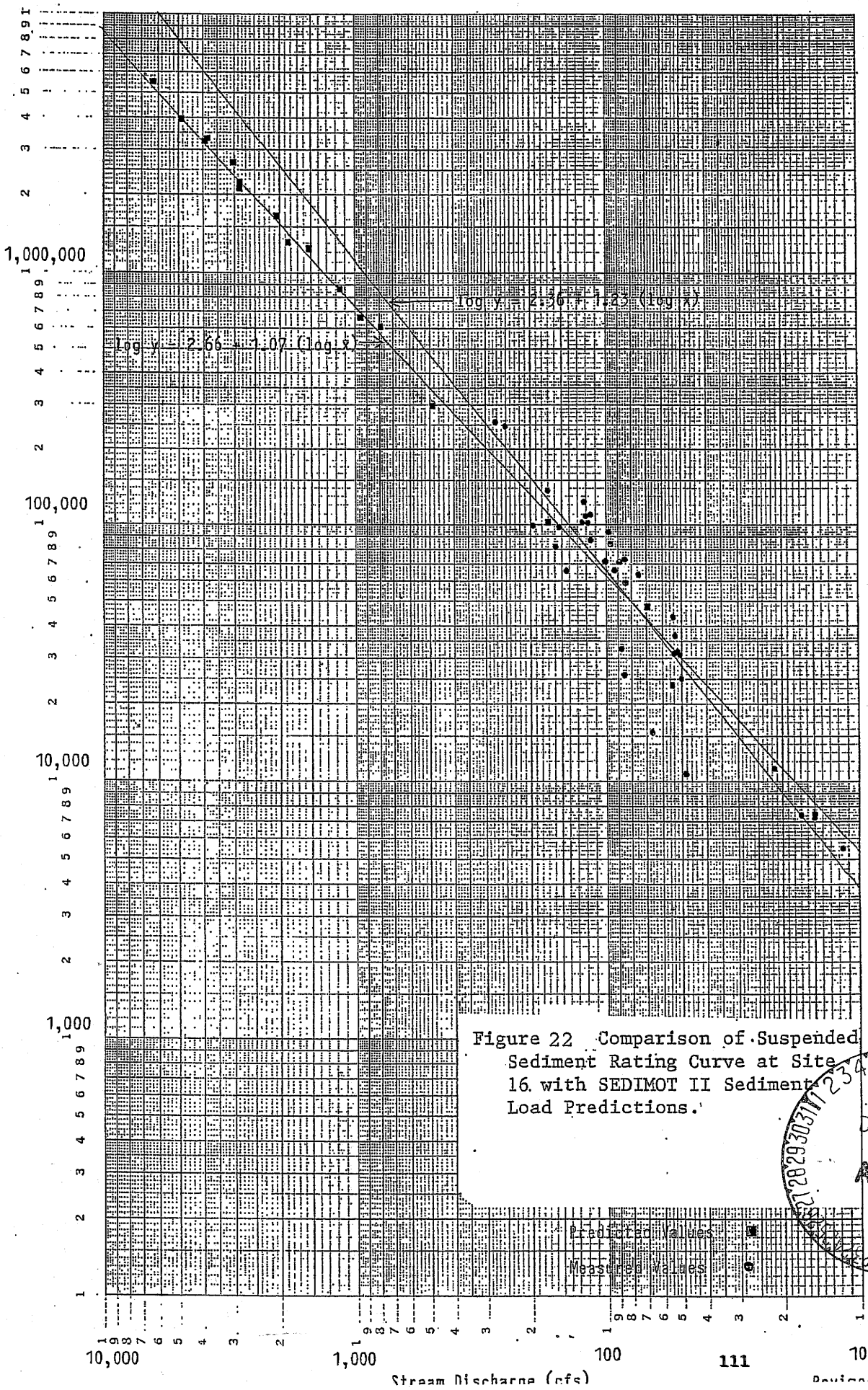

Figure 22 Comparison of Suspended Sediment Rating Curve at Site 16 with SEDIMOT II Sediment Load Predictions.

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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 for 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. Previously introduced tables 24 and 25 are summaries of sample means for selected major chemical parameters. Table 24 presents mean parameter values measured in PII's from 1986 through 2008 that were constructed in both pre-law and post-law areas, and Table 25 presents mean parameter values measured at stream station sites for the same period.

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 chemical parameter values from PII's are similar to but slightly lower in range and magnitude compared with stream flows, with the exception of PII's N1-RA and N2-RA. Mean pH measured in PII's range between 7.5 and 8.6 (except PII N1-RA), while stream pH values range similarly between 8.0 and 8.3. Excepting PII N2-RA, which receives a significant amount of high-TDS water from resaturated spoil in addition to runoff from reclaimed

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areas, mean TDS in PII's (144 to 939 mg/l) range lower than rainfall runoff measured in receiving streams (229 to 1503 mg/l). Although the mean values presented in Tables 24 and 25 indicate variability among PII's and stream flows, generally, TDS, sulfate, calcium, magnesium, sodium, and chloride are slightly lower in PII's compared with stream flows.

Tables 26 and 27 (previously discussed) indicate that water quality in most PII's and streams fall within the livestock drinking water limits (based largely on dissolved analyses of trace metals) recommended by Tribal agencies (NNEPA, 2008; Hopi, 2008), National Academy of Science (1974) and Botz and Pedersen (1976). Limited exceptions include high pH values in PII N1-RA, high TDS values in PII N2-RA, and infrequent exceedences of a limited number of the livestock drinking water limits at several stream sites.

Runoff water quality from reclaimed areas (including pre-law areas not topsoiled) will not significantly alter receiving stream water quality, nor change the potential use of receiving stream flows. Mixing of any infrequent pond discharge from PII's with the larger volumes of stream flow runoff will provide a slight diluting effect, rendering any potential impact on receiving stream water quality insignificant.

The Impact of the Reclamation Plan on the Stability of Reclaimed Areas. 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

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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

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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 in 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

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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

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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 28 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.

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TABLE 28

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	Three 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

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TABLE 28 (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 levels of Ca, Mg, Na, SO_4, HCO_3, and TDS in the resaturated portion of Wepo aquifer within mining areas only. Potential for acid formation and trace element 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

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TABLE 28 (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

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TABLE 28 (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	PWCC wellfield pumping will lower confined water levels basin-wide. The majority of drawdown has already occurred. Predicted drawdowns at surrounding communities are not large enough to affect aquifer productivity. At Rough Rock, where pre-pumping head was about 40 feet, PWCC-caused drawdown predicted to be only 2 feet. Water levels near the leasehold will begin to recover following the reduction or	No short or long term significant impact

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TABLE 28 (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.)	cessation of mining. No risk of structural damage to the aquifer. Maximum predicted reduction in baseflow of regional streams (all PWCC pumping) is 0.58 percent or less, except at Cow Springs, where a reduction of up to 1.00 percent is predicted. This assumes a low recharge rate, and is still insignificant.	
11. Impact of induced leakage from D-aquifer to N-aquifer	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.	No short or long term significant impact

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TABLE 28 (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
1. (Cont.)	Vegetation encroachment on new channels. Most ponds and dams temporary structures. Small 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 downstream of leasehold for several miles. Only 0.7 percent and 2.7 percent of total Dinnebito and Moenkopi watersheds to be dammed through 2013. Record review does not indicate significant impacts have or will occur downstream.	No short or long term significant impacts
3. Impact of dams, ponds or impoundments on stream water quality	Infrequent discharges will meet applicable NPDES effluent limits. Discharge from permanent internal impoundments unlikely.	No short or long term significant impacts

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TABLE 28 (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

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TABLE 28 (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

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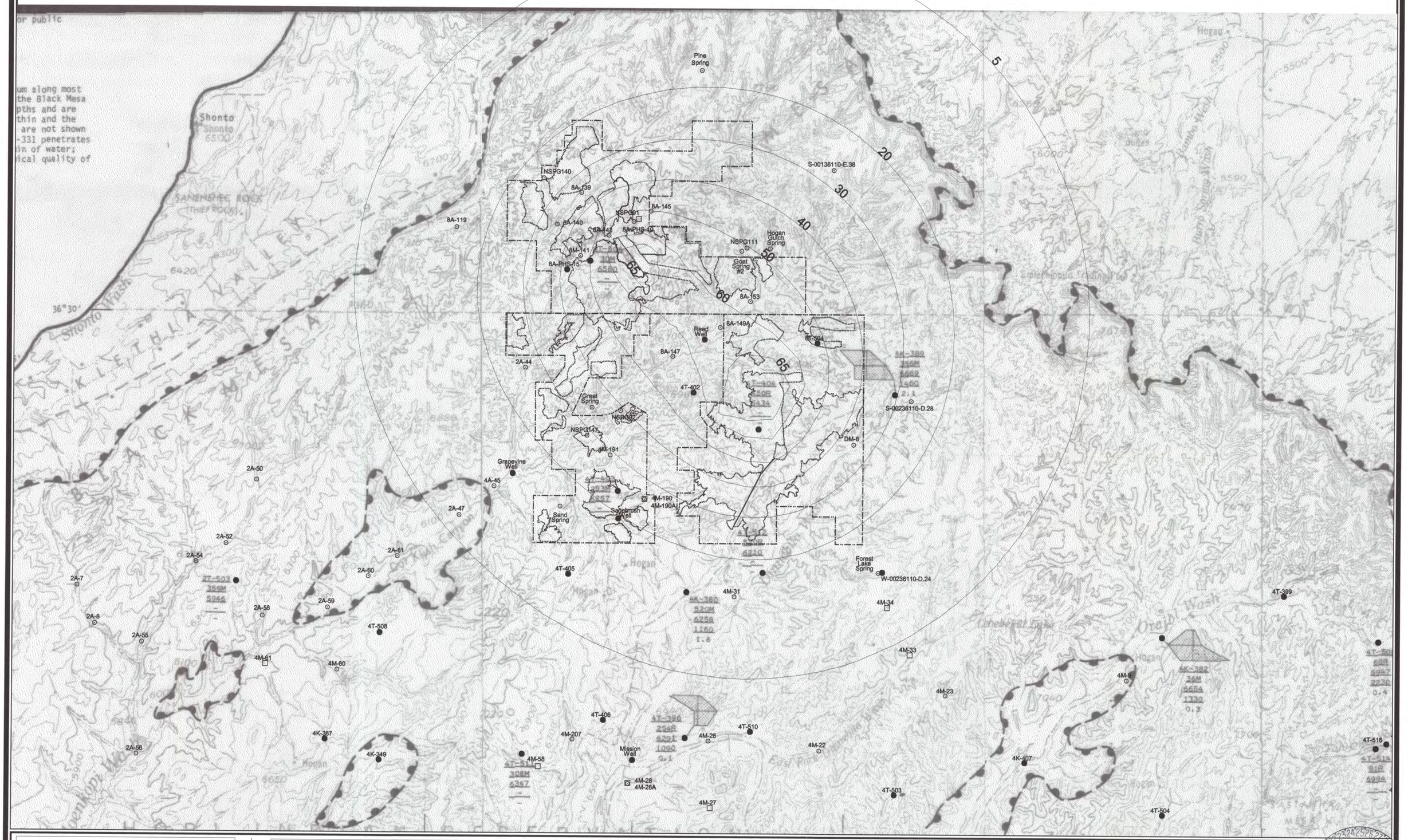


JOHN COCHRAN DATE:

PEABODY WESTERN

1 0 1 2 Miles

Spring and Well Locations

- Dug Well
- Spring
- Dug Well developed from Spring
- Dakota, Toreva and/or Wepo Well
- Lease Line
- 5 Drawdown Contour and Amount of Drawdown (ft.)

AREA MAP

Figure 1

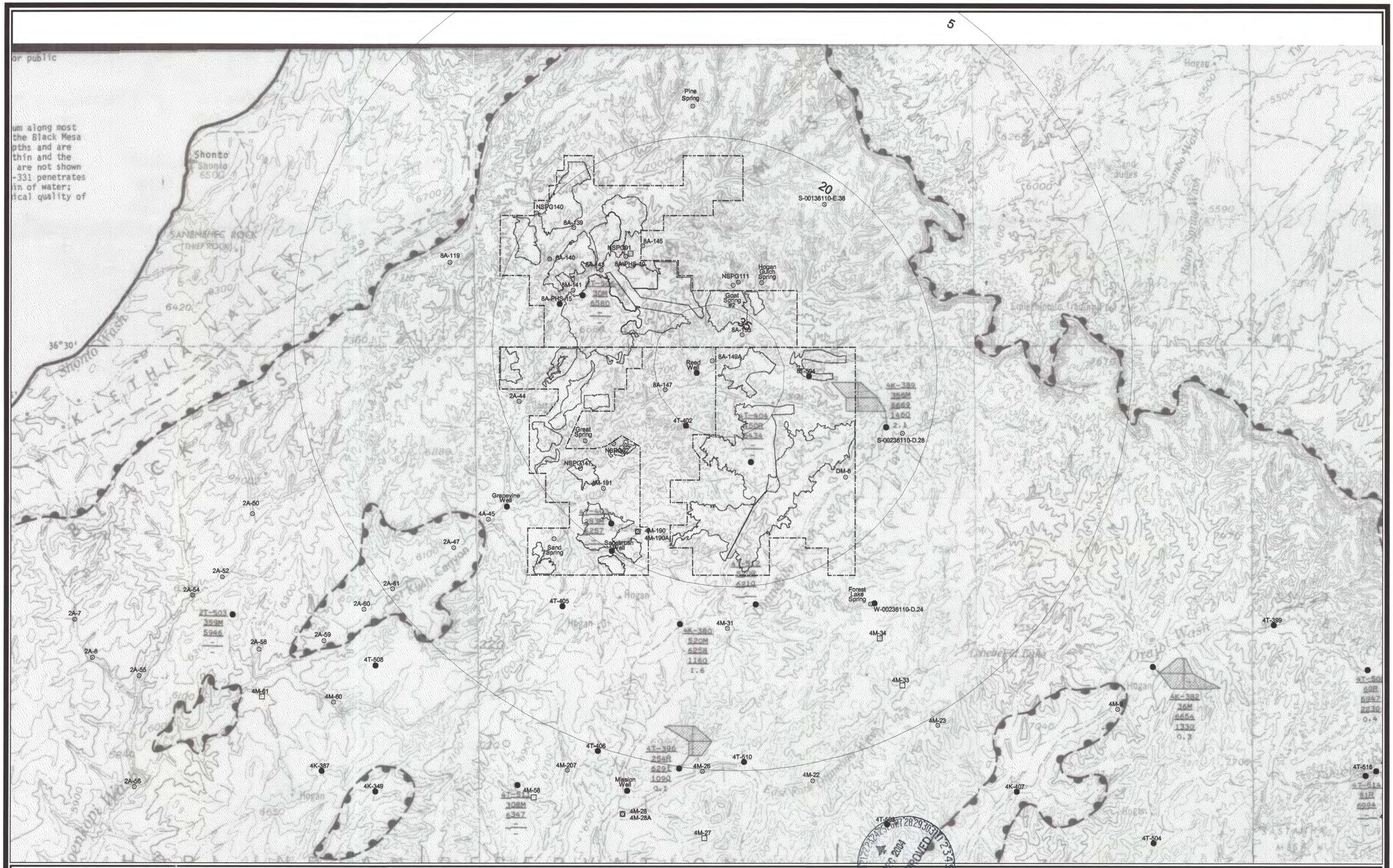
Maximum Water Level Drawdowns in the Wepo and Alluvial Aquifers in 2013 as a Result of Combined Pit Inflow Pumpage, and Locations of Private Wells and Springs in Relation to the Drawdown.

Figure 1

Black Mesa Complex
PO Box 605, Kayenta, Arizona 86033

Produced For:	John Cochran	Map By:	BMC-ERD
Map Scale:	1":10560' or 1":2 miles	Contour Interval:	200 Feet (Supplemental Interval 100 Feet)
Photo Date:		Photo Resolution:	N/A
	c:\hamilton\projects\c_wells99-1.apr	Plot Date:	Tuesday August 31, 2004

DEC 2004 APPROVED



JOHN COCHRAN DATE:

PEABODY WESTERN

1 0 1 2 Miles

Spring and Well Locations

- Dug Well
- Spring
- Dug Well developed from Spring
- Dakota, Toreva and/or Wepo Well
- Lease Line
- 5 Drawdown Contour and Amount of Drawdown (ft.)

AREA MAP

Figure 1

Maximum Water Level Drawdowns in the Wepo and Alluvial Aquifers in 2030 as a Result of Combined Pit Inflow Pumpage, and Locations of Private Wells and Springs in Relation to the Drawdown.

Figure 1a

Black Mesa Complex
PO Box 605, Kayenta, Arizona 86033

Produced For:	John Cochran	*Map By:*	BMC-ERD
Map Scale:	1":10560' or 1":2 miles	*Contour Interval:*	200 Feet (Supplemental Interval 100 Feet)
Photo Date:		*Photo Resolution:*	N/A
	c:\hamilton\projects\c_wells99-1.apr	*Plot Date:*	Tuesday August 31, 2004

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

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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.

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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:

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

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:

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

where

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

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

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

Intergrating both sides of equation 6 results in the following:

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

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

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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.

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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.

APPROVED DEC 2004

Attachment 3

DEC 2010
APPROVED

Revised 8/31/10

Annual Pumping Volumes from Community Wells Located in the Confined Portion of the N Aquifer un

Community Name	Well ID	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Bacavi	only well	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chilchinbito	1	0.00	0.00	0.00	0.00	0.00	10.01	2.12	10.01	1.92	20.02	18.01	18.01	12.01	10.67	10.34	10.34	13.76	15.94	15.94	14.49	14.49	16.66
Chilchinbito	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.01	10.67	10.34	10.34	13.76	15.94	15.21	15.21	15.21	15.94
Chilchinbito	PM2	0.00	0.00	0.00	0.00	0.00	0.00	21.01	20.01	20.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.21	17.61	4.90	5.60	7.90	7.60
Chilchinbito	PM3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.29	7.24	5.07	5.79	5.79	7.24
Forest Lake	4T-523	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	1.01	1.44	1.87	2.30	5.70	9.21	10.11	15.81	11.31
Hard Rock	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hopi Civic Center	only well	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
Hopi Cultural Center	only well	0.00	0.50	0.59	0.89	1.24	1.63	2.07	2.52	2.96	3.41	3.85	4.29	4.74	5.18	5.63	6.07	6.51	6.96	7.43	7.91	8.38	8.88
Hopi High School	No. 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.59	0.00	9.42	7.24	8.69	15.21
Hopi High School	No. 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.43	0.00	3.62	6.52	0.00	0.72
Hopi High School	No. 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.43	0.00	2.90	4.34	9.42	6.52
Hotevilla	PM1	7.23	7.59	7.95	8.31	8.67	9.03	9.40	9.76	10.12	10.48	10.84	11.20	11.56	11.93	12.29	12.65	13.04	13.37	1.45	12.31	14.49	21.73
Hotevilla	PM2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.25	4.88	6.51	8.13	9.76	11.38	13.04	14.64	15.21	12.31	7.24	7.97
Kayenta	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	74.03	64.37	70.00	63.57	57.98	62.77	64.37	64.46	66.65	58.68	88.38	86.93	73.89
Kayenta	2	31.89	36.27	42.49	49.01	42.99	74.59	75.24	70.29	75.89	74.03	64.37	70.00	63.57	57.98	62.77	64.37	64.46	66.65	58.68	89.11	86.93	74.62
Kayenta	3	31.89	36.27	42.49	49.01	42.99	74.59	75.24	70.29	75.89	74.03	64.37	70.00	63.57	57.98	62.77	64.37	64.46	66.65	58.68	89.11	86.21	73.89
Kayenta	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	74.03	64.37	70.00	63.57	57.98	62.77	64.37	64.46	66.65	58.68	89.11	86.93	73.89
Kayenta	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.37	70.00	63.57	57.98	62.77	64.37	64.46	66.65	59.40	88.38	86.93	73.89
Kayenta	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.37	70.00	63.57	57.98	62.77	64.37	64.46	67.37	58.68	89.11	86.21	73.89
Kayenta	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.37	70.00	63.57	57.98	62.77	64.37	64.46	66.65	58.68	89.11	86.93	73.89
Kayenta	PM2	31.89	36.27	42.49	49.01	42.99	74.59	75.24	70.29	75.89	74.03	64.37	70.00	63.57	57.98	62.77	64.37	81.86	125.33	99.97	68.82	63.03	64.47
Kayenta	PM3	31.89	36.27	42.49	49.01	42.99	74.59	75.24	70.29	75.89	74.03	64.37	70.00	63.57	57.98	62.77	64.37	81.86	30.42	11.59	12.31	21.01	23.18
Keams Canyon	No. 2	0.00	0.00	3.92	4.76	5.60	6.44	7.28	8.12	8.96	9.80	10.64	11.48	12.32	13.16	14.00	14.84	11.23	38.39	37.67	49.26	39.12	47.09
Keams Canyon	No. 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.92	5.39	6.86	8.33	9.80	11.27	11.27	11.27	11.23	12.31	26.80	26.08	26.08	37.67
Kitsillie	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.30	6.60	8.60	7.30	7.20	7.40
Kitsillie	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kykotsmovi	PM1	2.88	3.32	3.75	4.18	4.61	5.05	5.48	5.91	6.35	6.78	7.21	7.64	8.08	8.51	8.94	9.37	10.14	14.49	37.67	41.29	43.47	26.08
Kykotsmovi	PM2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.88	11.84	14.81	17.77	20.73	23.69	26.65	29.61	25.36	18.84	16.66	18.11	29.70
Kykotsmovi	PM3	2.45	2.91	3.37	3.83	4.29	4.75	5.21	5.67	6.13	6.59	7.05	7.51	7.97	8.43	8.89	9.35	9.81	15.94	0.00	0.00	0.00	0.00
Low Mountain	PM2	0.00	0.00	0.00	0.00	2.90	3.63	4.35	5.08	5.80	6.53	7.25	7.98	8.71	9.43	10.16	10.88	11.61	0.00	0.00	0.00	6.52	9.42
Mishongnovi	only well	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.17	1.20	1.30	1.70	2.80
Pinon	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.46	11.59	8.69	12.31	17.38	23.90
Pinon	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.18	11.59	8.69	12.31	17.38	24.63
Pinon	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.46	10.86	7.97	13.04	16.66	23.90
Pinon	PM6	0.00	0.00	4.25	5.16	6.08	6.99	7.90	8.81	9.72	10.63	11.55	12.46	13.37	14.28	15.19	16.10	17.01	35.32	37.32	31.22	31.15	37.72
Polacca	PM4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.61	29.61	34.77	37.67	34.05	31.15
Polacca	PM5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.61	29.61	0.00	0.00	48.54	84.03
Polacca	PM6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.61	29.61	0.00	0.00	27.53	0.00
Rocky Ridge	PM2	4.29	4.65	5.00	5.36	5.72	6.08	6.43	6.79	7.15	7.51	7.86	8.22	8.58	8.94	9.29	9.65	10.01	28.13	5.79	6.52	0.00	1.45
Rocky Ridge	PM3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.50	3.44	4.38	5.32	6.25	7.19	8.13	9.07	10.14	28.13	6.52	7.97	11.59	10.14
Rough Rock	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.11	12.51	9.61	11.20	12.61	12.41
Rough Rock	PM3	4.79	5.32	5.91	6.56	7.30	8.10	9.01	9.37	8.97	7.04	7.81	7.81	7.81	8.60	9.81	10.61	12.31	5.07	2.17	5.07	2.90	2.90
Rough Rock	PM5	4.79	5.32	5.91	6.56	7.30	8.10	9.01	9.37	8.97	7.04	7.81	7.81	7.81	8.60	9.81	10.61	13.04	12.31	12.31	7.97	0.00	11.59
Rough Rock	PM6	4.79	5.32	5.91	6.56	7.30	8.10	9.01	9.37	8.97	7.04	7.81	7.81	7.81	8.60	9.81	10.61	12.31	15.94	18.84	18.84	23.90	25.36
Rough Rock	PM7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.07	5.79	2.17	2.90	5.79
Second Mesa	No. 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.72	0.72
Second Mesa	PM2	1.09	1.29	1.50	1.70	1.90	2.11	2.31	2.52	2.72	2.92	3.13	3.33	3.54	3.74	3.94	4.15	4.35	16.66	10.14	10.14	8.69	7.97
Shipaulovi	No. 2	0.00	0.00	1.00	1.21	1.43	1.64	1.86	2.07	2.29	2.50	2.72	2.93	3.14	3.36	3.57	3.79	2.10	7.97	18.11	18.51	17.81	18.51
Shungopovi	only well	0.00	0.00	0.00	0.00	0.00	3.00	3.82	4.64	5.46	6.28	7.09	7.91	8.73	9.55	10.37	11.19	12.01	11.11	12.31	13.11	14.91	19.31

Annual Pumping Volumes from Community Wells Located in the Confined Portion of the N Aquifer ur

		Volume Pumped (af/yr)																					
Community Name	Well ID	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Bacavi	only well	5.32	5.46	5.61	5.75	5.91	6.06	6.23	6.39	6.57	6.75	6.93	7.11	7.30	7.50	7.70	7.91	8.13	8.35	8.57	8.80	9.04	9.29
Chilchinbito	1	18.51	19.00	19.50	20.02	20.55	21.10	21.67	22.25	22.85	23.47	24.10	24.75	25.42	26.11	26.81	27.54	28.28	29.04	29.83	30.63	31.46	32.31
Chilchinbito	2	31.35	32.18	33.03	33.91	34.81	35.74	36.70	37.69	38.71	39.75	40.82	41.93	43.06	44.22	45.42	46.64	47.90	49.19	50.52	51.89	53.29	54.73
Chilchinbito	PM2	4.32	4.44	4.56	4.68	4.80	4.93	5.06	5.20	5.34	5.48	5.63	5.78	5.94	6.10	6.27	6.43	6.61	6.79	6.97	7.16	7.35	7.55
Chilchinbito	PM3	6.65	6.83	7.01	7.20	7.39	7.59	7.79	8.00	8.22	8.44	8.66	8.90	9.14	9.39	9.64	9.90	10.17	10.44	10.72	11.02	11.31	11.62
Forest Lake	4T-523	15.07	15.47	15.88	16.30	16.74	17.19	17.64	18.12	18.61	19.11	19.63	20.16	20.70	21.26	21.84	22.43	23.03	23.65	24.29	24.95	25.62	26.31
Hard Rock	2	2.02	2.08	2.13	2.19	2.25	2.31	2.37	2.43	2.50	2.57	2.64	2.71	2.78	2.85	2.93	3.01	3.09	3.18	3.26	3.35	3.44	3.53
Hopi Civic Center	only well	3.80	3.90	4.01	4.11	4.22	4.33	4.45	4.57	4.69	4.82	4.95	5.08	5.22	5.36	5.51	5.66	5.81	5.97	6.13	6.29	6.46	6.64
Hopi Cultural Center	only well	11.95	12.26	12.59	12.92	13.27	13.62	13.99	14.37	14.75	15.15	15.56	15.98	16.41	16.86	17.31	17.78	18.26	18.75	19.26	19.78	20.31	20.86
Hopi High School	No. 1	4.28	4.40	4.52	4.63	4.76	4.89	5.02	5.15	5.29	5.43	5.58	5.73	5.88	6.04	6.21	6.38	6.55	6.72	6.91	7.09	7.28	7.48
Hopi High School	No. 2	6.52	6.70	6.87	7.06	7.25	7.44	7.64	7.84	8.05	8.27	8.50	8.73	8.96	9.20	9.45	9.71	9.97	10.24	10.51	10.80	11.09	11.39
Hopi High School	No. 3	13.64	13.99	14.36	14.75	15.14	15.54	15.96	16.39	16.83	17.29	17.75	18.23	18.73	19.23	19.75	20.28	20.83	21.39	21.97	22.56	23.17	23.80
Hotevilla	PM1	11.15	11.45	11.75	12.06	12.39	12.72	13.06	13.41	13.77	14.14	14.53	14.92	15.32	15.73	16.16	16.60	17.04	17.50	17.98	18.46	18.96	19.47
Hotevilla	PM2	25.22	25.88	26.57	27.27	28.00	28.75	29.52	30.32	31.13	31.97	32.83	33.72	34.63	35.57	36.53	37.52	38.53	39.57	40.64	41.74	42.86	44.02
Kayenta	1	87.69	90.00	92.38	94.83	97.36	99.96	102.64	105.40	108.25	111.17	114.17	117.26	120.42	123.67	127.01	130.44	133.96	137.58	141.29	145.11	149.03	153.05
Kayenta	2	73.00	74.93	76.91	78.96	81.06	83.23	85.46	87.76	90.13	92.56	95.06	97.63	100.26	102.97	105.75	108.60	111.54	114.55	117.64	120.82	124.08	127.43
Kayenta	3	89.75	92.11	94.55	97.06	99.65	102.31	105.06	107.88	110.80	113.79	116.86	120.02	123.26	126.58	130.00	133.51	137.12	140.82	144.62	148.53	152.53	156.65
Kayenta	4	108.93	111.81	114.76	117.81	120.95	124.18	127.51	130.95	134.48	138.11	141.84	145.67	149.60	153.64	157.79	162.05	166.43	170.92	175.54	180.28	185.14	190.14
Kayenta	5	158.85	163.04	167.35	171.79	176.37	181.08	185.94	190.95	196.10	201.39	206.83	212.42	218.15	224.04	230.09	236.31	242.68	249.24	255.97	262.88	269.98	277.27
Kayenta	6	85.22	87.46	89.78	92.16	94.61	97.14	99.75	102.43	105.20	108.04	110.96	113.95	117.03	120.19	123.43	126.77	130.19	133.71	137.31	141.02	144.83	148.74
Kayenta	7	87.34	89.65	92.02	94.47	96.98	99.57	102.24	105.00	107.83	110.74	113.73	116.80	119.96	123.20	126.52	129.94	133.45	137.05	140.75	144.55	148.45	152.46
Kayenta	PM2	60.94	62.55	64.20	65.90	67.66	69.47	71.33	73.25	75.23	77.26	79.35	81.49	83.69	85.95	88.27	90.65	93.10	95.61	98.20	100.85	103.57	106.37
Kayenta	PM3	50.26	51.58	52.95	54.35	55.80	57.29	58.83	60.41	62.04	63.72	65.44	67.21	69.02	70.88	72.80	74.76	76.78	78.86	80.98	83.17	85.42	87.72
Kearns Canyon	No. 2	25.85	26.53	27.24	27.96	28.70	29.47	30.26	31.08	31.91	32.78	33.66	34.57	35.50	36.46	37.45	38.46	39.50	40.56	41.66	42.78	43.94	45.12
Kearns Canyon	No. 3	14.47	14.85	15.25	15.65	16.07	16.50	16.94	17.40	17.87	18.35	18.84	19.35	19.87	20.41	20.96	21.53	22.11	22.71	23.32	23.95	24.60	25.26
Kitsillie	1	8.83	9.06	9.30	9.55	9.80	10.06	10.33	10.61	10.90	11.19	11.49	11.80	12.12	12.45	12.79	13.13	13.49	13.85	14.22	14.61	15.00	15.41
Kitsillie	2	13.76	13.99	14.23	14.48	14.73	14.99	15.26	15.54	15.83	16.12	16.42	16.73	17.05	17.38	17.71	18.06	18.42	18.78	19.15	19.54	19.93	20.34
Kykotsmovi	PM1	38.05	39.06	40.09	41.16	42.25	43.38	44.54	45.74	46.98	48.25	49.55	50.89	52.26	53.67	55.12	56.61	58.14	59.71	61.32	62.98	64.67	66.42
Kykotsmovi	PM2	43.32	44.46	45.64	46.85	48.10	49.38	50.71	52.07	53.48	54.92	56.41	57.93	59.49	61.10	62.75	64.44	66.19	67.97	69.81	71.69	73.63	75.62
Kykotsmovi	PM3	31.08	31.90	32.75	33.62	34.51	35.43	36.39	37.36	38.37	39.41	40.47	41.56	42.69	43.84	45.02	46.24	47.49	48.77	50.09	51.44	52.83	54.26
Low Mountain	PM2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mishongnovi	only well	8.63	8.86	9.09	9.33	9.58	9.84	10.10	10.38	10.65	10.94	11.24	11.54	11.85	12.17	12.50	12.84	13.19	13.54	13.91	14.28	14.67	15.07
Pinon	1	69.89	71.74	73.63	75.59	77.60	79.68	81.82	84.02	86.28	88.61	91.01	93.47	95.99	98.58	101.24	103.98	106.78	109.66	112.63	115.67	118.79	122.00
Pinon	2	58.60	60.14	61.74	63.38	65.07	66.80	68.60	70.44	72.34	74.30	76.30	78.36	80.48	82.65	84.88	87.18	89.53	91.95	94.43	96.98	99.60	102.29
Pinon	3	21.96	22.54	23.13	23.74	24.38	25.03	25.70	26.39	27.11	27.84	28.59	29.36	30.16	30.97	31.80	32.66	33.55	34.45	35.38	36.34	37.32	38.32
Pinon	PM6	21.55	56.65	58.15	59.70	61.29	62.92	64.61	66.35	68.14	69.98	71.87	73.81	75.81	77.85	79.95	82.11	84.33	86.61	88.95	91.35	93.81	96.35
Polacca	PM4	55.20	56.65	58.15	59.70	61.29	62.92	64.61	66.35	68.14	69.98	71.87	73.81	75.81	77.85	79.95	82.11	84.33	86.61	88.95	91.35	93.81	96.35
Polacca	PM5	108.82	111.69	114.64	117.69	120.82	124.05	127.38	130.81	134.34	137.97	141.69	145.52	149.45	153.48	157.62	161.88	166.25	170.74	175.35	180.08	184.95	189.94
Polacca	PM6	9.83	10.09	10.35	10.63	10.91	11.21	11.51	11.82	12.13	12.46	12.80	13.14	13.50	13.86	14.24	14.62	15.02	15.42	15.84	16.27	16.71	17.16
Rocky Ridge	PM2	11.16	11.46	11.76	12.07	12.39	12.73	13.07	13.42	13.78	14.15	14.54	14.93	15.33	15.75	16.17	16.61	17.06	17.52	17.99	18.47	18.97	19.49
Rocky Ridge	PM3	16.54	16.98	17.43	17.89	18.37	18.86	19.36	19.88	20.42	20.97	21.54	22.12	22.72	23.33	23.96	24.61	25.27	25.95	26.66	27.37	28.12	28.87
Rough Rock	1	15.52	15.91	16.31	16.73	17.16	17.61	18.07	18.55	19.06	19.57	20.10	20.64	21.20	21.77	22.36	22.96	23.58	24.22	24.87	25.54	26.23	26.94
Rough Rock	PM3	5.21	5.34	5.47	5.61	5.76	5.91	6.06	6.23	6.40	6.57	6.75	6.93	7.12	7.31	7.50	7.71	7.91	8.13	8.35	8.57	8.81	9.04
Rough Rock	PM5	14.10	14.46	14.82	15.20	15.59	16.00	16.42	16.86	17.32	17.79	18.27	18.76	19.27	19.79	20.32	20.87	21.43	22.01	22.60	23.22	23.84	24.49
Rough Rock	PM6	23.15	23.73	24.33	24.95	25.60	26.27	26.96	27.68	28.43	29.20	29.99	30.79	31.63	32.48	33.36	34.26	35.18	36.13	37.11	38.11	39.14	40.20
Rough Rock	PM7	4.19	4.30	4.40	4.52	4.63	4.76	4.88	5.01	5.15	5.29	5.43	5.58	5.73	5.88	6.04	6.20	6.37	6.54	6.72	6.90	7.09	7.28
Second Mesa	No. 1	0.29	0.30	0.30	0.31	0.32	0.33	0.34	0.35	0.36	0.36	0.38	0.38	0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.48	0.49	0.50
Second Mesa	PM2	5.52	5.66	5.81	5.96	6.12	6.29	6.46	6.63	6.81	6.99	7.18	7.38	7.57	7.78	7.99	8.21	8.43	8.66	8.89	9.13	9.37	9.63
Shipaulovi	No. 2	54.66	56.10	57.59	59.11	60.69	62.31	63.98	65.70	67.48	69.30	71.17	73.09	75.07	77.09	79.18	81.31	83.51	85.76	88.08	90.46	92.90	95.41
Shungopovi	only well	30.15	30.95	31.77	32.61	33.48	34.37	35.29	36.24	37.22	38.23	39.26	40.32	41.41	42.53	43.68	44.85	46.06	47.31	48.58	49.90	51.24	52.63

Annual PWCC Portion of Drawdown at Community Wells Located in the Confined Portion of the N Aquifer

Community Name	Well ID	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Bacavi	only well	30.4	31.4	32.2	33.0	33.7	34.3	34.8	35.2	35.4	35.6	35.7	35.7	35.6	35.5	35.3	35.1	34.8	34.5	34.2	33.9	33.5	33.1
Chilchinbito	1	70.0	68.9	67.1	64.9	62.6	60.2	58.0	55.9	53.9	52.1	50.5	49.0	47.7	46.5	45.4	44.5	43.6	42.7	42.0	41.2	40.3	39.2
Chilchinbito	2	53.3	52.6	51.3	49.7	47.9	46.2	44.4	42.8	41.3	39.9	38.7	37.6	36.5	35.6	34.8	34.1	33.4	32.8	32.2	31.6	31.0	30.2
Chilchinbito	PM2	6.7	6.7	6.5	6.4	6.2	6.0	5.8	5.6	5.5	5.3	5.2	5.1	5.0	4.9	4.8	4.7	4.6	4.6	4.5	4.5	4.4	4.3
Chilchinbito	PM3	70.0	68.9	67.1	64.9	62.6	60.2	58.0	55.9	53.9	52.1	50.5	49.0	47.7	46.5	45.4	44.5	43.6	42.7	42.0	41.2	40.3	39.2
Forest Lake	4T-523	174.1	165.1	157.4	150.8	145.0	140.0	135.6	131.6	128.0	124.8	121.8	119.2	116.7	114.4	112.3	110.4	108.6	107.0	105.0	102.2	99.2	95.5
Hard Rock	2	108.2	107.9	106.9	105.5	103.8	102.0	100.1	98.2	96.3	94.4	92.6	90.8	89.1	87.5	85.9	84.4	82.9	81.6	80.2	78.9	77.5	76.1
Hopi Civic Center	only well	27.2	28.1	29.0	29.8	30.5	31.1	31.7	32.1	32.4	32.7	32.8	32.9	33.0	32.9	32.8	32.7	32.5	32.3	32.0	31.7	31.4	31.1
Hopi Cultural Center	only well	23.3	24.1	24.9	25.7	26.3	27.0	27.5	28.0	28.4	28.7	29.0	29.1	29.2	29.3	29.2	29.2	29.1	28.9	28.7	28.5	28.2	28.0
Hopi High School	No. 1	8.9	9.3	9.5	9.8	10.1	10.4	10.6	10.8	11.0	11.1	11.2	11.3	11.4	11.4	11.4	11.3	11.3	11.2	11.2	11.1	11.0	10.9
Hopi High School	No. 2	8.7	9.0	9.3	9.6	9.9	10.1	10.3	10.5	10.7	10.8	10.9	11.0	11.0	11.0	11.0	11.0	11.0	10.9	10.8	10.7	10.6	10.5
Hopi High School	No. 3	9.8	10.2	10.6	10.9	11.3	11.6	11.9	12.1	12.3	12.5	12.7	12.8	12.9	13.0	13.1	13.1	13.1	13.1	13.0	13.0	13.0	12.9
Hotevilla	PM1	31.6	32.6	33.5	34.3	35.0	35.6	36.0	36.4	36.6	36.8	36.8	36.8	36.7	36.5	36.4	36.1	35.8	35.5	35.1	34.8	34.4	34.0
Hotevilla	PM2	28.5	29.4	30.3	31.1	31.8	32.3	32.8	33.2	33.5	33.7	33.8	33.9	33.8	33.7	33.6	33.4	33.2	32.9	32.6	32.3	32.0	31.6
Kayenta	1	25.8	25.3	24.7	23.9	23.2	23.0	22.9	22.9	22.7	21.6	20.8	20.2	19.7	18.8	17.1	16.1	15.7	15.6	15.5	15.8	16.3	16.5
Kayenta	2	13.4	13.8	14.1	14.4	14.6	14.9	15.1	15.3	15.6	15.9	16.1	16.2	16.4	16.5	16.3	16.1	15.9	15.7	15.5	15.3	15.0	14.7
Kayenta	3	22.2	22.0	21.8	21.4	21.0	21.4	21.4	21.5	21.6	21.0	20.4	20.0	19.7	18.7	17.5	16.8	16.4	16.3	16.2	15.8	15.6	15.3
Kayenta	4	25.6	25.1	24.3	23.5	22.7	22.3	22.2	22.2	21.9	20.6	19.5	18.9	18.3	17.6	15.0	13.4	12.7	12.6	12.4	13.5	15.0	15.8
Kayenta	5	29.9	29.3	28.6	27.8	27.0	26.8	26.6	26.5	26.2	25.4	24.5	23.9	23.4	22.4	21.0	20.2	19.8	19.7	19.5	19.4	19.4	19.2
Kayenta	6	25.7	25.3	24.9	24.2	23.5	22.7	22.3	22.1	21.9	21.8	21.5	21.1	20.7	20.2	19.7	19.3	19.0	18.8	18.6	18.5	18.4	18.3
Kayenta	7	10.3	10.5	10.7	10.8	10.9	10.9	11.0	11.0	11.1	11.2	11.3	11.3	11.4	11.4	11.3	11.2	11.0	10.8	10.7	10.6	10.6	10.5
Kayenta	PM2	15.5	15.8	16.2	16.6	16.9	17.3	17.7	18.1	18.7	19.2	19.7	20.0	20.3	20.5	20.3	20.0	19.7	19.4	19.1	18.8	18.3	17.8
Kayenta	PM3	15.5	15.8	16.2	16.6	16.9	17.3	17.7	18.1	18.7	19.2	19.7	20.0	20.3	20.5	20.3	20.0	19.7	19.4	19.1	18.8	18.3	17.8
Kearns Canyon	No. 2	9.4	9.8	10.1	10.4	10.7	10.9	11.2	11.4	11.5	11.6	11.7	11.8	11.8	11.8	11.8	11.8	11.7	11.6	11.6	11.5	11.4	11.3
Kearns Canyon	No. 3	9.4	9.8	10.1	10.4	10.7	10.9	11.2	11.4	11.5	11.6	11.7	11.8	11.8	11.8	11.8	11.8	11.7	11.6	11.6	11.5	11.4	11.3
Kitsillie	1	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Kitsillie	2	71.7	71.8	71.4	70.5	69.2	67.7	66.0	64.3	62.6	60.9	59.3	57.8	56.3	54.9	53.6	52.4	51.2	50.2	49.2	48.2	47.3	46.3
Kykotsmovi	PM1	27.0	27.9	28.7	29.6	30.3	31.0	31.6	32.1	32.4	32.7	33.0	33.1	33.2	33.2	33.1	33.1	32.9	32.7	32.5	32.3	32.0	31.7
Kykotsmovi	PM2	0.2	23.8	24.5	25.2	25.8	26.4	26.9	27.3	27.6	27.9	28.1	28.1	28.2	28.2	28.1	28.0	27.9	27.7	27.5	27.2	27.0	26.7
Kykotsmovi	PM3	25.6	26.5	27.3	28.0	28.7	29.3	29.8	30.2	30.5	30.8	30.9	31.0	31.0	31.0	30.9	30.8	30.6	30.4	30.1	29.9	29.6	29.2
Low Mountain	PM2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mishongnovi	only well	16.1	16.7	17.3	17.9	18.5	19.0	19.5	19.9	20.3	20.7	20.9	21.2	21.4	21.5	21.6	21.6	21.6	21.5	21.4	21.3	21.1	20.9
Pinon	1	67.2	68.3	69.0	69.3	69.2	68.9	68.3	67.6	66.8	65.8	64.8	63.7	62.7	61.6	60.5	59.5	58.4	57.4	56.4	55.5	54.6	53.6
Pinon	2	57.7	58.8	59.6	60.0	60.2	60.1	59.8	59.3	58.7	57.9	57.1	56.3	55.4	54.5	53.5	52.6	51.7	50.9	50.0	49.1	48.3	47.5
Pinon	3	39.0	39.9	40.6	41.2	41.5	41.7	41.6	41.5	41.2	40.8	40.3	39.8	39.2	38.6	38.1	37.5	36.8	36.3	35.7	35.1	34.5	34.0
Pinon	PM6	77.3	78.2	78.7	78.7	78.3	77.7	76.8	75.8	74.7	73.5	72.3	71.0	69.7	68.5	67.3	66.0	64.9	63.7	62.6	61.6	60.5	59.4
Polacca	PM4	17.6	18.2	18.8	19.4	19.9	20.4	20.9	21.3	21.6	21.9	22.1	22.2	22.3	22.4	22.4	22.3	22.3	22.1	22.0	21.9	21.7	21.5
Polacca	PM5	0.5	0.5	0.5	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Polacca	PM6	0.5	0.5	0.5	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Rocky Ridge	PM2	98.5	98.7	98.3	97.4	96.2	94.8	93.2	91.7	90.0	88.4	86.8	85.2	83.7	82.2	80.8	79.4	78.1	76.8	75.6	74.3	73.1	71.8
Rocky Ridge	PM3	98.5	98.7	98.3	97.4	96.2	94.8	93.2	91.7	90.0	88.4	86.8	85.2	83.7	82.2	80.8	79.4	78.1	76.8	75.6	74.3	73.1	71.8
Rough Rock	1	11.8	12.1	12.2	12.3	12.2	12.1	11.9	11.7	11.5	11.3	11.0	10.7	10.5	10.2	10.0	9.8	9.5	9.4	9.2	9.0	8.9	8.7
Rough Rock	PM3	11.2	11.4	11.5	11.5	11.5	11.4	11.3	11.1	10.9	10.6	10.4	10.2	9.9	9.7	9.5	9.3	9.1	8.9	8.7	8.6	8.4	8.3
Rough Rock	PM5	10.3	10.4	10.6	10.7	10.6	10.6	10.4	10.3	10.1	9.9	9.6	9.4	9.2	9.0	8.8	8.6	8.4	8.3	8.1	8.0	7.8	7.7
Rough Rock	PM6	8.2	8.4	8.5	8.6	8.6	8.5	8.4	8.3	8.2	8.0	7.8	7.6	7.5	7.3	7.2	7.0	6.9	6.7	6.6	6.5	6.4	6.3
Rough Rock	PM7	11.2	11.4	11.5	11.5	11.5	11.4	11.3	11.1	10.9	10.6	10.4	10.2	9.9	9.7	9.5	9.3	9.1	8.9	8.7	8.6	8.4	8.3
Second Mesa	No. 1	13.3	13.7	14.3	14.8	15.3	15.7	16.2	16.6	16.9	17.3	17.5	17.7	17.9	18.1	18.2	18.2	18.2	18.2	18.2	18.1	17.9	17.7
Second Mesa	PM2	15.3	15.8	0.2	17.0	17.5	18.0	18.5	18.9	19.3	19.6	19.9	20.1	20.3	20.4	20.5	20.6	20.6	20.5	20.5	20.3	20.2	20.0
Shipaulovi	No. 2	15.3	15.8	0.2	17.0	17.5	18.0	18.5	18.9	19.3	19.6	19.9	20.1	20.3	20.4	20.5	20.6	20.6	20.5	20.5	20.3	20.2	20.0
Shungopovi	only well	11.8	12.2	12.7	13.1	13.5	13.8	14.2	14.5	14.8	15.0	15.2	15.3	15.4	15.5	15.5	15.5	15.5	15.4	15.3	15.2	15.1	15.0

Annual PWCC Portion of Drawdown at Community Wells Located in the Confined Portion of the N Aquif

Community Name	Well ID	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	198
Bacavi	only well	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.9	1.3	1.8	2.5	3.2	4.0	4.9	5.9	6.9	7.9	9.0	10.
Chilchinbito	1	0.0	0.1	0.2	0.5	1.2	2.6	5.0	8.0	11.5	15.2	19.0	22.8	26.1	29.2	32.0	34.7	37.5	40.2	42.7	44.8	46.6	48.
Chilchinbito	2	0.0	0.0	0.1	0.3	0.8	1.8	3.4	5.7	8.3	11.1	13.9	16.8	19.5	21.9	24.0	26.1	28.2	30.3	32.2	33.8	35.2	36.
Chilchinbito	PM2	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.6	1.9	2.2	2.5	2.8	3.1	3.3	3.6	3.8	4.0	4.2	4.
Chilchinbito	PM3	0.0	0.1	0.2	0.5	1.2	2.6	5.0	8.0	11.5	15.2	19.0	22.8	26.1	29.2	32.0	34.7	37.5	40.2	42.7	44.8	46.6	48.
Forest Lake	4T-523	0.4	1.3	2.7	6.2	15.0	28.2	41.7	53.8	65.2	76.1	83.9	89.4	94.8	100.5	107.4	115.7	123.6	128.0	130.0	135.5	141.1	145.
Hard Rock	2	0.0	0.1	0.2	0.4	1.0	2.4	4.7	7.8	11.5	15.6	19.8	24.1	28.2	32.1	36.0	39.9	44.0	48.1	52.0	55.5	59.1	62.
Hopi Civic Center	only well	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.9	1.3	1.9	2.5	3.1	3.9	4.7	5.5	6.5	7.4	8.
Hopi Cultural Center	only well	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.6	0.9	1.3	1.7	2.2	2.8	3.5	4.2	4.9	5.7	6.
Hopi High School	No. 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.
Hopi High School	No. 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.
Hopi High School	No. 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.8	1.0	1.3	1.5	1.9	2.2	2.
Hotevilla	PM1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.6	0.9	1.4	2.0	2.7	3.5	4.3	5.2	6.3	7.3	8.4	9.5	10.
Hotevilla	PM2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.7	1.1	1.6	2.2	2.9	3.6	4.4	5.2	6.2	7.2	8.2	9.
Kayenta	1	0.0	0.1	0.2	0.4	0.9	1.9	3.2	4.8	6.2	7.5	9.1	10.6	11.9	13.1	14.3	15.6	17.0	18.3	19.4	17.5	17.9	19.
Kayenta	2	0.0	0.0	0.0	0.1	0.3	0.4	0.8	1.2	1.6	2.0	2.5	3.0	3.6	4.1	4.7	5.3	6.0	6.6	7.3	7.4	7.8	8.
Kayenta	3	0.0	0.0	0.1	0.3	0.7	1.3	2.3	3.4	4.3	5.2	6.3	7.4	8.5	9.4	10.4	11.5	12.6	13.6	14.6	13.9	14.3	15.
Kayenta	4	0.0	0.1	0.2	0.4	1.0	2.0	3.5	5.1	6.6	8.1	9.7	11.3	12.7	14.0	15.2	16.6	18.0	19.4	20.5	17.8	18.2	20.
Kayenta	5	0.0	0.1	0.2	0.5	1.0	2.2	3.7	5.4	7.1	8.6	10.3	12.0	13.5	14.8	16.1	17.6	19.2	20.6	21.7	20.3	20.6	22.
Kayenta	6	0.0	0.1	0.2	0.5	1.2	2.5	4.3	6.3	8.3	10.2	12.1	14.1	15.8	17.3	18.7	20.2	21.9	23.4	24.7	13.3	14.7	21.
Kayenta	7	0.0	0.0	0.1	0.1	0.3	0.7	1.1	1.6	0.5	0.9	1.2	1.6	2.1	2.5	3.0	3.4	3.9	4.4	5.0	5.3	5.6	6.0
Kayenta	PM2	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.8	1.1	1.4	1.8	2.3	2.8	3.3	3.9	4.5	5.2	5.8	6.5	7.0	7.5
Kayenta	PM3	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.5	0.8	1.1	1.4	1.8	2.3	2.8	3.3	3.9	4.5	5.2	5.8	6.5	7.0	7.5
Kearns Canyon	No. 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.9	1.1	1.3	1.6	2.0	2.3	2.6
Kearns Canyon	No. 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.9	1.1	1.3	1.6	2.0	2.3	2.6
Kitsillie	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Kitsillie	2	0.0	0.0	0.1	0.2	0.5	1.1	2.3	4.1	6.5	9.2	12.3	15.5	18.6	21.7	24.6	27.4	30.2	33.0	35.8	38.3	40.7	43.0
Kykotsmovi	PM1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.6	0.9	1.2	1.8	2.3	3.0	3.7	4.5	5.3	6.2	7.2	8.1
Kykotsmovi	PM2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.4	0.7	1.0	1.4	1.9	2.5	3.1	3.7	4.5	5.2	6.0	6.9
Kykotsmovi	PM3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.6	0.9	1.2	1.7	2.3	3.0	3.6	4.4	5.2	6.1	7.0	7.9
Low Mountain	PM2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.7	1.0	1.2	1.5	1.8	2.2	2.5	2.9	3.2
Mishongnovi	only well	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.6	0.8	1.1	1.4	1.8	2.3	2.7	3.2	3.8
Pinon	1	0.0	0.0	0.0	0.1	0.2	0.4	0.9	1.7	2.9	4.5	6.3	8.4	10.7	13.1	15.5	17.9	20.4	22.9	25.5	28.0	30.5	32.9
Pinon	2	0.0	0.0	0.0	0.0	0.1	0.2	0.6	1.1	2.0	3.1	4.6	6.3	8.1	10.1	12.1	14.2	16.3	18.5	20.7	22.9	25.1	27.2
Pinon	3	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.9	1.5	2.3	0.0	4.4	5.7	7.0	8.4	9.8	11.3	12.7	14.2	15.7	17.2
Pinon	PM6	0.0	0.0	0.0	0.1	0.3	0.6	1.4	2.6	4.2	6.3	8.7	11.3	14.1	16.9	19.6	22.4	25.3	28.2	31.2	34.0	36.8	39.5
Polacca	PM4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.8	1.1	1.4	1.9	2.4	2.9	3.4	4.0	4.7
Polacca	PM5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Polacca	PM6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Rocky Ridge	PM2	0.0	0.0	0.1	0.3	0.7	1.7	3.4	5.8	8.8	12.2	15.8	19.6	23.3	26.8	30.3	33.9	37.5	41.2	44.8	48.2	51.5	54.8
Rocky Ridge	PM3	0.0	0.0	0.1	0.3	0.7	1.7	3.4	5.8	8.8	12.2	15.8	19.6	23.3	26.8	30.3	33.9	37.5	41.2	44.8	48.2	51.5	54.8
Rough Rock	1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.8	1.1	1.5	2.0	2.5	3.1	3.5	4.0	4.5	5.0	5.5	6.0	6.4
Rough Rock	PM3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.7	1.0	1.4	1.8	2.3	2.8	0.0	3.7	4.2	4.7	5.1	5.5	5.9
Rough Rock	PM5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.6	2.1	2.5	3.0	3.4	3.8	4.2	4.6	5.0	5.4
Rough Rock	PM6	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.5	0.7	1.0	1.3	1.6	2.0	2.3	2.7	3.0	3.3	3.7	4.0	4.3
Rough Rock	PM7	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.7	1.0	1.4	1.8	2.3	2.8	0.0	3.7	4.2	4.7	5.1	5.5	5.9
Second Mesa	No. 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.4	0.6	0.8	1.0	1.3	1.7	2.0	2.5	2.9
Second Mesa	PM2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.7	1.0	1.3	1.7	2.1	2.5	3.0	3.5
Shipaulovi	No. 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.7	1.0	1.3	1.7	2.1	2.5	3.0	3.5
Shungopovi	only well	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.6	0.8	1.1	1.4	1.7	2.1	2.5	2.9