Stocks Impounding Reservoir Assessment - Impact on downstream flows

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Stocks IR Spill Assessment
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Contents

Appendices

Tables

Figures

1. Introduction

Modifications are proposed to the spillway at Stocks Reservoir to increase capacity to improve the deployable output from Hodder WTW. The spillway height will increase by 300mm. This may lead to changes in the flow regime downstream. This study has examined the potential for changes in flow conditions. This has been achieved by constructing a daily time step water balance model of Stocks Reservoir, with existing and future spillway arrangements represented.

Changes to flow rates and frequency are assessed, both at the reservoir and at downstream locations.

2. Method

The model developed is a simple spreadsheet mass balance tool. There is a single inflow sequence, a constant abstraction and a seasonally variable compensation flow. When the volume exceeds the reservoir capacity at TWL water is routed through a simple broad crested weir to represent the spillway. In practice, at a daily timestep this does not cause water to be retained above TWL.

The model has been setup for pre and post modification scenarios, and with two approaches:

- Using a continuous simulation from 1927 to 2018, which better represents the impact of dry winters;
- Resetting the reservoir volume to full on the 1st Jan each year, which results in greater spills.

The Stocks inflow sequence runs from 1927 to 2018. This was provided by UU and is a sequence used in their water resources modelling work. The model uses this in both pre and post development scenarios. An alternative sequence has been used for examining climate change impact, described in section 3.4.

Abstraction is included as the current WTW maximum capacity of 85 Ml/d as a flat profile. This is consistent with recent operation following the downrating of the WTW.

Compensations flows are included as shown in the table below. The waterbank allocation is included as a flat profile from 25th May to 30th September.

Season	Compensation Flow	Waterbank allocation
October - April	13.64 + 0.59 Ml/d	
May - September	18.18 + 0.59 Ml/d	9.09 Ml/d

Table 2.1 Compensation flow requirements

The existing reservoir volume is 12000 Ml at a Top Water Level (TWL) of 180.57m aOD. The increase of 300mm in spillway crest height will result in additional volume of 396.21 Ml creating a total of 12396.21 Ml. This is based on an assumption of a bank angle of 1:1 as per Technical note 80040117-01-MMB-STOKS-NA-RP-C-04007 Rev C1. Deadwater is taken as 349 Ml in all scenarios.

The spillway is modelled as the same width and breadth in both existing and proposed scenarios. Extracts of the engineering drawings showing plan and cross section are included in Figure 2-1 and Figure 2-2

Operational rules

The abstraction is configured to cease at 600Ml net capacity, and this emergency storage is available to maintain compensation flows only. Compensation releases cease only when the reservoir is empty.

[redacted]

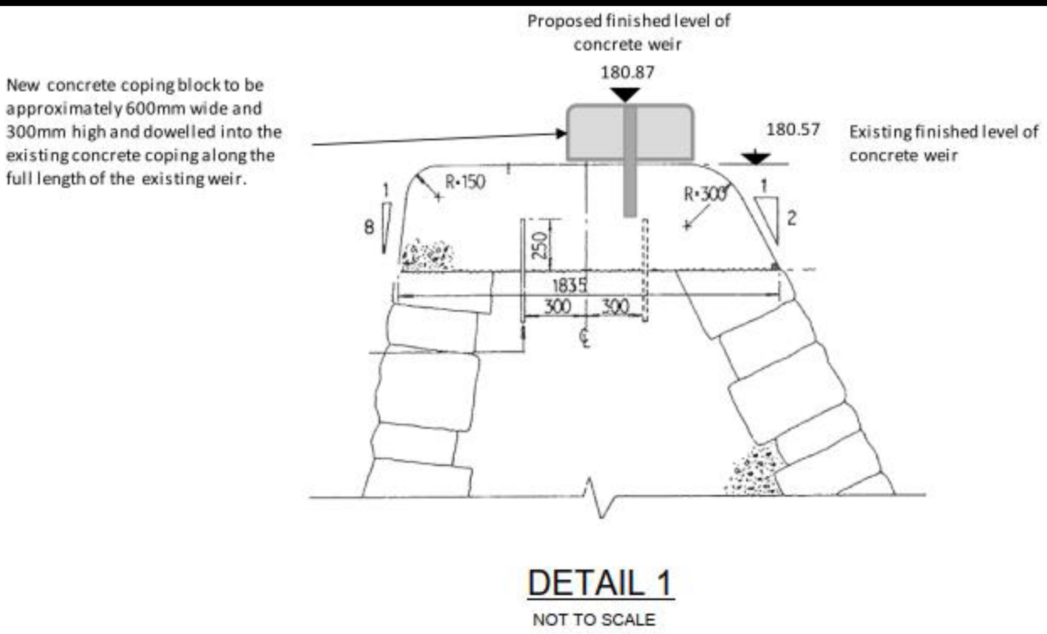

Figure 2-2 Cross section of Spillway with modification. From drawing 80040117-01-MMB-STOKS-NA-DR-C-04003

3. Results

3.1 Spill Frequency

Running model

In the existing situation the reservoir spills 42.9 days a year on average, with a range between 0 and 162, which occurred in 2012. In the proposed situation the average is 42.5, with the same peak of 162 days in 2012.

Annual reset model

In the existing situation the reservoir spills 48.11 days a year on average and in the proposed situation the average is 48.04. The range from 0 to 162 days spill is the same as the running model, but there is only one year with 0 spills compared to 9 in the running model.

The occurrence of spills by year is shown in Figure 3-1and Figure 3-2. Figure 3-3 and Figure 3-4 show the variance between pre and post modification by year and month.

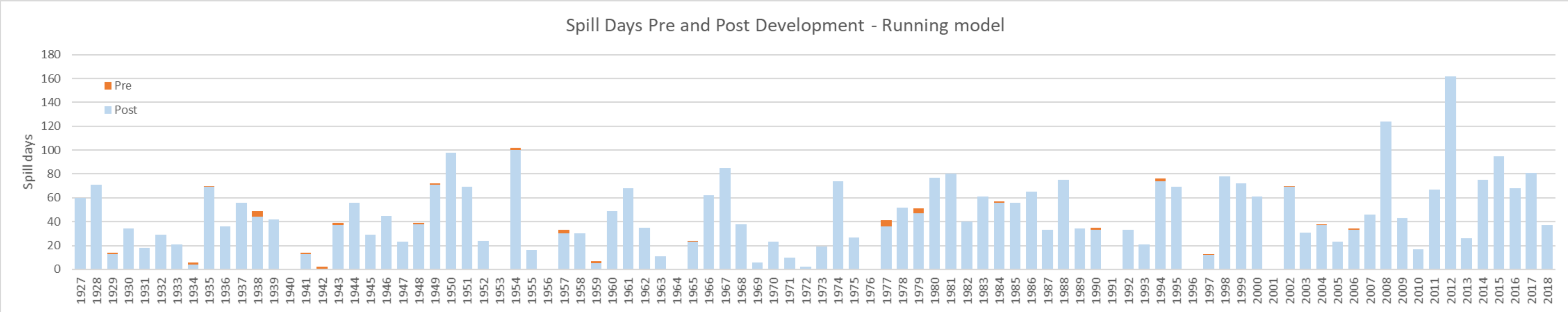

Figure 3-1 Spill Days Pre and Post Development - Running model

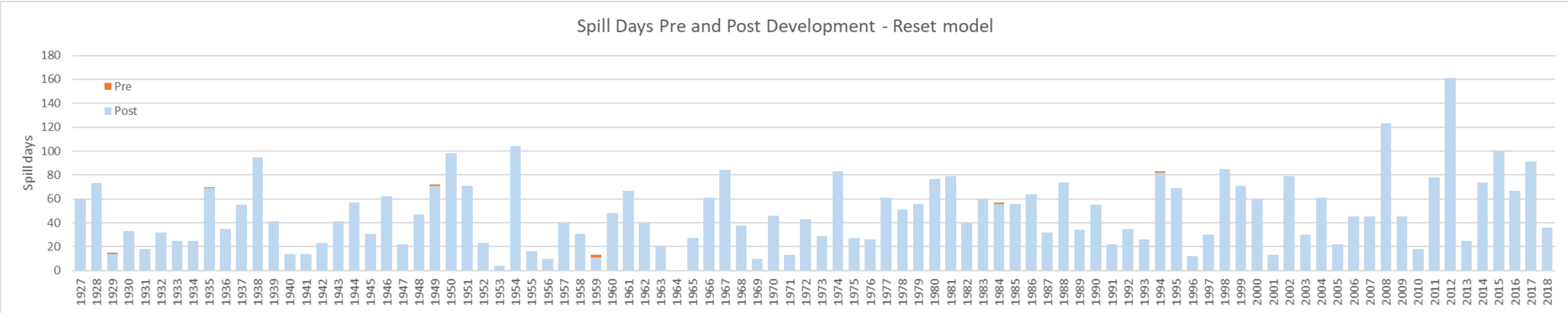

Figure 3-2 Spill Days Pre and Post Development - Annual Reset model

Year	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
Jan																	2					1	
Feb															1								
Mar																							
Apr																2							
May																							
Jun																							
Jul																							
Aug																							
Sep																							
Oct									1			5											
Nov																							
Dec			1					2															1

Year	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Jan					2			3									1						
Feb																							
Mar																							
Apr																							
May																							
Jun																							
Jul																							
Aug																							
Sep																							
Oct																							
Nov																							
Dec										2													

Year	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan																		2				1	
Feb					4																		
Mar					1		4																
Apr																							
May																							
Jun																							
Jul																							
Aug																							
Sep																							
Oct																							
Nov												1											
Dec																						1	

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Jan							1		1														
Feb		1																					
Mar																							
Apr											1												
May																							
Jun																							
Jul																							
Aug																							
Sep																							
Oct																							
Nov																							
Dec																							

Figure 3-3 Change in spill days by year and month – Running model

Year	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949
Jan																							
Feb																							
Mar																							
Apr																							
May																							
Jun																							
Jul																							
Aug																							
Sep																							
Oct									1														
Nov																							
Dec			1																				1

Year	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Jan																							
Feb																							
Mar																							
Apr																							
May																							
Jun																							
Jul																							
Aug																							
Sep																							
Oct																							
Nov																							
Dec										2													

Year	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan																							
Feb																							
Mar																							
Apr																							
May																							
Jun																							
Jul																							
Aug																							
Sep																							
Oct																							
Nov												1											
Dec																						1	

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Jan																							
Feb																							
Mar																							
Apr																							
May																							
Jun																							
Jul																							
Aug																							
Sep																							
Oct																							
Nov																							
Dec																							

Figure 3-4 Change in spill days by year and month – Annual Reset model

3.2 Flows at Reservoir

Flow duration statistics for total flows downstream from Stocks reservoir (spills and compensation flows) are presented in Table 3.1 for running and reset approaches. The table includes mode detail in the upper part of the flow regime. Annual flow duration curves are presented in Figure 3-5 and Figure 3-6. In practice the small changes in flows are not discernible in the plots. Monthly FDCs are included in Appendix A

For the running model, which is more representative of natural conditions and includes the impacts of dry winters, the changes in the annual FDC are limited to flows greater then Q12 and concentrated in the Q5-Q10 range. This amounts to a 6.4% change at its greatest.

	Running Model			Reset Model		
Flow Percentile	Pre	Post	Variation %	Pre	Post	Variation %
1	653.80	653.14	0.1	688.19	687.60	0.1
2	446.19	443.77	0.5	475.20	474.59	0.1
3	338.46	336.39	0.6	368.68	368.23	0.1
4	266.51	264.52	0.7	294.28	293.15	0.4
5	213.91	211.10	1.3	238.19	237.69	0.2
6	168.25	165.30	1.8	193.00	191.89	0.6
7	132.55	129.59	2.2	155.31	154.49	0.5
8	100.38	98.15	2.2	124.98	124.28	0.6
9	74.28	72.28	2.7	97.40	96.78	0.6
10	52.03	49.76	4.4	74.50	73.96	0.7
11	30.00	28.09	6.4	54.51	54.00	0.9
12	27.86	27.86	0.0	35.88	35.68	0.5
13	27.86	27.86	0.0	27.86	27.86	0.0
14	27.86	27.86	0.0	27.86	27.86	0.0
15	27.86	27.86	0.0	27.86	27.86	0.0
20	27.86	27.86	0.0	27.86	27.86	0.0
30	27.86	27.86	0.0	27.86	27.86	0.0
40	27.86	27.86	0.0	27.86	27.86	0.0
50	18.77	18.77	0.0	18.77	18.77	0.0
60	14.23	14.23	0.0	14.23	14.23	0.0
70	14.23	14.23	0.0	14.23	14.23	0.0
80	14.23	14.23	0.0	14.23	14.23	0.0
90	14.23	14.23	0.0	14.23	14.23	0.0
95	14.23	14.23	0.0	14.23	14.23	0.0

Table 3.1 Flow duration statistics – Downstream flows at Stocks Reservoir

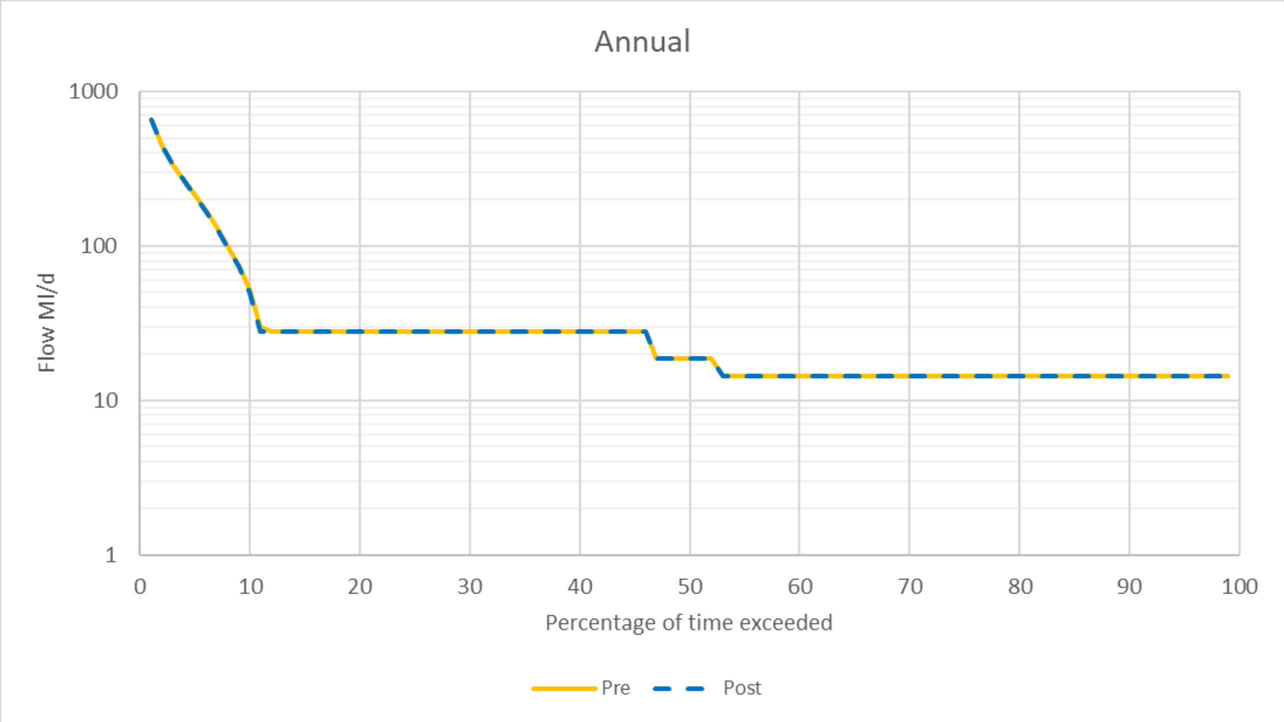

Figure 3-5 Flow Duration Curve – Downstream flows at Stock Reservoir – Running model

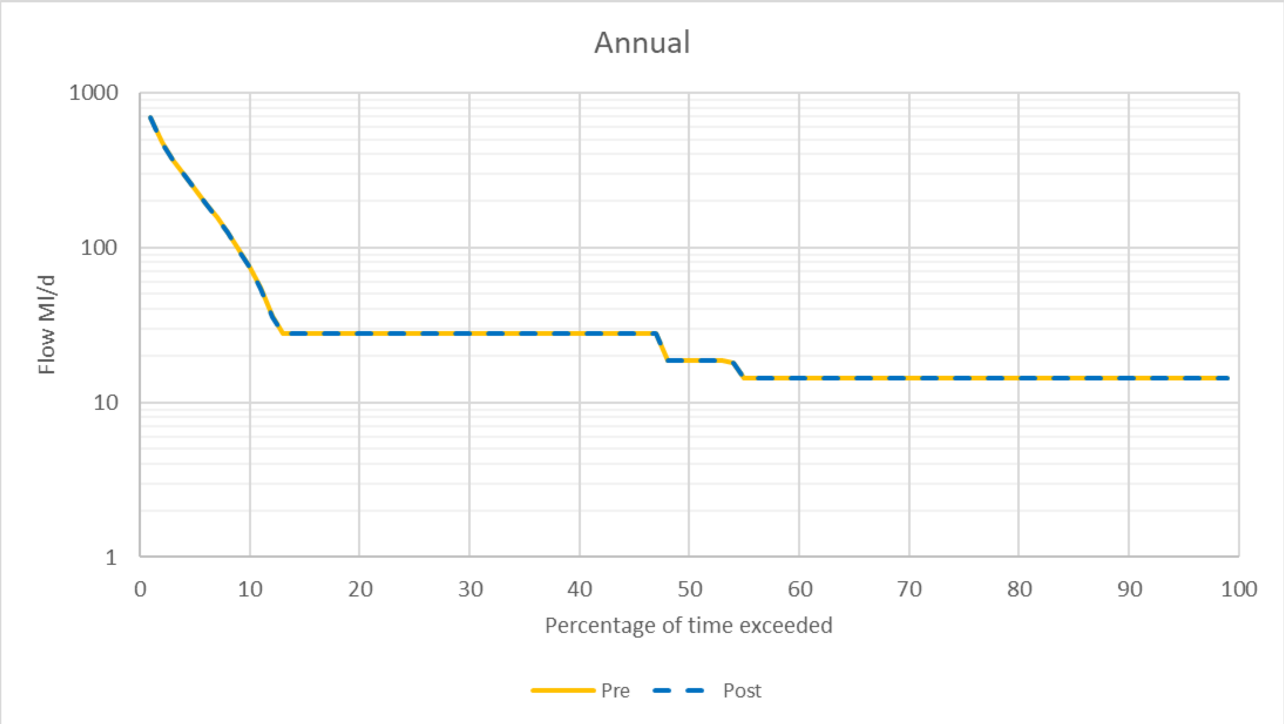

Figure 3-6 Flow Duration Curve – Downstream flows at Stock Reservoir – Annual Reset model

3.3 Flows downstream

The impacts on flows downstream have been considered at two locations, at the confluence with eh Croasdale Beck and the confluence with the Easington Beck.

Given the similar catchment characteristics the flows for the additional catchments have been scaled by area from the Stocks sequence. The running model indicates a maximum 0.6% change in spills at the confluence with Croasdale Beck and 0.4% change at the confluence with the Easington Beck. In both cases the peak variation occurs between Q5 and Q10.

The reset model creates much smaller variations, consistent with that seen at the reservoir.

The statistics are summarised in Table 3.2 and Table 3.3. Given the very small changes these are not presented graphically.

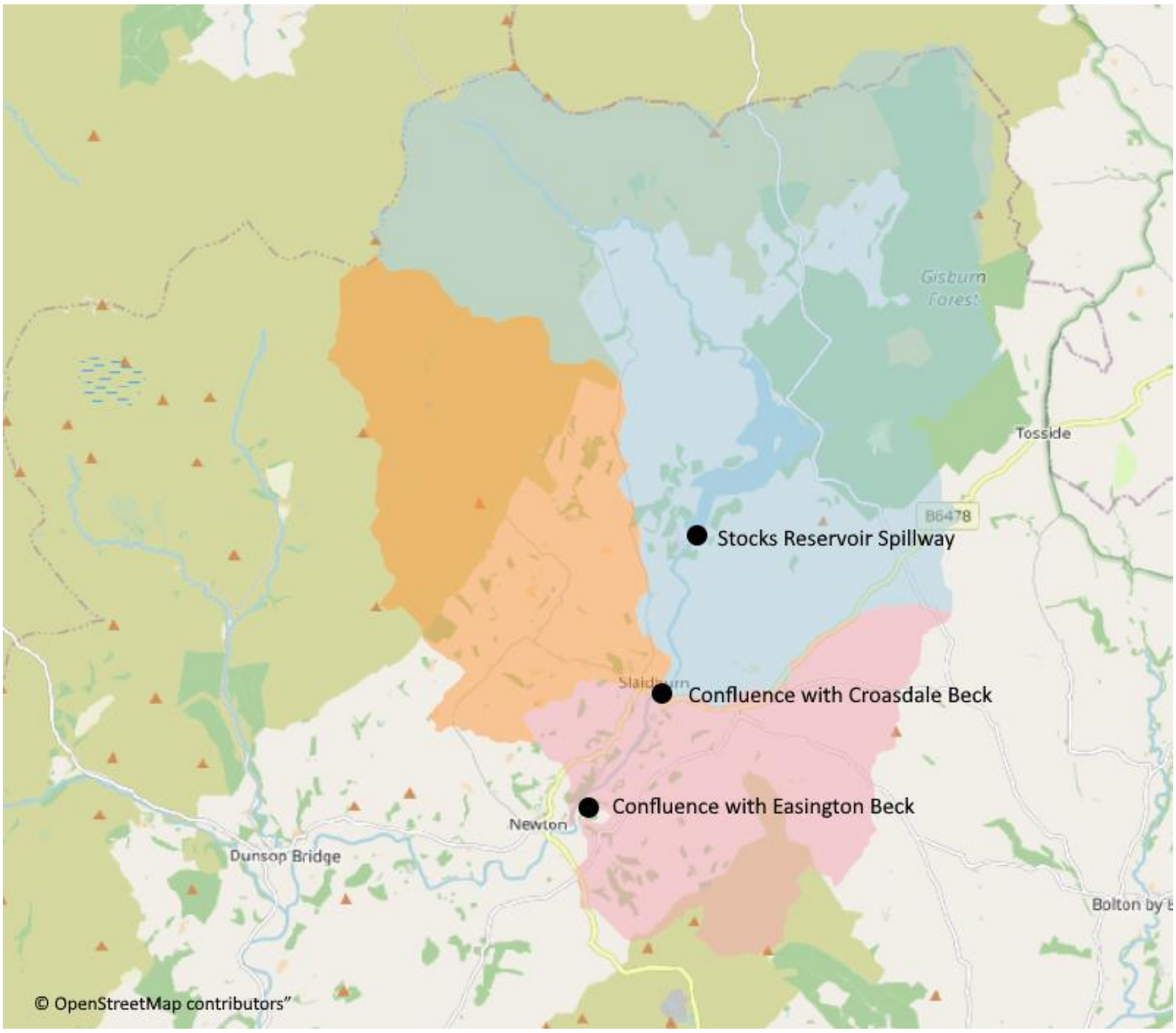

Figure 3-7 Map showing location of three assessment points.

Flow Percentile	Confluence with Croasdale Beck			Confluence with Easington Beck		
	Pre	Post	Variation %	Pre	Post	Variation %
1	1551.28	1550.62	0.0	1991.18	1990.52	0.0
2	1150.30	1147.88	0.2	1495.43	1493.01	0.2
3	929.70	927.63	0.2	1219.50	1217.43	0.2
4	783.44	781.45	0.3	1036.82	1034.83	0.2
5	674.32	671.51	0.4	899.99	897.19	0.3
6	588.62	585.67	0.5	794.68	791.72	0.4
7	518.48	515.51	0.6	707.64	704.68	0.4
8	454.46	452.22	0.5	628.01	625.78	0.4
9	401.99	399.99	0.5	562.63	560.62	0.4
10	357.99	355.72	0.6	507.96	505.69	0.4
11	315.80	313.88	0.6	455.88	453.97	0.4
12	297.06	297.06	0.0	429.01	429.01	0.0
13	279.68	279.68	0.0	403.10	403.10	0.0
14	264.83	264.83	0.0	380.99	380.99	0.0
15	251.79	251.79	0.0	361.55	361.55	0.0
20	197.84	197.84	0.0	281.16	281.16	0.0
30	131.80	131.80	0.0	182.75	182.75	0.0
40	93.43	93.43	0.0	125.57	125.57	0.0
50	63.60	63.60	0.0	85.57	85.57	0.0
60	46.72	46.72	0.0	62.64	62.64	0.0
70	38.02	38.02	0.0	49.68	49.68	0.0
80	30.82	30.82	0.0	38.95	38.95	0.0
90	24.00	24.00	0.0	28.78	28.78	0.0
95	20.09	20.09	0.0	22.96	22.96	0.0

Table 3.2Flow Duration statistics – Downstream flows at Croasdale and Easington Becks – Running model

Flow Percentile	Confluence with Croasdale Beck Pre	Post	Variation %	Confluence with Easington Beck Pre	Post	Variation %
1	1585.67	1585.08	0.0	2025.57	2024.98	0.0
2	1179.31	1178.70	0.1	1524.43	1523.83	0.0
3	959.92	959.47	0.0	1249.72	1249.27	0.0
4	811.21	810.08	0.1	1064.59	1063.46	0.1
5	698.61	698.10	0.1	924.28	923.77	0.1
6	613.38	612.27	0.2	819.43	818.32	0.1
7	541.24	540.41	0.2	730.41	729.58	0.1
8	479.06	478.36	0.1	652.61	651.91	0.1
9	425.11	424.49	0.1	585.74	585.12	0.1
10	380.46	379.92	0.1	530.44	529.89	0.1
11	340.30	339.80	0.1	480.39	479.88	0.1
12	305.08	304.88	0.1	437.03	436.84	0.0
13	279.68	279.68	0.0	403.10	403.10	0.0
14	264.83	264.83	0.0	380.99	380.99	0.0
15	251.79	251.79	0.0	361.55	361.55	0.0
20	197.84	197.84	0.0	281.16	281.16	0.0
30	131.80	131.80	0.0	182.75	182.75	0.0
40	93.43	93.43	0.0	125.57	125.57	0.0
50	63.60	63.60	0.0	85.57	85.57	0.0
60	46.72	46.72	0.0	62.64	62.64	0.0
70	38.02	38.02	0.0	49.68	49.68	0.0
80	30.82	30.82	0.0	38.95	38.95	0.0
90	24.00	24.00	0.0	28.78	28.78	0.0
95	20.09	20.09	0.0	22.96	22.96	0.0

Table 3.3 Flow Duration statistics – Downstream flows at Croasdale and Easington Becks – Annual Reset model

3.4 Climate change

Potential impacts of the proposed changes to the spillway under future climate change scenarios have been briefly examined. The Stocks inflow sequence has been replaced with flows from the Lune catchment (72005 - Lune at Killington), scaled by catchment area. The flows are taken from the eFLAG dataset, produced using UKCP18 RCM outputs for a Representative Concentration Pathway (RCP) 8.5 This provides flows from 2018 to 2080 using 12 different RCMs, which provide a wide variation of flows. This exercise has used the RCMs that produce the highest and lowest flows at the upper part of the flow regime. The flows used are from 2070 to 2080. This has only been modelled with the running level model. Given the different length of record plotted the FDCs have not been plotted side by side with the Stocks inflow sequence. However some simple comparisons highlight that there is a significant increase in high flows and the resulting spills are more frequent in both pre and post modification scenarios. The variation in flows pre and post modification is less than the current day for both the RCMs with the “drier” RCP12 showing a greater variation.

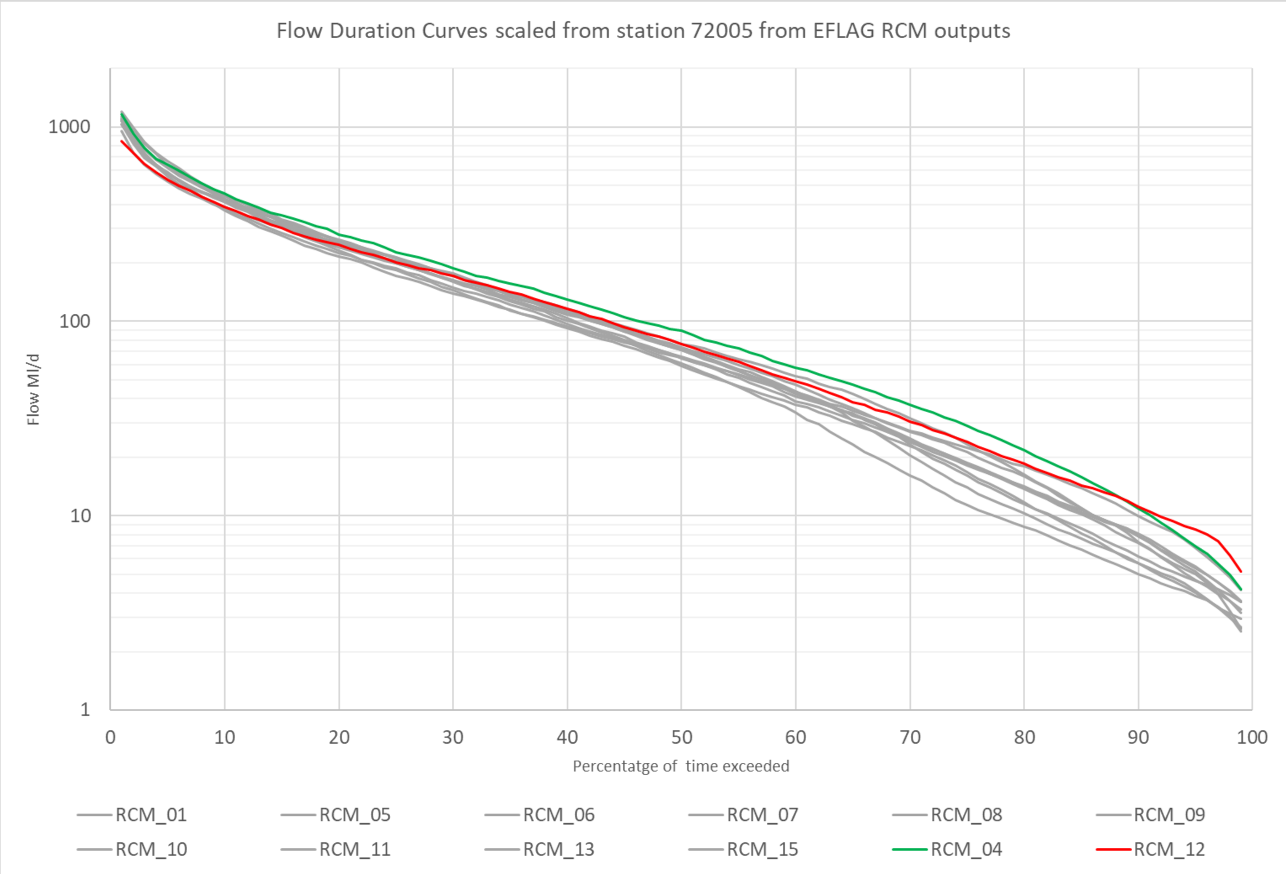

Figure 3-8 Flow Duration Curves scaled from station 72005 from EFLAG RCM outputs

	RCM 04			RCM 12		
Flow Percentile	Pre	Post	Variation %	Pre	Post	Variation %
1	934.05	934.05	0.0	659.97	659.97	0.0
2	693.16	693.16	0.0	530.56	529.23	0.3
3	588.95	575.61	2.3	440.64	439.07	0.4
4	512.65	507.53	1.0	389.42	387.67	0.4
5	451.35	450.03	0.3	341.34	341.06	0.1
6	402.71	400.58	0.5	304.65	299.72	1.6
7	363.15	358.46	1.3	269.37	265.36	1.5
8	323.58	323.28	0.1	243.10	238.83	1.8
9	298.55	297.00	0.5	219.09	216.44	1.2
10	272.25	271.98	0.1	196.56	192.44	2.1
11	254.85	254.21	0.2	179.54	176.42	1.7
12	240.42	240.12	0.1	165.83	163.69	1.3
13	218.57	217.92	0.3	149.40	148.11	0.9
14	198.61	196.60	1.0	135.73	131.92	2.8
15	183.65	180.82	1.5	117.98	114.49	3.0
16	169.78	169.47	0.2	104.35	102.79	1.5
17	154.35	154.07	0.2	93.71	91.50	2.4
18	138.36	138.18	0.1	79.12	76.52	3.3
19	128.24	127.44	0.6	69.03	66.18	4.1
20	115.42	115.13	0.3	57.79	56.32	2.5
30	27.86	27.86	0.0	27.86	27.86	0.0
40	27.86	27.86	0.0	27.86	27.86	0.0
50	27.86	27.86	0.0	27.86	27.86	0.0
60	27.86	27.86	0.0	18.77	18.77	0.0
70	18.77	18.77	0.0	14.23	14.23	0.0
80	14.23	14.23	0.0	14.23	14.23	0.0
90	14.23	14.23	0.0	14.23	14.23	0.0
95	14.23	14.23	0.0	14.23	14.23	0.0

Table 3.4 Flow Duration statistics for downstream flows at reservoir under climate change scenarios – running model

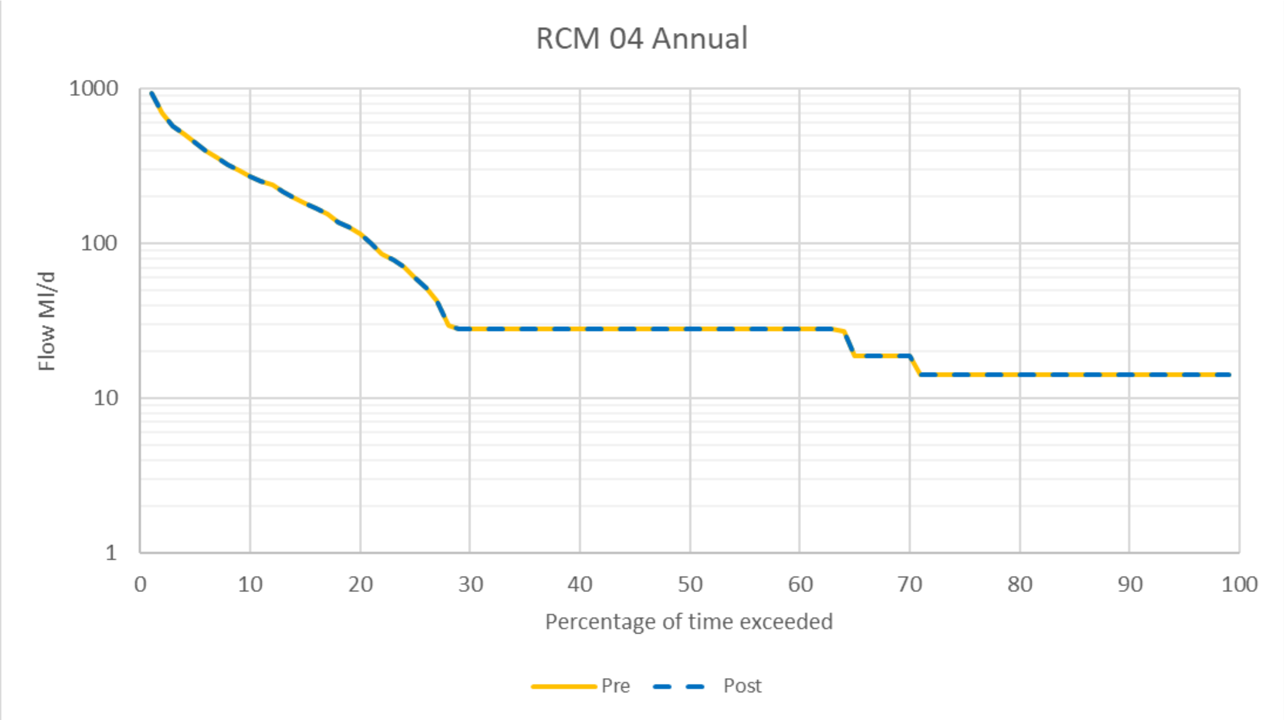

Figure 3-9 Flow Duration curve for downstream flows at reservoir using RCM04 input – running model

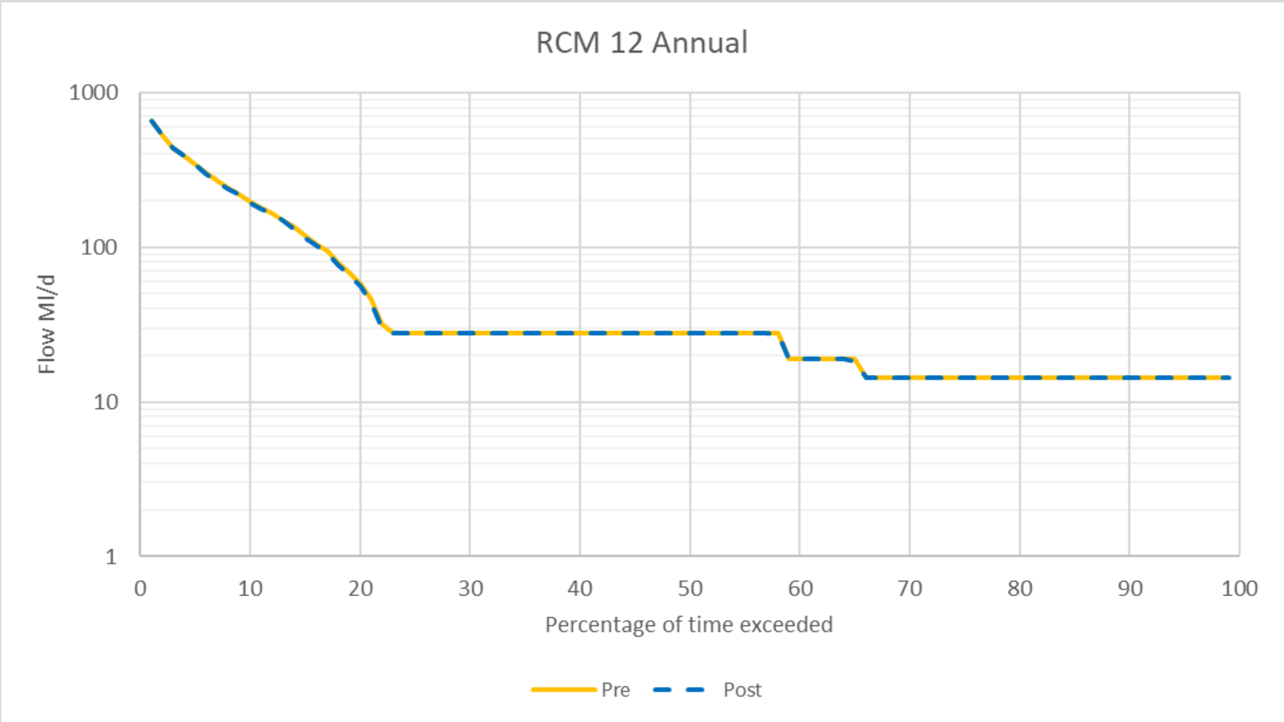

Figure 3-10 Flow Duration curve for downstream flows at reservoir using RCM12 input – running model

4. Conclusions

The proposed modification to the spillway would result in a modest change to spills of 6.4% at Q11, with no change to flows below this which are governed by the compensation releases. The impact at the confluence with the Croasdale Beck is 0.6% and 0.4% at the confluence with the Easington Beck.

The number of spill days decreases on average by 0.4 from 42.9 to 42.5. There is significant variability from year to year, but the maximum reduction in spill days is 5 days, which occurs twice in the record.

A high level representation of climate change indicates that there may be reduced impact in the future due to wetter winters meaning the reservoir spills more frequently in both pre and post development settings.

Appendix A. Monthly Flow Duration Curves

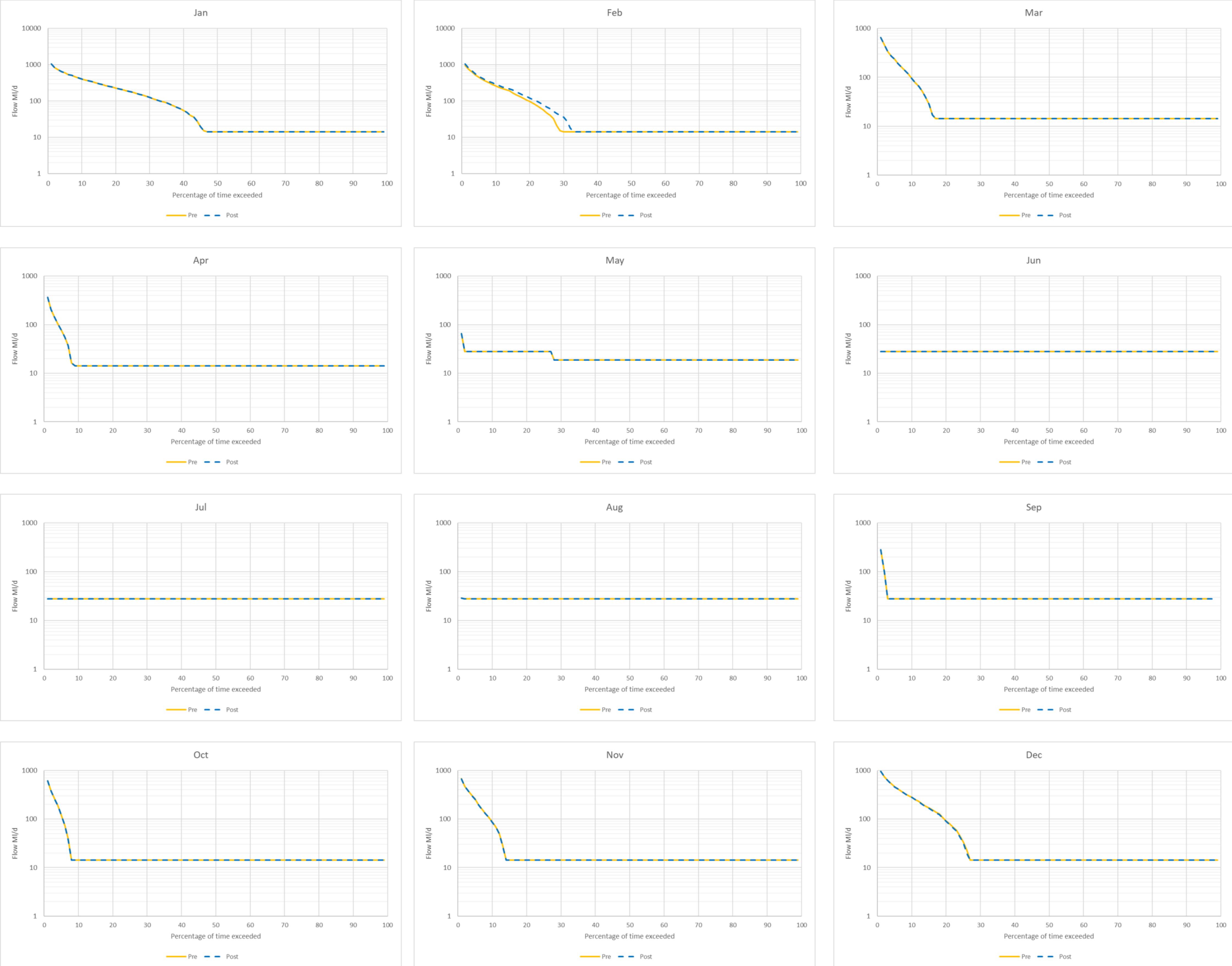

Figure A1 Flow Duration Curves by month for Running model

Figure A2 Flow Duration Curves by month for Annual Reset model