"Assessment of Impact of Climate Change on Water Resources in Sungai Muda Watershed using Soil and Water Assessment Tools (SWAT) "

MOHD SYAZWAN FAISAL BIN MOHD[1]
ASC. PROF. DR. LIEW JUNENG[2]
KHAIRUL ANUAR BIN MOHAMAD[1]

1-National Hydraulic Research Institute of Malaysia (NAHRIM)
2-National University of Malaysia (UKM)

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OUTLINE

1. **Introduction**
2. **SWAT Model Development**
3. **Preliminary Findings of CMIP5 Downscaling Over Malaysia**
4. **Case Study: Impact Assessment on Water Resources**
5. **Conclusions**
6. **Way Forward**

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Study objectives

The main objectives of this study:

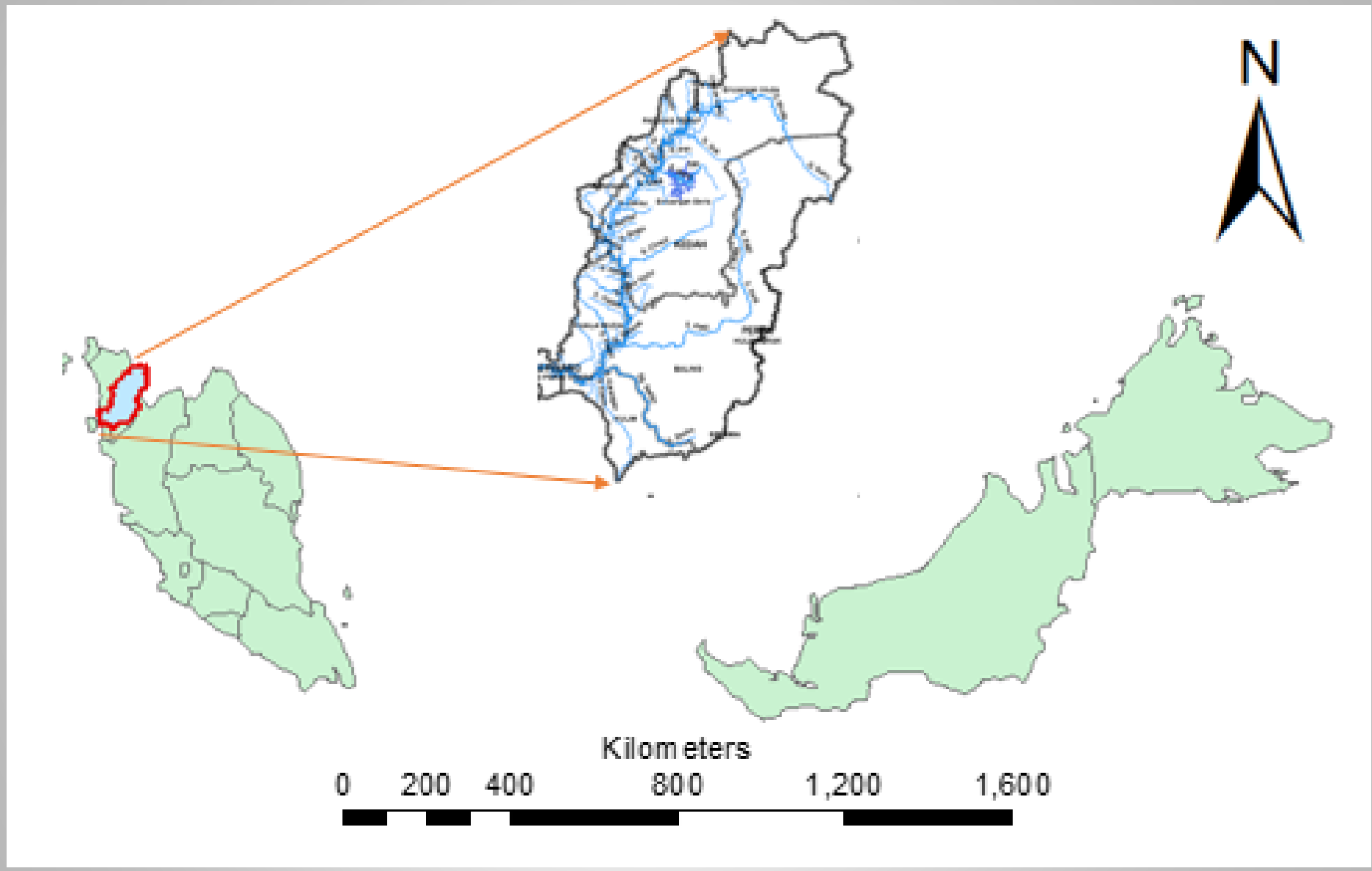
- To develop and test the performance and feasibility of SWAT by inspecting the influence of topography, land use, soil and climatic condition on water resources.

- To calibrate and validate the model output on a Monthly time step using SWATCUP-Sufi2 and perform the Sensitivity and Uncertainty Analyses.

- To assess and analyze the observed water balance/budget component in Sg. Muda Watershed.

- To assess and analyze the projection of climate change scenarios and the impacts to Sungai Muda Watershed regarding several engineering aspects such as streamflow return period, flood frequency analysis, flow duration curves and projected mean and minimum future streamflow using the latest IPCC AR5 scenarios namely RCP 4.5 and RCP 8.5.

Study Area



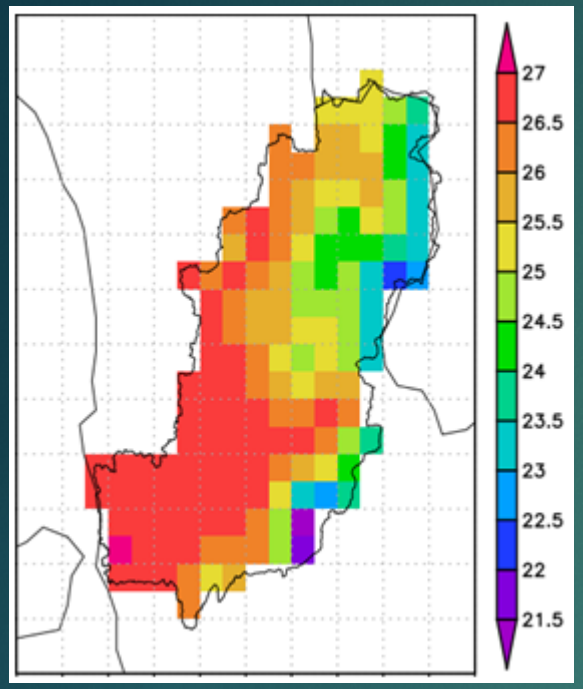
- Sg. Muda Watershed which is located within the boundary of Kedah State and Penang State with a catchment area of 4210 km2 and 180 km length.

- The main functions of Sg. Muda Watershed are water supplies for agriculture activities and also fresh water sources of people in Kedah and Penang.

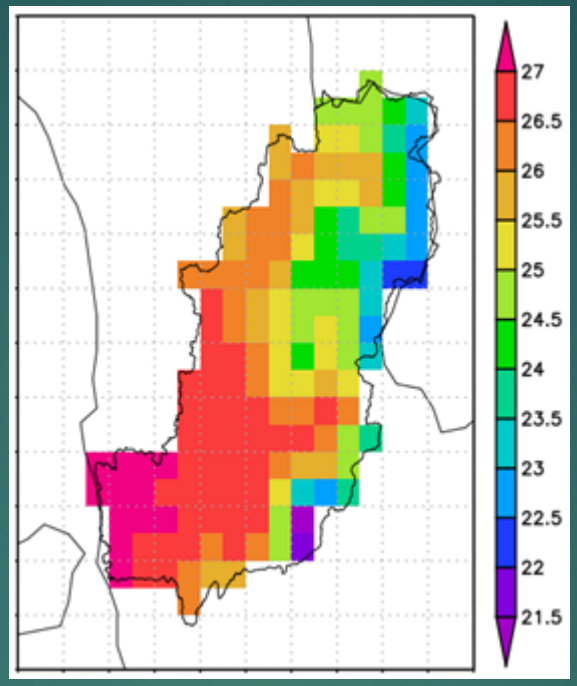
- These areas contain almost 3500 irrigation schemes that come from various sources, including Muda River tributaries and MADA canals.

Source: Saudi et al. (2014)

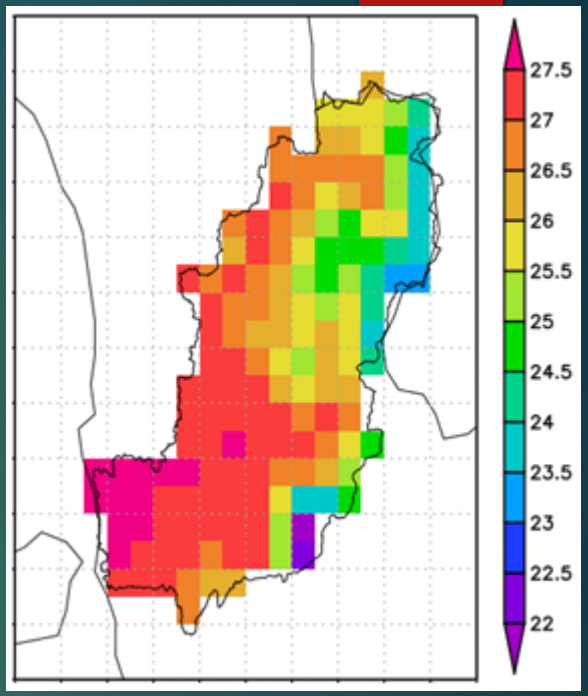
Observed Temperature



Annual mean temperature for Sungai Muda watershed during 1976-2006 (°C)

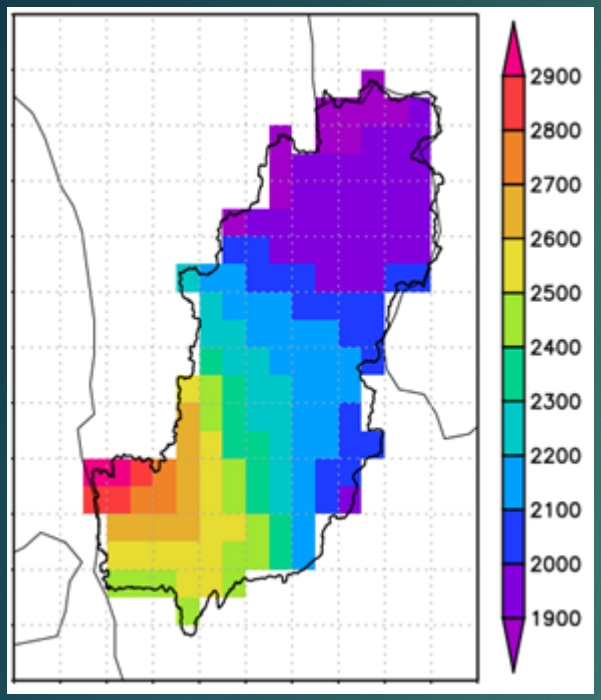


DJF Seasonal mean temperature for Sungai Muda watershed during 1976-2006 (°C)

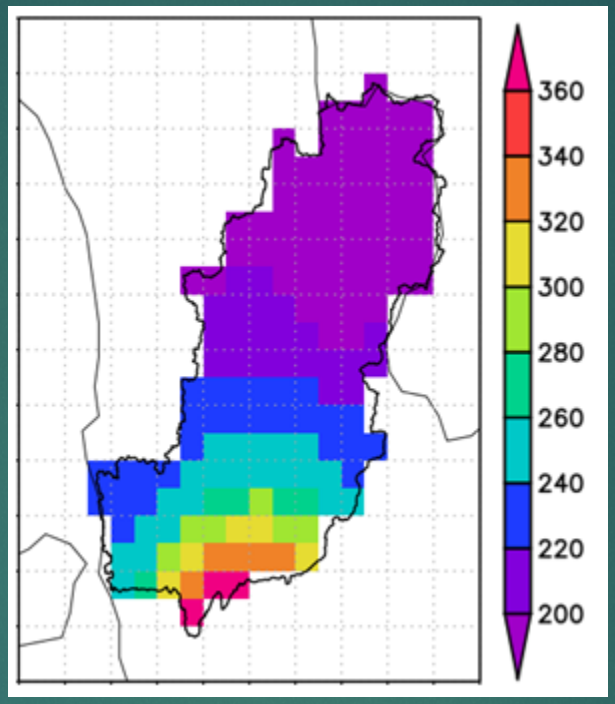


JJA Seasonal mean temperature for Sungai Muda watershed 1976-2006 (°C)

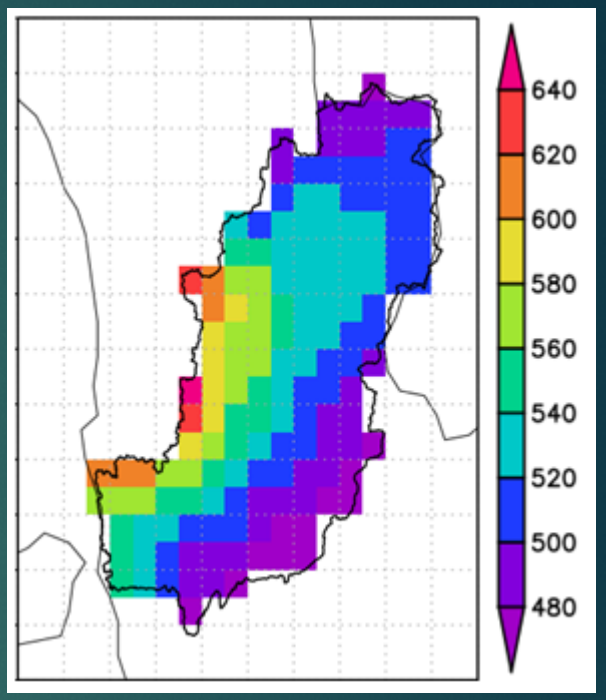
Observed Precipitation



Annual mean precipitation for Sungai Muda watershed during 1976-2006 (mm/year)



DJF Seasonal mean precipitation for Sungai Muda watershed during 1976-2006 (mm/season)



JJA Seasonal mean precipitation for Sungai Muda watershed during 1976-2006 (mm/season)

This watershed is sheltered by the central mountain chain of the peninsula and receives little rain during the Northeast monsoon season from December to January. From May to July, the Southwest monsoon brings moderate rainfall to this watershed.

In the transition period between the monsoons, from April to May and August to October, this watershed experiences a peak in rainfall compared to that of other monsoons season. Due to these climatic characteristics, there are two distinct rainy periods and a dry period.

The dry period that is associated with the Northeast monsoon often spans the month of December to March. Major floods generally occur between the months of September to December.

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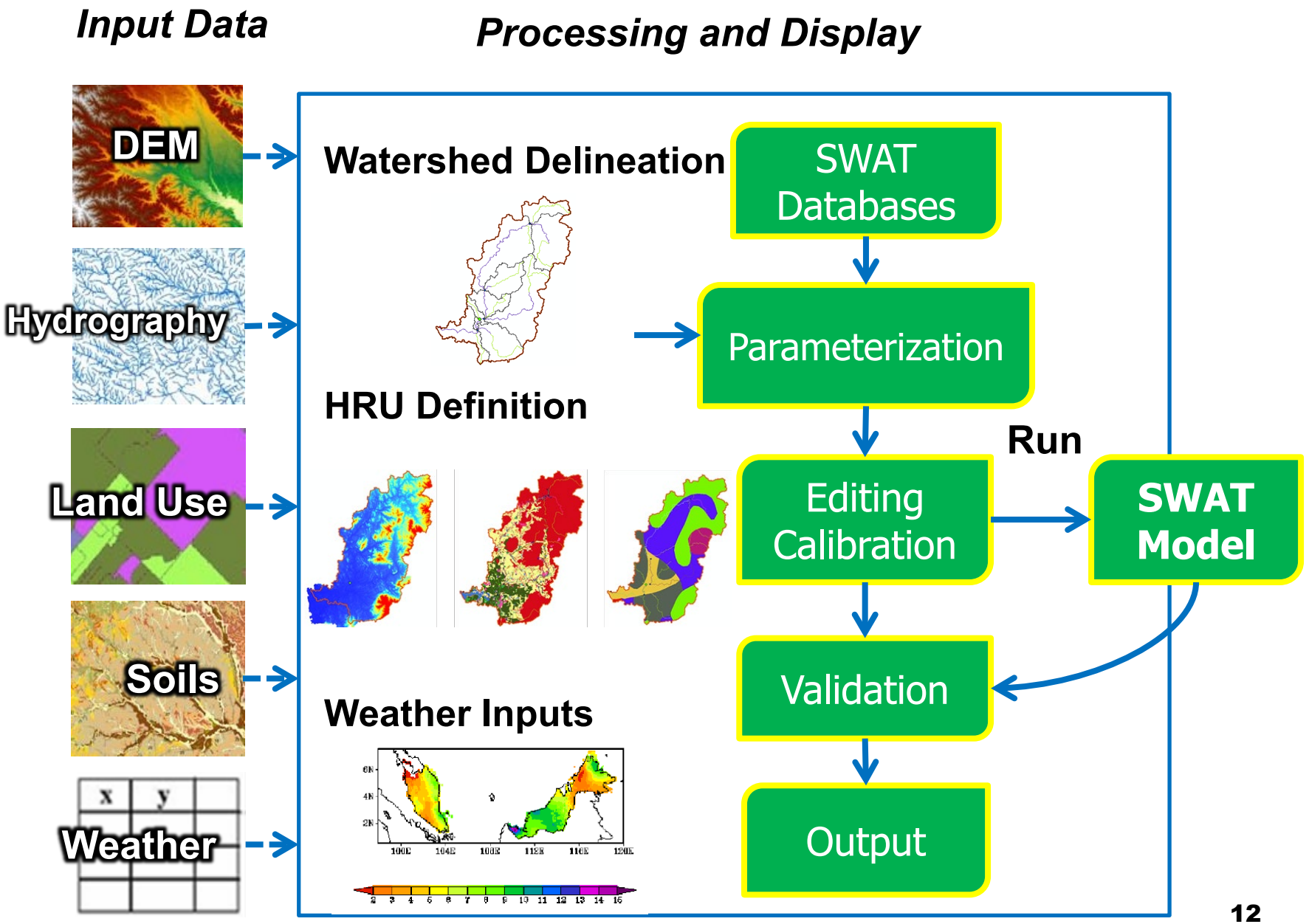
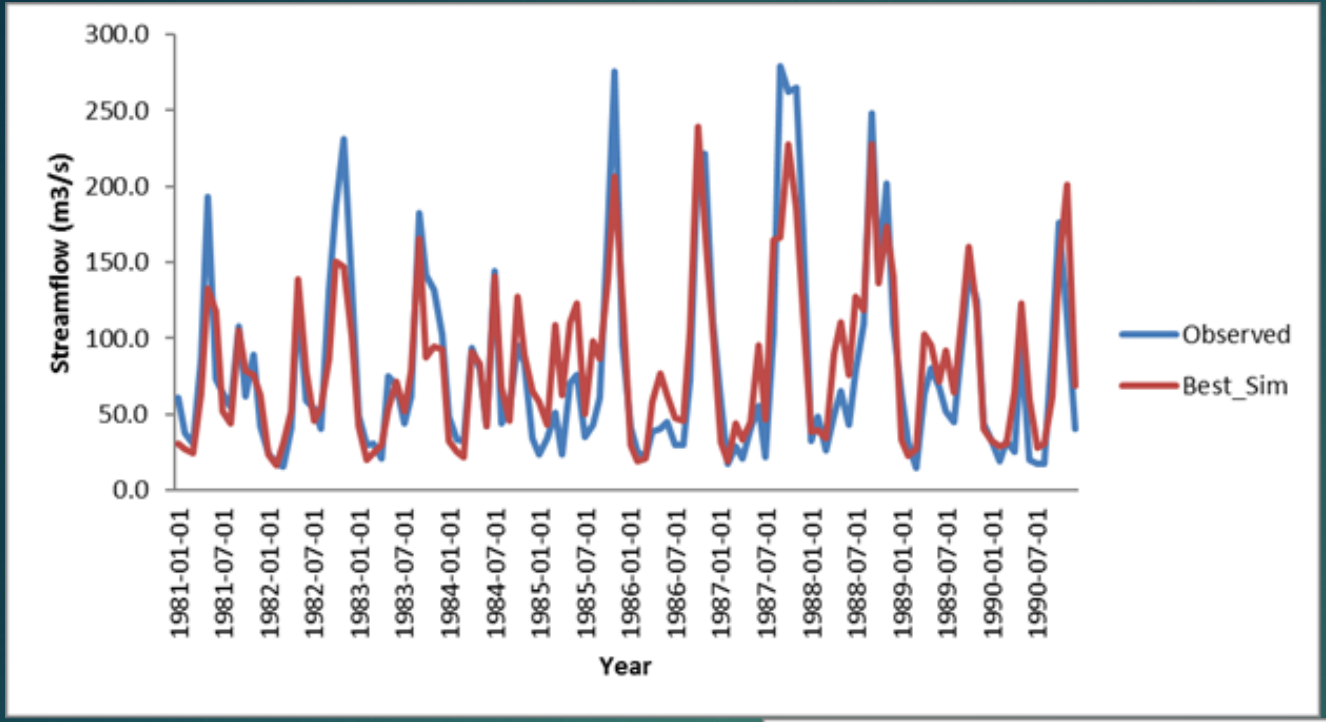
Sources of Spatial and Weather Dataset

No.	Variables/Dataset	Source	Resolution	Format
1	Spatial Dataset			
1(a)	Topography	SRTM DEM	90 m	Raster Grid
1(b)	LULC	Land-use from Department of Agriculture Malaysia	1 km	Polygon Shapefile
1(c)	Soil and their Physical Properties	FAO Dataset	1 km	Polygon Shapefile
2	Climate and Hydrological Time Series Dataset			
2(a)	Air Temperature (maximum & minimum)	Berkeley Earth	Daily (Deg. Celcius)	Text
2(b)	Observed Precipitation	Observed Gridded Dataset (Wong et al. 2010)	Daily (in mm)	Text
2(c)	Wind Speed		Daily (ms^{-1})	Text
2(d)	Solar Radiation		Daily (MJ/sq m/day)	Text
2(e)	Relative Humidity		Daily (Fraction)	Text
2(f)	Projected Precipitation	NASA NEX-GDDP	Daily	Text
2(g)	Discharge Data	Department of Irrigation and Drainage (DID) Malaysia	Daily & Monthly	Text

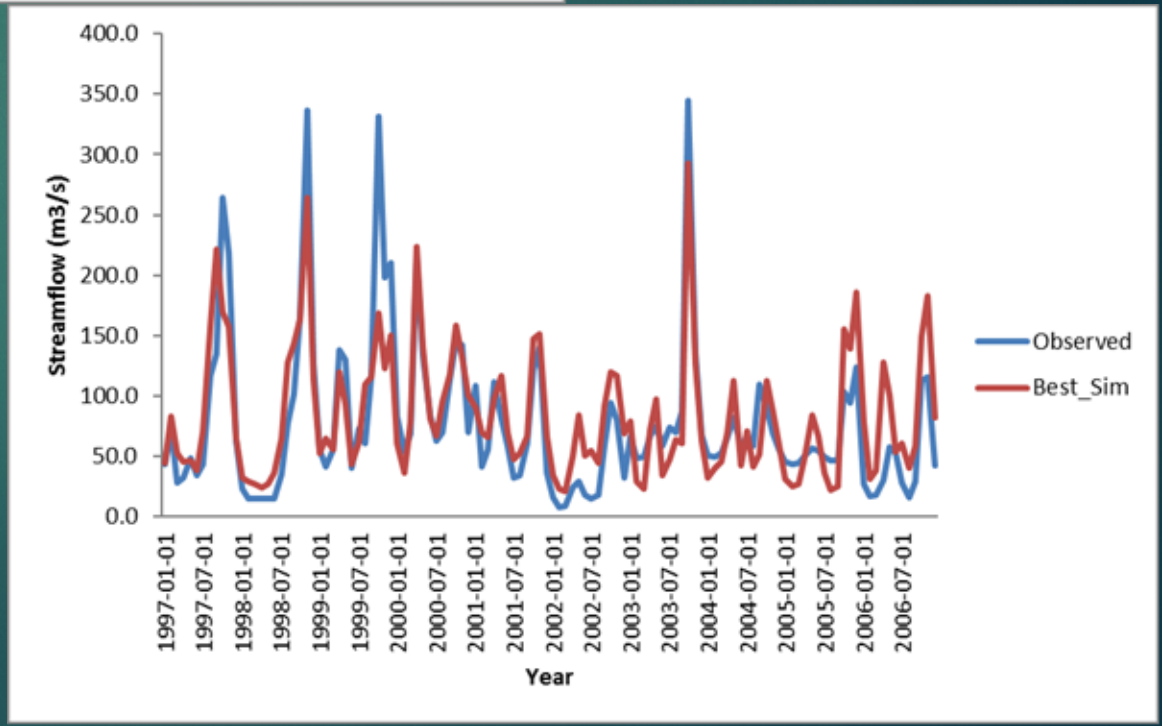
SWAT Model setup





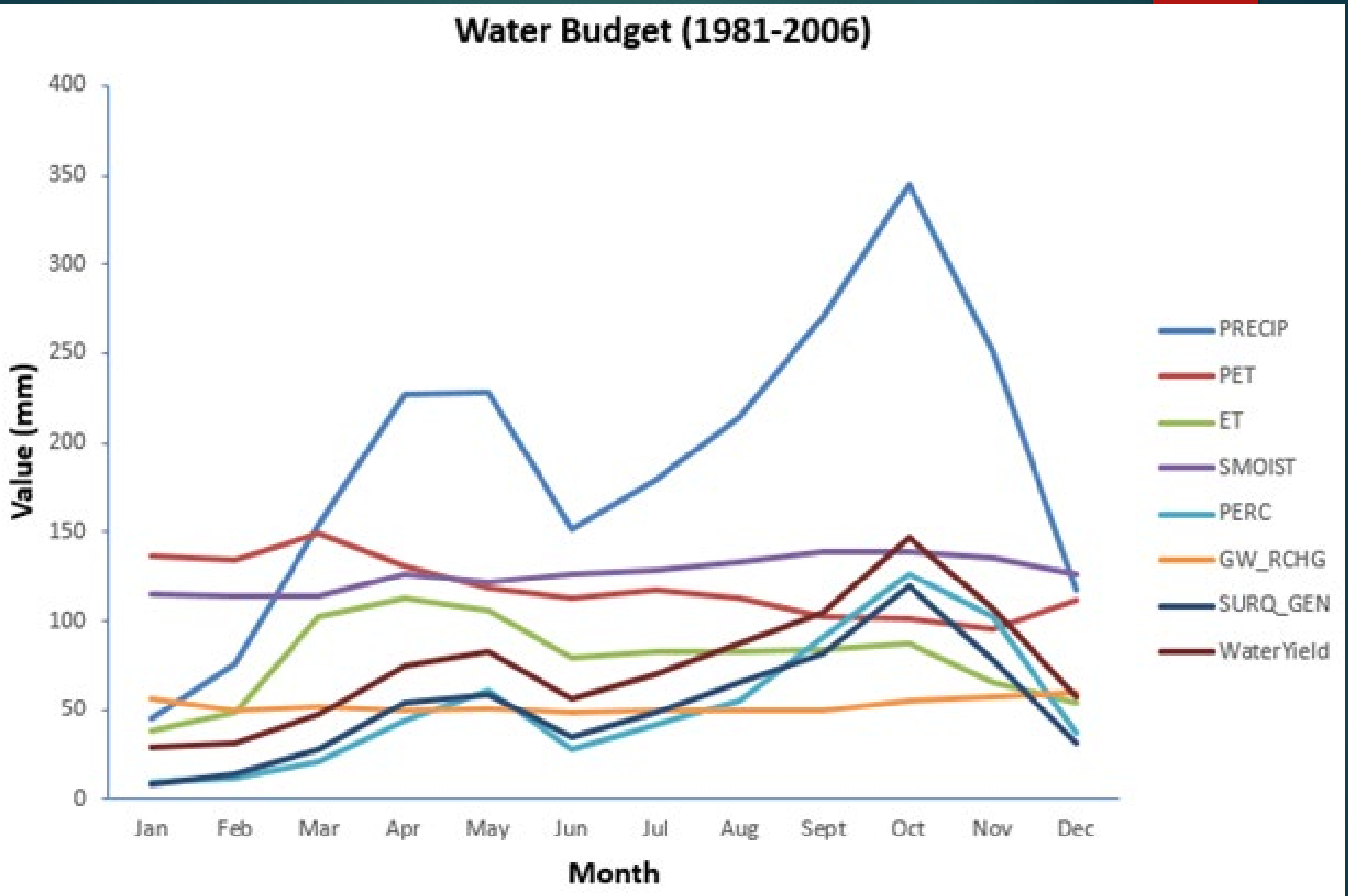
Hydrograph of observed and simulated flow during calibration period (1981-1990)

Hydrograph of observed and simulated flow during validation period (1997-2006)



Statistical indicator	Calibration	Validation
R^2	0.76	0.71
NSE	0.76	0.70
PBIAS	-3.6	-8.6

No.	Parameter Name	t-Stat	P-Value
1	GW_DELAY	-0.43	0.66
2	ALPHA_BF	1.14	0.25
3	CH_K2	1.26	0.21
4	GW_REVAP	15.56	0.00
5	RCHRG_DP	-19.26	0.00
6	GWQMN	30.97	0.00


Water Budget (1981-2006)
Value (mm)
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Month
PRECIP
PET
ET
SMOIST
PERC
GW_RCHG
SURQ_GEN
WaterYield

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CMIP5 Data sets

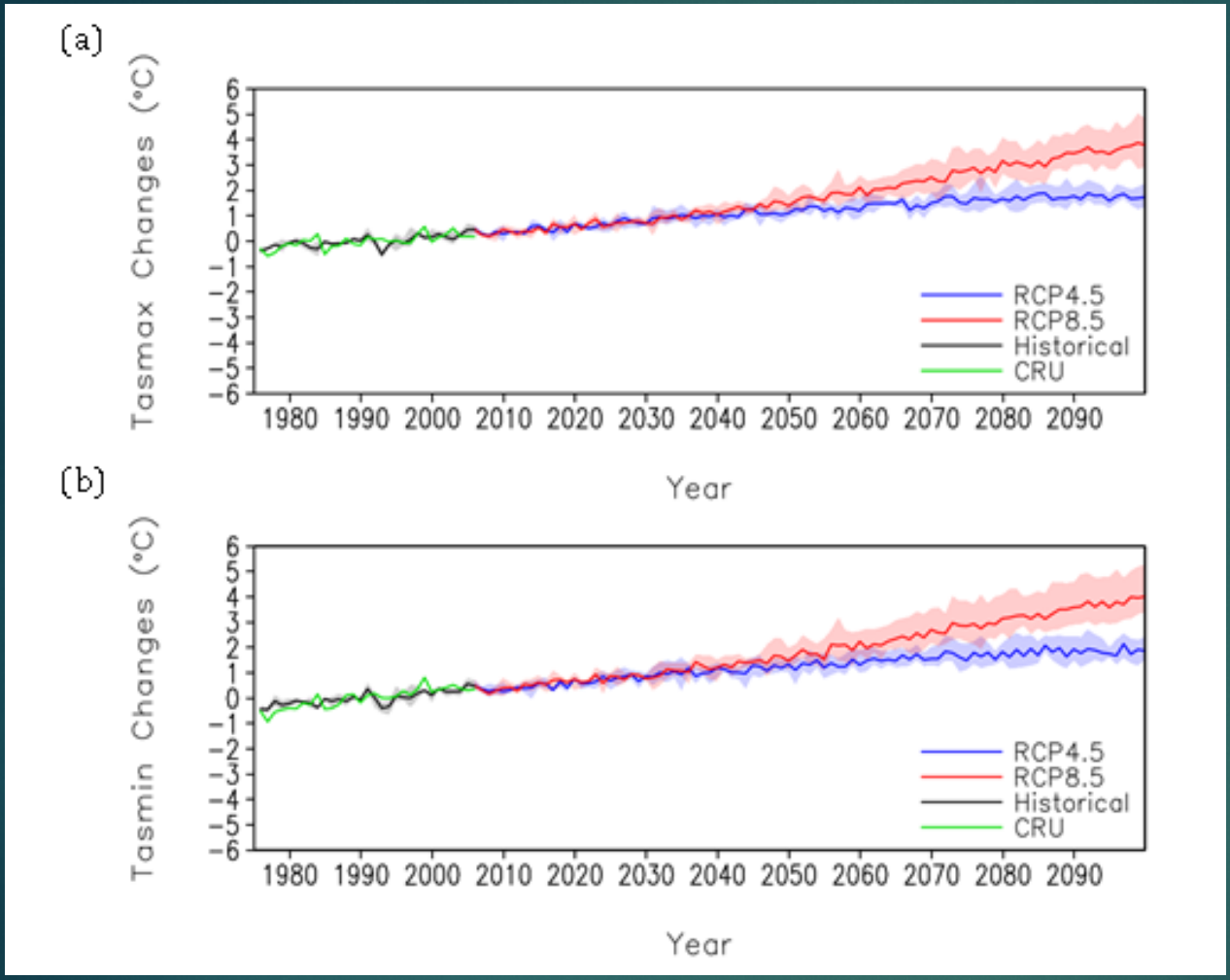
- The projection is based on the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) datasets.
- Downscaled from 3 Global Climate Models.
- Resolution - 0.25°×0.25°
- Emission scenarios – RCP4.5 (lower case scenario) and RCP8.5 (worst case scenario).

Scenario	Description
RCP 4.5	An intermediate "stabilization pathway" in which radiative forcing is stabilized at approximately 4.5 W/m^2 after 2100 (Wayne 2013)
RCP 8.5	Highest pathway which radiative forcing reaches > 8.5 W/m^2 by 2100 and continues to rise for some amount of time (Wayne 2013)

- This NASA dataset is provided to assist the science community in conducting studies of climate change impacts at local to regional scales, and to enhance public understanding of possible future climate patterns at the spatial scale of individual towns, cities, and watersheds.

- **This dataset is intended for use in scientific research only, and use of this dataset for other purposes, such as commercial applications, and engineering or design studies is not recommended without consultation with a qualified expert.**

Changes in the annual maximum (upper) and minimum (lower) temperature anomalies averaged over Malaysia



The spreads of RCP generally split from 2050 to the end of century 2100 due to the different levels of radiative forcing. The uncertainties associated with GCMs also increase toward the end of the century.

- Simulations from the selected downscaled models showed that surface temperature in Malaysia is **increasing** in the range of **~1 ° C to ~2 ° C for RCP4.5** by the end of century.
- While for the highest emission scenario **RCP8.5,** by the end of century both Tasmax and Tasmin are expected **to rise by ~3 ° C and up to ~5 ° C** over the entire Malaysia.
- The warming rates of the projected temperature anomalies for both RCPs are similar in the early to mid century.

Changes in the annual anomalies averaged over Malaysia

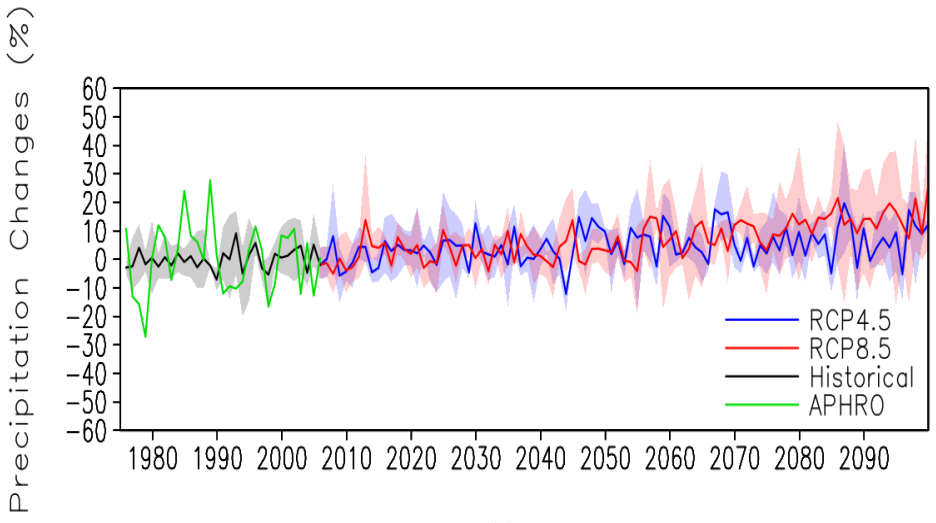
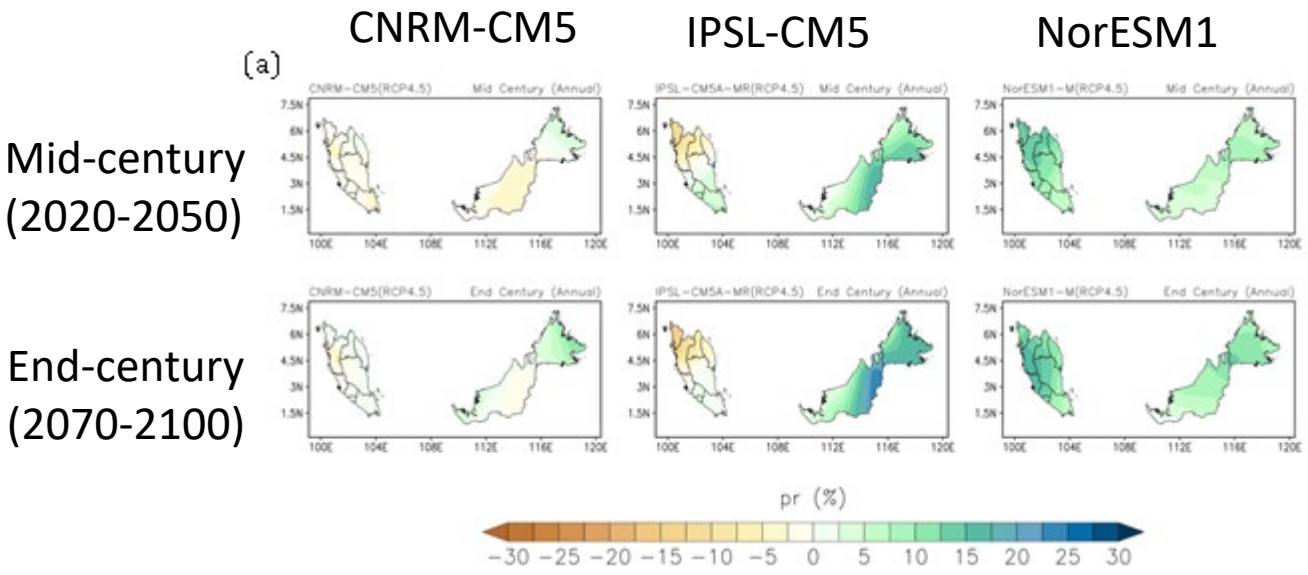


Figure shows the historical and projections of annual rainfall anomalies in Malaysia from 1975 (historical) until 2100 (projection) according to both RCP4.5 and RCP8.5 scenario.



In contrast to temperature projections, the projected rainfall shows higher more variations over Malaysia regions. The downscaled rainfall projections in Malaysia show larger uncertainties associated to the driving GCMs toward end of the century for both RCPs.

In general, the projections suggest that Malaysia rainfall is likely to increase slightly by 5-10%.

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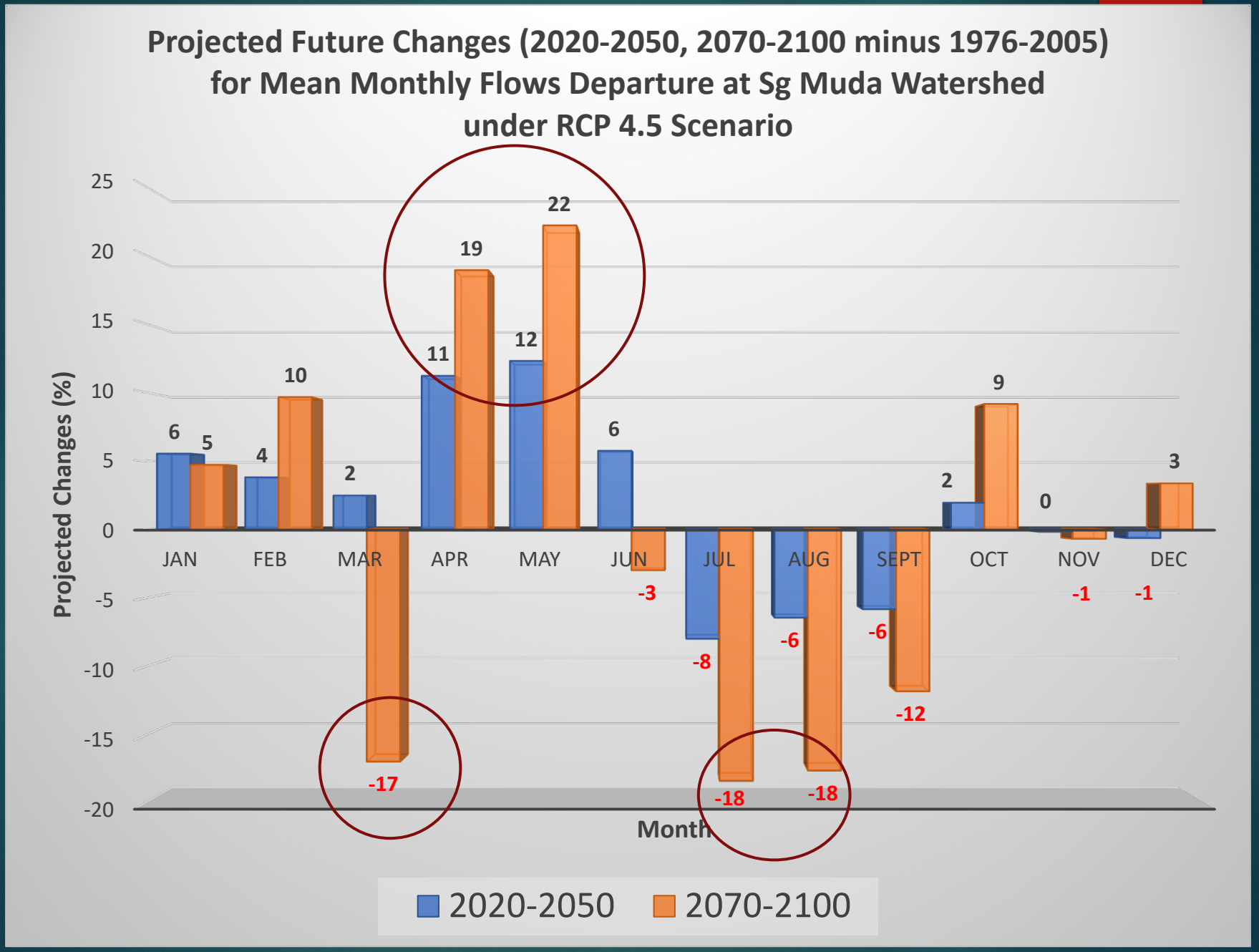
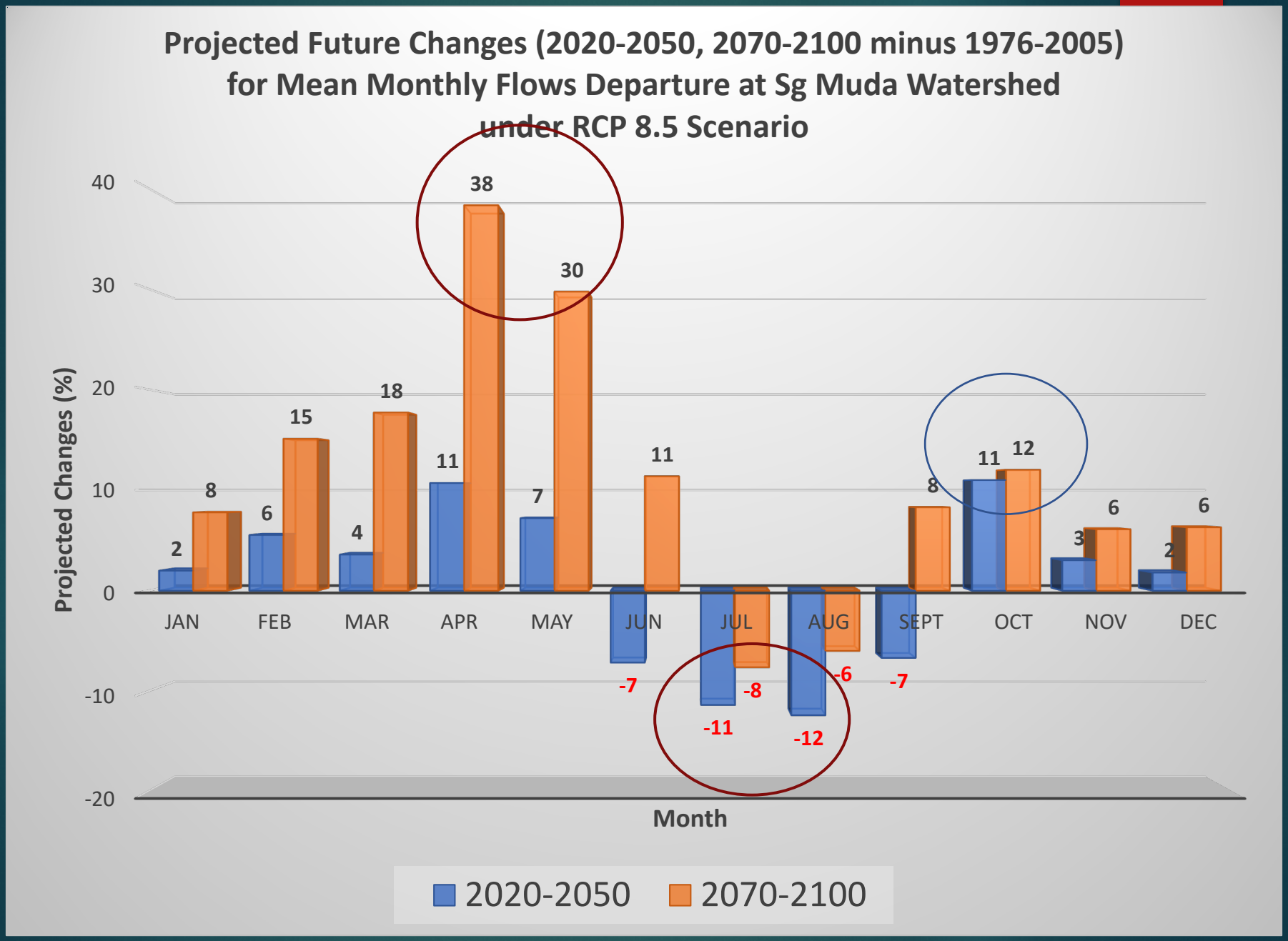
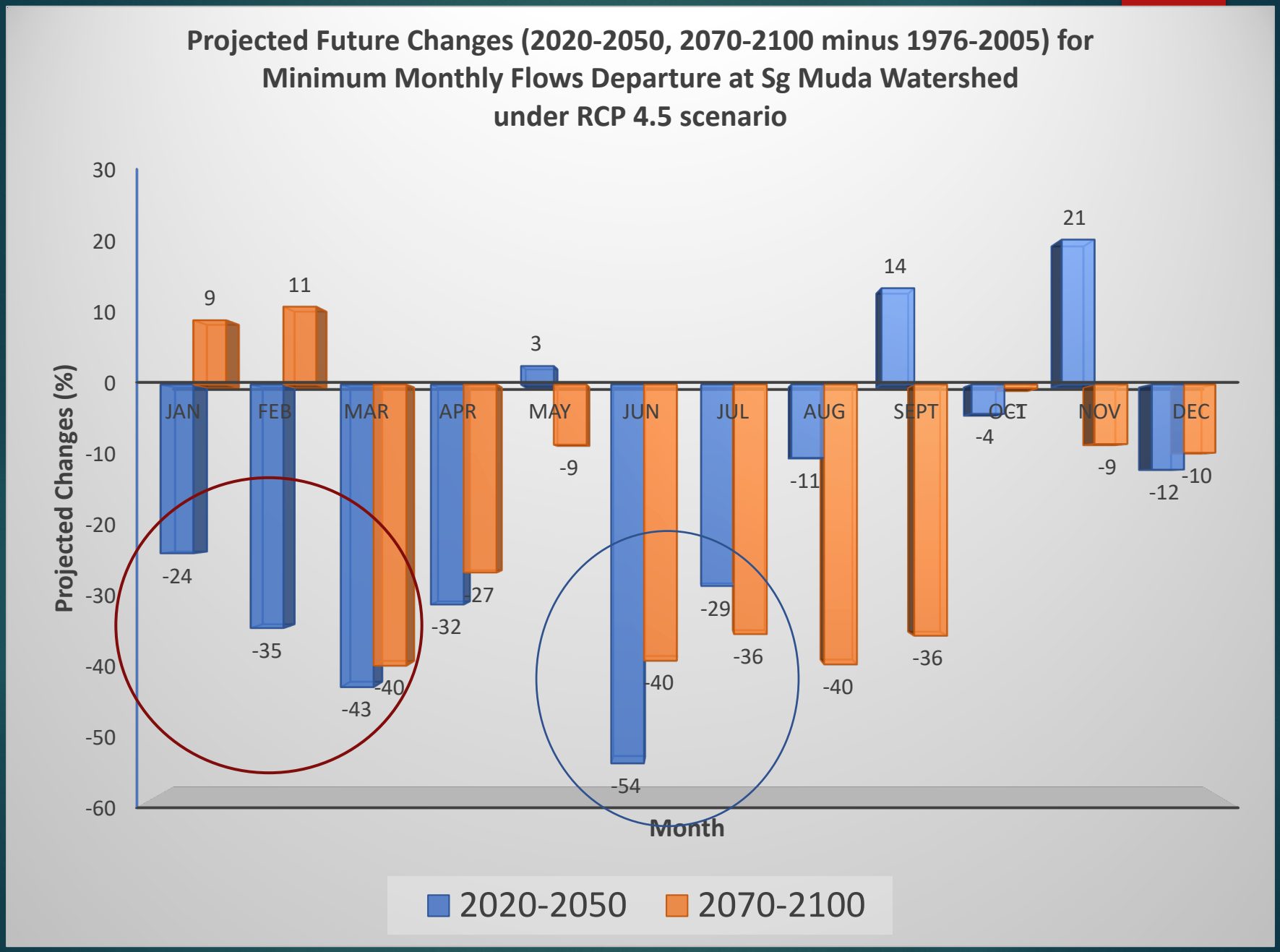
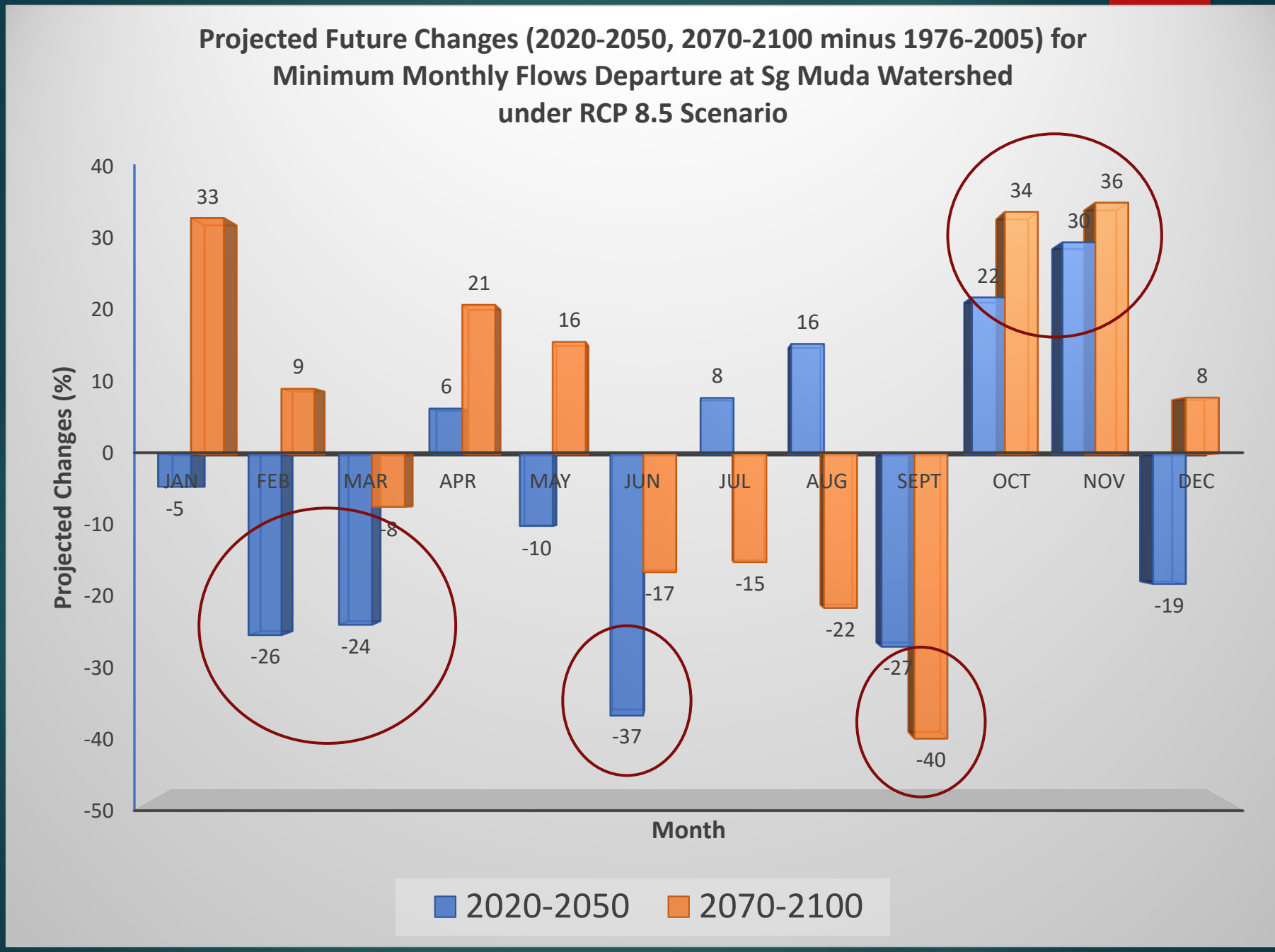
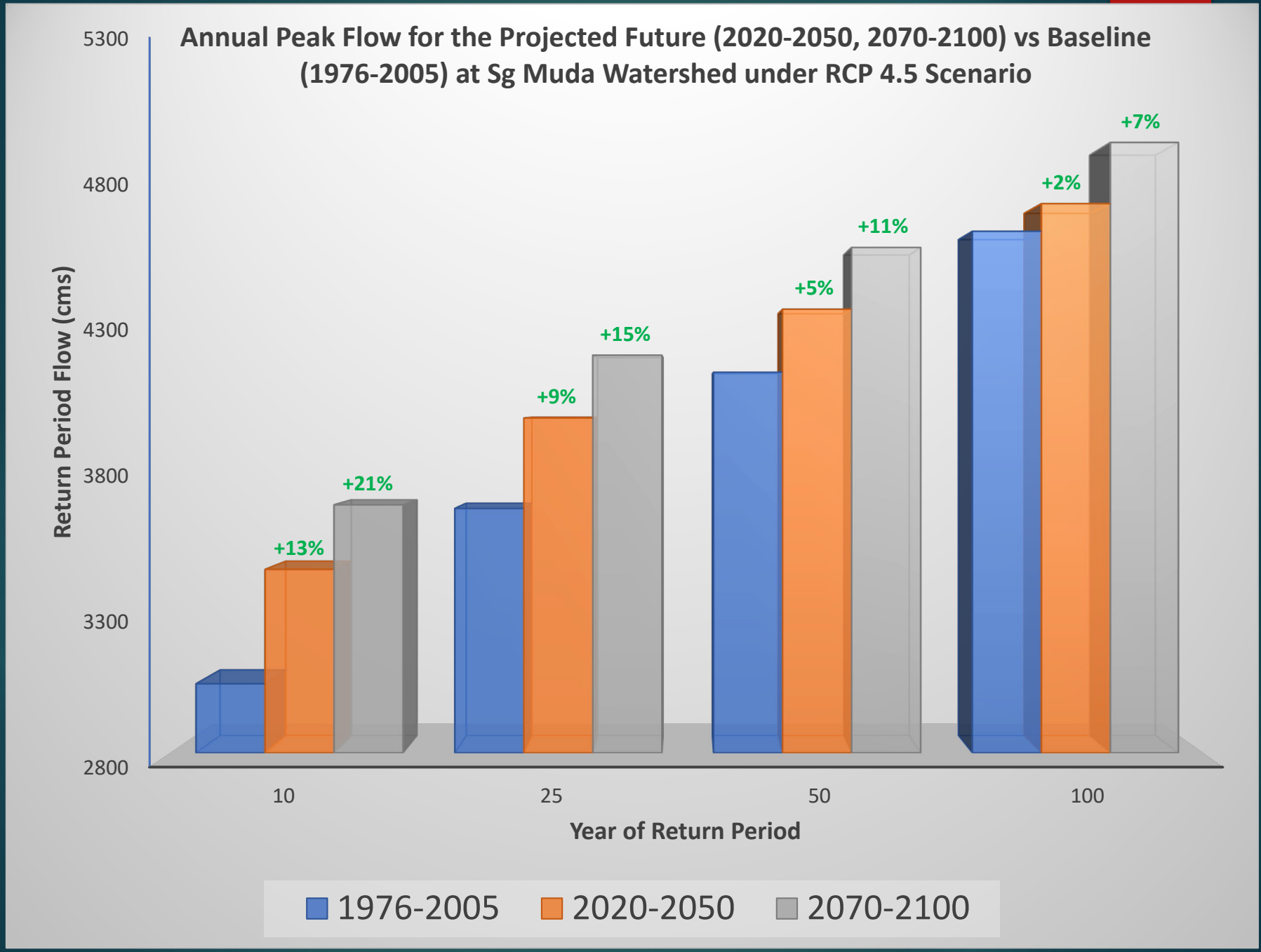
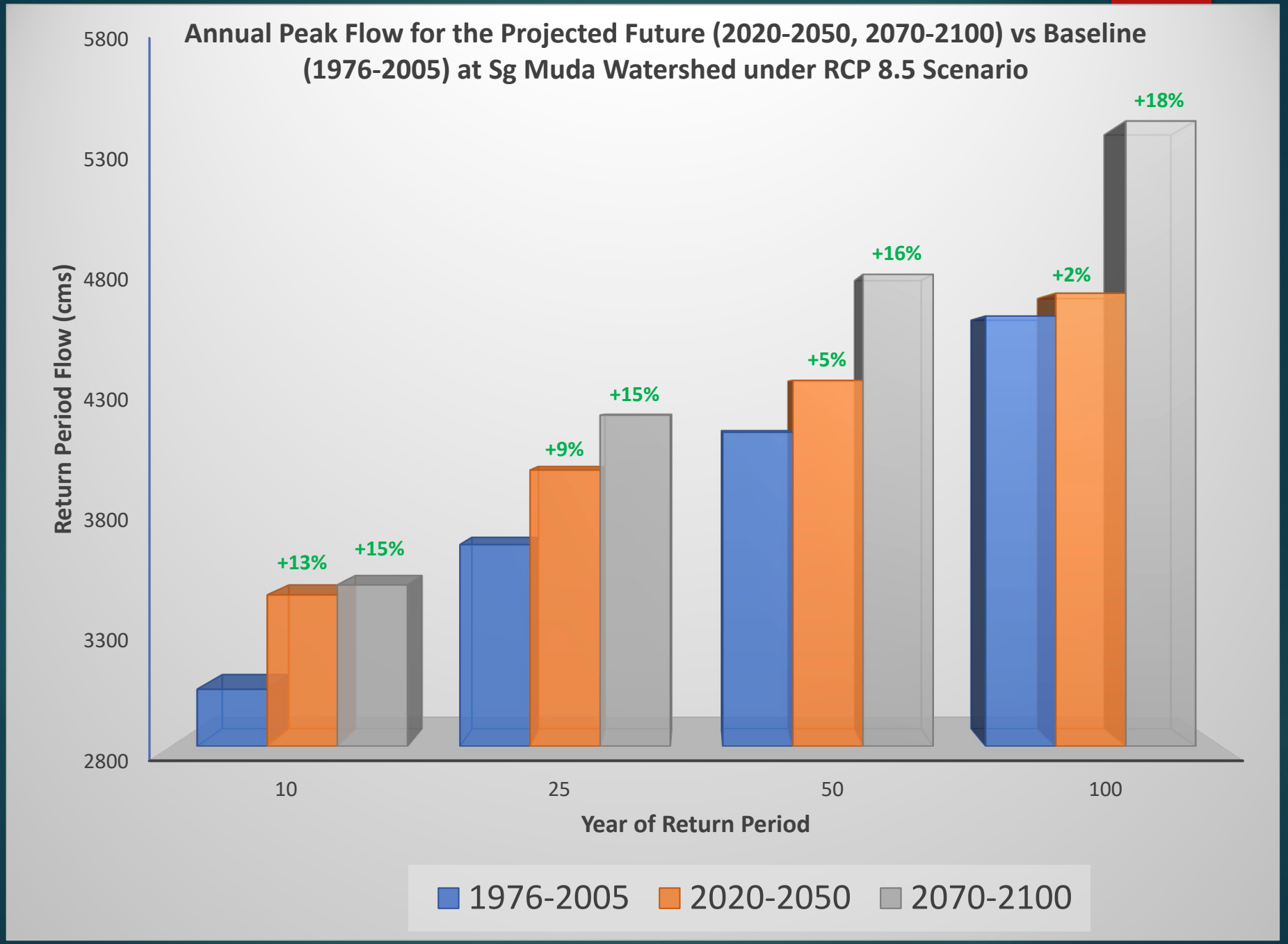

Projected Future Changes (2020-2050, 2070-2100 minus 1976-2005)
for Mean Monthly Flows Departure at Sg Muda Watershed
under RCP 4.5 Scenario
Projected Changes (%)
25
20
15
10
5
0
-5
-10
-15
-20
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEPT
OCT
NOV
DEC
Month
6
5
4
10
2
-17
11
19
12
22
6
-3
-8
-18
-6
-18
-6
-12
2
9
0
-1
-1
3
2020-2050
2070-2100


Projected Future Changes (2020-2050, 2070-2100 minus 1976-2005)
for Mean Monthly Flows Departure at Sg Muda Watershed
under RCP 8.5 Scenario
Projected Changes (%)
40
30
20
10
0
-10
-20
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEPT
OCT
NOV
DEC
2
8
6
15
4
18
11
38
7
30
-7
11
-11
-8
-12
-6
-7
8
11
12
3
6
2
6
Month
2020-2050
2070-2100

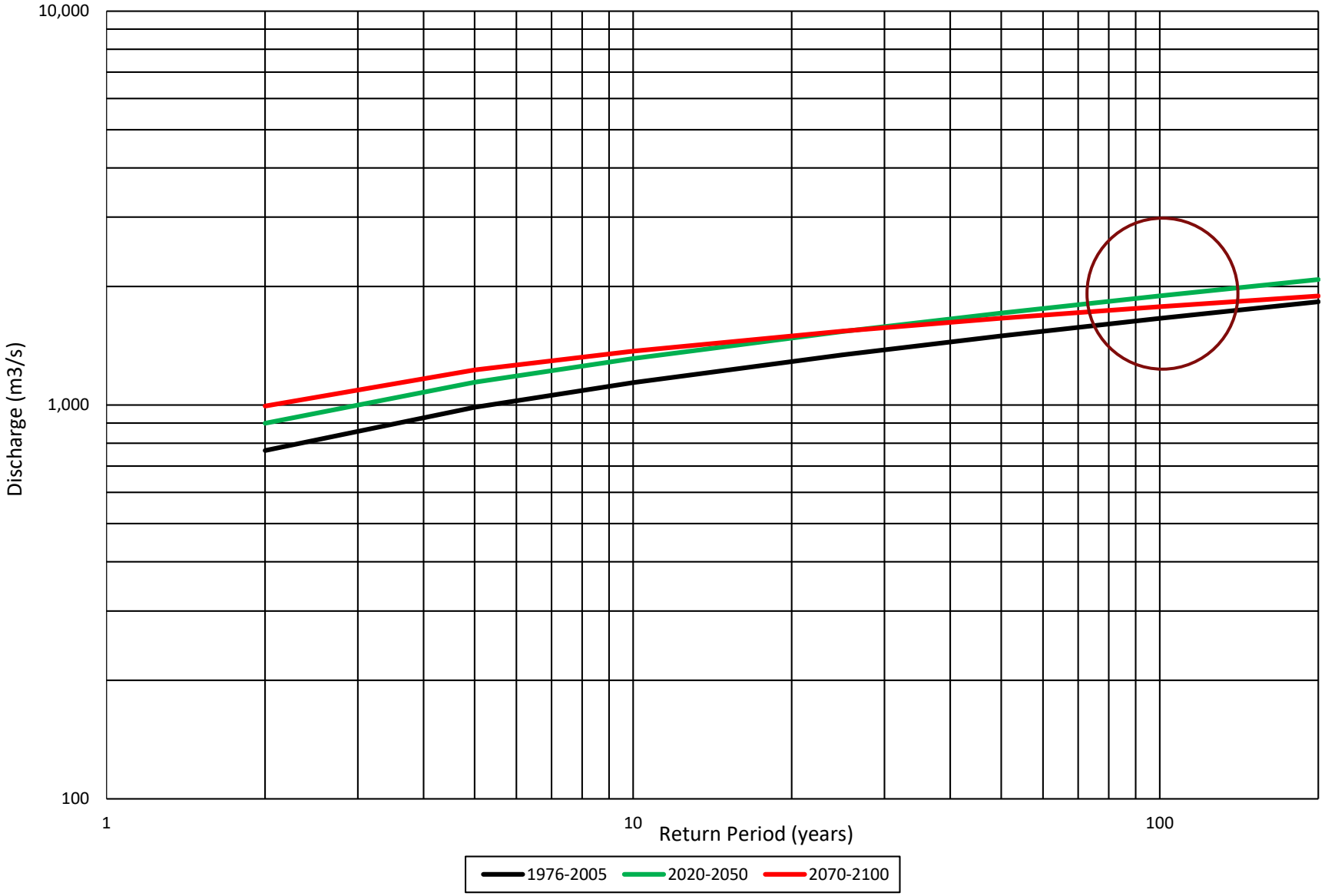

Projected Future Changes (2020-2050, 2070-2100 minus 1976-2005) for Minimum Monthly Flows Departure at Sg Muda Watershed under RCP 4.5 scenario
Projected Changes (%)
30
20
10
0
-10
-20
-30
-40
-50
-60
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEPT
OCT
NOV
DEC
9
11
3
-24
-35
-43
-40
-32
-27
-9
-54
-40
-29
-36
-11
-40
14
-36
-4
21
-9
-12
-10
Month
2020-2050
2070-2100


Projected Future Changes (2020-2050, 2070-2100 minus 1976-2005) for Minimum Monthly Flows Departure at Sg Muda Watershed under RCP 8.5 Scenario
Projected Changes (%)
40
30
20
10
0
-10
-20
-30
-40
-50
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEPT
OCT
NOV
DEC
33
-5
9
-26
-8
-24
6
21
16
-10
8
-37
-17
16
-15
-22
-27
-40
22
34
30
36
8
-19
Month
2020-2050
2070-2100

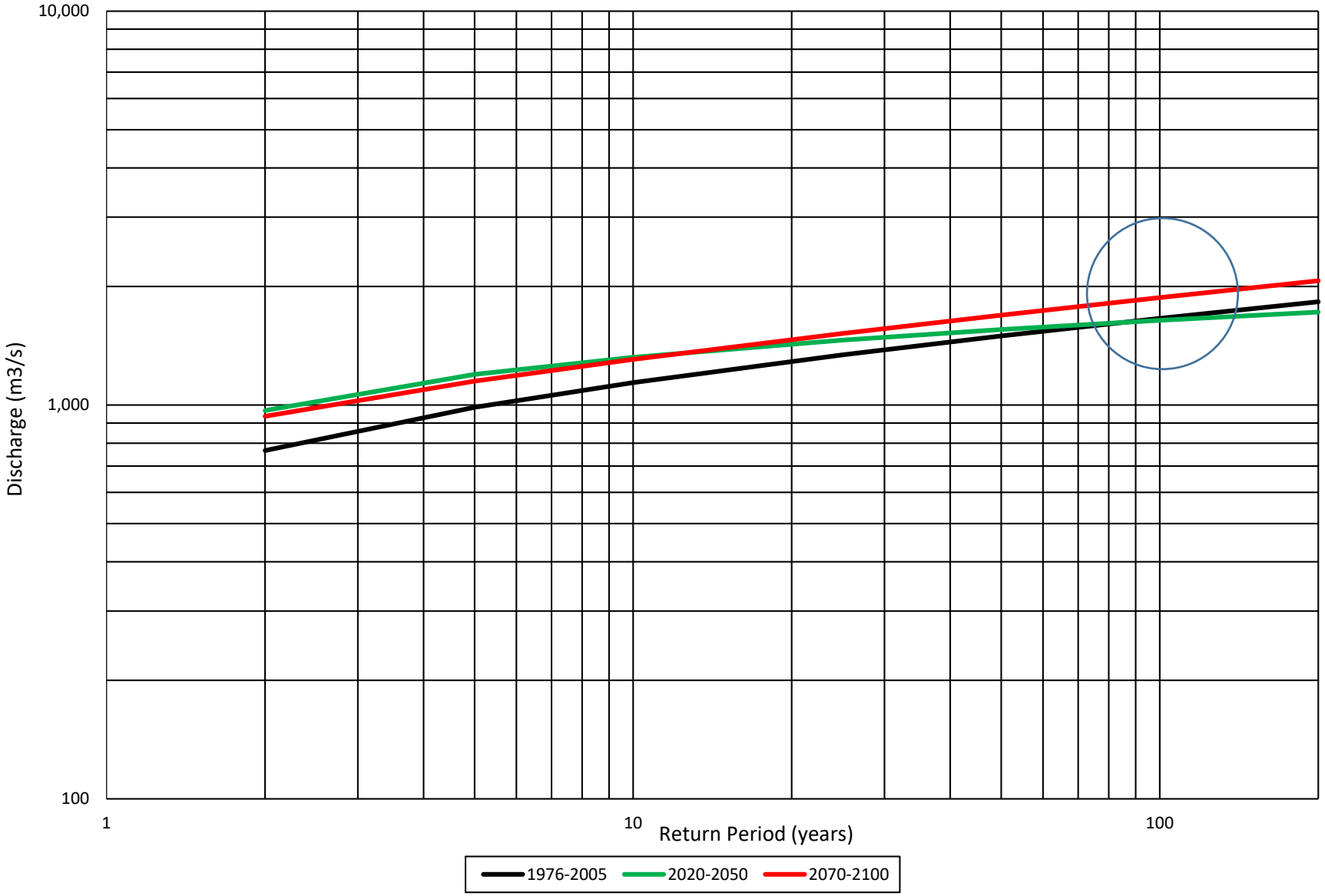

Annual Peak Flow for the Projected Future (2020-2050, 2070-2100) vs Baseline (1976-2005) at Sg Muda Watershed under RCP 4.5 Scenario
Return Period Flow (cms)
5300
4800
4300
3800
3300
2800
+13%
+21%
+9%
+15%
+5%
+11%
+2%
+7%
10
25
50
100
Year of Return Period
1976-2005
2020-2050
2070-2100


Annual Peak Flow for the Projected Future (2020-2050, 2070-2100) vs Baseline (1976-2005) at Sg Muda Watershed under RCP 8.5 Scenario
Return Period Flow (cms)
5800
5300
4800
4300
3800
3300
2800
+13%
+15%
+9%
+15%
+5%
+16%
+2%
+18%
10
25
50
100
Year of Return Period
1976-2005
2020-2050
2070-2100

Ensemble Average for Flood Frequency Analysis at Sg.Muda streamflow station under RCP4.5 Scenario



Ensemble Average for Flood Frequency Analysis at Sg.Muda streamflow station under RCP8.5 Scenario

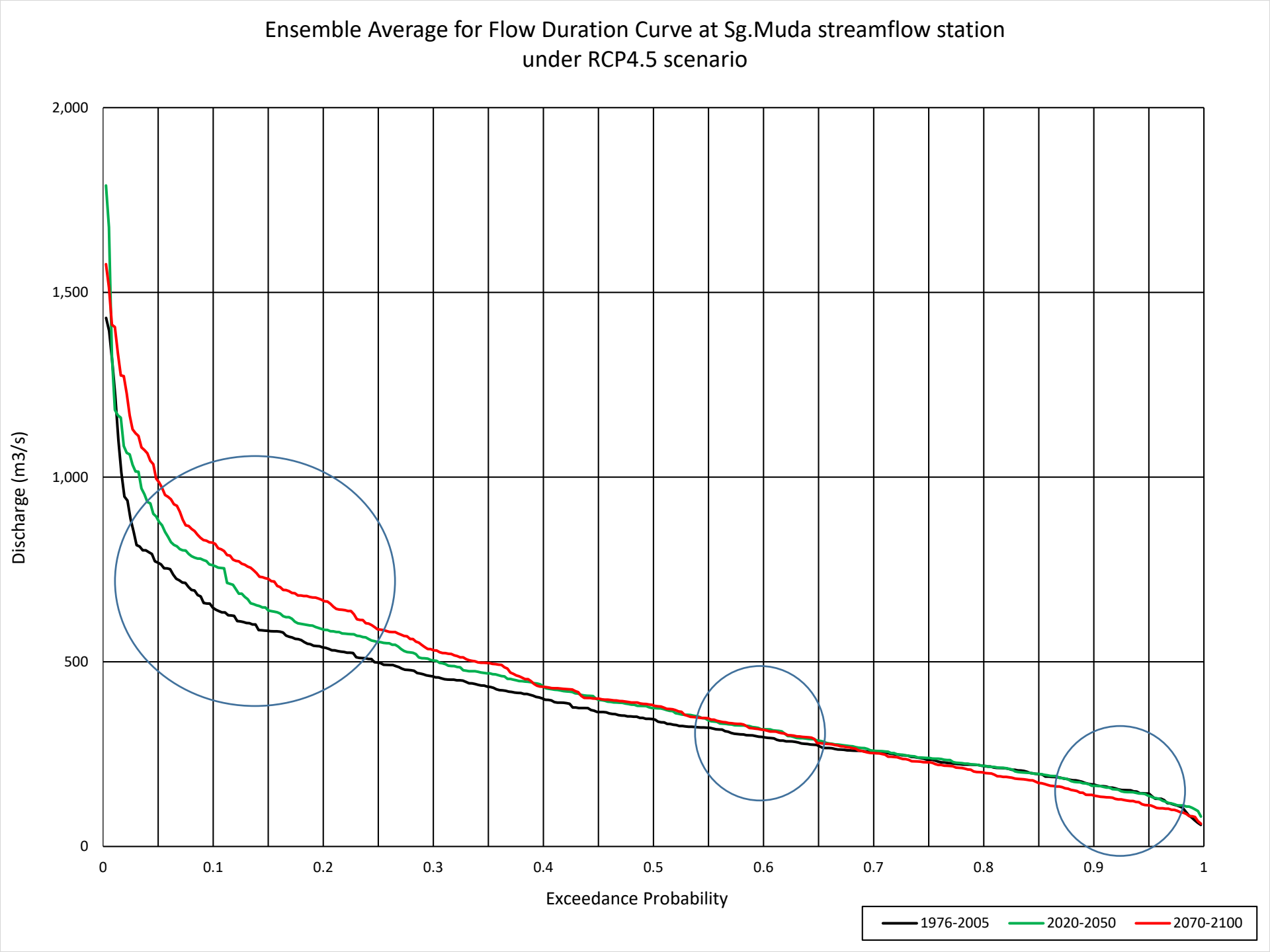


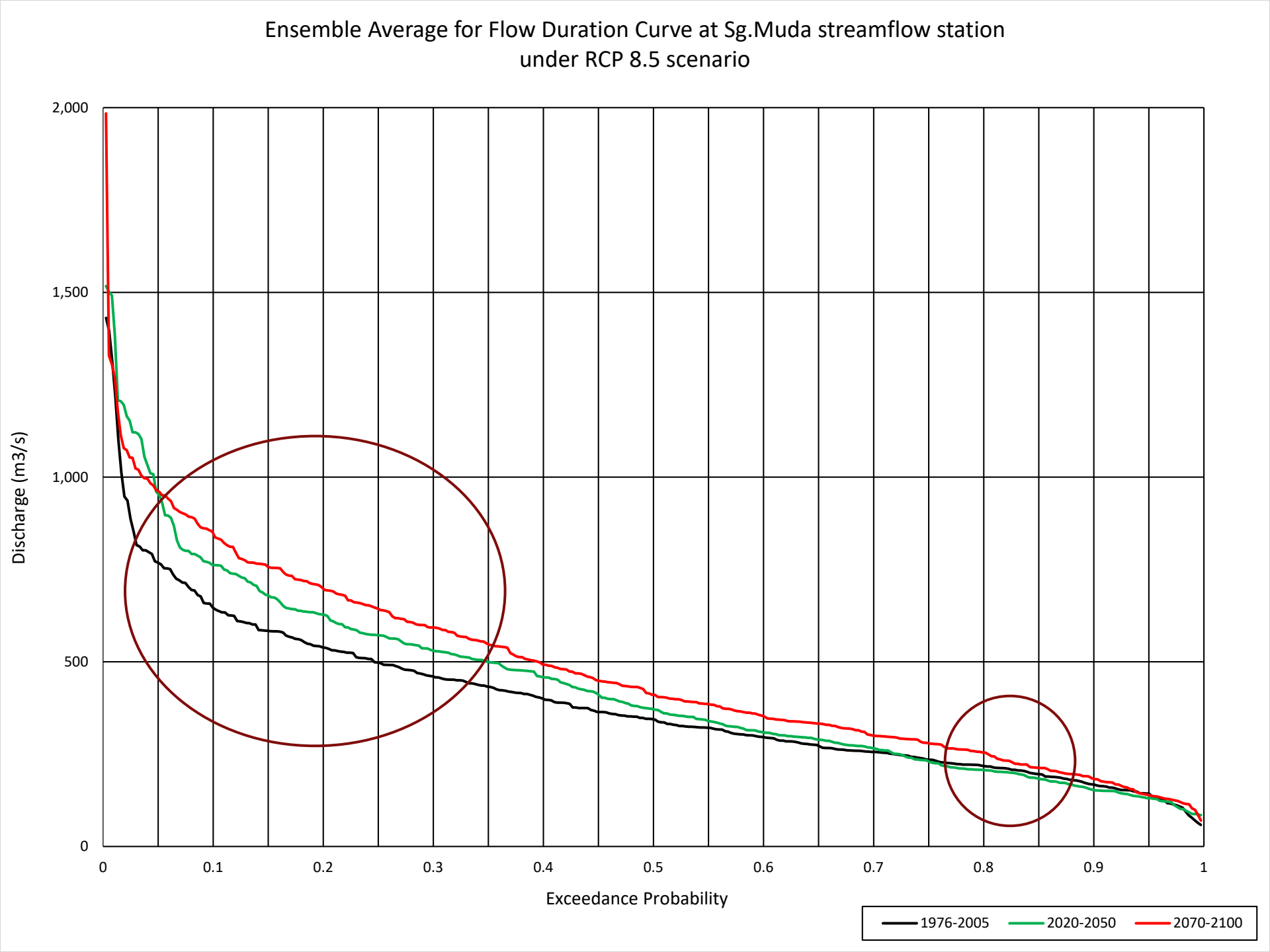
RCP4.5

	1976-2005	2020-2050		2070-2100	
Return Period	Q (m3/s)	Q (m3/s)	% change	Q (m3/s)	% change
2	766.3	898.7	17.3	994.0	29.7
5	986.8	1142.3	15.8	1227.2	24.4
10	1140.0	1312.1	15.1	1369.8	20.2
25	1341.3	1536.5	14.5	1540.0	14.8
50	1497.8	1711.5	14.3	1660.8	10.9
100	1659.7	1893.0	14.1	1777.3	7.1
200	1828.6	2082.6	13.9	1891.4	3.4

RCP8.5

	1976-2005	2020-2050		2070-2100	
Return Period	Q (m3/s)	Q (m3/s)	% change	Q (m3/s)	% change
2	766.3	968.3	26.4	936.7	22.2
5	986.8	1196.3	21.2	1150.0	16.5
10	1140.0	1322.0	16.0	1306.1	14.6
25	1341.3	1461.4	8.9	1519.7	13.3
50	1497.8	1554.5	3.8	1691.3	12.9
100	1659.7	1640.4	-1.2	1873.3	12.9
200	1828.6	1721.8	-5.8	2067.9	13.1


Ensemble Average for Flow Duration Curve at Sg.Muda streamflow station under RCP4.5 scenario
2,000
1,500
1,000
500
0
Discharge (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Exceedance Probability
1976-2005
2020-2050
2070-2100


Ensemble Average for Flow Duration Curve at Sg.Muda streamflow station under RCP 8.5 scenario
2,000
1,500
1,000
500
0
Discharge (m3/s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Exceedance Probability
1976-2005
2020-2050
2070-2100

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- Soil and Water Assessment Tool (SWAT) was successfully used to model the streamflow of the Sungai Muda Watershed. The simulation results show pretty good performance for the calibration period and acceptable skill for validation period, with NSE values of 0.76 and 0.70, respectively.

- From the results, we may inferred that the hydrologic extremes will be magnified significantly in Sg Muda watersheds. The dry season is expected to be drier and the wet season is expected to be wetter in future according to the simulations

- In the future minimum monthly flows will be lower and the annual maximum flows will be significantly higher than their historical counterparts in these watersheds.

- From a combined analysis of the results, an increase in inter-annual and intra-seasonal variability with increased hydrologic extremes (higher high flows, and lower low flows) are expected in Sg Muda Watersheds in the future.

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- This study need to be refine with much higher resolution rainfall data (<10km resolution), higher DEM resolution, more GCMs & climate scenarios, more downscaling methods, latest land-use data, accurate soil information and with the new SWAT+.

- Dynamical downscaling technique is recommended to be done to address the uncertainties coming from the downscaling techniques.

- Future consideration of this study is to conduct an assessment of the impact of climate change on the water quality, erosion, sediment, and nutrient transport.

- The need of seasonal and sub-seasonal streamflow forecast on water quantity and water quality towards better watershed management

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Department of Agriculture (DOA) Malaysia

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Food and Agricultural Organization (FAO)


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