APPENDIX 1

Hydrological Data

Table A1.1 – Monthly streamflow series – Malibamatso River at Katse Dam (MCM)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
1930	28.42	12.06	32.58	112.84	67.94	69.45	162.98	22.95	1.49	20.87	5.32	1.09	538.0
1931	14.30	47.76	21.56	22.67	127.57	96.74	14.50	4.45	2.58	1.98	1.25	3.46	358.8
1932	4.43	59.96	40.76	10.85	35.72	41.85	10.39	3.75	2.75	3.60	2.41	1.69	218.2
1933	2.93	150.85	162.76	244.14	123.30	100.24	79.05	74.70	31.61	54.66	42.22	7.12	1073.6
1934	46.19	205.00	112.71	33.87	35.69	67.28	28.22	12.70	4.96	2.41	5.26	3.75	558.1
1935	10.74	14.88	33.30	30.87	59.79	75.53	12.73	48.39	8.49	2.31	1.45	1.36	299.8
1936	53.98	244.80	69.64	176.15	183.71	83.84	12.03	1.99	0.96	1.79	1.25	0.86	831.0
1937	9.49	10.92	22.49	149.82	147.68	21.92	61.24	12.69	40.01	14.34	51.07	14.14	555.8
1938	54.25	17.02	74.77	86.56	213.63	46.17	5.93	24.25	6.43	17.95	17.42	8.80	573.2
1939	52.66	130.40	51.90	54.53	57.51	54.33	88.03	75.36	12.98	3.20	2.18	45.43	628.5
1940	10.47	75.67	96.00	108.94	97.79	29.65	52.66	9.09	1.19	4.10	2.81	8.30	496.7
1941	83.77	15.28	8.90	77.56	99.72	111.11	60.30	11.71	2.75	6.09	27.41	11.26	515.8
1942	65.06	89.33	111.52	109.72	29.30	74.48	78.36	82.26	15.78	149.98	67.99	10.58	884.4
1943	206.46	157.40	145.90	67.49	123.91	48.00	6.08	5.37	69.21	11.86	1.88	59.49	903.0
1944	65.03	44.68	10.39	11.57	68.39	186.21	44.76	12.21	4.64	1.95	1.32	0.86	452.0
1945	4.81	9.53	10.25	80.96	53.74	95.69	19.62	32.67	6.94	2.68	1.65	1.46	320.0
1946	140.73	94.95	24.45	18.89	68.09	62.05	61.05	10.25	4.88	5.19	2.70	26.16	519.4
1947	57.17	62.77	90.46	73.51	52.40	244.24	78.81	9.80	1.56	1.35	1.52	1.96	675.6
1948	30.18	9.59	6.59	64.27	35.79	97.34	70.61	14.62	3.05	2.38	2.48	4.80	341.7
1949	21.50	40.28	53.34	46.68	93.13	165.78	105.16	55.89	8.64	16.96	90.59	15.72	713.7
1950	11.32	11.67	74.24	64.03	74.53	49.12	43.27	12.45	5.57	2.91	7.80	6.28	363.2
1951	158.62	27.35	14.43	63.94	154.26	68.01	23.68	4.83	2.15	23.46	22.27	7.46	570.4
1952	7.58	40.73	39.24	29.91	158.41	30.84	19.02	6.54	2.65	1.55	5.17	3.55	345.2
1953	63.44	27.54	54.02	56.38	60.66	66.69	14.48	10.47	5.51	2.64	1.55	3.59	367.0
1954	4.42	30.20	26.34	165.64	204.66	37.26	33.03	24.27	5.71	3.27	2.18	1.36	538.3
1955	11.06	65.56	81.43	34.74	144.48	74.82	30.73	26.82	5.46	2.31	1.88	4.29	483.6
1956	74.76	120.01	222.70	118.19	48.34	92.17	26.09	4.45	9.16	21.12	29.65	240.62	1007.3
1957	269.63	72.95	45.54	175.48	37.31	24.46	66.59	32.15	6.60	1.94	1.25	15.39	749.3
1958	17.73	71.00	41.89	18.35	44.75	18.53	96.50	191.48	25.69	44.25	9.21	1.89	581.3
1959	103.72	70.89	96.94	49.45	123.39	101.16	46.50	9.79	3.24	4.03	13.31	8.92	631.3
1960	61.62	78.48	90.40	85.66	24.86	78.17	111.34	53.60	31.92	8.78	4.46	7.19	636.5
1961	2.79	105.59	59.55	61.81	177.36	65.42	44.20	8.20	1.52	0.99	2.28	3.49	533.2
1962	6.24	65.10	30.01	176.89	85.52	92.02	99.36	18.82	18.16	11.50	4.52	2.02	610.2
1963	33.30	65.93	42.47	108.76	38.70	142.68	36.69	4.95	26.43	5.84	4.76	6.79	517.3
1964	176.91	37.64	60.18	72.69	14.43	21.38	60.24	10.59	16.50	8.59	16.37	5.58	501.1
1965	10.14	36.05	12.46	166.26	85.59	21.72	7.42	4.24	3.11	1.98	2.83	2.72	354.5
1966	9.53	32.62	44.13	247.31	150.17	97.35	76.71	29.01	6.27	3.19	4.77	2.62	703.7
1967	1.85	91.56	68.74	16.32	5.87	25.52	25.01	82.98	8.76	5.98	4.00	6.05	342.6
1968	12.22	11.33	58.94	6.10	5.21	27.17	55.00	29.20	24.49	4.96	4.01	2.96	241.6
1969	75.61	29.72	39.56	39.95	46.18	3.60	2.11	1.72	0.96	1.00	1.03	17.82	259.3
1970	89.45	41.30	76.60	103.88	54.60	42.87	69.11	20.20	3.73	2.99	1.52	0.66	506.9
1971	1.65	10.72	25.50	106.11	111.82	152.12	20.77	27.92	7.04	2.83	1.59	1.55	469.6
1972	14.97	50.11	3.83	0.66	103.02	31.83	34.95	5.10	2.24	0.97	51.01	28.64	327.3
1973	30.77	31.01	71.51	107.18	115.16	23.98	41.10	15.24	16.88	6.26	10.97	11.46	481.5
1974	3.60	228.34	46.85	117.48	142.38	148.76	19.11	10.27	3.34	5.10	2.01	50.81	778.0
1975	77.42	252.16	113.31	204.24	190.59	113.48	56.94	32.82	48.15	9.22	4.32	18.24	1120.9
1976	225.21	211.43	13.33	63.29	120.71	190.46	20.85	10.01	3.46	2.02	1.37	6.41	868.6
1977	120.06	39.33	14.72	232.19	51.78	46.25	223.89	14.85	4.20	2.72	2.84	64.13	817.0
1978	60.36	26.33	164.31	33.42	26.90	27.63	3.10	8.75	10.33	31.14	157.03	92.32	641.6
1979	128.66	58.99	121.38	30.82	76.52	18.64	4.74	2.43	1.57	0.83	0.73	18.14	463.4
1980	24.02	73.03	52.09	247.90	64.46	95.98	63.81	24.01	35.73	4.41	33.75	33.92	753.1
1981	7.91	65.18	116.38	11.93	10.38	13.64	104.29	18.84	3.72	4.13	2.20	3.98	362.6
1982	53.65	158.69	14.54	5.14	10.44	18.00	5.81	17.07	8.65	2.63	4.60	3.12	302.3
1983	20.17	30.60	46.19	58.14	5.95	12.62	13.70	20.70	2.12	1.70	1.10	20.60	233.6
1984	14.76	44.29	22.18	11.33	102.85	54.98	11.88	1.92	0.83	0.75	0.20	0.13	266.1
1985	21.03	90.99	198.42	20.10	66.40	13.16	37.64	7.17	21.00	2.65	9.98	32.40	521.0
1986	133.20	240.45	22.64	19.71	20.13	23.87	61.67	4.32	1.29	1.03	44.75	271.68	844.7
1987	178.16	124.01	107.97	72.00	71.20	355.59	59.69	22.34	22.66	22.07	8.90	89.58	1134.2
1988	84.67	104.89	153.34	76.51	236.10	54.04	34.35	46.15	99.39	27.62	8.47	3.85	929.4
1989	15.31	139.10	52.27	16.56	54.94	47.91	124.15	36.85	7.89	14.27	26.89	8.33	544.5
1990	7.01	5.44	14.35	104.31	141.15	78.06	7.24	2.29	1.69	1.33	0.30	2.94	366.1
1991	140.24	50.35	24.61	8.65	2.44	5.25	3.12	0.79	0.13	0.13	0.60	7.63	243.9
1992	16.40	129.13	16.24	11.76	47.71	37.04	82.12	9.09	3.24	1.96	3.73	1.91	360.3
1993	142.47	57.96	93.71	117.50	167.36	45.67	81.74	30.18	4.50	2.80	2.25	1.49	747.6
1994	1.51	9.73	3.78	19.42	43.80	20.39	21.32	25.65	4.37	2.57	2.22	1.86	156.6
1995	11.43	27.87	106.47	108.10	115.85	132.07	10.57	10.85	10.87	20.00	17.39	8.75	580.2
AVE.	56.05	74.04	61.82	79.52	85.06	71.43	48.30	22.99	11.66	10.00	13.24	20.66	554.8
SDV.	62.14	63.71	49.14	65.27	57.35	60.94	41.18	28.81	16.83	20.34	25.06	46.33	232.3

Table A1.2 – Monthly streamflow series – Senqunyane River at Mohale Dam (MCM)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
1930	7.68	4.75	7.59	29.34	38.23	33.05	114.68	20.54	1.64	30.98	6.47	0.60	295.6
1931	28.74	54.45	10.53	9.84	40.99	54.28	9.15	5.87	2.59	1.98	1.29	5.09	224.8
1932	2.16	11.05	22.26	4.14	3.02	13.89	5.78	1.98	2.33	3.88	1.98	0.95	73.4
1933	0.52	96.30	98.11	181.73	52.47	50.48	67.05	57.99	10.96	14.67	13.63	2.85	646.8
1934	23.99	68.26	31.76	11.82	40.73	72.74	48.41	15.36	5.87	2.33	7.68	1.98	330.9
1935	6.04	21.75	44.44	11.48	37.28	29.77	5.52	15.79	3.62	1.47	1.12	0.60	178.9
1936	40.21	112.44	39.52	99.32	87.07	53.42	8.89	2.07	1.64	3.54	1.64	1.04	450.8
1937	0.95	15.71	31.84	62.04	73.61	11.99	59.02	11.65	11.13	3.80	4.40	1.38	287.5
1938	50.83	16.14	31.15	58.25	68.95	14.07	1.29	18.64	4.40	8.97	20.11	5.87	298.7
1939	64.81	46.60	7.51	1.12	23.73	45.13	62.56	38.92	6.21	2.33	1.38	63.25	363.6
1940	11.99	30.12	44.27	34.43	72.83	21.06	44.70	8.46	1.21	3.88	1.73	1.73	276.4
1941	44.79	7.85	0.35	64.63	50.39	57.47	45.99	7.77	1.04	11.39	26.66	5.26	323.6
1942	49.70	64.03	55.05	57.21	10.60	12.34	86.29	65.93	22.26	37.97	52.29	8.46	522.1
1943	63.08	119.00	44.70	15.79	64.72	19.16	3.19	7.16	46.94	9.15	1.04	5.95	399.9
1944	8.03	10.10	1.81	8.72	18.98	55.83	10.18	17.09	16.65	3.62	1.04	0.43	152.5
1945	0.60	8.72	9.84	39.18	25.97	51.09	17.17	21.75	9.32	2.33	1.04	1.04	188.0
1946	26.32	6.47	22.09	8.72	35.64	8.46	7.85	6.13	2.59	1.98	1.29	32.19	159.7
1947	34.52	8.11	50.48	27.87	31.93	113.39	29.60	5.00	1.64	1.47	1.04	0.43	305.5
1948	5.26	1.12	0.26	17.34	20.80	32.36	7.08	13.03	3.62	3.02	1.55	1.21	106.7
1949	10.27	30.63	28.22	20.45	50.22	110.54	110.11	42.11	6.13	32.70	80.17	14.15	535.7
1950	0.69	5.44	37.54	52.47	44.96	56.78	28.82	4.75	5.61	2.50	2.68	3.62	245.8
1951	72.23	12.86	0.95	15.19	47.98	19.85	5.95	1.81	3.71	31.32	14.76	8.11	234.7
1952	2.59	34.09	16.31	8.03	71.28	30.81	48.32	9.75	1.55	1.21	6.82	1.98	232.7
1953	42.89	43.23	34.86	8.11	48.15	67.14	14.32	8.37	5.18	1.98	1.04	0.78	276.0
1954	0.60	9.41	11.56	126.25	113.91	27.35	24.94	8.46	2.33	3.71	1.81	0.60	330.9
1955	12.60	24.08	55.49	13.03	107.87	75.94	21.23	21.49	4.57	1.55	1.12	0.78	339.7
1956	31.93	8.63	99.75	49.10	22.18	23.21	22.61	4.14	3.54	7.08	17.17	84.48	373.8
1957	34.26	33.83	23.04	84.65	36.67	21.83	43.15	42.11	7.42	1.21	0.95	2.59	331.7
1958	2.68	34.60	31.50	16.05	28.99	30.20	69.81	45.56	7.16	35.73	7.33	0.52	310.1
1959	21.75	28.65	74.73	15.27	41.68	51.86	27.96	5.26	3.28	4.23	12.77	2.93	290.4
1960	34.95	39.09	14.41	28.22	7.85	55.83	69.55	29.17	18.81	5.18	3.19	1.12	307.4
1961	0.35	47.29	26.41	8.28	119.52	48.76	21.23	3.80	0.95	0.86	1.21	0.86	279.5
1962	1.04	61.35	11.39	65.67	28.65	65.24	83.70	17.69	3.19	17.60	4.57	0.69	360.8
1963	15.01	77.06	59.46	22.61	18.55	106.74	21.14	0.95	0.95	0.52	0.60	0.86	324.5
1964	98.72	20.19	36.67	32.96	5.18	1.98	83.96	15.36	8.97	9.58	14.15	17.17	344.9
1965	18.12	35.03	14.93	90.43	117.36	11.13	7.33	7.25	3.88	1.73	1.12	1.29	309.6
1966	2.50	14.93	11.39	113.73	56.44	23.99	71.80	32.88	62.30	22.44	21.49	14.93	448.8
1967	3.62	123.66	23.04	4.83	1.64	7.68	16.40	49.45	7.85	10.10	3.80	3.02	255.1
1968	8.37	2.50	30.55	1.55	0.95	14.76	35.12	18.64	8.89	2.85	5.35	2.59	132.1
1969	51.52	17.26	7.08	9.58	17.95	1.98	1.04	1.21	0.95	1.04	1.04	10.44	121.1
1970	29.94	11.82	52.38	56.00	44.87	22.44	26.15	18.47	2.42	1.81	1.21	0.52	268.0
1971	1.29	2.93	18.12	97.60	53.16	89.40	13.20	33.40	9.84	4.40	1.81	1.38	326.5
1972	13.89	27.18	2.50	1.21	63.17	16.22	17.78	3.28	1.64	1.55	49.01	9.15	206.6
1973	7.68	9.92	29.34	79.65	97.08	16.48	21.75	7.85	6.47	3.11	13.81	12.51	305.6
1974	3.19	108.21	23.21	56.61	83.62	102.34	13.81	8.11	2.16	7.51	1.73	20.45	430.9
1975	23.21	123.31	53.24	121.67	125.56	148.25	52.72	30.03	30.37	5.18	2.33	31.07	746.9
1976	144.19	73.26	4.92	22.61	61.70	138.33	13.38	7.42	3.19	2.33	1.90	14.58	487.8
1977	58.33	23.64	21.14	148.77	14.67	26.66	151.18	7.77	3.02	1.73	1.55	33.91	492.4
1978	29.77	11.13	81.46	10.96	18.55	5.87	1.64	6.99	4.14	31.84	88.28	20.28	310.9
1979	80.34	29.51	35.90	10.10	18.55	8.37	5.78	2.42	1.38	1.12	1.21	6.82	201.5
1980	6.90	29.17	36.42	141.43	37.54	60.58	29.43	15.53	27.53	2.76	40.13	27.61	455.0
1981	5.87	56.44	44.18	9.84	23.30	9.66	82.58	13.38	3.28	3.19	2.16	2.07	255.9
1982	38.23	103.55	12.08	5.78	6.13	5.26	3.71	4.31	2.59	3.45	2.76	1.90	189.8
1983	9.92	50.48	22.87	33.40	3.37	7.85	7.25	35.55	1.64	1.04	2.93	11.22	187.5
1984	5.78	13.72	8.63	7.16	20.71	36.59	11.82	1.81	0.95	0.69	0.35	0.26	108.5
1985	2.16	11.65	52.72	8.89	16.31	5.70	9.66	2.24	15.88	1.90	12.69	16.40	156.2
1986	80.08	113.30	7.42	1.12	5.18	11.56	34.17	2.24	0.86	0.86	21.40	131.34	409.5
1987	36.07	62.13	46.08	15.88	52.29	128.32	67.74	15.27	13.81	24.33	6.99	54.80	523.7
1988	68.95	35.21	64.72	53.76	133.75	24.59	17.60	39.52	58.16	11.30	6.30	2.07	515.9
1989	4.66	54.88	11.91	7.68	17.69	27.01	82.50	21.75	8.03	11.22	9.15	2.59	259.1
1990	1.04	0.43	10.10	109.76	95.87	90.00	5.00	1.38	1.21	0.78	0.43	2.24	318.2
1991	103.38	22.26	8.89	1.04	0.86	0.78	0.69	0.17	0.17	0.17	0.69	2.68	141.8
1992	11.99	54.54	3.19	6.73	44.96	22.09	56.95	6.56	2.68	2.07	2.59	1.29	215.6
1993	61.27	42.54	35.90	70.67	99.41	20.19	16.22	8.46	1.47	1.21	1.04	0.43	358.8
1994	0.26	3.45	1.81	8.89	7.42	6.90	7.77	14.41	1.98	1.47	1.21	0.95	56.5
1995	29.51	42.46	108.90	34.78	86.12	105.19	10.61	9.92	16.48	19.07	15.45	4.40	482.9
AVE.	27.19	38.24	30.32	40.17	45.72	41.52	33.70	15.60	8.25	7.42	9.69	11.01	308.83
SDV.	30.08	34.04	24.94	42.44	34.91	36.72	32.59	14.98	12.27	9.80	17.10	21.57	135.39

Table A1.3 – Monthly streamflow series - Senqu River at Mashai Dam (MCM)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
1930	90.10	30.70	51.88	282.26	164.46	159.74	451.83	93.92	7.12	54.69	20.97	3.71	1411.4
1931	28.50	97.43	53.88	41.24	268.91	210.61	39.33	11.34	8.93	7.22	4.11	6.12	777.6
1932	6.42	191.95	90.10	21.57	119.30	106.16	25.99	8.63	6.32	9.53	7.43	3.51	596.9
1933	3.61	373.06	359.62	609.66	329.31	205.90	204.39	189.54	71.84	88.40	67.13	14.55	2517.0
1934	82.38	498.89	301.92	101.74	93.82	196.57	86.39	36.62	17.66	9.73	13.35	8.13	1447.2
1935	19.87	30.20	73.95	91.71	121.61	181.61	37.93	79.47	20.67	6.82	3.71	2.21	669.8
1936	122.31	775.93	270.01	500.80	598.93	238.81	40.14	6.92	3.21	4.52	3.51	1.61	2566.7
1937	12.24	16.36	48.97	419.22	361.32	58.30	167.57	52.58	77.56	37.33	101.95	31.41	1384.8
1938	166.16	53.98	208.81	334.43	468.69	104.75	13.35	74.35	26.29	30.40	34.32	19.47	1535.0
1939	105.06	248.94	152.52	127.13	120.81	121.21	184.42	253.16	64.62	12.44	6.22	142.58	1539.1
1940	45.25	123.72	229.78	352.59	287.27	68.43	122.92	31.71	4.21	7.53	6.22	16.36	1296.0
1941	198.87	40.14	12.94	176.90	242.22	266.90	135.56	30.10	7.12	13.45	50.77	21.77	1196.8
1942	93.72	290.18	362.03	304.43	82.60	112.98	192.75	199.98	71.74	350.99	236.60	56.49	2354.5
1943	743.12	514.70	437.38	202.08	357.71	120.61	16.76	11.74	111.08	33.41	7.12	108.67	2664.4
1944	166.66	88.70	19.06	26.69	219.64	455.04	111.28	25.69	11.24	4.82	2.91	1.51	1133.2
1945	6.32	13.04	15.05	234.09	113.68	192.85	49.07	61.21	17.76	6.22	3.61	2.41	715.3
1946	268.71	206.70	60.50	42.64	117.00	109.37	113.08	23.08	16.66	17.36	9.33	63.41	1047.8
1947	131.34	143.69	161.95	205.90	161.05	553.57	178.50	24.28	6.32	3.61	3.21	2.81	1576.2
1948	41.44	14.55	8.73	161.55	91.91	148.50	108.87	27.19	8.13	5.52	4.92	9.13	630.4
1949	63.92	116.09	214.83	164.56	259.48	744.12	332.22	107.56	19.27	58.40	349.58	83.28	2513.3
1950	17.06	24.98	141.88	138.57	147.40	88.00	74.95	23.68	11.64	7.43	15.15	10.13	700.9
1951	299.41	65.52	20.47	113.89	337.94	133.85	51.47	14.35	7.02	71.14	91.41	28.50	1235.0
1952	14.35	80.17	73.85	96.93	351.79	79.67	41.24	18.76	28.70	14.15	13.45	9.23	822.3
1953	117.50	53.58	109.47	110.77	165.36	168.57	45.75	44.45	23.28	8.23	3.81	5.22	856.0
1954	8.93	62.71	68.73	420.82	502.30	104.35	66.22	43.95	15.35	10.13	6.02	2.61	1312.1
1955	19.47	114.19	126.33	76.96	462.57	241.32	73.15	45.05	13.85	6.62	4.62	5.52	1189.6
1956	104.96	226.47	725.56	364.83	123.22	165.06	55.39	13.14	17.36	35.62	49.37	517.65	2398.6
1957	732.38	206.40	167.77	567.52	127.13	72.85	160.44	109.77	31.51	8.93	4.01	20.37	2209.1
1958	24.78	128.84	91.01	37.93	82.78	38.53	185.93	664.15	132.55	107.46	33.21	5.82	1533.0
1959	247.14	254.26	237.60	196.16	403.47	250.25	98.23	27.39	9.93	9.03	22.28	17.26	1773.0
1960	95.62	200.48	212.32	255.06	65.62	157.63	245.83	107.46	61.91	22.68	13.65	14.05	1452.3
1961	5.32	223.56	187.43	228.17	531.30	201.38	91.11	22.68	6.32	3.01	4.92	5.32	1510.5
1962	8.73	179.21	105.76	442.20	219.64	274.73	237.30	51.37	27.39	27.39	14.65	5.32	1593.7
1963	56.69	192.45	121.31	373.26	99.54	432.76	135.66	20.17	60.81	21.97	11.54	12.74	1538.9
1964	504.51	105.16	110.37	148.50	32.21	40.84	99.94	22.88	72.24	38.13	35.52	13.95	1224.2
1965	18.06	67.13	22.18	392.03	233.49	51.67	12.84	8.73	6.72	4.31	7.43	5.52	830.1
1966	14.35	69.84	181.61	734.79	339.05	230.88	190.75	68.23	18.66	10.64	10.64	5.42	1874.8
1967	4.62	227.67	170.88	51.57	24.98	57.59	51.17	186.73	22.98	15.55	9.03	14.15	836.9
1968	20.57	28.20	88.10	22.98	24.68	77.06	122.62	45.35	56.89	9.23	9.33	5.72	510.7
1969	118.80	73.15	146.60	106.26	122.21	20.17	6.62	3.21	2.01	1.30	8.03	43.95	652.3
1970	222.25	102.75	190.54	192.25	164.06	136.76	145.79	46.96	11.64	11.84	13.35	12.94	1251.1
1971	17.66	40.74	93.12	349.38	374.17	495.78	46.06	54.18	19.06	7.73	4.62	3.81	1506.3
1972	29.10	117.40	30.00	10.94	175.69	109.77	97.63	18.06	7.43	3.91	108.77	84.69	793.4
1973	141.78	76.86	138.67	460.46	633.75	193.45	98.53	33.51	40.24	17.16	21.17	21.17	1876.8
1974	10.33	397.85	195.96	391.12	756.16	407.18	71.04	30.70	17.46	18.56	10.13	104.15	2410.7
1975	213.02	499.19	387.01	735.29	801.21	711.51	271.92	70.74	107.16	17.86	7.12	40.14	3862.2
1976	670.07	604.95	53.88	134.15	418.22	458.65	89.20	25.59	10.44	8.43	3.41	13.85	2490.8
1977	222.95	103.85	38.73	537.72	164.46	147.70	445.11	40.24	14.45	10.13	9.43	118.80	1853.6
1978	133.95	63.31	428.65	93.12	81.98	85.69	13.35	22.28	20.17	57.80	278.04	232.59	1510.9
1979	217.94	154.12	247.34	115.99	221.75	131.34	24.48	10.33	8.13	6.32	5.22	48.06	1191.0
1980	61.01	158.24	145.89	528.99	249.34	164.96	94.52	59.00	65.72	11.04	55.99	128.23	1722.9
1981	22.78	100.34	198.87	38.73	23.88	54.69	168.27	56.39	10.54	12.54	5.72	5.82	698.6
1982	81.88	298.41	31.11	25.89	40.54	44.25	27.99	29.70	13.55	8.13	10.84	7.43	619.7
1983	62.51	72.24	114.69	188.54	50.67	75.56	54.69	36.82	9.03	6.92	6.12	37.53	715.3
1984	24.08	65.42	43.25	80.97	457.75	165.36	28.50	8.93	6.92	6.52	4.72	3.31	895.7
1985	52.28	320.18	508.92	120.11	175.39	41.84	47.96	18.36	39.73	9.43	21.57	76.26	1432.0
1986	305.53	651.81	126.73	51.98	38.53	38.03	74.25	10.54	5.82	5.42	71.94	734.89	2115.5
1987	1082.6	195.96	155.83	111.98	228.07	1125.1	124.52	49.67	50.87	45.55	25.89	226.47	3422.6
1988	211.42	216.43	385.20	262.19	708.50	209.21	80.27	109.37	250.15	78.26	23.68	10.03	2544.7
1989	35.82	327.91	139.47	53.18	107.76	102.55	224.96	145.89	21.07	33.31	59.70	19.67	1271.3
1990	18.36	8.83	61.81	159.54	322.89	103.55	13.14	7.32	4.31	3.21	2.81	5.02	710.8
1991	246.33	110.88	58.30	30.70	12.24	22.78	4.72	1.81	0.30	0.30	1.10	19.57	509.0
1992	35.72	321.09	43.35	42.24	165.36	120.11	168.37	22.07	8.33	5.12	8.23	4.31	944.3
1993	377.98	150.41	241.22	357.91	609.16	154.62	180.81	69.13	9.63	6.22	5.92	4.62	2167.6
1994	4.31	21.97	11.44	47.06	105.96	86.59	78.26	58.00	13.65	9.43	7.02	7.73	451.4
1995	28.40	69.23	286.87	343.26	383.90	484.54	23.38	23.38	33.41	51.88	45.65	22.38	1796.3
AVE.	141.81	177.32	160.61	223.40	249.21	198.71	111.47	59.84	30.36	24.98	32.17	50.62	1460.5
SDV.	203.04	164.76	136.77	183.34	192.76	194.62	94.02	90.87	39.55	46.48	62.11	115.02	728.9

Table A1.4 – Incremental monthly streamflow series - Senqu River at Mashai Dam (MCM)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
1930	57.95	17.58	16.01	159.46	89.05	79.18	248.12	65.99	5.19	29.10	14.32	2.36	784.3
1931	11.71	43.54	30.45	16.88	122.66	97.33	22.78	6.27	5.64	4.53	2.33	2.22	366.3
1932	1.81	123.54	44.54	10.10	80.12	58.89	14.44	4.35	2.95	4.96	4.22	1.56	351.5
1933	0.59	196.77	174.88	321.40	190.81	90.45	107.20	98.66	33.83	24.94	19.31	6.45	1265.3
1934	30.77	266.67	179.96	64.85	53.41	119.41	53.28	21.70	11.55	6.43	6.84	3.84	818.7
1935	7.71	13.73	36.83	57.37	54.26	95.50	23.60	24.67	10.67	3.71	1.64	0.58	330.3
1936	59.35	498.04	192.99	299.65	389.16	141.90	26.51	4.49	1.81	2.10	1.73	0.48	1618.2
1937	2.22	4.81	24.61	245.48	191.50	33.97	92.54	37.58	30.97	20.58	40.38	15.13	739.8
1938	100.61	35.28	129.05	241.47	230.69	53.95	6.97	43.52	18.35	10.68	14.22	9.69	894.5
1939	44.31	106.44	95.10	67.98	57.69	59.58	80.47	163.12	49.24	8.44	3.33	86.30	822.0
1940	33.10	40.40	124.44	228.71	172.67	34.96	62.34	21.29	2.67	2.80	2.70	6.99	733.1
1941	101.67	23.17	3.51	88.93	130.76	143.79	64.49	16.53	3.84	5.93	18.47	9.01	610.1
1942	19.50	187.51	235.38	183.23	50.63	31.66	100.34	102.06	53.47	181.18	152.43	43.78	1341.2
1943	490.76	330.26	270.41	125.52	213.70	65.67	9.88	5.75	33.23	19.69	4.62	40.19	1609.7
1944	91.32	38.32	8.05	14.23	142.54	243.48	60.38	11.70	5.80	2.24	1.06	0.47	619.6
1945	1.25	2.98	4.27	141.48	54.69	85.78	26.87	22.40	9.40	2.83	1.34	0.68	354.0
1946	105.03	97.25	33.03	20.99	42.41	42.34	40.47	11.05	10.53	10.66	5.74	31.56	451.1
1947	63.14	73.09	60.81	124.20	102.68	275.80	86.17	12.53	4.23	1.73	1.16	0.58	806.1
1948	8.32	4.34	2.05	89.01	51.50	35.24	25.54	10.35	4.37	2.34	1.73	3.80	238.6
1949	40.46	72.35	155.00	112.27	153.89	539.92	203.50	40.82	8.94	35.75	233.20	64.09	1660.2
1950	5.47	12.33	56.61	65.20	65.31	33.10	25.11	9.54	5.09	3.63	5.84	3.23	290.5
1951	105.66	33.72	5.15	45.24	159.67	58.73	24.86	8.72	4.25	40.21	63.80	19.88	569.9
1952	6.41	34.99	31.41	62.92	170.79	45.09	19.47	11.34	23.38	11.62	7.03	5.15	429.6
1953	43.92	23.37	48.87	46.12	94.73	91.12	29.06	31.58	16.61	4.79	1.64	1.27	433.1
1954	4.07	28.78	39.81	233.84	270.33	62.92	28.21	15.68	8.31	5.89	3.13	0.98	701.9
1955	7.08	40.27	38.85	39.64	293.36	158.31	37.70	15.38	7.41	3.51	2.02	0.96	644.5
1956	20.06	95.79	466.57	233.84	68.56	56.26	25.82	8.07	6.60	12.19	16.87	247.15	1257.8
1957	415.43	124.20	116.80	364.03	84.66	45.10	83.36	71.04	23.31	6.19	2.14	3.74	1340.0
1958	5.09	51.88	45.11	18.06	35.36	18.66	74.13	430.24	101.35	52.72	21.96	3.66	858.2
1959	125.80	173.41	128.30	140.31	258.55	132.37	44.88	16.09	5.89	4.11	7.28	7.45	1044.5
1960	27.25	110.61	112.75	157.39	37.74	69.59	113.86	46.48	23.77	12.03	8.03	6.15	725.7
1961	2.35	104.54	121.30	159.96	323.97	126.62	40.24	13.23	4.36	1.66	2.10	1.56	901.9
1962	2.13	105.92	72.81	245.74	122.56	165.45	116.60	29.17	8.17	13.66	8.98	2.94	894.1
1963	19.21	118.78	74.84	250.72	57.37	265.00	93.01	14.33	30.46	14.80	5.89	5.24	949.7
1964	296.91	63.60	42.54	69.58	16.97	17.32	30.63	10.78	51.39	27.85	16.93	7.75	652.3
1965	6.50	27.34	9.10	208.07	134.56	27.37	4.62	3.87	2.99	1.71	3.89	2.44	432.5
1966	3.84	33.48	130.90	440.07	172.61	117.08	94.92	34.42	11.24	6.56	4.98	2.44	1052.5
1967	2.41	119.84	89.86	33.21	18.41	28.96	22.69	92.02	13.06	8.42	4.23	6.95	440.1
1968	6.13	14.82	18.67	16.17	18.94	45.62	59.88	12.06	28.85	3.30	4.61	2.23	231.3
1969	29.67	38.09	100.01	61.68	69.81	16.04	4.25	1.22	0.96	0.13	6.82	22.75	351.4
1970	116.89	54.06	100.25	72.27	98.87	87.31	66.64	24.00	7.38	8.32	11.56	12.20	659.7
1971	15.74	28.95	63.25	223.18	251.05	304.97	21.55	24.22	11.23	4.63	2.76	2.00	953.5
1972	11.82	59.20	25.46	10.10	63.24	70.74	60.55	12.43	4.92	2.77	49.22	47.95	418.4
1973	104.70	44.07	62.00	333.71	487.55	166.18	49.96	17.03	21.67	10.27	8.52	7.67	1313.3
1974	6.11	143.01	140.75	261.90	582.48	229.87	48.64	19.10	13.59	12.75	7.86	44.01	1510.1
1975	115.86	205.32	258.85	488.62	575.67	568.76	207.33	31.78	55.81	7.66	2.27	11.94	2529.9
1976	398.34	358.66	38.59	62.94	275.62	236.26	65.42	14.42	6.44	6.05	1.86	6.20	1470.8
1977	83.95	58.30	21.43	259.81	103.25	94.07	189.82	21.83	9.54	6.88	6.06	42.22	897.1
1978	60.52	32.45	242.55	53.20	51.16	53.43	9.71	12.82	8.86	23.28	91.66	114.48	754.1
1979	66.95	84.10	102.56	79.22	136.33	110.03	19.12	7.55	6.38	5.31	4.31	26.54	648.4
1980	31.11	76.76	85.89	248.63	177.23	64.71	23.86	30.45	24.48	5.83	14.68	87.20	870.8
1981	13.80	29.38	64.62	25.03	12.61	38.02	54.64	32.74	6.02	7.88	3.16	1.57	289.5
1982	20.49	107.88	15.23	20.04	28.41	24.02	21.39	10.14	3.83	4.97	5.35	3.68	265.4
1983	38.78	36.58	60.22	121.06	44.28	60.81	40.45	14.79	6.56	5.05	4.84	15.06	448.5
1984	8.52	18.02	19.74	67.78	338.00	105.93	15.37	6.74	6.00	5.68	4.52	3.18	599.5
1985	27.51	213.62	278.57	95.56	103.57	27.44	7.12	10.31	16.06	6.43	9.63	37.90	833.7
1986	145.74	364.40	101.60	31.56	17.07	13.63	9.03	5.59	4.35	4.21	19.90	410.46	1127.5
1987	865.00	51.59	30.69	32.33	144.77	722.83	57.01	24.21	25.01	18.77	14.85	118.74	2105.8
1988	111.63	92.69	204.29	171.71	430.42	146.36	40.85	56.37	135.01	44.95	13.25	5.39	1452.9
1989	17.94	164.09	77.24	34.04	49.00	50.37	73.15	97.84	11.22	16.11	26.85	9.38	627.2
1990	10.11	2.68	44.61	49.72	153.82	20.16	4.66	4.59	2.36	1.61	2.42	1.54	298.3
1991	83.77	52.61	31.11	20.63	9.45	16.99	1.51	0.93	0.17	0.17	0.41	10.51	228.3
1992	16.74	168.92	23.99	28.44	107.42	77.01	75.66	11.56	4.56	2.71	3.79	2.05	522.9
1993	208.38	81.68	130.25	221.64	412.63	102.19	87.69	34.60	4.51	2.98	3.23	2.59	1292.4
1994	2.45	10.64	7.04	24.71	57.53	64.51	54.46	28.70	8.57	6.33	4.63	5.78	275.3
1995	14.92	36.38	133.26	219.69	235.67	321.07	10.05	11.02	19.96	27.70	24.97	12.56	1067.3
AVE.	75.83	92.54	89.93	132.77	151.46	116.47	55.22	32.82	16.80	13.10	16.24	26.16	819.34
SDV.	139.24	97.05	85.28	112.92	134.19	132.03	50.55	57.59	22.49	23.72	35.62	61.56	474.74

Table A1.5 – Monthly streamflow series - Matsoku River at Matsoku Diversion (MCM)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
1930	3.74	1.07	3.29	9.96	7.47	11.12	40.74	4.98	0.44	4.71	1.33	0.27	89.1
1931	2.49	6.14	1.87	1.69	18.68	16.54	2.05	0.62	0.71	0.71	0.53	0.44	52.5
1932	0.18	8.45	4.80	0.62	3.47	5.43	1.16	0.53	0.62	0.98	0.80	0.27	27.3
1933	0.09	25.44	21.97	44.12	15.21	15.21	18.14	16.19	6.40	8.81	5.60	0.98	178.2
1934	5.43	27.22	9.25	3.02	4.71	9.87	4.89	2.22	1.16	0.89	1.25	0.53	70.4
1935	1.42	1.60	3.82	3.47	7.56	10.58	1.60	6.40	1.51	0.80	0.62	0.27	39.7
1936	8.98	33.09	7.38	24.99	26.06	13.07	1.60	0.44	0.44	0.62	0.53	0.27	117.5
1937	0.53	0.62	1.87	23.93	22.15	2.40	13.79	2.31	6.58	2.40	10.50	2.13	89.2
1938	11.30	1.69	4.98	6.40	24.37	4.62	0.44	6.58	1.51	1.78	2.67	0.98	67.3
1939	8.09	12.10	5.51	4.62	5.60	7.29	15.92	14.68	2.40	0.80	0.71	10.85	88.6
1940	1.69	7.65	9.34	14.94	16.81	3.82	7.92	1.33	0.36	0.62	0.71	1.07	66.3
1941	13.43	1.69	0.53	10.41	11.74	12.01	10.76	1.87	0.53	1.42	4.89	1.51	70.8
1942	9.16	13.34	15.12	11.47	2.67	6.85	14.05	15.65	2.49	19.83	16.19	2.13	129.0
1943	45.89	27.04	21.08	9.07	20.10	6.94	0.80	0.62	8.63	1.87	0.62	8.98	151.6
1944	10.32	5.69	0.62	0.89	8.72	25.35	6.14	1.78	0.80	0.62	0.53	0.18	61.6
1945	0.27	0.53	0.53	11.65	5.25	11.38	2.58	6.14	1.42	0.71	0.62	0.27	41.4
1946	22.95	14.50	3.02	2.76	6.49	4.98	11.56	1.78	1.25	1.51	0.89	5.69	77.4
1947	11.03	7.83	10.67	8.18	5.96	33.53	13.52	1.96	0.53	0.53	0.53	0.27	94.5
1948	2.94	0.62	0.09	8.27	4.62	15.92	12.72	2.22	0.71	0.80	0.71	0.53	50.2
1949	1.96	3.47	6.49	5.60	12.45	38.42	23.57	10.85	1.69	5.69	25.79	3.47	139.5
1950	0.27	0.98	11.03	9.34	7.56	5.78	6.58	1.69	0.98	0.89	1.51	0.62	47.2
1951	35.13	4.45	0.89	4.71	24.01	7.12	2.94	0.80	0.62	7.47	5.34	1.16	94.6
1952	0.36	4.45	3.20	4.09	22.59	3.74	2.76	0.89	2.67	0.98	1.25	0.53	47.5
1953	10.14	2.67	6.58	8.27	9.96	10.76	2.22	2.40	1.16	0.80	0.62	0.36	55.9
1954	0.44	3.74	2.58	21.35	27.31	4.18	4.98	4.00	1.33	0.98	0.71	0.27	71.9
1955	1.33	8.36	6.05	2.58	24.73	8.18	4.71	2.85	0.98	0.80	0.71	0.27	61.5
1956	10.14	10.67	36.29	12.81	6.31	16.63	3.47	0.62	1.60	2.31	2.85	29.88	133.6
1957	47.32	9.25	5.43	28.02	5.16	3.29	10.50	6.58	1.60	0.80	0.62	1.25	119.8
1958	1.96	5.96	4.00	1.51	2.67	1.33	15.30	42.43	5.51	10.50	2.05	0.27	93.5
1959	17.61	9.96	12.36	6.40	21.52	16.72	6.85	1.51	0.80	0.89	1.69	0.89	97.2
1960	6.76	11.38	9.16	12.01	3.02	9.87	20.63	7.38	6.23	1.87	1.16	0.71	90.2
1961	0.18	13.43	6.58	6.40	29.97	9.34	6.67	1.25	0.44	0.36	0.53	0.27	75.4
1962	0.36	8.18	2.94	19.57	11.56	17.25	21.35	3.38	1.07	2.22	1.16	0.36	89.4
1963	4.18	7.74	4.00	13.79	3.47	25.08	5.96	0.89	3.91	1.33	0.89	0.71	72.0
1964	30.68	3.91	7.65	6.23	0.80	2.13	9.07	1.51	4.36	1.69	2.22	0.62	70.9
1965	1.42	3.74	0.62	17.70	13.34	2.58	0.80	0.62	0.62	0.62	0.71	0.36	43.1
1966	0.98	3.74	6.58	47.41	16.28	16.45	19.12	4.80	1.16	0.89	0.89	0.36	118.6
1967	0.36	16.28	12.27	2.05	0.71	3.11	3.47	11.74	1.16	1.16	0.80	1.16	54.3
1968	2.22	2.05	10.50	0.71	0.53	4.27	7.74	4.09	3.56	0.98	0.71	0.53	37.9
1969	13.52	5.34	7.03	4.62	6.23	0.53	0.27	0.27	0.09	0.18	0.18	3.38	41.6
1970	15.92	7.38	13.70	16.10	10.58	6.58	10.05	2.76	0.53	0.53	0.27	0.09	84.5
1971	0.27	1.07	4.36	20.10	11.30	38.69	3.74	2.05	0.80	0.27	0.27	0.27	83.2
1972	2.31	8.09	0.71	0.18	9.43	7.20	2.13	0.53	0.27	0.18	8.54	8.09	47.7
1973	6.31	1.78	5.16	19.57	31.04	3.29	7.47	1.25	1.69	0.62	1.69	2.05	81.9
1974	0.62	26.50	8.36	11.74	31.31	28.55	3.29	1.33	0.53	0.71	0.27	9.34	122.6
1975	19.75	41.71	14.85	42.43	34.95	29.26	7.65	6.14	3.20	0.98	0.53	9.96	211.4
1976	46.52	34.87	1.96	7.92	21.88	31.93	2.94	1.16	0.53	0.36	0.18	1.25	151.5
1977	18.94	6.23	2.58	45.72	9.43	7.38	31.40	3.56	0.71	0.53	0.53	12.45	139.5
1978	13.07	4.54	21.79	6.49	3.91	4.62	0.53	0.71	0.98	3.38	29.35	25.79	115.2
1979	22.32	11.03	23.39	5.96	8.89	2.67	0.62	0.36	0.18	0.18	0.18	3.38	79.2
1980	5.87	8.45	7.92	32.46	7.65	4.27	6.85	4.54	5.51	0.80	7.56	7.12	99.0
1981	1.07	5.78	17.88	1.78	0.89	3.02	9.34	4.80	0.80	0.53	0.36	0.27	46.5
1982	7.74	31.84	1.33	0.71	1.69	2.22	0.80	2.49	1.07	0.53	0.89	0.62	51.9
1983	3.56	5.07	8.27	9.34	0.44	2.13	0.53	1.33	0.36	0.18	0.18	1.87	33.3
1984	0.80	3.11	1.33	1.87	16.90	4.45	1.25	0.27	0.09	0.09	0.00	0.00	30.2
1985	3.74	15.56	31.93	4.45	5.43	1.25	3.20	0.89	2.67	0.36	1.96	5.96	77.4
1986	26.59	46.96	2.49	0.71	1.33	0.53	3.56	0.62	0.18	0.18	7.29	52.74	143.2
1987	39.40	20.37	17.17	7.65	12.10	46.78	7.83	3.11	3.20	4.71	2.13	18.14	182.6
1988	15.12	18.86	27.57	13.96	41.98	8.81	5.07	6.85	15.74	5.69	1.96	0.80	162.4
1989	2.58	24.73	9.96	2.58	3.82	4.27	27.66	11.21	1.96	2.94	5.96	1.96	99.6
1990	1.25	0.71	2.85	5.51	27.93	5.34	1.25	0.44	0.27	0.27	0.09	0.53	46.4
1991	22.32	7.92	2.58	1.42	0.36	0.53	0.09	0.09	0.00	0.00	0.09	1.42	36.8
1992	2.58	23.04	3.11	2.05	10.23	6.05	10.58	1.42	0.53	0.44	0.71	0.36	61.1
1993	27.13	10.76	17.25	18.77	29.17	6.76	11.38	4.36	0.62	0.44	0.44	0.53	127.6
1994	0.36	1.60	0.62	2.94	4.62	1.69	2.49	3.65	0.71	0.53	0.18	0.09	19.5
1995	2.05	4.98	47.14	15.48	32.37	31.40	2.76	1.51	2.58	4.18	3.29	1.07	148.8
AVE.	9.93	10.74	8.85	11.11	12.69	10.81	7.94	4.03	1.91	1.87	2.69	3.81	86.4
SDV.	12.34	10.63	9.22	11.33	10.39	10.68	8.10	6.09	2.51	3.06	5.26	8.33	42.3

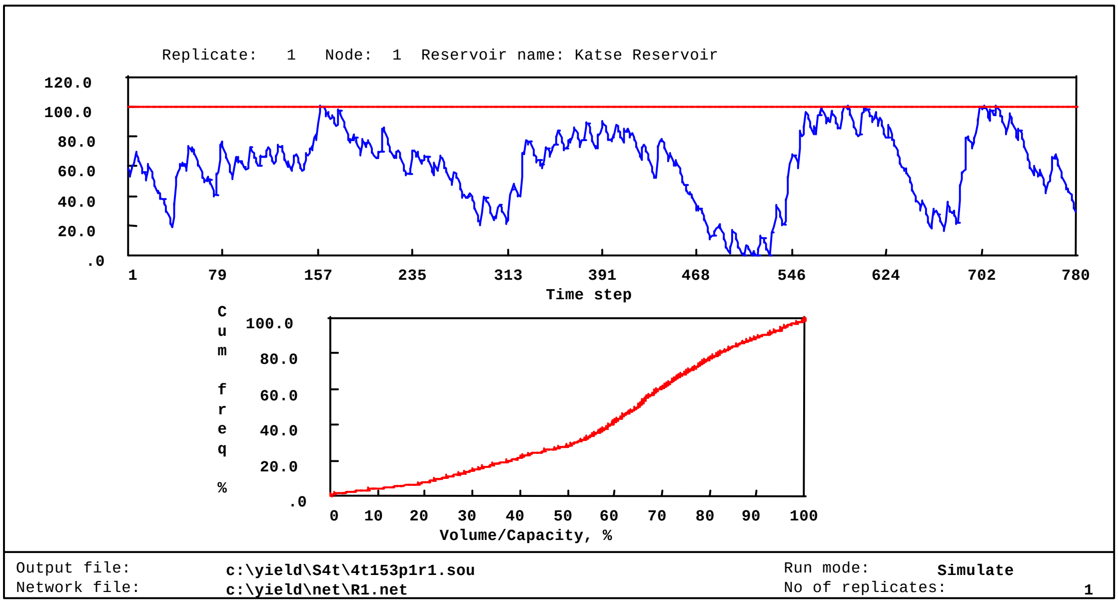
Table A1.6 – Open water evaporation data (mm)

Month	Mohale Reservoir	Katse Reservoir	Mashai Reservoir
January	133.6	134.9	138.6
February	102.0	102.8	105.1
March	103.3	103.5	104.0
April	72.7	73.3	74.8
May	70.6	71.6	74.7
June	48.4	49.2	51.6
July	57.1	57.7	59.7
August	87.0	87.9	90.6
September	103.9	105.2	109.1
October	126.0	127.5	132.0
November	124.9	126.0	129.6
December	121.7	122.0	122.9
TOTAL	**1151.2**	**1161.6**	**1192.7**

APPENDIX 2

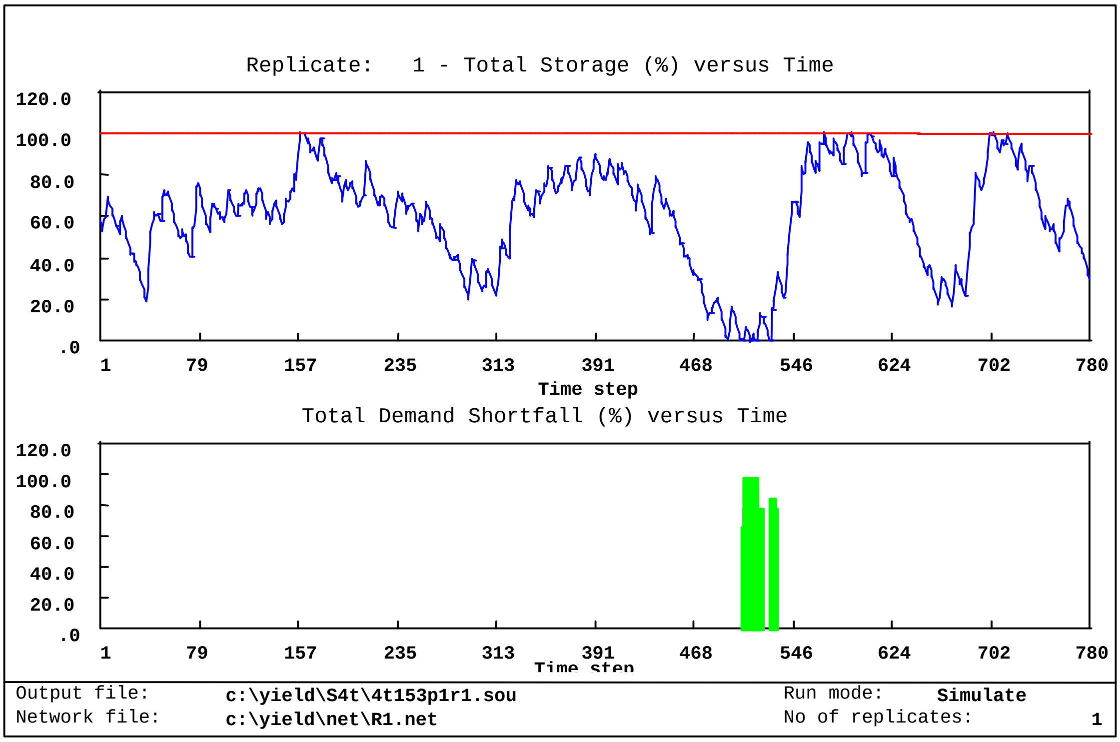
Configuration I system analysis results

PHASE 1A



Scale: Vertical axis: Upper graph is expressed in percent of active storage of the reservoir.
Horizontal axis: Time step in months, starting from October 1930

Graphs : The upper graph shows the fluctuation of the reservoirs active storage
The lower graph shows the frequency curve for the reservoir storage level



Scale: Vertical axis: Upper graph is expressed in percent of active storage and the lower graph is shortfalls expressed as percentage of yield
Horizontal axis: Time step in months, starting from October 1930

Graphs: The upper graph shows the fluctuation of the reservoirs active storage
The lower graph shows possible shortfalls within the same period.

Figure A2.1 – Katse Reservoir storage levels – Scenario 4 (1930-1994)

Table A2.1 - WATHNET OUTPUT SUMMARY (Version 3.01) for Scenario 4

WATHNET OUTPUT SUMMARY (Version 3.01)

Output file: c:\yield\S4t\4t153p1r1.sou
Network file: c:\yield\net\R1.net
Flow file: c:\yield\lhd-ssdatab.bin

Run title: R1
Historical Simulation

Network title: ALTERNATIVE 1: Katse Dam (Present)
SMEC International - S Yance

Degree of shortfall balance among demand nodes with same priority = 5
Degree of balance among reservoirs with same filling priority = 5

Number of replicates = 1
First replicate corresponds to replicate 1 in streamflow data file

Number of seasons in year = 12

Run mode: Simulate system using perfect one-season flow and demand forecasts

```
!-----------------------------------------------------------------!
! Default demand shortfall and storage carryover penalties were used !
!-----------------------------------------------------------------!
```

CPU time (secs):			
	Total	=	1.3
	Network setup	=	.5
	Network LP algoritm	=	.1
	Disk write	=	.1
	Disk read	=	.2

LP algorithm: Bertsekas RELAX code
Prior information option: Never use
Crash option: Simple

Arc	Arc name	Type	Node: Frm	To	Cost Constant	Time-mul	Monthly capacity Minimum	Maximum	Comm year	Decom year	Loss %
1	System Yield	Conduit	1	3	0	.000	0	99999999	1930	9999	0
2	Katse Outflow/Spill	Stream	1	7	0	.000	Variable	99999999			0
3	Inflow to IFR2	Stream	7	4	-1	.000	Variable	99999999			0
4	Jn Malibam/Matsoku	Stream	5	9	0	.000	Variable	99999999			0
5	Inflow to IFR3	Stream	9	8	-1	.000	Variable	99999999			0
6	Waste	Stream	10	2	0	.000	Variable	99999999			0
7	Outflow from IFR2	Stream	4	5	0	.000	Variable	99999999			0
8	Outflow from IFR3	Stream	8	10	0	.000	Variable	9999999			0
9	Matsoku Inflow	Stream	6	5	0	.000	Variable	99999999			0

Summary of variable monthly arc capacities

Arc	Arc name	Type	Monthly capacity 1 / 7	2 / 8	3 / 9	4 / 10	5 / 11	6 / 12
2	Katse Outflow/Spill	Minimum	0	0	0	0	0	0
			0	0	0	0	0	0
3	Inflow to IFR2	Minimum	0	0	0	0	0	0
			0	0	0	0	0	0
4	Jn Malibam/Matsoku	Minimum	0	0	0	0	0	0
			0	0	0	0	0	0
5	Inflow to IFR3	Minimum	0	0	0	0	0	0
			0	0	0	0	0	0
6	Waste	Minimum	0	0	0	0	0	0
			0	0	0	0	0	0
7	Outflow from IFR2	Minimum	0	0	0	0	0	0
			0	0	0	0	0	0
8	Outflow from IFR3	Minimum	0	0	0	0	0	0
			0	0	0	0	0	0
9	Matsoku Inflow	Minimum	0	0	0	0	0	0
			0	0	0	0	0	0

Node	Node name	Comm year	Node type	Stream inflow name

```
   1  Katse Reservoir            1930  Reservoir          KATSE INFLOW TCM
   2  Waste Node                       Waste node
   3  Sytem Yield                1930  Consumptve demand
   4  IFR2                       1930  Instream demand
   5  Jn of Malib&Mats                 Stream junction
   6  Matsku Inflow                    Stream junction
   7  Malibam/IFR2 Inc Inf             Stream junction    IFR2 INC FLOW TCM
   8  IFR3                       1930  Instream demand
   9  Malibam/IFR3 Inc Inf             Stream junction    IFR3 INC FLOW TCM
  10  Senqu/IFR4 Inc Inf               Stream junction    IFR4 INC FLOW TCM

Summary of hydropower nodes
Node  Node name             Descriptor            Data
-----------------------------------------------------------------------------------------

Node  Node name             Node type  Arc penalty
-----------------------------------------------------------------------------------
   1  Katse Reservoir       Reservoir  Default target carryover penalties over 1 arcs
   3  Sytem Yield           Demand     Default shortfall penalties over 1 arcs
   4  IFR2                  Demand     Default shortfall penalties over 5 arcs
   8  IFR3                  Demand     Default shortfall penalties over 5 arcs

Demand data was read from file: c:\yield\s4t\p14tdmd.bin
which had    1 replicates

Demand node          Name in demand file  Priority Multiplier
-------------------------------------------------------------
Sytem Yield          SYSTEM YIELD A 18.0        2     .85000
IFR2                 IFR 2 REQUIREMENTS T       1    1.00000
IFR3                 IFR 3 REQUIREMENTS T       1     .00000


********************************************************************************
>> Restriction Policy <<

>> Demand restriction group: 1        Policy applies till 1994
Restriction level:                    1         2         3         4
% restriction:                        1         2         3         4
Threshold storage level (%):          1         0         0         0

Group Demand Nodes
Node  Name
--------------------------
   4  IFR2
   8  IFR3

>> Revise restrictions at start of every season

Group Reservoirs
Node  Name
--------------------------

>> Demand restriction group: 2        Policy applies till 1994
Restriction level:                    1         2         3         4
% restriction:                       97        98        99       100
Threshold storage level (%):          0         0         0         0

Group Demand Nodes
Node  Name
--------------------------
   3  Sytem Yield

>> Revise restrictions at start of every season

Group Reservoirs
Node  Name
--------------------------
   1  Katse Reservoir


Evaporation and arc loss convergence parameters:
   Max no. of iterations =40
   Max evaporation error =  1%
   Max arc loss error    =  1%
********************************************************************************


Reservoir name        Capacity   Initial   Stream  Filling
                        ml        volume   inflow?  priority
------------------------------------------------------------
Katse Reservoir        1518600    911160      Y      1
```

Reservoir name	Target as % of capacity till 1994 for month 1	2	3	4	5	6	7	8	9	10	11	12
Katse Reservoir	100	100	100	100	100	100	100	100	100	100	100	100

Reservoir name	Evaporation site name	Area = a + b*V**c where V = volume/capacity a	b	c
Katse Reservoir	KATSE EVAPORATION MM	13.140	22.940	.84460

Reservoir name	Flood Control Volume as % of capacity for month 1	2	3	4	5	6	7	8	9	10	11	12
Katse Reservoir	0	0	0	0	0	0	0	0	0	0	0	0

++

Step = 1 Year = 1930 Season = 1 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity
1	System Yield	1	3	0	0	99999999	40208	0
2	Katse Outflow/Spill	1	7	0	0	99999999	10390	0
3	Inflow to IFR2	7	4	-1	0	99999999	0	0
4	Jn Malibam/Matsoku	5	9	0	0	99999999	11806	0
5	Inflow to IFR3	9	8	-1	0	99999999	20534	0
6	Waste	10	2	0	0	99999999	27774	0
7	Outflow from IFR2	4	5	0	0	99999999	11806	0
8	Outflow from IFR3	8	10	0	0	9999999	20534	0
9	Matsoku Inflow	6	5	0	0	99999999	0	0

Reservoir no.	name	Active capacity	Initial - volume	Net release =	Final volume
1	Katse Reservoir	1518600	911160	25242	885918
	Totals	1518600	911160	25242	885918

>>> Total waste from system = 27774

Demand centre no.	name	Demand volumes: Unrestricted -	Shortfall =	Actual
1	Sytem Yield	40208	0	40208
2	IFR2	11806	0	11806
3	IFR3	0	0	0
	Totals	52014	0	52014

++

Step = 2 Year = 1930 Season = 2 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity
1	System Yield	1	3	0	0	99999999	40208	0
2	Katse Outflow/Spill	1	7	0	0	99999999	11205	0
3	Inflow to IFR2	7	4	-1	0	99999999	0	0
4	Jn Malibam/Matsoku	5	9	0	0	99999999	11806	0
5	Inflow to IFR3	9	8	-1	0	99999999	13583	0
6	Waste	10	2	0	0	99999999	16050	0
7	Outflow from IFR2	4	5	0	0	99999999	11806	0
8	Outflow from IFR3	8	10	0	0	9999999	13583	0
9	Matsoku Inflow	6	5	0	0	99999999	0	0

Reservoir no.	name	Active capacity	Initial - volume	Net release =	Final volume
1	Katse Reservoir	1518600	885918	42617	843301
	Totals	1518600	885918	42617	843301

>>> Total waste from system = 16050

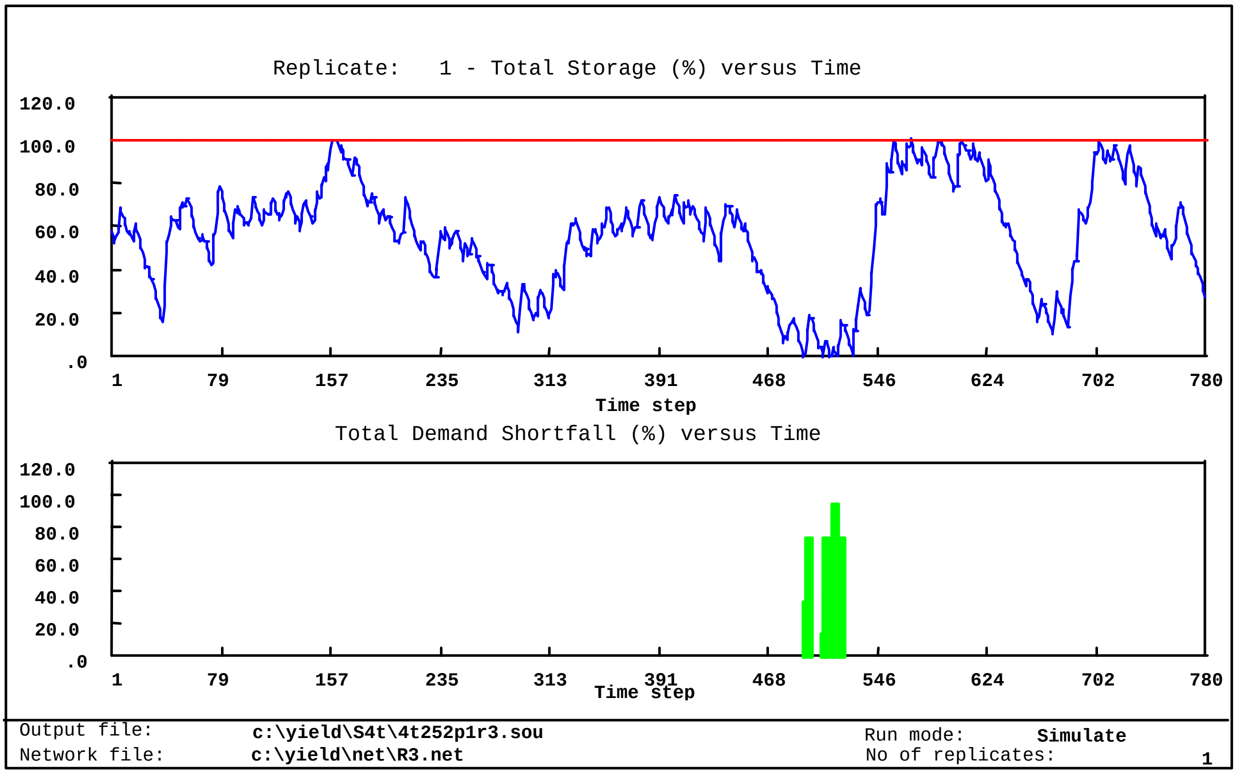
```
Demand centre                          Demand volumes:
no.  name                   Unrestricted - Shortfall =  Actual
--------------------------------------------------------------
  1  Sytem Yield                   40208           0     40208
  2  IFR2                          11806           0     11806
  3  IFR3                              0           0         0
--------------------------------------------------------------
     Totals                        52014           0     52014

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Step =   3 Year = 1930 Season =   3 Replicate =    1

Arc  Arc name                Node:         Cost        Capacities:        Flow  percent
                          From    To               Minimum    Maximum           Capacity
------------------------------------------------------------------------------------------
  1  System Yield            1     3          0          0   99999999     40208     0
  2  Katse Outflow/Spill     1     7          0          0   99999999     10183     0
  3  Inflow to IFR2          7     4         -1          0   99999999         0     0
  4  Jn Malibam/Matsoku      5     9          0          0   99999999     11806     0
  5  Inflow to IFR3          9     8         -1          0   99999999     17115     0
  6  Waste                  10     2          0          0   99999999     21284     0
  7  Outflow from IFR2       4     5          0          0   99999999     11806     0
  8  Outflow from IFR3       8    10          0          0    9999999     17115     0
  9  Matsoku Inflow          6     5          0          0   99999999         0     0

  Reservoir                  Active      Initial -  Net     =  Final
 no.  name                   capacity    volume     release    volume
----------------------------------------------------------------------
  1  Katse Reservoir          1518600     843301      20563     822738
----------------------------------------------------------------------
     Totals                   1518600     843301      20563     822738

 >>> Total waste from system =      21284

Demand centre                          Demand volumes:
no.  name                   Unrestricted - Shortfall =  Actual
--------------------------------------------------------------
  1  Sytem Yield                   40208           0     40208
  2  IFR2                          11806           0     11806
  3  IFR3                              0           0         0
--------------------------------------------------------------
     Totals                        52014           0     52014

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Step =   4 Year = 1930 Season =   4 Replicate =    1

Arc  Arc name                Node:         Cost        Capacities:        Flow  percent
                          From    To               Minimum    Maximum           Capacity
------------------------------------------------------------------------------------------
  1  System Yield            1     3          0          0   99999999     40208     0
  2  Katse Outflow/Spill     1     7          0          0   99999999      6185     0
  3  Inflow to IFR2          7     4         -1          0   99999999         0     0
  4  Jn Malibam/Matsoku      5     9          0          0   99999999     11806     0
  5  Inflow to IFR3          9     8         -1          0   99999999     28885     0
  6  Waste                  10     2          0          0   99999999     51566     0
  7  Outflow from IFR2       4     5          0          0   99999999     11806     0
  8  Outflow from IFR3       8    10          0          0    9999999     28885     0
  9  Matsoku Inflow          6     5          0          0   99999999         0     0

  Reservoir                  Active      Initial -  Net     =  Final
 no.  name                   capacity    volume     release    volume
----------------------------------------------------------------------
  1  Katse Reservoir          1518600     822738     -64619     887357
----------------------------------------------------------------------
     Totals                   1518600     822738     -64619     887357

 >>> Total waste from system =      51566

Demand centre                          Demand volumes:
no.  name                   Unrestricted - Shortfall =  Actual
--------------------------------------------------------------
  1  Sytem Yield                   40208           0     40208
  2  IFR2                          11806           0     11806
  3  IFR3                              0           0         0
--------------------------------------------------------------
     Totals                        52014           0     52014

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Step =   5 Year = 1930 Season =   5 Replicate =    1

Arc  Arc name                Node:         Cost        Capacities:        Flow  percent
                          From    To               Minimum    Maximum           Capacity
```

```
------------------------------------------------------------------------------------------
  1  System Yield         1     3         0         0   99999999    40208     0
  2  Katse Outflow/Spill  1     7         0         0   99999999     8422     0
  3  Inflow to IFR2       7     4        -1         0   99999999        0     0
  4  Jn Malibam/Matsoku   5     9         0         0   99999999    11806     0
  5  Inflow to IFR3       9     8        -1         0   99999999    22116     0
  6  Waste               10     2         0         0   99999999    35331     0
  7  Outflow from IFR2    4     5         0         0   99999999    11806     0
  8  Outflow from IFR3    8    10         0         0    9999999    22116     0
  9  Matsoku Inflow       6     5         0         0   99999999        0     0

  Reservoir                 Active      Initial -  Net     =   Final
 no.  name                  capacity    volume     release     volume
----------------------------------------------------------------------
  1  Katse Reservoir         1518600     887357     -17579     904936
----------------------------------------------------------------------
     Totals                  1518600     887357     -17579     904936

 >>> Total waste from system =      35331

Demand centre                              Demand volumes:
no.  name                  Unrestricted - Shortfall =  Actual
--------------------------------------------------------------
  1  Sytem Yield                  40208          0     40208
  2  IFR2                         11806          0     11806
  3  IFR3                             0          0         0
--------------------------------------------------------------
     Totals                       52014          0     52014

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Step =   6 Year = 1930 Season =   6 Replicate =    1

Arc  Arc name               Node:         Cost        Capacities:        Flow  percent
                         From    To                Minimum    Maximum           Capacity
------------------------------------------------------------------------------------------
  1  System Yield         1     3         0         0   99999999    40208     0
  2  Katse Outflow/Spill  1     7         0         0   99999999        0     0
  3  Inflow to IFR2       7     4        -1         0   99999999      682     0
  4  Jn Malibam/Matsoku   5     9         0         0   99999999     3459     0
  5  Inflow to IFR3       9     8        -1         0   99999999    19337     0
  6  Waste               10     2         0         0   99999999    32173     0
  7  Outflow from IFR2    4     5         0         0   99999999     3459     0
  8  Outflow from IFR3    8    10         0         0    9999999    19337     0
  9  Matsoku Inflow       6     5         0         0   99999999        0     0

  Reservoir                 Active      Initial -  Net     =   Final
 no.  name                  capacity    volume     release     volume
----------------------------------------------------------------------
  1  Katse Reservoir         1518600     904936     -27492     932428
----------------------------------------------------------------------
     Totals                  1518600     904936     -27492     932428

 >>> Total waste from system =      32173

Demand centre                              Demand volumes:
no.  name                  Unrestricted - Shortfall =  Actual
--------------------------------------------------------------
  1  Sytem Yield                  40208          0     40208
  2  IFR2                          2777          0      2777
  3  IFR3                             0          0         0
--------------------------------------------------------------
     Totals                       42985          0     42985
```

APPENDIX 3

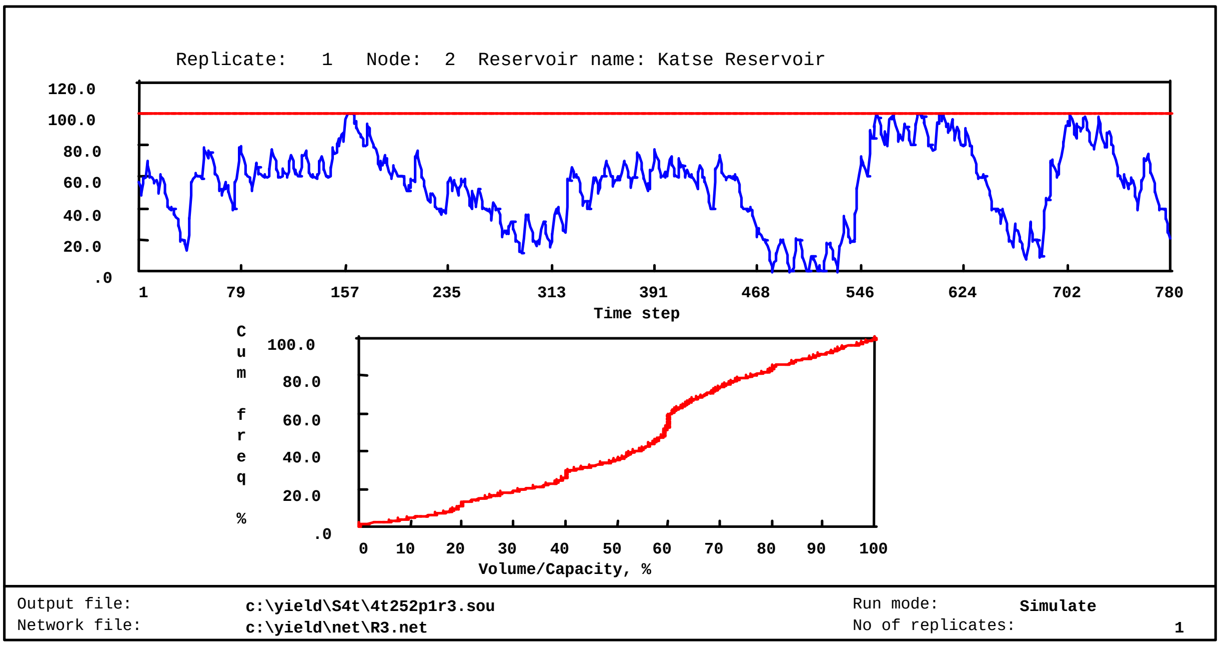
Configuration II system analysis results

PHASE 1



Scale: Vertical axis: Upper graph is expressed in percent of active storage and the lower graph is shortfalls expressed as percentage of yield
Horizontal axis: Time step in months, starting from October 1930

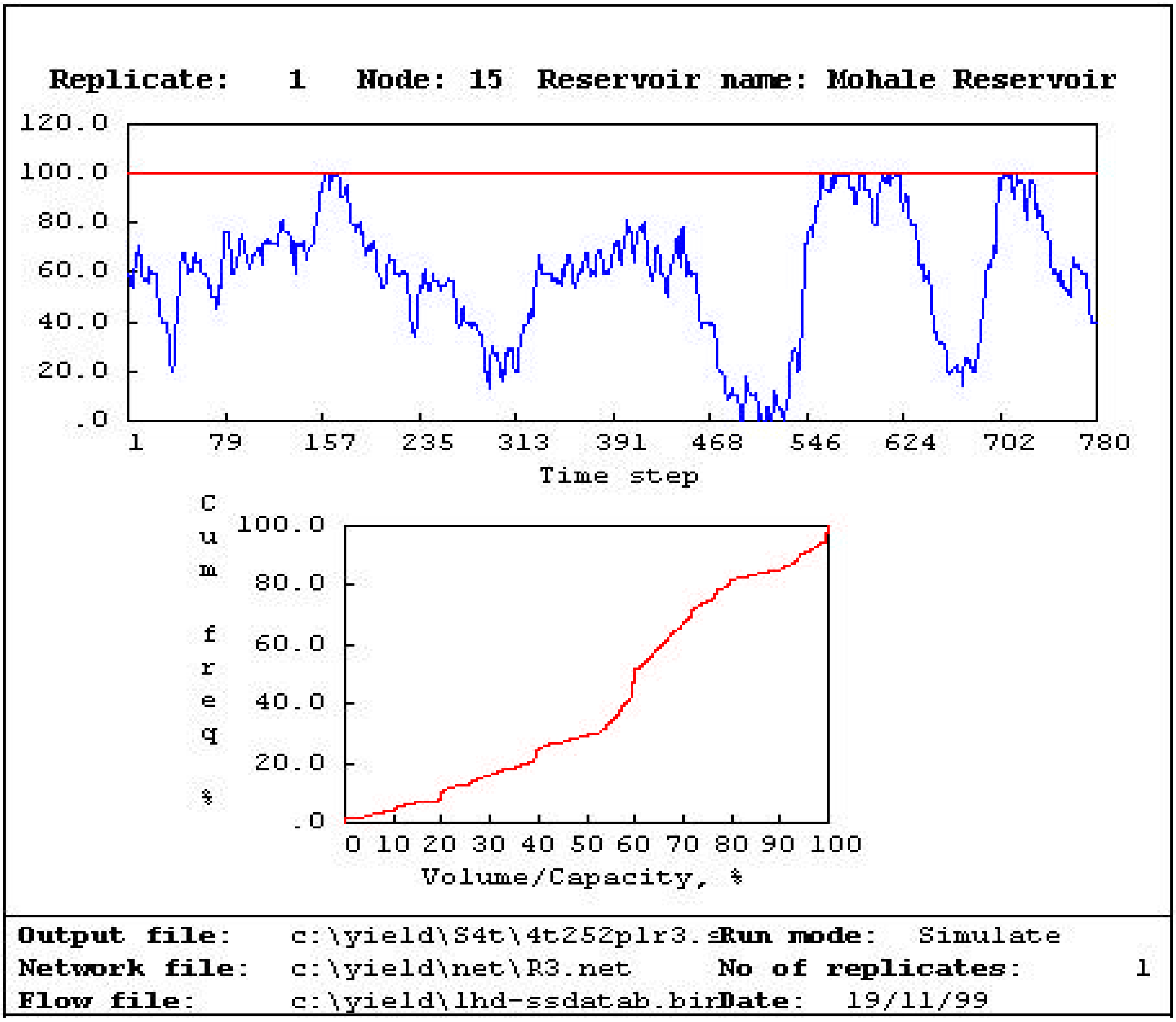
Graphs: The upper graph shows the fluctuation of the reservoirs active storage
The lower graph shows the possible shortfall within the same period



Scale: Vertical axis: Upper graph is expressed in percent of active storage.
Horizontal axis: Time step in months, starting from October 1930

Graphs : The upper graph shows the fluctuation of the reservoirs active storage
The lower graph shows the frequency curve for the reservoir storage level

Figure A3.1 – Combined reservoir storage levels – Scenario 4 - Phase 1 (1930-1994)



Scale: Vertical axis: Upper graph is expressed in percent of active storage.
Horizontal axis: Time step in months, starting from October 1930

Graphs : The upper graph shows the fluctuation of the reservoirs active storage
The lower graph shows the frequency curve for the reservoir storage level

Figure A3.2 – Combined reservoir storage levels – Scenario 4 - Phase 1&2 (1930-1994)

Table A3.1 – WATHNET OUTPUT SUMMARY (Version 3.01) FOR SCENARIO 4 PHASE 1

```
Output file:  c:\yield\S4t\4t252p1r3.sou
Network file: c:\yield\net\R3.net
Flow file:    c:\yield\lhd-ssdatab.bin


Run title: R3
           Historical Simulation


Network title: ALTERNATIVE 2:Katse + Matso Div + Mashai
               SMEC International - S Yance

Degree of shortfall balance among demand nodes with same priority =  5
Degree of balance among reservoirs with same filling priority =  5

Number of replicates =   1
First replicate corresponds to replicate   1 in streamflow data file

Number of seasons in year =  12

Run mode: Simulate system using perfect one-season flow and demand forecasts


!-------------------------------------------------------------------!
! Default demand shortfall and storage carryover penalties were used !
!-------------------------------------------------------------------!


CPU time (secs): Total               =     2.6
                 Network setup       =      .6
                 Network LP algoritm =     1.3
                 Disk write          =      .3
                 Disk read           =      .2


LP algorithm: Bertsekas RELAX code
              Prior information option: Never use
              Crash option: Simple
```

Arc	Arc name	Type	Node: Frm	To	<------Cost-------> Constant	Time-mul	Monthly capacity Minimum	Maximum	Comm year	Decom year	Loss %
1	Matsoku Tunnel	Stream	1	2	0	.000	Variable	12000			0
2	System Yield	Conduit	2	3	0	.000	0	99999999	1930	9999	0
3	Matsoku outflow	Stream	1	7	0	.000	Variable	99999999			0
4	Inflow to IFR1	Stream	7	4	0	.000	Variable	99999999			0
5	Katse Outflow/Spill	Stream	2	8	0	.000	Variable	99999999			0
6	Inflow to IFR2	Stream	8	5	0	.000	Variable	99999999			0
7	Jn Malibam/Matsoku	Stream	6	10	0	.000	Variable	99999999			0
8	Inflow to IFR3	Stream	10	9	0	.000	Variable	99999999			0
9	Outflow from IFR1	Stream	4	6	0	.000	Variable	99999999			0
10	Outflow from IFR3	Stream	9	11	0	.000	Variable	99999999			0
11	Inflow to IFR5	Stream	12	13	0	.000	Variable	99999999			0
12	Outflow from IFR5	Stream	13	14	0	.000	Variable	99999999			0
13	Mohale Tunnel	Conduit	15	2	0	.000	Vol dep	Vol-vol	1930	9999	0
14	Mohale Outflow/Spill	Stream	15	16	0	.000	Variable	99999999			0
15	Inflow to IFR7	Stream	16	17	0	.000	Variable	99999999			0
16	Outflow from IFR7	Stream	17	18	0	.000	Variable	99999999			0
17	Inflow to IFR8	Stream	18	19	0	.000	Variable	99999999			0
18	Outflow from IFR8	Stream	19	14	0	.000	Variable	99999999			0
19	Jn Sequnyane/Senqu	Stream	14	20	0	.000	Variable	99999999			0
20	Inflow to IFR6	Stream	20	21	0	.000	Variable	99999999			0
21	Waste	Stream	21	22	0	.000	Variable	99999999			0
22	Outflow from IFR2	Stream	5	6	0	.000	Variable	9999999			0
23	Outflow form IFR4	Stream	23	12	0	.000	Variable	99999999			0
24	Inflow to IFR4	Stream	11	23	0	.000	Variable	99999999			0

Summary of variable monthly arc capacities

Arc	Arc name	Type	Monthly capacity 1 / 7	2 / 8	3 / 9	4 / 10	5 / 11	6 / 12
1	Matsoku Tunnel	Minimum	0	0	0	0	0	0
			0	0	0	0	0	0

```
  3 Matsoku outflow      Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
  4 Inflow to IFR1       Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
  5 Katse Outflow/Spill  Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
  6 Inflow to IFR2       Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
  7 Jn Malibam/Matsoku   Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
  8 Inflow to IFR3       Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
  9 Outflow from IFR1    Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 10 Outflow from IFR3    Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 11 Inflow to IFR5       Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 12 Outflow from IFR5    Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 14 Mohale Outflow/Spill Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 15 Inflow to IFR7       Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 16 Outflow from IFR7    Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 17 Inflow to IFR8       Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 18 Outflow from IFR8    Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 19 Jn Sequnyane/Senqu   Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 20 Inflow to IFR6       Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 21 Waste                Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 22 Outflow from IFR2    Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 23 Outflow form IFR4    Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0
 24 Inflow to IFR4       Minimum      0       0       0       0       0       0
                                      0       0       0       0       0       0

Summary of volume-dependant arc capacities
Arc  Arc name             Type     Reservoir node        Max flow        Look-up table
-------------------------------------------------------------------------------------------------
 13  Mohale Tunnel        Minimum  Katse Reservoir       99999999  Flow %:   0   0   0   0   0   0
                                    Average                         Vol %:   0   0   0   0   0 100

Summary of volume-volume dependant arc capacities
Arc  Arc name             Location    Reservoir node       Head = a + b*V**c where V = volume/capacity
                                                                    a         b         c
------------------------------------------------------------------------------------------
 13  Mohale Tunnel        Upstream    Mohale Reservoir        16.0      72.6      .701
                          Downstream  Katse Reservoir         .000      64.1      .702
                 Capacity =   .108E+05*(U/s head-D/s head)**  .500

Node  Node name            Comm year  Node type          Stream inflow name
-----------------------------------------------------------------------------
   1  Matsoku Diversion               Gravity diversion  MATSOKU INFLOW TCM
   2  Katse Reservoir           1929  Reservoir          KATSE INFLOW TCM
   3  Sytem Yield               1930  Consumptve demand
   4  IFR1                      1930  Instream demand
   5  IFR2                      1930  Instream demand
   6  Jn of Malib&Mats                Stream junction
   7  Matsku/IFR1 inc                 Stream junction    IFR1 INC FLOW TCM
   8  Malibam/IFR2 Inc Inf            Stream junction    IFR2 INC FLOW TCM
   9  IFR3                      1930  Instream demand
  10  Malibam/IFR3 Inc Inf            Stream junction    IFR3 INC FLOW TCM
  11  Senqu/IFR4 Inc Infl             Stream junction    IFR4 INC FLOW TCM
  12  Senqu/IFR5 Inc Inf              Stream junction    IFR5 INC FLOW TCM
  13  IFR5                      1930  Instream demand
  14  Conf Senqunyane/Senq            Stream junction
  15  Mohale Reservoir          1930  Reservoir          MOHALE INFLOW TCM
  16  Senquny/IFR7 Inc Inf            Stream junction    IFR7 INC FLOW TCM
  17  IFR7                      1930  Instream demand
  18  Senquny/IFR8 Inc Inf            Stream junction    IFR8 INC FLOW TCM
  19  IFR8                      1930  Instream demand
  20  IFR6 Inc Inf                    Stream junction    IFR6 INC FLOW TCM
  21  IFR6                      1930  Instream demand
  22  Waste Node                      Waste node
  23  IFR4                      1930  Instream demand
```

```
Summary of hydropower nodes
Node  Node name             Descriptor            Data
------------------------------------------------------------------------------------------

Node  Node name             Node type  Arc penalty
------------------------------------------------------------------------------------
   2  Katse Reservoir       Reservoir  Default target carryover penalties over 5 arcs
   3  Sytem Yield           Demand     Default shortfall penalties over 1 arcs
   4  IFR1                  Demand     Default shortfall penalties over 5 arcs
   5  IFR2                  Demand     Default shortfall penalties over 5 arcs
   9  IFR3                  Demand     Default shortfall penalties over 5 arcs
  13  IFR5                  Demand     Default shortfall penalties over 5 arcs
  15  Mohale Reservoir      Reservoir  Default target carryover penalties over 5 arcs
  17  IFR7                  Demand     Default shortfall penalties over 5 arcs
  19  IFR8                  Demand     Default shortfall penalties over 5 arcs
  21  IFR6                  Demand     Default shortfall penalties over 5 arcs
  23  IFR4                  Demand     Default shortfall penalties over 5 arcs

Demand data was read from file: c:\yield\s4t\p14tdmd.bin
which had    1 replicates

Demand node          Name in demand file  Priority Multiplier
-------------------------------------------------------------
Sytem Yield          SYSTEM YIELD A 18.0        2    1.40000
IFR1                 IFR 1 REQUIREMENTS T       1    1.00000
IFR2                 IFR 2 REQUIREMENTS T       1    1.00000
IFR3                 IFR 3 REQUIREMENTS T       1     .00000
IFR5                 IFR 5 REQUIREMENTS T       1     .00000
IFR7                 IFR 7 REQUIREMENTS T       1    1.00000
IFR8                 IFR 8 REQUIREMENTS T       1     .00000
IFR6                 IFR 6 REQUIREMENTS T       1     .00000
IFR4                 IFR 4 REQUIREMENTS T       1     .00000


********************************************************************************
>> Restriction Policy <<

>> Demand restriction group: 1        Policy applies till 1994
Restriction level:                    1         2         3         4
% restriction:                        1         2         3         4
Threshold storage level (%):          1         0         0         0

Group Demand Nodes
Node  Name
--------------------------
   4  IFR1
   5  IFR2
   9  IFR3
  13  IFR5
  17  IFR7
  19  IFR8
  21  IFR6
  23  IFR4

>> Revise restrictions at start of every season

Group Reservoirs
Node  Name
--------------------------

>> Demand restriction group: 2        Policy applies till 1994
Restriction level:                    1         2         3         4
% restriction:                       97        98        99       100
Threshold storage level (%):          0         0         0         0

Group Demand Nodes
Node  Name
--------------------------
   3  Sytem Yield

>> Revise restrictions at start of every season

Group Reservoirs
Node  Name
--------------------------
   2  Katse Reservoir
  15  Mohale Reservoir


Evaporation and arc loss convergence parameters:
   Max no. of iterations =40
```

```
   Max evaporation error =  1%
   Max arc loss error    =  1%
********************************************************************************


Reservoir name        Capacity   Initial   Stream  Filling
                        ml        volume   inflow?  priority
------------------------------------------------------------
Katse Reservoir        1518600    911160      Y      1
Mohale Reservoir        857120    514272      Y      1


Reservoir name       Target as % of capacity till 1994 for month
                       1   2   3   4   5   6   7   8   9  10  11  12
----------------------------------------------------------------------
Katse Reservoir      100 100 100 100 100 100 100 100 100 100 100 100
Mohale Reservoir     100 100 100 100 100 100 100 100 100 100 100 100


Reservoir name        Evaporation site        Area = a + b*V**c where V = volume/capacity
                      name                       a           b           c
-------------------------------------------------------------------------------------
Katse Reservoir       KATSE EVAPORATION MM    13.140      22.940      .84460
Mohale Reservoir      MOHALE EVAPORATION M    4.3300      18.359      .82210


Reservoir name         Flood Control Volume as % of capacity for month
                        1    2    3    4    5    6    7    8    9   10   11   12
--------------------------------------------------------------------------------
Katse Reservoir         0    0    0    0    0    0    0    0    0    0    0    0
Mohale Reservoir        0    0    0    0    0    0    0    0    0    0    0    0




++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Step =   1 Year = 1930 Season =   1 Replicate =    1

Arc  Arc name              Node:         Cost        Capacities:        Flow  percent
                        From    To                Minimum    Maximum          Capacity
------------------------------------------------------------------------------------------
  1  Matsoku Tunnel          1     2         0          0      12000       119     0
  2  System Yield            2     3         0          0   99999999     66225     0
  3  Matsoku outflow         1     7         0          0   99999999      3617     0
  4  Inflow to IFR1          7     4         0          0   99999999         0     0
  5  Katse Outflow/Spill     2     8         0          0   99999999     10390     0
  6  Inflow to IFR2          8     5         0          0   99999999         0     0
  7  Jn Malibam/Matsoku      6    10         0          0   99999999     15475     0
  8  Inflow to IFR3         10     9         0          0   99999999     24203     0
  9  Outflow from IFR1       4     6         0          0   99999999      3669     0
 10  Outflow from IFR3       9    11         0          0   99999999     24203     0
 11  Inflow to IFR5         12    13         0          0   99999999     35914     0
 12  Outflow from IFR5      13    14         0          0   99999999     35914     0
 13  Mohale Tunnel          15     2         0          0      51234      5754    11
 14  Mohale Outflow/Spill   15    16         0          0   99999999      7128     0
 15  Inflow to IFR7         16    17         0          0   99999999         0     0
 16  Outflow from IFR7      17    18         0          0   99999999      8348     0
 17  Inflow to IFR8         18    19         0          0   99999999     10948     0
 18  Outflow from IFR8      19    14         0          0   99999999     10948     0
 19  Jn Sequnyane/Senqu     14    20         0          0   99999999     46862     0
 20  Inflow to IFR6         20    21         0          0   99999999     71466     0
 21  Waste                  21    22         0          0   99999999     71466     0
 22  Outflow from IFR2       5     6         0          0    9999999     11806     0
 23  Outflow form IFR4      23    12         0          0   99999999     31443     0
 24  Inflow to IFR4         11    23         0          0   99999999     31443     0

  Reservoir                Active      Initial -  Net     =   Final
 no.  name                 capacity    volume     release     volume
----------------------------------------------------------------------
  1  Katse Reservoir        1518600     911160      45371     865789
  2  Mohale Reservoir        857120     514272       7128     507144
----------------------------------------------------------------------
     Totals                 2375720    1425432      52499    1372933

 >>> Total waste from system =      71466

Demand centre                          Demand volumes:
no.  name                     Unrestricted - Shortfall =  Actual
----------------------------------------------------------------
  1  Sytem Yield                    66225          0     66225
```

2	IFR1	3669	0	3669
3	IFR2	11806	0	11806
4	IFR3	0	0	0
5	IFR5	0	0	0
6	IFR7	8348	0	8348
7	IFR8	0	0	0
8	IFR6	0	0	0
9	IFR4	0	0	0
	Totals	90048	0	90048

++

Step = 2 Year = 1930 Season = 2 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity
1	Matsoku Tunnel	1	2	0	0	12000	0	0
2	System Yield	2	3	0	0	99999999	66225	0
3	Matsoku outflow	1	7	0	0	99999999	1067	0
4	Inflow to IFR1	7	4	0	0	99999999	0	0
5	Katse Outflow/Spill	2	8	0	0	99999999	11205	0
6	Inflow to IFR2	8	5	0	0	99999999	0	0
7	Jn Malibam/Matsoku	6	10	0	0	99999999	12888	0
8	Inflow to IFR3	10	9	0	0	99999999	14665	0
9	Outflow from IFR1	4	6	0	0	99999999	1082	0
10	Outflow from IFR3	9	11	0	0	99999999	14665	0
11	Inflow to IFR5	12	13	0	0	99999999	20230	0
12	Outflow from IFR5	13	14	0	0	99999999	20230	0
13	Mohale Tunnel	15	2	0	0	53117	0	0
14	Mohale Outflow/Spill	15	16	0	0	99999999	4746	0
15	Inflow to IFR7	16	17	0	0	99999999	0	0
16	Outflow from IFR7	17	18	0	0	99999999	5500	0
17	Inflow to IFR8	18	19	0	0	99999999	7300	0
18	Outflow from IFR8	19	14	0	0	99999999	7300	0
19	Jn Sequnyane/Senqu	14	20	0	0	99999999	27530	0
20	Inflow to IFR6	20	21	0	0	99999999	40215	0
21	Waste	21	22	0	0	99999999	40215	0
22	Outflow from IFR2	5	6	0	0	9999999	11806	0
23	Outflow form IFR4	23	12	0	0	99999999	17132	0
24	Inflow to IFR4	11	23	0	0	99999999	17132	0

Reservoir no.	name	Active capacity	Initial - volume	Net release	= Final volume
1	Katse Reservoir	1518600	865789	68579	797210
2	Mohale Reservoir	857120	507144	1948	505196
	Totals	2375720	1372933	70527	1302406

>>> Total waste from system = 40215

Demand centre no.	name	Demand volumes: Unrestricted -	Shortfall =	Actual
1	Sytem Yield	66225	0	66225
2	IFR1	1082	0	1082
3	IFR2	11806	0	11806
4	IFR3	0	0	0
5	IFR5	0	0	0
6	IFR7	5500	0	5500
7	IFR8	0	0	0
8	IFR6	0	0	0
9	IFR4	0	0	0
	Totals	84613	0	84613

++

Step = 3 Year = 1930 Season = 3 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity
1	Matsoku Tunnel	1	2	0	0	12000	0	0
2	System Yield	2	3	0	0	99999999	66225	0
3	Matsoku outflow	1	7	0	0	99999999	3291	0
4	Inflow to IFR1	7	4	0	0	99999999	0	0
5	Katse Outflow/Spill	2	8	0	0	99999999	10183	0
6	Inflow to IFR2	8	5	0	0	99999999	0	0
7	Jn Malibam/Matsoku	6	10	0	0	99999999	15143	0
8	Inflow to IFR3	10	9	0	0	99999999	20452	0
9	Outflow from IFR1	4	6	0	0	99999999	3337	0

10	Outflow from IFR3	9	11	0	0	99999999	20452	0
11	Inflow to IFR5	12	13	0	0	99999999	30584	0
12	Outflow from IFR5	13	14	0	0	99999999	30584	0
13	Mohale Tunnel	15	2	0	0	55212	0	0
14	Mohale Outflow/Spill	15	16	0	0	99999999	7142	0
15	Inflow to IFR7	16	17	0	0	99999999	0	0
16	Outflow from IFR7	17	18	0	0	99999999	8348	0
17	Inflow to IFR8	18	19	0	0	99999999	10648	0
18	Outflow from IFR8	19	14	0	0	99999999	10648	0
19	Jn Sequnyane/Senqu	14	20	0	0	99999999	41232	0
20	Inflow to IFR6	20	21	0	0	99999999	49431	0
21	Waste	21	22	0	0	99999999	49431	0
22	Outflow from IFR2	5	6	0	0	9999999	11806	0
23	Outflow form IFR4	23	12	0	0	99999999	24621	0
24	Inflow to IFR4	11	23	0	0	99999999	24621	0

Reservoir no.	name	Active capacity	Initial - volume	Net release =	Final volume
1	Katse Reservoir	1518600	797210	46495	750715
2	Mohale Reservoir	857120	505196	1395	503801
	Totals	2375720	1302406	47890	1254516

>>> Total waste from system = 49431

Demand centre no.	name	Demand volumes: Unrestricted -	Shortfall =	Actual
1	Sytem Yield	66225	0	66225
2	IFR1	3337	0	3337
3	IFR2	11806	0	11806
4	IFR3	0	0	0
5	IFR5	0	0	0
6	IFR7	8348	0	8348
7	IFR8	0	0	0
8	IFR6	0	0	0
9	IFR4	0	0	0
	Totals	89716	0	89716

++

Step = 4 Year = 1930 Season = 4 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity
1	Matsoku Tunnel	1	2	0	0	12000	6431	53
2	System Yield	2	3	0	0	99999999	66225	0
3	Matsoku outflow	1	7	0	0	99999999	3530	0
4	Inflow to IFR1	7	4	0	0	99999999	0	0
5	Katse Outflow/Spill	2	8	0	0	99999999	6185	0
6	Inflow to IFR2	8	5	0	0	99999999	0	0
7	Jn Malibam/Matsoku	6	10	0	0	99999999	15475	0
8	Inflow to IFR3	10	9	0	0	99999999	32554	0
9	Outflow from IFR1	4	6	0	0	99999999	3669	0
10	Outflow from IFR3	9	11	0	0	99999999	32554	0
11	Inflow to IFR5	12	13	0	0	99999999	66628	0
12	Outflow from IFR5	13	14	0	0	99999999	66628	0
13	Mohale Tunnel	15	2	0	0	53073	53073	100 *
14	Mohale Outflow/Spill	15	16	0	0	99999999	3687	0
15	Inflow to IFR7	16	17	0	0	99999999	0	0
16	Outflow from IFR7	17	18	0	0	99999999	8348	0
17	Inflow to IFR8	18	19	0	0	99999999	20248	0
18	Outflow from IFR8	19	14	0	0	99999999	20248	0
19	Jn Sequnyane/Senqu	14	20	0	0	99999999	86876	0
20	Inflow to IFR6	20	21	0	0	99999999	139307	0
21	Waste	21	22	0	0	99999999	139307	0
22	Outflow from IFR2	5	6	0	0	9999999	11806	0
23	Outflow form IFR4	23	12	0	0	99999999	55235	0
24	Inflow to IFR4	11	23	0	0	99999999	55235	0

Reservoir no.	name	Active capacity	Initial - volume	Net release =	Final volume
1	Katse Reservoir	1518600	750715	-98158	848873
2	Mohale Reservoir	857120	503801	29044	474757
	Totals	2375720	1254516	-69114	1323630

>>> Total waste from system = 139307

Demand centre no.	name	Demand volumes: Unrestricted	- Shortfall =	Actual
1	Sytem Yield	66225	0	66225
2	IFR1	3669	0	3669
3	IFR2	11806	0	11806
4	IFR3	0	0	0
5	IFR5	0	0	0
6	IFR7	8348	0	8348
7	IFR8	0	0	0
8	IFR6	0	0	0
9	IFR4	0	0	0
	Totals	90048	0	90048

++

Step = 5 Year = 1930 Season = 5 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity	
1	Matsoku Tunnel	1	2	0	0	12000	3906	32	
2	System Yield	2	3	0	0	99999999	66225	0	
3	Matsoku outflow	1	7	0	0	99999999	3565	0	
4	Inflow to IFR1	7	4	0	0	99999999	0	0	
5	Katse Outflow/Spill	2	8	0	0	99999999	8422	0	
6	Inflow to IFR2	8	5	0	0	99999999	0	0	
7	Jn Malibam/Matsoku	6	10	0	0	99999999	15475	0	
8	Inflow to IFR3	10	9	0	0	99999999	25785	0	
9	Outflow from IFR1	4	6	0	0	99999999	3669	0	
10	Outflow from IFR3	9	11	0	0	99999999	25785	0	
11	Inflow to IFR5	12	13	0	0	99999999	73460	0	
12	Outflow from IFR5	13	14	0	0	99999999	73460	0	
13	Mohale Tunnel	15	2	0	0	48452	48452	100	*
14	Mohale Outflow/Spill	15	16	0	0	99999999	2276	0	
15	Inflow to IFR7	16	17	0	0	99999999	0	0	
16	Outflow from IFR7	17	18	0	0	99999999	8348	0	
17	Inflow to IFR8	18	19	0	0	99999999	27348	0	
18	Outflow from IFR8	19	14	0	0	99999999	27348	0	
19	Jn Sequnyane/Senqu	14	20	0	0	99999999	100808	0	
20	Inflow to IFR6	20	21	0	0	99999999	191249	0	
21	Waste	21	22	0	0	99999999	191249	0	
22	Outflow from IFR2	5	6	0	0	9999999	11806	0	
23	Outflow form IFR4	23	12	0	0	99999999	39000	0	
24	Inflow to IFR4	11	23	0	0	99999999	39000	0	

Reservoir no.	name	Active capacity	Initial - volume	Net release	= Final volume
1	Katse Reservoir	1518600	848873	-43942	892815
2	Mohale Reservoir	857120	474757	13445	461312
	Totals	2375720	1323630	-30497	1354127

>>> Total waste from system = 191249

Demand centre no.	name	Demand volumes: Unrestricted	- Shortfall =	Actual
1	Sytem Yield	66225	0	66225
2	IFR1	3669	0	3669
3	IFR2	11806	0	11806
4	IFR3	0	0	0
5	IFR5	0	0	0
6	IFR7	8348	0	8348
7	IFR8	0	0	0
8	IFR6	0	0	0
9	IFR4	0	0	0
	Totals	90048	0	90048

++

Step = 6 Year = 1930 Season = 6 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity	
1	Matsoku Tunnel	1	2	0	0	12000	10190	84	<
2	System Yield	2	3	0	0	99999999	66225	0	
3	Matsoku outflow	1	7	0	0	99999999	928	0	
4	Inflow to IFR1	7	4	0	0	99999999	0	0	
5	Katse Outflow/Spill	2	8	0	0	99999999	0	0	

6	Inflow to IFR2	8	5	0	0	99999999	682	0
7	Jn Malibam/Matsoku	6	10	0	0	99999999	4542	0
8	Inflow to IFR3	10	9	0	0	99999999	20420	0
9	Outflow from IFR1	4	6	0	0	99999999	1083	0
10	Outflow from IFR3	9	11	0	0	99999999	20420	0
11	Inflow to IFR5	12	13	0	0	99999999	75169	0
12	Outflow from IFR5	13	14	0	0	99999999	75169	0
13	Mohale Tunnel	15	2	0	0	48071	0	0
14	Mohale Outflow/Spill	15	16	0	0	99999999	0	0
15	Inflow to IFR7	16	17	0	0	99999999	1543	0
16	Outflow from IFR7	17	18	0	0	99999999	5250	0
17	Inflow to IFR8	18	19	0	0	99999999	22750	0
18	Outflow from IFR8	19	14	0	0	99999999	22750	0
19	Jn Sequnyane/Senqu	14	20	0	0	99999999	97919	0
20	Inflow to IFR6	20	21	0	0	99999999	206979	0
21	Waste	21	22	0	0	99999999	206979	0
22	Outflow from IFR2	5	6	0	0	9999999	3459	0
23	Outflow form IFR4	23	12	0	0	99999999	33256	0
24	Inflow to IFR4	11	23	0	0	99999999	33256	0

Reservoir no.	name	Active capacity	Initial - volume	Net release =	Final volume
1	Katse Reservoir	1518600	892815	-11682	904497
2	Mohale Reservoir	857120	461312	-31984	493296
	Totals	2375720	1354127	-43666	1397793

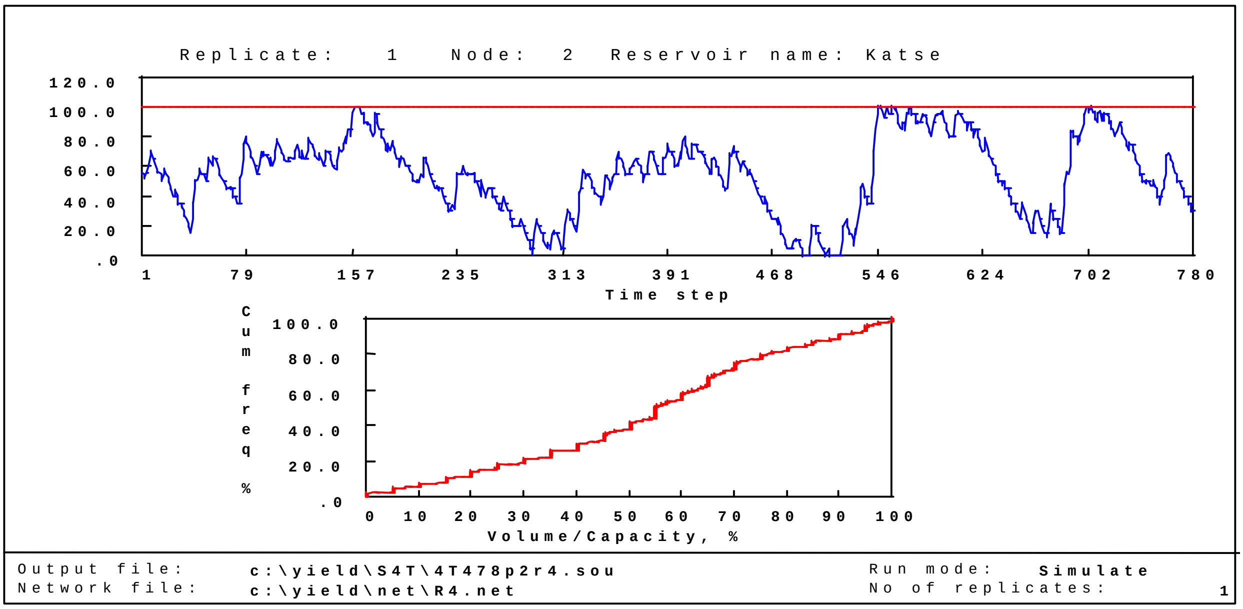
>>> Total waste from system = 206979

Demand centre no.	name	Demand volumes: Unrestricted -	Shortfall =	Actual
1	Sytem Yield	66225	0	66225
2	IFR1	1083	0	1083
3	IFR2	2777	0	2777
4	IFR3	0	0	0
5	IFR5	0	0	0
6	IFR7	3707	0	3707
7	IFR8	0	0	0
8	IFR6	0	0	0
9	IFR4	0	0	0
	Totals	73792	0	73792

APPENDIX 4

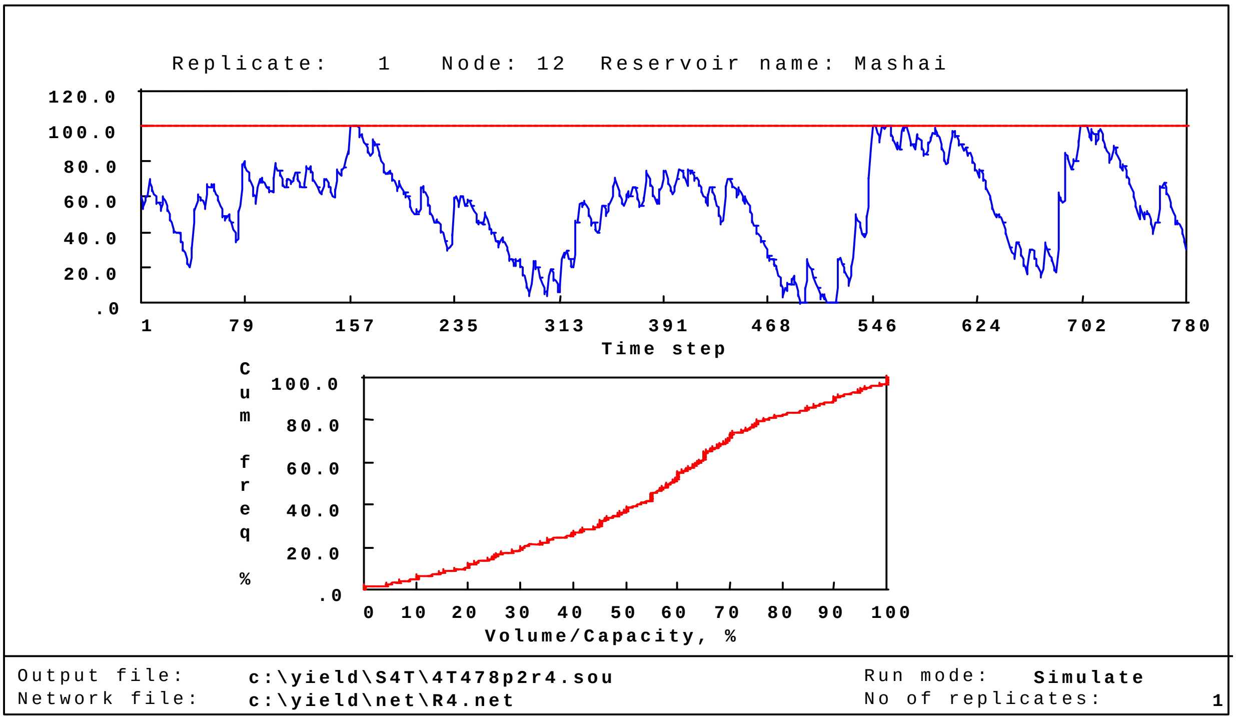
Configuration II system analysis results

PHASE 1&2



Scale: Vertical axis: of the upper graph is expressed in percent of active storage.
Horizontal axis: Time step in months, starting in October 1930

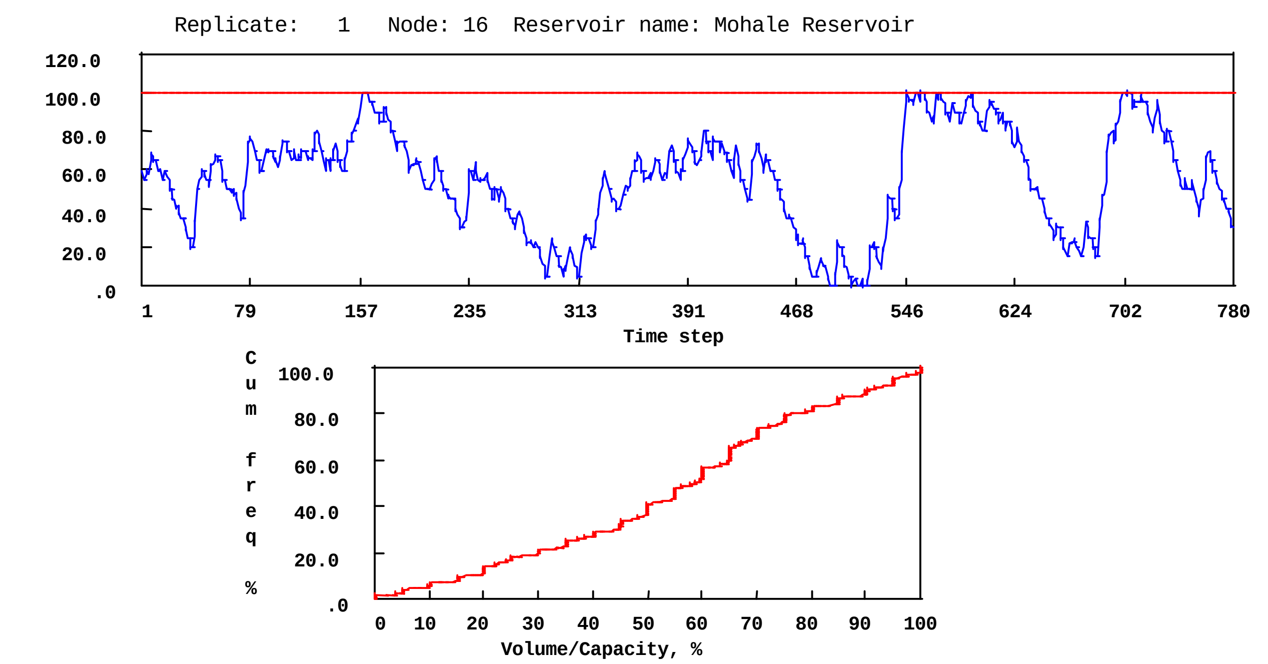
Graphs : The upper graph shows the fluctuation of the reservoirs active storage
The lower graph shows the frequency curve for the reservoir storage level



Scale: Vertical axis: of the upper graph is expressed in percent of active storage.
Horizontal axis: Time step in months, starting in October 1930

Graphs : The upper graph shows the fluctuation of the reservoirs active storage
The lower graph shows the frequency curve for the reservoir storage level

Figure A4.1(a) – Reservoir storage levels – Scenario 4 - Phase 1&2 (1930-1994)



Output file:	c:\yield\S4T\4T478p2r4.sou	Run mode:	Simulate
Network file:	c:\yield\net\R4.net	No of replicates:	1

Scale: Vertical axis: of the upper graph is expressed in percent of active storage.

Horizontal axis: Time step in months, starting in October 1930

Graphs : The upper graph shows the fluctuation of the reservoirs active storage
The lower graph shows the frequency curve for the reservoir storage level

Figure A4.1(b) – Reservoir storage levels – Scenario 4 - Phase 1&2 (1930-1994)

TABLE A4.1 - WATHNET OUTPUT SUMMARY (Version 3.01) FOR SCENARIO 4 PHASE 1&2

```
 Output file:  c:\yield\S4T\4T478p2r4.sou
 Network file: c:\yield\net\R4.net
 Flow file:    c:\yield\lhd-ssdatab.bin


 Run title: R4
            Historical Simulation


 Network title: ALTERNATIVE 3:Katse+Mat Div+Mohale+Masha
                SMEC International - S Yance

 Degree of shortfall balance among demand nodes with same priority =  5
 Degree of balance among reservoirs with same filling priority = 20

 Number of replicates =   1
 First replicate corresponds to replicate   1 in streamflow data file

 Number of seasons in year =  12

 Run mode: Simulate system using perfect one-season flow and demand forecasts


!--------------------------------------------------------------------!
! Default demand shortfall and storage carryover penalties were used !
!--------------------------------------------------------------------!


 CPU time (secs): Total              =     3.3
                  Network setup      =      .3
                  Network LP algoritm =    1.8
                  Disk write         =      .5
                  Disk read          =      .2


 LP algorithm: Bertsekas RELAX code
               Prior information option: Never use
               Crash option: Simple
```

Arc	Arc name	Type	Node: Frm	To	<------Cost-------> Constant	Time-mul	Monthly capacity Minimum	Maximum	Comm year	Decom year	Loss %
1	Matsoku Tunnel	Stream	1	2	0	.000	Variable	12000			0
2	System Yield	Conduit	2	3	0	.000	0	99999999	1930	9999	0
3	Matsoku outflow	Stream	1	7	2	.000	0	99999999			0
4	Inflow to IFR1	Stream	7	4	0	.000	Variable	99999999			0
5	Katse Outflow/Spill	Stream	2	8	2	.000	0	99999999			0
6	Inflow to IFR2	Stream	8	5	0	.000	Variable	99999999			0
7	Jn Malibam/Matsoku	Stream	6	10	0	.000	Variable	99999999			0
8	Inflow to IFR3	Stream	10	9	0	.000	Variable	99999999			0
9	Outflow from IFR1	Stream	4	6	0	.000	Variable	99999999			0
10	Outflow from IFR3	Stream	9	11	0	.000	Variable	99999999			0
11	Mashai Inflow	Stream	11	12	0	.000	Variable	99999999			0
12	Inflow to IFR5	Stream	13	14	0	.000	Variable	99999999			0
13	Outflow from IFR5	Stream	14	15	0	.000	Variable	99999999			0
14	Mohale Tunnel	Conduit	16	2	0	.000	Vol dep	Vol-vol	1930	9999	0
15	Mohale Outflow/Spill	Stream	16	17	2	.000	0	99999999			0
16	Inflow to IFR7	Stream	17	18	0	.000	Variable	99999999			0
17	Outflow from IFR7	Stream	18	19	0	.000	Variable	99999999			0
18	Inflow to IFR8	Stream	19	20	0	.000	Variable	99999999			0
19	Outflow from IFR8	Stream	20	15	0	.000	Variable	99999999			0
20	Jn Sequnyane/Senqu	Stream	15	21	0	.000	Variable	99999999			0
21	Inflow to IFR6	Stream	21	22	0	.000	Variable	99999999			0
22	Waste	Stream	22	23	0	.000	Variable	99999999			0
23	inflow to Mashai PS	Conduit	12	24	0	.000	0	99999999	1930	9999	0
24	Mashai PS Outflow	Conduit	24	2	0	.000	0	131400	0	9999	0
25	Outflow from IFR2	Stream	5	6	0	.000	Variable	9999999			0
26	Outflow from IFR4	Stream	25	13	0	.000	Variable	99999999			0
27	Mashai Outflow/Spill	Stream	12	26	1000	.000	0	99999999			0
28	Inflow to IFR4	Stream	26	25	0	.000	0	99999999			0

Summary of variable monthly arc capacities

Arc	Arc name	Type	Monthly capacity 1 / 7	2 / 8	3 / 9	4 / 10	5 / 11	6 / 12
1	Matsoku Tunnel	Minimum	0	0	0	0	0	0
			0	0	0	0	0	0
4	Inflow to IFR1	Minimum	0	0	0	0	0	0

```
                                     0       0       0       0       0       0
  6 Inflow to IFR2       Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
  7 Jn Malibam/Matsoku   Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
  8 Inflow to IFR3       Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
  9 Outflow from IFR1    Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 10 Outflow from IFR3    Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 11 Mashai Inflow        Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 12 Inflow to IFR5       Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 13 Outflow from IFR5    Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 16 Inflow to IFR7       Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 17 Outflow from IFR7    Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 18 Inflow to IFR8       Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 19 Outflow from IFR8    Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 20 Jn Sequnyane/Senqu   Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 21 Inflow to IFR6       Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 22 Waste                Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 25 Outflow from IFR2    Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0
 26 Outflow from IFR4    Minimum     0       0       0       0       0       0
                                     0       0       0       0       0       0

Summary of volume-dependant arc capacities
Arc  Arc name             Type     Reservoir node        Max flow       Look-up table
----------------------------------------------------------------------------------------------------
 14  Mohale Tunnel        Minimum  Katse Reservoir       99999999  Flow %:   0   0   0   0   0   0
                                    Average                         Vol %:   0   0   0   0   0 100

Summary of volume-volume dependant arc capacities
Arc  Arc name             Location    Reservoir node        Head = a + b*V**c where V = volume/capacity
                                                                     a         b         c
------------------------------------------------------------------------------------------
 14  Mohale Tunnel        Upstream    Mohale Reservoir        16.0      72.6      .701
                          Downstream  Katse Reservoir         .000      64.1      .702
                  Capacity =   .108E+05*(U/s head-D/s head)**  .500

Node  Node name            Comm year  Node type          Stream inflow name
-----------------------------------------------------------------------------
   1  Matsoku Diversion               Gravity diversion  MATSOKU INFLOW TCM
   2  Katse Reservoir          1929   Reservoir          KATSE INFLOW TCM
   3  Sytem Yield              1930   Consumptve demand
   4  IFR1                     1930   Instream demand
   5  IFR2                     1930   Instream demand
   6  Jn of Malib&Mats                Stream junction
   7  Matsku/IFR1 inc                 Stream junction
   8  Malibam/IFR2 Inc Inf            Stream junction
   9  IFR3                     1930   Instream demand
  10  Malibam/IFR3 Inc Inf            Stream junction
  11  Senqu/Mashai Infflow            Stream junction    MASHAI INC INFLOW TC
  12  Mashai Reservoir         1930   Reservoir
  13  Senqu/IFR5 Inc Inf              Stream junction    IFR5 INC FLOW TCM
  14  IFR5                     1930   Instream demand
  15  Conf Senqunyane/Senq            Stream junction
  16  Mohale Reservoir         1930   Reservoir          MOHALE INFLOW TCM
  17  Senquny/IFR7 Inc Inf            Stream junction    IFR7 INC FLOW TCM
  18  IFR7                     1930   Instream demand
  19  Senquny/IFR8 Inc Inf            Stream junction    IFR8 INC FLOW TCM
  20  IFR8                     1930   Instream demand
  21  IFR6 Inc Inf                    Stream junction    IFR6 INC FLOW TCM
  22  IFR6                     1930   Instream demand
  23  Waste Node                      Waste node
  24  Mashai Pumping Stn              Pump diversion
  25  IFR4                     1930   Instream demand
  26  IF4 Inc Inf                     Stream junction    IFR4 INC FLOW TCM

Summary of hydropower nodes
Node  Node name            Descriptor            Data
-----------------------------------------------------------------------------------------
```

```
Node  Node name             Node type  Arc penalty
-----------------------------------------------------------------------------------
   2  Katse Reservoir       Reservoir  Default target carryover penalties over20 arcs
   3  Sytem Yield           Demand     Default shortfall penalties over 1 arcs
   4  IFR1                  Demand     Default shortfall penalties over 5 arcs
   5  IFR2                  Demand     Default shortfall penalties over 5 arcs
   9  IFR3                  Demand     Default shortfall penalties over 5 arcs
  12  Mashai Reservoir      Reservoir  Default target carryover penalties over20 arcs
  14  IFR5                  Demand     Default shortfall penalties over 5 arcs
  16  Mohale Reservoir      Reservoir  Default target carryover penalties over20 arcs
  18  IFR7                  Demand     Default shortfall penalties over 5 arcs
  20  IFR8                  Demand     Default shortfall penalties over 5 arcs
  22  IFR6                  Demand     Default shortfall penalties over 5 arcs
  25  IFR4                  Demand     Default shortfall penalties over 5 arcs

Demand data was read from file: c:\yield\s4t\p24tdmda.bin
which had    1 replicates

Demand node          Name in demand file  Priority Multiplier
-------------------------------------------------------------
Sytem Yield          SYSTEM YIELD 6 54.0         2     .88518
IFR1                 IFR 1 REQUIREMENTS T        1    1.00000
IFR2                 IFR 2 REQUIREMENTS T        1     .00000
IFR3                 IFR 3 REQUIREMENTS T        1     .00000
IFR5                 IFR 5 REQUIREMENTS T        1     .00000
IFR7                 IFR 7 REQUIREMENTS T        1    1.00000
IFR8                 IFR 8 REQUIREMENTS T        1     .00000
IFR6                 IFR 6 REQUIREMENTS T        1     .00000
IFR4                 IFR 4 REQUIREMENTS T        1    1.00000


********************************************************************************
>> Restriction Policy <<

>> Demand restriction group: 1        Policy applies till 1994
Restriction level:                    1         2         3         4
% restriction:                       97        98        99       100
Threshold storage level (%):          1         0         0         0

Group Demand Nodes
Node  Name
--------------------------
   3  Sytem Yield
   4  IFR1
   5  IFR2
   9  IFR3
  14  IFR5
  18  IFR7
  20  IFR8
  22  IFR6
  25  IFR4

>> Revise restrictions at start of every season

Group Reservoirs
Node  Name
--------------------------


Evaporation and arc loss convergence parameters:
   Max no. of iterations =40
   Max evaporation error =  1%
   Max arc loss error    =  1%
********************************************************************************


Reservoir name        Capacity   Initial   Stream  Filling
                        ml        volume   inflow?  priority
------------------------------------------------------------
Katse Reservoir        1518600    911160       Y      1
Mashai Reservoir       2433400   1460040       N      1
Mohale Reservoir        857118    514272       Y      1


Reservoir name       Target as % of capacity till 1994 for month
                       1   2   3   4   5   6   7   8   9  10  11  12
----------------------------------------------------------------------
Katse Reservoir      100 100 100 100 100 100 100 100 100 100 100 100
Mashai Reservoir     100 100 100 100 100 100 100 100 100 100 100 100
Mohale Reservoir     100 100 100 100 100 100 100 100 100 100 100 100
```

Reservoir name	Evaporation site name	a	b	c
Katse Reservoir	KATSE EVAPORATION MM	13.140	22.940	.84460
Mashai Reservoir	MASHAI EVAPORATION M	28.750	40.510	.89440
Mohale Reservoir	MOHALE EVAPORATION M	4.3300	18.359	.82210

Area = a + b*V**c where V = volume/capacity

Flood Control Volume as % of capacity for month

Reservoir name	1	2	3	4	5	6	7	8	9	10	11	12
Katse Reservoir	0	0	0	0	0	0	0	0	0	0	0	0
Mashai Reservoir	0	0	0	0	0	0	0	0	0	0	0	0
Mohale Reservoir	0	0	0	0	0	0	0	0	0	0	0	0

++

Step = 1 Year = 1930 Season = 1 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity
1	Matsoku Tunnel	1	2	0	0	12000	67	0
2	System Yield	2	3	0	0	99999999	125617	0
3	Matsoku outflow	1	7	2	0	99999999	3669	0
4	Inflow to IFR1	7	4	0	0	99999999	0	0
5	Katse Outflow/Spill	2	8	2	0	99999999	0	0
6	Inflow to IFR2	8	5	0	0	99999999	0	0
7	Jn Malibam/Matsoku	6	10	0	0	99999999	3669	0
8	Inflow to IFR3	10	9	0	0	99999999	3669	0
9	Outflow from IFR1	4	6	0	0	99999999	3669	0
10	Outflow from IFR3	9	11	0	0	99999999	3669	0
11	Mashai Inflow	11	12	0	0	99999999	61617	0
12	Inflow to IFR5	13	14	0	0	99999999	36873	0
13	Outflow from IFR5	14	15	0	0	99999999	36873	0
14	Mohale Tunnel	16	2	0	0	51949	0	0
15	Mohale Outflow/Spill	16	17	2	0	99999999	7128	0
16	Inflow to IFR7	17	18	0	0	99999999	0	0
17	Outflow from IFR7	18	19	0	0	99999999	8348	0
18	Inflow to IFR8	19	20	0	0	99999999	10948	0
19	Outflow from IFR8	20	15	0	0	99999999	10948	0
20	Jn Sequnyane/Senqu	15	21	0	0	99999999	47821	0
21	Inflow to IFR6	21	22	0	0	99999999	72425	0
22	Waste	22	23	0	0	99999999	72425	0
23	inflow to Mashai PS	12	24	0	0	99999999	29872	0
24	Mashai PS Outflow	24	2	0	0	131400	29872	22
25	Outflow from IFR2	5	6	0	0	9999999	0	0
26	Outflow from IFR4	25	13	0	0	99999999	32402	0
27	Mashai Outflow/Spill	12	26	1000	0	99999999	25162	0
28	Inflow to IFR4	26	25	0	0	99999999	0	0

Reservoir no.	name	Active capacity	Initial - volume	Net release	= Final volume
1	Katse Reservoir	1518600	911160	70288	840872
2	Mashai Reservoir	2433400	1460040	0	1460040
3	Mohale Reservoir	857118	514272	1381	512891
	Totals	4809118	2885472	71669	2813803

>>> Total waste from system = 72425

Demand centre no.	name	Demand volumes: Unrestricted -	Shortfall =	Actual
1	Sytem Yield	125617	0	125617
2	IFR1	3669	0	3669
3	IFR2	0	0	0
4	IFR3	0	0	0
5	IFR5	0	0	0
6	IFR7	8348	0	8348
7	IFR8	0	0	0
8	IFR6	0	0	0
9	IFR4	32402	0	32402
	Totals	170036	0	170036

++

Step = 2 Year = 1930 Season = 2 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity

1	Matsoku Tunnel	1	2	0	0	12000	0	0
2	System Yield	2	3	0	0	99999999	125617	0
3	Matsoku outflow	1	7	2	0	99999999	1067	0
4	Inflow to IFR1	7	4	0	0	99999999	0	0
5	Katse Outflow/Spill	2	8	2	0	99999999	0	0
6	Inflow to IFR2	8	5	0	0	99999999	0	0
7	Jn Malibam/Matsoku	6	10	0	0	99999999	1067	0
8	Inflow to IFR3	10	9	0	0	99999999	1067	0
9	Outflow from IFR1	4	6	0	0	99999999	1067	0
10	Outflow from IFR3	9	11	0	0	99999999	1067	0
11	Mashai Inflow	11	12	0	0	99999999	18648	0
12	Inflow to IFR5	13	14	0	0	99999999	24596	0
13	Outflow from IFR5	14	15	0	0	99999999	24596	0
14	Mohale Tunnel	16	2	0	0	51770	39570	76
15	Mohale Outflow/Spill	16	17	2	0	99999999	4746	0
16	Inflow to IFR7	17	18	0	0	99999999	0	0
17	Outflow from IFR7	18	19	0	0	99999999	5500	0
18	Inflow to IFR8	19	20	0	0	99999999	7300	0
19	Outflow from IFR8	20	15	0	0	99999999	7300	0
20	Jn Sequnyane/Senqu	15	21	0	0	99999999	31896	0
21	Inflow to IFR6	21	22	0	0	99999999	44581	0
22	Waste	22	23	0	0	99999999	44581	0
23	inflow to Mashai PS	12	24	0	0	99999999	71565	0
24	Mashai PS Outflow	24	2	0	0	131400	71565	54
25	Outflow from IFR2	5	6	0	0	9999999	0	0
26	Outflow from IFR4	25	13	0	0	99999999	21498	0
27	Mashai Outflow/Spill	12	26	1000	0	99999999	19031	0
28	Inflow to IFR4	26	25	0	0	99999999	0	0

Reservoir no.	name	Active capacity	Initial - volume	Net release	= Final volume
1	Katse Reservoir	1518600	840872	5642	835230
2	Mashai Reservoir	2433400	1460040	78725	1381315
3	Mohale Reservoir	857118	512891	41486	471405
	Totals	4809118	2813803	125853	2687950

>>> Total waste from system = 44581

Demand centre no.	name	Demand volumes: Unrestricted	- Shortfall	= Actual
1	Sytem Yield	125617	0	125617
2	IFR1	1082	0	1082
3	IFR2	0	0	0
4	IFR3	0	0	0
5	IFR5	0	0	0
6	IFR7	5500	0	5500
7	IFR8	0	0	0
8	IFR6	0	0	0
9	IFR4	21498	0	21498
	Totals	153697	0	153697

++

Step = 3 Year = 1930 Season = 3 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity
1	Matsoku Tunnel	1	2	0	0	12000	0	0
2	System Yield	2	3	0	0	99999999	125617	0
3	Matsoku outflow	1	7	2	0	99999999	3291	0
4	Inflow to IFR1	7	4	0	0	99999999	0	0
5	Katse Outflow/Spill	2	8	2	0	99999999	0	0
6	Inflow to IFR2	8	5	0	0	99999999	0	0
7	Jn Malibam/Matsoku	6	10	0	0	99999999	3291	0
8	Inflow to IFR3	10	9	0	0	99999999	3291	0
9	Outflow from IFR1	4	6	0	0	99999999	3291	0
10	Outflow from IFR3	9	11	0	0	99999999	3291	0
11	Mashai Inflow	11	12	0	0	99999999	19298	0
12	Inflow to IFR5	13	14	0	0	99999999	27588	0
13	Outflow from IFR5	14	15	0	0	99999999	27588	0
14	Mohale Tunnel	16	2	0	0	50541	0	0
15	Mohale Outflow/Spill	16	17	2	0	99999999	7142	0
16	Inflow to IFR7	17	18	0	0	99999999	0	0
17	Outflow from IFR7	18	19	0	0	99999999	8348	0
18	Inflow to IFR8	19	20	0	0	99999999	10648	0
19	Outflow from IFR8	20	15	0	0	99999999	10648	0
20	Jn Sequnyane/Senqu	15	21	0	0	99999999	38236	0

21	Inflow to IFR6	21	22	0	0	99999999	46435	0
22	Waste	22	23	0	0	99999999	46435	0
23	inflow to Mashai PS	12	24	0	0	99999999	77115	0
24	Mashai PS Outflow	24	2	0	0	131400	77115	58
25	Outflow from IFR2	5	6	0	0	9999999	0	0
26	Outflow from IFR4	25	13	0	0	99999999	21625	0
27	Mashai Outflow/Spill	12	26	1000	0	99999999	17456	0
28	Inflow to IFR4	26	25	0	0	99999999	0	0

Reservoir no.	name	Active capacity	Initial - volume	Net release	= Final volume
1	Katse Reservoir	1518600	835230	18664	816566
2	Mashai Reservoir	2433400	1381315	81575	1299740
3	Mohale Reservoir	857118	471405	1320	470085
	Totals	4809118	2687950	101559	2586391

>>> Total waste from system = 46435

Demand centre no.	name	Demand volumes: Unrestricted	- Shortfall	= Actual
1	Sytem Yield	125617	0	125617
2	IFR1	3337	0	3337
3	IFR2	0	0	0
4	IFR3	0	0	0
5	IFR5	0	0	0
6	IFR7	8348	0	8348
7	IFR8	0	0	0
8	IFR6	0	0	0
9	IFR4	21625	0	21625
	Totals	158927	0	158927

++

Step = 4 Year = 1930 Season = 4 Replicate = 1

Arc	Arc name	Node: From	To	Cost	Capacities: Minimum	Maximum	Flow	percent Capacity
1	Matsoku Tunnel	1	2	0	0	12000	6292	52
2	System Yield	2	3	0	0	99999999	125617	0
3	Matsoku outflow	1	7	2	0	99999999	3669	0
4	Inflow to IFR1	7	4	0	0	99999999	0	0
5	Katse Outflow/Spill	2	8	2	0	99999999	0	0
6	Inflow to IFR2	8	5	0	0	99999999	0	0
7	Jn Malibam/Matsoku	6	10	0	0	99999999	3669	0
8	Inflow to IFR3	10	9	0	0	99999999	3669	0
9	Outflow from IFR1	4	6	0	0	99999999	3669	0
10	Outflow from IFR3	9	11	0	0	99999999	3669	0
11	Mashai Inflow	11	12	0	0	99999999	163125	0
12	Inflow to IFR5	13	14	0	0	99999999	43795	0
13	Outflow from IFR5	14	15	0	0	99999999	43795	0
14	Mohale Tunnel	16	2	0	0	51020	0	0
15	Mohale Outflow/Spill	16	17	2	0	99999999	3687	0
16	Inflow to IFR7	17	18	0	0	99999999	0	0
17	Outflow from IFR7	18	19	0	0	99999999	8348	0
18	Inflow to IFR8	19	20	0	0	99999999	20248	0
19	Outflow from IFR8	20	15	0	0	99999999	20248	0
20	Jn Sequnyane/Senqu	15	21	0	0	99999999	64043	0
21	Inflow to IFR6	21	22	0	0	99999999	116474	0
22	Waste	22	23	0	0	99999999	116474	0
23	inflow to Mashai PS	12	24	0	0	99999999	48762	0
24	Mashai PS Outflow	24	2	0	0	131400	48762	37
25	Outflow from IFR2	5	6	0	0	9999999	0	0
26	Outflow from IFR4	25	13	0	0	99999999	32402	0
27	Mashai Outflow/Spill	12	26	1000	0	99999999	9721	0
28	Inflow to IFR4	26	25	0	0	99999999	0	0

Reservoir no.	name	Active capacity	Initial - volume	Net release	= Final volume
1	Katse Reservoir	1518600	816566	-40466	857032
2	Mashai Reservoir	2433400	1299740	-98850	1398590
3	Mohale Reservoir	857118	470085	-24044	494129
	Totals	4809118	2586391	-163360	2749751

>>> Total waste from system = 116474

Demand centre Demand volumes:

```
no.  name                Unrestricted - Shortfall =  Actual
--------------------------------------------------------------
  1  Sytem Yield               125617          0    125617
  2  IFR1                        3669          0      3669
  3  IFR2                           0          0         0
  4  IFR3                           0          0         0
  5  IFR5                           0          0         0
  6  IFR7                        8348          0      8348
  7  IFR8                           0          0         0
  8  IFR6                           0          0         0
  9  IFR4                       32402          0     32402
--------------------------------------------------------------
     Totals                    170036          0    170036

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Step =   5 Year = 1930 Season =   5 Replicate =    1

Arc  Arc name              Node:        Cost       Capacities:        Flow  percent
                         From    To              Minimum    Maximum           Capacity
-----------------------------------------------------------------------------------------
  1  Matsoku Tunnel         1     2          0          0      12000      3802    31
  2  System Yield           2     3          0          0   99999999    125617     0
  3  Matsoku outflow        1     7          2          0   99999999      3669     0
  4  Inflow to IFR1         7     4          0          0   99999999         0     0
  5  Katse Outflow/Spill    2     8          2          0   99999999         0     0
  6  Inflow to IFR2         8     5          0          0   99999999         0     0
  7  Jn Malibam/Matsoku     6    10          0          0   99999999      3669     0
  8  Inflow to IFR3        10     9          0          0   99999999      3669     0
  9  Outflow from IFR1      4     6          0          0   99999999      3669     0
 10  Outflow from IFR3      9    11          0          0   99999999      3669     0
 11  Mashai Inflow         11    12          0          0   99999999     92719     0
 12  Inflow to IFR5        13    14          0          0   99999999     66862     0
 13  Outflow from IFR5     14    15          0          0   99999999     66862     0
 14  Mohale Tunnel         16     2          0          0      52128     14833    28
 15  Mohale Outflow/Spill  16    17          2          0   99999999      2276     0
 16  Inflow to IFR7        17    18          0          0   99999999         0     0
 17  Outflow from IFR7     18    19          0          0   99999999      8348     0
 18  Inflow to IFR8        19    20          0          0   99999999     27348     0
 19  Outflow from IFR8     20    15          0          0   99999999     27348     0
 20  Jn Sequnyane/Senqu    15    21          0          0   99999999     94210     0
 21  Inflow to IFR6        21    22          0          0   99999999    184651     0
 22  Waste                 22    23          0          0   99999999    184651     0
 23  inflow to Mashai PS   12    24          0          0   99999999     32402     0
 24  Mashai PS Outflow     24     2          0          0     131400     32402    24
 25  Outflow from IFR2      5     6          0          0    9999999         0     0
 26  Outflow from IFR4     25    13          0          0   99999999     32402     0
 27  Mashai Outflow/Spill  12    26       1000          0   99999999     19187     0
 28  Inflow to IFR4        26    25          0          0   99999999         0     0

  Reservoir                 Active      Initial -  Net     =   Final
 no.  name                  capacity    volume     release     volume
----------------------------------------------------------------------
  1  Katse Reservoir        1518600     857032       8333     848699
  2  Mashai Reservoir       2433400    1398590     -36349    1434939
  3  Mohale Reservoir        857118     494129     -20131     514260
----------------------------------------------------------------------
     Totals                 4809118    2749751     -48147    2797898

 >>> Total waste from system =     184651

Demand centre                          Demand volumes:
no.  name                Unrestricted - Shortfall =  Actual
--------------------------------------------------------------
  1  Sytem Yield               125617          0    125617
  2  IFR1                        3669          0      3669
  3  IFR2                           0          0         0
  4  IFR3                           0          0         0
  5  IFR5                           0          0         0
  6  IFR7                        8348          0      8348
  7  IFR8                           0          0         0
  8  IFR6                           0          0         0
  9  IFR4                       32402          0     32402
--------------------------------------------------------------
     Totals                    170036          0    170036

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Step =   6 Year = 1930 Season =   6 Replicate =    1

Arc  Arc name              Node:        Cost       Capacities:        Flow  percent
                         From    To              Minimum    Maximum           Capacity
-----------------------------------------------------------------------------------------
  1  Matsoku Tunnel         1     2          0          0      12000     10035    83  <
```

2	System Yield	2	3	0	0	99999999	125617	0
3	Matsoku outflow	1	7	2	0	99999999	1083	0
4	Inflow to IFR1	7	4	0	0	99999999	0	0
5	Katse Outflow/Spill	2	8	2	0	99999999	0	0
6	Inflow to IFR2	8	5	0	0	99999999	0	0
7	Jn Malibam/Matsoku	6	10	0	0	99999999	1083	0
8	Inflow to IFR3	10	9	0	0	99999999	1083	0
9	Outflow from IFR1	4	6	0	0	99999999	1083	0
10	Outflow from IFR3	9	11	0	0	99999999	1083	0
11	Mashai Inflow	11	12	0	0	99999999	80261	0
12	Inflow to IFR5	13	14	0	0	99999999	54749	0
13	Outflow from IFR5	14	15	0	0	99999999	54749	0
14	Mohale Tunnel	16	2	0	0	51848	31935	61
15	Mohale Outflow/Spill	16	17	2	0	99999999	0	0
16	Inflow to IFR7	17	18	0	0	99999999	1543	0
17	Outflow from IFR7	18	19	0	0	99999999	5250	0
18	Inflow to IFR8	19	20	0	0	99999999	22750	0
19	Outflow from IFR8	20	15	0	0	99999999	22750	0
20	Jn Sequnyane/Senqu	15	21	0	0	99999999	77499	0
21	Inflow to IFR6	21	22	0	0	99999999	186559	0
22	Waste	22	23	0	0	99999999	186559	0
23	inflow to Mashai PS	12	24	0	0	99999999	78375	0
24	Mashai PS Outflow	24	2	0	0	131400	78375	59
25	Outflow from IFR2	5	6	0	0	9999999	0	0
26	Outflow from IFR4	25	13	0	0	99999999	12836	0
27	Mashai Outflow/Spill	12	26	1000	0	99999999	0	0
28	Inflow to IFR4	26	25	0	0	99999999	797	0

Reservoir no.	name	Active capacity	Initial - volume	Net release	= Final volume
1	Katse Reservoir	1518600	848699	-62461	911160
2	Mashai Reservoir	2433400	1434939	2973	1431966
3	Mohale Reservoir	857118	514260	0	514260
	Totals	4809118	2797898	-59488	2857386

>>> Total waste from system = 186559

Demand centre no.	name	Demand volumes: Unrestricted -	Shortfall =	Actual
1	Sytem Yield	125617	0	125617
2	IFR1	1083	0	1083
3	IFR2	0	0	0
4	IFR3	0	0	0
5	IFR5	0	0	0
6	IFR7	3707	0	3707
7	IFR8	0	0	0
8	IFR6	0	0	0
9	IFR4	12039	0	12039
	Totals	142446	0	142446

APPENDIX 5

REVIEW OF MODELING TECHNIQUES USED IN PLANNING AND OPERATION OF WATER RESOURCES SYSTEMS

A5.1 INTRODUCTION

Water resources modeling has become one of the essential tools for planning and operation of water resources systems. Reservoir system operations are complex and often offer substantial increases in benefits for relatively small improvements in operating efficiency. Reservoir operation involves determining decision policies which will optimise certain objectives subject to various constraints. There is no single type of reservoir operation problem but rather a multitude of decision problems and situations. Two main categories of methods used in modeling single or multi-reservoir systems are simulation and optimisation techniques.

Mathematical simulation and optimisation models are used for various purposes in various situations. Many models have been developed for use during project planning and design. Other models are for real-time operation. The tradeoffs between purposes such as hydroelectric power, irrigation, municipal and industrial water supply could be investigated from various perspectives. Optimising hydroelectric power generation from a system of reservoirs is often the primary objective. Many actual planning and real-time operating decisions are based largely on the results of simulation models. Simulation models have been proven through practical application to be a valuable aid in sizing reservoir performance for a given operating policy or set of conditions. Numerous simulations may be required to achieve acceptable results, and the optimum decision policy may never be found. Consequently, application of mathematical optimisation techniques, which automatically find the optimum decision policy, to reservoir operation problems has received much attention.

During the past twenty years, a major thrust of research has been in application of optimisation techniques such as linear programming, dynamic programming, and various non-linear programming algorithms to modeling water resources systems. Although extensive research has been undertaken, these techniques are not yet widely used by the reservoir planning and management community for routine use. However, research results, case studies, and actual applications of optimisation models indicate a high potential for improving reservoir operations through their use.

The random nature of streamflow and other hydrologic variables is a fundamental complicating factor in determining optimum reservoir operating policies. While many simulation and optimisation models are strictly deterministic, others incorporate various stochastic analysis methods. Stochastic methods were actually first introduced into hydrology and water resources systems engineering to cope with problems associated with reservoir design and operation. Stochastic storage theory, reservoir reliability, and hydrologic time series analysis are key aspects of reservoir system and analysis. However, with regard to stochastic methods in reservoir operation there is also a big gap between the research and application.

A5.2 SIMULATION MODELS

a simulation model is a representation of a system used to predict the behavior of the system under a given set of conditions. Simulation is the process of experimenting with a simulation model to analyse the performance of the system under varying condition including alternative decision policies. Even though a pure simulation model contains no algorithm for defining an optimum, solution directly, numerous runs of a model can be made with alternative decision policies in a trial-and-error search for an optimal or near optimal solution.

Simulation is the fundamental starting point for modeling to support decisions regarding the optimum sizing and operation of reservoir projects. Optimisation and stochastic methods extend and supplement simulation in order to deal with the complexities of searching through possible decision policies and handling uncertainties including the random characteristics of hydrologic phenomena.

Mathematical programming or optimisation automatically compute values for the decision variables which optimise an objective function. Since simulation models are limited to predicting the system performance for a given decision policy, optimisation models have a distinct advantage in this regard. However, simulation models have certain other advantages over optimisation models. Optimisation typically requires significant simplifications in the mathematical representation of a system. Simulation models generally permit more detailed and realistic representation of the complex hydrologic and economic characteristics of a reservoir system.

Optimisation and simulation are often used in combination. Preliminary screening with an optimisation model may be used to develop a manageable range of alternative decision policies for further detailed analysis with a simulation model.

Simulation techniques could either be system specific or generalised. System specific models are developed for a certain system and could not be applied elsewhere. Generalised simulation models could be ported and applied to variety of systems. A few examples of generalised simulation models are given in the following section.

A5.2.1 Generalised Simulation Models

HEC-5 - Simulation of Flood Control and Conservation Systems.

The HEC-5 - Simulation of Flood Control and Conservation Systems computer program is probably the most versatile of the available models in the sense of being applicable to a wide range of reservoir operation problems. HEC -5 simulates the operation of multipurpose, multi-reservoir systems. The reservoir system consists of a number of reservoir and control points. Water demands for municipal, industrial, and/or agricultural water use, hydropower, or instream flow maintenance are specified at the reservoirs or at downstream control points. Flood control storage is operated based on flows at downstream control points. The model operates the system of reservoir in order to best meet specified flood control and conservation requirements.

Southwestern Division reservoir Regulation Simulation Model

A generalised reservoir regulation model developed by the Southwestern Division (SWD) of the US Army Corps of Engineers is described by Hula (1981). The SWD model simulates the daily sequential regulation of a multipurpose reservoir system. The model performs the same types of hydrologic and economic simulation computations as HEC-5. The SWD model uses a one-day computation interval whereas HEC-5 uses a variable time interval. Details of handling input data and various computational capabilities differ somewhat between the two models.

Texas Department of Water Resources Models

The Texas Water Development Board began development of a series of surface water simulation models in the late 1960's in conjunction of the Texas Water Plan (TWDP, 1974). The present RESOP-II SIMYLD-II, AL-V and SIM-V computer programs evolved from earlier versions. SIMYLD-II provides the capability for analysing water storage and water transfer within a multi-reservoir or multi basin system (TWDB, 1974). SIMYLD-II simulates the operation of a system subject to a specified sequence of demands and hydrologic conditions. The model simulates catchment, storage and transfer of water within a system of reservoirs, rivers and conduits on a monthly basis with the object of meeting a set of specified demands in a given order of priority.

The Surface Water Resources Allocation model (AL-V) and Multi-reservoir Simulation and Optimisation Model (SIM-V) simulate and optimise the operation of an interconnected system of reservoirs, hydroelectric power plants, pump canals, pipelines, and river reaches (Martin 1981, 1982). SIM-V is used to analyse short-term reservoir operations. AL-V is for long-term operations. The model combine simulation and optimisation. The steady-state operation of a surface water system is represented as a network flow problem.

A5.2.2 System Specific Simulation Models

The system specific models are developed and used for complex systems which do not led themselves to using generalised models. The planing and operation of such systems often involves contractual obligations and operating procedures, which could not be handled by generalised models. One of examples of system specific model is COLOSSUS which is a large scale simulation/optimisation model (Sabet and Coe, 1986) provides schedule for operation of water and power for the California State Water Project (SWP). The SWP consists of series of reservoirs linked by rivers, pumping plants, canals, tunnels and generating plans. The projects provides water for municipal and agricultural users, and generates power which is either sold to electric utility companies or utilised in pumping. The model is used for operation planning (one-two years duration), annual plan of operation (one year), pre-scheduling (one-two weeks), and real-time operation (daily with hourly detail). It consists of several simulation models.

A5.3 OPTIMISATION TECHNIQUES

The academic research community in particular, and many practitioners as well, have been extremely enthusiastic about optimisation techniques, applied to water resources systems. The characteristics of certain reservoir operation problems are ideally suited for applying linear and dynamic programming and various other non-linear optimisation algorithms. Research results, case studies, and experience in application of optimisation models in actual planning and real-time operation decision indicate a high potential for improving water resource operations through their use. However, optimisation techniques have not been extensively used in planning and operation of actual systems.

Mathematical optimisation techniques require that the real system be represented in the proper mathematical format. Representing complex project objectives and performance criteria in the required format, without unrealistic simplifications, is a particular difficult aspect of the modeling process which limits the application of optimisation techniques. Once the system is well represented the role of formal mathematical optimisation models is to search through a large number of possible combinations of values for the decision variables to fins the decision policy which maximises or minimises a defined objective function. Defining system objectives, developing criteria for quantitatively measuring system performances fulfilling the objectives, and handling interactions and conflicts between objectives is a major area of complexity.

By looking at the water industry it appears that the simulation techniques will continue to be the "work-horse" of water resource system analysis for a while. The optimisation techniques will provide valuable supplemental analysis capabilities. The use of optimisation techniques as simulation tools would in many type of water resources problems replace the classical simulation methods.

The optimisation techniques may be broadly divided into the following categories:

- Linear Programming (LP),
- Dynamic programming (DP), and
- Nonlinear programming (NLP).

Application of these techniques and their extensions are extensively addressed in the literature of operations research, systems engineering, and mathematics. Application of these techniques to water resource operation problems has been a major focus of the water resources planning and management literature during the past two decades. Most of the applications of optimisation techniques in water resource systems analysis involve LP, DP, or combining a simulation model with a nonlinear search algorithm. A special type of LP known as Network Flow Programming (NFP) has become popular in recent years. The NFP has been both used as optimisation and simulation tool in planning and operation of water resources systems. The numerous other available NLP techniques have been used relatively little in water resource planning and operation.

A5.3.1 Linear Programming:

This solution technique has been ranked as one of the most important scientific advances in the mid-twentieth century by many people. The use of LP and other mathematical optimisation techniques has increased tremendously since 1970. The technique has been widely used by the management sciences and is the mainstay for operations research for a number of reasons:

1. The solution structure is such that a very definite algorithm is followed which leads to very general computer programs.
2. There is a large proliferation of computer packages that can solve LP problems.
3. This solution technique is applicable to a large number of different problems.

Though LP can be used to solve problems of many different disciplines, it is limited to only solving linear problems. The objective function, which defines the desired output, along with the constraint equations, which define the limits of the resources, must be linear equations. There are techniques, which allow nonlinear problems to be solved by LP, but these techniques add another step of approximation and tend to increase the number of constraints on the problem.

LP has the advantage of being a well-defined, easy-to-understand, readily applicable algorithm. Numerous generalised computer programs are available for solving LP problems. Many water resource operation problems can be represented realistically by a linear objective function and set of linear constraints. Various linearisation techniques have been used successfully to deal with non-linearities. However, the strict linear form of the mathematical model limits its applicability.

Dynamic Programming:

DP (Bellman, 1962) is a mathematical technique that can be used to solve a variety of problems involving a sequence of interrelated decisions, such as the release policy for a multipurpose reservoir. DP problems are not formulated to fit a precise algorithm as LP problems, but are fitted to a very general structure that will allow for their solution. This structuring of the problem will vary with each problem, and a great deal of ingenuity and insight must be exercised by the modeler in the model development process.

The modeler must divide the problem into stages in which a decision must take place. In reservoir operation DP problems, the stages are typically time periods (months, weeks, seasons, contractual time periods, etc.) and the decisions are water releases from outlet structures, the amount of water through the turbines, or the storage levels in the reservoir.

The modeling technique of DP is very well suited to water resources problems (Codner, 1979). The limitations of LP, most notably the forced linearity of the system, have been lifted. The DP technique can handle nonlinear objective functions, such as calculations for hydropower which is a product of the head and flow and therefore nonlinear, and the procedure allows for nonlinear constraints. Unlike LP, the general DP procedure allows modifications to be made for specific problems without a tremendous amount of time and effort, as long as the problem has a limited number of constraints and decision variables.

DP is applicable to water resource operation problems, which can be formulated as optimising a multi-stage decision process. The approach decomposes a highly complex problem with a large number of variables into a series of sub-problems, which are solved recursively. DP is not a precise algorithm like LP, but rather a general approach to solving optimisation problems. Nonlinear and stochastic properties of a problem can be reflected in a DP formulation. The various assumptions, including a separable objective function, limit the range of applicability and require ingenuity and understanding by the modeler in applying DP. The so-called "curse of dimensionality" is a major consideration to in DP.

One of the major problems involved in modeling a system is developing the objective function. Since this function must quantify the response of the system, the validity of the model output depends on this function.

Differential dynamic programming (DDP) is a successive approximation technique, based on DP. In each iteration the system equations are integrated in forward using the current nominal control law. This control law is applied to the system equations, producing a new and improved trajectory. By continued iteration, the procedure produces control functions that successively approximate the optimal control function (Jacobson and Mayne, 1970).

In an effort to eliminate some of the limitations of DP, a number of improvements have been suggested by various authors. To overcome the "curse of dimensionality" a method called Discrete Differential Dynamic Programming (DDDP) can be applied to help streamline the solution procedure. The solution technique is based on some initial trajectory which satisfies the constraint of the problem. The recursive relation of the DP model is then used to search for an improved solution. The iterations continue until the optimum solution is found.

A5.3.3 Network Flow Programming

In recent years the network flow programming (NFP) a special type of LP have been frequently applied for simulation and optimisation of water resources systems. The Network Flow Programming (NFP) technique can be used to solve models characterised by a linear objective and constraints. Non-linear systems may also be solved iteratively using NFP in conjunction with linearisation methods. The NFP technique does not suffer from the "curse of dimensionality" common to DP.

The out-of-kilter algorithm (OKA) was developed by Ford & Fulkerson (1962) to solve NFP problems (Jensen & Wesley 1980). Several computer codes are available for solving NFP problems using the OKA. Barr, et al. (1974) compared one such computer code called SUPERK to other techniques for solving NFP problems and found that the procedure was superior in terms of execution time. One of the computer codes included in the comparison was the Texas Development Board code incorporated in SYMYLD and SYMLYDII (Texas Water Development Board 1972).

NFP has been extensive used in modeling planning and operation of the California State Water Project (Sabet, 1985, 1986, 1990 & Chung 1981). NFP was also used in a model known as WASP which was developed and applied to simulation of Melbourne water supply system (Kuczera 1986). WASP was later modified and enhanced by Kuczera for application to any water supply system (Kuczera 1990). This model is referred to as WATHNET.

Although NFP is highly flexible, computationally fast, and conceptually very easy to understand it can not be used to model every linear system. Most systems may be innovatively translated to a network model, but some aspect of the system may have to either be approximated by a network model or solved iteratively.

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