

Development and Evaluation of Stochastic Rainfall Models for Urban Drought Security Assessment

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.....
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Principal Supervisor

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Table of Contents

1.	INTRODUCTION	1
1.1	General Background	1
1.2	Aims.....	3
1.3	Stochastic Models Developed and Assessed.....	3
1.4	Overview.....	4
2.	BACKGROUND	9
2.1	Introduction.....	9
2.2	Hydrology for Water Security Assessment.....	9
2.3	Influence of Large-scale Climate Drivers	11
2.4	Selection of a Model Framework.....	12
2.5	Resolving the Underestimation of Long-term Variability	19
2.6	The Modified Markov Kernel Density (MMKD) Model.....	23
2.7	SimHyd Hydrology Model for Streamflow Generation.....	26
2.8	East Coast Lows and its Importance for Water Security.....	27
2.9	Conclusion	29
3.	DATA, STUDY SITES AND ASSESSMENT METHODS	31
3.1	Introduction.....	31
3.2	Data.....	31
3.3	Study Sites	34
3.4	Model Assessment Procedures.....	43
3.5	Temporal Resolutions	46
3.6	Gummun Site for Preliminary Assessment	46
3.7	Distribution of Z Scores in Gridded Dataset.....	47
3.8	Calculation of Temporally and Spatially Averaged Statistics.....	48
3.9	Assessment Method for Validation	48
3.10	Assessment Method for Streamflow Generation	49
4.	DEVELOPMENT OF THE MARKOV CHAIN DAILY RAINFALL MODEL.....	50
4.1	Introduction.....	50
4.2	Average Parameter Markov Chain (APMC) Model.....	52
4.3	Decadal Parameter Markov Chain (DPMC) Model.....	63
4.4	Compound Distribution Markov Chain (CDMC) Model.....	71
4.5	Hierarchical Markov Chain (HMC) Model.....	78
4.6	Decadal and Hierarchical Markov Chain (DHMC) Model	87
4.7	Methodological Comparison of Five MC Models	88
4.8	Discussion.....	89
4.9	Conclusion	92
5.	COMPARISON OF MC MODELS AT GUMMUN	93
5.1	Introduction.....	93
5.2	Distribution Statistics of Rainfall Depths and Wet Periods	93
5.3	Model Comparison for Distribution Statistics	96
5.4	Potential Impact of Climate Modes.....	105
5.5	Impact of Stochasticity of MC Parameters	105
5.6	Model Comparison for Autocorrelations	106
5.7	Discussion	108
5.8	Conclusion	111

6.	COMPARISON OF MC MODELS IN GOULBURN RIVER SITE	113
6.1	Introduction.....	113
6.2	Calibrated Parameters	113
6.3	Distribution Statistics of Rainfall Depths and Wet Periods	118
6.4	Model Comparison for Distribution of Rainfall Depths	122
6.5	Model Comparison for Distribution of Wet Periods.....	129
6.6	Summary of Model Comparison for Distribution Statistics.....	139
6.7	Model Comparison for Autocorrelation.....	142
6.8	Discussion.....	146
6.9	Conclusion	149
7.	COMPARISON OF MC MODELS IN WILLIAMS RIVER SITE	150
7.1	Introduction.....	150
7.2	Calibrated Parameters	150
7.3	Distribution Statistics of Rainfall Depths and Wet-Dry Periods.....	154
7.4	Model Comparison for Distribution of Rainfall Depths	157
7.5	Model Comparison for Distribution of Wet-Dry Periods	160
7.6	Summary of Model Comparison for Distribution Statistics.....	166
7.7	Model Comparison for Autocorrelation.....	169
7.8	Climate Change Trend of Model Parameters.....	170
7.9	Discussion.....	172
7.10	Conclusion	174
8.	COMPARISON OF MC MODELS IN SYDNEY SITE	176
8.1	Introduction.....	176
8.2	Calibrated Parameters	176
8.3	Distribution Statistics of Rainfall Depths and Wet Periods	179
8.4	Model Comparison for Distribution of Rainfall Depths	181
8.5	Model Comparison for Distribution of Wet Periods.....	183
8.6	Summary of Model Comparison for Distribution Statistics.....	187
8.7	Model Comparison for Autocorrelation.....	190
8.8	Discussion.....	191
8.9	Conclusion	192
9.	COMPARISON OF MC MODELS IN RICHMOND RIVER SITE.....	193
9.1	Introduction.....	193
9.2	Calibrated Parameters	193
9.3	Distribution Statistics of Rainfall Depths and Wet Periods	196
9.4	Model Comparison for Distribution of Rainfall Depths	198
9.5	Model Comparison for Distribution of Wet Periods.....	199
9.6	Summary of Model Comparison for Distribution Statistics.....	202
9.7	Model Comparison for Autocorrelation.....	205
9.8	Discussion.....	206
9.9	Conclusion	207
10.	COMPARISON OF MC MODELS IN BEGA RIVER SITE	208
10.1	Introduction.....	208
10.2	Calibrated Parameters.....	208
10.3	Distribution Statistics of Rainfall Depths and Wet Periods	211
10.4	Model Comparison for Distribution of Rainfall Depths	212
10.5	Model Comparison for Distribution of Wet Periods.....	214
10.6	Summary of Model Comparison for Distribution Statistics.....	218
10.7	Model Comparison for Autocorrelation.....	220
10.8	Discussion.....	221
10.9	Conclusion	222

11. GEOGRAPHICAL COMPARISON OF RAINFALL AND MODEL PERFORMANCES.....	223
11.1 Introduction.....	223
11.2 Five Case Study Sites along East Coast of Australia	223
11.3 Rainfall Variability along the East Coast of Australia	224
11.4 Comparison of CDMC, HMC and DHMC	227
11.5 Conclusion	228
12. COMPARISON OF MC AND MMKD FOR RAINGAUGE DATA AROUND AUSTRALIA..	229
12.1 Introduction.....	229
12.2 Methodological Comparison.....	230
12.3 Distribution Statistics of Observed Rainfall.....	231
12.4 Model Comparison for Distribution Statistics	238
12.5 Autocorrelations of Monthly Wet Days and Rainfall Depth.....	249
12.6 Model Comparison for Autocorrelations	252
12.7 Insights for Simulation of Mean of Multiyear Rainfall Depths	253
12.8 Discussion	254
12.9 Conclusion	255
13. COMPARISON OF MC AND MMKD FOR RAINGAUGE DATA AROUND SYDNEY	257
13.1 Introduction.....	257
13.2 Mean and SD of Daily and Monthly Rainfall Depths	257
13.3 Mean and SD of Multiyear Rainfall Depths.....	260
13.4 Mean and SD of Monthly and Multiyear Number of Wet Days	261
13.5 Mean and SD of Monthly and Annual Mean Length of Wet Spells	263
13.6 Discussion and Conclusion	265
14. COMPARISON OF MC AND MMKD FOR VALIDATION PERIODS.....	266
14.1 Introduction.....	266
14.2 Observed Statistics.....	266
14.3 Model Comparison for Calibration Period.....	271
14.4 Model Comparison for Validation Period.....	271
14.5 Discussion and Conclusion	277
15. COMPARISON OF MC AND MMKD FOR STREAMFLOW GENERATION	279
15.1 Introduction.....	279
15.2 Justification of Using Single-site Rainfall Model.....	281
15.3 Distribution of Rainfall and Streamflow	283
15.4 Model Comparison for Distribution Statistics	287
15.5 Model Comparison for Autocorrelation.....	298
15.6 Discussion and Conclusion	299
16. CONCLUSION.....	302
16.1 Overview.....	302
16.2 Selection of Modelling Structure and Relevant Issues.....	302
16.3 Development of Markov Chain Daily Rainfall Models	303
16.4 Comparison of Five MC Models for Rainfall Generation	303
16.5 Comparison of MC and MMKD for Rainfall Generation.....	305
16.6 Comparison of MC and MMKD for Streamflow Generation	306
16.7 Future Works	307
16.8 Concluding Remarks.....	308
REFERENCES	309
APPENDICES.....	316

List of Figures

Figure 1.1: Flowchart of the chapter arrangement of this study.	5
Figure 3.1: Elevation map for NARcliM data boundary in the eastern seaboard of Australia.	32
Figure 3.2: Location of the five case study sites (in rectangular boxes) of this study. The green circles indicate the major cities/towns along the east coast of NSW.	34
Figure 3.3: NARcliM elevation map (at 10 km resolution) of the case study area in Goulburn River site.	35
Figure 3.4: NARcliM elevation map (at 10 km resolution) of the case study area in Williams River site. White region is in ocean.	36
Figure 3.5: NARcliM elevation map (at 10 km resolution) of the case study area in the Sydney site. The white region is in the ocean.	37
Figure 3.6: NARcliM elevation map (at 10 km resolution) of the case study area in Richmond River site. The white region is in the ocean.	37
Figure 3.7: NARcliM elevation map (at 10 km resolution) of the case study area in Bega River site. The white region is in the ocean.	38
Figure 3.8 Location map of 12 raingauge stations around Australia.	39
Figure 3.9: Location map of 30 raingauge stations around Sydney (from Mehrotra et al. [2015]). Station numbers correspond to the station names listed in Table 3.2.....	40
Figure 3.10: The Grahamstown, Tillegra and Chichester sub-catchments of Williams River site are shown in left. The location and elevation of the sub-catchments area within Williams River site are shown in right. The boxes represent the 10 km $\times$ 10 km NARcliM grid pixels. The (x, y) coordinates shown in the left figure corresponds to the (x, y) coordinates of right figure. The distance scale refers to the left hand figure with the catchment boundaries.	42
Figure 3.11: Location of Gummun and Blackville, and 17 other raingauge stations within the NARcliM data boundary at Goulburn River site in the east coast of Australia.	47
Figure 4.1: Schematic of the APMC. Compare the red boxes with the same of Figure 4.10, Figure 4.21, Figure 4.30 and Figure 4.31 to see the changes in DPMC, CDMC, HMC and DHMC respectively.	56
Figure 4.2: MC parameters P00 and P11 (transition probabilities of dry-to-dry and wet-to-wet day respectively), and Gamma distribution parameters μ and σ (mean and SD of wet day rainfall depths respectively) of APMC in RCM2 and AWAP. The parameters are shown for each month, where the first month is January.	57
Figure 4.3: Month-to-month autocorrelations of monthly rainfall depths and number of wet days in RCM2 and AWAP.	58
Figure 4.4: Distribution of wet day rainfall depths in RCM2 and APMC simulation for January, April, July, and September (typical months).	59
Figure 4.5: Distribution of wet day rainfall depths between 0.3 mm and 1mm in RCM2 and APMC simulation for January, April, July and September (typical months).	60

Figure 4.6: Gamma distribution with different α and β .	61
Figure 4.7: Changes of μ and σ with changes of α and β .	61
Figure 4.8: Box-cox transformation of wet day rainfall depths in RCM2 using $\lambda = 0.1402$ (left). Correlation of transformed rainfall depths in successive wet days (right).	62
Figure 4.9: Simulation of wet and dry spells in APMC for January (a typical month) for RCM2.	63
Figure 4.10: Schematic of the DPMC. Compare the red boxes with the same of Figure 4.1 Figure 4.21, Figure 4.30 and Figure 4.31 to see the relative differences in APMC, CDMC, HMC and DHMC respectively.	64
Figure 4.11: Comparison of the decadal variability of the DPMC parameters (wet-to-wet probabilities P11 and mean wet day rainfalls μ) with the APMC parameters. The coloured lines are the values of DPMC parameters and the thick black lines are the values of APMC parameters.	65
Figure 4.12: Sampling distributions of DPMC parameters (P11 and μ) for January and July as two representative months. The blue horizontal bars are the 5 th to 95 th percentile bounds, the boxes are the 25 th to 75 th percentile bounds, and the red horizontal bars are the 50 th percentiles of the $6 \times$ 1000 realisations of simulated parameter. The red dots show the DPMC parameter values, calculated from each of the 10-year samples of RCM2 data at Gummun. The green dots show the respective APMC value of a parameter.	67
Figure 4.13: Parameters (P11 and μ) of sub-samples of RCM2 according to the two IPO (positive and negative) and three ENSO phases (La Niña, Neutral and El Niño).	69
Figure 4.14: Correlation between the 12x 60 values of each parameter (P00, P11, μ , and σ) for RCM2 and ONI, nino3.4, MEI, PDOI climate indices.	70
Figure 4.15: Correlation between the 12x 60 values of each parameter (P00, P11, μ , and σ) for RCM2 and SOI, SAMI, DMI, and IPOI climate indices.	70
Figure 4.16: Boxplot distribution of μ and σ for every month. Each boxplot is fitted to the 60 values a parameter for respective month. The blue horizontal bars are the 5 th to 95 th percentile bounds, the boxes are the 25 th to 75 th percentile bounds, and the red horizontal bars are the 50 th percentiles. The green dots show the APMC parameters (equivalent to the average of 60 distributed values).	73
Figure 4.17: Lognormal probability plots of μ for each month for RCM2.	74
Figure 4.18: Lognormal probability plots of σ for each month for RCM2.	75
Figure 4.19: Correlation between $\log \mu$ and $\log \sigma$ for each month for RCM2.	75
Figure 4.20: Month-to-month autocorrelations of $\log \mu$ and $\log \sigma$ for RCM2 and AWAP.	76
Figure 4.21: Schematic of the CDMC (compare with the Figure 4.1, Figure 4.10, Figure 4.30 and Figure 4.31).	77
Figure 4.22: Normal probability plots of P00 for each month for RCM2.	79
Figure 4.23: Normal probability plots of P11 for each month for RCM2.	79
Figure 4.24: Correlation between P00 and P11 for each month for RCM2.	80
Figure 4.25: Month-to-month autocorrelations of P00 and P11 for RCM2 and AWAP.	80
Figure 4.26: Correlation between $\log \mu$ and P11 for each month for RCM2.	81
Figure 4.27: Correlation between $\log \sigma$ and P11 for each month for RCM2.	82

Figure 4.28: Correlation between $\log \mu$ and P00 for each month for RCM2.	82
Figure 4.29: Correlation between $\log \sigma$ and P00 for each month for RCM2.	83
Figure 4.30: Schematic of the HMC (compare with the Figure 4.1, Figure 4.10, Figure 4.21 and Figure 4.31).	84
Figure 4.31: Schematic of the DHMC (compare with the Figure 4.1, Figure 4.10, Figure 4.21 and Figure 4.30).	87
Figure 5.1: Mean and SD of rainfall depths for RCM2 and AWAP at daily and monthly resolutions.	94
Figure 5.2: Mean and SD of rainfall depths for RCM2 and AWAP at multiyear (aggregated rainfall depths for multiple overlapping years) resolutions.	94
Figure 5.3: Mean and SD of monthly number of wet days for RCM2 and AWAP.	95
Figure 5.4: Mean and SD of multiyear number of wet days in RCM2 and AWAP.	95
Figure 5.5: Mean and SD of monthly mean length of wet spells for RCM2 and AWAP.	96
Figure 5.6: Comparison of APMC, DPMC, CDMC, HMC, and DHMC to reproduce the mean and SD of daily (wet day) rainfall depths for RCM2 and AWAP.	97
Figure 5.7: Comparison of APMC, DPMC, CDMC, HMC, and DHMC to reproduce the mean and SD of monthly rainfall depths for RCM2 and AWAP.	98
Figure 5.8: Comparison of APMC, DPMC, CDMC, HMC and DHMC to reproduce the mean and SD of multiyear rainfall depths for RCM2 and AWAP.	99
Figure 5.9: Comparison of APMC, DPMC, CDMC, HMC and DHMC to reproduce the mean and SD of monthly number of wet days for RCM2 and AWAP.	100
Figure 5.10: Comparison of APMC, DPMC, CDMC, HMC and DHMC to reproduce the mean and SD of multiyear number of wet days for RCM2 and AWAP. The Z scores of APMC and CDMC for AWAP are out of the +6 range.	101
Figure 5.11: Comparison of APMC, DPMC, CDMC, HMC, and DHMC to reproduce the mean and SD of monthly mean length of wet spells for RCM2 and AWAP.	102
Figure 5.12: Comparison of APMC, DPMC, CDMC, HMC, and DHMC to reproduce the mean and SD of annual mean length of wet spells for RCM2 and AWAP.	103
Figure 5.13: Comparison of DPMC and other DPMC-like models (e.g. model with sub-samples of 5-year length, model with sub-samples according to IPO and ENSO phases) to reproduce the mean and SD of monthly rainfall depths for RCM2.	105
Figure 5.14: Comparison of HMC and other HMC-like models (e.g. model with lag-1 autocorrelation equation and model with multivariate sampling for stochastic MC parameters) to reproduce the mean and SD of monthly rainfall depths for RCM2.	106
Figure 5.15: Comparison of APMC, DPMC, CDMC, HMC and DHMC to reproduce the month-to-month autocorrelations of monthly rainfall depths and monthly number of wet days for RCM2.	107
Figure 5.16: Comparison of APMC, DPMC, CDMC, HMC and DHMC to reproduce the month-to-month autocorrelations of monthly rainfall depths and monthly number of wet days for AWAP.	108
Figure 6.1: Intra-annual and spatial variability of dry-to-dry transition probabilities (P00). The colourbars indicate the parameter values.	115

Figure 6.2: Intra-annual and spatial variability of wet-to-wet transition probabilities (P11). The colourbars indicate the parameter values.	115
Figure 6.3: Intra-annual and spatial variability of the mean of wet day rainfall depths (μ) for all RCMs and AWAP at Goulburn. The colourbars indicate the parameter values.	116
Figure 6.4: Intra-annual and spatial variability of the SD of wet day rainfall depths (σ) for all RCMs and AWAP at Goulburn. The colourbars indicate the parameter values.	116
Figure 6.5: Correlation between elevation and model parameters for each month.	117
Figure 6.6: Mean and SD of rainfall depths at daily, monthly and multiyear resolutions.	119
Figure 6.7: Intra-annual and spatial variability of the mean monthly number of wet days.	120
Figure 6.8: Intra-annual and spatial variability of the SD of monthly number of wet days.	120
Figure 6.9: Mean and SD of number of wet days at monthly and multiyear resolutions.	120
Figure 6.10: Mean and SD of mean length of wet spells at monthly and annual resolutions.	121
Figure 6.11: Z Scores of CDMC, HMC and DHMC for the mean of wet day rainfall depths.	123
Figure 6.12: Z Scores of CDMC, HMC and DHMC for the SD of wet day rainfall depths.	124
Figure 6.13: Z Scores of CDMC, HMC, and DHMC for the SD of monthly rainfall depths.	126
Figure 6.14: Z Scores of CDMC, HMC and DHMC for the mean annual rainfall depths.	127
Figure 6.15: Z Scores of CDMC, HMC and DHMC for the SD of multiyear rainfall depths.	128
Figure 6.16: Z Scores of CDMC, HMC and DHMC for the mean of monthly number of wet days.	130
Figure 6.17: Z Scores of CDMC, HMC and DHMC for the SD of monthly number of wet days.	131
Figure 6.18: Z Scores of CDMC, HMC and DHMC for the mean of multiyear number of wet days.	132
Figure 6.19: Z Scores of CDMC, HMC and DHMC for the SD of multiyear number of wet days.	133
Figure 6.20: Z Scores of CDMC, HMC and DHMC for the mean of monthly mean length of wet spells.	135
Figure 6.21: Z Scores of CDMC, HMC and DHMC for the SD of monthly mean length of wet spells.	136
Figure 6.22: Z Scores of CDMC, HMC and DHMC for the mean of annual mean length of wet spells.	137
Figure 6.23: Z Scores of CDMC, HMC and DHMC for the SD of annual mean length of wet spells.	138
Figure 6.24: Month-to-month autocorrelations of monthly rainfall depths and number of wet days in all RCMs and AWAP at Goulburn.	143
Figure 6.25: Comparison of CDMC, HMC and DHMC to reproduce the month-to-month autocorrelations of monthly rainfall depths for all RCMs and AWAP.	144
Figure 6.26: Comparison of CDMC, HMC and DHMC to reproduce the month-to-month autocorrelations of monthly number of wet days for all RCMs and AWAP.	145
Figure 7.1: Intra-annual and spatial variability of dry-to-dry and wet-to-wet transition probabilities. The colourbars indicate the parameter values.	151
Figure 7.2: Intra-annual and spatial variability of mean and SD of wet day rainfall depths. The colourbars indicate the parameter values.	152
Figure 7.3: Correlation between elevation and model parameters (APMC values).	153
Figure 7.4: Mean and SD of rainfall depths at daily, monthly and multiyear resolutions.	154
Figure 7.5: Mean and SD of number of wet and dry days at monthly and annual resolutions.	155

Figure 7.6: Mean and SD of mean length of wet and dry spells at monthly and annual resolutions.	156
Figure 7.7: Z Scores of CDMC, HMC and DHMC for the SD of multiyear rainfall depths.	158
Figure 7.8: 100 CDMC realisations of SD of multiyear rainfall depths (dashed lines) for RCM2 data at two NARClIM pixels. The green solid lines indicate the expected values with 95% confidence limit. The red lines indicate the RCM2 values.	159
Figure 7.9: Z Scores of CDMC, HMC and DHMC for the mean of monthly mean length of wet spells.	161
Figure 7.10: Z Scores of CDMC, HMC and DHMC for the mean of monthly mean length of dry spells.	162
Figure 7.11: Z Scores of CDMC, HMC and DHMC for the SD of monthly number of wet days.	163
Figure 7.12: Z Scores of CDMC, HMC and DHMC for the SD of monthly mean length of dry spells.	164
Figure 7.13: Z Scores of CDMC, HMC and DHMC for the SD of annual mean length of wet spells.	165
Figure 7.14: Z Scores of CDMC, HMC and DHMC for the SD of multiyear number of wet days.	166
Figure 7.15: Month-to-month autocorrelations of monthly rainfall depths in all RCMs and AWAP.	169
Figure 7.16: Month-to-month autocorrelations of monthly number of wet days.	169
Figure 7.17: Intra-annual and spatial variability of model parameters (APMC values) for reanalysis and CCCMA 3.1 of RCM2.	171
Figure 8.1: Intra-annual and spatial variability of dry-to-dry and wet-to-wet transition probabilities. The colourbars indicate the parameter values.	177
Figure 8.2: Intra-annual and spatial variability of mean and SD of wet day rainfall depths. The colourbars indicate the parameter values.	178
Figure 8.3: Correlation between elevation and model parameters for each month.	179
Figure 8.4: Spatial variability of the SD of multiyear rainfall depths.	180
Figure 8.5: Spatial variability of the SD of multiyear number of wet days.	180
Figure 8.6: Z Scores of CDMC, HMC and DHMC for the SD of multiyear rainfall depths.	182
Figure 8.7: Z Scores of CDMC, HMC and DHMC for the SD of monthly number of wet days.	184
Figure 8.8: Z Scores of CDMC, HMC and DHMC for the SD of multiyear number of wet days.	186
Figure 8.9: Z Scores of CDMC, HMC and DHMC for the SD of annual mean length of wet spells.	187
Figure 8.10: Month-to-month autocorrelations of monthly rainfall depths in all RCMs and AWAP.	190
Figure 8.11: Month-to-month autocorrelations of monthly number of wet days in all RCMs and AWAP.	190
Figure 9.1: Intra-annual and spatial variability of dry-to-dry and wet-to-wet transition probabilities. The colourbars indicate the parameter values.	194
Figure 9.2: Intra-annual and spatial variability of mean and SD of wet day rainfall depths. The colourbars indicate the parameter values.	195
Figure 9.3: Correlation between elevation and model parameters for each month.	196
Figure 9.4: Spatial variability of the SD of multiyear rainfall depths.	197
Figure 9.5: Spatial variability of the SD of multiyear number of wet days.	197
Figure 9.6: Z Scores of CDMC, HMC and DHMC for the SD of multiyear rainfall depths.	199

Figure 9.7: Z Scores of CDMC, HMC and DHMC for the SD of monthly number of wet days.	200
Figure 9.8: Z Scores of CDMC, HMC and DHMC for the SD of multiyear number of wet days.	201
Figure 9.9: Z Scores of CDMC, HMC and DHMC for the SD of annual mean length of wet spells.	202
Figure 9.10: Month-to-month autocorrelations of monthly rainfall depths in all RCMs and AWAP.	205
Figure 9.11: Month-to-month autocorrelations of monthly number of wet days in all RCMs and AWAP.	205
Figure 10.1: Intra-annual and spatial variability of dry-to-dry transition probabilities.	209
Figure 10.2: Intra-annual and spatial variability of wet-to-wet transition probabilities.	209
Figure 10.3: Intra-annual and spatial variability of mean wet day rainfall depths.	209
Figure 10.4: Intra-annual and spatial variability of SD of wet day rainfall depths.	210
Figure 10.5: Correlation between elevation and model parameters for each month.	210
Figure 10.6: Spatial variability of the SD of multiyear rainfall depths.	211
Figure 10.7: Spatial variability of the SD of multiyear number of wet days.	211
Figure 10.8: Z Scores of CDMC, HMC and DHMC for the SD of multiyear rainfall depths.	213
Figure 10.9: Z Scores of CDMC, HMC and DHMC for the SD of monthly number of wet days.	215
Figure 10.10: Z Scores of CDMC, HMC and DHMC for the SD of multiyear number of wet days.	217
Figure 10.11: Z Scores of CDMC, HMC and DHMC for the SD of annual mean length of wet spells.	217
Figure 10.12: Month-to-month autocorrelations of monthly rainfall depths.	220
Figure 10.13: Month-to-month autocorrelations of monthly number of wet days.	220
Figure 12.1: Mean and SD of monthly number of wet days and rainfall depth for the coastal (top 6 panels), inland (middle 4 panels), and monsoonal (bottom 2 panels) stations around Australia. Each left y-axis denotes mean and SD of number of wet days per month, and each right y-axis denotes mean and SD of monthly rainfall depths. Note the change in vertical scales.	233
Figure 12.2: SD of multiyear number of wet days (each left y-axis) and multiyear rainfall depth (each right y-axis) for 1 to 10 overlapping years. Note the change in vertical scale.	236
Figure 12.3: Mean and SD of annual mean length of wet spells.	237
Figure 12.4: Comparison of model performances for mean of daily rainfall depths.	239
Figure 12.5: Comparison of model performances for SD of daily rainfall depths.	240
Figure 12.6: Comparison of model performances for mean of multiyear rainfall depths.	242
Figure 12.7: Comparison of model performances for SD of multiyear rainfall depths.	243
Figure 12.8: Comparison of model performances for mean of monthly number of wet days.	245
Figure 12.9: Comparison of model performances for SD of monthly number of wet days.	246
Figure 12.10: Comparison of model performances for SD of multiyear number of wet days.	247
Figure 12.11: Comparison of models for mean of annual mean length of wet spells.	248
Figure 12.12: Comparison of models for SD of annual mean length of wet spells.	249
Figure 12.13: Month-to-month autocorrelations of monthly number of wet days and monthly rainfall depths for coastal stations.	250
Figure 12.14: Month-to-month autocorrelations of monthly number of wet days and monthly rainfall depths for the inland and monsoonal stations.	251

Figure 12.15: Comparison of model performances for autocorrelations of monthly number of wet days and monthly rainfall depths for Perth as a representative station.....	252
Figure 12.16: Comparison of DHMC, MMKD and Combined Model (occurrence from MMKD and depth from DHMC) to reproduce the mean of multiyear rainfall depths.	253
Figure 13.1: Comparison of model performances for mean of wet day rainfall depths.	258
Figure 13.2: Comparison of model performances for SD of wet day rainfall depths.	258
Figure 13.3: Comparison of model performances for mean of monthly rainfall depths.	259
Figure 13.4: Comparison of model performances for SD of monthly rainfall depths.	259
Figure 13.5: Comparison of model performances for mean of annual rainfall depths.	260
Figure 13.6: Comparison of model performances for SD of multiyear rainfall depths.	260
Figure 13.7: Comparison of model performances for mean monthly number of wet days.	261
Figure 13.8: Comparison of model performances for SD of monthly number of wet days.	262
Figure 13.9: Comparison of model performances for mean of annual number of wet days.	262
Figure 13.10: Comparison of model performances for SD of multiyear number of wet days.	263
Figure 13.11: Comparison of model performances for mean of monthly mean length of wet spells.	264
Figure 13.12: Comparison of model performances for SD of monthly mean length of wet spells.	264
Figure 13.13: Comparison of model performances for mean (left) and SD (right) of the annual mean length of wet spells.	265
Figure 14.1: Mean and SD of the daily and monthly rainfall depths. The daily statistics are the mean and SD for the days on which rain occurs and does not include dry days.	268
Figure 14.2: Mean and SD of the multiyear rainfall depths.	268
Figure 14.3: Mean and SD of the monthly (left) and multiyear (right) number of wet days.	269
Figure 14.4: Mean and SD of the monthly mean length of wet spells.	270
Figure 14.5: Comparison of performances to reproduce the mean and SD of daily and monthly rainfall depths for four validation periods.	272
Figure 14.6: Comparison of performances to reproduce the mean and SD of multiyear rainfall depths for four validation periods.	273
Figure 14.7: Comparison of performances to reproduce the mean and SD of monthly number of wet days in four validation periods.	274
Figure 14.8: Comparison of performances to reproduce the mean and SD of multiyear number of wet days in four validation periods.	275
Figure 14.9: Comparison of performances to reproduce the mean and SD of monthly mean length of wet spells in four validation periods.	276
Figure 14.10: Comparison of performances to reproduce the mean and SD of annual mean length of wet spells for four validation periods.	276
Figure 15.1: The boxes in the right figure show three pixel windows (around Gummun) of three different sizes. The figures in left panel show changes of the wet-to-wet probabilities (P11) and mean of wet day rainfall depths (μ) with the changes in size of pixel windows.	282

Figure 15.2: Distribution of correlation of daily rainfall timeseries (rts) between pairs of pixels at different distances for RCM2 at Williams River site.	282
Figure 15.3: Distribution statistics of daily rainfall depths and streamflow volumes for the calibration (1980–2009) and validation (1950–1979) periods at Grahamstown catchment.....	284
Figure 15.4: Distribution statistics of daily rainfall depths and streamflow volumes for the calibration (1980–2009) and validation (1950–1979) periods at Tillegra catchment.	284
Figure 15.5: Distribution statistics of multiyear rainfall depths and streamflow volumes for the calibration (1980–2009) and validation (1950–1979) periods at Grahamstown.	286
Figure 15.6: Distribution statistics of multiyear rainfall depths and streamflow volumes for the calibration (1980–2009) and validation (1950–1979) periods at Tillegra.....	286
Figure 15.7: Model comparison to reproduce the distribution statistics of daily rainfall and streamflow for calibration (1980–2009) period of RCM1 at Grahamstown.	288
Figure 15.8: Model comparison to reproduce the distribution statistics of daily rainfall and streamflow for validation (1950–1979) period of RCM1 at Grahamstown.	288
Figure 15.9: Model comparison to reproduce the distribution statistics of daily rainfall and streamflow for calibration (1980–2009) period of RCM1 at Tillegra.....	289
Figure 15.10: Model comparison to reproduce the distribution statistics of daily rainfall and streamflow for validation (1950–1979) period of RCM1 at Tillegra.....	289
Figure 15.11: Model comparison to reproduce the distribution statistics of multiyear rainfall and streamflow for calibration (1980–2009) period of RCM1 at Grahamstown.	291
Figure 15.12: Model comparison to reproduce the distribution statistics of multiyear rainfall and streamflow for validation (1950–2079) period of RCM1 at Grahamstown.	291
Figure 15.13: Model comparison to reproduce the distribution statistics of multiyear rainfall and streamflow for calibration (1980–2009) period of RCM1 at Tillegra.....	292
Figure 15.14: Model comparison to reproduce the distribution statistics of multiyear rainfall and streamflow for validation (1950–2079) period of RCM1 at Tillegra.....	292
Figure 15.15: Model Comparison for the autocorrelations of monthly rainfall (left panel) and streamflow (right panel) for RCM1 at Grahamstown.	298
Figure 15.16: Model Comparison for the autocorrelations of monthly rainfall (left panel) and streamflow (right panel) for RCM1 at Tillegra.....	299

List of Tables

Table 2.1: Pre-calibrated SimHyd parameters for three sub-catchments of the Williams River site. Adapted from Mortazavi et al. [2013].	27
Table 3.1: Geographical features (location and elevation) of the 12 raingauge stations.	39
Table 3.2: List of 30 raingauge stations around Sydney. Daily rainfall data of 1979–2008 period for each of these raingauge stations are obtained from Mehrotra et al. [2015].	40
Table 3.3: Area of the Grahamstown, Tillegra and Chichester sub-catchments.	41
Table 4.1: Methodological comparison among five MC models of this study.	88
Table 5.1: Mean and SD of annual mean length of wet spells (μ_{wet}) for RCM2 and AWAP.	96
Table 5.2: Temporally averaged Z scores of five MC models of this study.	104
Table 6.1: Spatially and temporally averaged APMC values of model parameters.	115
Table 6.2: Average of the absolute values of correlation coefficients between elevation and parameters.	118
Table 6.3: Spatially and temporally averaged values of the mean and SD of rainfall depth and wet period statistics at annual and multiyear resolutions.	122
Table 6.4: Spatial (all pixels) and temporal (all months and years) average of the absolute values of Z scores for mean and SD of rainfall depths.	140
Table 6.5: Spatial (all pixels) and temporal (all lags 1-12) average of the absolute values of Z scores for mean and SD of wet period statistics.	141
Table 6.6: Spatial (all pixels) and temporal (all lags 1-12) average of autocorrelations of monthly rainfall depths and number of wet days.	142
Table 7.1: Spatially and temporally averaged APMC values of model parameters.	151
Table 7.2: Average of the absolute values of correlation coefficients between elevation and parameters.	153
Table 7.3: Spatially and temporally averaged values of the mean and SD of rainfall depth and wet-dry period statistics at annual and multiyear resolutions.	156
Table 7.4: Spatially and temporally average of the absolute value of Z scores for mean and SD of rainfall depths.	167
Table 7.5: Spatially and temporally average of the absolute value of Z scores for mean and SD of wet period statistics.	168
Table 7.6: Spatial (all pixels) and temporal (all lags 1-12) average of autocorrelations of monthly rainfall depths and number of wet days.	170
Table 7.7: Spatially and temporally averaged APMC values of model parameters for reanalysis and four GCMs of RCM2.	172
Table 8.1: Spatially and temporally averaged APMC values of model parameters.	177
Table 8.2: Average of the absolute values of correlation coefficients between elevation and parameters.	179

Table 8.3: Spatially and temporally averaged values of the mean and SD of rainfall depth and wet period statistics at annual and multiyear resolutions.	180
Table 8.4: Spatially and temporally average of the absolute value of Z scores for mean and SD of rainfall depths.	188
Table 8.5: Spatially and temporally average of the absolute value of Z scores for mean and SD of wet period statistics.	189
Table 8.6: Spatial (all pixels) and temporal (all lags 1-12) average of autocorrelations of monthly rainfall depths and number of wet days.	191
Table 9.1: Spatially and temporally averaged APMC values of model parameters.	194
Table 9.2: Average of the absolute values of correlation coefficients between elevation and parameters.	196
Table 9.3: Spatially and temporally averaged values of the mean and SD of rainfall depth and wet period statistics at annual and multiyear resolutions.	197
Table 9.4: Spatially and temporally average of the absolute value of Z scores for mean and SD of rainfall depths.	203
Table 9.5: Spatially and temporally average of the absolute value of Z scores for mean and SD of wet period statistics.	204
Table 9.6: Spatial (all pixels) and temporal (all lags 1-12) average of autocorrelations of monthly rainfall depths and number of wet days.	206
Table 10.1: Spatially and temporally averaged APMC values of model parameters.	208
Table 10.2: Average of the absolute values of correlation coefficients between elevation and parameters.	210
Table 10.3: Spatially and temporally averaged values of the mean and SD of rainfall depth and wet period statistics at annual and multiyear resolutions.	212
Table 10.4: Spatially and temporally average of the absolute value of Z scores for mean and SD of rainfall depths.	218
Table 10.5: Spatially and temporally average of the absolute value of Z scores for mean and SD of wet period statistics.	219
Table 10.6: Spatial (all pixels) and temporal (all lags 1-12) average of autocorrelations of monthly rainfall depths and number of wet days.	221
Table 11.1: Average of the elevation-parameters correlations (absolute values).	225
Table 11.2: Spatially and temporally averaged values of the mean and SD of rainfall depth at annual and multiyear resolutions.	226
Table 11.3: Spatially and temporally averaged values of the mean and SD of wet period statistics at annual and multiyear resolutions.	226
Table 11.4: Comparison of MC models for mean and SD of rainfall depths.	227
Table 11.5: Comparison of MC models for mean and SD of wet period statistics.	228
Table 12.1: Methodological differences among CDMC, HMC, DHMC and MMKD.	231
Table 12.2: Mean of annual number of wet days and rainfall depth.	235

Table 14.1: Mean and SD of the annual mean length of wet spells.....	270
Table 15.1: Model comparison by the average of the absolute values of Z scores for rainfall depths for calibration period (1980–2009).....	294
Table 15.2: Model comparison by the average of the absolute values of Z scores for streamflow volume for calibration period (1980–2009).....	295
Table 15.3: Model comparison by the average of the absolute values of Z scores for rainfall depth for validation period (1950–1979).....	296
Table 15.4: Model comparison by the average of the absolute values of Z scores for streamflow volume for validation period (1950–1979).	297

List of Symbols and Notations

The following is a description of the symbols and notation commonly used in this thesis.

Symbol	Description	Unit
$P_{00,i}$	Probability of dry-to-dry day for month i , for January, $i = 1$	—
$P_{11,i}$	Probability of wet-to-wet day for month i	—
μ_i	Mean of wet day rainfall depths for month i	mm
σ_i	Standard deviation of wet day rainfall depths for month i	mm
$r_{c,i}$	Coefficient of correlation between $\log \mu_i$ and $\log \sigma_i$ values for month i	—
$\lambda_{\mu,i}$	Mean of $\log \mu_i$ values for month i	mm
$\zeta_{\mu,i}$	Standard deviation of $\log \mu_i$ values for month i	mm
$\lambda_{\sigma,i}$	Mean of $\log \sigma_i$ values for month i	mm
$\zeta_{\sigma,i}$	Standard deviation of $\log \sigma_i$ values for month i	mm
E	Elevation	m
r_0	Coefficient of correlation between Elevation and Parameters of MC model	—
r_{ts}	Coefficient of correlation between rainfall timeseries in pairs of pixels	—
Z	Z score	—

Abbreviations

The following abbreviations are commonly used in this thesis:

BoM	Bureau of Meteorology
NARcliM	NSW/ACT Regional Climate Modelling
RCM	Regional Climate Model
AWAP	Australian Water Availability Project
ECL	East Coast Low
MC	Markov Chain
APMC	Average Parameter Markov Chain
DPMC	Decadal Parameter Markov Chain
CDMC	Compound Distribution Markov Chain
HMC	Hierarchical Markov Chain
DHMC	Decadal and Hierarchical Markov Chain
MMKD	Modified Markov Kernel Density

Abstract

The key objective of this study is to develop a stochastic daily rainfall model, which can be used in streamflow and reservoir water simulation for urban drought security assessment. After critically reviewing the existing rainfall simulation techniques, this study has developed a Markov Chain (MC) model for stochastic generation of daily rainfall. The MC model uses a two-state MC process with two parameters (wet-to-wet and dry-to-dry transition probabilities) to simulate rainfall occurrence and a Gamma distribution with two parameters (mean and standard deviation of wet day rainfall) to simulate wet day rainfall depths. One of the major focuses of the study is to evaluate the ability of the stochastic model to preserve the rainfall variability and autocorrelation at daily, monthly and multiyear resolutions. Preserving monthly to multiyear variabilities in a daily rainfall model is always challenging, while those longer-term variabilities are critically important for the drought security analysis of reservoirs as the reservoir water levels usually vary in monthly to multiyear resolutions. The traditional models usually underestimate the monthly to multiyear variability, which results in the overestimation of reservoir reliability. On the other hand, the daily variability is also important in many parts of the world to take the influence of short-term extreme rainfall events into account (e.g. East Coast Lows in eastern Australia, which may occur for a few days or weeks, but substantially contribute to the reservoir water level).

Five variants of the MC model with different parameterisation techniques have been tested in this study. The first model, referred to as the Average Parameter Markov Chain (APMC) model, uses deterministic parameters of MC and Gamma distribution, that is, the same parameter set is used to simulate the rainfall in all years. The second model, referred to as the Decadal Parameter Markov Chain (DPMC) model, also uses deterministic parameters of MC and Gamma distribution, but the parameters vary for each decade. The third model, referred to as the Compound Distribution Markov Chain (CDMC) model, uses deterministic parameters of MC (same as APMC) and stochastic parameters of the Gamma distribution by sampling the mean and standard deviation of wet day rainfall depths from fitted distributions for each month. The fourth model, referred to as the Hierarchical Markov Chain (HMC) model, uses stochastic parameters of both MC, by sampling wet-to-wet and dry-to-dry transition probabilities from fitted distributions, and Gamma distribution (same as CDMC). The fifth and final model, referred to as the Decadal and Hierarchical Markov Chain (DHMC) model, uses decade-varied parameters of MC (same as DPMC) and stochastic parameters of Gamma distribution (same as CDMC).

To calibrate the model parameters and compare their performance, this study has used dynamically downscaled rainfall data produced by the NSW/ACT Regional Climate Modelling (NARClIM) project (reanalysis data for three Regional Climate Models (RCMs)), gridded data by the Australian Water Availability Project (AWAP), and ground-based data of raingauge stations. The MC models have been assessed in five catchments of coastal NSW – (i) Goulburn River site (ii) Williams River site (iii) Sydney site (iv) Richmond River site and (v) Bega River site using the NARClIM and AWAP datasets. In addition, raingauge data for 12 raingauge stations around Australia and 30 stations around Sydney have been used to compare the MC models with an existing model. To compare the model performance for streamflow generation, this study has used area-averaged rainfall data of NARClIM and AWAP in a SimHyd hydrology model for three sub-catchments of the Williams River site (i.e. Hunter Water System).

The APMC satisfactorily reproduces the variability of rainfall depths and wet periods at daily resolution only, and significantly underestimates the variability at monthly to multiyear resolutions. The DPMC also significantly underestimates the variability of rainfall depths at monthly to multiyear resolutions, but mostly preserves the variability of wet periods at monthly to multiyear resolutions. The CDMC satisfactorily reproduces the variability of rainfall depth at daily to multiyear resolutions, but significantly underestimates the variability of wet periods at multiyear resolution. The performance of CDMC for wet period variability is consistent with the respective performance of APMC, as both models use the same deterministic parameters of the MC process. The HMC also satisfactorily reproduces the variability of rainfall depths at daily to multiyear resolutions, which is consistent with CDMC as both models use the same stochastic parameters of Gamma distribution. However, the HMC can preserve the variability of wet periods at multiyear resolutions, but significantly overestimates the variability of wet periods at monthly resolution. The DHMC performs better than the other four models, and satisfactorily reproduces the variability of rainfall depths and wet periods at all resolutions, although it significantly underestimates the variability of wet days at shorter multiyear resolutions. For mean of rainfall depths and wet periods, all five MC models perform satisfactorily, although the CDMC, HMC and DHMC show a slight tendency to underestimate the mean of rainfall depths, particularly at multiyear resolutions. For month-to-month autocorrelations of monthly rainfall depths and monthly wet days, all five models perform satisfactorily, except the HMC shows a tendency to underestimate the autocorrelations. The above results suggest the following conclusions:

- The models with deterministic parameters of Gamma distribution (e.g. APMC and DPMC) cannot reproduce the monthly to multiyear variability of rainfall depths. Stochastic parameters of Gamma distribution (e.g. CDMC, HMC and DHMC) are useful for satisfactorily reproducing the short and long-term variability of rainfall depths.
- Deterministic parameters of MC (e.g. APMC and CDMC) underestimate the multiyear variability of wet periods, while stochastic parameters of MC (e.g. HMC) overestimate the monthly variability of wet periods. Decadally varied parameters of MC (e.g. DPMC and DHMC) are better to satisfactorily reproduce the variability of wet periods at monthly to multiyear resolutions.
- The stochastic parameters of Gamma distribution (e.g. CDMC, HMC and DHMC) yield a slight underestimation of mean rainfall depths.
- The MC models are adequate to reproduce the autocorrelations of monthly rainfall depths and monthly wet days. The underestimation of the autocorrelations in HMC might be linked with the overestimation of wet period variability.

This study has compared the performance of CDMC, HMC and DHMC with an existing Modified Markov Kernel Density (MMKD) model by Mehrotra and Sharma [2007]. The MMKD uses a modified MC process with memory of past periods to simulate rainfall occurrence and resamples rainfall depths for wet days from observed records using a kernel-density estimation. The MC models are methodologically simple and straightforward in comparison with the relative complexity of the MMKD. Despite the methodological simplicity, the DHMC shows comparable satisfactory performance as MMKD to reproduce the distribution and autocorrelations of rainfall depths and wet periods at daily to multiyear resolutions. The other two MC models, CDMC and HMC, also show comparable performance to reproduce the distribution of rainfall depths at all resolutions, but fail to preserve the distribution of wet periods at all resolutions. However, MMKD tends to overestimate the mean of rainfall depths at all resolutions, which might be caused by the resampling of wet day rainfall depths using kernel-density estimation.

The performance of CDMC, HMC, DHMC and MMKD have also been compared for streamflow generation. The performance of each model for streamflow generation is consistent with their respective performance for the rainfall depths. The MC models perform similarly and

slightly better than the MMKD to reproduce the distribution and autocorrelation of streamflow volume.