ผลกระทบของระดับน้ำทะเลที่เพิ่มขึ้นและอัตราการไหลที่น้อยลงต่อการลุกล้ำของน้ำเค็มในพื้นที่สามเหลี่ยมปากแม่น้ำโขง

นายเจิ่น คอร์ก ดัท

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาโครงสร้างพื้นฐานทางวิศวกรรมโยธา ภาควิชาวิศวกรรมโยธา
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2553

ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

EFFECTS OF SEA WATER LEVEL RISE AND LOW FLOW ON SALINITY INTRUSION IN MEKONG DELTA

Mr. Tran Quoc Dat

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Engineering Program in Infrastructure in Civil Engineering

Department of Civil Engineering

Faculty of Engineering

Chulalongkorn University

Academic Year 2010

Copyright of Chulalongkorn University

Thesis Title:	EFFECTS OF SEA WATER LEVEL RISE AND LOW FLOW ON SALINITY INTRUSION IN MEKONG DELTA
By	Mr. Tran Quoc Dat
Field of Study	Infrastructure in Civil Engineering
Thesis Advisor	Assistant.Professor. Kanchit Likitdecharote, Ph.D.

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

.... Dean of the Faculty of Engineering

(Associate Professor Boonsom Lerdhirunwong, Dr.Ing.)

THESIS COMMITTEE

.... Chairman

(Associate.Professor. Suched Likitlersuang, Ph.D.)

.... Thesis Advisor

(Assistant.Professor. Kanchit Likitdecharote, Ph.D.)

.... Examiner Member

(Associate .Professor. Thares Srisatit, Ph.D.)

.... External Examiner

(Associate .Professor. Wanpen Wirojanagud, Ph.D.)

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

นายเงิ่น คอร์ก ดัท:ผลกระทบของระดับน้ำทะเลที่เพิ่มขึ้นและอัตราการไหลที่น้อยลงต่อการรุกล้ำของน้ำเค็มในพื้นที่สามเหลี่ยมปากแม่น้ำโขง (EFFECTS OF SEA WATER LEVEL RISE AND LOW FLOW ON SALINITY INTRUSION IN MEKONG DELTA). อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ.ดร. ครรชิต ลิขิตเดชาโรจน์, 185 หน้า.

การรุกล้ำของน้ำเค็มเป็นปัญหาสำคัญของพื้นที่ดินดอนสามเหลี่ยมปากแม่น้ำ ซึ่งในอนาคตการรุกล้ำของน้ำเค็มจะมากยิ่งขึ้น เนื่องจากระดับน้ำทะเลที่เปลี่ยนแปลงไปในทางมากขึ้น และลดลงของปริมาณน้ำท่าทางด้านเหนือน้ำ

การศึกษานี้ได้กำหนดใช้แบบจำลองทางชลศาสตร์ควบคู่ไปกับแบบจำลองการรุกล้ำของน้ำเค็ม บริเวณพื้นที่ดินดอนสามเหลี่ยม ปากแม่น้ำโขง ประเทศเวียดนาม แบบจำลองได้ใช้ข้อมูลระดับน้ำขึ้นลงที่ปากแม่น้ำเป็นขอบเขตทางด้านท้ายน้ำ และอัตราการไหลทางด้านเหนือน้ำเป็นขอบเขตด้านเหนือน้ำและใช้ลักษณะทางกายภาพของปี พเพื่อดำเนินการ 2548 .ศ.และปี พ2541 .ศ. ค่าความเสียดทานลำน้ำและค่าสัมประสิทธิ์การกระจาย ผลลัพธ์จากปรับเทียบและสอบทานแบบจำลองกับข้อมูลจริงในสนามไปในทิศทางเดียวกัน หลังจากที่สอบทานแบบจำลองแล้วได้นำแบบจำลองไปใช้ในการประเมินอิทธิพลของการเปลี่ยนแปลงของระดับน้ำทะเลที่สูงขึ้นกับอัตราไหลที่จะลดลง ตามภาพฉายเหตุการณ์แบบต่างๆ พบว่าความเค็มที่ กรัมต่อลิตร รุกล้ำไปเป็นระยะทาง 2.5 กิโลเมตรจากปาก 15แม่น้ำของแม่น้ำสายหลัก เมื่อเทียบกับปี พ 2541 .ศ.ที่เกิดปัญหาวิกฤตของการรุกล้ำน้ำเค็ม แสดงให้เห็นว่าเกิดการรุกล้ำของน้ำเค็มเป็นบริเวณกว้างในพื้นที่ดินดอนสามเหลี่ยม ปากแม่น้ำโขง ซึ่งปริมาณน้ำที่ลดลงทางด้านเหนือน้ำ เป็นปัจจัยหลักที่มีผลต่อการรุกล้ำน้ำเค็มเข้าไปตามแม่น้ำสายหลักของพื้นที่ดินดอนสามเหลี่ยมปากแม่น้ำโขง นอกจากนี้ได้แสดงความสัมพันธ์ระหว่างระยะทางของความเค็มที่รุกล้ำเข้าไปกับปริมาณน้ำท่าที่เข้ามาจากทางด้านเหนือน้ำ ซึ่งสามารถนำไปใช้ในการทำนายการรุกล้ำของน้ำเค็มที่สภาพปริมาณน้ำแตกต่างกัน

ภาควิชา วิศวกรรมโยธา ลายมือชื่อนิสิต..

สาขาวิชา โครงสร้างพื้นฐานทางวิศวกรรมโยธา ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก..........................

ปีการศึกษา 2553

##5271637021: MAJOR INFRASTRUCTURE IN CIVIL ENGINEERING

KEYWORDS : FRESHWATER DISCHARGE, MEKONG DELTA, SALINITY INTRUSION, SEA LEVEL RISE, UPSTREAM FLOW.

TRAN QUOC DAT: EFFECTS OF SEA WATER LEVEL RISE AND LOW FLOW ON SALINITY INTRUSION IN MEKONG DELTA. THESIS ADVISOR: ASSIST. PROF. KANCHIT LIKITDECHAROTE, Ph.D., 185 pp.

Salinity intrusion is one of the major problems in the Mekong Delta (MD). It would increase in the future due to sea level rise and upstream flow decline. In this study, hydrodynamic and salinity model was implemented and applied to the main river systems in the MD, Viet Nam. The model forcing functions consist of tidal elevations along the downstream boundaries and freshwater discharges from the upstream boundaries of the Mekong River with topographical in 1998 and 2005. The bottom friction coefficient was adjusted to achieve model calibration and verification while advection-dispersion coefficients were ascertained through comparison of simulated salinity time series with observations. The model simulation results are in qualitative agreement with the available field data. The validated model was then used to investigate the influence of freshwater discharge and sea level rise on salinity intrusion under sea level rise and upstream flow reduction scenarios. The model results reveal that 2.5g/l saline likely shifted 15km from downstream to upstream in main rivers in comparison to serious salinity intrusion time in 1998. Also, saline intrusion area was expanded most of saline intrusion projects in MD. River discharge is one of dominating factors affecting the salinity intrusion in the main river system of the Mekong River into MD. A correlation between the distance of salt intrusion and freshwater discharge has been established, allowing prediction of salt intrusion for different inflow conditions.

Department: .....Civil Engineering.......................... Student's Signature ....

Field of Study:...Infrastructure in Civil Engineering.. Advisor's Signature Kanchit Likitdecharote

Academic Year:..2010..

ACKNOWLEDGEMENTS

The author would like to express his special thanks to the promoter and supervisor, Asst. Prof. Dr. Kanchit Likitdecharote, without his support, enthusiasm, countless help and encouragement, this study would have lasted forever. The author greatly appreciates his time devoted during the study.

He expresses gratitude to Assoc. Prof. Dr. Thares Srisatit, Chulalongkorn University, Dr. Nguyen Hieu Trung, Can Tho University and Mr. Le Ngoc Lan, Can Tho University, for sharing the fruit of their experiment with water quality modeling. He expresses appreciation to Mr. Pham Duc Nghia, Southern Institute of Water Resources Research for sharing his experiment with water model and data for the study. He thanks Ms. Le Ngoc Kieu, Can Tho University, for reviewing and providing constructive comments on word choice and thesis editing.

He is grateful for the financial support afforded him by Graduate Scholarship Program of Chulalongkorn University. He would like to express his gratitude to the committee members, Assoc. Prof. Dr. Suched Likitlersuang, Assoc. Prof. Dr. Wanpen Wirojanagud and Assoc. Prof. Dr. Thares Srisatit for being in the committee, reading the draft thesis and giving their constructive comments.

Finally, He would like to acknowledge his family and friends for their love and encouragement. He also sends his special thanks to those that have not been named for their support and understanding.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

CONTENTS

Page

ABSTRACT (THAI)………………………………………………………………… iv
ABSTRACT (ENGLISH)…………………………………………………………..... v
ACKNOWLEDGEMENTS……………………………………………………….....vi
CONTENTS……………………………………………………………………...vii
LIST OF TABLES………………………………………………………….......xi
LIST OF FIGURES………………………………………………………….....xii
LIST OF ABBREVIATIONS……………………………………………….........xvii
CHATER I: INTRODUCTION.. 1
1.1. General.. 1
1.2. Problem Statement.. 3
1.3. Rational 4
1.4. Objectives.. 5
1.5. Scope of Study 6
CHATER II: LITERATURE REVIEW 7
2.1. Salinity Intrusion Problem... 7
2.2. Salinity Intrusion in MD and Previous Study.. 9
2.3. Influences on Salinity Intrusion... 11
2.4. Sea Level Rise... 12
2.5. Discharge Decline... 12
2.6. MIKE 11 MODEL 13
2.6.1 The Overall of MIKE 11 13
2.6.2 Hydrodynamic Module.. 14
2.6.3 Saint Venant Equations 15
2.6.3.1. Solution Scheme... 18
2.6.3.2. Boundary Conditions 22
2.6.3.3. Calibration Hydrodynamic Model 23
2.6.3.4. Bed Resistance 23
2.6.4 Advection-Dispersion Module 26

Page

2.6.4.1. Dispersion-Advection Equation 27
2.6.4.2. Solution Scheme, AD 28
2.6.4.3. Boundary Conditions 29
2.6.4.4. Calibration of AD module 30
2.6.4.5. Dispersion Coefficient 30
2.6.5 Limitation of MIKE 11 Model 31

CHATER III: METHODOLOGY 33

3.1. Software and Program 33
3.2. Methods 33
3.2.1. Investigation of Salinity Intrusion in the Year 1998 (Calibration Model) 36
3.2.2. Investigation of Salinity Intrusion in the Year 2005 (Verification the Model) 44
3.3. Simulation Salinity Intrusion in the Year 2020 and 2030 with Scenarios 44
3.3.1 Scenarios 44
3.3.1.1. Baseline Scenario 44
3.3.1.2. Projected Sea Level Rise and Decrease Upstream Discharge Scenarios 44
3.3.2 Simulation Model 46

CHATER IV: RESULTS 47

4.1. Population and Water Consumption Prediction 47
4.1.1. Population in Mekong River Basin (MKB) 47
4.1.2. Water Resources and Water Consumption in MKB 50
4.1.2.1 Irrigation Sector 50
4.1.2.2 Hydropower Sectors 52
4.1.2.3 Domestic and Industrial Sectors 53
4.1.2.4 Estimate the Mekong River Flow in MD in Dry Season 55
4.2. Salinity Intrusion Simulation 59
4.2.1 Model Setup 62
4.2.2 Investigation of Salinity Intrusion in the Year 1998 (Calibration Model) 63
4.2.2.1. HD Module 64
4.2.2.2. AD Module 69
4.2.3 Investigation of Salinity Intrusion in 2005 72

Page

4.2.4.1 HD Module 72
4.2.4.2 AD Module 76
4.2.4 Simulation Salinity Intrusion in the Year 2020 and 2030 with Scenarios 78
4.2.4.1 Maximum Distance of Salinity Intrusion 78
4.2.4.2 Salinity Intrusion Areas 79
4.2.4.3 . Relationship between Upstream Flow and Limit of Salinity Intrusion 86
CHATER V: CONCLUSION AND RECOMENDATION 88
5.1 Conclusion 88
5.1.1 Modeling Capacity 88
5.1.2 Salinity intrusion in MD 88
5.1.2.1 Investigation of Salinity Intrusion in MD in the Year 1998 88
5.1.2.2 Investigation of Salinity Intrusion in MD in the Year 2005 89
5.1.2.3 Simulation Salinity Intrusion in the Year 2020 and 2030 with Scenarios 90
5.1.2.4 Relationship between Upstream Flow and Salinity Intrusion 90
5.2 Recommendations 90
REFERENCES 93
APPENDICES 99
APPENDIX A 100
APPENDIX B 102
APPENDIX C 104
APPENDIX D 108
APPENDIX E 111
APPENDIX F 122
APPENDIX G 151
APPENDIX H 168
APPENDIX I 172
APPENDIX J 180

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Page

BIOGRAPHY.. 185

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

LIST OF TABLES

Page

Table 2. 1. A rough guide to values of Manning's *n* 26
Table 2. 2. Summary of dispersion coefficient in some rivers 31
Table 3. 1. Inputs of Hydrodynamic module 37
Table 3. 2. Water level station location and observed time on rivers 40
Table 3. 3. Water level station location and observed time of estuaries 41
Table 3. 4. Flow Stations location and observed time 42
Table 3. 5. Salinity concentration 43
Table 3. 6. Summary scenarios for model simulation 46
Table 4.1. Population estimation with two scenarios (million) 49
Table 4. 2. Water availability of two scenarios 51
Table 4.3. Water demand for domestic and industrial 55
Table 4.4. Population prediction for two scenarios 56
Table 4. 5. Water consumption estimation for two scenarios 56
Table 4. 6. Percent of water use of the Mekong River catchment in Vietnam 58
Table 4. 7. Hydrological and salinity observation stations used for model calibration and verification in the study 61
Table A. Distributed rainfall and runoff in each country belong in to MKB 101
Table B. Irrigation area in the period 1985-2000 (x 1000 ha) 103
Table C. Eight dams on Lancang River (China) 107

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

LIST OF FIGURES

Page

Figure 1. 1. The Mekong River in Viet Nam and its nine branches.................................. 1
Figure 1. 2. The Mekong Delta.. 3
Figure 2. 1. Cross-section divided into a series of rectangular channels 16
Figure 2. 2. Channel section with computational grid... 18
Figure 2. 3. Centred 6-point Abbott scheme.. 18
Figure 2. 4. Centering of continuity equation in 6-point Abbott scheme......................... 19
Figure 2. 5. Centering of momentum equation in 6-point Abbott scheme 20
Figure 2. 6. Centering of momentum equation in 6-point Abbott scheme 21
Figure 2. 7. Definition sketch for the control volume. 28
Figure 3. 1. Overall framework of research study 34
Figure 3. 2. Conceptual flow diagram for using MIKE 11 in this study.......................... 35
Figure 3. 3. Flow of method... 36
Figure 3. 4. River network of the Model 38
Figure 3. 5. Location of water level (WL), flow and salinity concentration observation stations 39
Figure 4. 1. MD, the hydrological and salinity observation stations used for model calibration and verification in the study 60
Figure 4. 2. River network and boundaries of the year 2005 63
Figure 4. 3. River network and boundaries of the year 1998 64
Figure 4. 4. Comparison of water level between simulation result and observation result at DN station (R=0.95) 65
Figure 4. 5. Comparison of water level between simulation result and observation result at TV station (R=0.97)... 65
Figure 4. 6. Comparison of water level between simulation result and observation result at MO station (R=0.99)... 66
Figure 4. 7. Comparison of water level between simulation result and observation result at MT station (R=0.97) 66
Figure 4. 8. Comparison of water level between simulation result and observation result at CT station (R=0.95) 67
Figure 4. 9. Comparison of water level between simulation result and observation result at LX station (R=0.95)... 67

Page

Figure 4. 10. Comparison of water level between simulation result and observation result at CL station (R=0.97) 67
Figure 4. 11. Comparison of water level between simulation result and observation result at VN station (R=0.97) 68
Figure 4. 12. Comparison of water level between simulation result and observation result at TC station (R=0.89) 68
Figure 4. 13. Comparison of water level between simulation result and observation result at CD station (R=0.87) 69
Figure 4. 14. Comparison of salinity concentration between simulation result and observation result at DN station (R=0.817) 70
Figure 4. 15. Comparison of salinity concentration between simulation result and observation result at TV station (R=0.89) 70
Figure 4. 16. Comparison of salinity concentration between simulation result and observation result at HB station (R=0.82) 71
Figure 4. 17. Comparison of salinity concentration between simulation result and observation result at MO station (R=0.89) 72
Figure 4. 18. Comparison of salinity concentration between simulation result and observation result at DN station (R=0.98) 73
Figure 4. 19. Comparison of water level between simulation result and observation result at TV station (R=0.98) 73
Figure 4. 20. Comparison of water level between simulation result and observation result at MT station (R=0.97) 74
Figure 4. 21. Comparison of water level between observation and simulation result at CT station (R=0.95) 74
Figure 4. 22. Comparison of water level between observation and simulation result at LX station (R=0.97) 75
Figure 4. 23. Comparison of water level between observation and simulation result at TC station (R=0.94) 75
Figure 4. 24. Comparison of discharge between observation and simulation result at VN station (R=0.96) 75

Page

Figure 4. 25. Comparison of discharge level between observation and simulation result at CD station (R=0.87) 76
Figure 4. 26. Comparison of discharge level between observation and simulation result at MO station (R=0.835) 76
Figure 4. 27. Comparison of discharge level between observation and simulation result at TV station (R=0.87) 77
Figure 4. 28. Comparison of discharge level between observation and simulation result at HB station (R=0.812) 77
Figure 4. 29. Comparison of saline concentration between simulation and observation at TK (R=0.81) 78
Figure 4. 30. Maximum distance of salinity intrusion (2.5g/l) upstream of the Mekong and the Bassac branches 79
Figure 4. 31. Salinity intrusion area in baseline scenario 80
Figure 4. 32. Salinity intrusion area in scenario 1 81
Figure 4. 33. Salinity intrusion area in scenario 2 82
Figure 4. 34. Salinity intrusion area in scenario 3 83
Figure 4. 35. Salinity intrusion area in scenario 4 84
Figure 4. 36. Salinity intrusion area in scenario 5 85
Figure 4. 37. The relationship between the distance of salinity intrusion (2.5g/l) and flow from the upstream of Mekong River 87
Figure C. 1. Location of hydropower dams with very high scenario (MRC, 2009) 105
Figure C. 2. Location of 11 proposed hydropower dams on the Mekong mainstream. Also shown are mainstream dams in existence, under construction and proposed in Upper Mekong (Lancang River) Basin (MRC, 2010) 106
Figure D. 1. Cross Sections Location 109
Figure D. 2. Example of Data in a Cross Section 110
Figure E. 2. Boundary Condition (Discharge) at PrekDam Station in 1998 113
Figure E. 3. Boundary Condition (Discharge) at East Vam Co Station in 1998 114
Figure E. 6. Boundary Condition (Discharge) at Kratie Station in 2005 117
Figure E. 7. Boundary Condition (Discharge) at Prekdam Station in 2005 118
Figure E. 8. Boundary Condition (Discharge) at East Vam Co Station in 2005 119

Page

Figure E. 9. Boundary Condition (Discharge) at Dau Tieng Station in 2005 120
Figure E. 10. Boundary Condition (Discharge) at Tri An Station in 2005 121
Figure F. 1. Boundary Condition (Water Level) at Vung Tau Station in 1998 123
Figure F. 2. Boundary Condition (Water Level) at Binh Dai Station in 1998 124
Figure F. 3. Boundary Condition (Water Level) at An Thuan Station in 1998 125
Figure F. 4. Boundary Condition (Water Level) at Vam Kenh Station in 1998 126
Figure F. 5. Boundary Condition (Water Level) at Rach Gia Station in 1998 127
Figure F. 6. Boundary Condition (Water Level) at Ganh Hao Station in 1998 128
Figure F. 7. Boundary Condition (Water Level) at Song Doc Station in 1998.............. 129
Figure F. 8. Boundary Condition (Water Level) at My Thanh Station in 1998............. 130
Figure F. 9. Boundary Condition (Water Level) at Ben Trai Station in 1998 131
Figure F. 10. Boundary Condition (Water Level) at Vung Tau Staiton in 2005 132
Figure F. 11. Boundary Condition (Water Level) at Binh Dai Station in 2005............. 133
Figure F. 12. Boundary Condition (Water Level) at An Thuan Station in 2005 134
Figure F. 13. Boundary Condition (Water Level) at Vam Kenh Station in 2005.......... 135
Figure F. 14. Boundary Condition (Water Level) at Rach Gia in 2005......................... 136
Figure F. 15. Boundary Condition (Water Level) at Ganh Hao Station 137
Figure F. 16. Boundary Condition (Water Level) at Song Doc Station......................... 138
Figure F. 17. Boundary Condition (Water Level) at My Thanh Station in 2005........... 139
Figure F. 18. Boundary Condition (Water Level) at Ben Trai in 2005.......................... 140
Figure F. 19. Boundary Condition (Water Level) at Xeo Ro in 2005 141
Figure F. 20. Boundary Condition (Salt Concentration) at Binh Dai Station in 2005... 142
Figure F. 21. Boundary Condition (Salt Concentration) at An Thuan Station in 2005 . 143
Figure F. 22. Boundary Condition (Salt Concentration) at Vam Kenh Station in2005......144
Figure F. 23. Boundary Condition (Salt Concentration) at Rach Gia Station in 2005 .. 145
Figure F. 24. Boundary Condition (Salt Concentration) at Ganh Hao Station in 2005. 146
Figure F. 25. Boundary Condition (Salt Concentration) at Song Doc Station in 2005 . 147
Figure F. 26. Boundary Condition (Salt Concentration) at My Thanh Station in 2005 148
Figure F. 27. Boundary Condition (Salt Concentration) at Ben Trai Station in 2005 ... 149
Figure F. 28. Boundary Condition (Salt Concentration) at Xeo Ro Station in 2005..... 150

Page

Figure I. 1. Comparison of Salinity Concentration between Simulation and Observation Result at Go Quao Station in 1998 173
Figure I. 2. Comparison of Salinity Concentration between Simulation and Observation Result at Cai Lon Station in 1998 174
Figure I. 3. Comparison of Salinity Concentration between Simulation and Observation Result at Quan Lo-Phung Hiep Station in 1998 175
Figure I. 4. Comparison of Salinity Concentration between Simulation and Observation Result at Soc Trang Station in 1998 176
Figure I. 5. Comparison of Salinity Concentration between Simulation and Observation Result at Vi Thanh Station in 1998 177
Figure I. 6. Comparison of Salinity Concentration between Simulation and Observation Result at Tra Kha Station in 2005 178
Figure I. 7. Comparison of Salinity Concentration between Simulation and Observation Result at Soc Trang Station in 2005 179
Figure J. 1. Salinity Distribution along the Dinh An Branch 181
Figure J. 2. Salinity Distribution along the Ham Luong Branch 182
Figure J. 3. Salinity Distribution along the Co Chien Branch 183
Figure J. 4. Salinity Distribution along the Tieu Branch 184

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

LIST OF ABBREVIATIOS

1-D	One - Dimensional
2-D	Two - Dimensional
3-D	Three - Dimensional
AD	Dispersion-Advection
CD	Chau Doc Gauging Station
CT	Can Tho Gauging Station
CTU	Can Tho University, Viet Nam
DN	Dai Ngai Saline Station
DOE-PCM3	Department of Energy- Parallel Climate Model
HB	Hoa Binh Saline Station
HCCPR-CM	Hadley Centre for Climate Prediction and Research-Climate Change (UK)
HD	Hydrodynamic
IPCC	Intergovernmental Panel on Climate Change
MCM	Million Cubic Meter
MKB	Mekong River Basin
MD	Mekong Delta
MPI	Max Planck Institute
MRC	Mekong River Commission
MT	My Thuan Gauging Station
NCHMF	National Centre for Hydro-Meteorological Forecasting, Viet Nam
PMU10	Project Management Unit 10, Viet Nam
SIWRR	Southern Institute of Water Resource and Research, Viet Nam
SLURP	Simple Lumped Reservoir Parametric Model
SRES	Special Report on Emission Scenarios
SUB-NIAPP	Sub-National Institute for Agriculture Planning and Projection, Viet Nam
SWAP	Soil, Water, Atmosphere and Plant
TC	Tan Chau Gauging Station

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

TV	Tra Vinh Saline Station
VNG	Viet Nam Government
VNMC	Viet Nam Mekong Commission, Viet Nam
WL	Water Level
WQ	Water Quality

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

CHAPTER I

INTRODUCTION

1.1. General

Mekong Delta (MD), with the area of 39,000 square kilometres, is home to 18 million people, spreading in 13 provinces and cities of Viet Nam. Population is estimated at nearly 17.826 million people (in 2009). MD is the main agriculture and aquaculture area in Vietnam. 50% of the stable food and 60% of the fish-shrimp of Vietnam are produced from the delta. Traditionally, lives in the delta base on intensive river water use, including transportation, commerce, irrigation, aquaculture, fishing, domestic and industrial use. Almost all the delta people's activities and infrastructure are highly dependent on the river water regime.

The Mekong River meets Tonle Sap River to the west of Phnom Penh, and splits into the Mekong (Tien) and the Bassac (Hau) Rivers. The Mekong River then flows across the border of Vietnam, especially from the Tonle Sap River in Cambodia to the South China Sea. The Mekong River is about 230km long and branches into six tributaries: Cua Tieu, Cua Dai, Ba Lai, Ham Luong, Co Chien, Cung Hau. The Bassac River is divided into three tributaries: Dinh An, Bassac and Tran De as Figure 1.1

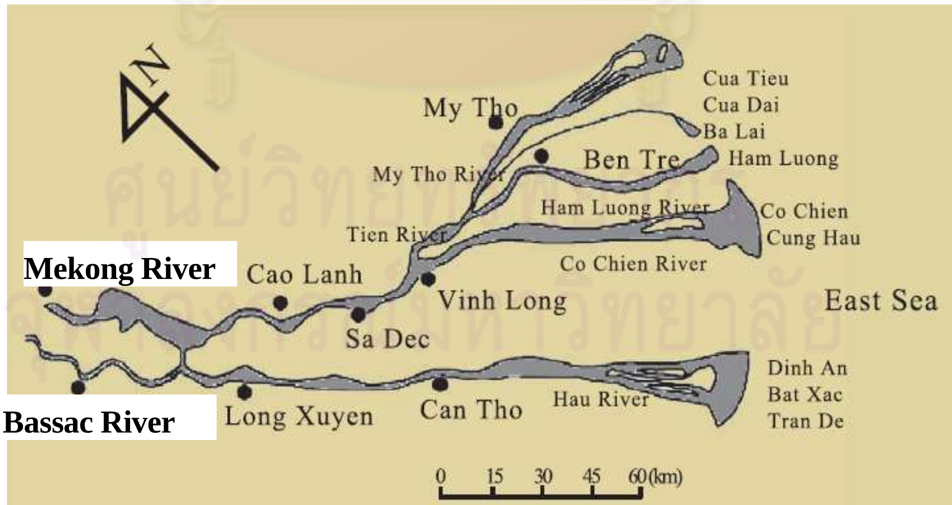


Figure 1. 1. The Mekong River in Viet Nam and its nine branches
(Source: Modified from http://cantho.cool.ne.jp)

The Vam Co River includes two main branches East Vam Co and West Vam Co. The West Vam Co River, about 148km long rises on the Soai Rieng (Campodia).

It flows through Viet Nam at Binh Tu, Vinh Hung, Moc Hoa, Tan An and then it is confluent East Vam Co at Tan Tru.

East Vam Co, about 260km long flows from Kongpongcham (Cambodia) to meet West Vam Co at Ben Luc and then flow directly to South China Sea in Xoai Rap estuary. Cai Lon River and Cai Be River connect Bassac River with Gulf of Thailand.

The river network of the Mekong is a dense canal and hydrology is very complicated (Hoanh et al, 2009). It highly depends on flow from upstream, tidal of South China Sea, Gulf of Thailand and rainfall in MD (Sam, 1996).

The MD is affected rapidly by tropical monsoon climate. There are two seasons, rainy and dry. Annual rainfall of 1500 to 2000mm, distributed unevenly though. Approximately 70% of the rainfall occurs during the main rainy season. Geology is divided by a river network of 5000km totally. MD is effected strongly by tidal of South China Sea and the gulf of Thailand from three sides. As a result, hydrology of MD is very complicated and is one of factors effecting salinity intrusion, flooding, pollution and so on (Sam, 1996).

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

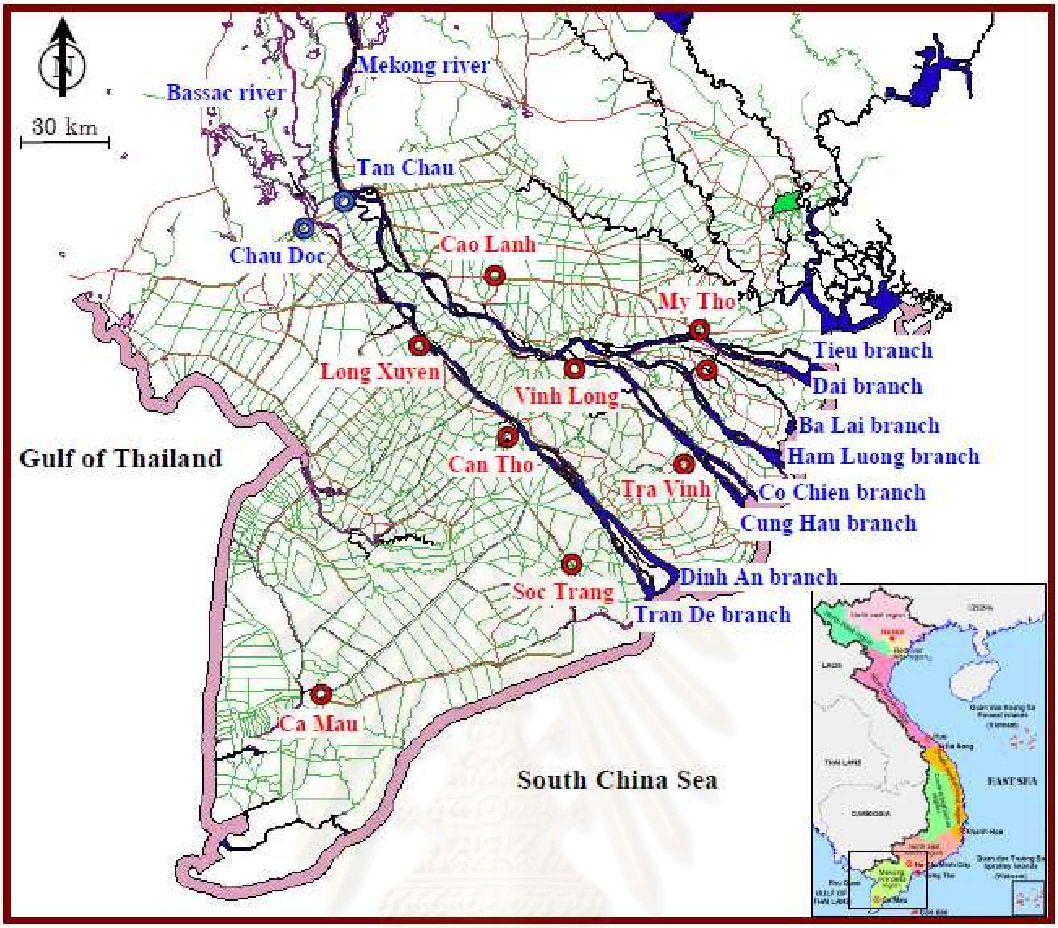


Figure 1. 2. The Mekong Delta
(Source: Modified from Duc et al., 2008)

1.2. Problem Statement

Most of the MD people's activities and infrastructure are highly dependent on the river water regime. Water resources are abundant, average discharge is 39,000m^3/sec in wet season. Besides, in dry season (from December to May) the average discharge is under 2,500 m^3/s and even as low as 1,500m^3/s (Kite, 2001), with the groundwater table lowering by 2 - 3 m in some places (Tuan et al., 2007). However, tides in the South China Sea are semidiurnal but irregular and has large tidal amplitude from 3m to 3.5m. Meanwhile, tides in the Bay of Thailand occur in a diurnal and have amplitude from 0.8 m to 1.2m (MRC, 2005; Tuan et al., 2007). Tide level in the South China Sea reaches a peak in December and gets a break level in July. The tidal effects from these sides propagate over much of the Delta through the main and farm canal systems. Salinity intrusion problems are not present that due to the effects of such flow, tide conditions and small slope of river bed, the reverse flow of saltwater is one of the biggest problems confronting the MD region of Vietnam (Tuan et al., 2007; Nhan et al., 2007).

In recent years, countries in the river basin are tending to grab development opportunities sooner than previous years, leading to the frequent occurrence of cross-border disputes. The primary focus of future development and water-related economic activities is placed on irrigated agriculture, hydroelectricity generation, fisheries, marshlands, flood mitigation, navigation, tourism, city and industrial water supply. As a result, flow from upstream of the Mekong River could be reduced (Hoanh et al., 2003) and water shortages will rise in the MD region especially during April and May (Sunada, 2009).

In addition, Sea level will increase in the future because of climate change (IPCC, 2007). Sea water level rise has already been observed along many shorelines in Southeast Asia, including Vietnam (Bouman et al., 2001; Nguyen, 2009).

1.3. Rational

Salinity intrusion is one of the major looming problems that the MD is facing. It will increase in the future due to increasing sea level and decreasing flow from upstream. Recently, studies have been carried out to assess the potential impacts of climate change to the MD, identified the MD as one of the most vulnerable areas (Nijssen et al., 2001; Hoanh et al., 2003; IPCC, 2007; World Bank, 2007). Among the ascertained consequences of global climate change, the changing of the Mekong River flow in upstream and sea level rise were identified as two main factors affecting salinity intrusion (Sam, 2006; Tuan et al., 2007; Sunada, 2009). Khang at al., (2008) investigated on the effects of increasing sea level and reducing of upstream flow on salinity intrusion and rice cropping in MD. Those authors used mathematical model and GIS to determine effects of salinity intrusion on rice crops in MD in dry season. However, the mathematical model was constructed by using topographic and hydrological database available in SIWRR, which was collected from previous years up to 1998. From 1999 to 2007, the cooperation between VNG and World Bank

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

establishes "MD Water Resources Project". The project adopts the approach of integrated water resources planning and management, including improvement and rehabilitation of irrigation, drainage, saline water intrusion control, and flood protection structures; provision of drinking water and improved sanitation; support for community participation in water delivery; improvement of local transport; and institutional strengthening for water management. As a result, the water regime of MD changed and salinity intrusion pattern was changed (Sam, 2006). Moreover, the river flow rate reducing scenarios were assumed to decrease -29% by 2099 (Khang et al., 2008) while it was estimated to reduce from -90% to -100% by 2099 (Hoanh et al., 2003).

In this study, Salinity intrusion in The MD was simulated by using mathematical model (i.e., Mike 11) under sea level rise and upstream flow reducing scenarios by water consumption and dam regulation in the upstream. The model was constructed by using new topographical (from 1999 to 2005) of MD.

1.4. Objectives

Salinity intrusion in Lower Mekong River is getting worse because of sea level rise and reducing fresh water from upstream. Saline water intrusion affection is different among localities due to topography, location, and water level in the coastal area. Therefore, salinity intrusion study during dry season in the MD is necessary to find out the cause and propose the possible solutions, especially in case of climate change causing higher sea level, local water consumption and fresh water restricted from upstream. The research aims at simulation of salinity intrusion into two rivers (i.e., the Mekong River, the Bassac River) of the Mekong River in MD Viet Nam as Figure 1.2. In which, there are five branches on the Mekong river (i.e., Tieu, Dai, Ham Luong, Co Chien, Cung Hau) and two branches belong to the Bassac river (i.e., Dinh An, Tran De).

In order to achieve this, the following sub-objectives should be carried out:

- To investigate salinity intrusion in four main estuaries of the Mekong River, Viet Nam in 1998 and 2005 by using mathematical model
- To project salinity intrusion in the four estuaries of the Mekong River, Viet Nam in years 2020 and 2030 by using mathematical model

1.5. Scope of Study

The scope of study focuses on the following:

- Study rivers are two rivers (i.e. the Mekong river, the Bassac river) with seven estuaries of the Mekong River at the MD, Viet Nam as Figure 1.2
- Inputs of Mike 11 model were acquired from relative sectors such as MRC, SIWRR…
- Calibration Mike 11 Model: Hydrodynamic Module, Advection-Dispersion Module took place during low flow period of 1998 (from February to May).
- Verification Mike 11 model took place during low flow period of 2005 (from February to May).
- Simulation of Mike 11 model took place during low flow period (from February to May) in years 2020 and 2030 in the four estuaries.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

CHAPTER II

LITERATURE REVIEW

2.1. Salinity Intrusion Problem

Arons and Stommel (1951) used a time averaged over a tidal cycle approach for an estuary of rectangular cross section and assumed that the longitudinal dispersion coefficient was proportional to the product of the tidal excursion length and the maximum tidal velocity at the entrance.

Prichhard (1959) studied the longitudinal distribution of salinity in the Delaware Estuary as a function of time by using this time-averaged-over-a-tidal-cycle version of the 1- D convective-diffusion equation. This study was made primary to compare the effect of different modification of river inflow, and for this purpose has achieved its aim. However, the method does not present a complete solution to predict longitudinal salinity.

Ippen and Harleman (1961) made an analytical study of salinity intrusion for the case of an estuary of rectangular cross section which took into account the tidal hydraulics in as much as the low water slack salinity distribution served for predicting the distribution at any other time during tidal cycle. By analyzing twenty different salinity flume tests conducted at the Waterways Experiment Station (WES), they found that the dispersion coefficient at low slack could be expressed as follows:

$$E_x^{lws} = \frac{BE_0^{lws}}{(x+B)} \qquad (2.\ 1)$$

Where, B is a distance parameter defining the distance seaward from the boundary x=0 to the point where $s=s_0$ at low water slack. E_0^{lws} is the dispersion coefficient at river mouth x=0 at low water slack. It was found that the parameter B and E_0^{lws} should be correlated with a stratification number, G/J ratio which equal rate of energy dissipation per unit mass of fluid divided by rate of potential energy gain per unit mass of fluid.

Harleman and Abrahan (1966) re-analyzed the WES data using the low water slack condition and the dispersion relationship of equation (2.1) and found that a dimensionless parameter consisting tidal prism, Froude number, freshwater discharge and tidal period was uniquely related to the stratification number G/J.

Stigter and Siemons (1967) used the salt balance equation and the tidal dynamics equations in couple form to study the salinity intrusion in a constant width representation of the Rotter Dam Waterway. They showed that including the effect of density differences in the tidal calculations, a definite effect on tidal elevation and the dispersion coefficient relationship for their study was taken as a function of x, the form being:

$$E = E_0\left(1 - \frac{x}{L}\right)^3 \qquad (2.2)$$

Where E_0 value were determined by fitting the available data

Harleman et al., (1968) have used their numerical tidal model to provide the unsteady discharge and areas required for solution of the unsteady one dimensional mass balance equation for non-conservative pollutant. They showed that in the freshwater region of the estuary the dispersion coefficient can express by relationship in terms of cross sectional velocity u, Manning's n and the hydraulic radius. This relationship was obtained from Taylor (1954). The form is:

$$E_T = 10.1 a\, u^* \qquad (2.3)$$

Where a is the pipe radius and u* is the friction velocity. Halerman (1966) has shown that the relationship of Equation 2.3 can be written in terms of hydraulic radius, R_h, average velocity, u, and Manning's n as

$$E_T = 77\, n\, u\, R_h^{\frac{5}{6}} \qquad (2.4)$$

Boicourt (1969) has applied the same technique as Prichart to study salinity intrusion of Upper Chesapeake Bay by using an entire year's salinity record that he interpolated to even intervals.

Thatcher and Halerman (1972) study presented a predictive numerical model of unsteady salinity intrusion in estuaries (i.e. Delaware, Potomac and Hodson) by formulating the problem in finite-difference terms using one-dimensional, tidal time, variable area equations for conservation of water mass, conservation of momentum and conservation of salt. The longitudinal dispersion coefficient has been shown to be proportional to the magnitude of the local, time-varying longitudinal salinity gradient as below

$$E(x,t)= E_T+K\left|\frac{\partial \overset{0}{s}}{\partial \overset{0}{x}}\right| \qquad (2.5)$$

Where s is salinity concentration, $\overset{0}{s}=\frac{s}{s_0}$ and $\overset{0}{x}=\frac{x}{L}$, L is length of the estuary. K is dispersion parameter.

Vu et al., (1991) used a numerical model to study salinity intrusion in the Red River Delta, Viet Nam. The study found out that in dry season, salinity intrusion length may be up to 20 km in main rivers and more than 20 km for fields. Besides, Chezy coefficient (C) and Advection- Dispersion coefficient (D_x) were determined in the range 65-75$m^{1/2}$/s and 800-1000m^2/s, respectively.

Duy (1992) applied a numerical model to determine dispersion coefficient for prediction of salinity intrusion in the Mekong estuaries. He found that the dispersion coefficient varies in the same manner as those of salinity intrusion.

Dac (1996) applied SAL model to study salinity intrusion of the Sai Gon River System, a river system in Vietnam. He showed that dispersion coefficient is a constant number in a branch or segment of river.

Sam (2006) used numerical model (Hydro-Gis model) to find out dispersion coefficient for main rivers of MD. He showed that the dispersion coefficient for salinity intrusion prediction of those rivers in the range from 700 to 50.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

2.2. Salinity Intrusion in MD and Previous Study

Chanh (1991) applied Mesal Model to predict salinity intrusion in MD in case sea level rises. The results indicated that the salinity intrusion in MD would not be intensively affected under the effect of the “Greenhouse” considered in terms of sea level rise.

Hung et al., (2001) studied the effect of water management projects on salinity intrusion in the MD, and simulated the intrusion of saline water in the main branches (Bassac and Mekong) in an extreme unfavourable case by using SAL99 model. There were four scenarios in the study: Scenario a studied the saline intrusion with the situation before constructing the Quan Lo-Phung Hiep project (with specific year 1990); Scenario b analyzed the effect of Quan Lo-Phung Hiep project and the new canals in the Plain of Red (with specific year 1996); Scenario c looked into the effect of Flood Control Project in Long Xuyen Quadrant with the several sluices along the West Sea (with specific year 2000); Scenario d surveyed the intrusion of saline water in the main branches (Bassac and Mekong) in the maximum water abstraction and minimum discharge of water from the upstream. The study showed how the fresh water areas increased after the Quang Lo-Phung Hiep project and the embankment were completed. Besides, salinity intrusion in the Mekong River and the Bassac River in extreme use of water was found.

Halcrow (2004) manipulated a mathematical model to evaluate salinity intrusion in MD during dry season (with specific year 1998). The scope of maximum saltwater backflow according to each salt concentration stage between January and June illustrated that at least seven million hectares of land in the MD impacted by various salt concentrations (2,163,000 ha > 1g/L, 1,928,700 ha > 4g/L, 1,727,900 ha > 8g/L, 1,419,500 ha > 15g/L).

Sam (2006) predicted salinity intrusion in MD by using Hydro-Gis model. Inputs of the model includes six types of hydraulic, meteorological and hydrological data, i.e. geometry, hydrology, sea level, amplitude of water level, operation of control structures and flow from the upstream of the Mekong River. The study indicated that the model can be use for simulation salinity intrusion in MD but the author need more time to improve the method for predicting salinity intrusion in MD with higher accuracy.

Khang et al., (2008) integrated MIKE 11 and GIS to simulate flow, salinity intrusion and assessed rice cropping from December to June for the medium-term (2030) and long-term (2090) scenarios by using SRES B2 climate change projection. In this study, the sea level rises in two scenarios were +20cm and +45cm while the Mekong River flow rates were assumed to reduce -15% and -29%, respectively. Most input data of MIKE 11 model was collected from previous years up to 1998. The study indicated that approximately 0.6 million ha of potential rice cropping area in the eastern central region of the MD will significantly affected by rising sea level and reducing the Mekong flow in dry season.

Hoanh et al., (2009) used the VRSAP (Vietnam River System and Plains) model to evaluate these conflicts and synergies in the development of agriculture, fishery and aquaculture in Ca Mau peninsula, MD, Vietnam. They showed that empirical methods could not be applied for a dense network as Ca Mau peninsular while mathematical model was an appropriate one. The VRSAP results helped planers to make better decision by bringing highest net return on investment. Such analysis is not possible without the model because no statistical methods can provide the effects of sluice operation on water level and salinity each year in the whole region.

2.3. Influences on Salinity Intrusion

Cohen and McCarthy (1962) have made observations of the salinity distribution in the Dalaware estuary. They showed that the peak chloride was the result of an abnormally high tide as reflected in the mean river level peak for the same time and salinity intrusion increased by reducing freshwater discharge.

The geometry of each estuary has its effect on the circulation and salinity intrusion; however, given a particular geometry, the two primary factors influencing the salinity intrusion are the freshwater inflows and the range and mean tidal elevation at the ocean entrance (Thatcher and Harleman, 1972).

Sam (2006) used numerical model and historical data for saltwater intrusion study. He indicated that salinity intrusion in MD influenced discharge from the upstream and range and mean tidal elevation at the sea.

Sunada (2009) have analyzed salinity intrusion in MD by using historical data. They showed that salinity intrusion in MD affected discharge from the upstream and tidal from the downstream.

2.4. Sea Level Rise

A worldwide rise of sea level is among predicted consequences of the "Greenhouse effect", the global warming expected as a result of the accumulation in the earth's atmosphere of carbon dioxide and other gases generated by industrial and agricultural activities. It has been suggested that increasing concentrations of these gases will lead to rise of average temperature with ranges for 2090 to 2099 relative to 1980 to 1999 was 1.8^0C to 4^0C. Such an increase will cause expansion of the volume of near surface ocean water, and partial melting of now smelting of snowfield, ice sheets and glaciers, releasing water to augment the oceans, thereby producing worldwide sea level rise. All of those factors have released water to augment the oceans, thereby producing worldwide sea level rise. The Intergovernmental Panel on Climate Change has recently concluded that the climate has changed during the 20th century and larger changes are projected for the 21st century. In this report, sea level was projected with the range from 0.28 to 0.43m increasing between period 1980 to 1999 and period 2090 to 2099 depending on SRES market scenarios (IPCC, 2007).

Nguyen (2009) analyzed historical data of gauging stations in Vietnam. The study showed that SRES B2 was the most appropriate scenario for Vietnam and sea level at South China Sea was projected to rise about 17cm in 2030 with respect to period 1988 -1999.

2.5. Discharge Decline

The Mekong River is an international river. It goes through six countries (China, Myanmar, Thailand, Lao, Cambodia and Vietnam). Looking at the policy goals of the countries in the Mekong River Basin, the primary focus of future development and water related economic activities is based on irrigated agriculture, hydroelectricity generation, fisheries, marshlands, flood mitigation, navigation, tourism and city and industrial water supply. Abnormal flow fluctuations caused by upstream and downstream activities (Sunada, 2009). In recent years, countries in the river basin regard hydropower. Currently, dams are either under construction or are being planned in the main stream and tributaries of the Mekong River. These dams can affect discharge in dry season (Sundana, 2009). Lu et al., (2005) analyzed the historical data (from 1962 to 2000) which was published by the Secretariat of Mekong River Commission (MRC). They indicated a disruption in water discharge, water fluctuations and sediment transport downstream of the Manwan Dam, after its reservoir was filled in 1992. Dry season flows showed a declining trend, and water level fluctuations in the dry season increased considerably in the post-dam (1993–2000) period. Monthly suspended sediment concentration (SSC) has also decreased significantly in several gauging stations in the post-dam period (Lu et al., 2005, 2008). Moreover, climate change would influence hydrology regime of the Mekong River. Nijssen et al., (2001) exploited general circulation models (GCMs) to assess the hydrologic sensitivity to climate change of nine large continental river basins (Amazon, Amur, Mackenzie, Mekong, Mississippi, Severnaya Dvina, Xi, Yellow, Yenisei). The four climate models (HCCPR-CM2, HCCPR-CM3, MPI-ECHAM4, and DOE-PCM3) all predicted transient climate response to changing greenhouse gas concentrations, and incorporated modern land surface parameterizations. Model-predicted monthly average precipitation and temperature changes were downscaled to the river basin level using model increments (transient minus control) to adjust for GCM bias. The variable infiltration capacity (VIC) macro-scale hydrological model (MHM) was used to calculate the corresponding changes in hydrologic fluxes (especially stream flow and evapotranspiration) and moisture storages. Hydrologic model simulations were performed for decades centred in 2025 and 2045. A sensitivity study was performed in which temperature and precipitation increased independently by 2^0C and 10%, respectively, during each of four seasons. The result indicated that spring runoff would be decreased for decades centred in 2025 and 2045. Besides, SWAP and SLURP model were used to asset discharge of the Mekong River with climate change A2 and B2 scenarios and water consumption in the upstream. The output of SLURP model showed that flow of the Mekong River decreased 15% to 17% in 2010-2039 and 90%-100% in 2070-2099 in comparison to 1961-1990 (Hoanh et al., 2003).

2.6. MIKE 11 Model

2.6.1 The Overall of MIKE 11

MIKE 11 is a computer program that simulates flow and water level, water quality and sediment transport in rivers, flood plains, irrigation canals, reservoirs and other inland water bodies. MIKE 11 is a one dimensional river model (DHI, 2007). It was developed by DHI Water and Environment. MIKE11 has long been known as a software tool with advanced interface facilities. Since the beginning MIKE11 was operated through an efficient interactive menu system with systematic layouts and sequencing of menus. It is within the framework where the latest 'Classic' version of MIKE 11 - version 3.20 was developed. The new generation of MIKE11 combines the features and experiences from MIKE 11 'Classic' period, with the powerful Windows based user interface including graphical editing facilities and improved computational speed gained by the full utilization of 32-bit technology. MIKE 11 is user friendly now. It becomes an effective tool for many purposes such as designing, management and operation of river basins and channel networks.

Basic equations of Hydrodynamic module and Advection-Dispersion module are Saint Venant (i.e., mass conservation equation, momentum equation) and Advection-Dispersion. Except for few particular cases (DHI, 2007), remote from the real world, a general analytical solution of the Saint Venant equation cannot be found. The particular solutions must be considered by adopting finite difference method with boundary conditions and initial conditions.

MIKE 11 has three main modules. Those are Hydrodynamic module (HD), Advection-Dispersion module (AD), Water Quality module (WQ).

2.6.2 Hydrodynamic Module

The MIKE 11 HD uses an implicit finite difference scheme for the computation of unsteady flows in rivers and estuaries. The module can describe sub-critical as well as supercritical flow conditions through a numerical scheme which adapts according to the local flow conditions (in time and space). Advanced computational modules are included for description of flow over hydraulic structures, including possibilities to describe structure operation.

The formulations can be applied to looped networks and quasi two-dimensional flow simulation on flood plains. The computational scheme is applicable for vertically homogeneous flow conditions extending from steep river flows to tidal influenced estuaries. The system has been used in numerous engineering studies around the world.

2.6.3 Saint Venant Equations

MIKE 11 HD applied with the dynamic wave description solves the vertically integrated equations of conservation of continuity and momentum (the Saint Venant equations), based on the following assumptions:

- The water is incompressible and homogeneous, i.e. negligible variation in density.
- The bottom-slope is small, thus the cosine of the angle with the horizontal one may be taken as 1.
- The wave lengths are large compared to the water depth. This ensures that the flow everywhere can be regarded as having a direction parallel to the bottom, i.e. vertical accelerations can be neglected and a hydrostatic pressure variation along the vertical can be assumed
- The flow is sub-critical (Supercritical flow is modelled in MIKE 11, using more restrictive conditions). For a rectangular cross-section with a horizontal bottom and a constant width, the conservation of mass and momentum can be expressed as follows (in the first instance neglecting friction and lateral inflows)

Conservation of mass:

$$\frac{\partial(\rho Hb)}{\partial t} = -\frac{\partial(\rho Hb\bar{u})}{\partial x} \qquad (2.6)$$

Conservation of momentum:

$$\frac{\partial(\rho Hb\bar{u})}{\partial t} = -\frac{\partial\left(\alpha^{/}\rho Hb\bar{u}^{2} + \frac{1}{2}\rho gbH^{2}\right)}{\partial x} \qquad (2.7)$$

where ρ is the density, H is the depth, b is the width, $\bar{u}$ is the average velocity along the vertical and $\alpha^{/}$ is the vertical velocity distribution coefficient. Introducing the bottom slope, I_b, and allowing for the channel width to vary will lead to two more terms in the momentum equation. These terms describe the projections in the flow direction of the reactions of the bottom and side-walls to the hydrostatic pressure.

The momentum equation now becomes:

$$\frac{\partial(\rho Hb\bar{u})}{\partial t} = -\frac{\partial\left(\alpha^{/}\rho Hb\bar{u}^{2} + \frac{1}{2}\rho gbH^{2}\right)}{\partial x} + \frac{\partial b}{\partial x}\frac{\rho gH^{2}}{2} - \rho gHbI_{b}$$

$$= \frac{\partial(\alpha^{/}\rho Hb\bar{u}^{2})}{\partial x} - b\frac{\partial\left(\frac{1}{2}\rho gH^{2}\right)}{\partial x} - \rho gHbI_{b} \qquad (2.\ 8)$$

When the water level, *h*, is introduced into the relationship instead of water depth:

$$\frac{\partial h}{\partial x} = I_{b} + \frac{\partial H}{\partial x} \qquad (2.\ 9)$$

and the equations are divided by ρ, the conservation laws of mass and momentum become:

$$\frac{\partial(Hb)}{\partial t} = -\frac{\partial(Hb\bar{u})}{\partial x}$$

$$\frac{\partial(Hb\bar{u})}{\partial t} = -\frac{\partial(\alpha^{/}Hb\overline{u^{2}})}{\partial x} - Hbg\frac{\partial h}{\partial x} \qquad (2.\ 10)$$

These equations can be integrated to describe the flow through cross-sections of any shape when divided into a series of rectangular cross sections as shown in Figure 2.1:

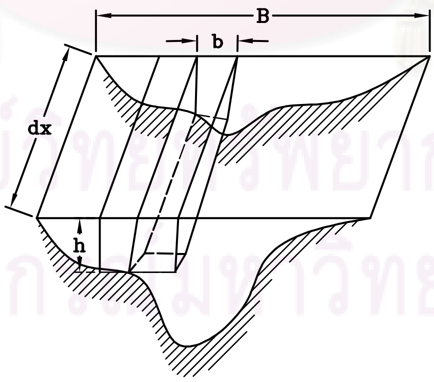


Figure 2. 1. Cross-section divided into a series of rectangular channels

According to the previous assumptions, $\frac{\partial h}{\partial x}$ is constant across the channel and no exchange of momentum occurs between the sub-channels. If the integrated cross

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

sectional area is called A and the integrated discharge Q, and B is the full width of the channel, then:

$$A = \int_0^B H db \tag{2. 11}$$

$$Q = \int_0^B H\bar{u} db = \bar{u}A \tag{2. 12}$$

Integrating the mass and momentum conservation equations and introducing Equations (2.11) and (2.12) yields:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \tag{2. 13}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial h}{\partial x} = 0 \tag{2. 14}$$

Including the hydraulic resistance, e.g. using the Chezy description and the lateral inflow; *q* into these equations leads to the basic equations used in MIKE 11:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \tag{2. 15}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2 AR} = 0 \tag{2. 16}$$

where,

Q = discharge (m^3/s)

A = flow area (m^2)

q = lateral inflow (m^2/s)

h = stage above datum (m)

C = Chezy resistance coefficient ($m^{1/2}/s$)

R = hydraulic or resistance radius (m)

α = momentum distribution coefficient

2.6.3.1. Solution Scheme

The solution to the combined system of equations at each time step is performed according to the procedure outlined below. The solution method is the same for each model level (kinematics, diffusive and dynamic). The transformation of Equations (2.15) and (2.16), to a set of implicit finite difference equations is performed in a computational grid consisting of alternating Q and h points, i.e. points where the discharge, Q and water level h, respectively, are computed at each time step, see Figure 2.2. The computational grid is generated automatically by the model on the basis of the user requirements. Q-points are always placed midway between neighboring h points, while the distance between h-points may differ. The discharge, as a rule, will be defined as positive in the positive x-direction (increasing chainage).

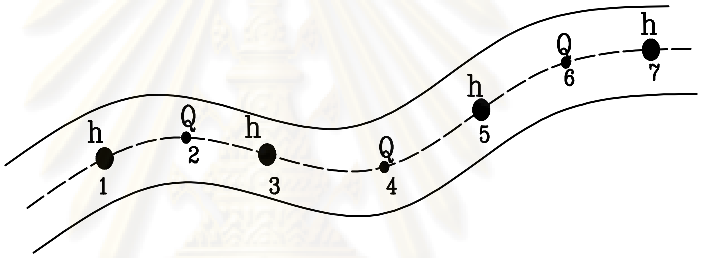


Figure 2. 2. Channel section with computational grid

The adopted numerical scheme is a 6-point Abbott-scheme as shown in Figure 2.3

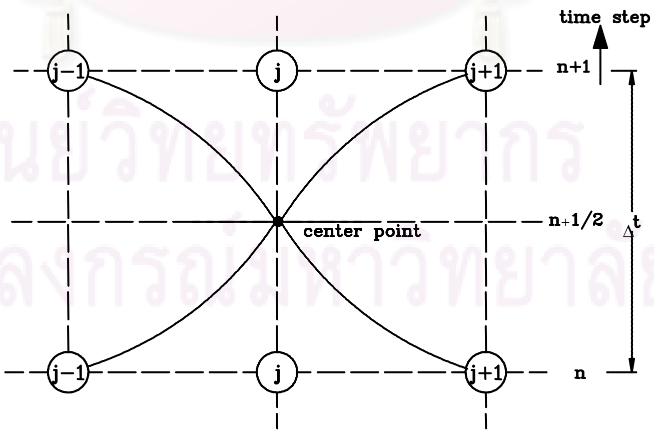


Figure 2. 3. Centred 6-point Abbott scheme

Continuity equation

In the continuity equation the storage width, b_s, is introduced as:

$$\frac{\partial A}{\partial t} = b_s \frac{\partial h}{\partial t} \qquad (2.17)$$

giving:

$$\frac{\partial A}{\partial t} = b_s \frac{\partial h}{\partial t} \qquad (2.\ 18)$$

As only Q has a derivative with respect to x, the equation can easily be centered at an h-point, see Figure 2.4.

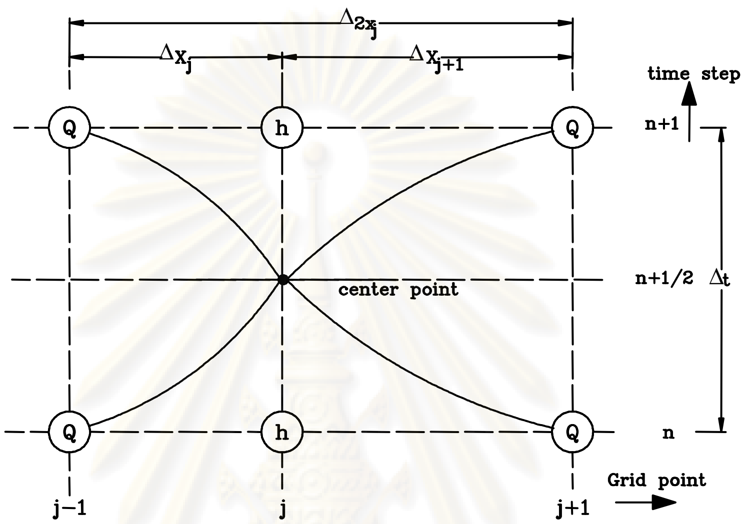


Figure 2. 4. Centering of continuity equation in 6-point Abbott scheme

The derivatives in Equation (2.18) are expressed at the time level, $n + \frac{1}{2}$ as follows:

$$\frac{\partial Q}{\partial x} \approx \frac{\frac{\left(Q_{j+1}^{n+1} + Q_{j+1}^{n}\right)}{2} - \frac{\left(Q_{j-1}^{n+1} + Q_{j-1}^{n}\right)}{2}}{\Delta 2x_j} \qquad (2.\ 19)$$

$$\frac{\partial h}{\partial t} \approx \frac{\left(h_j^{n+1} - h_j^{n}\right)}{\Delta t} \qquad (2.\ 20)$$

b_s in Equation (2.18) is approximated by:

$$b_s = \frac{A_{o,j} + A_{o,j+1}}{\Delta 2x_j} \qquad (2.\ 21)$$

where:

$A_{o,j}$ is the surface area between grid point j-1 and j

$A_{o,j+1}$ is the surface area between grid point j and j+1

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Δ_{2xj} is the distance between point j-1 and j+1

Substituting for the derivatives in Equation (2.18) gives a formulation of the following form:

$$\alpha_j Q_{j-1}^{n+1} + \beta_j h_j^{n+1} + \gamma_j Q_{j+1}^{n+1} = \delta_j \tag{2. 22}$$

where, α, β and γ are functions of b and δ, moreover, depend on Q and h at time level n and Q on time level $n+\frac{1}{2}$.

Momentum equation

The momentum equation is centered at *Q*-points as illustrated in Figure 2.5.

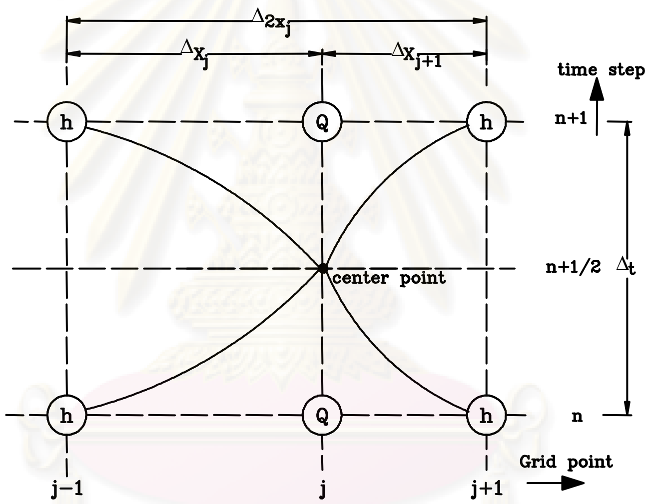


Figure 2. 5. Centering of momentum equation in 6-point Abbott scheme

The momentum equation is centered at *Q*-points as illustrated in Figure 2.6.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

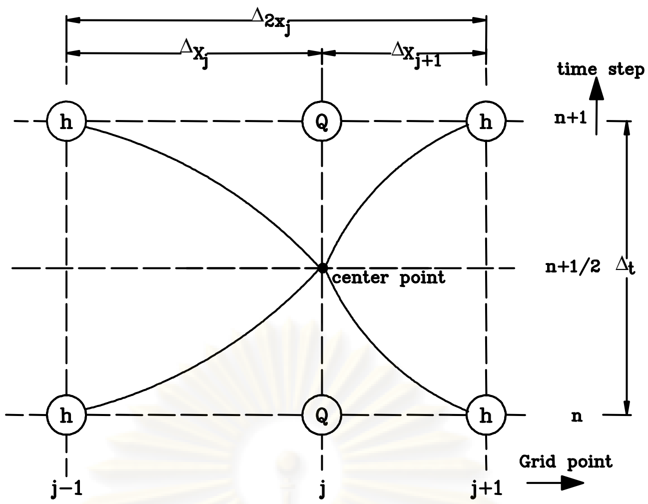


Figure 2. 6. Centering of momentum equation in 6-point Abbott scheme

The derivatives of Equation (2.16), Saint Venant Equations are expressed in the following way:

$$\frac{\partial Q}{\partial t} \approx \frac{Q_j^{n+1} - Q_j^n}{\Delta t} \qquad (2.\ 23)$$

$$\frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} \approx \frac{\left[\alpha \frac{Q^2}{A}\right]_{j+1}^{n+\frac{1}{2}} - \left[\alpha \frac{Q^2}{A}\right]_{j-1}^{n+\frac{1}{2}}}{\Delta 2x_j} \qquad (2.24)$$

$$\frac{\partial h}{\partial x} \approx \frac{\frac{\left(h_{j+1}^{n+1} + h_{j+1}^{n}\right)}{2} - \frac{\left(h_{j-1}^{n+1} + h_{j-1}^{n}\right)}{2}}{\Delta 2x_j} \qquad (2.\ 25)$$

For the quadratic term in (2.24), a special formulation is used to ensure the correct sign for this term when the flow direction change during a time step:

$$Q^2 \approx \theta Q_j^{n+1} Q_j^n - (\theta - 1) Q_j^n Q_j^n \qquad (2.\ 26)$$

where θ can be specified by the user (THETA coefficient under the default values in the HD parameter editor) and by default is set to 1.0 with all the derivatives substituted, the momentum equation can be written in the following form:

$$\alpha_j h_{j-1}^{n+1} + \beta_j Q_j^{n+1} + \gamma_j h_{j+1}^{n+1} = \delta_j \qquad (2.\ 27)$$

where,

$$\alpha_j = f(A)$$
$$\beta_j = f(Q_j^n, \Delta t, \Delta x, C, A, R)$$
$$\gamma_j = f(A)$$
$$\delta_j = f\left(A, \Delta t, \Delta x, \alpha, q, v, \theta, h_{j-1}^n, Q_{j-1}^{n+\frac{1}{2}}, Q_j^n, h_{j+1}^n, Q_{j+1}^{n+\frac{1}{2}}\right)$$

To obtain a fully centered description of A_{j+1}, these terms should be valid at time level $n+\frac{1}{2}$ which can only be fulfilled by using iteration. For this reason, the equations are solved by default two times at every time step, the first iteration starting from the results of the previous time step, and the second iteration using the centered values from this calculation.

2.6.3.2. Boundary Conditions

External boundary conditions are required at all model boundaries, i.e. all upstream and downstream ends of model branches, which are not connected at a junction. The relationships applied at these limits can consist of:

- Constant values of *h* or *Q*
- Time varying values of *h* or *Q*
- A relationship between *h* and *Q* (e.g. a rating curve) (Should only be used at downstream boundaries)

The choice of boundary condition depends on the physical situation simulated and the availability of data.

Typical upstream boundaries could be

- Constant discharge from a reservoir
- A discharge hydrograph of a specific event

Typical downstream boundaries include:

- Constant water level, e.g. in a large receiving water body
- Time series of water level, e.g. tidal cycle
- A reliable rating curve, e.g. from a gauging station

2.6.3.3. Calibration Hydrodynamic Model

Calibration hydrodynamic model is done by adjusting bed resistance until simulated discharges and water level are quite well observations.

2.6.3.4. Bed Resistance

MIKE 11 allows for two different types of bed resistance descriptions:

- Chezy, and
- Manning

The description is set in the Hydrodynamic Editor under the Bed Resistance tab. For the Chezy description, the bed resistance term in the momentum equation is described as:

$$\frac{gQ|Q|}{C^2AR} \qquad (2.\ 28)$$

Where,

Q is discharge (m^3/s)

A is flow area (m^2)

R is the resistance or hydraulic radius (m)

For the Manning description, the term is: $\dfrac{gQ|Q|}{M^2AR^{\frac{4}{3}}}$

The Manning number, *M*, is equivalent to the Strickler coefficient. Its inverse is the more conventional Manning's *n*. The value of *n* is typically in the range 0.01 (smooth channel) to 0.10 (thickly vegetated channel). The corresponding values for *M* are from 100 to 10. The Chezy coefficient is related to Manning's *n*:

$$C = \frac{R^{\frac{1}{6}}}{n} = MR^{\frac{1}{6}} \qquad (2.\ 29)$$

Values for the resistance numbers, *C*, *M* or *n*, should be determined through model calibration where possible, or based on other calibrated models with similar topographic

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

characteristics. R is calculated using either a resistance radius, R_*, or a hydraulic radius, R_h, formulation as specified by the user in the cross section editor. The default formulation for R may be set individually for each cross section. The formulations for R_* and R_h are discussed follow:

Resistance Radius

The resistance radius is calculated as

$$\sqrt{R_*} = \frac{1}{A}\int_0^B y^{\frac{3}{2}} db \qquad (2.\ 30)$$

where

y is the local water depth, A is the cross sectional area and B is the water width at the same elevation. This formulation ensures that the Manning number is almost independent of the water depth in the case of composite cross sections. The effect of the relative resistance, r_r, is included in the above formulation by adjusting the physical area to give the effective flow area, A_e as:

$$A_e = \sum_{i=1}^{N_S}\left(\frac{A_i}{r_{r_i}}\right) \qquad (2.\ 31)$$

where Ns = Number of sub-sections which equals the number of x-z values in the raw data less one. Equation (2.30) is now read as:

$$\sqrt{R_*} = \frac{1}{A_e}\int_0^B \frac{y^{\frac{3}{2}}}{r_r} db \qquad (2.\ 32)$$

Hydraulic Radius

The hydraulic radius formulation is based on a parallel channel analysis where the total conveyance, K, of the section at a given elevation is equal to the sum of the conveyances of the parallel channels. The parallel channels of a cross-section are defined as those parts of the cross-section where the relative resistance, r_r, remains constant.

Where, N is the number of parallel channels we have,

$$K = \sum_{i=1}^{N} K_i \qquad (2.\ 33)$$

which may be expressed using Manning's *n* as:

$$\frac{AR_h^{\frac{2}{3}}}{n} = \sum_{i=1}^{N} \frac{A_i R_{h_i}^{\frac{2}{3}}}{n r_{r_i}} \qquad (2.34)$$

Setting A equal to either the effective flow area of the cross-section as given by Equation (2.31) or the total flow area we have the general formula:

$$R_h = \left(\frac{\sum_{i=1}^{N} \left(\frac{A_i^{\frac{5}{3}}}{r_{r_i} P_i^{\frac{2}{3}}} \right)}{A} \right)^{\frac{3}{2}} \qquad (2.35)$$

where, P_i is the wetted perimeter of the parallel channel. P_i does not include the interface between adjoining parallel channels, i.e. a zero shear interface has been adopted. Where the relative resistance is constant across the whole cross-section the well-known form:

$$R_h = \frac{A}{P} \qquad (2.36)$$

is used. Both hydraulic radius using effective flow area and hydraulic radius using total flow area are offered as options in the cross section editor.

In this study, values for the resistance numbers *n*, was determined through model calibration where possible, or based on other calibrated models with similar topographic characteristics. A rough guide to values of Manning's *n* was reference as Table below:

Table 2. 1. A rough guide to values of Manning's *n*

Open Channels	Manning’s n		
	Minimum	Regular	Maximum
Natural stream channels			
Clean, strange	0.025	0.030	0.033
Clean, Winding	0.033	0.040	0.045
Weeds and Pools	0.035	0.045	0.050
Heavy brush and timber	0.035	0.035	0.100
Artificially channels		0.012	
Concrete			
Asphalt		0.016	
Glass		0.010	
Gravel bottom with side			
Concrete		0.020	
Mortared with stone		0.023	
Riprap		0.033	

2.6.4 Advection-Dispersion Module

ศูนย์วิทยทรัพยากร จุฬาลงกรณ์มหาวิทยาลัย

The transport dissolve matter in water principally depends on two phenomena: advection and dispersion (Schnoor, 1996). Advection-Dispersion process occurs three directions (i.e. longitudinal, lateral, vertical). In this study, longitudinal was investigated.

The advection-dispersion (AD) module is based on the one-dimensional equation of conservation of mass of dissolved or suspended material, i.e. the advection-dispersion equation. The module requires output from the hydrodynamic module, in time and space, in terms of discharge and water level, cross-sectional area and hydraulic radius. The advection-dispersion equation is solved numerically using an implicit finite difference scheme, which, in principle, is unconditionally stable and has negligible numerical dispersion.

2.6.4.1. Dispersion-Advection Equation

Dispersion-Advection equation is basing on mass conservation equation and Fick'law:

The mass conservation principle can be applied for a conservative substance (Schnoor, 1996)

$$\frac{\partial C}{\partial t} = -\frac{v\partial C}{\partial x} + D_x \frac{\partial^2 C}{\partial x^2} \qquad (2.\ 37)$$

Where: C is the concentration (g/m^3), D is the longitudinal dispersion coefficient (m^2/s), v is velocity (m/s)

For non-conservative substance, it also has degradation process

$$\frac{\partial C}{\partial t} = -KC \qquad (2.\ 38)$$

Where: K is linear decay coefficient

So the one-dimensional (vertically and laterally integrated) equation for the conservation of mass of a substance in solution, i.e. the one-dimensional advection-dispersion equation reads:

$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} - \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial x} \right) = -AKC + C_2 q \qquad (2.\ 39)$$

Where C is the concentration (g/m^3), D is the dispersion coefficient (m^2/s), A is the cross-sectional area (m^2), K is the linear decay coefficient ($\frac{1}{s}$), C_2 is the source/sink concentration (g/m^3), q is the lateral inflow (m^3/s), x is the space coordinate (m) and t is the time coordinate (s), Q is the discharge (m^3/s).

The equation reflects two transport mechanisms:

1. Advective (or convective) transport with the mean flow;
2. Dispersive transport due to concentrations gradients

The main assumptions underlying the advection-dispersion equation are:

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

- The considered substance is completely mixed over the cross-sections, implying that a source/sink term is considered to mix instantaneously over the cross-section
- The substance is conservative or subject to a first order reaction (linear decay)
- Fick's diffusion law applies, i.e. the dispersive transport is proportional to the concentration gradient

2.6.4.2. Solution Scheme, AD

The advection-dispersion equation is solved with a fully time and space centered implicit finite difference scheme in order to minimize any artificial (numerical) dispersion. Moreover, it has been ensured that the discretization mass conservative. The finite difference scheme is derived by considering the mass flux into a control volume situated around the grid point j. The boundaries of this control volume are the river bed, the water surface and the two cross-sections situated at $j-\frac{1}{2}$ and $j+\frac{1}{2}$, respectively, see Figure 2.7 .

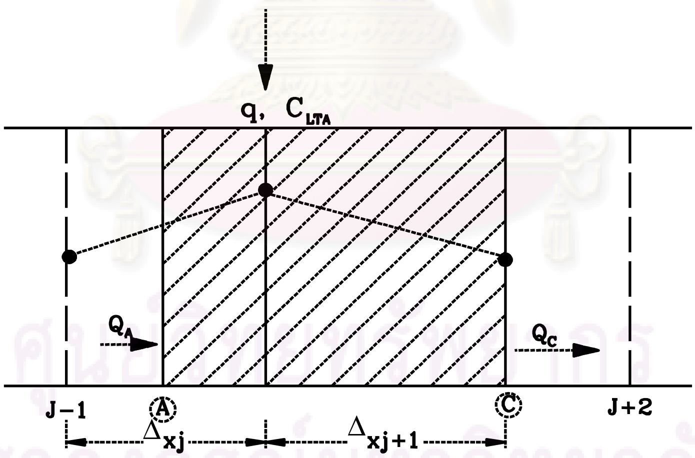


Figure 2. 7. Definition sketch for the control volume.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

The two equations considered are the continuity equation and the advective-dispersive transport equation.

Continuity equation:

$$\frac{V_j^{n+\frac{1}{2}}C_j^{n+1}}{\Delta t}-\frac{V_j^{n+\frac{1}{2}}C_j^{n}}{\Delta t}+T_{j+\frac{1}{2}}^{n+\frac{1}{2}}-T_{j+\frac{1}{2}}^{n+\frac{1}{2}}=q^{n+\frac{1}{2}}C_q^{n+\frac{1}{2}}-V_j^{n+\frac{1}{2}}KC_j^{n} \qquad (2.\ 40)$$

Where C is the concentration, V the storage volume, T is the transport through box walls, q is the lateral inflow, Δt is the time step, C_q is the concentration of lateral inflow source, K is the linear decay coefficient, j is the grid point and n is the time level.

Advective-dispersive transport equation:

$$T_{j+\frac{1}{2}}^{n+\frac{1}{2}} = Q_{j+\frac{1}{2}}^{n+\frac{1}{2}} C_{j+\frac{1}{2}}^{*} - A_{j+\frac{1}{2}}^{n+\frac{1}{2}} D \frac{C_{j+1}^{n+\frac{1}{2}} - C_{j}^{n+\frac{1}{2}}}{\Delta x} \qquad (2.\ 41)$$

where,

$Q_{j+\frac{1}{2}}^{n+\frac{1}{2}}$ is the discharge at the right wall of the box

$A_{j+\frac{1}{2}}^{n+\frac{1}{2}}$ is the cross sectional area of the right wall

D is the dispersion coefficient

$C_{j+\frac{1}{2}}^{*}$ is an upstream interpolated concentration given by:

$$C_{j+\frac{1}{2}}^{*} = \frac{1}{4}\left(C_{j+1}^{n+1} + C_{j}^{n+1} + C_{j+1}^{n} + C_{j}^{n}\right) - \min\left(\frac{1}{6}\left(1 + \frac{\sigma^2}{2}\right), \frac{1}{4\sigma}\right)\left(C_{j+1}^{n} - 2C_{j}^{n} + C_{j-1}^{n}\right) \qquad (2.\ 42)$$

in which σ is the Courant number $\frac{u\Delta t}{\Delta x}$. The last term of Equation (2.41) is an explicit third order corrective term. Substitution and rearrangement of the above equations give a general implicit finite difference equation, which relates the concentration in three neighboring grid points to each other at any time level as:

$$\alpha_j C_{j-1}^{n+1} + \beta_j C_{j}^{n+1} + \gamma_j C_{j+1}^{n+1} = \delta_j \qquad (2.\ 43)$$

2.6.4.3. Boundary Conditions

At external boundaries, a series of conditions can be applied:

- Open boundary outflow
- Open boundary inflow - User defined values of the concentration (time varying or constant)
- Closed boundary

2.6.4.4. Calibration of AD module

Calibrations of AD module operated by adjusting dispersion coefficient until outputs (i.e. salinity concentration) are quite well with observation data.

2.6.4.5. Dispersion Coefficient

Longitudinal dispersion is caused by the combined action of a non-uniform velocity distribution and diffusion. The longitudinal spreading under the influence of a non-uniform velocity distribution is much greater than would be achieved by molecular and turbulent diffusion alone. The dispersive transport follows Fick's diffusion law. The dispersion coefficient is determined as a function of the mean flow velocity, viz:

$$D_j^{n+1} = a\left|\frac{Q^{n+\frac{1}{2}}}{A^{n+\frac{1}{2}}}\right|_j^b \qquad (2.\ 44)$$

Where a and b are constants to be specified by the user. A constant dispersion coefficient is obtained by selecting b=0. In rivers the dispersion coefficient is in the order of 5 to 10 m^2/s increasing to between 30 and 100 m^2/s as two-dimensional processes (secondary currents, wind induced turbulence) become more dominant, e.g. in estuaries.

The dispersion coefficient, D, can be described as a function of the mean flow velocity, V, as shown below.

$$D = aV^b \qquad (2.\ 45)$$

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Where a is the dispersion factor and b is the dispersion exponent. Typical value ranges for *D*: 1-5 m^2/s (for small streams), 5-20 m^2/s (for rivers) (DHI, 2007). Both the “dispersion factor” and the “dispersion exponent” can be specified. If the dispersion exponent is zero then the dispersion coefficient *D* becomes constant (equal to the dispersion factor).

A literature summary dispersion coefficient of some rivers and estuaries

Table 2. 2. Summary of dispersion coefficient in some rivers

Reach	Depth (m)	Width (m)	V (m/s)	Longitudinal Dispersion Coefficient(m^2/s)	Reference
The Bassac River, Viet Nam				50-700	Sam, 2006
The Dong Nai River, Viet Nam				100-300	Sam, 2006
The Sai Gon River, Viet Nam				50-100	Sam, 2006
The Mekong River, Viet Nam				100-700	Sam, 2006
The Vam Co River, Viet Nam				75-300	Sam, 2006
The Bayou Ancoco, LA, US		19.8		13.9	Schnoor, 1996
The Clinch River, TN, US	0.85	47	67	14	Schnoor, 1996
	2.1	60	10.4	54	Schnoor, 1996
	2.1	53	10.7	47	Schnoor, 1996
The Missouri, US	2.7	200	0.074	5290.8	Schnoor, 1996
The Sabine River, TX, US		35.1		39.5	Schnoor, 1996
The Sabine River, LA, US		42,4		316	Schnoor, 1996
The Yadkin River, NC, US		127.4		699.1	Schnoor, 1996
		70.1		213.8	Schnoor, 1996

2.6.5 Limitation of MIKE 11 Model

MIKE 11 is a professional model. Although MIKE 11 has some limitations, it has been applied in many large diversity projects in the world such as Flood Action Plans (FAP) in Bangladesh, Flood Forecasting in The Yangtze River (China), Drainage Master Plans for all seven major drainage areas in Hong Kong, Salt River Project (USA) involving control of irrigation systems, Flood Management in Czech Republic, Flood forecasting in Poland, Water Quality modeling in upper part of The Yangtze River

(China), Urban Pollution Management projects in UK, etc. Mike 11 uses finite difference method of Abbott and Ionescu for solving Saint Venant Equation (DHI, 2007). The equation was solved by iteration method; therefore, solution time in HD module is long. In case of large scale area simulation, it takes long time to run its modules. In addition, advection-dispersion equation is solved with a full time and space centered implicit finite difference scheme in AD module, so numerical dispersion may occur. It causes low accurate result such as simulation results are higher than values in boundary condition, simulation result may be minus. Moreover, MIKE 11 is a commercial model, so its price is quite high.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

CHAPTER III

METHODOLOGY

This chapter comes up with study tools and data needed for research and their possible sources. Methodology is followed in determining the potential of simulation salinity intrusion by using Mike 11. The framework of methodology is divided into three parts namely (1) Calibration model, (2) Verification model and (3) Simulation salinity intrusion.

3.1. Software and Program

Neary et al., (2001) showed that 1-D modeling might offer a practical and cost-effective alternative compared 2-D or 3-D models with relatively less model set-up and run-time requirement. Moreover, the MIKE 11 model is suitable for studies related to flow and water level conditions in the Mekong-Bassac-Tonle Sap River and Great Lake system including associated floodplains (MRC, 2005). Therefore, MIKE 11 model (version 2007) and MIKE view (version 2007) are chosen for this study.

3.2. Methods

The method in this study can be divided into three parts:

- Investigation of salinity intrusion in year 1998. In this study, the simulation result for the year 1998 was chosen as baseline scenario to measure any changes in salinity intrusion in the year 2020 and 2030. The reason for selecting the year is that salinity intrusion in 1998 was considered one of the most serious events in recent decades (Sam, 2006). Moreover, data for the year is available for model calibration.
- Verification of salinity intrusion in year 2005
- Simulation salinity intrusion in years 2020 and 2030 with five scenarios

Figure 3.1 and 3.2 display overall framework and conceptual flow diagram of this study

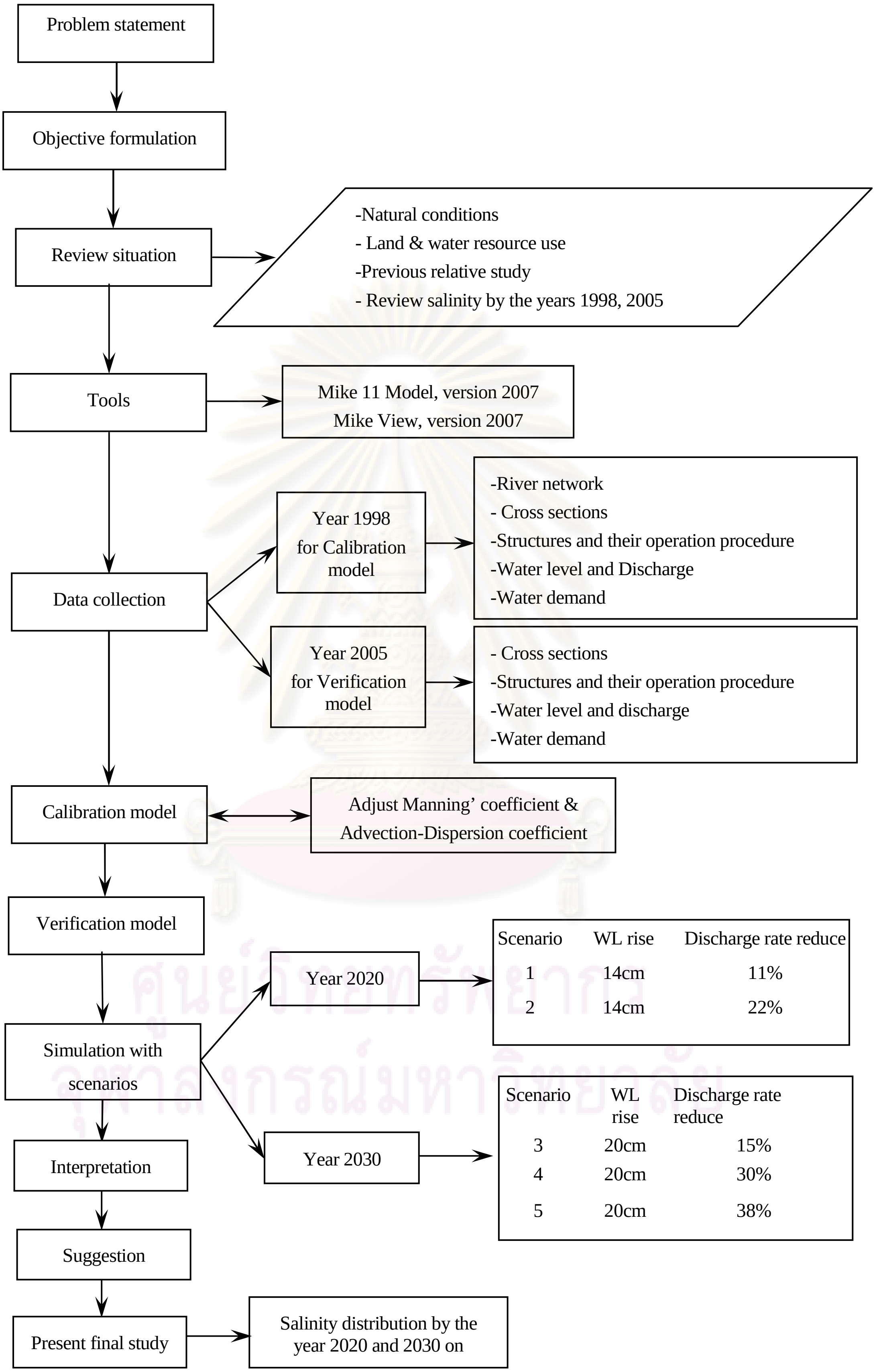


Figure 3. 1. Overall framework of research study

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

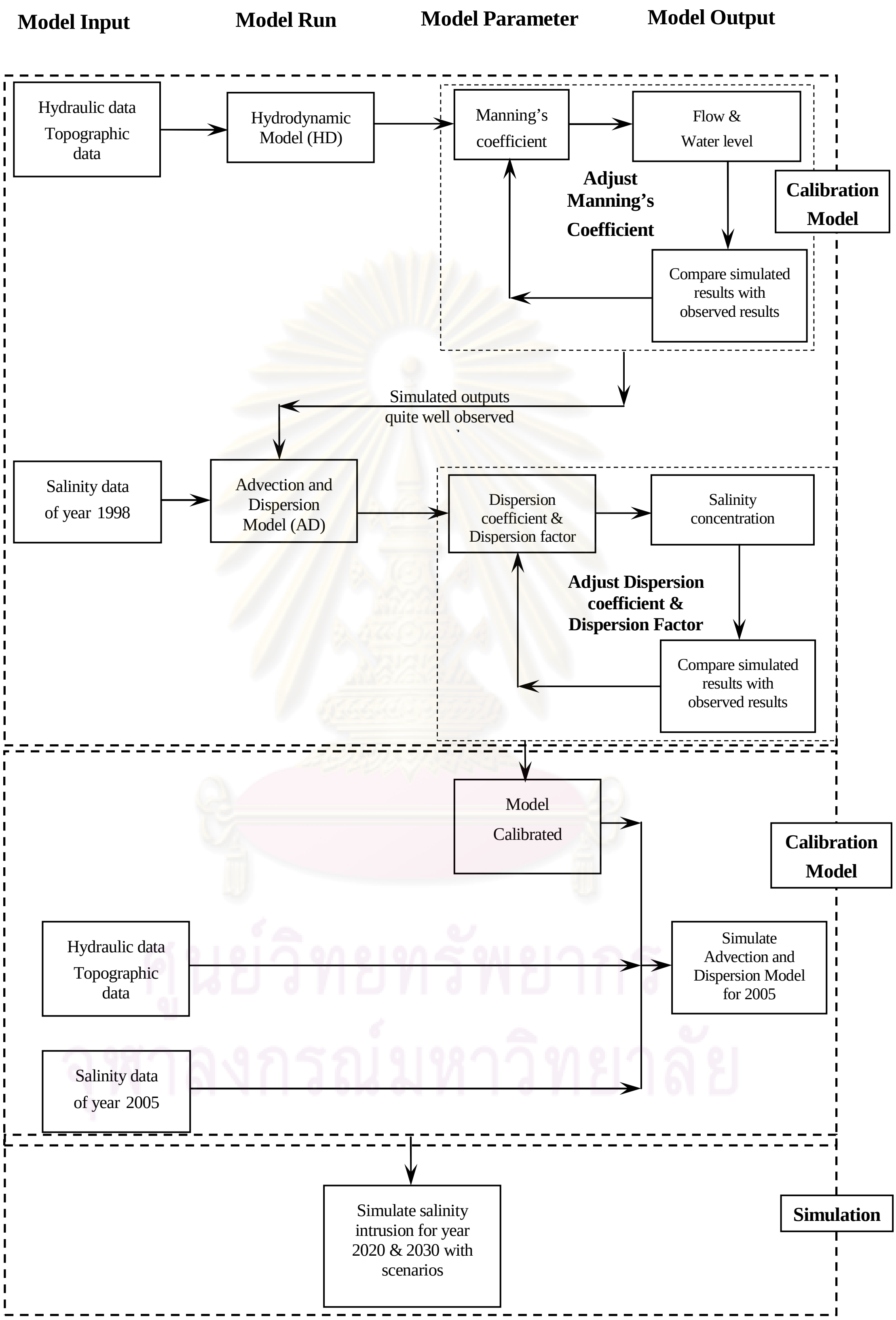


Figure 3. 2. Conceptual flow diagram for using MIKE 11 in this study

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

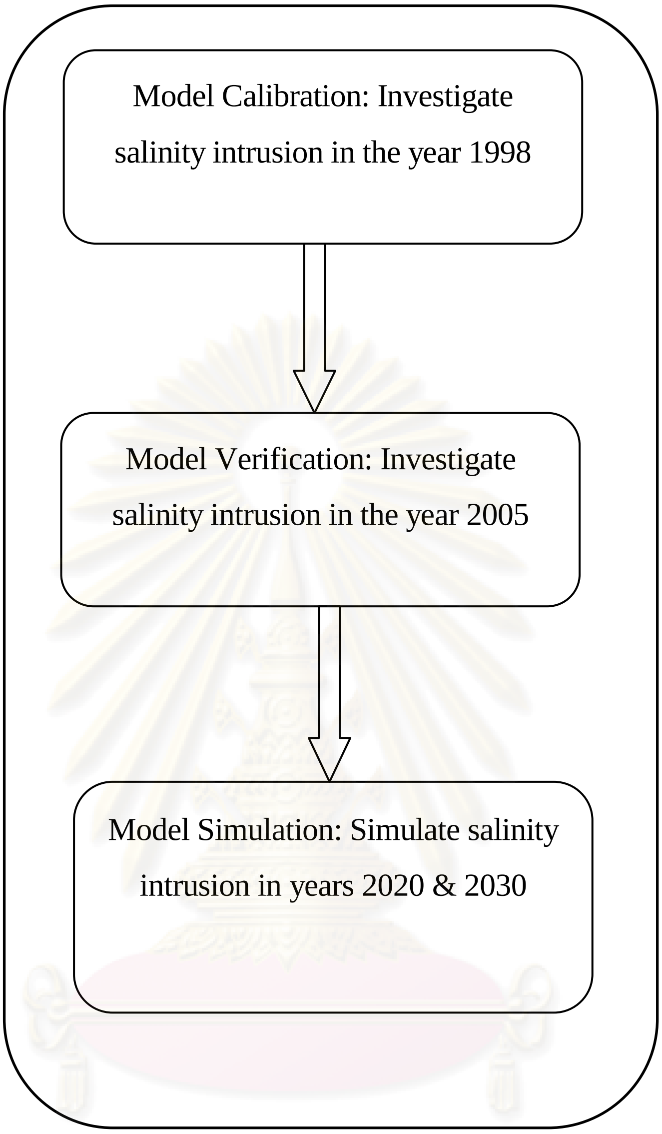


Figure 3. 3. Flow of method

3.2.1. Investigation of Salinity Intrusion in the Year 1998 (Calibration Model)

Calibration of MIKE 11 model for salinity intrusion simulation can be summarized into two modules as HD Model and AD Model. The calibration was performed to the typical low flow season. Low flow season is defined as the period from the beginning of February to May inclusively.

Hydrodynamic Model (HD Model)

The HD module is based on conservation of mass and momentum. Inputs of the module are hydrodynamic data, topographic data and Manning's resistance (n). These data were collected from relevant governmental offices at provinces, districts and sub-districts. The data and their sources are listed in Table 3.1.

Table 3. 1. Inputs of Hydrodynamic module

No	Data	Description	Data Source
1	Meteorological and hydrological data	Flow and water level data in main rivers in MD	SIWRR, CTU, VNMC, NCHMF
2	Topography map	Topography map of main rivers of MD	SIWRR, CTU
3	River system in Lover MD	Map of river system; Geometric data (length, width, depth, etc.)	SIWRR, CTU, VNMC
4	Geometric and location of any control structures	Operation rules of hydraulic structures	SIWRR, PMU 10
5	Water demand	Water demand in the study area	SUB-NIAPP

River network includes:

- 1095 rivers (these river were been digital by using satellite image).
- 153 control structures
- 4 weirs
- 1 culverts
- 6 discharge boundaries at the upstream. Two of them are located on main The Mekong River and 82 water level boundaries at the sea as Figure 3.4.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

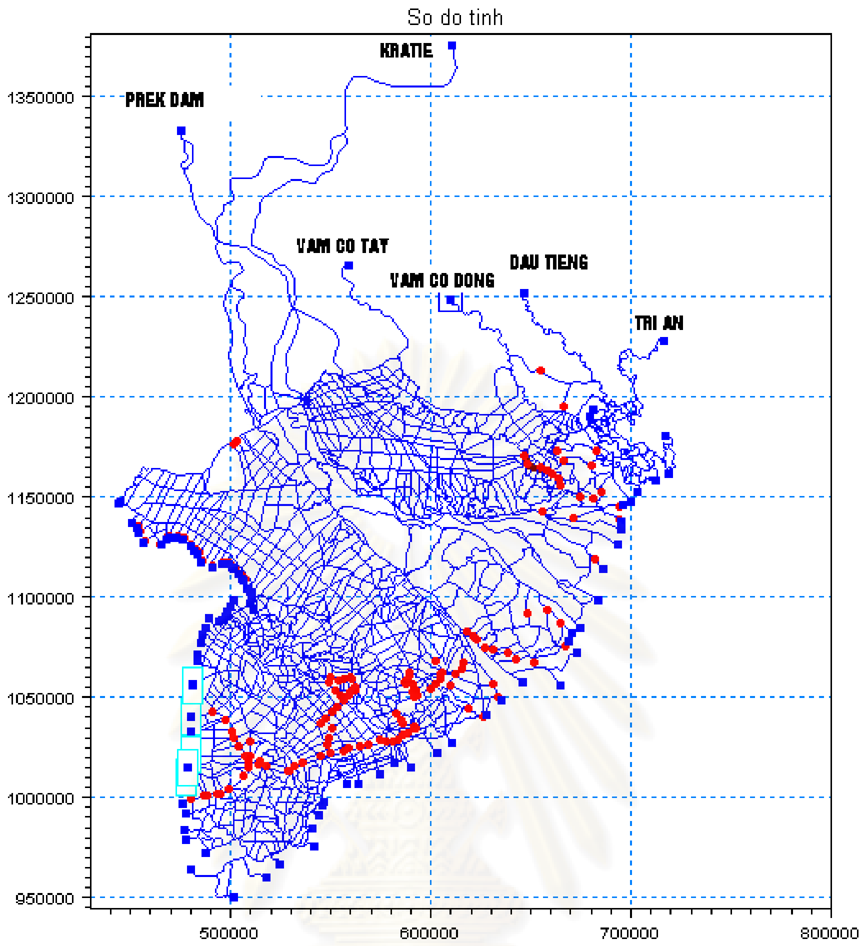


Figure 3. 4. River network of the Model

The HD module was calibrate by adjust Manning's coefficient until simulated output quite well observed data at several gauging stations (e.g. CD, TC, CT and MT) as Figure 3.5.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

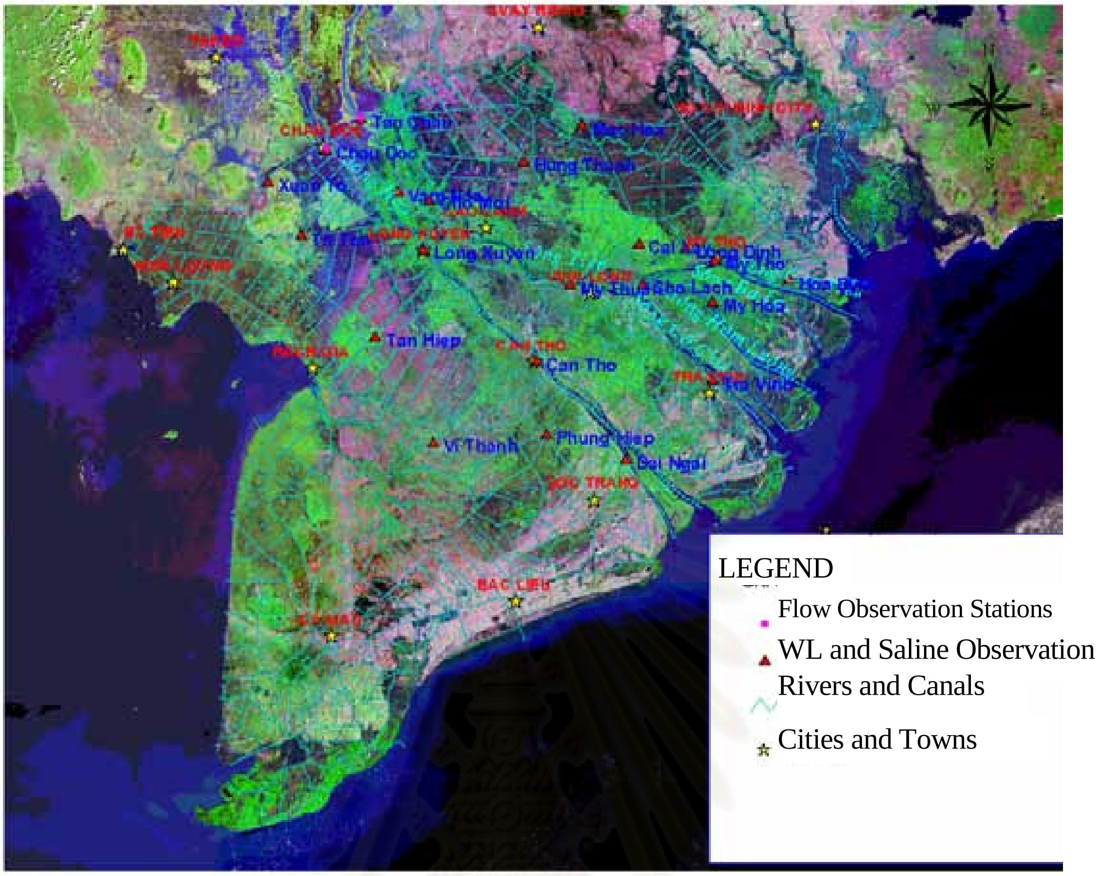


Figure 3. 5. Location of water level (WL), flow and salinity concentration observation stations

(Source: Southern Institute of Water Resource and Research)

Water level and discharge data were collected as Table 3.2, 3.3 and 3.4

Table 3. 2. Water level station location and observed time on rivers

No	Station name	River Name	Location (km)	Observed time		Time step
				Year 1998	Year 2005	
1	Chau Doc	The Bassac River	120,0	March to April		Every hour
2	Long Xuyen	The Bassac River	177,5	March to April	April to June	Every hour
3	Dai Ngai	The Bassac River	273,7	March to April	Jan to June	Every hour
4	Tan Chau	The Mekong River	103,4	March to April	March to April	Every hour
5	Vam Nao	The Vam Nao River	0	Feb to April		Every hour
6	Cao Lanh	The Mekong River	175,0	Feb to April	April to June	Every hour
7	My Thuan	The Mekong River	210,3	March to April	Jan to June	Every hour
8	My Tho	The Mekong River	262,3	March to April		Every hour
9	Tra Vinh	The Co Chien River	55,0	March to April	Jan to June	Every hour
10	Can Tho	The Bassac River	231,5	March to April	Jan to June	Every hour

(Source: National Hydro-Meteorological Service)

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table 3. 3. Water level station location and observed time of estuaries

No	Station name	River Name	Location (km)	Observed time		Time step
				Year 1998	Year 2005	
1	Vung Tau	Vung Tau	sea	Jan to June	Jan to May	Every hour
2	Vam Kenh	The Tieu estuary	sea	Jan to December	Jan to May	Every hour
3	Binh Dai	The Dai estuary	sea	Jan to December	Jan to May	Every hour
4	An Thuan	The Ham Luong estuary	sea	Jan to December	Jan to May	Every hour
5	Ben Trai	The Co Chien estuary	sea	Jan to December	Jan to May	Every hour
6	My Thanh	The My Thanh estuariy	sea	Jan to December	Jan to May	Every hour
7	Ganh Hao	The Ganh Hao River	sea	Jan to December	Jan to May	Every hour
8	Song Doc	The Ong Doc estuary	sea	Jan to December	Jan to May	Every hour
9	Rach Gia	The Rach Gia town	sea	Jan to December	Jan to May	Every hour

(Source: National Hydro-Meteorological Service)

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table 3. 4. Flow Stations location and observed time

No	Station Name	River Name	Location	Observed time		Time step
			(Km)	1998	2005	
1	Chau Doc	The Bassac River	119,3	Jan to December		Every hour
2	Tan Chau	The Mekong River	104,0	Jan to December		Every hour
3	Vam Nao	The Vam Nao River	2,5	Jan to May		Every hour
4	Can Tho	The Bassac River	231,5	Jan to May		Every hour
5	My Thuan	The Mekong River	210,3	Jan to May		Every hour
6	Kratie	Kratie	0	Jan to December	Jan to May	Every hour
7	PrekDam	Tonlesap	0	Jan to December	Jan to December	Every hour

Source: National Centre for Hydro-Meteorological Forecasting, Mekong River Commission (MRC)

Advection-Dispersion Model (AD Model)

Inputs of AD module include all inputs of HD module, time series of salinity concentration at boundaries and advection-dispersion coefficient. The AD module is calibrated by adjusting advection-dispersion coefficient until the simulated outputs quite well observed data at several stations (e.g. DN, TV and HB) as Figure 3.5 .

Salinity concentration data was collected as Table 3.5

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table 3. 5. Salinity concentration

No	Station Name	River Name	Location	Obsered Time		
			(Km)	1998	2005	Time step
I. On Rivers						
1	Dai Ngai	The Bassac River	273,7	March to June	Feb to May	Every 2 hours
2	Tra Vinh	The Co Chien River	54.9	March to April	Feb to May	Every 2 hours
3	Hoa Binh	The Mekong River	14,0	March to April	Feb to May	Every 2 hours
4	My Tho	The Bassac River	262,3	March to May	Feb to May	Every 2 hours
II. Estuaries						
1	Vam Kenh	The Tieu Estuary		Feb to June	Jan to May	Every 2 hours
2	My Thanh	The My Thanh Estuary		Feb to June	Jan to May	Every 2 hours
3	Ganh Hao	The Ganh Hao River		Feb to June	Jan to May	Every 2 hours
4	Binh Dai	The Dai Estuary		Feb to June	Jan to May	Every 2 hours
5	Ben Trai	The Co Chien Estuary		Feb to June	Jan to May	Every 2 hours
6	An Thuan	The Ham Luong Estuary		Feb to June	Jan to May	Every 2 hours
7	Rach Gia	The Rach Gia town		Feb to June	Jan to May	Every 2 hours
8	Song Doc	The Ong Doc Estuary		Feb to June	Jan to May	Every 2 hours

(Source: National Centre for Hydro-Meteorological Forecasting, Viet Nam)

3.2.2. Investigation of Salinity Intrusion in the Year 2005 (Verification the Model)

Verification the model during low flow period in 2005 (February to May), is carried out with hydrology and geometry conditions in the year 2005 while Manning's coefficient and advection-dispersion coefficient at segments of rivers were kept as the previous step. As best fit between simulated outputs and observed discharge, water level and salinity concentration at stations are illustrated as Figure 3.5.

3.3. Simulation Salinity Intrusion in the Year 2020 and 2030 with Scenarios

3.3.1 Scenarios

In this study, the results of five modeled scenarios were summarized. The scenarios have been chosen to present a range of the Mekong River reducing and sea level rise next twenty years. The main purpose of the scenarios is providing a perspective on development and their impacts. All scenarios reflect the impact of dams, water consumption increasing and sea level rise on salinity intrusion in MD.

3.3.1.1. Baseline Scenario

In this study, the simulation result for the year 1998 was chosen as baseline scenario to measure any changes in salinity intrusion in the year 2020 and 2030. The reason for selecting the year is that salinity intrusion in 1998 was considered the most serious events in recent decade (Sam, 2006). Moreover, data for the year is available for model calibration.

3.3.1.2. Projected Sea Level Rise and Decrease Upstream Discharge Scenarios

Nijiseen et al., (2001) conducted research on the hydrologic sensitive of global river to climate change in which hydrologic model simulation performed for the decades centred on 2025 and 2045. Their study indicated that the discharge of the Mekong River decreased in dry season and increased in wet season. Hoanh et al. (2003) obtained similar results for the SRES (Special Report on Emission Scenarios) B2 scenario. They estimated minimum flow in the Mekong River reducing 15%-17% with CC-NoAgri (slightly change in agriculture area) scenario in year 2010 to 2039 compared with 1961 to 1990 and decreasing 90%-100% with CC-Agri (change in agriculture) scenario in year 2070 to 2099 compared with the period 1961 - 1990.

According to "IPCC Fourth Assessment Report Climate Change 2007" by the mid 2090s the global average sea level was projected to increase 43cm, at rate 5.6mm/year, above the 1990 levels for SRES B2 scenario. It means that sea level at South China Sea was projected to rise about 20cm in 2030 compared with 1980 to 1999.

In this study, five modelling scenarios were set up basing on sea level rise scenarios (IPCC, 2007) and the Mekong River flow reducing (Hoanh et al., 2003). SWAP and SLURP models were used. Especially, the changing in water resource in the Lower Mekong Sub-Basins was focused. The SWAP model was used to analyze the variation of food production at field scale level (Hoanh et al., 2003). SLURP was applied to simulate the hydrological cycle from precipitation to runoff, including the effects of reservoirs, regulators, water extractions, and irrigation schemes to assess impacts of climate change and climate variability on food production, food security and environment (ecological and social) and develop adaptation strategies to alleviate the negative impacts on food and environment in Lower Mekong Sub-Basins. The authors estimated that the Mekong River flow in dry season in MD will be reduced 15%-17% with Agri-Scenarios (no change or change agricultural area) in the period 2010-2039 in comparison to period 1961-1990 depending on scenarios for climate change and adaptation strategies (Hoanh et al, 2003). Inputs of those mathematical models include many kinds of data such as climate, topography, land use, characteristic of soils, hydrology, water consumption in MKB and so on in which water demand for all activities requirement in MKB is key factor that effects the Mekong River flow (Hoanh et al., 2003; MRC, 2010). Typically, water consumption prediction is performed basing on three main factors in MKB: i) irrigation water demand; ii) hydropower water demand; iii) domestic and industrial water demand (Kite, 2001; Hoanh et al., 2003; MRC, 2010). In the study, the predictions of water consumption for irrigation, hydropower, domestic and industrial in MKB are lightly smaller than Hoanh et al (2003) prediction while water consumption in MD is predicted that is higher than it was expected. Therefore, all of values of the Mekong River flow reducing in five scenarios were undertook higher than Hoanh et al (2003) prediction. Specifically, the first scenario, sea level is projected to increase 14cm while upstream discharge rate of the Mekong River is assumed to have decreased 11%. Second scenario is that the value of sea level rise and reduce upstream discharge rate of the Mekong River are 14cm and 22%, respectively. Third scenario, sea level increase 20cm and upstream discharge rate decrease 15%. The fourth scenario is supposed that sea level will rise 20cm while discharge rate reduce 30% and the last scenario is assumed that the Mekong River will decline 38% and sea level will rise 20cm as Table 3.6.

Table 3. 6. Summary scenarios for model simulation

Scenario	Sea level rise	Upstream discharge rate reduce	Year projected
Baseline scenario			
1	14 cm	11%	2020
2	14 cm	22%	2020
3	20 cm	15%	2030
4	20 cm	30%	2030
5	20cm	38%	2030

3.3.2 Simulation Model

The calibrated and verified model was applied to simulate salinity intrusion with five scenarios as mentioned.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

CHAPTER IV

RESULTS

4.1. Population and Water Consumption Prediction

Looking at the policy goals of the countries in the MKB, the primary focus of future development and water related economic activities is based on irrigated agriculture, hydroelectricity generation, fisheries, marshlands, flood mitigation, navigation, tourism and city and industrial water supply. Abnormal flow fluctuations caused by upstream and downstream activities (Sunada, 2009). In recent years, countries in the river basin regard hydropower. Currently, dams have been either under construction or have been planned in the main stream and tributaries of the Mekong River. These dams can affect discharge in dry season (Sundana, 2009). Moreover, water consumption will increase in the future causing of development and water related economic activities (ENSIC, 1999; Hoanh, 2003; MRC, 2010) while the Mekong River flow in dry season is one of the core factors that effects salinity intrusion in MD (Sam, 2006; Tuan, 2007; Sundana, 2009, MRC, 2010). Therefore, estimation of the Mekong River flow is one of the most important tasks that have been investigated in recent years (Hoanh, 2003; MRC, 2004 and MRC, 2009). Typically, study the Mekong River flow was carried out by coupling of mathematical models (i.e. SLURP, SWAT, IQQM, and ISIS). In general, inputs of those mathematical models include many kinds of data such as climate, topography, land use, characteristic of soils, hydrology, water consumption in MKB and so on in which water demand for all activities requirement in MKB is key factor that effects the Mekong River flow. Typically, water consumption prediction is performed basing on three main factors in MKB: i) irrigation water demand; ii) hydropower water demand; iii) domestic and industrial water demand. In this study, the two main scenarios of development in Mekong Basin which were undertaken were high development and low development.

4.1.1. Population in Mekong River Basin (MKB)

Population in the MKB has continued to increase rapidly over the past 30 to 50 years (ENSIC, 1999; MRC, 2004; Sundana, 2009; MRC, 2010). The average population rate growth is about 2% (Hoanh, 2003; MRC, 2004). This trend has been especially conspicuous in Cambodia, Laos and Myanmar. Total population in MKB is one of the major important factors that effect water and economic activities in the area. Linear growth model was used for computing population increasing. The future population of the Mekong River Basin was estimated basing on the moderate population increase scenario (A) and the high population increase scenario (B) that correspond with scenarios in the report of IPCC. Two scenarios were divided into three period of time, following the national master planning in MD (i.e. 1995-2000 as baseline; 2020 and 2030). After 2000, ADB and UNEP were strongly suggested that the population growth rate will reduce 25% for the period 2000-2020 and the period 2020-2040. As the result in Table 4.1, it is estimated that the basin population of 66 million in 2000 will increase by 50 percent to 99.1 million in 2020 or 123 percent to 145.69 million in 2030 as Table 4.1.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table 4.1. Population estimation with two scenarios (million)

Catchment of MRB	Overall population growth rate, %			Base population	Population in Scenario A			Population in Scenario B		
	1995-2000 (Scenario A,B)	2000-2020 (Scenario A)	2020-2030 (Scenario A)		2000	2020	2030	2000	2020	2030
Yunnan	1.6	1.2	0.9	9.9(1995)	10.72	13.60	14.90	10.72	14.72	20.22
Myanmar	1.4	1.1	0.8	0.5(1994)	0.55	0.70	0.80	0.55	0.73	0.96
Lao PDR	2.6	2	1.5	4.9(2000)	4.90	7.30	8.50	4.90	8.19	13.68
Thailand	1.6	1.2	0.9	23.1(2000)	23.10	29.30	32.00	23.10	31.73	43.59
Cambodia	2.8	2.1	1.6	9.8(2000)	9.80	14.90	17.50	9.80	17.03	29.58
Vietnam	2.1	1.6	1.2	16.4(2000)	16.40	22.50	25.40	16.40	24.85	37.66
Total					65.47	88.30	99.10	65.47	97.24	145.69

Source of population base and population growth rate: ENSIC, 1999; MRC, 2004 and GSOV, 2008

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

49

4.1.2. Water Resources and Water Consumption in MKB

4.1.2.1 Irrigation Sector

Water use in MKB can be divided into three main sectors: i) Agricultural-Aquaculture sector ii) industrial and domestic sector iii) hydropower sectors (Hoanh, 2003; MRC, 2004; MRC, 2009; Sundana, 2009 and MRC, 2010). Agricultural is a dominant sector in MKB. Approximately 75% population is highly depending on agricultural and fishery. Total irrigation area in Lower Mekong Basin (LMB) was projected of 11,394million ha in 2020 (MRC, 2004). Irrigation area in the period 1985-2000 in LMB was showed in appendix B.

Per capita water availability (in Table 4.2) was calculated by dividing the total available runoff (Appendix A) by population (Table 4.1). In the scenario A, per capital water availability in the whole MRB in 2030 is only 60.49% in comparison to 1995. The high reduction is in Cambodia (56%) and Lao PRD (57.65%) while water availability in Yunnan, Myanmar, Thailand and Vietnam is reduced fewer. It is from about 60% to 70%. However, water availability drops gradually in scenario B. It is 42% in 2030 compared with 1995. In scenario B, water availability in Vietnam and Thailand are lowest with 1852.2 and 1390.1m^3/capita-year, respectively. In generally, water availability in 2030 is half of it in 1995 in the scenario B.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table 4. 2. Water availability of two scenarios

Catchment of MRB	1995	water availability of Scenario A (m^3/capita-year)					water availability of Scenario B (m^3/capita-year)				
		2000	2020	%	2030	%	2000	2020	%	2030	%
Yunnan	7689.70	7103.00	5597.60	72.79	5109.30	66.44	7103.00	5170.90	67.24	3764.40	48.95
Myanmar	18922.00	17203.00	13515.70	71.43	11826.30	62.50	17203.00	13027.00	68.85	9864.80	52.13
Lao PRD	33917.30	33917.30	22766.40	67.12	19552.40	57.65	33917.30	20299.00	59.85	12148.60	35.82
Thailand	3494.90	3494.90	2755.40	78.84	2522.90	72.19	3494.90	2544.20	72.80	1852.20	53.00
Cambodia	9203.40	9203.40	6053.20	65.77	5153.90	56.00	9203.40	5297.70	57.56	3049.50	33.13
Vietnam	3192.10	3192.10	2326.70	72.89	2061.00	64.57	3192.10	2106.50	65.99	1390.10	43.55
Total	76419.40	74113.70	53015.00	69.37	46225.80	60.49	74113.70	48445.30	63.39	32069.60	41.97

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

51

4.1.2.2 Hydropower Sectors

The hydropower is the second major water use in the Mekong Basin (MRC, 2010). Many hydropower dams in mainstream have either been constructed or have been planned. These include the three existing hydropower dams, the Manwan , the Dachaosan and the Jinghong Dams in the Lancang mainstream. The Xiaowan under constructed, and the Nuozhadu Dam for which preparations are being made for its construction. In Thailand, six major tributary reservoirs are in operation, namely the Ubol Ratana, Chulabhorn, Sirindhorn, Pak Mun, Lam Pao and Nam Oun Dams. These dams are used for hydropower and irrigation in the North East of Thailand where a significant number of irrigation systems exist and many of them are planned. In Lao PDR, three major tributary reservoirs, namely the Nam Ngum, Nam Theun Hinboun, Huai Ho, Nam Ngum 2 and Nam Theun 2, are hydropower dams. In Cambodia, the Great Lake, linked to the Mekong River by the Tonle Sap River, covers an area varying from 3,000 km^2 in the dry season to 15,000 km^2 in the wet season, and is considered the heart of the LMB. It is also the largest sources of freshwater fish in South East Asia. In Viet Nam, the largest existing reservoir for hydropower is the Yali Falls on the Se San River, a major tributary in the East of the Mekong Basin; an area identified as having a high hydropower potential. The MD in Viet Nam is the most important rice producing region in the country. In the low-flow seasons, the tidal effect in the Delta is observed up to Phnom Penh in Cambodia (Sam, 2006; Tuan, 2007; MRC, 2005; MRC, 2010). About 2.5 million hectares in the Delta are irrigated and drained for rice cultivation. However, in the low-flow seasons agriculture is practiced only in a small fraction of this area because of insufficient freshwater and seawater intrusion (MRC, 2010). All proposed dams in mainstream of the Mekong River was shown in Appendix C (Figure C.1) . Those proposed reservoirs on the mainstream are not expected to be built due to approval requirement from all the four riparian countries of the MRC.

Figure C.2 demonstrates large dams in the Mekong Basin. Especially, eight dams are in existence, under construction and proposed in Lancang River (China) as Table C.1 (Appendix C). In the upper reaches of the Mekong main stream in Yunnan Province, China, two dams have already been constructed, another two are being constructed and four more are in the planning stage. Out of these, Manwan Dam was completed in 1993 and Dachaoshan Dam in 2003. Currently, work is advanced on the Xiaowan Dam, which will be the second largest dam in China. Jinghong Dam was finished last year. The impact of the Manwan Dam on downstream flow and suspended sediment load has been estimated by the Mekong River Commission based on observation data. In the analysis, comparison of mean annual peak flow was carried out before and after completion of the dam (up to December 31, 1992 and from January 1, 1993) at hydrological observation posts in the lower reaches of the Mekong. The flow decreased at Chiang Sean but increased at Luang Prabang. The peak annual flow generally falls. In Kratie, the Mekong River flow in dry season reduced 2% after operation of the dam (MRC, 2009).

However, it is not clear whether this can be attributed wholly to Manwan Dam (Sundana, 2009). Moreover, Lu et al., (2005) analyzed the historical data (from 1962 to 2000) which was published by the Secretariat of Mekong River Commission (MRC). They indicated a disruption in water discharge, water fluctuations and sediment transport downstream of the Manwan Dam, after its reservoir was filled in 1992. Dry season flows showed a declining trend, and water level fluctuations in the dry season increased considerably in the post-dam (1993–2000) period. Monthly suspended sediment concentration (SSC) has also decreased significantly in several gauging stations in the post-dam period (Lu et al., 2005, 2008). However, flow reduction at numerous observation points is the result of various factors such as reservoir adjustment, weather changes and other human activities. It is thus impossible to distinctly view the impact on flow (Sundana, 2009). In addition, Lu et al., (2005) showed that the decrease is only statistically significant at Chiang Saen. Areas located in the mid-length of the river show less sensitivity to the operation of the Manwan Dam, as sediment fluxes have remained stable or even increased in the post-dam period (Lu et al., 2005). China is not a full MRC member. Therefore, operational characteristic of those dams is unknown. It expected that those dams will be operated with the lowest impacts on LMB and China will not have any project to divert water from those reservoirs to another basin.

4.1.2.3 Domestic and Industrial Sectors

In this study, water demands in the MRB for domestic and industrial consumption were estimated two scenarios corresponding with population increasing scenarios. Water demand per capital was taken as Table 4.3 (MRC, 2005). Annual demand is about

5577.57 mcm in 2030 in scenario A. in scenario B, the water demand for domestic and industrial is about 1.5 times of that in scenario A. In generally, water demand for domestic and industrial in MKB is not quite high. It is about 6% in comparison to irrigation water demand and approximately 80% of water used for domestic and industrial is returned to the water body as waste water (DPC, 1997). The amount of water demand for environmental protection is not clearly defined.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table 4.3. Water demand for domestic and industrial

Catchment of MRB	Demand per capital litres/day	Annual demand(mcm)			
		Scenario A		Scenario B	
		2020	2030	2020	2030
Yunnan	170	843.88	924.55	913.52	1254.86
Myanmar	140	35.77	40.88	37.11	49.01
Lao PRD	140	373.03	434.35	418.37	699.06
Thailand	170	1818.07	1985.60	1968.92	2704.59
Cambodia	140	761.39	894.25	869.98	1511.37
Vietnam	140	1149.75	1297.94	1269.93	1924.40
Total		4981.89	5577.57	5477.84	8143.28

Obviously, water consumption in MKB will increase in the future due to water demand increasing of all water use sectors.

4.1.2.4 Estimate the Mekong River Flow in MD in Dry Season

Food demand and irrigation water consumption in MD (Table 4.4 and Table 4. 5) were projected with two assumptions: i) food demand in MKB is about 300kg/capita-year of paddy or equivalent; ii) an average production of 0.32kg of paddy or equivalent is needed 1m3 of irrigation water with the present irrigation techniques (ENSIC, 1999). Results were indicated as Table 4.4 and Table 4.5.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table 4.4. Population prediction for two scenarios

Catchment of MRB	Overall population growth rate, %			Base population	Population in Scenario A			Population in Scenario B		
	1995-2000 (Scenario A,B)	2000-2020 (Scenario A)	2020-2040 (Scenario A)		2000	2020	2030	2000	2020	2030
Vietnam	1.96	1.5	1.1	16.34 (2000)	16.34	22.00	24.50	16.34	24.20	35.52

Table 4. 5. Water consumption estimation for two scenarios

Scenario	Food demand (million ton)			Irrigation water demand (mcm)			Domestic and industrial(mcm)		
	2000	2020	2030	2000	2020	2030	2000	2020	2030
Scenario A	2.45	3.3	3.68	7659.38	10312.50	11484.38	62.62	84.32	93.89
Scenario B	2.45	3.61	5.33	7659.38	11292.49	16648.93	62.62	92.33	136.12

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

56

The water consumption in MD greatly varies with rice variety, growth duration, soil and hydrological conditions and farming practices (Bouman and Tuong, 2001). Water requirement for rice greatly varies with cropping calendars, cropping patterns and areas. Based on water productivity of rice farming that was estimated by ENSIC. As interpereted from Table 4.5, rice cultivation in the MD can abstract a water volume between 7,722 and 16,785mcm from December to May.

Basing on the prediction of the magnitudes order of discharge at Phnompenh (Chanh, 1991), the Mekong River flow was chosen as Table 4.6. The percentage of the Mekong River flow rate reducing was estimated as Table 4.6.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table 4. 6. Percent of water use of the Mekong River catchment in Vietnam

Discharge m^3/s	Water demand in MD estimation in dry season (mcm)						Percent of river flow rate reducing (%)			
	Scenario A			Scenario B			Scenario A		Scenario B	
	2000	2020	2030	2000	2020	2030	2020	2030	2020	2030
1500	7722.00	10396.82	11578.27	7722.00	11384.82	16785.05	11.31	16.30	15.49	38.32
2000							8.48	12.23	11.61	28.74
2500							6.79	9.78	9.29	22.99
3000							5.65	8.15	7.74	19.16

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

58

4.2. Salinity Intrusion Simulation

Following the conceptual flow diagram (Figure 3.2), the study can be categorized into four main steps model setup, calibration model, verification model and model prediction.

Firstly, the model was created and calibrated with data in 1998. The model was calibrated by adjustment or turning model parameters (i.e. Manning' coefficient in HD module, Advection-Dispersion coefficient in AD module) that were allowed within the range of experimentally determined reported in literature review as Table 2.1 and Table 2.2 until simulation results fixed well with observation results at different stations on main rivers as Figure 4.1. Then model verification was performed by using data in 2005

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

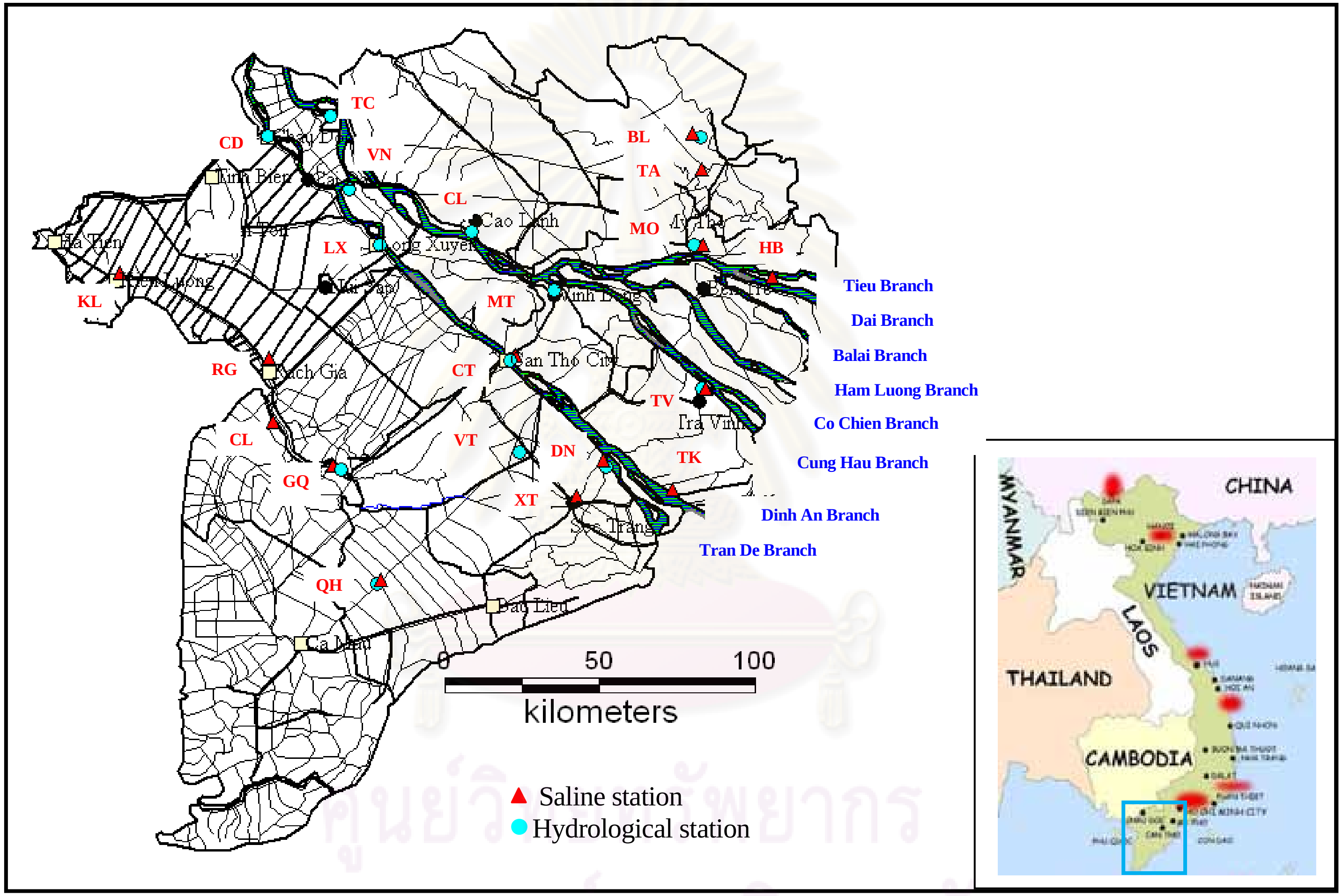


Figure 4. 1. MD, the hydrological and salinity observation stations used for model calibration and verification in the study

60

Table 4. 7. Hydrological and salinity observation stations used for model calibration and verification in the study

Station Name	Acronym	Location	Calibration			Verification		
			Water Level	Discharge	Salinity	Water Level	Discharge	Salinity
Cai Lon	CL	River	X		X	X		X
Can Tho	CT	River	X	X		X	X	
Cao Lanh	CL	River	X		X			
Chau Doc	CD	River	X	X			X	
Dai Ngai	DN	River	X		X	X		X
Go Quao	GQ	Field	X		X	X		X
Hoa Binh	HB	River			X			
Kien Luong	KL	Field	X			X		
Long Xuyen	LX	River	X			X		
My Tho	MO	River			X			
My Thuan	MT	River	X			X		
Quan Lo-PH	QH	Field	X		X	X		
Rach Gia	RG	Field	X			X		
Soc Trang	ST	Field	X		X	X		X
Tan Chau	TC	River	X			X	X	
Tra Kha	TK	Field						X
Tra Vinh	TV	River	X		X	X		X
Vam Nao	VN	River	X	X			X	
Vi Thanh	VT	Field	X			X		

4.2.1 Model Setup

In the study, two modules in MIKE 11 (i.e., HD and AD modules) were applied to simulate salinity distribution in main rivers in MD. In the HD module, two sets of input data were required for the module: (i) the configuration and dimension of river network, including control structures and their operation procedure, (ii) time series data (water level and discharge) and initial conditions at boundaries. The HD module was defined by six time series of discharge at the upstream points. Two of them locate in the main Mekong River of MD (Kratie and Prekdam) and eighty-two time series of water level at the downstream points in the South China Sea and Gulf of Thailand. Those boundary conditions were then altered to project sea level rise and river flow rate reducing. In the AD module, a constant of zero salinity was imposed at six upstream discharge boundaries while time series of salinity was set up at eighty-two downstream boundaries. The time step of $\Delta t=2$ minutes and maximum horizontal grid space of $\Delta x=750$m with the cross sectional profile at each 1km and 3km. The model included saline control structures which were constructed up to 2005 as Figure 4.2. Inputs of the model were collected from SIWRR.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

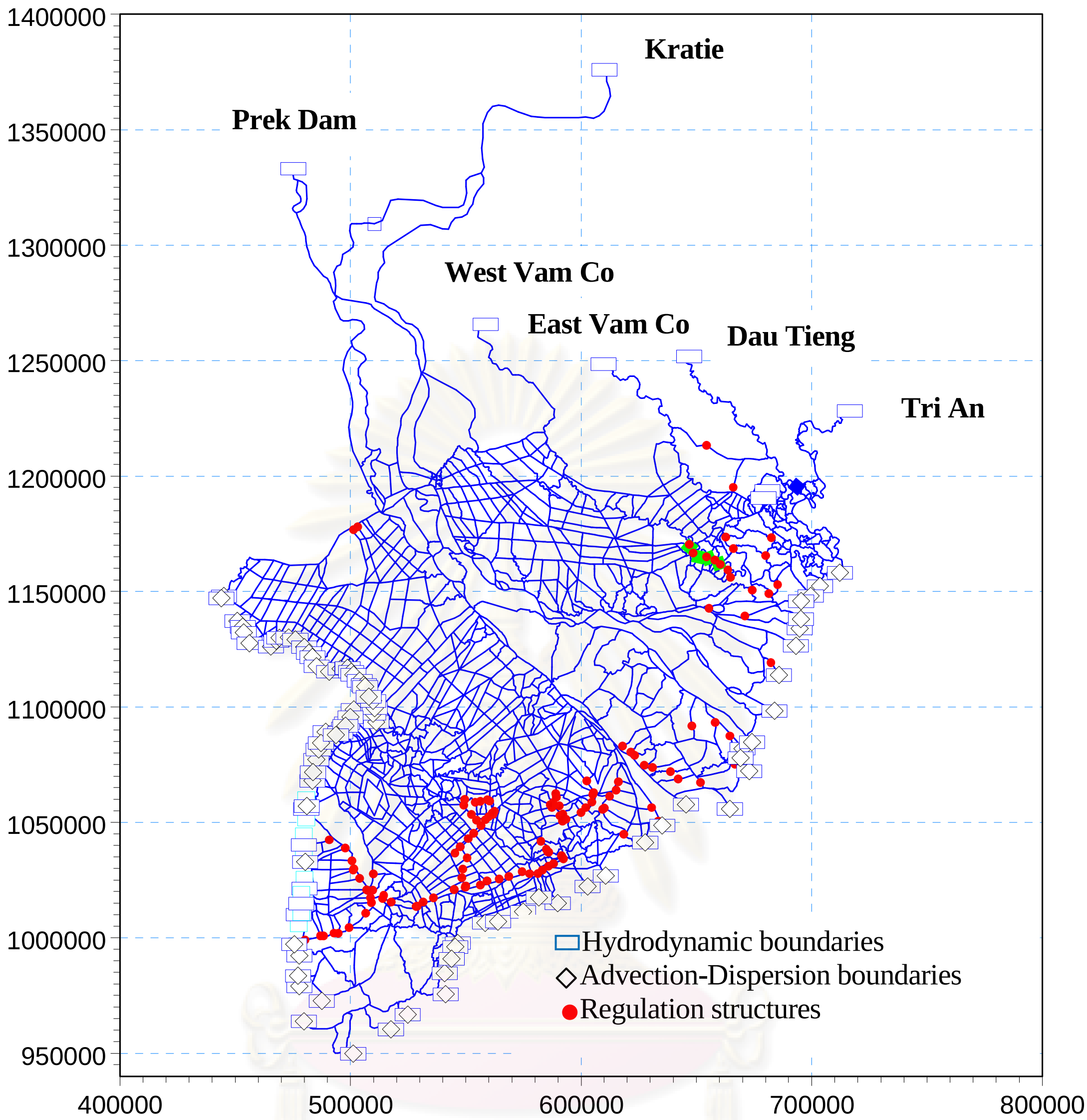


Figure 4. 2. River network and boundaries of the year 2005

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

4.2.2 Investigation of Salinity Intrusion in the Year 1998 (Calibration Model)

Salinity simulation in the year 1998 was applied the river network and boundaries as Figure 4.3.

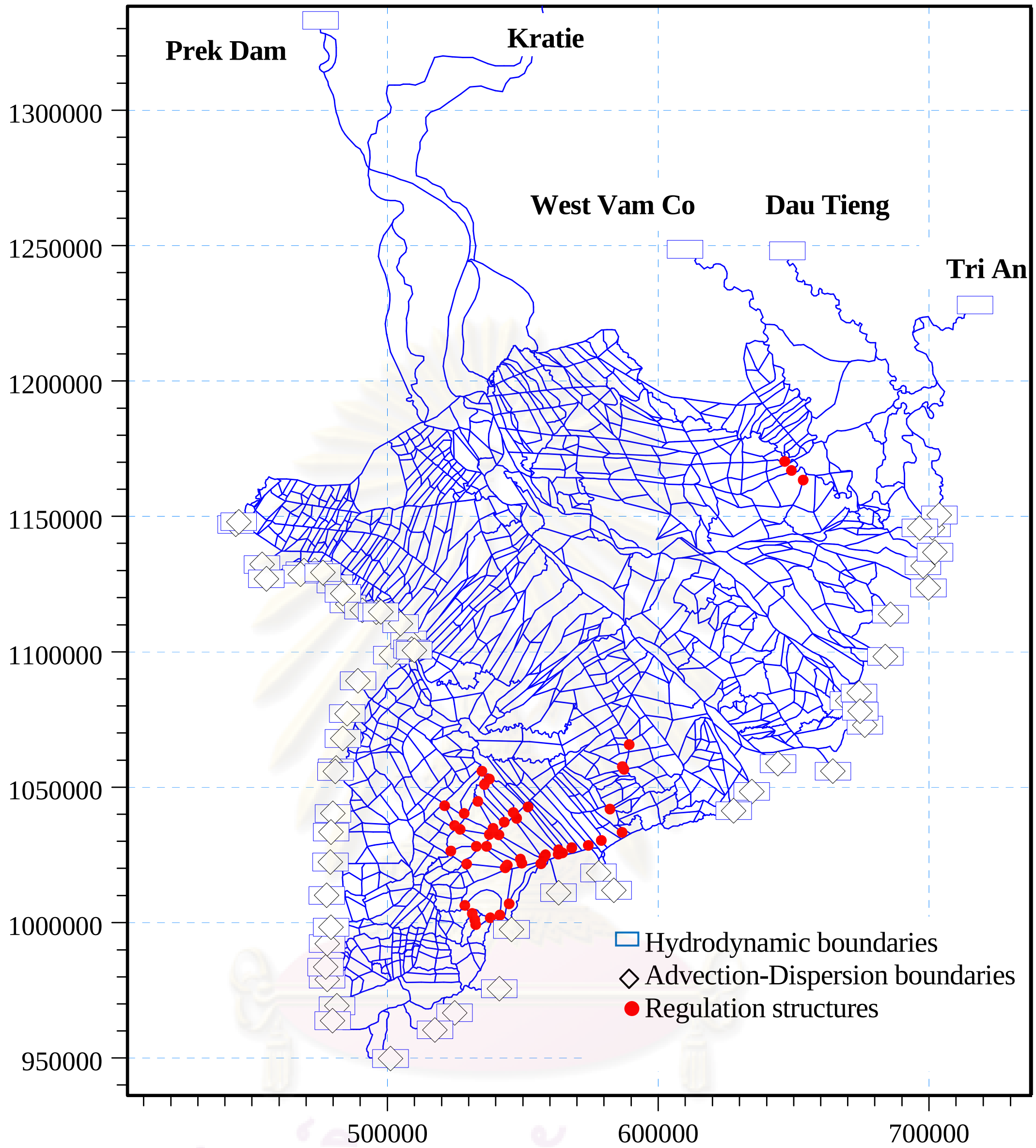


Figure 4. 3. River network and boundaries of the year 1998

4.2.2.1. HD Module

Firstly, the HD module was calibrated by adjustment or turning model parameters (i.e. Manning' coefficient) that were allowed within the range of experimentally determined reported in literature review as Table 2.1 until simulation results fixed well with observation results at different stations along the Mekong River and the Basac River. The calibration HD model obtains Manning's friction ranging from 0.03 to 0.018. From Figure 4.4 to Figure 4.13 calibration results are shown for DN station (about 35 km from the river mouth), TV station (about 25 km from the river mouth), MO station (about 50 km from the river mouth), MT station (station (about 127 km from the river mouth), CT station (about 90 km from the river mouth), CL station (about 175km from the river mouth), LX station (about 180 km from the river mouth), VN station (about 210 km from the river mouth), TC station (about 230 km from the river mouth) and CD station (about 220 km from the river mouth). Those indicate that simulation results are fixed well with observation data. All Correlation coefficient R between observation results and simulation results are greater than 0.85.

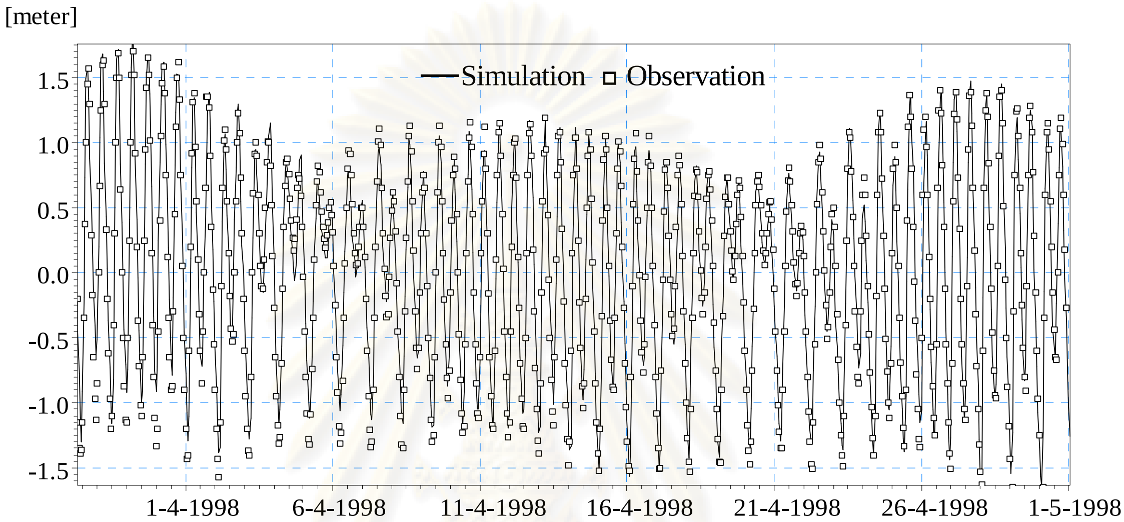


Figure 4. 4. Comparison of water level between simulation result and observation result at DN station (R=0.95)

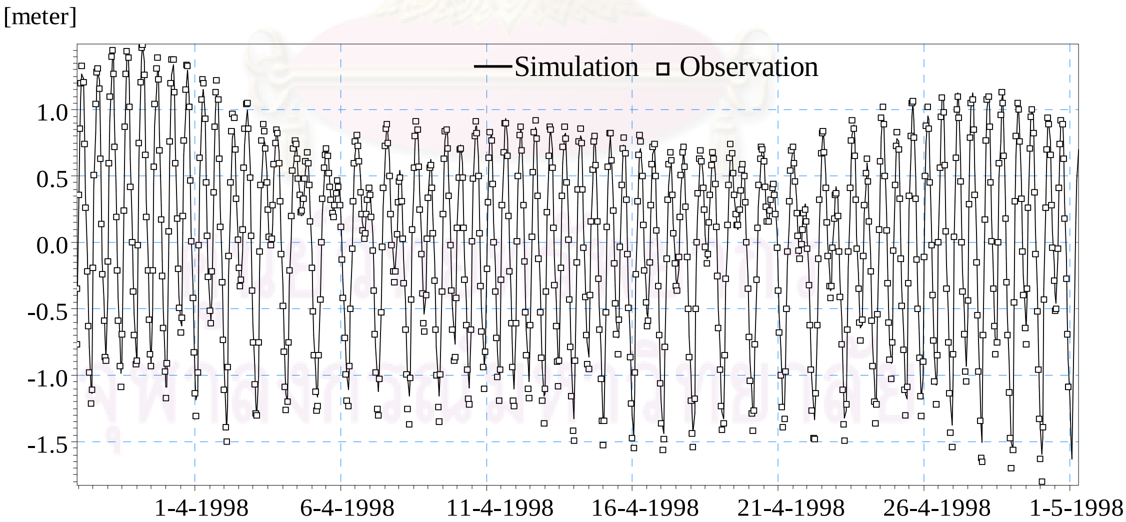


Figure 4. 5. Comparison of water level between simulation result and observation result at TV station (R=0.97)

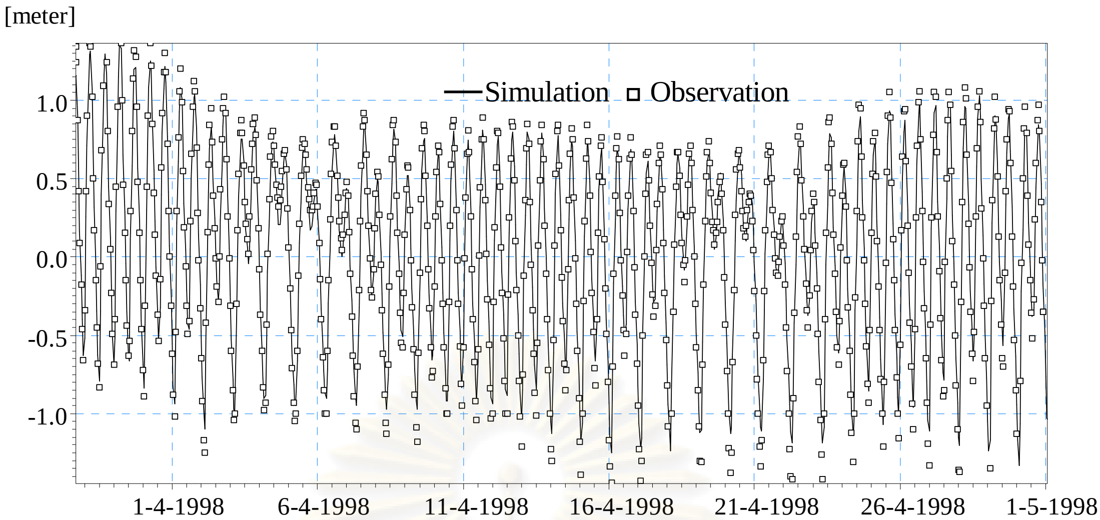


Figure 4. 6. Comparison of water level between simulation result and observation result at MO station (R=0.99)

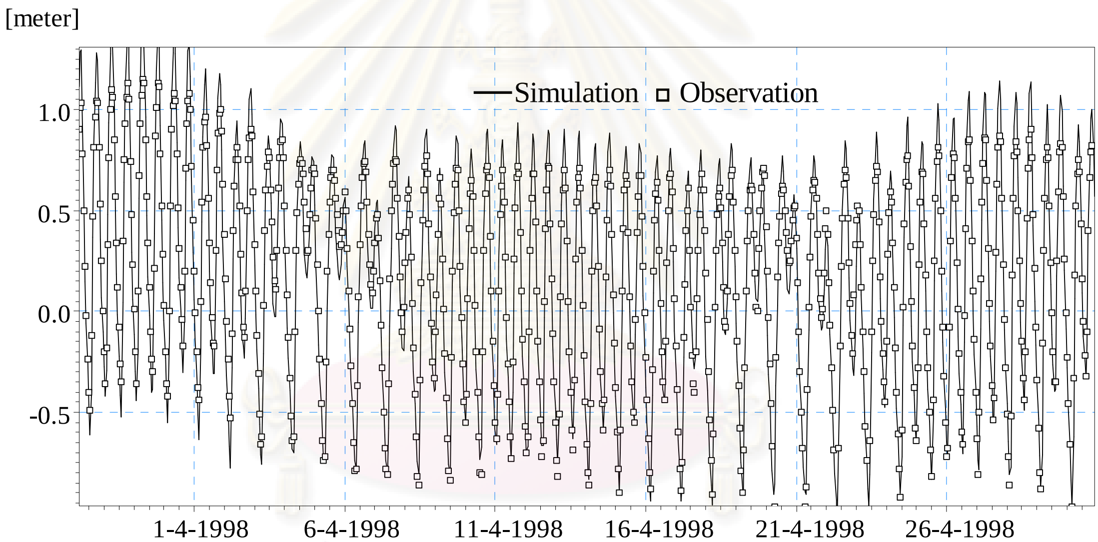


Figure 4. 7. Comparison of water level between simulation result and observation result at MT station (R=0.97)

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

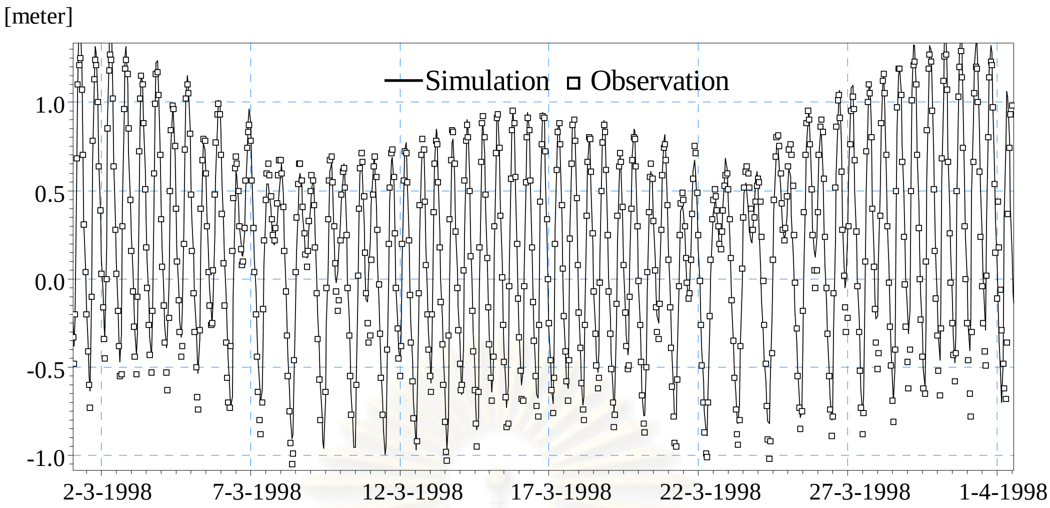


Figure 4. 8. Comparison of water level between simulation result and observation result at CT station (R=0.95)

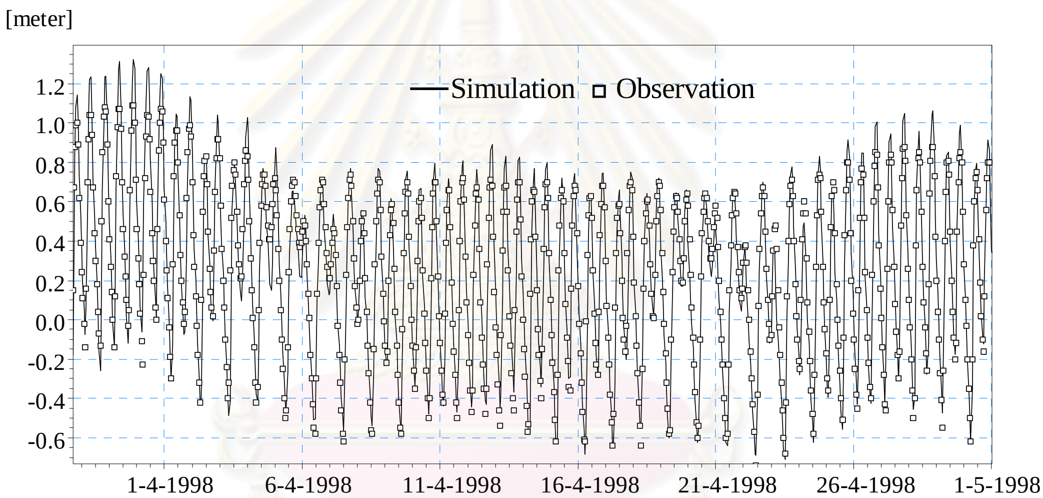


Figure 4. 9. Comparison of water level between simulation result and observation result at LX station (R=0.95)

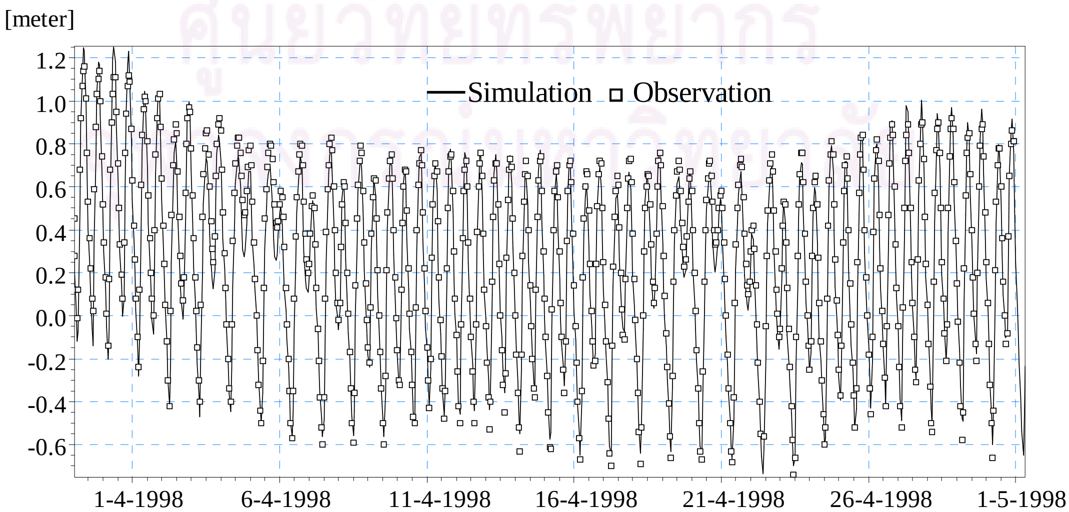


Figure 4. 10. Comparison of water level between simulation result and observation result at CL station (R=0.97)

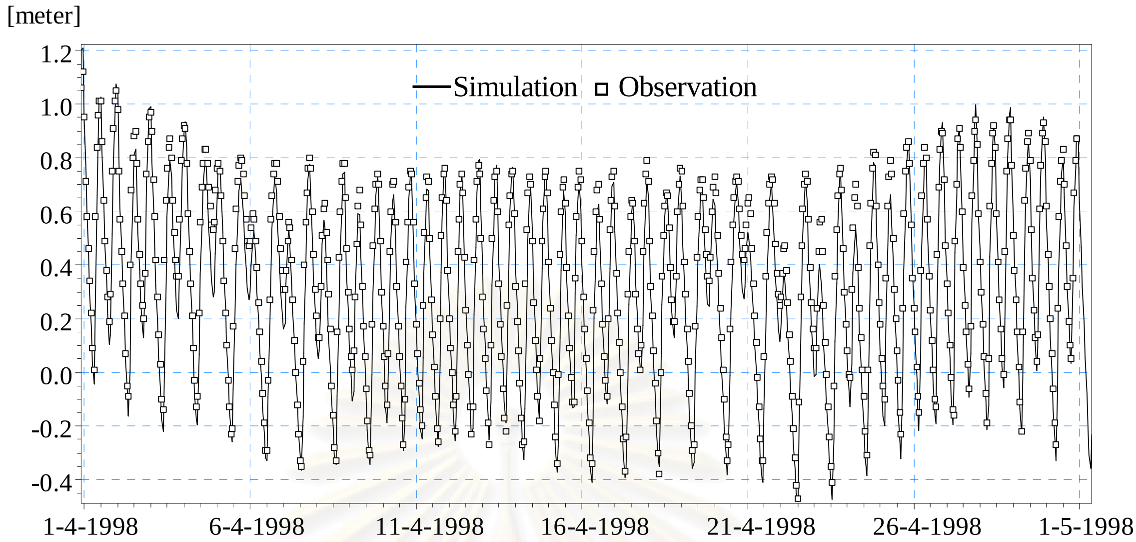


Figure 4. 11. Comparison of water level between simulation result and observation result at VN station (R=0.97)

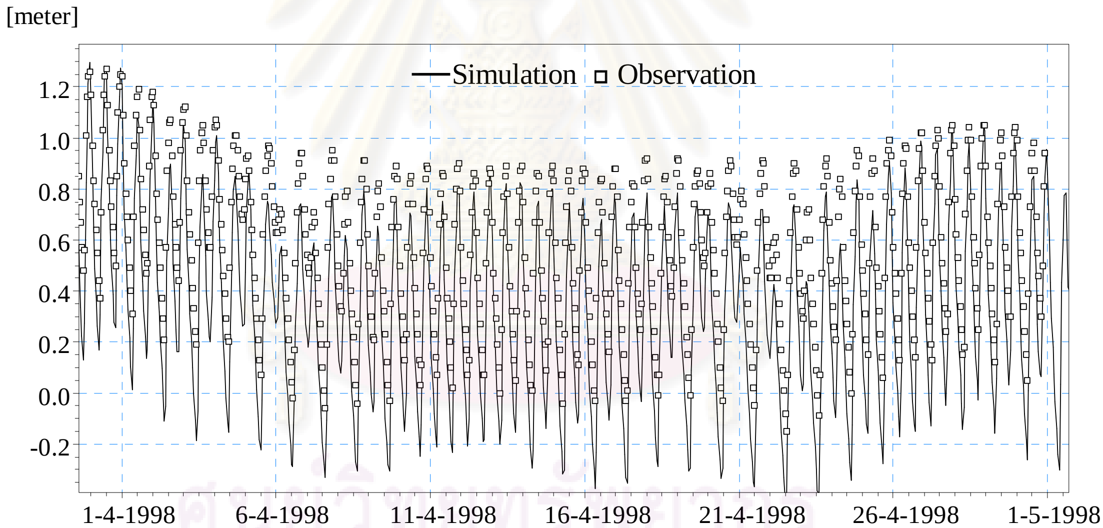


Figure 4. 12. Comparison of water level between simulation result and observation result at TC station (R=0.89)

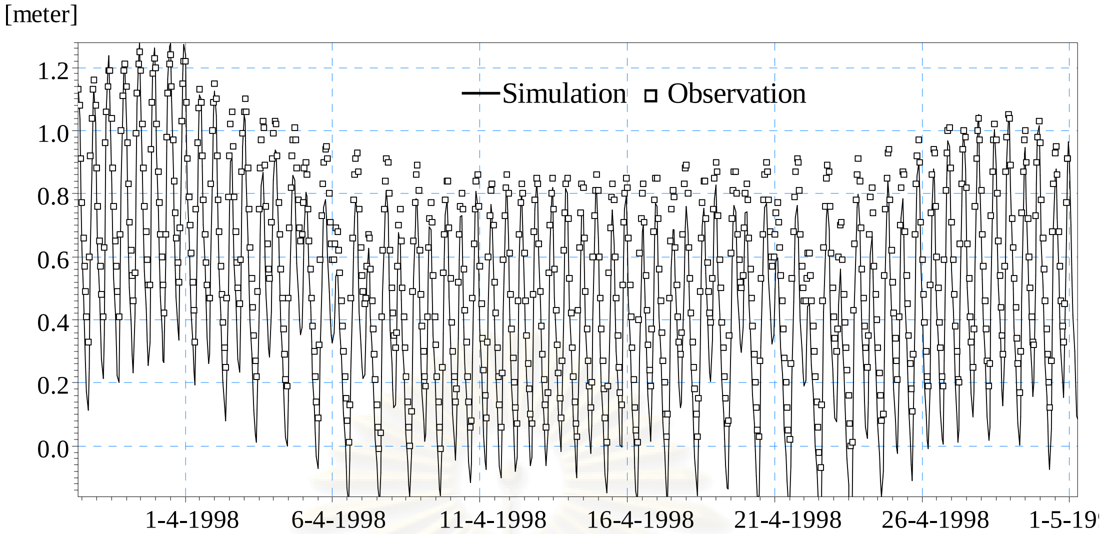


Figure 4. 13. Comparison of water level between simulation result and observation result at CD station (R=0.87)

4.2.2.2. AD Module

Salinity data in 1998 was used to calibrate AD model. Calibration results of DN station (about 50km from the river mouth), TV station (about 22km from the river mouth), HB station (about 25km from the river mouth) and MO station (about 60km from the river mouth) are shown in Figure 4.14, Figure 4.15, Figure 4.16 and Figure 4.17. The calibration AD model has Advection-Dispersion coefficient ranging from 700 to 300 m/s^2 for Mekong River and from 125 to 50 for other rivers into MD. To verify the AD model, the field measurement and computed salinity concentration values in the year 2005 were compared. AD module calibration is more complicated than HD model because salinity intrusion in MD are influenced by many factors such as monsoon wind (ignore in the model), water consumption into the delta, operation of saline control structures. Moreover, saline distribution in the AD model is very sensitive with Advection-Dispersion coefficient. The river network of MD is dense; therefore, it is difficult to find out appropriate Advection-Dispersion coefficients for every river or segment of river as well as canal into the MD. Besides, shortage of salinity data for calibration and verification the AD model were also a concern in this study. Especially, salinity data for calibration (in 1998) was not measured continuously. It was observed in high tidal time. Although, the model simulated salinity intrusion with acceptable accuracy from Figure 4.14 to Figure 4.17, showing comparative salinity values of simulation and observation at difference time in 1998. The result indicates that the AD model was simulated quite well in the trend of salinity intrusion in MD in dry season 1998.

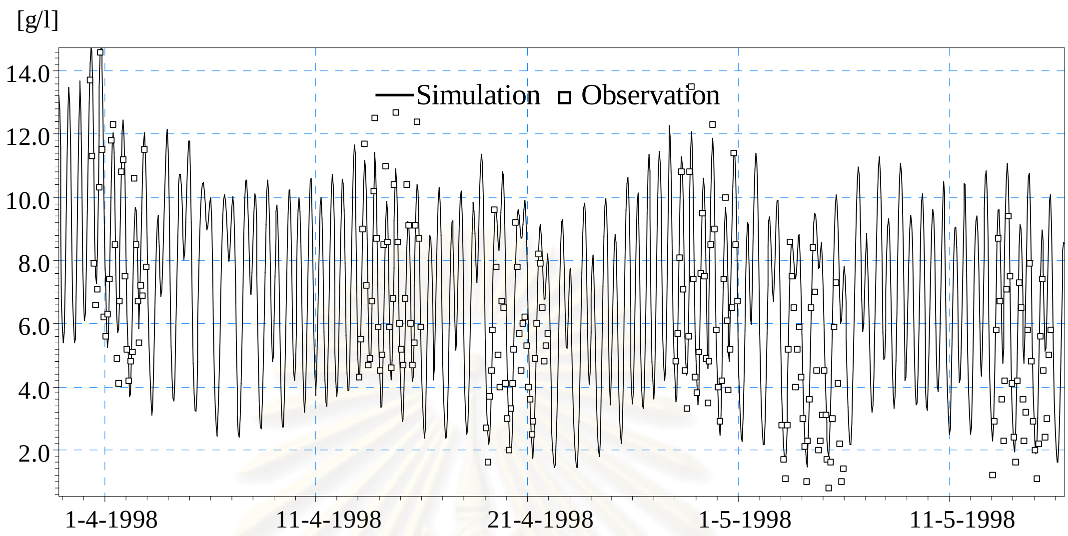


Figure 4. 14. Comparison of salinity concentration between simulation result and observation result at DN station (R=0.817)

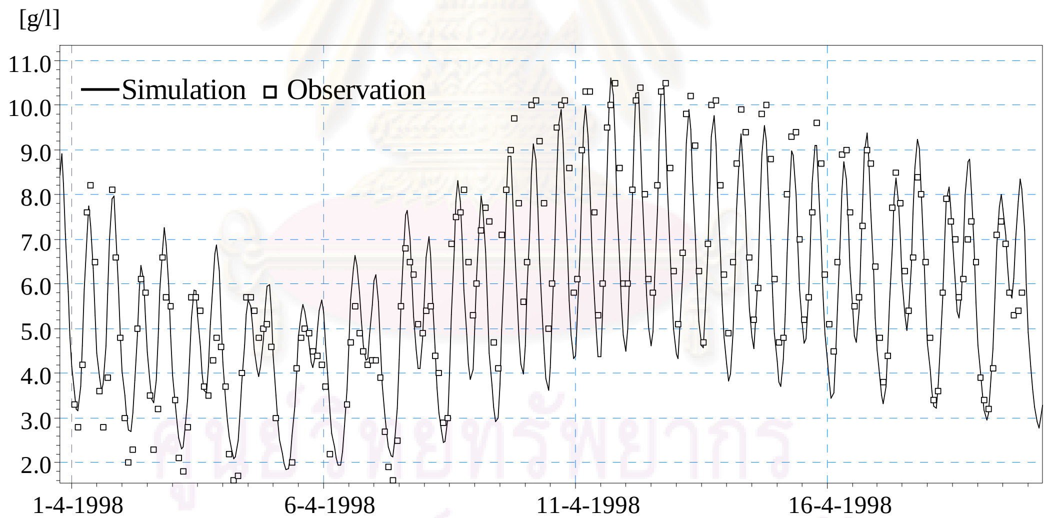


Figure 4. 15. Comparison of salinity concentration between simulation result and observation result at TV station (R=0.89)

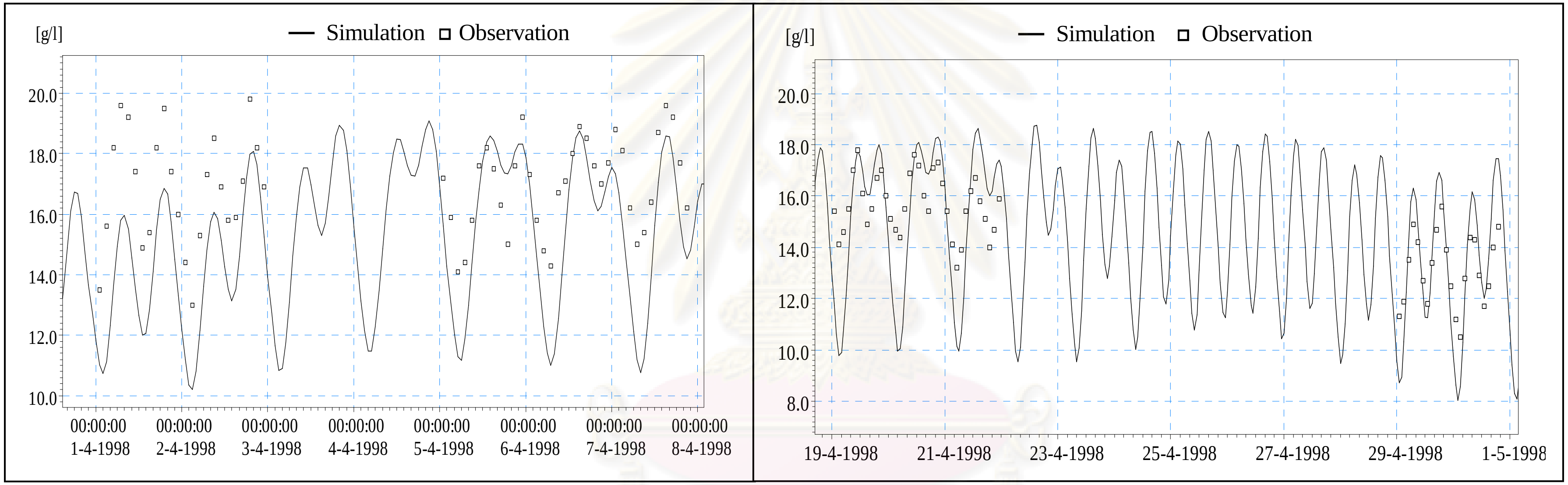


Figure 4. 16. Comparison of salinity concentration between simulation result and observation result at HB station (R=0.82)

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

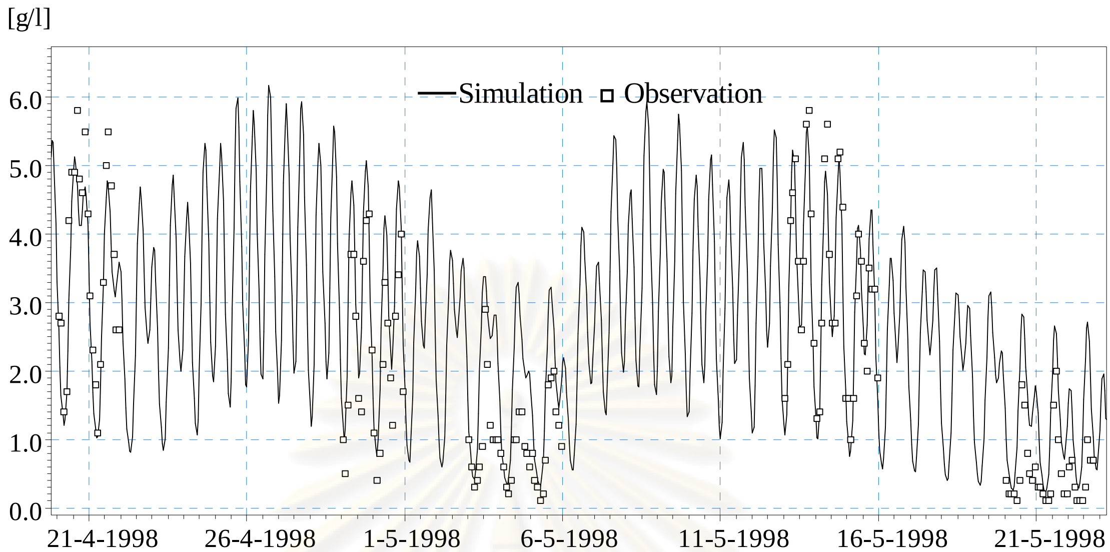


Figure 4. 17. Comparison of salinity concentration between simulation result and observation result at MO station (R=0.89)

4.2.3 Investigation of Salinity Intrusion in 2005

Verification model was performed by using data in 2005. The model was run with database in 2005 and all of parameters that were achieved in the calibration steps. Then simulation results were compared with observation results at different stations in main rivers as Table 4.9. If simulation results fix well with observation results, the model can be used to simulate scenarios otherwise the calibration steps need to be carried out again.

From 1999 to 2007, the cooperation between Vietnam Government and World Bank established "MD Water Resources Project". The project adopted the approach of integrated water resources planning and management. Many canals and saline water intrusion control structures were constructed (as Figure 4.2). Most of them were finished in 2005. As a result, the water regime of MD changed and salinity intrusion pattern was changed too. Therefore, the model needed to be verified with database in 2005 before applied to simulation with scenarios.

4.2.4.1 HD Module

The HD module was verified with database in 2005. Results were shown from Figure 4.19 to Figure 4.26. Those results indicate that HD module is stable. Therefore, we can use all of HD parameters that were obtained in the calibration process for verification steps.

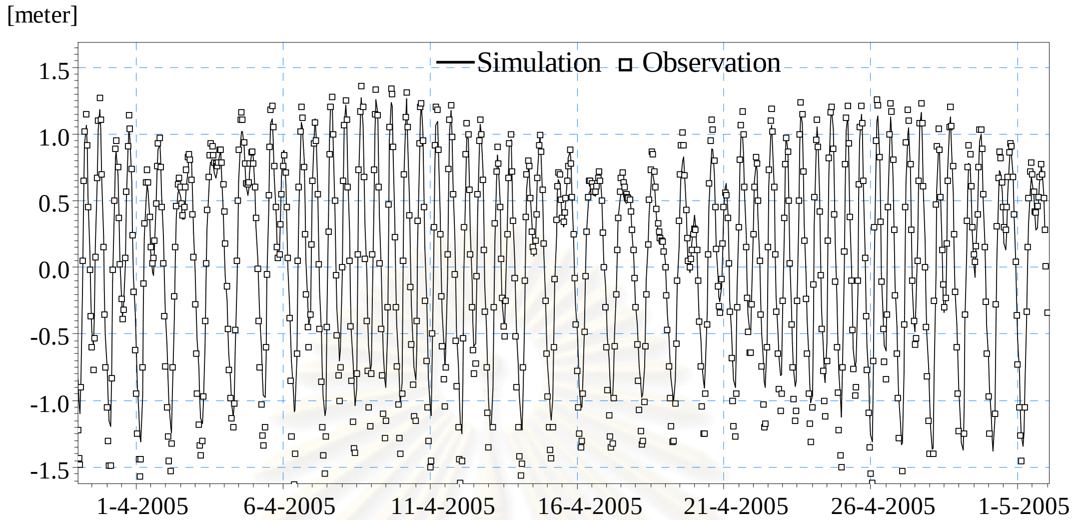


Figure 4. 18. Comparison of salinity concentration between simulation result and observation result at DN station (R=0.98)

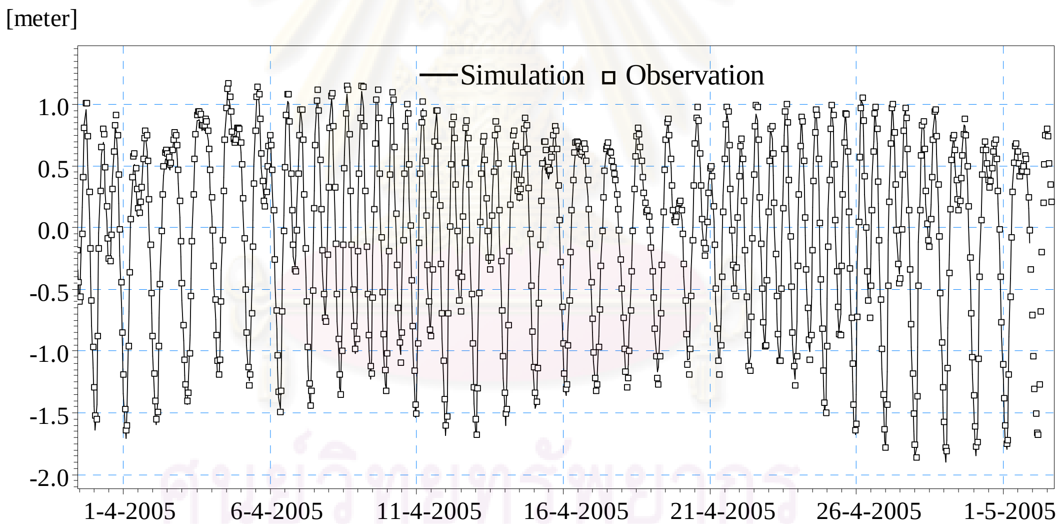


Figure 4. 19. Comparison of water level between simulation result and observation result at TV station (R=0.98)

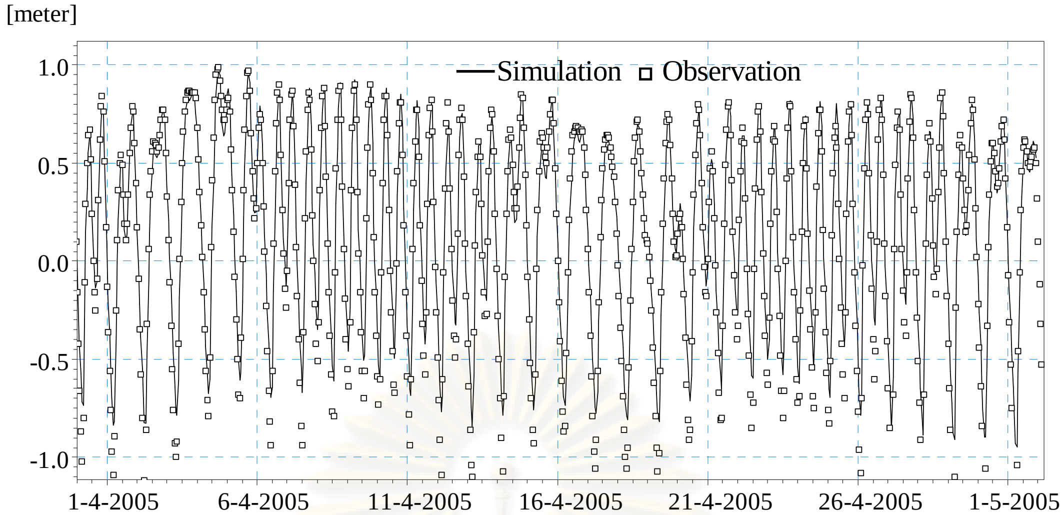


Figure 4. 20. Comparison of water level between simulation result and observation result at MT station (R=0.97)

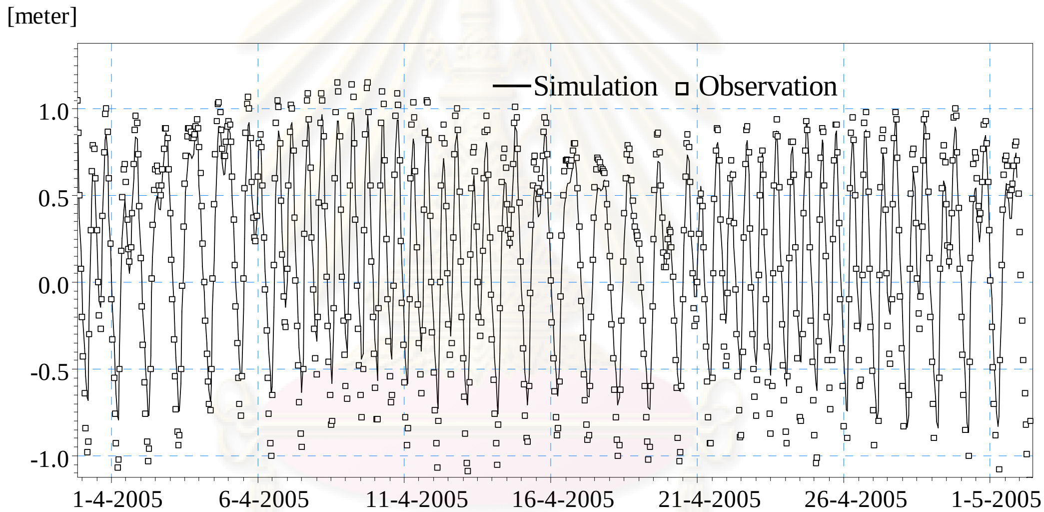


Figure 4. 21. Comparison of water level between observation and simulation result at CT station (R=0.95)

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

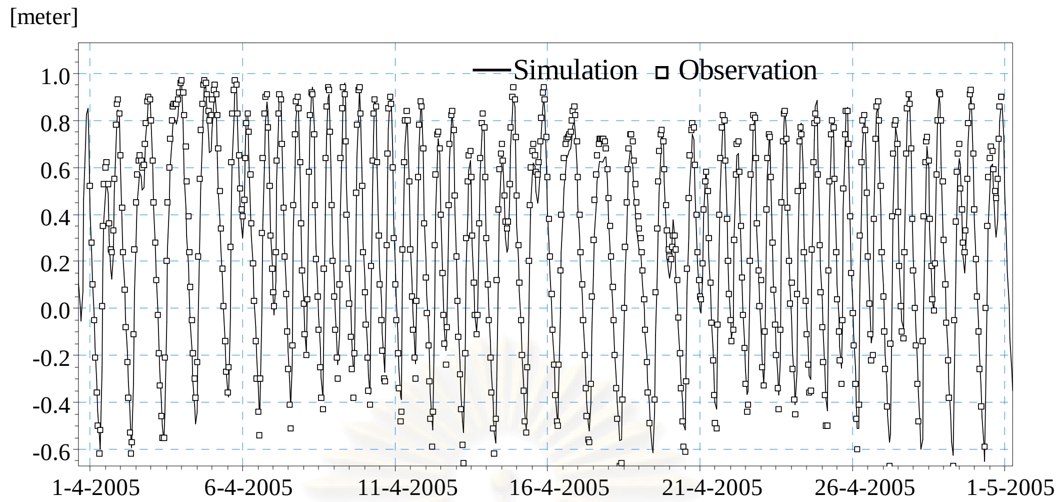


Figure 4. 22. Comparison of water level between observation and simulation result at LX station (R=0.97)

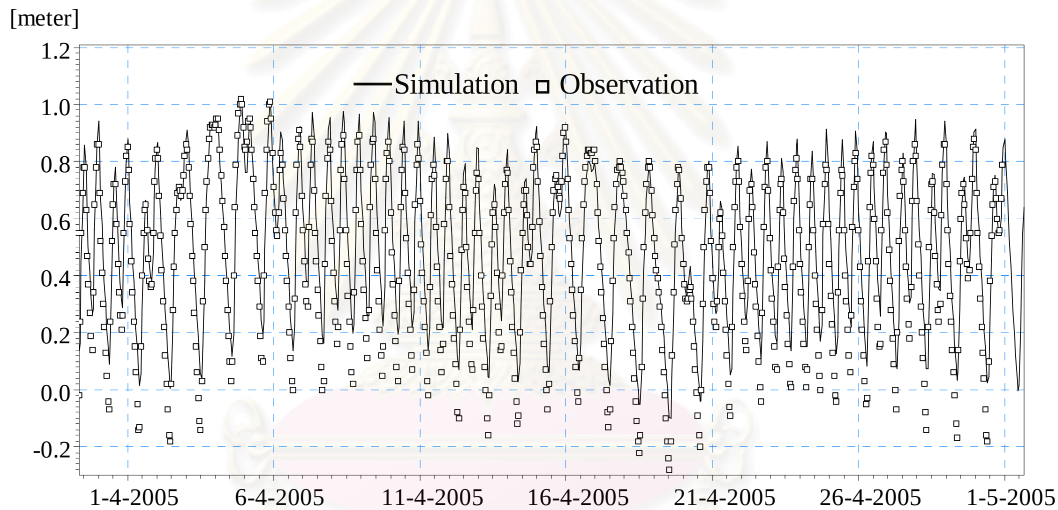


Figure 4. 23. Comparison of water level between observation and simulation result at TC station (R=0.94)

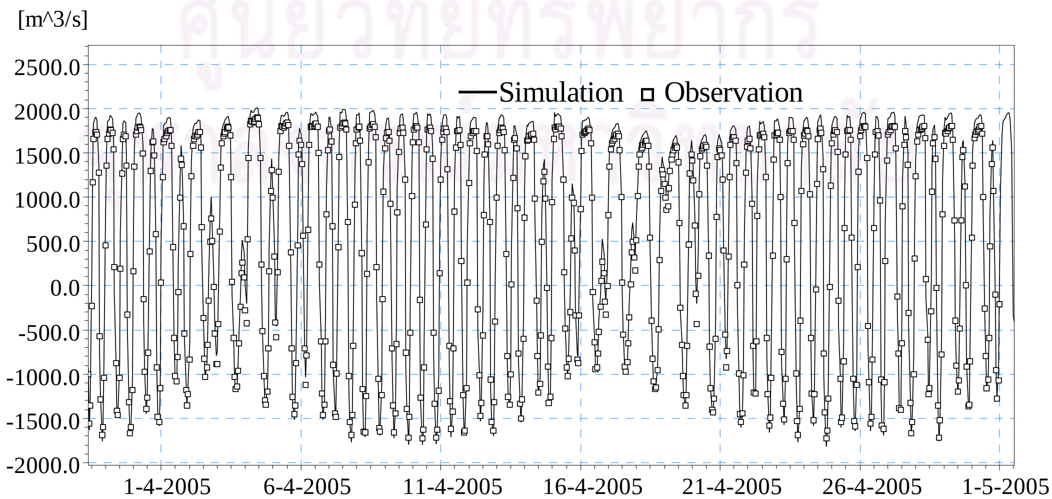


Figure 4. 24. Comparison of discharge between observation and simulation result at VN station (R=0.96)

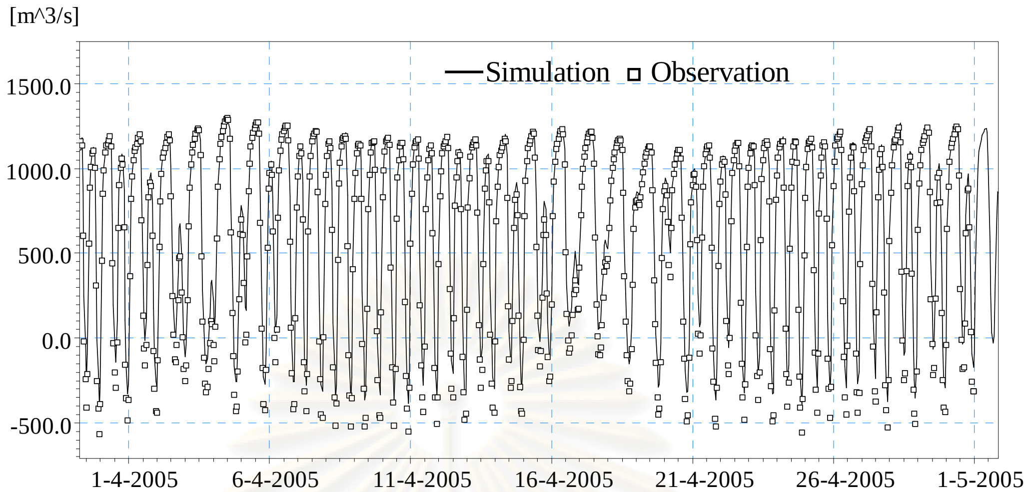


Figure 4. 25. Comparison of discharge level between observation and simulation result at CD station (R=0.87)

4.2.4.2 AD Module

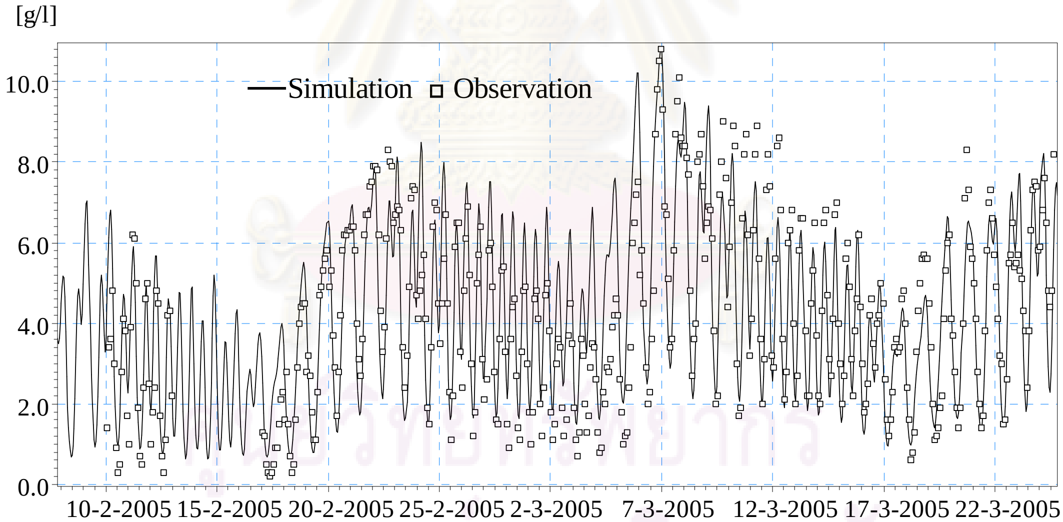


Figure 4. 26. Comparison of discharge level between observation and simulation result at MO station (R=0.835)

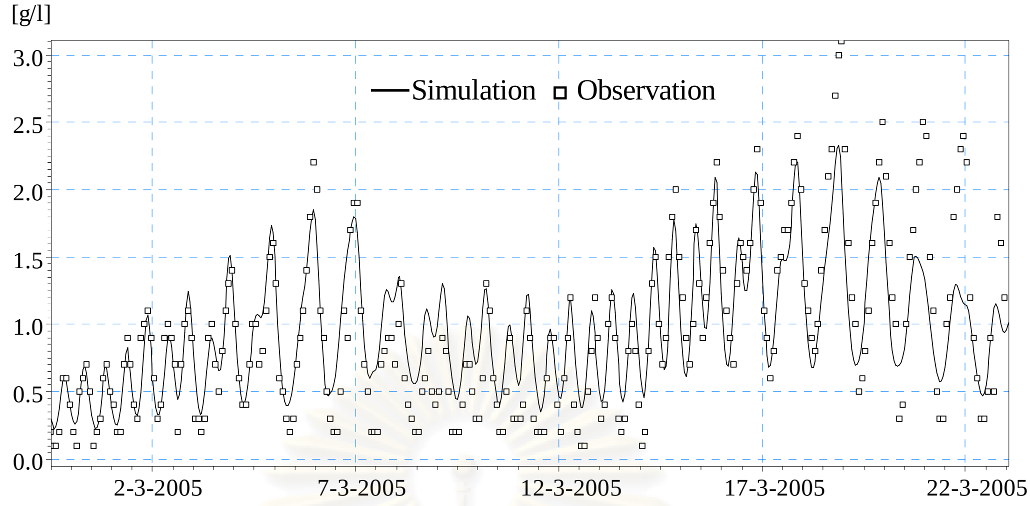


Figure 4. 27. Comparison of discharge level between observation and simulation result at TV station (R=0.87)

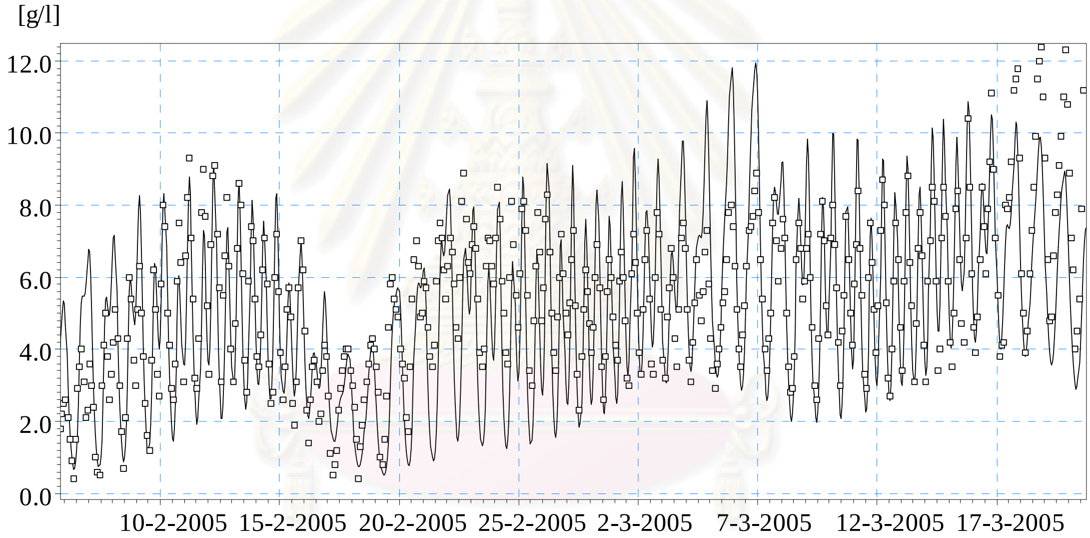


Figure 4. 28. Comparison of discharge level between observation and simulation result at HB station (R=0.812)

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

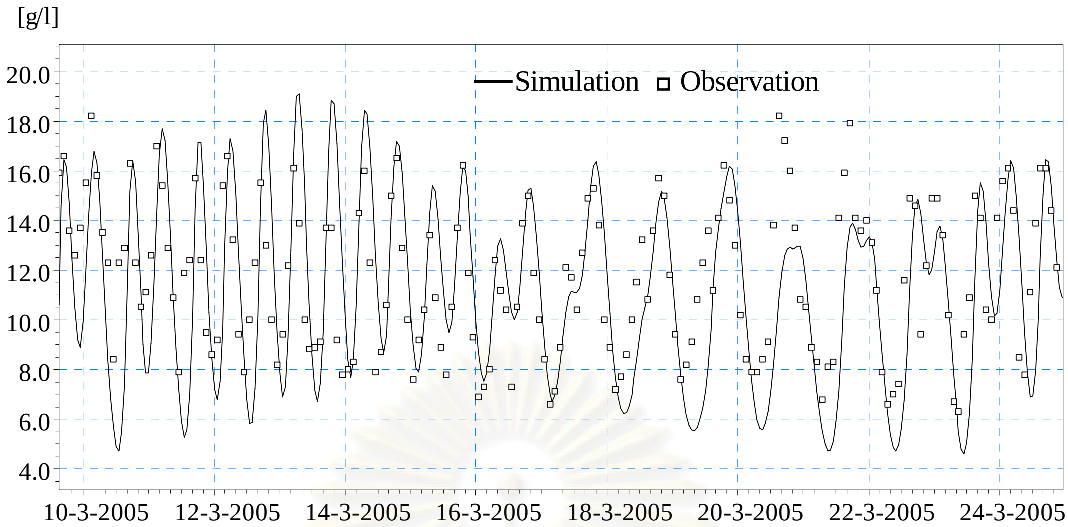


Figure 4. 29. Comparison of saline concentration between simulation and observation at TK (R=0.81)

Figure 4.26 to Figure 4.29 show that simulation provides good results with observation results. Therefore, the AD model can be used to simulate salinity intrusion with all AD parameters which were achieved from the calibration step.

4.2.4 Simulation Salinity Intrusion in the Year 2020 and 2030 with Scenarios

The model was used to project salinity intrusion in the year 2020 and 2030 with five scenarios that were mentioned in Chapter three.

4.2.4.1 Maximum Distance of Salinity Intrusion

In this study, Isohalines of 2.5ppt NaCl in river water is selected as threshold value for the irrigation water. This value is the salinity level that caused 25% rice yield conducted by US Department of Agriculture's Agricultural Research Service (Zeng and Shannon, 2000; Grattan et al., 2002). Longitudinal of salinity distribution in main branch of scenarios in Mekong River (Co Chien, Ham Luong and Tieu branches) and Bassac River (Dinh An branch) are displayed as Figure 4.30. The result indicated that salinity intrusion increases causing river flow reduction and sea level rise. The result also obtained, namely 2.5g/l saline likely shifted 15km to upstream in main rivers in comparison to serious salinity intrusion time in 1998 in recent decays.

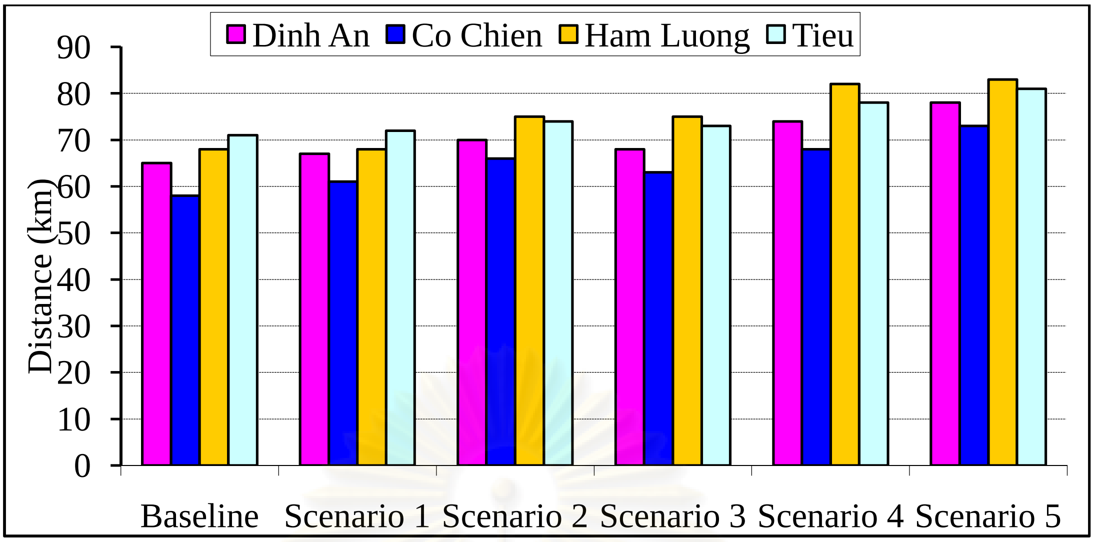


Figure 4. 30. Maximum distance of salinity intrusion (2.5g/l) upstream of the Mekong and the Bassac branches

4.2.4.2 Salinity Intrusion Areas

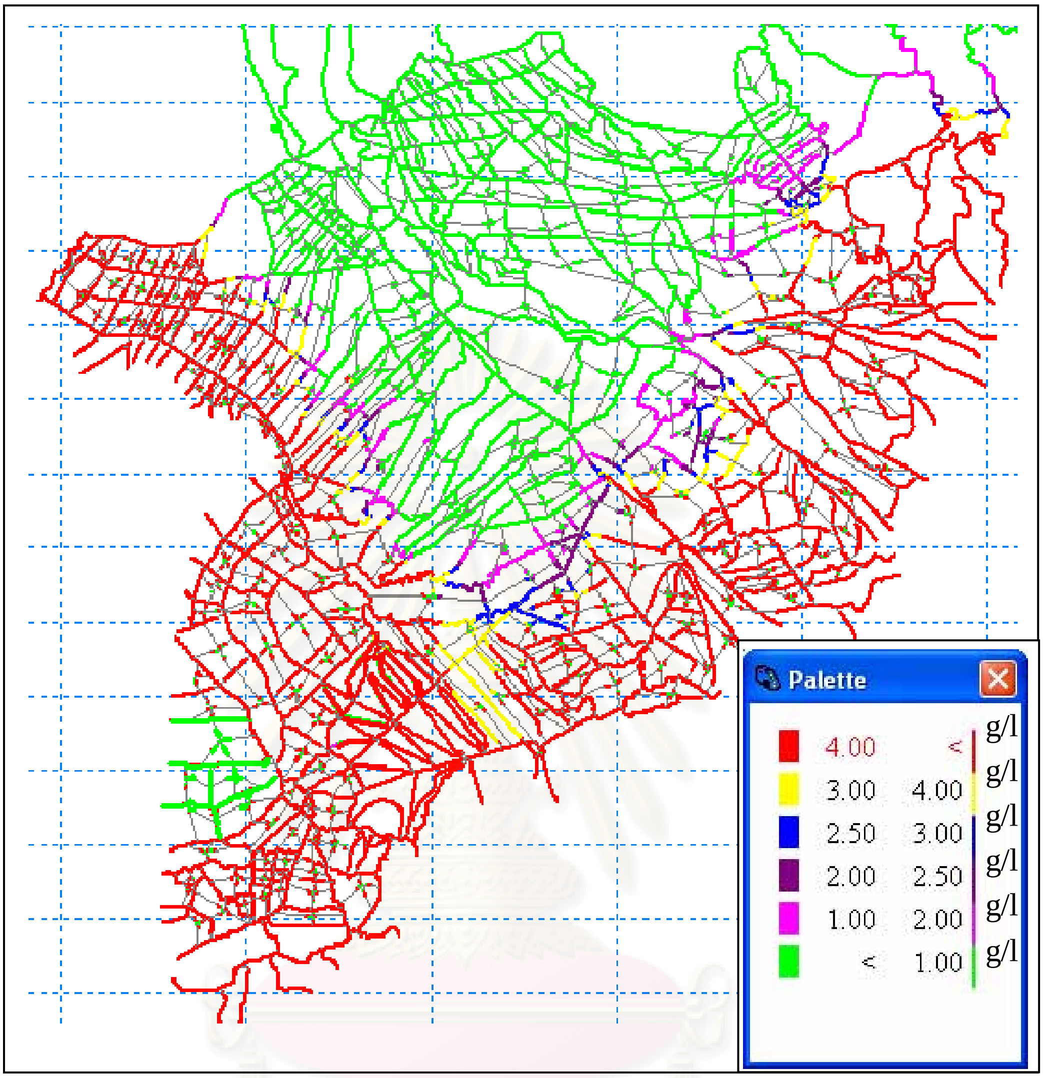


Figure 4. 31. Salinity intrusion area in baseline scenario

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

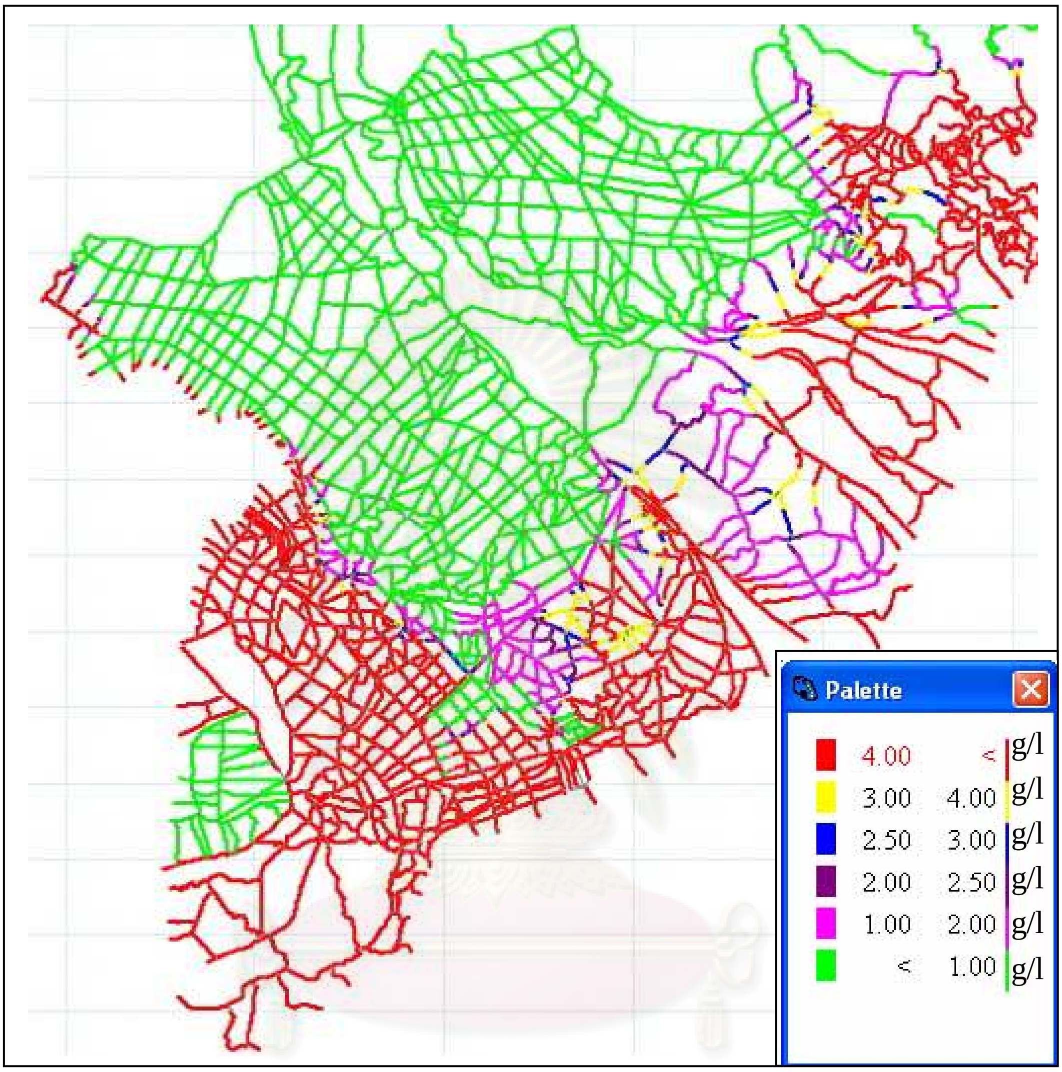
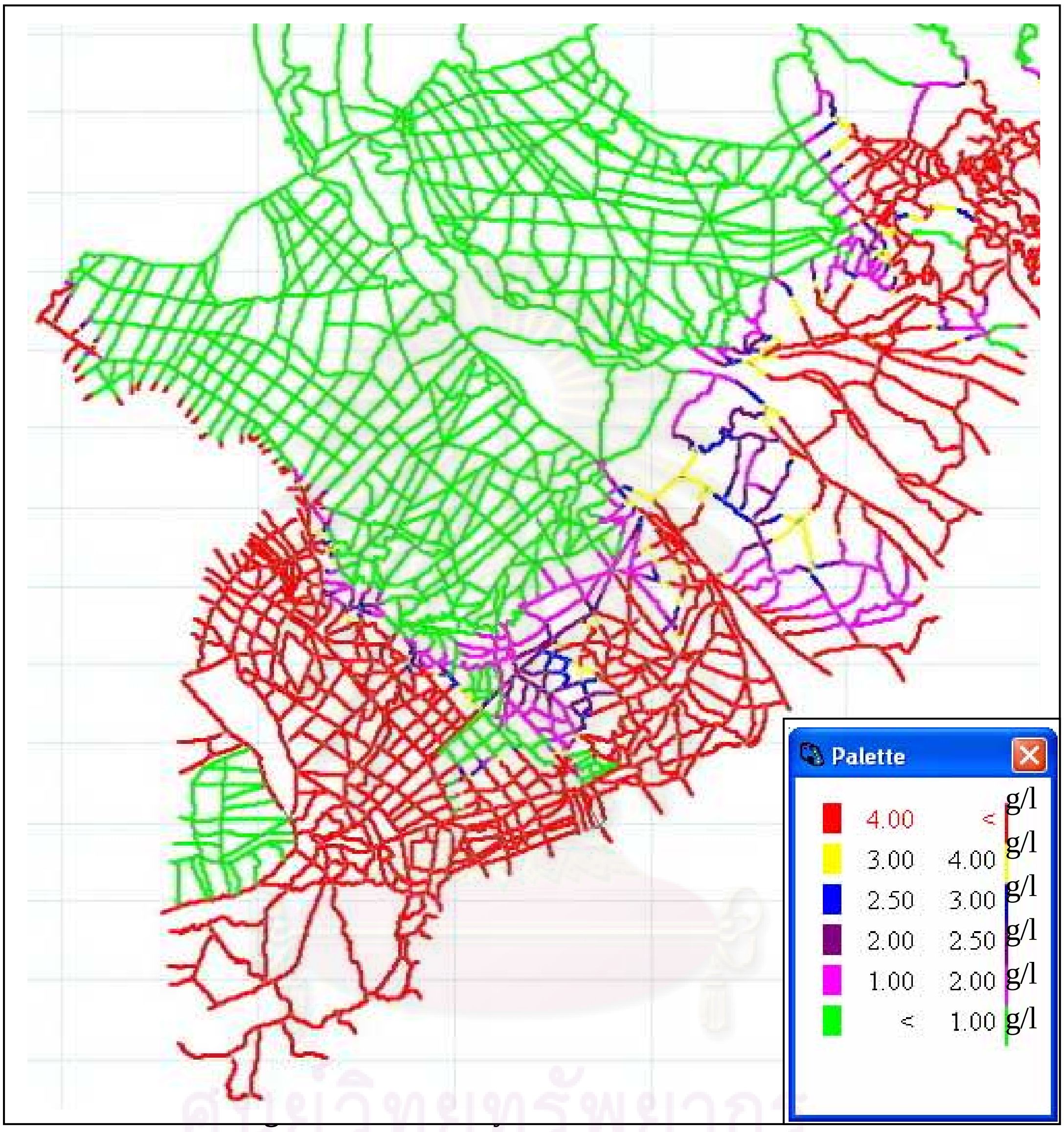


Figure 4. 32. Salinity intrusion area in scenario 1

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย



ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

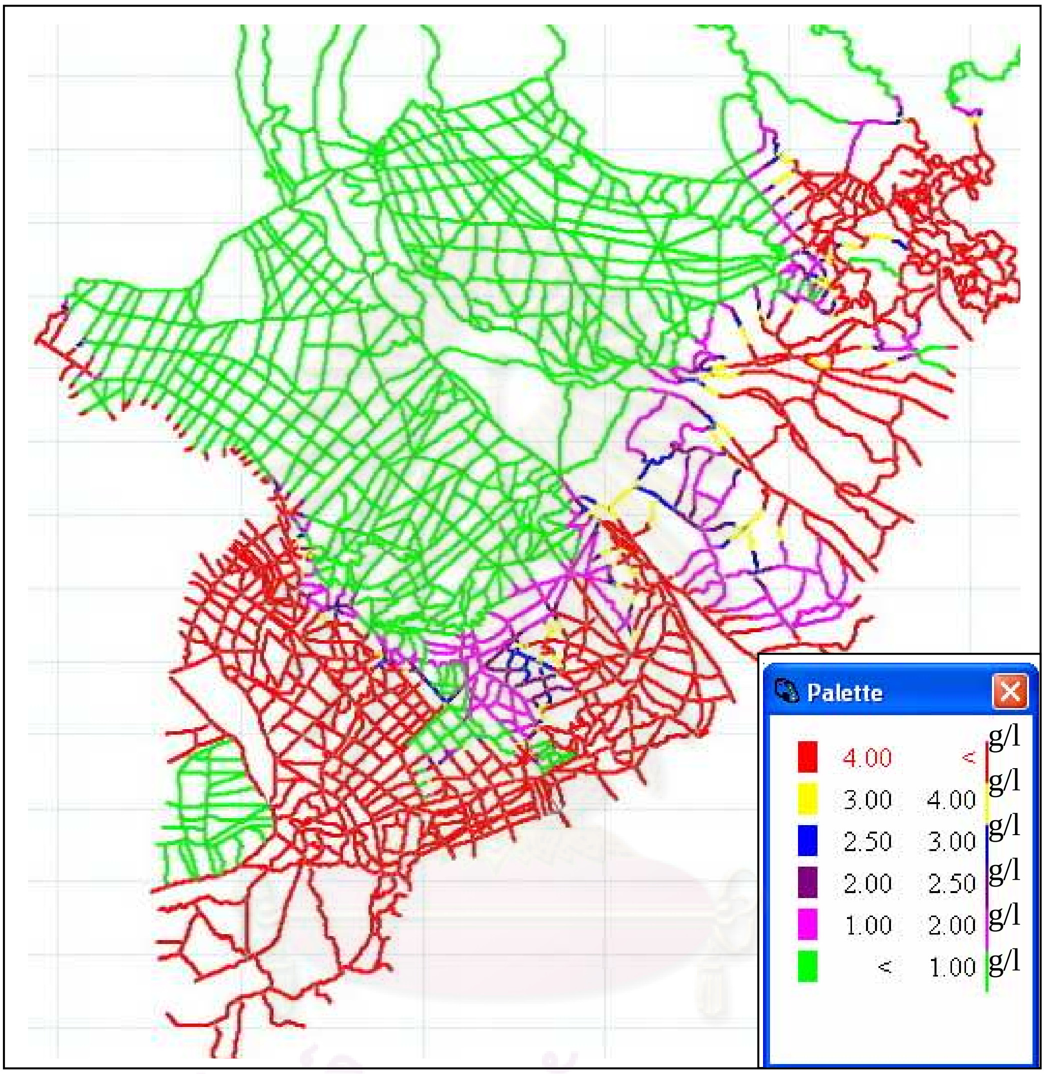


Figure 4. 34. Salinity intrusion area in scenario 3

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

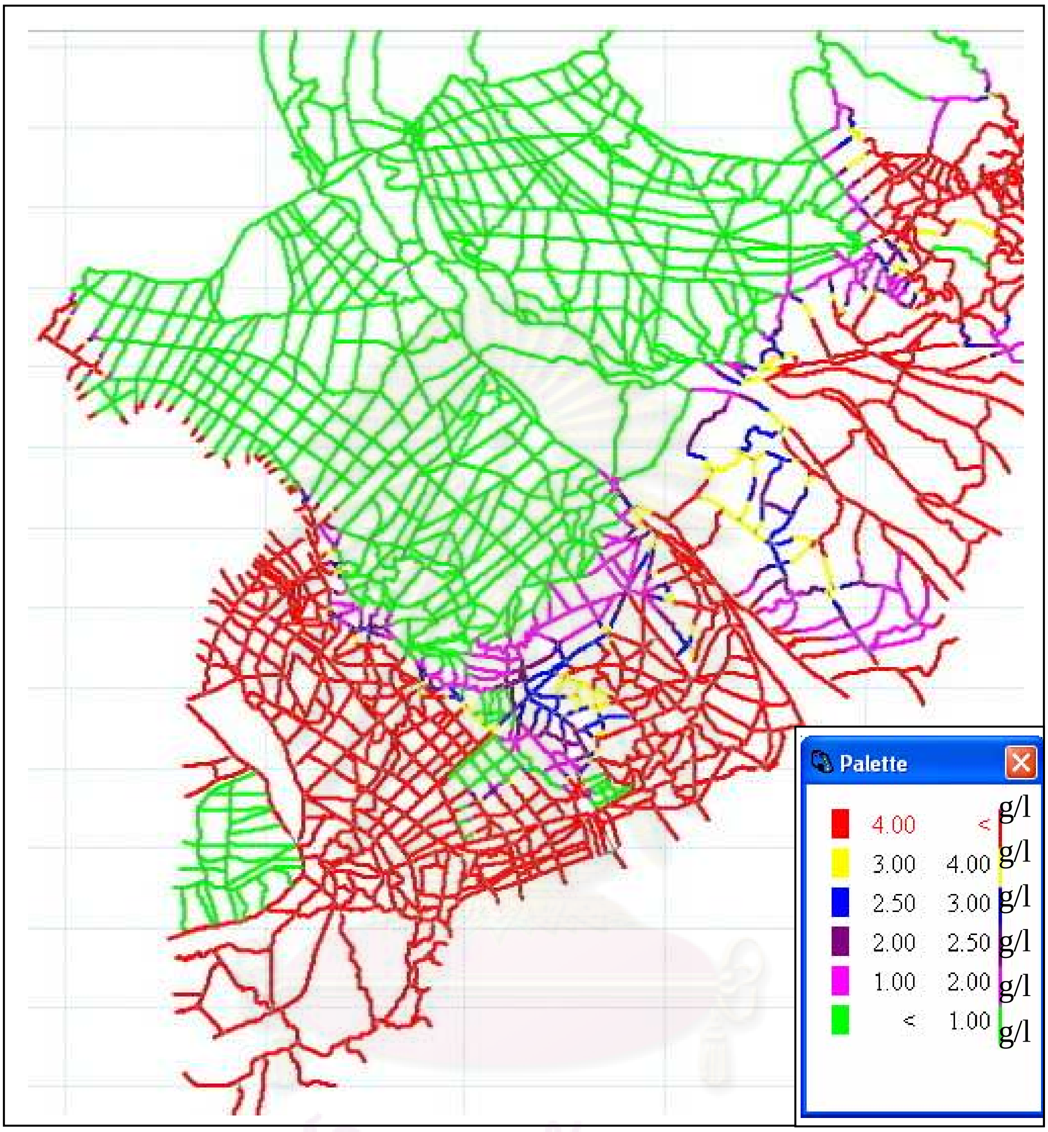


Figure 4. 35. Salinity intrusion area in scenario 4

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

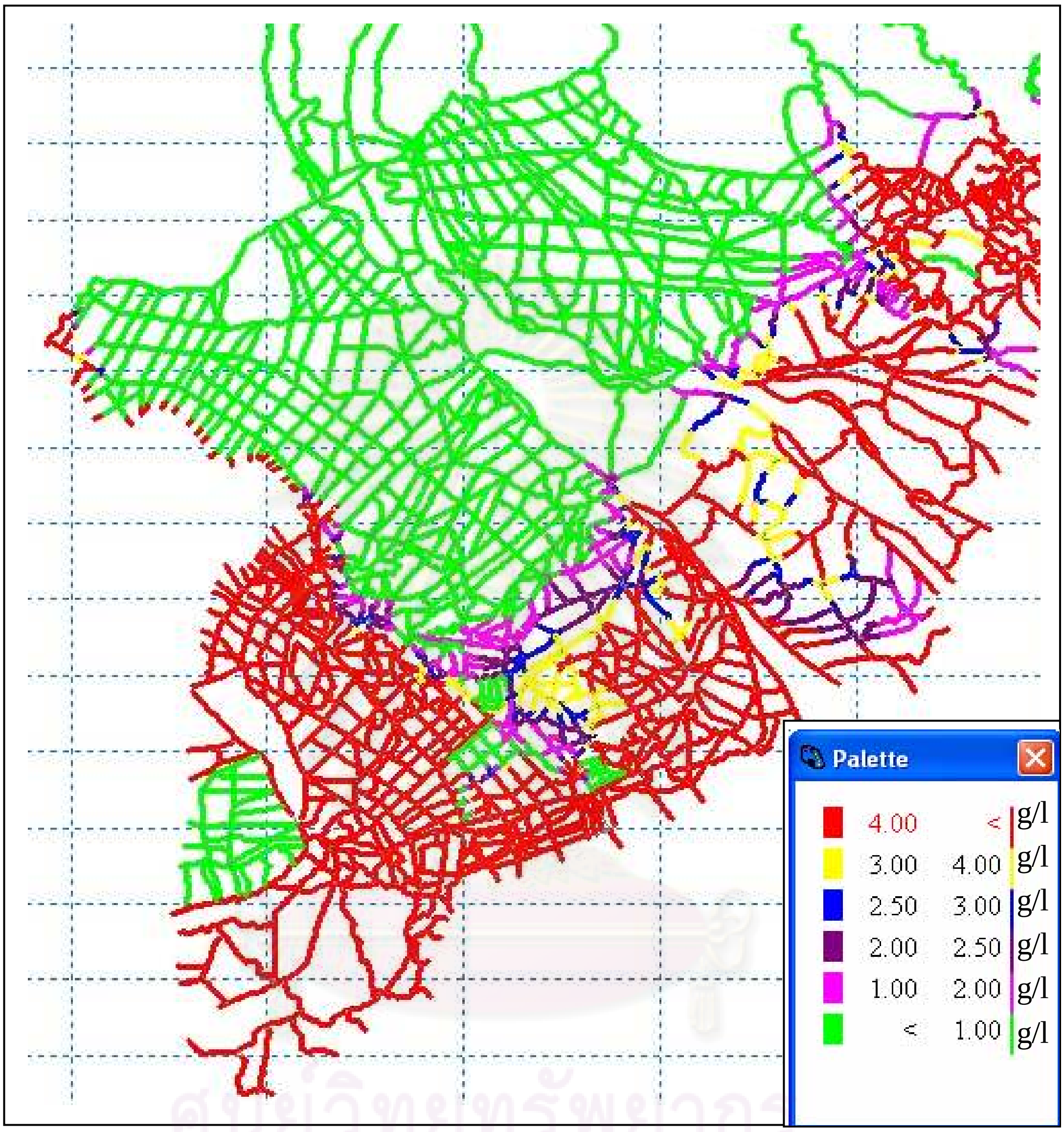


Figure 4. 36. Salinity intrusion area in scenario 5

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

The result of baseline scenario (Figure 4.31) indicates that saline concentration value of 2.5g/l effect most of Ca Mau Peninsular, Tra Vinh province, a segment of Vinh Long province and Ben Tre province. The 2.5g/l will reduce to intrude main rivers, canals and fields even water level rise and low river flow in comparison to the serious case in 1998 (see Figure 4.31 and 4.32). The situation can be explained by many saline control projects which were implemented from 1999. Those projects covered 534,860 ha and included three sub-projects as Figure 5.1 (i.e. Quan Lo-Phung Hiep, O Mon-Xa No and South Mang Thit sub-projects) (World Bank, 2008). Moreover, the results of scenarios showed saline concentration, 2.5g/l can expand to most of South Mang Thit and Quan Lo-Phung Hiep project as in Figure 4.33, 4.34, 4.35 and 4.36.

4.2.4.3. Relationship between Upstream Flow and Limit of Salinity Intrusion

The verified model was used to simulate several freshwater discharge scenarios to establish a relationship between freshwater discharge and the distance of salinity intrusion. The boundary conditions were kept the same case in 2005. Based on the predicted distance of salinity intrusion as a function of upstream flow of Mekong River at four estuaries of Mekong River in MD (Figure 4.37), a logarithmic least square regression fit is developed by assuming the salinity intrusion distance is logarithm that correlates with the upstream flow at Kratie. The trend correlations yielded the maximum of salinity intrusion distance (Y) and upstream flow of Mekong River (X) at each estuary

Tieu estuary $Y = -14.1\ln(X) + 148.7$ R^2=0.874

Dinh An estuary $Y = -27.3\ln(X) + 268.1$ R^2=0.992

Co Chien estuary $Y = -11.4\ln(X) + 127.6$ R^2=0.98

Ham Luong estuary $Y = -16.5\ln(X) + 179.1$ R^2=0.994

The high correlation coefficient reveals that upstream flow plays important role in salinity intrusion in the Mekong River into MD. The regression equations can be used as a simple tool for salinity prediction in MD.

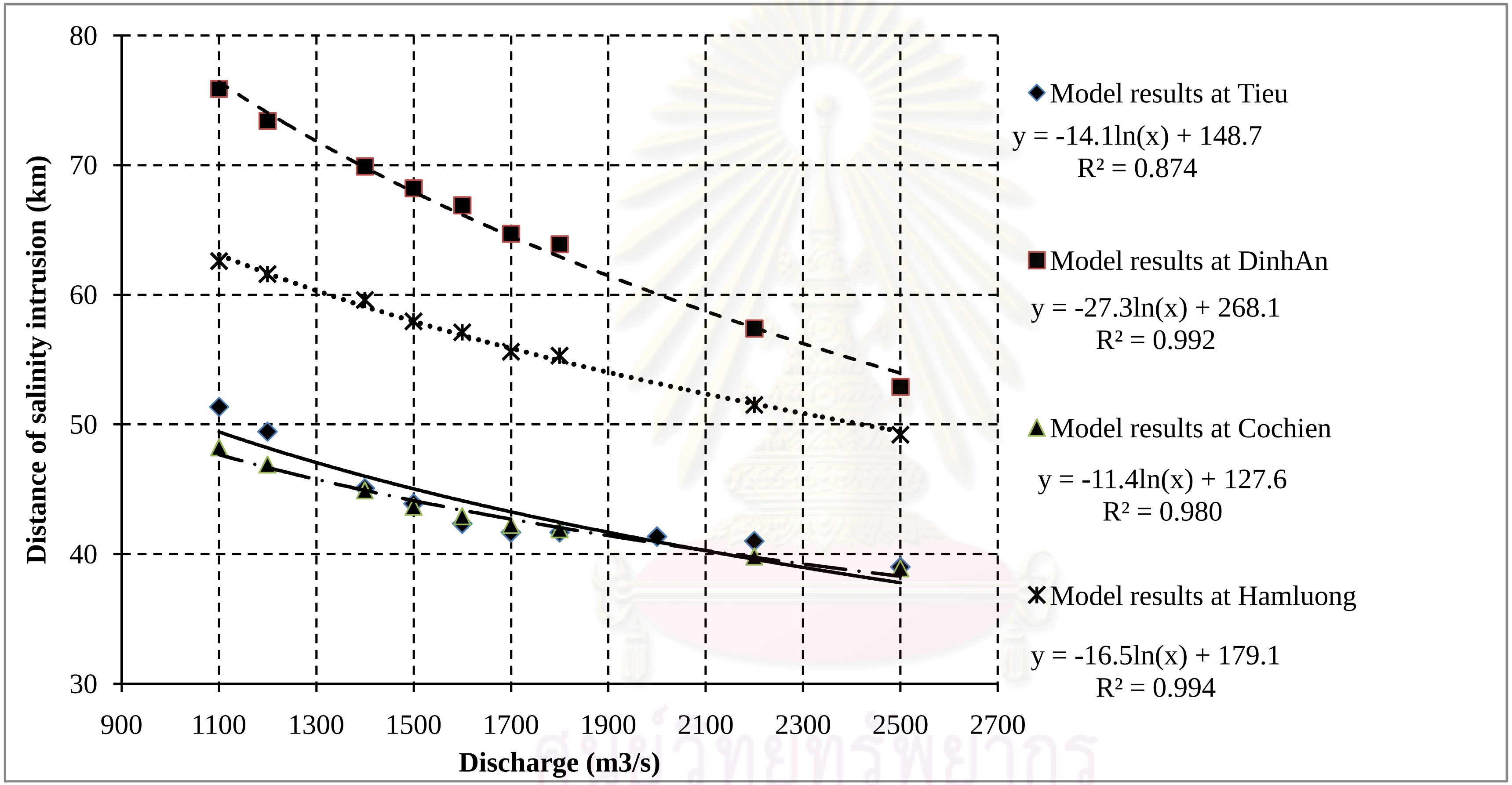


Figure 4. 37. The relationship between the distance of salinity intrusion (2.5g/l) and flow from the upstream of Mekong River

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

87

CHAPTER V

CONCLUSION AND RECOMENDATION

5.1 Conclusion

5.1.1 Modeling Capacity

The MIKE 11 model has been applied to simulate hydraulic regime and salinity intrusion with accepted accuracy. It is highly valuable in case of MD, a complex hydraulic and hydrology regime, density river network and a lot of water control structures in the area. The model is robust and provides insights into the impacts of sea level rise and the Mekong River flow reducing in salinity intrusion in MD. The model also showed the potential impacts of salinity intrusion in MD in the future.

The importations provided by the model will allow specification of key the Mekong River flow that required for salinity prevention. The results of those scenarios are very useful for the water resources planners, managers and decision maker to decide where saline control structures should be built along the Mekong and the Bassac rivers in case of climate change and river flow reducing.

The model is capable of reporting a range of salinity intrusion indicators in MD (i.e. sea level and the Mekong River flow). The relationship between flow and sea level and the environmental issue in MD (i.e. salinity intrusion) is recognized. During the study, MIKE 11 model has been applied. It showed what possible salinity intrusion in MD is.

5.1.2 Salinity intrusion in MD

5.1.2.1 Investigation of Salinity Intrusion in MD in the Year 1998

The calibration HD model obtains Manning's friction ranging from 0.03 to 0.018. The Mekong River and the Bassac River are ranging from 0.027 to 0.03. As mentioned in Chapter 2, Manning's friction for natural stream channels with clean and strange status should be ranging 0.025 to 0.033. Obviously, the Manning's frictions of the study are consistent with previous study. Moreover, hydraulic conditions in the model (i.e. water level and discharge) fix well with observations. The Manning's frictions were found out in the study. They indicated Mekong River and the Bassac River are clean and strange while primary canals in MD are smooth channels with Manning's friction in ranging 0.018 to 0.02.

The AD module was calibrated with Advection-Dispersion coefficient ranging from 700 to 300 m/s^2 for the Mekong River and the Bassac River and from 125 to 50 m/s^2 for other rivers into MD. The results are in agreement with previous study that was shown in Chapter 2. Advection-Dispersion coefficient was found out in the study that demonstrated non-uniform velocity distribution and diffusion in the Mekong River and the Bassac River occur strongly. While, the turbulent process in other rivers are lower than the Mekong and the Bassac River.

The results of the AD model also pointed out that salinity intrusion in the year 1998 that is very serious. Salt water intruded about 60- 72km from the sea in main rivers and salinity intrusion effected about haft of the MD. The results are consistent in comparison to Miller study (Miller, 2003).

5.1.2.2 Investigation of Salinity Intrusion in MD in the Year 2005

The results illustrated that simulation was closely related to observation results. Especially, HD module demonstrated high accuracy results in comparison to HD module in 1998. The situation can be explained that database for model in 2005 is more sufficient than database in 1998. The model also illustrated whole pattern of salinity intrusion in this year. Effect of salinity intrusion in this year was reduced. Salinity intrusion did not affect large area in MD as 1998.

From 1999 to 2007, Vietnam Government cooperated with World Bank to establish saline control projects in MD. Those projects covered 534,860 ha and included three sub-projects (i.e. Quan Lo-Phung Hiep, O Mon-Xa No and South Mang Thit sub-projects). The result of salinity intrusion in this year illustrated that regulation structures of those projects have been preventing salinity intrusion field well even salinity penetrated inland through various branches of the Mekong River, the Bassac river and canals over 40 to 62 km from the shore.

5.1.2.3 Simulation Salinity Intrusion in the Year 2020 and 2030 with Scenarios

The result of scenarios interpreted that 2.5g/l saline intruded 15km to upstream in main rivers compared with serious salinity intrusion time in 1998 (scenario 5). Also, saline intrusion area was affected in most of saline control projects in MD (scenario 2, 3, 4 and 5). The result of baseline scenario showed that saline concentration value of 2.5g/l effected most of Ca Mau Peninsular, Tra Vinh province, a segment of Vinh Long province and Ben Tre province. Salinity intrusion in 2005 reduced to intrude main rivers, canals and fields even water level rise and low river flow in comparison to a serious case in 1998. Moreover, the results of five scenarios illustrated that even with saline control projects those operated well. Nevertheless, in case of sea level rise and river flow reducing, the saline water can still intrude the MD through other upper canals and rivers that are not gated. Saline concentration, 2.5g/l can expand to most of South Mang Thit and Quan Lo-Phung Hiep project.

5.1.2.4 Relationship between Upstream Flow and Salinity Intrusion

The correlation between salinity intrusion distance and upstream flow was ascertained by using MIKE 11 model. The distance of salinity intrusion increases logarithmic as the upstream flow decreases. The correlation coefficient of salinity intrusion and upstream flow at estuaries of Mekong River were greater than 0.87 thus these regression equations can be applied as a simple tool for salinity intrusion prediction at estuaries of Mekong River into MD.

5.2 Recommendations

The hydrological regime in the MD is very complex due to the dense of canals network, the complex tidal movement, and water demand into the delta, etc. The model cannot provide a high accuracy salinity intrusion picture in the delta. Especially, in case of climate change and unknown future of the Mekong River, the model should be calibrated with more updated data. Moreover, more scenarios should be carried out considering scenarios of water demand into MD and MKB to assist with decision-making in water planning and management.

The model showed overall picture of salinity in MD in 1998, 2005 and five scenarios of sea level rise and the Mekong River flow reducing. Although, the study did not consider factors which can influence salinity intrusion in MD such as monsoon wind, deeper and longer flooding time etc. Therefore, the newest study should consider those factors.

To prevent salinity intrusion into agricultural areas in MD, saline water intrusion gates were constructed in the area (Tuan, 2007, World Bank, 2008). Many saline control projects (i.e. Quan Lo-Phung Hiep project, South Mang Thit Project, O mon-Xa No project) have been built during the last two decades. The main structures in those projects are dikes, canal embankments and regulation gate systems. They were built not only for salinity intrusion prevention but also for production and domestic freshwater use. After construction, large area previously effected by salinity intrusion that is protected to allow production of double or triple of paddy field. However, in present years, the development of brackish aquaculture has rapidly leaded to a new utility requirement for salt water. As result, water competition is occurring in dry season. Thus, regulation gate systems into saline control project need to be reformed their priority regulation to reduce water competition. The mathematical model is one of approach that should be concerned for making new priority regulation of those saline control gates in MD.

According to the results of five scenarios, minimum flow is 1,500m^3/s in February and March when the flow rate is extremely low and demand for irrigation is very high. The flow is required in dry years in order to prevent salt water reverse flow in the MD in present but it should be equal or higher than 2000m^3/s in the next twenty years. Obviously, minimum flow of 2000m^3/s in Mekong River will not come true in the future because of increasing water use in MKB. Therefore, saving fresh water strategies in dry season should be highly concerned in MD.

The main uses of water in the MKB are agriculture (irrigation and livestock), domestic and industry. Nowadays, uses of the river for navigation, fisheries, tourism, recreation and environment have also come to be viewed as equitable and valuable purposes, while the conventional use of irrigation for rice cultivation in the dry season and complementation of production in the rainy season is increasing in low land areas. When making forecasts of the demand for agricultural water, in addition to differing scenarios of cultivation area change and land water utilization efficiency, it is also necessary to consider the necessary monthly water demand in the dry season, which is a major limiting factor.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

REFERENCES

Abbott, M. B., and Ionescu, F. One the numerical computation of nearly horizontal flows. *Journal of Hydraul Research* 5 (1967):97–117.

Abd-Elhamid, H. F., and Javadi, A. A Mathematical models to control saltwater intrusion in coastal aquifers. *ASCE Conference Proceedings* 311, 98 (2008):790-797.

Arons, A.B., and Stommel, H. A Mixing-length theory of tidal flushing, Transactions, *America Geophysical Union*, 32 (1951): 419-451.

Boicourt, W. A numerical Model of the salinity distribution in Upper Cheapeake Bay. *Technical Report 54, Chesapeake Bay Institute*, The Johns Hopkins University, 1969.

Bouman, B.A.M., and Tuong, T.P. Field water management to save water and increase its productivity in irrigated lowland rice. *Agricultural Water Management* 49 (2001) :11-30.

Chanh, M. T. *Salinity intrusion in the Mekong Estuaries system under the effect of sea level rise*, AIT master's thesis No.WA-91-20, Asian Institute of Technology, Bangkok, Thailand, 1991.

Chappa, S. C. *Surface Water-Quality Modelling*. Singapo: McGraw-Hill, 1997.

Chow, V.T. *Open Chanels Hydraulic*. International Edition. Singapo: McGraw – Hill, 1959.

Cohen, B., and McCarthy, L.T.Jr. Salinity of the Delaware Estuary. U.S. *Geological Survey Water-Supply Paper* 1586-B, 1962.

Dac, N.T. *SAL - The model Flood in MD*. Ho Chi Minh City, 1996.

Department of Pollution Control (DPC). *Development of an action plan to improve water quality in central river basin*, Thailand, 1997.

DHI. *A Modelling System for River and Chanels-Mike 11 User Manual*, 2007.

Duy, N. T. *Dispersion coefficients in the estuarine network*, AIT master's thesis No.WA-92-20, Asian Institute of Technology, Bangkok, Thailand, 1992.

Duc, N. A., Savenije, H. H. G., Pham, N.P., and Tang, D. T. Using salt intrusion measurements to determine the freshwater discharge distribution over the branches of a multi-channel estuary:The Mekong Delta case. *Journal of Estuarine, Coastal and Shelf Science* 77 (2008): 433-445.

ENSIC. *Directions to sustainable water management: Mekong river basin*. Environmental System Information Center (ENSIC), Asian Institute of Technology (AIT) Bangkok, Thailand, 1999.

General Statistic of Vietnam (GSOV). *Statistic Year Book of Vietnam 2008*. Hanoi: Statistical Publishing House, 2008.

Grattan, S. R., Zeng, L., Shamnon, M. C., and Robert, S. R. Rice is more sensitivity than previous thought. *California Agriculture*, 56 (2002): 189-195. Available from:http://www.escholarship.org/uc/item/4037j9jf?display=all [2010,May].

Greco, F. ,and Panattoni. Numerical Solution methods of the St Venant Equation. *Processding of Mathematical Models for Surface Water Hydrology*, 181-194: Pisa, A-Wiley- Interscience Publication, 1974.

Halcrow Group. Development of Basin Modelling Package and Knowledge Base (WUP-A), *DSF650 Technica1 Reference Report, Appendix A 1-6*, Halcrow Group Limited, 2004.

Halerman, D.R.F., and Abraham, G. *One-dimensional analysis of salinity intrusion in the Rotterdam Waterway, Publication No.44*, Delft Hydraulics Laboratory, 1966.

Halerman, D.R.F., Lee, C.H., and Hall, L.C. Numerical studies of unsteady dispersion in estuaries. *Journal of the salinity engineering division, ASCE*, 94 (1968) :897-911.

Hoanh, C. T., Guttuman, H., Droogers, P., and Aerts, J. Water, *Climate, Food, and Environment in the Mekong basin in South Asia*. Final Report , contribution to the Adaption strategies to changing environment ADAPT project, 2003. Available from :http://www.geo.vu.nl/~ivmadapt/paper.htm [2010, January].

Hoanh, C. T., et al. Hydraulic and water quality modeling: a tool for managing land use conflicts in inland coastal zones. *Journal of Water Policy* 11 (2009) : 106–120.

Hung, N. N., Thinh, L. V., and Trung, N. H. *Macro-level perspective on water use in the dry season in MD*, Can Tho University, 2001.

IPCC, 2007. Fourth Assessment Report: Climate Change 2007. Working Group I Report "The Physical Science Basis". Available from :

http://www.ipcc.ch/ipccreports/ar4-wgl.htm [2010,January].

Ippen, A.T., and Harleman, D.R.F. *One-dimensional analysis of salinity intrusion in estuaries. T.B.5, Committee on tidal hydraulics*, U.S. Army Corps of Engineers, 1961.

Khang, D. N., Kotera, A., Sakamoto, T., and Yokozawa, M. Sensitivity of Salinity Intrusion to Sea Level Rise and River Flow Change in Vietnamese MD-Impacts on Availability of Irrigation Water for Rice Cropping. *Journal of Agricultural and Meteorological*, 64 (2008): 167-176.

Kite, G. Modelling the Mekong: hydrological simulation for environmental impact studies. *Journal of Hydrology*, 253 (2001): 1-13.

Kummu, M., Lu, X.X., Rasphone, A., Sarkkula, J., and Koponen, J. Riverbank changes along the Mekong River: Remote sensing detection in the Vientiane-Nong Khai area. *Quaternary International*, 186 (2008): 100-112.

Lu, X. X., and Siew, R. Y. Water discharge and sediment flux changes in the Lower Mekong River. *Journal Hydrology and Earth System Sciences*, 2 (2005): 2287–2325.

Lu, X. X., Wang, J. J., and Carl, G. W. Are the Chinese dams to be blamed for the lower water levels in the Lower Mekong. *Water & Development Publications* - Helsinki University of Technology, 2008. Avalable from :

http://www.water.tkk.fi/English/wr/.../04_Lu&al_Myths-of-Mekong.pdf [2010,May]

Mekong River Commission (MRC). *MRC Work Programme 2003*, Mekong River Commission, 2003b.

Miller, F. *Society-Water Relations in the MD: A Political Ecology of Risk*. PhD thesis. University of Sydney , Australia, 2003.

Molle, F. *Irrigation and water policies in the Mekong region: Current discourses and practices*. Colombo, Sri Lanka: International Water Management Institute(IWMI). 43p. (Research report 95), 2005.

MRC. *State of the Basin Report*, Mekong River Commission, 2003a.

MRC. *Modelled Observations on Development Scenarios in the Lower Mekong* Basin, Vientiane, 2004.

MRC. *Overview of the Hydrology of the Mekong Basin*. Mekong River Commission, Vientiane, 2005.

MRC. *Modelling the cumulative barrier and passage effects of mainstream hydropower dams on migratory fish populations in the Lower Mekong Basin*. Technical Paper No. 25, 2009.

MRC. *Impacts of climate change and development on Mekong flow regimes -First assessment*. Technical Paper No. 29, 2010.

Nash, I.E., and Sutcliffe, I.V. River flow forecasting through conceptual models, Part I. *Journal of Hydrology*, 10(1970): 282-290.

Neary, V. S., Wright, S. A., and Bereciartua, P. Case study: Sediment transport in proposed geomorphic channel for Napa River. *ASCE Journal of Hydraulic Engineering*, 127 (2001) : 901–910.

Nguyen, A. D., and Savenije, H. H. G. Salt intrusion in multi-channel estuaries: a case study in the MD, Vietnam. *Journal of Hydrology*. Earth Syst. Sci., 10 (2006): 743-754.

Nguyen, P. K. *Climate change scenario for Vietnam*. Ministry of Agricultural and Rural Development. Hanoi, 2009.

Nhan, D.K., Be, N.V., and Trung, N.H. Water Use and Competition in the MD, Vietnam. In: Be, T,T., Sinh, B.T., Miller, F. (Eds), Challenges to Sustainable Development in the MD: Regional and National Policy Issues and research Needs. *The Sustainable Mekong Research Network*, (2007) : 143-188.

Nien, N.A., and Xo, L.Q. Phan tich cac mo hinh tinh toan thuy luc su dung cho Dong bang song Cuu Long (Analysis the hydraulics modeling applied for the MD).

Proceedings on Scientific and Technology Researches in 2001. The Southern Water Resources Science Institute. Agriculture Publishing House. Ho Chi Minh City, 2001.

Nijssen, B., O'Donnell, G. M., Hamlet, A. F., and Lettenmaier, D. P. Hydrologic sensitivity of global rivers to climate change. *Climate Change*, 50 (2001): 143-175.

Parsa, J., Etemad-Shahidi, A., Hosseiny, S., and Yeganeh-Bakhtiary, A. Evaluation of computer and empirical models for simulation of salinity intrusion in the Bahmanshir Estuary. *Journal of Coastal Research*, SI 50 (2007): 658–662.

Peter, V. S., and Frederick, W. M. Salinity intrusion in the St. Johns River, Florida. *Proceedings of the Seventh International Conference on Estuarine and Coastal Modeling*. 268(2001), 120-139.

Pritchard, D.W. *Computation of the longitudinal salinity distribution in the Delaware estuary for various degree of river inflow regulation.* Technical Report 18, Chesapeake Bay Institute, The Johns Hopkins University, 1959.

Sam, L. Results of study on salinity intrusion for socio-economic development in the MD. In: Sam, L., Hoi, T.N., Nien, N.A., Tho, N.V., Huan, H.V., Hung, L.M., and Thang, T.D. (Eds), Results of Science and Technology. *Agriculture Press*, (2006) : 104-112.

Sam, L. *Salinity intrusion in MD*. Hochiminh: Agricultural Publishing, 2006.

Sam, L. *Water Management in the MD*. HCM City : Agriculture, 1996.

Schnoor, S.J. *Environment Modelling*, United States of America: John Wiley & Son, 1996.

Sethaputra, S., Thanopanuwat, S., Kumpa, L., and Pattanee, S. *Thailand's water vision: A case study. In Ti and Facon (Eds.) From vision to action: A synthesis of experiences in Southeast Asia*. Food and Agriculture Organization/Economic and Social Commission for Asia-Pacific, 2001.

Shahidi, A. E., Shahkolahi, A., and Liu, W. C. Modeling of Hydrodynamics and Cohesive Sediment Processes in an Estuarine System: Study Case in Danshui River, Taiwan. *Journal of Environmental Modeling and Assessment*, 127 (2009) : 1573-2967.

Stigter, C., and Siemons, J. *Calculation of longitudinal salt distribution in estuaries as function time*. Publication No.52, Delft Hydraulic Laboratory, 1967.

Sunada, K. *Study on Asian River Basin*. CREST Asian River Basins: Water Policy Study Team, 2009.

Taylor, G.I. The Dispersion of matter in turbulent flow through a pipe. *Proceeding, Royal Society of London,* Series A, Vol 1155 (1954), 446-468.

Thatcher, M. L., and Halerman, D.R.F. *A mathematical model for the prediction of unsteady salinity intrusion in estuaries*. Technical Report 144, Ralph M. Parsons Lab, Massachusetts Institute of Technology,1972.

Tuan, L. A., Hoanh, C. T., Miller, F., and Sinh, B. T. Flood and Salinity Management in the MD, Vietnam, In Be, T. T.; Sinh, B. T.; Miller, F. (Eds.). Challenges to sustainable development in the MD: Regional and national policy issues and research needs: Literature analysis. Bangkok, Thailand: *The Sustainable Mekong Research Network (Sumernet).* (2007) : 15-68.

Vu, T.C., Suphat, V., and Asaeda, T. Study on salinity intrusion in the Red River Delta. Environmental System Research, *Japan Society of Civil Engineers*, 22 (1991): 213-218.

World Bank. *The Impact of Sea Level Rise on Developing Countries: Comparative Analysis*. World Bank Policy Research Working Paper 4136, 2007. Available from: http://go.worldbank.org/XU9B5UFR30 [2010, May]

World Bank. Vietnam MD Water Resources Project Implementation Completion And Results Report (Report No: ICR0000826), 2008. Available from : http://web.worldbank.org/external/projects/main?pagePK=64283627&piPK=73230&theSitePK=40941&menuPK=228424&Projectid=P004845 [2010, June]

Zeng, L., and Shannon, M. C. Salinity Effects on Seedling Growth and Yield Components of Rice. *California Agriculture* 40(2000):996-1003. Available from : http://crop.scijournals.org/cgi/content/full/40/4/996 [2010, May]

APPENDICES

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

APPENDIX A

Distributed Rainfall and Runoff in Each Country Belong in to MKB

Table A. Distributed rainfall and runoff in each country belong in to MKB

Description	Catchment inside MKB						Total
	Yunnan	Myanmar	Lao PDR	Thailand	Cambodia	Vietnam	
Catchment area(km^2)	147000	24000	202000	184000	155000	65000	777000
Catchment area as % of total MRB (km^2)	22	3	25	23	19	8	100
Average rainfall(mm/year)	1561	-	2400	1400	1600	1500	
Average flow (m^3/s)	2414	300	5270	2560	2860	1660	15064
Average runoff (mil m^3)	76128	9461	166195	80732	90193	52350	475059
Dry season runoff (mil m^3)	19032	1419	24929	12110	13529	7852	78871
Average run off as % of total MRB^3	16	2	35	17	19	11	100

Source: MRC, 2004 and GSOV, 2008

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

APPENDIX B

Irrigation Area

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table B. Irrigation area in the period 1985-2000 (x 1000 ha)

Annual production of paddy	Yunnan	Myanmar	Thailand	Laos	Cambodia	Vietnam
1985						
Annual irrigation area	-	-	4200	663	1345	2251
Annual Yield(t/ha)	-	-	1.7	2.3	1.3	3.1
2000						
Annual irrigation area	-	-	4813	718	2079	3987
Annual Yield(t/ha)	-	-	1.97	2.92	1.81	4.08

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

APPENDIX C

Location of Hydropower Dams

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

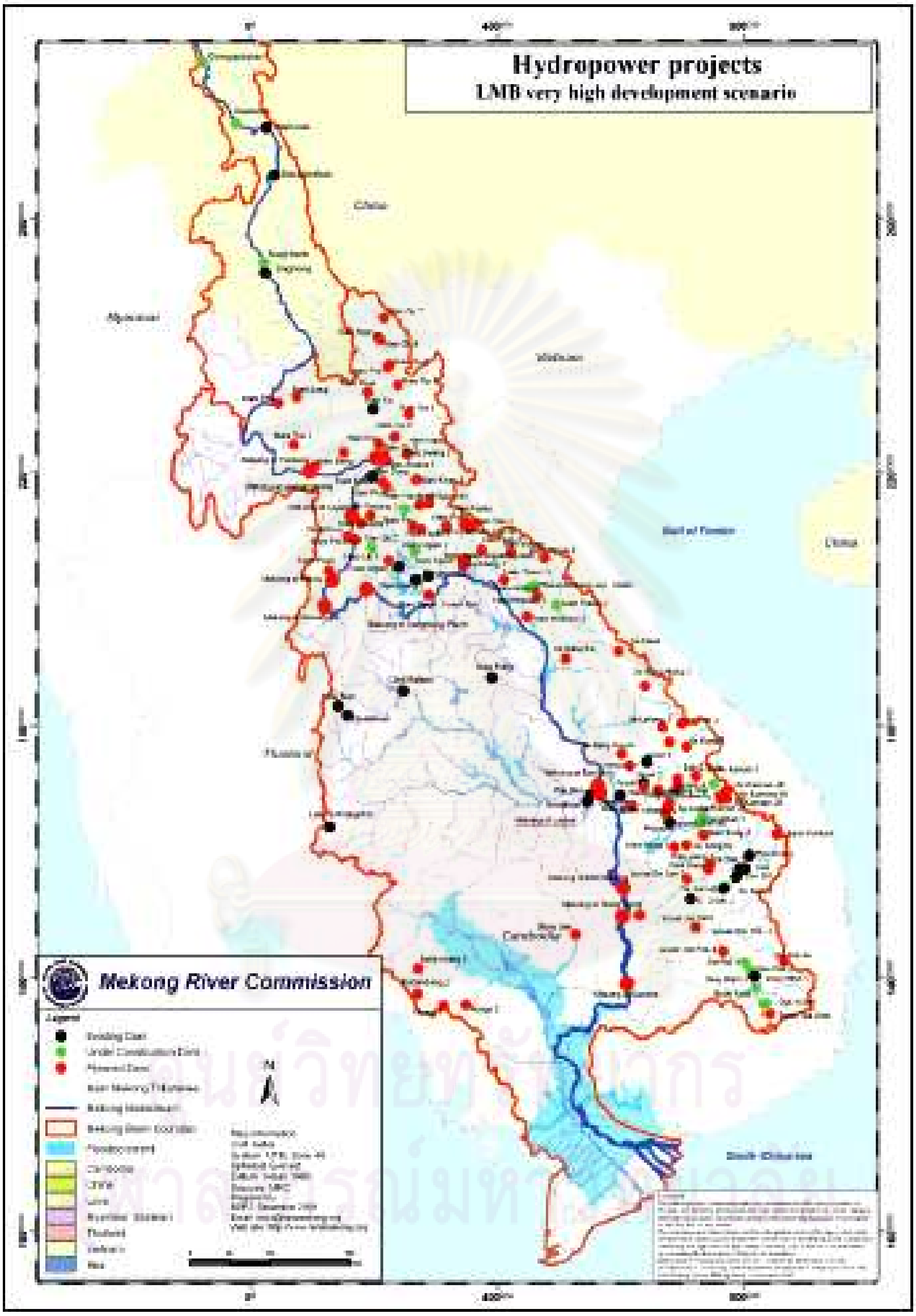


Figure C. 1. Location of hydropower dams with very high scenario (MRC, 2009)

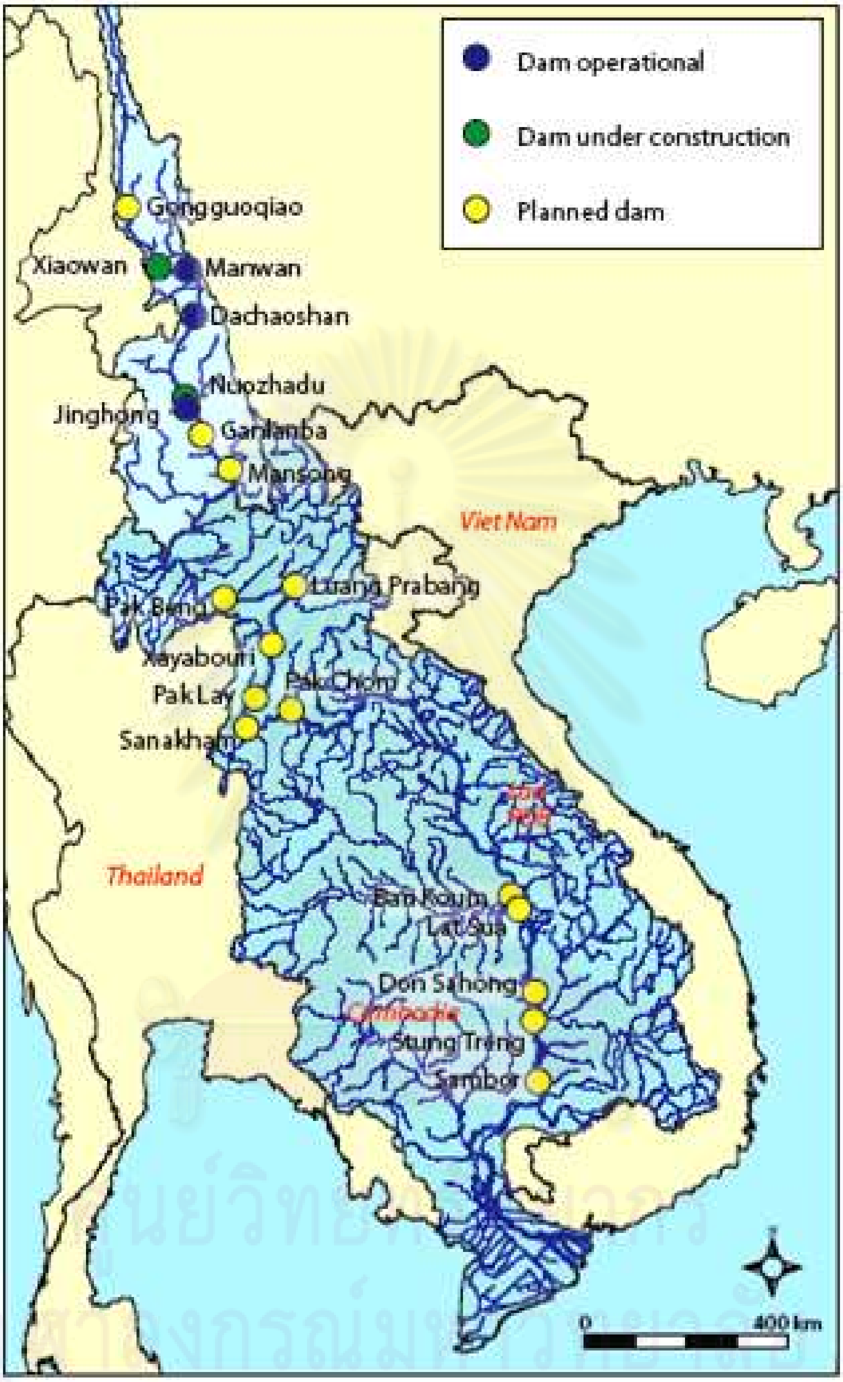


Figure C. 2. Location of 11 proposed hydropower dams on the Mekong mainstream. Also shown are mainstream dams in existence, under construction and proposed in Upper Mekong (Lancang River) Basin (MRC, 2010)

Table C. Eight dams on Lancang River (China)

Name of Project	Install capacity (MW)	Annual generation (MW)	Total storage Million m^3	Catchment area (Km^2)	Average flow (m3/s)	Commissioning
Gongguoqiao	750	4670	510	97300	985	-
Xiaowan	4200	18540	510	113300	1220	2010-2012
Manwan	1500	7870	920	114500	1230	1993
Dachaosan	1350	7090	880	121000	1230	2001
Nuozhadu	5500	22670	24670	144700	1750	2012-2016
Jinghong	1500	8470	1040	149100	1840	2012-2013
Ganlanba	150	1010	-	151800	1880	-
Mengsong	600	3740	-	160000	2020	-
Total	15500	74060				

Source: MRC, 2005

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

APPENDIX D

Cross Section Data

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

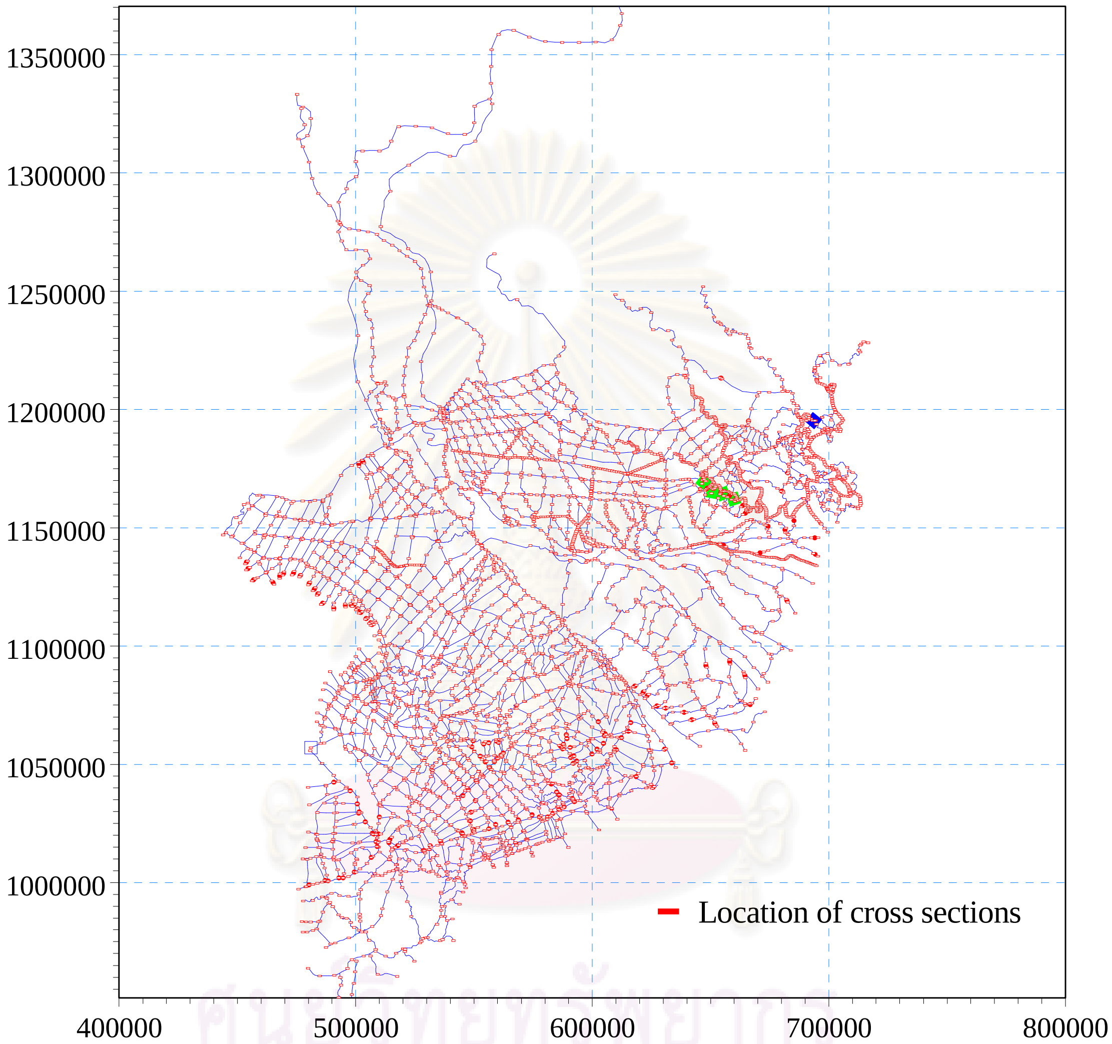


Figure D. 1. Cross Sections Location

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

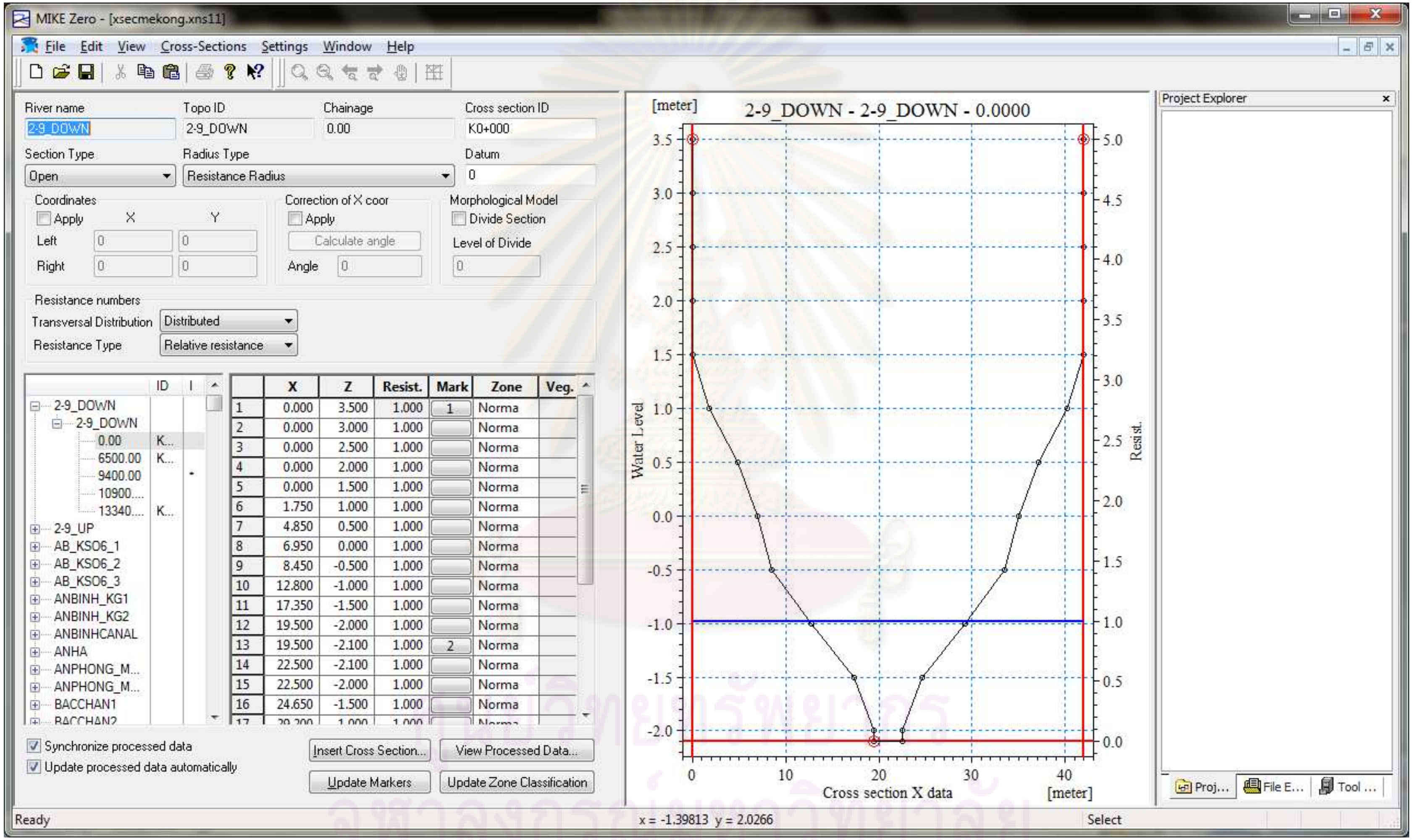


Figure D. 2. Example of Data in a Cross Section

110

APPENDIX E

Upstream boundaries Data

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

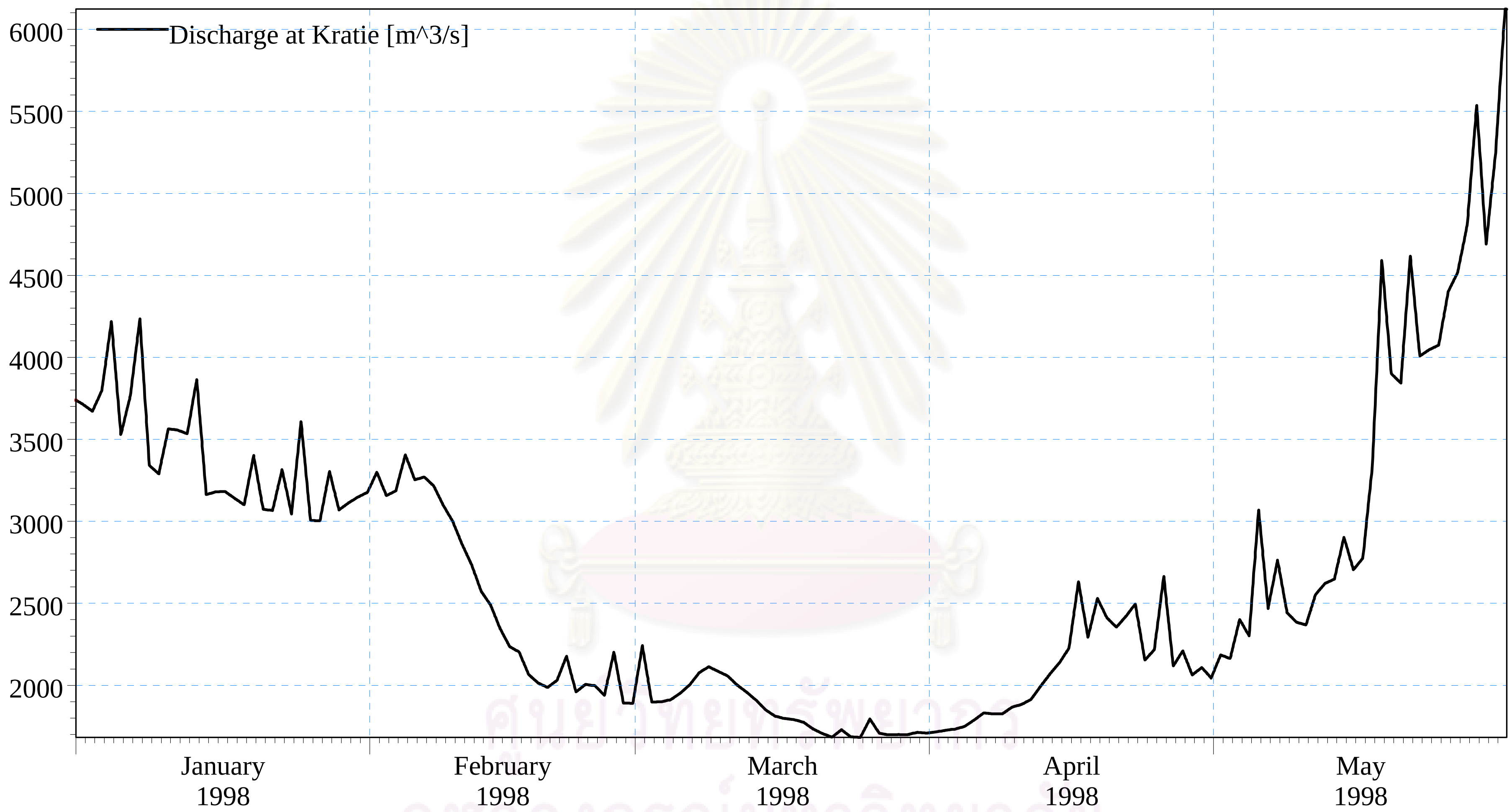


Figure E. 1. Boundary Condition (Discharge) at Kratie Station in 1998

112

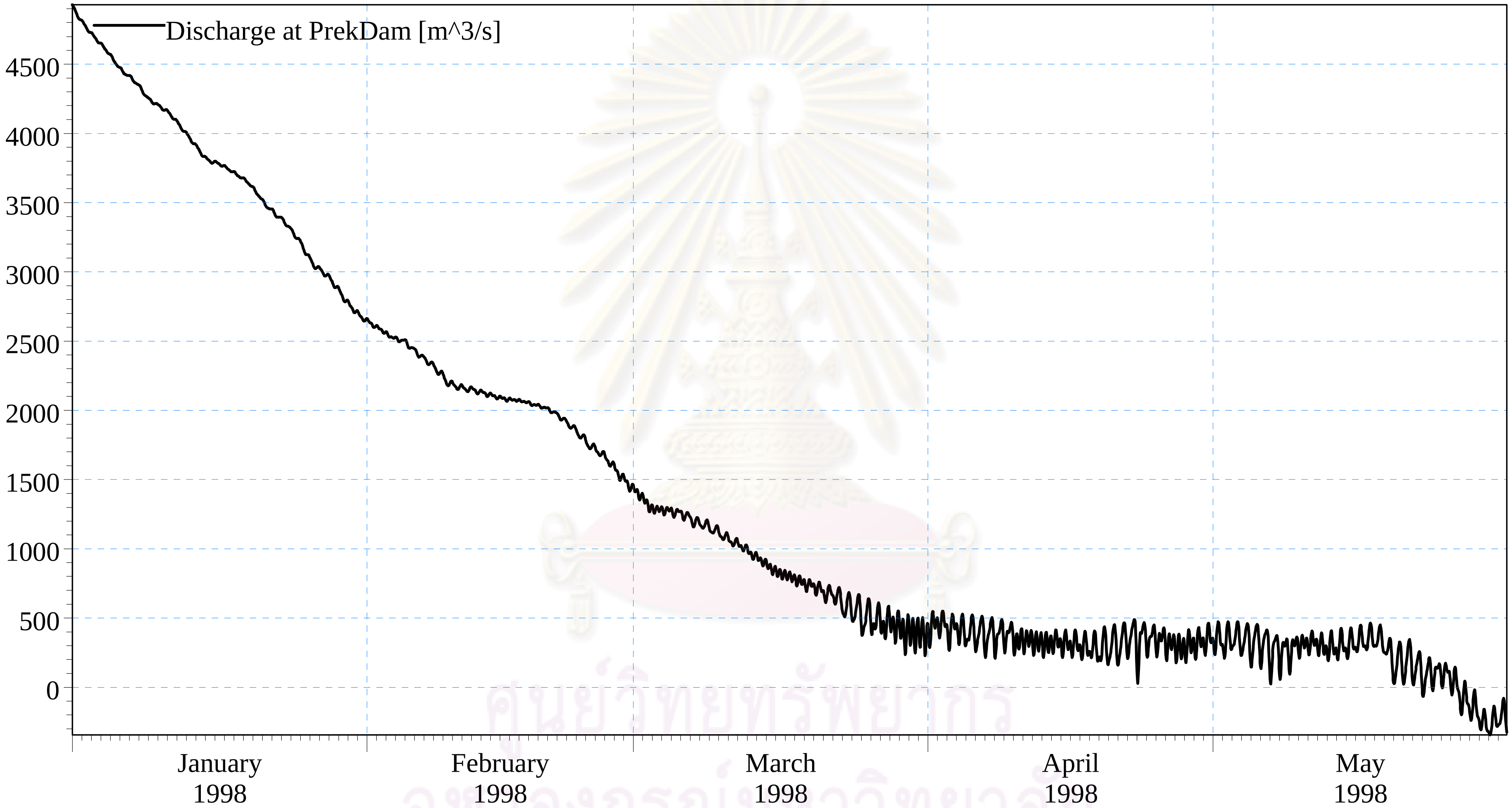


Figure E. 2. Boundary Condition (Discharge) at PrekDam Station in 1998

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

113

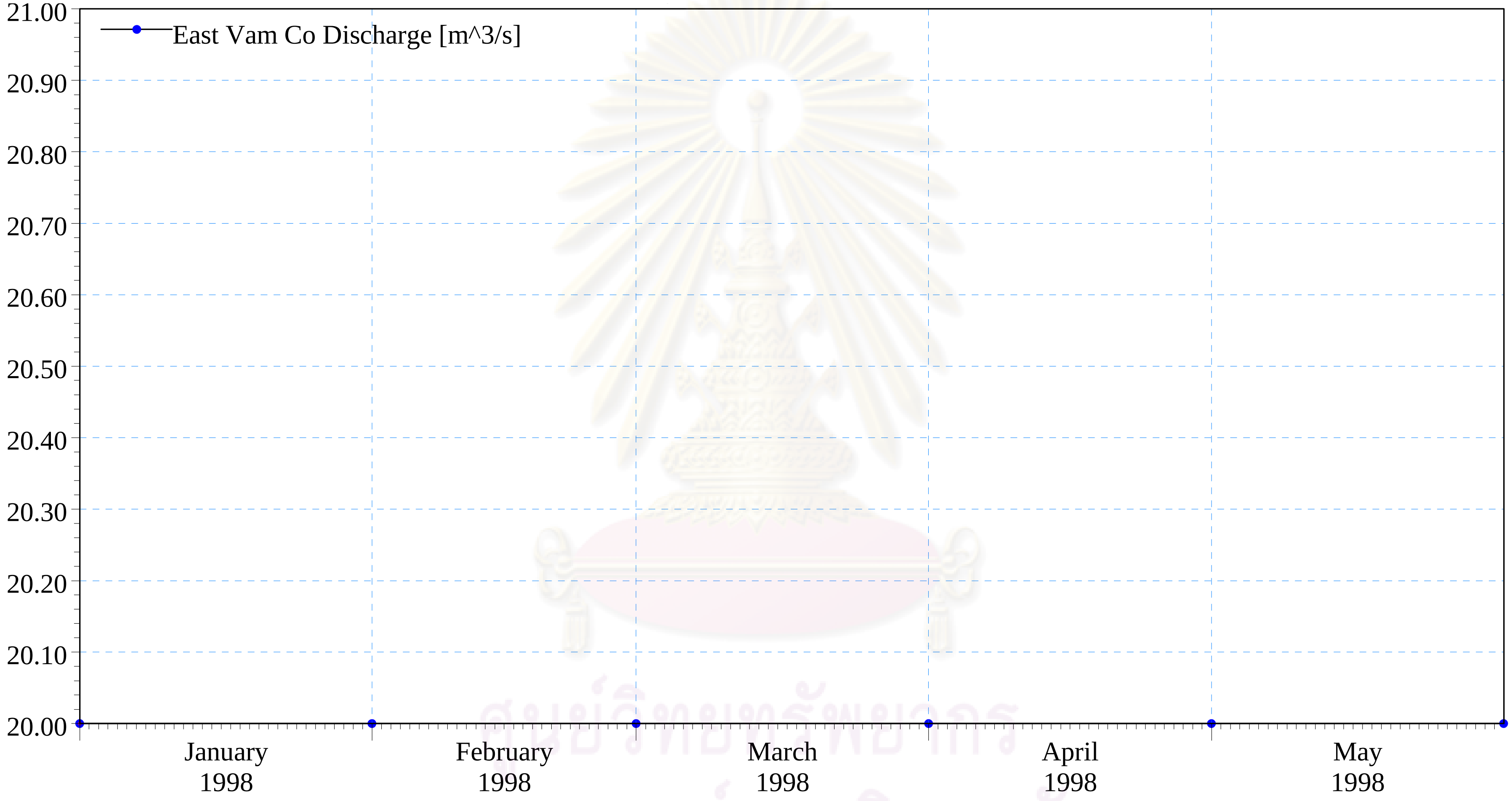


Figure E. 3. Boundary Condition (Discharge) at East Vam Co Station in 1998

114

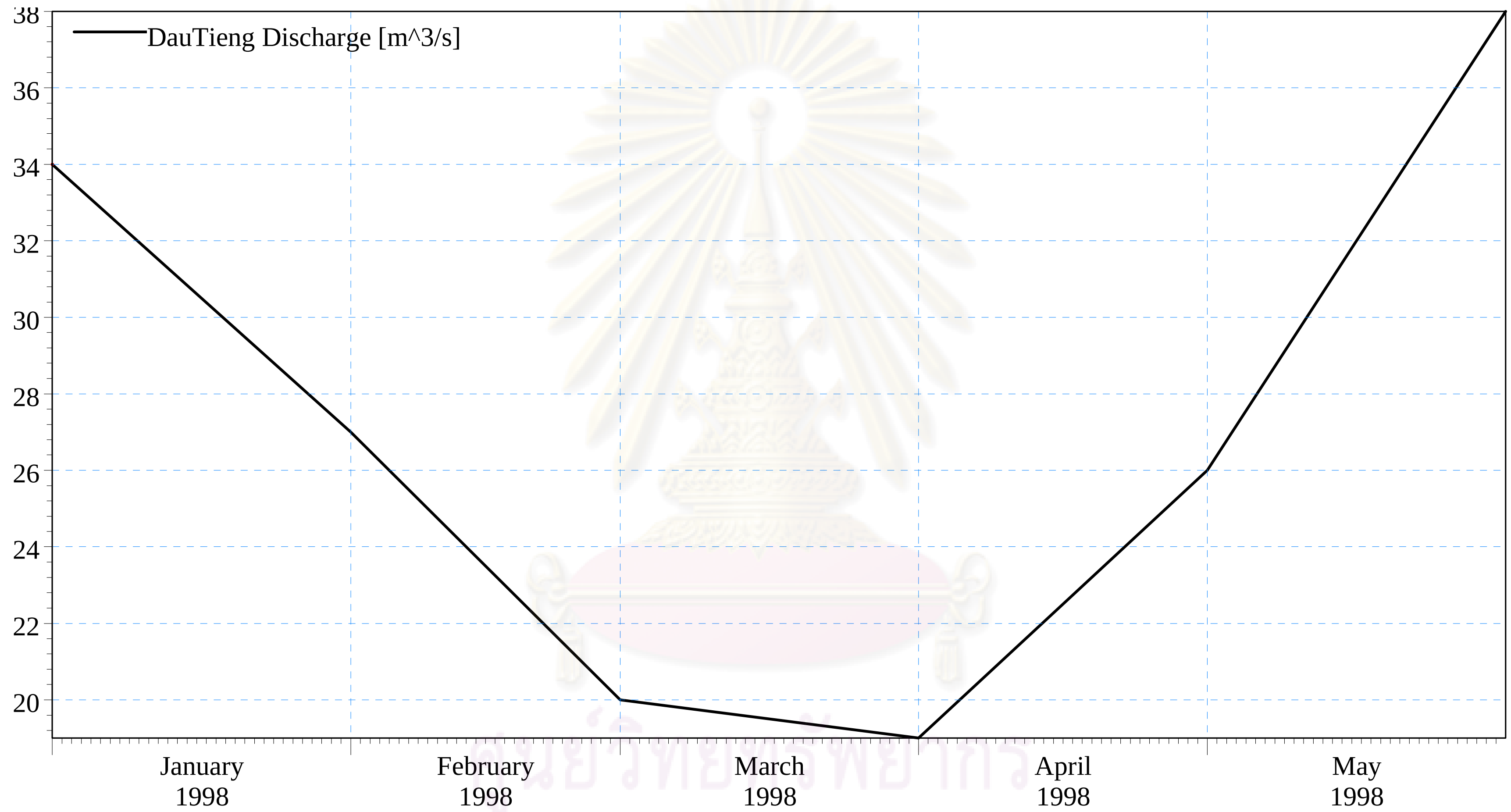


Figure E. 4. Boundary Condition (Discharge) at Dau Tieng Station in 1998

115

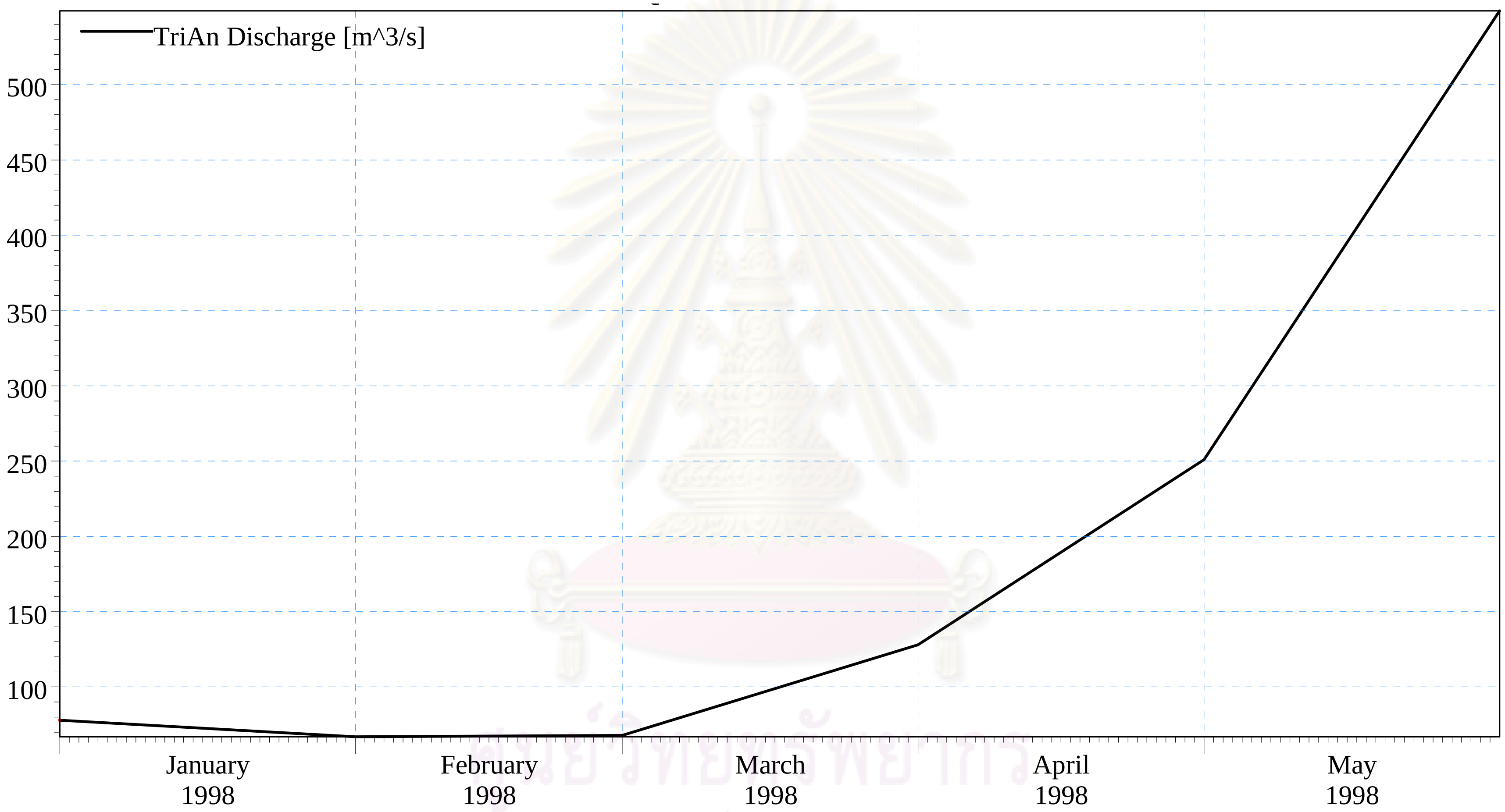


Figure E. 5. Boundary Condition (Discharge) at Tri An Station in 1998

116

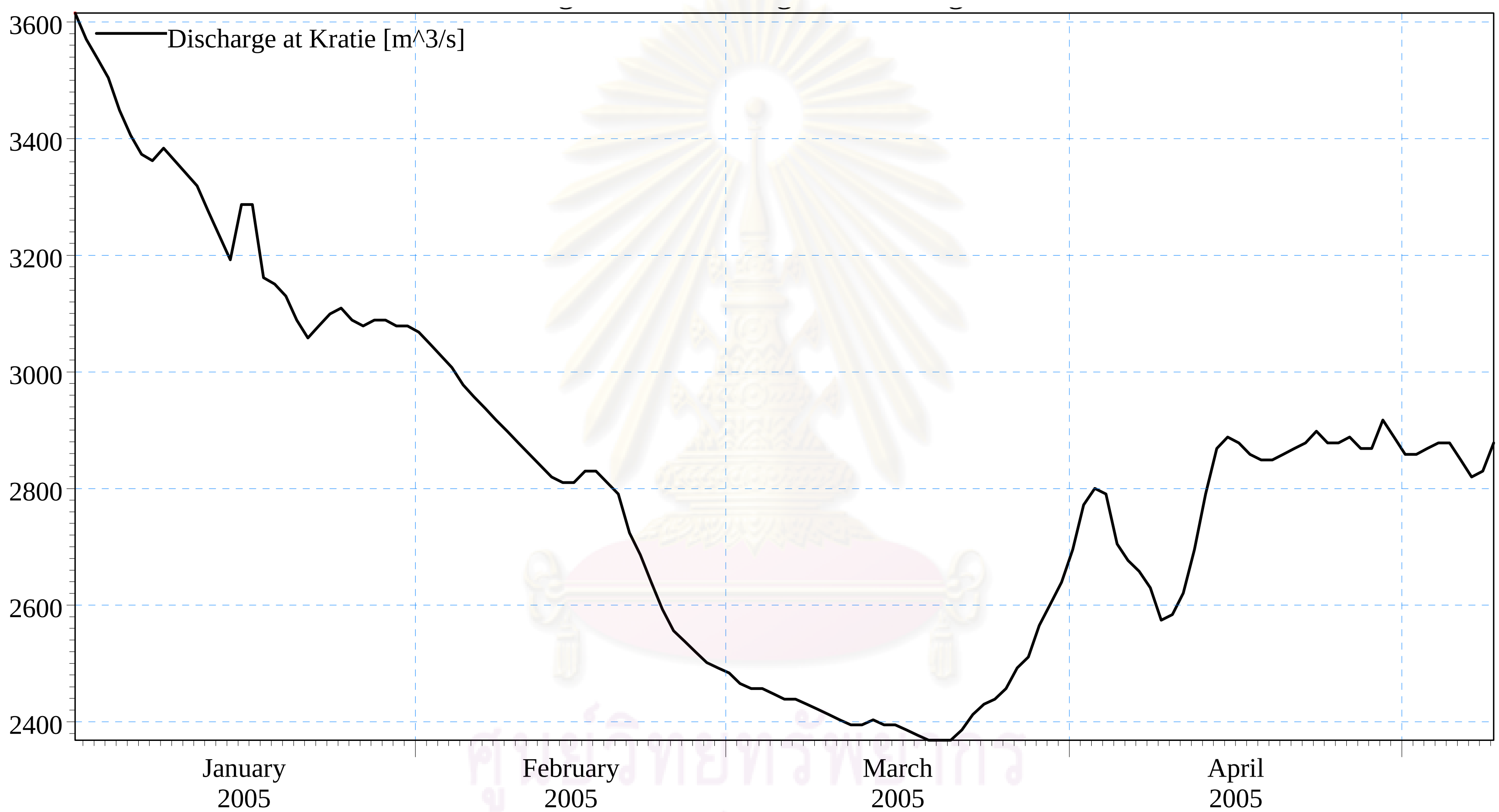


Figure E. 6. Boundary Condition (Discharge) at Kratie Station in 2005

117

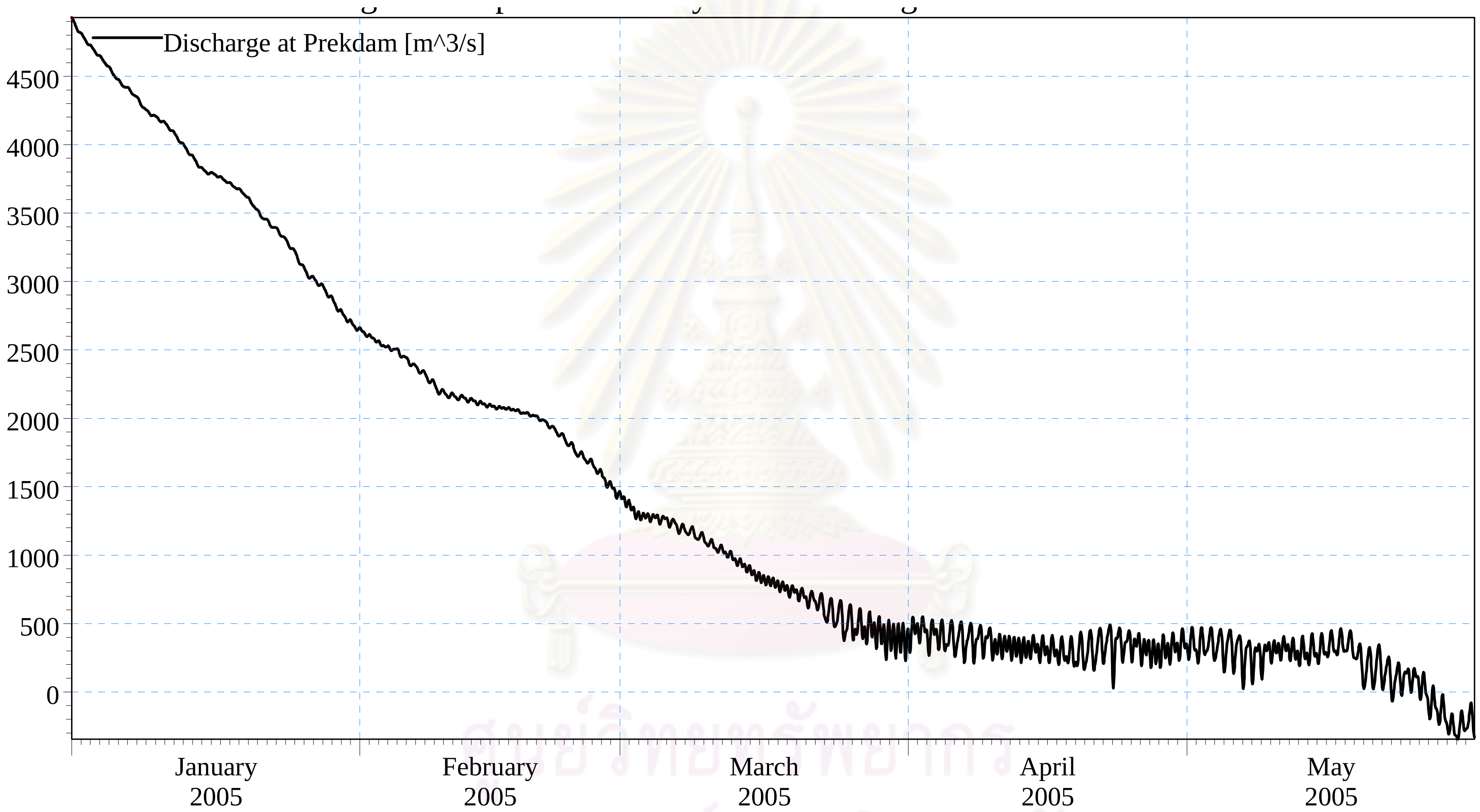


Figure E. 7. Boundary Condition (Discharge) at Prekdam Station in 2005

118

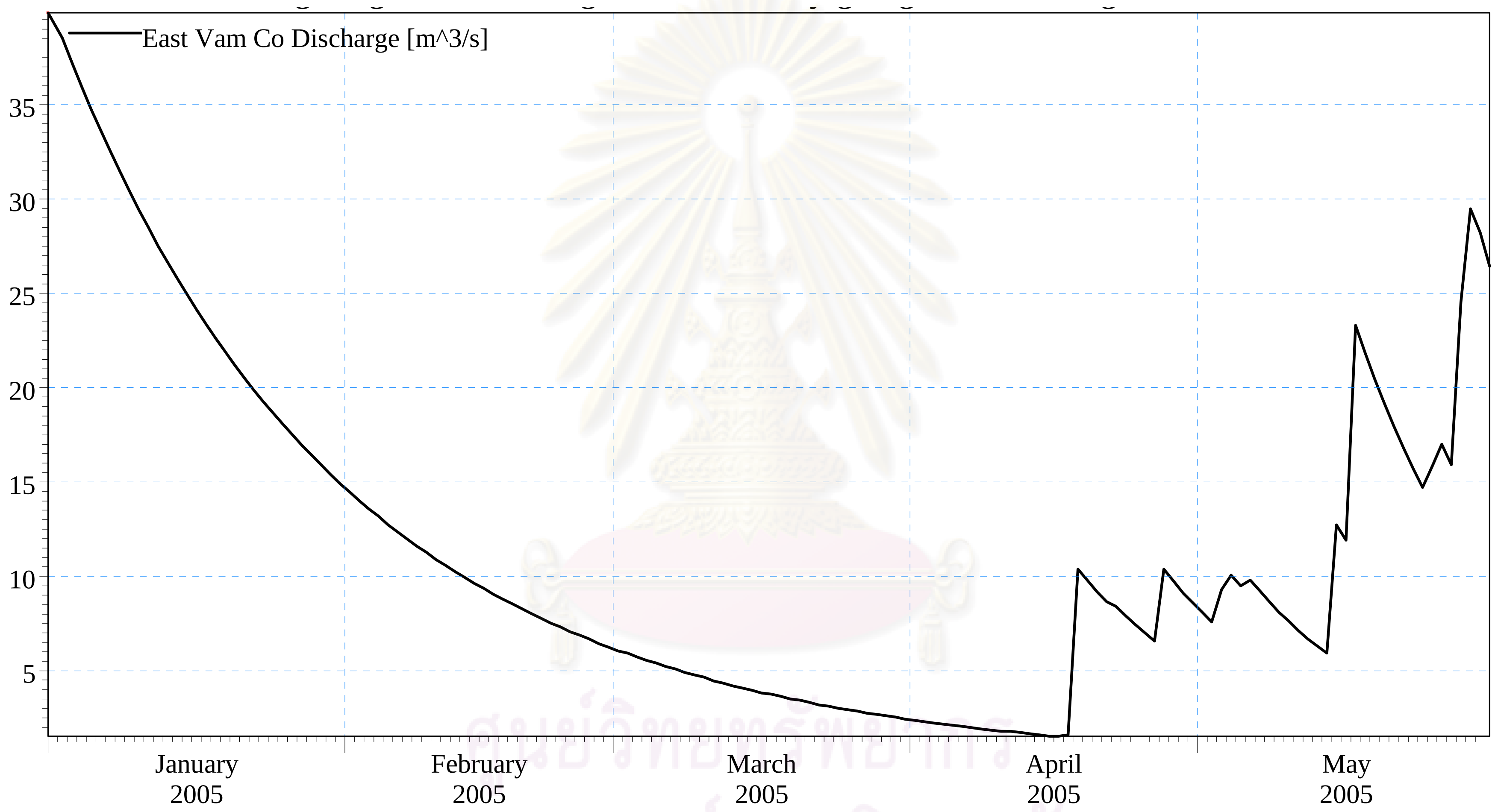


Figure E. 8. Boundary Condition (Discharge) at East Vam Co Station in 2005

119

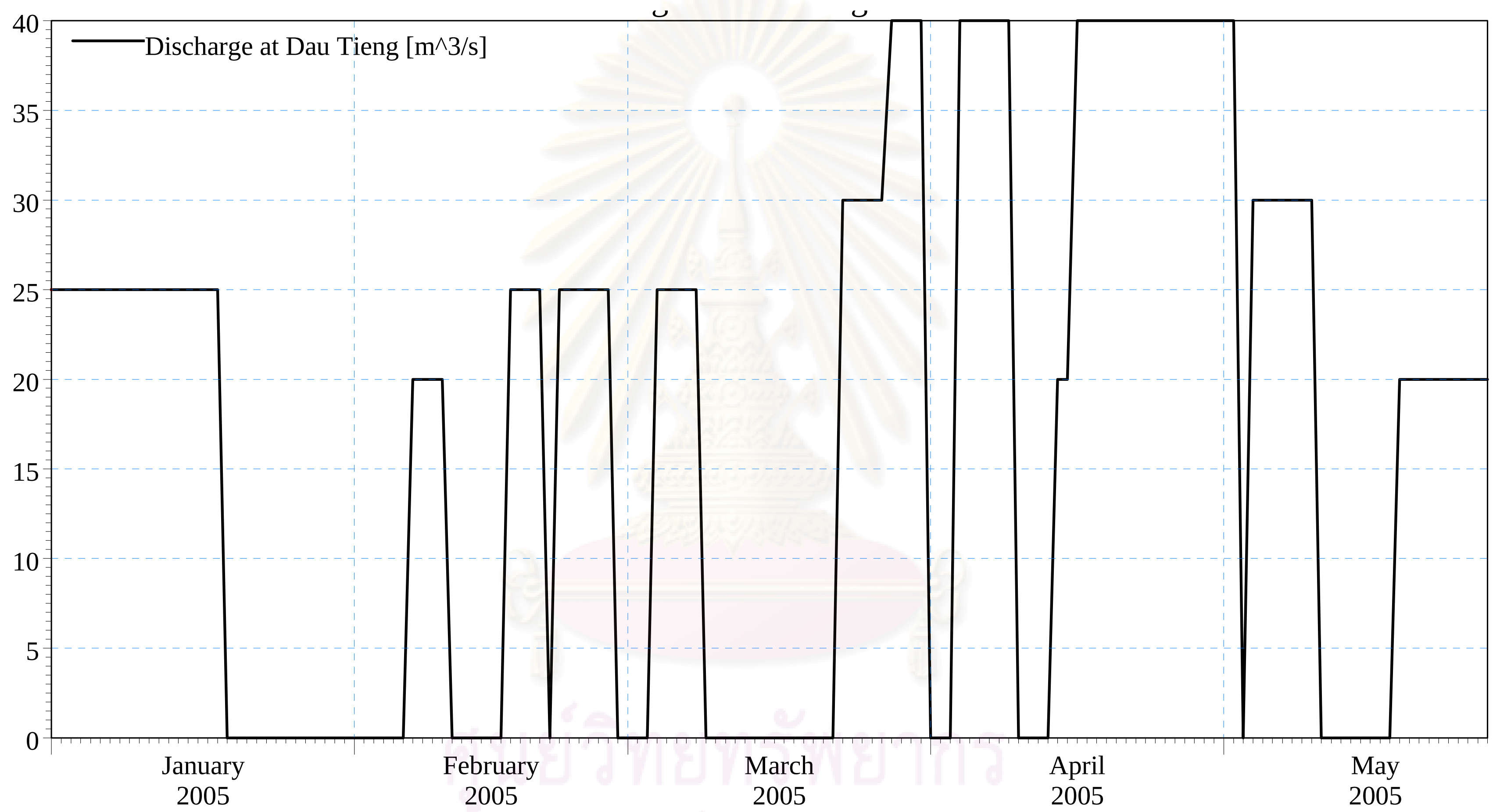


Figure E. 9. Boundary Condition (Discharge) at Dau Tieng Station in 2005

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

120

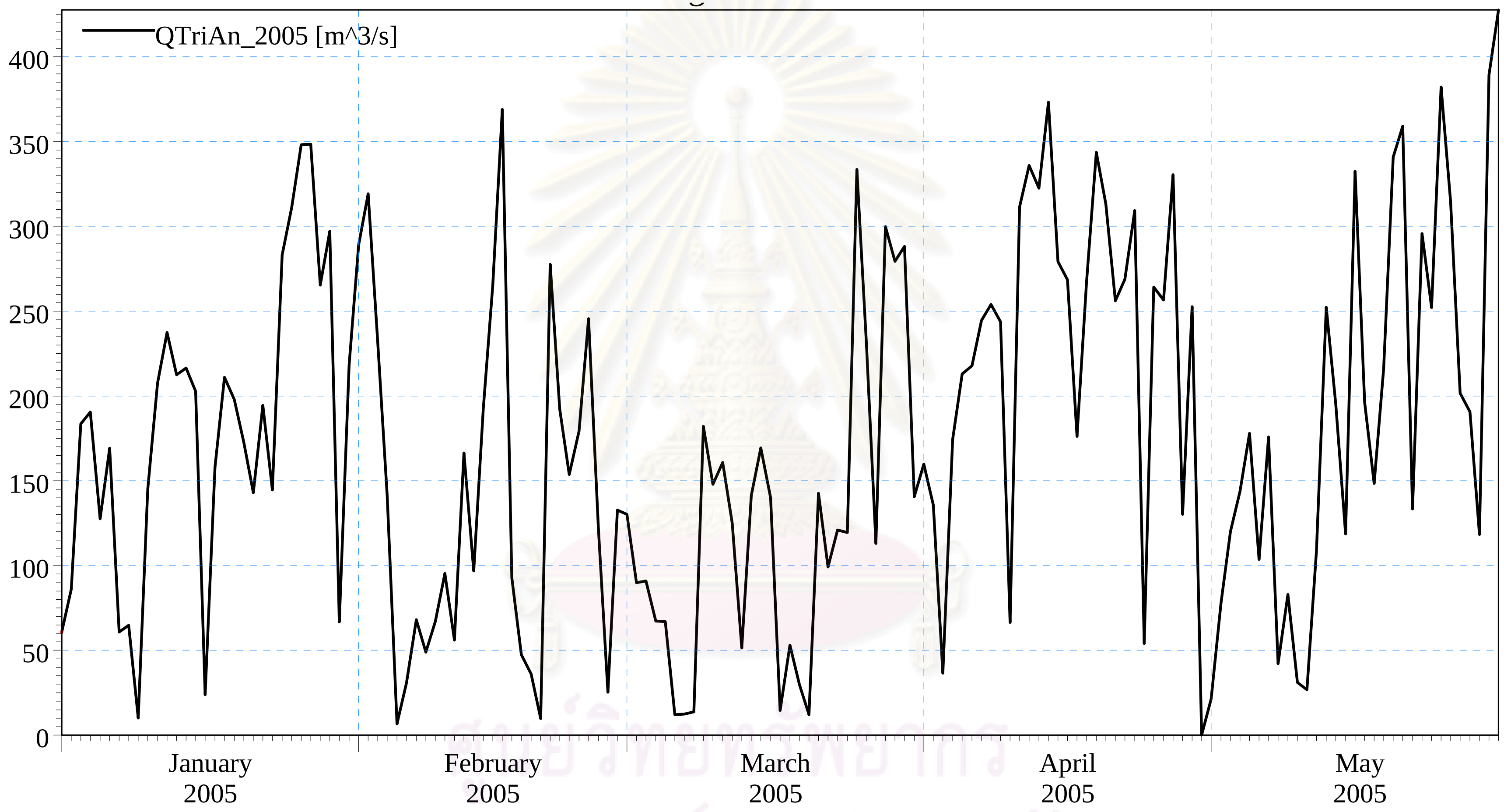


Figure E. 10. Boundary Condition (Discharge) at Tri An Station in 2005

121

APPENDIX F

Downstream boundaries Data

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

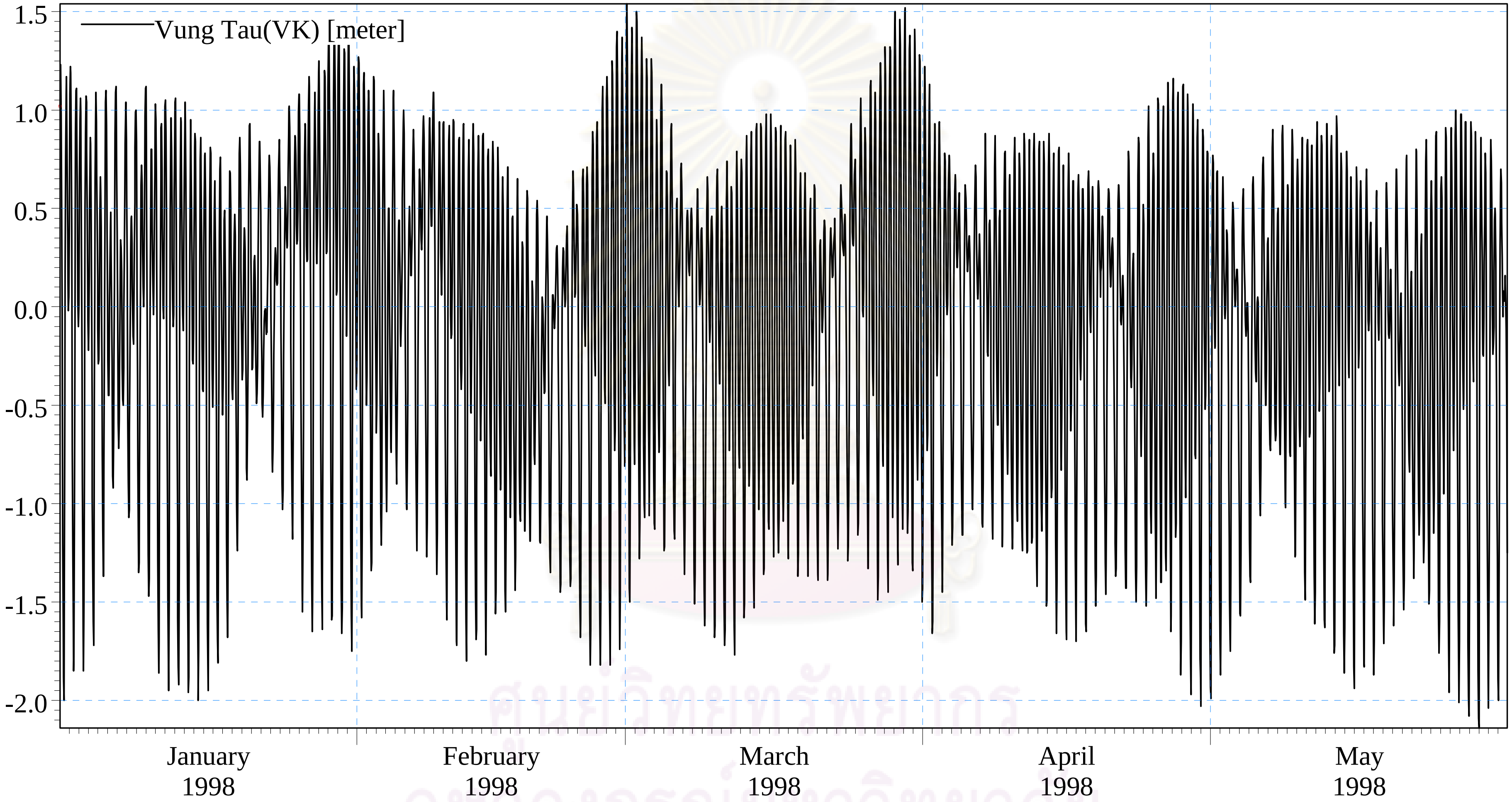


Figure F. 1. Boundary Condition (Water Level) at Vung Tau Station in 1998

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

123

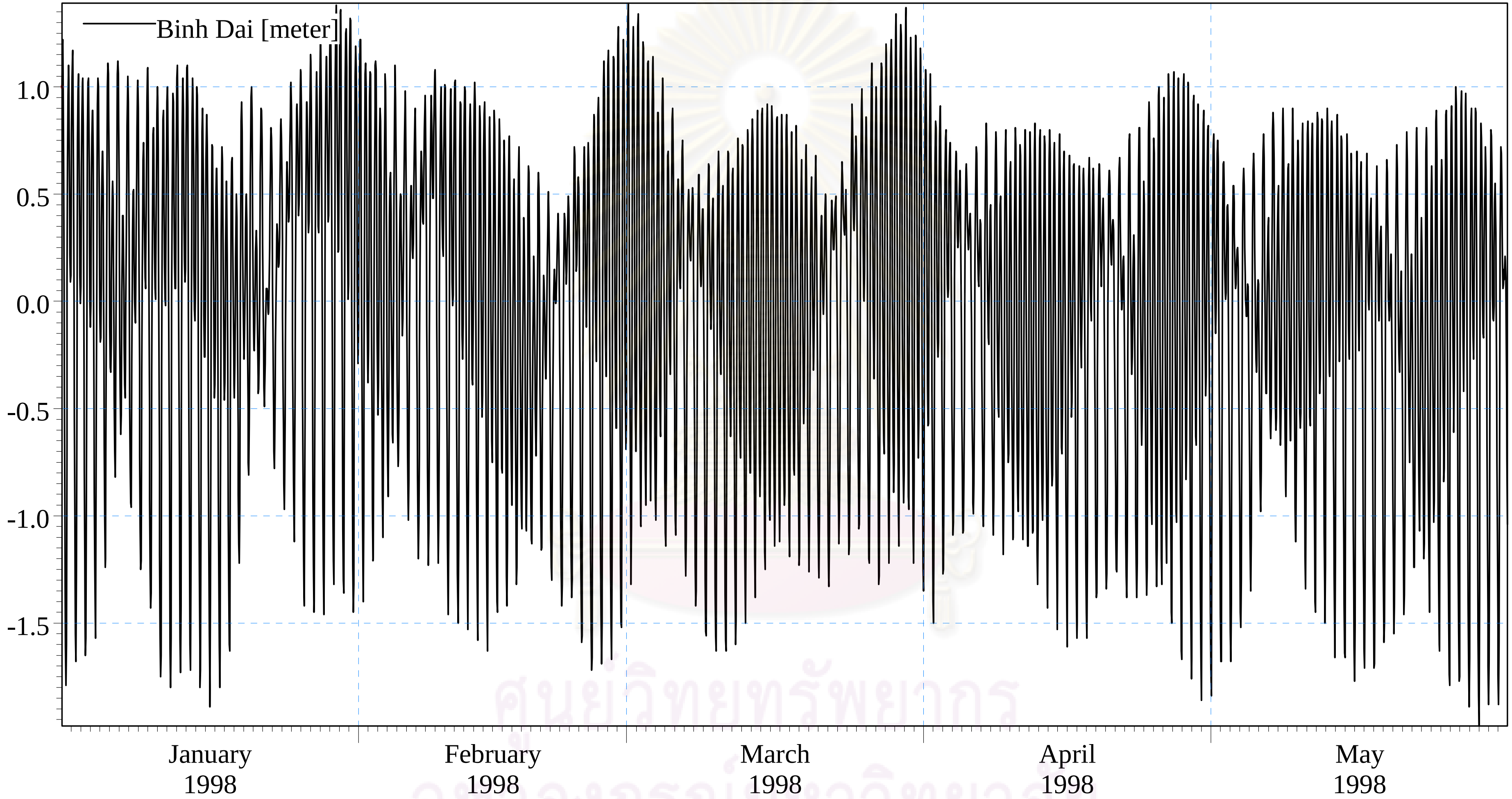


Figure F. 2. Boundary Condition (Water Level) at Binh Dai Station in 1998

124

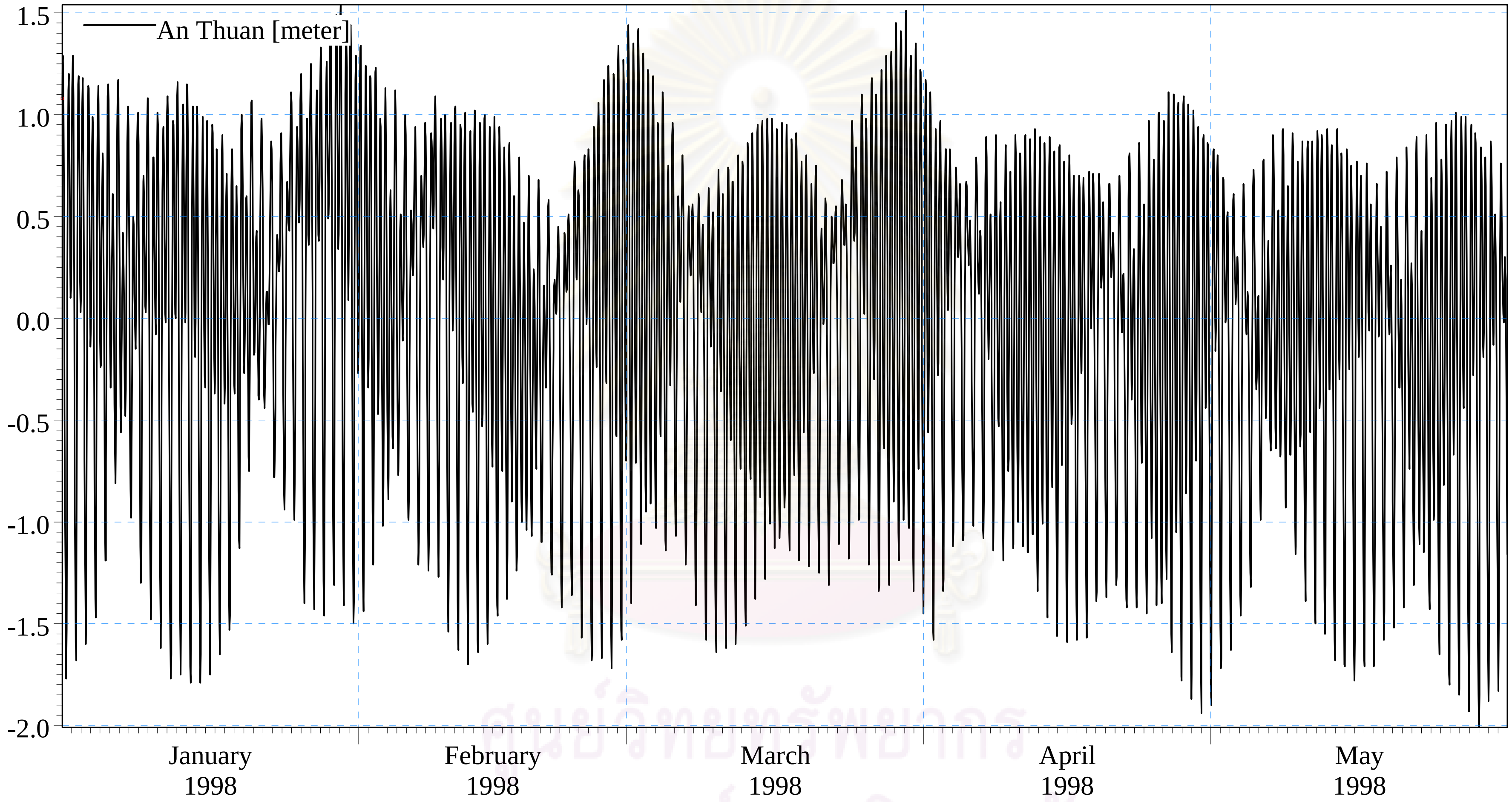


Figure F. 3. Boundary Condition (Water Level) at An Thuan Station in 1998

125

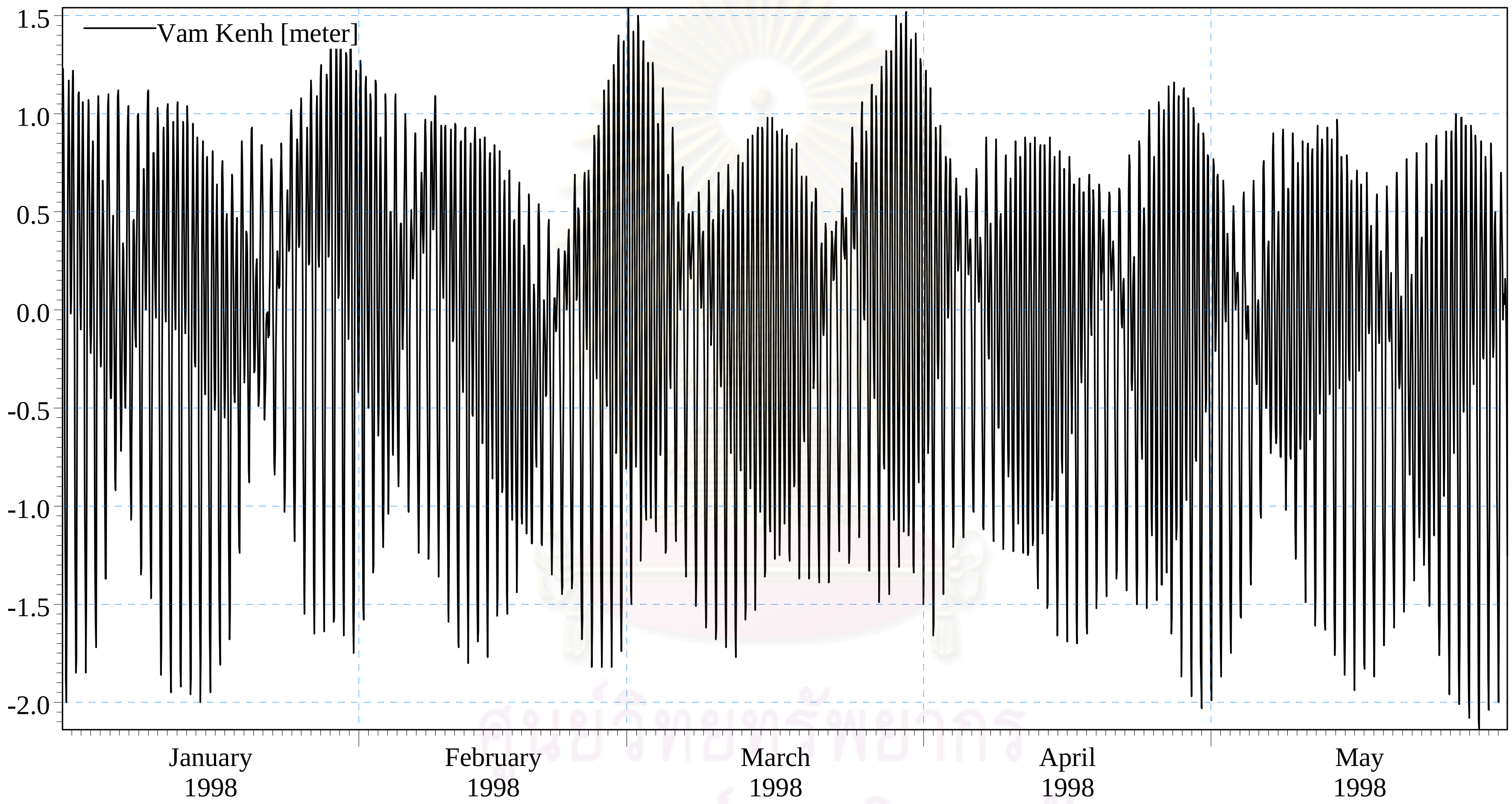


Figure F. 4. Boundary Condition (Water Level) at Vam Kenh Station in 1998

126

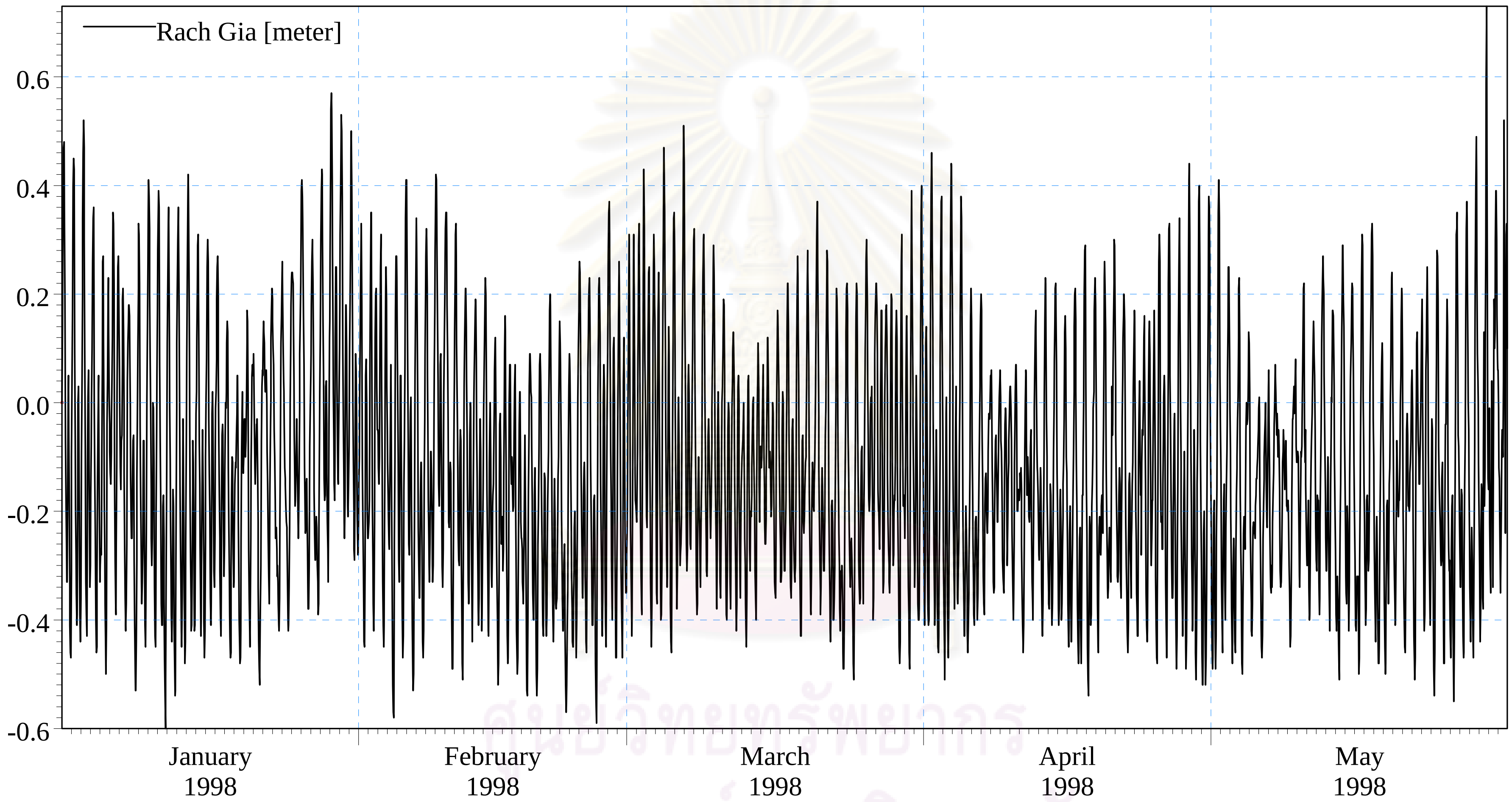


Figure F. 5. Boundary Condition (Water Level) at Rach Gia Station in 1998

127

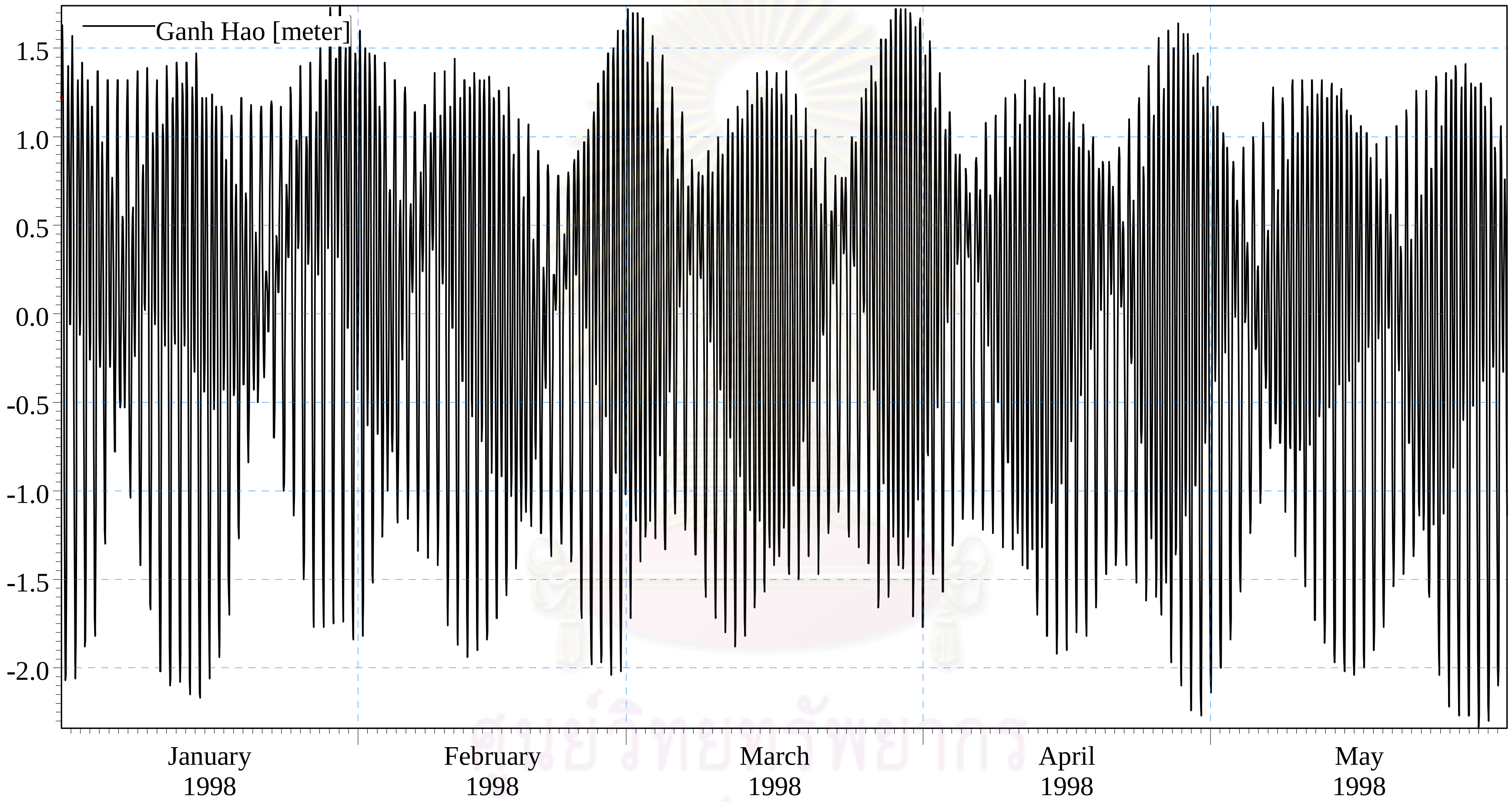


Figure F. 6. Boundary Condition (Water Level) at Ganh Hao Station in 1998

128

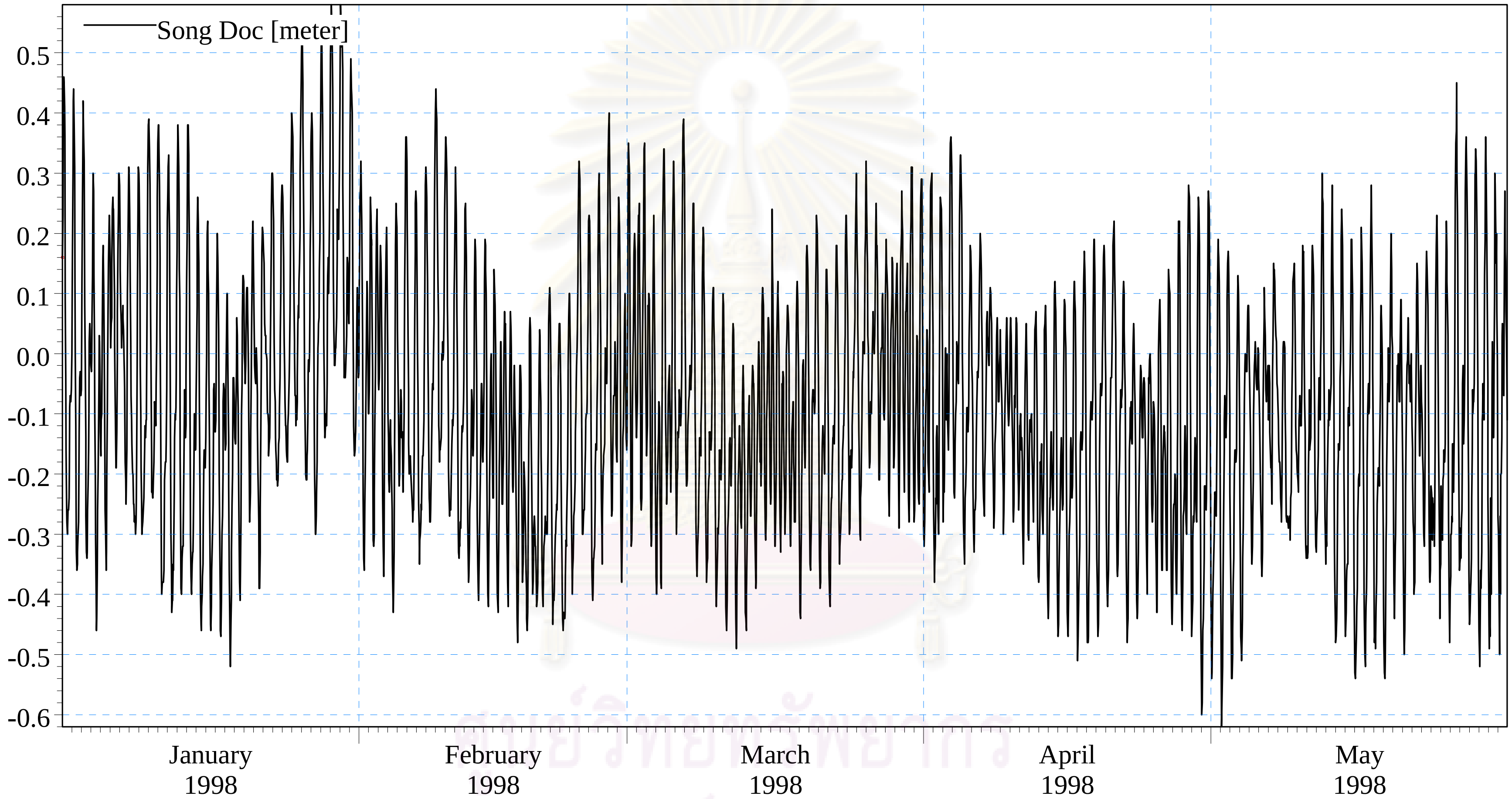


Figure F. 7. Boundary Condition (Water Level) at Song Doc Station in 1998

129

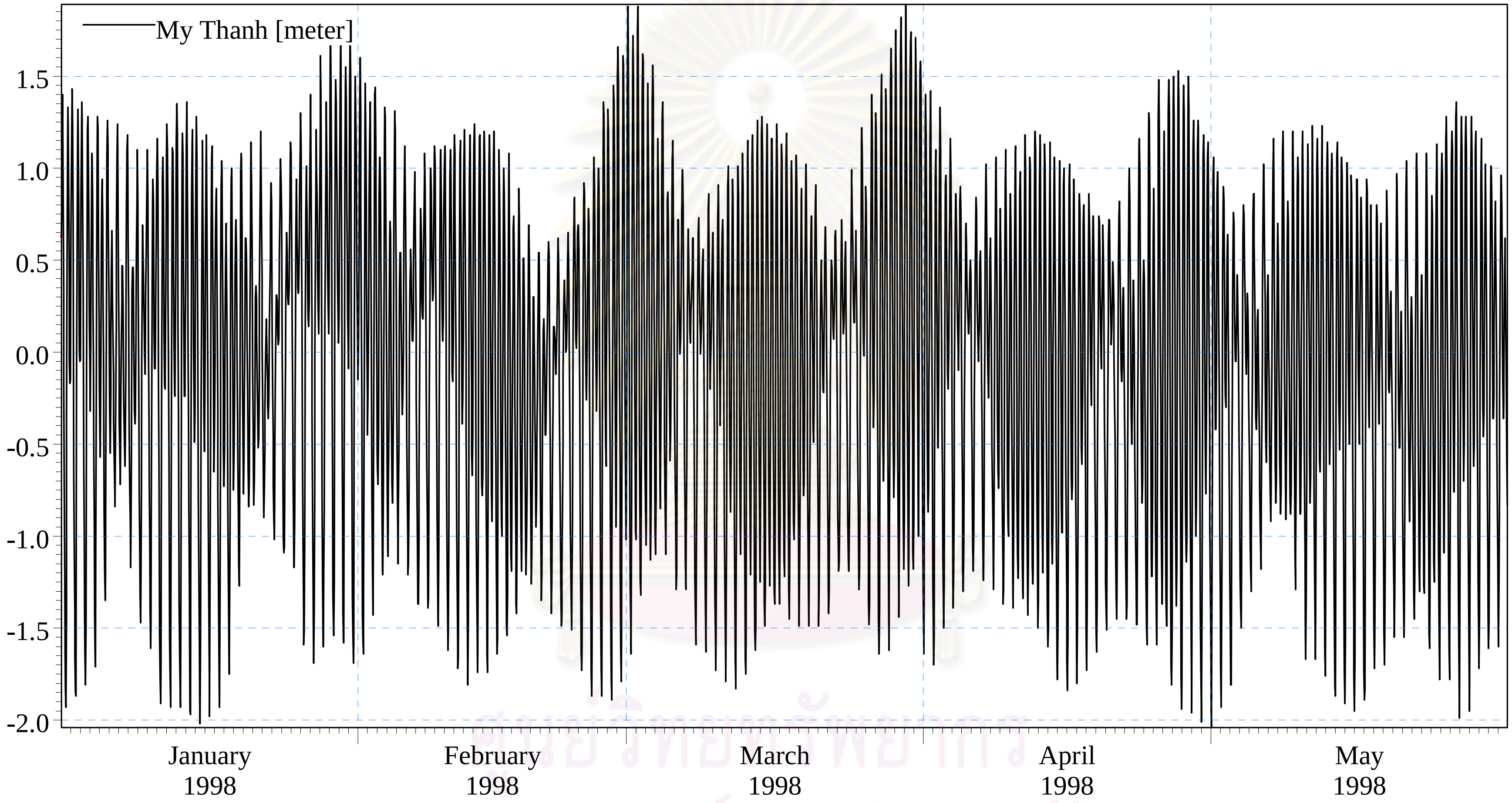


Figure F. 8. Boundary Condition (Water Level) at My Thanh Station in 1998

130

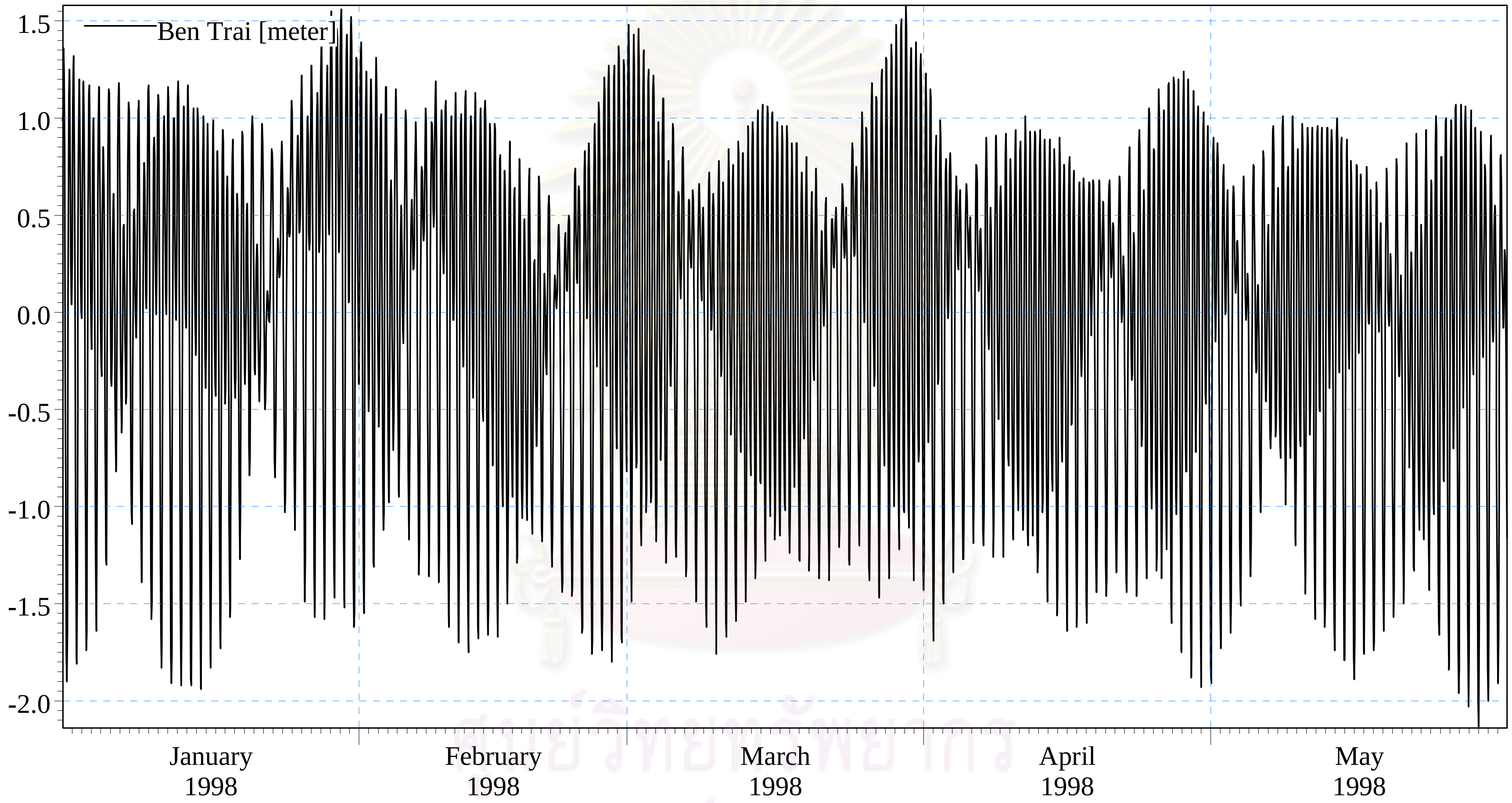


Figure F. 9. Boundary Condition (Water Level) at Ben Trai Station in 1998

131

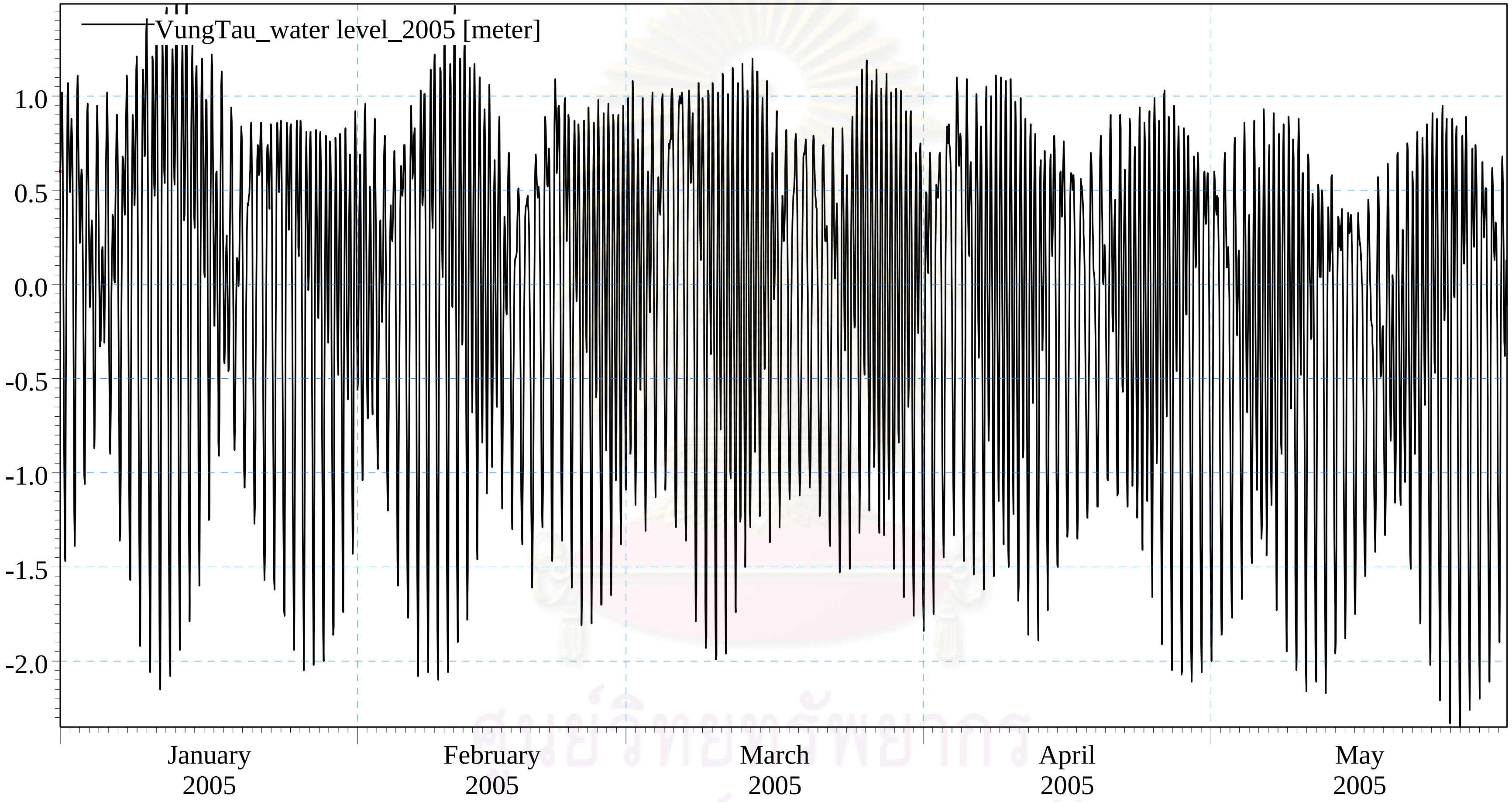


Figure F. 10. Boundary Condition (Water Level) at Vung Tau Staiton in 2005

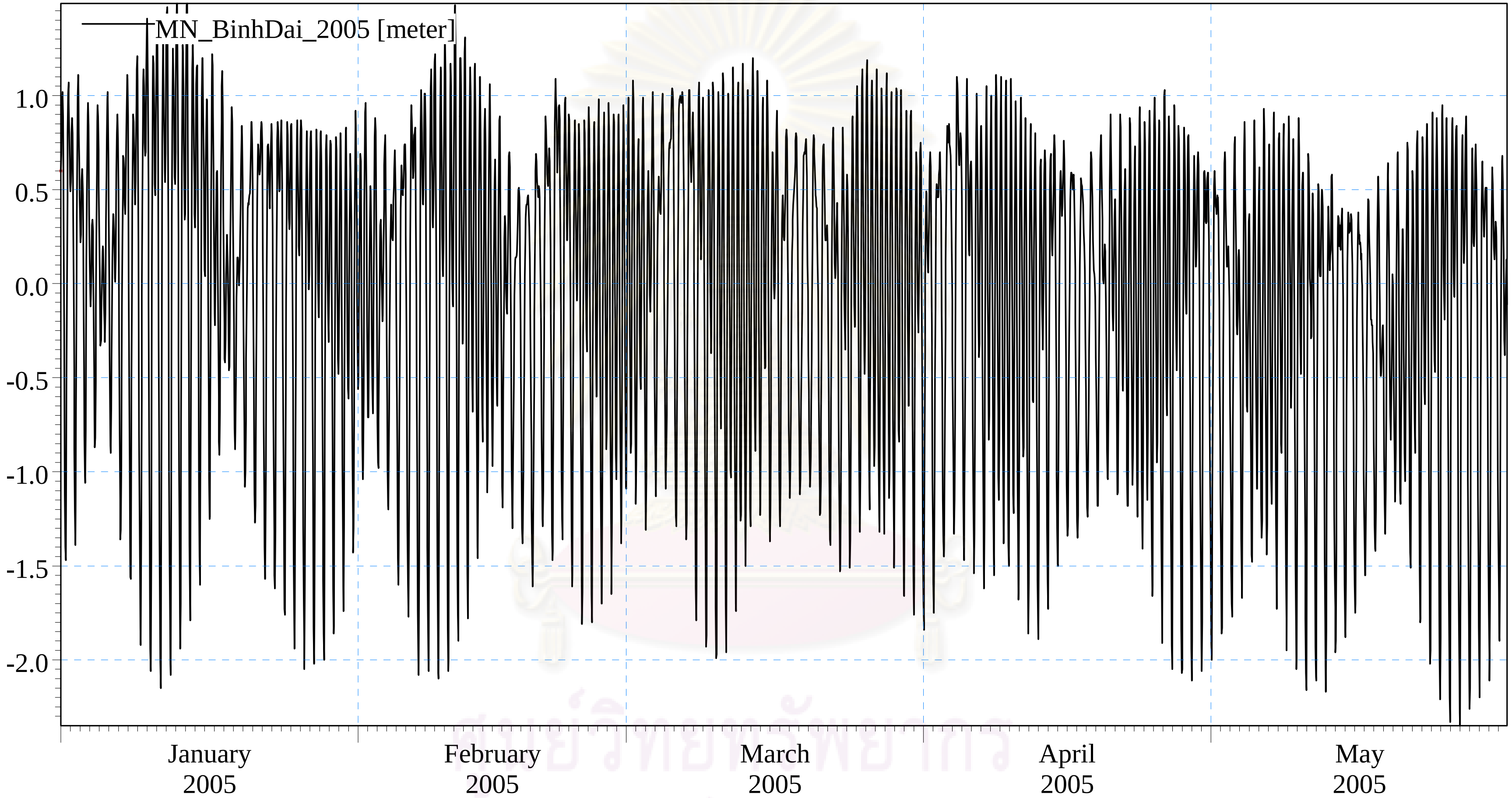


Figure F. 11. Boundary Condition (Water Level) at Binh Dai Station in 2005

133

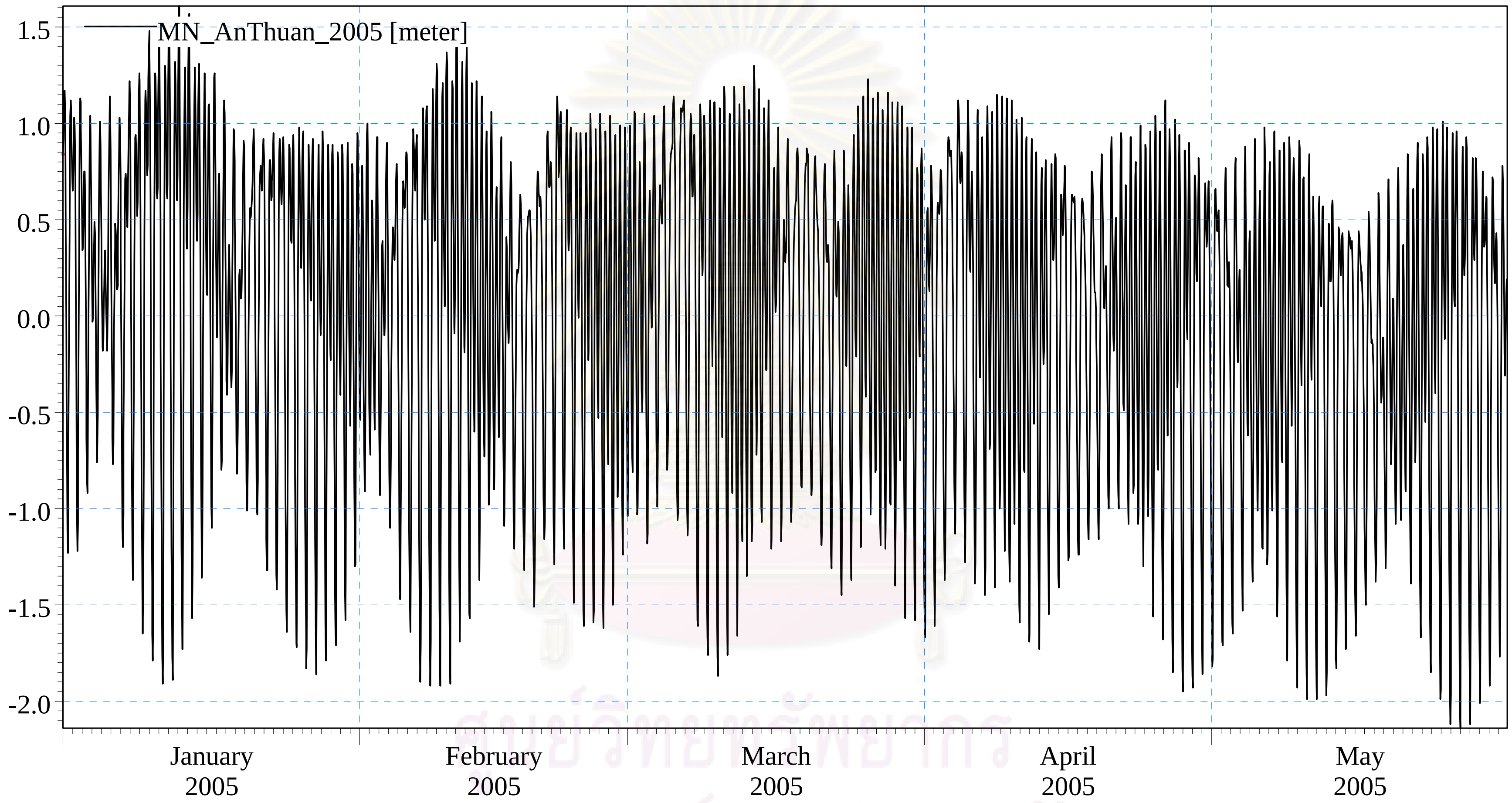


Figure F. 12. Boundary Condition (Water Level) at An Thuan Station in 2005

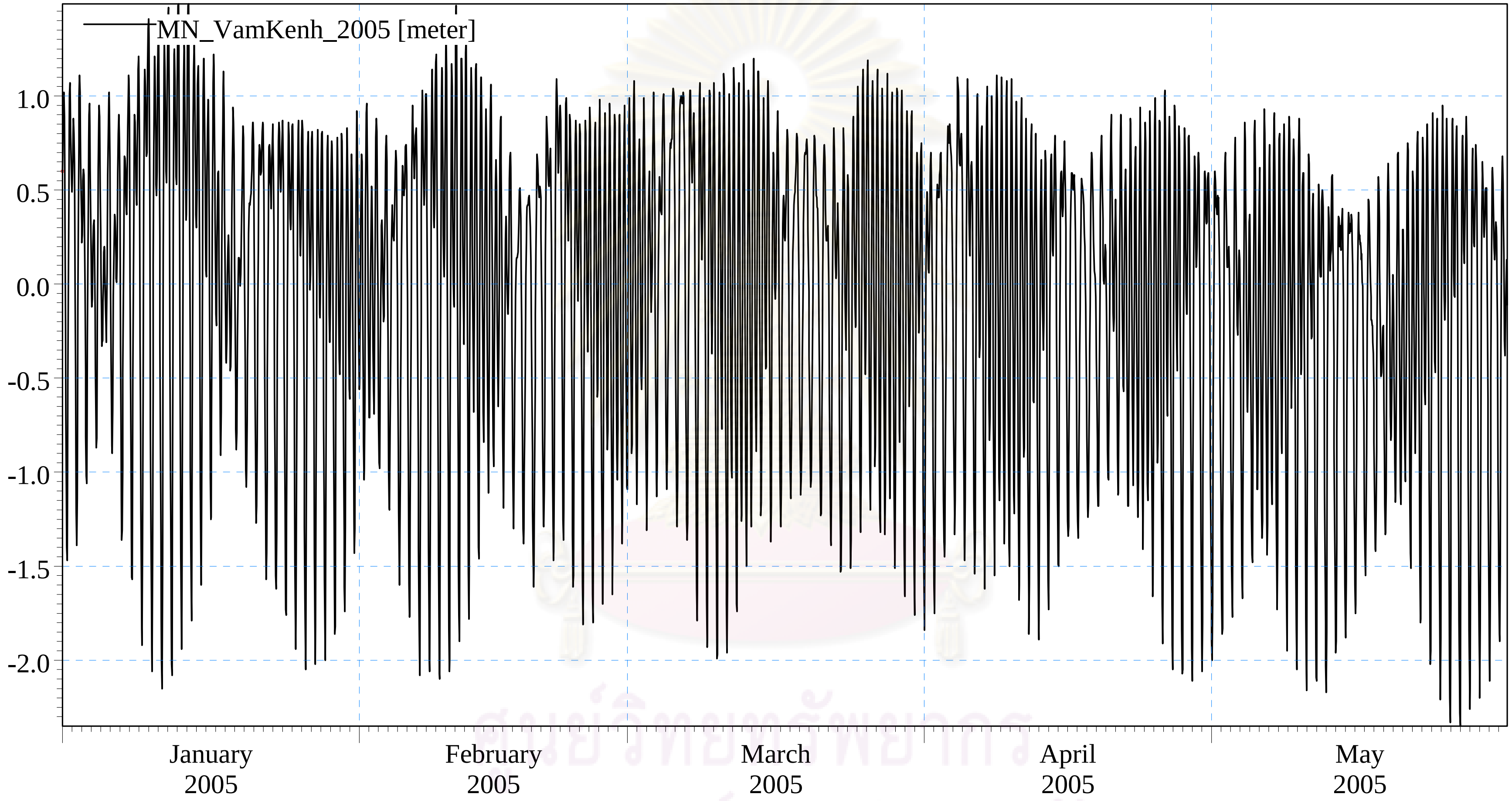


Figure F. 13. Boundary Condition (Water Level) at Vam Kenh Station in 2005

135

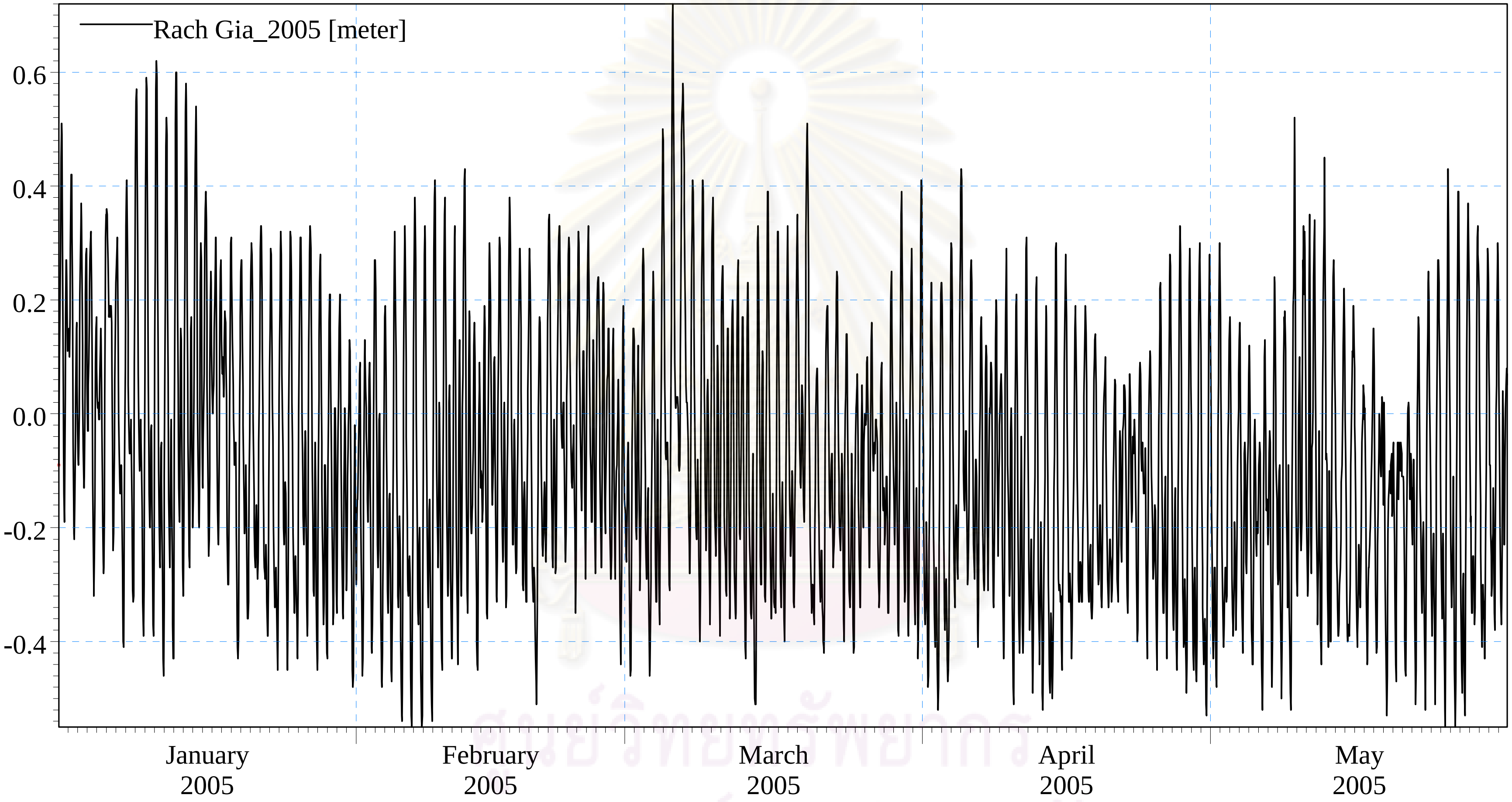


Figure F. 14. Boundary Condition (Water Level) at Rach Gia in 2005

136

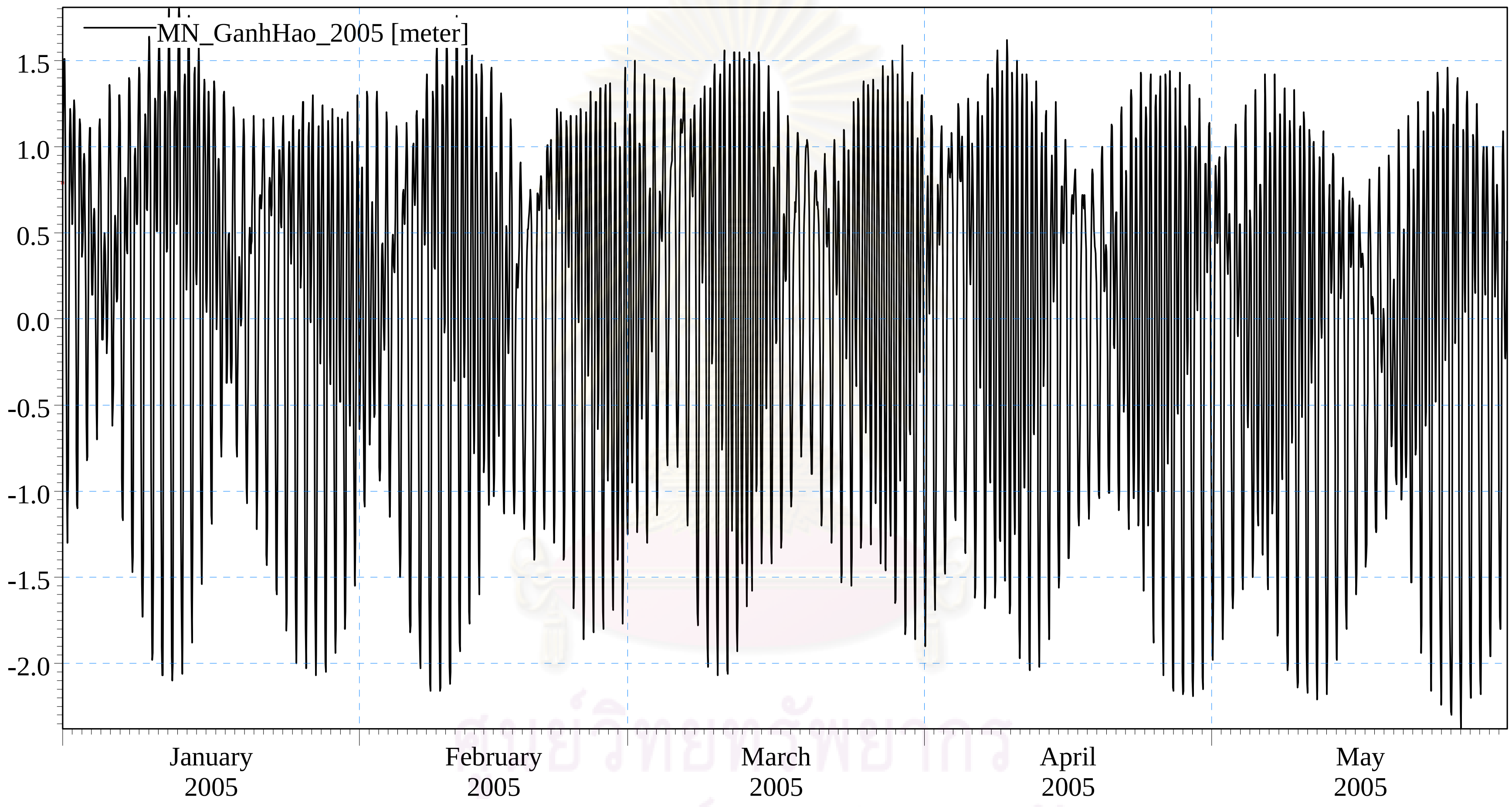


Figure F. 15. Boundary Condition (Water Level) at Ganh Hao Station

137

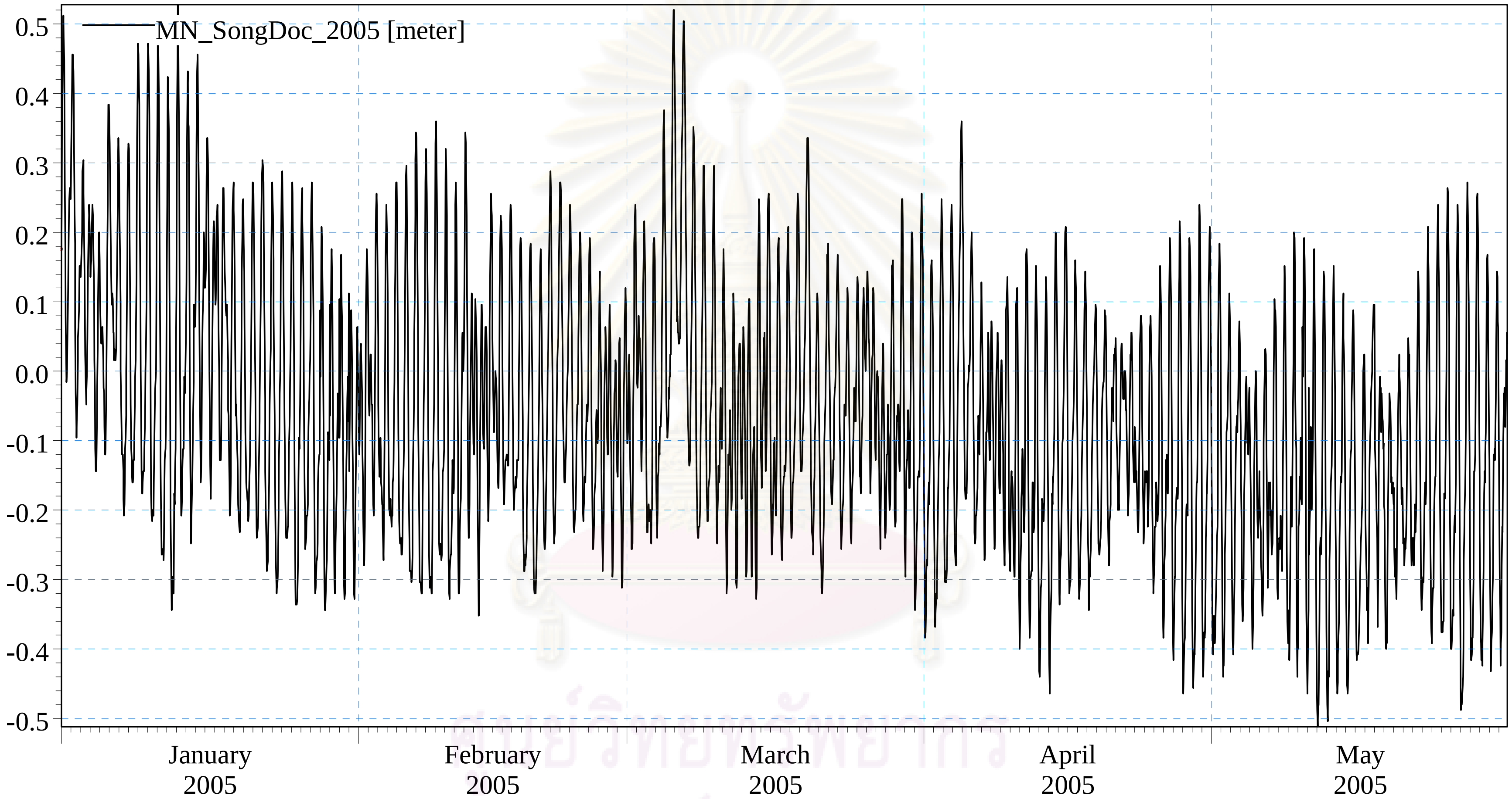


Figure F. 16. Boundary Condition (Water Level) at Song Doc Station

138

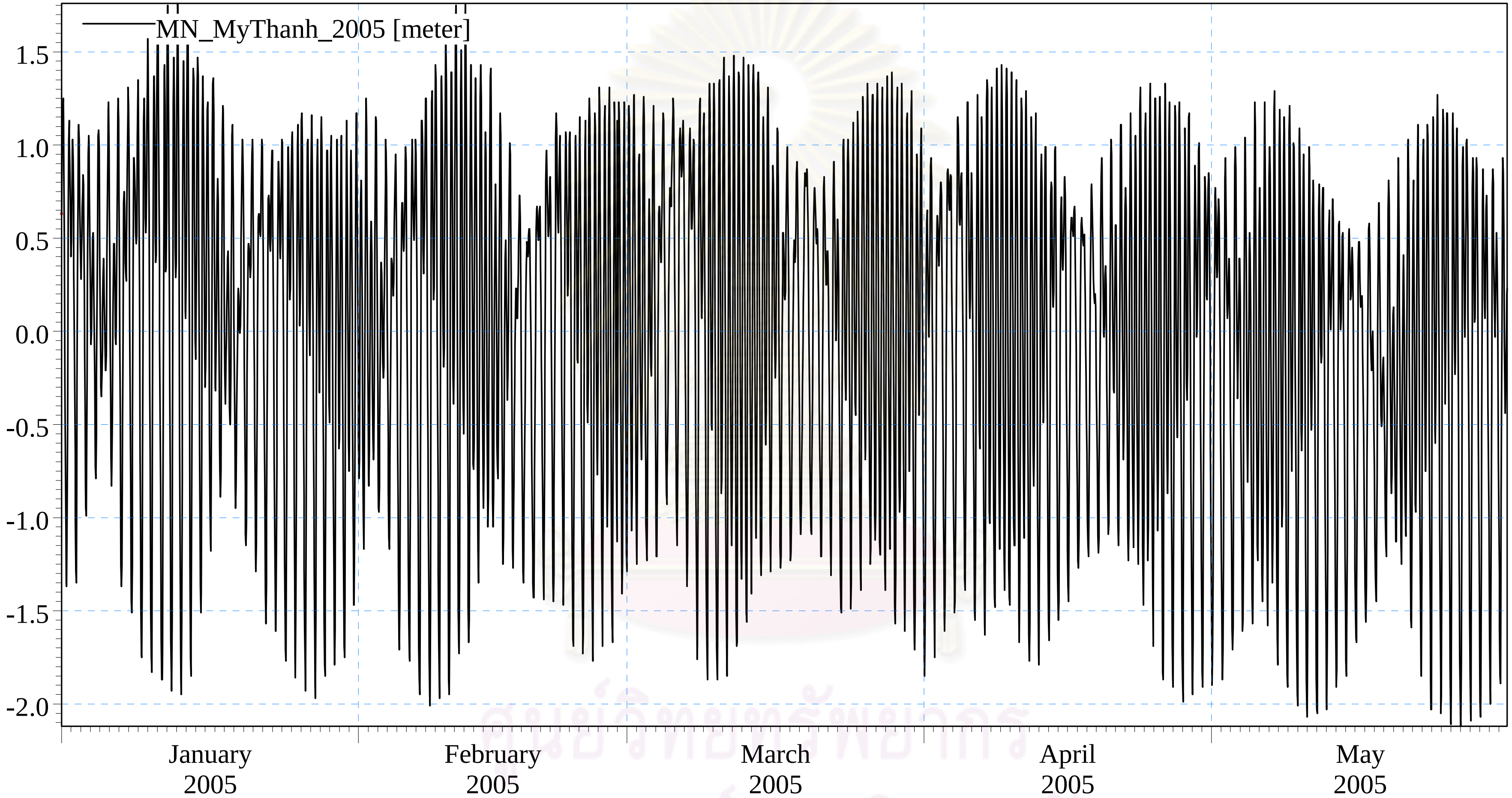


Figure F. 17. Boundary Condition (Water Level) at My Thanh Station in 2005

139

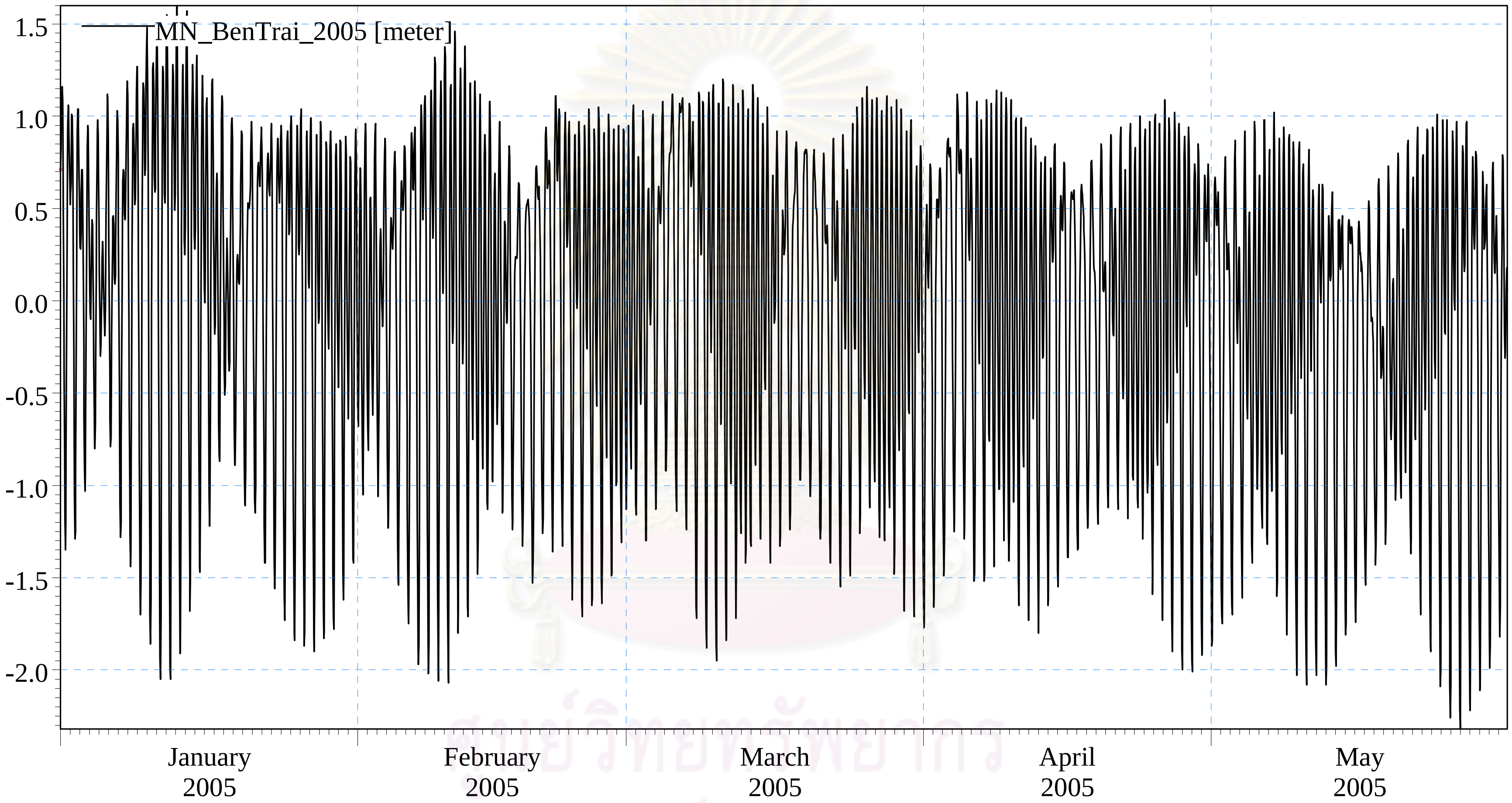


Figure F. 18. Boundary Condition (Water Level) at Ben Trai in 2005

140

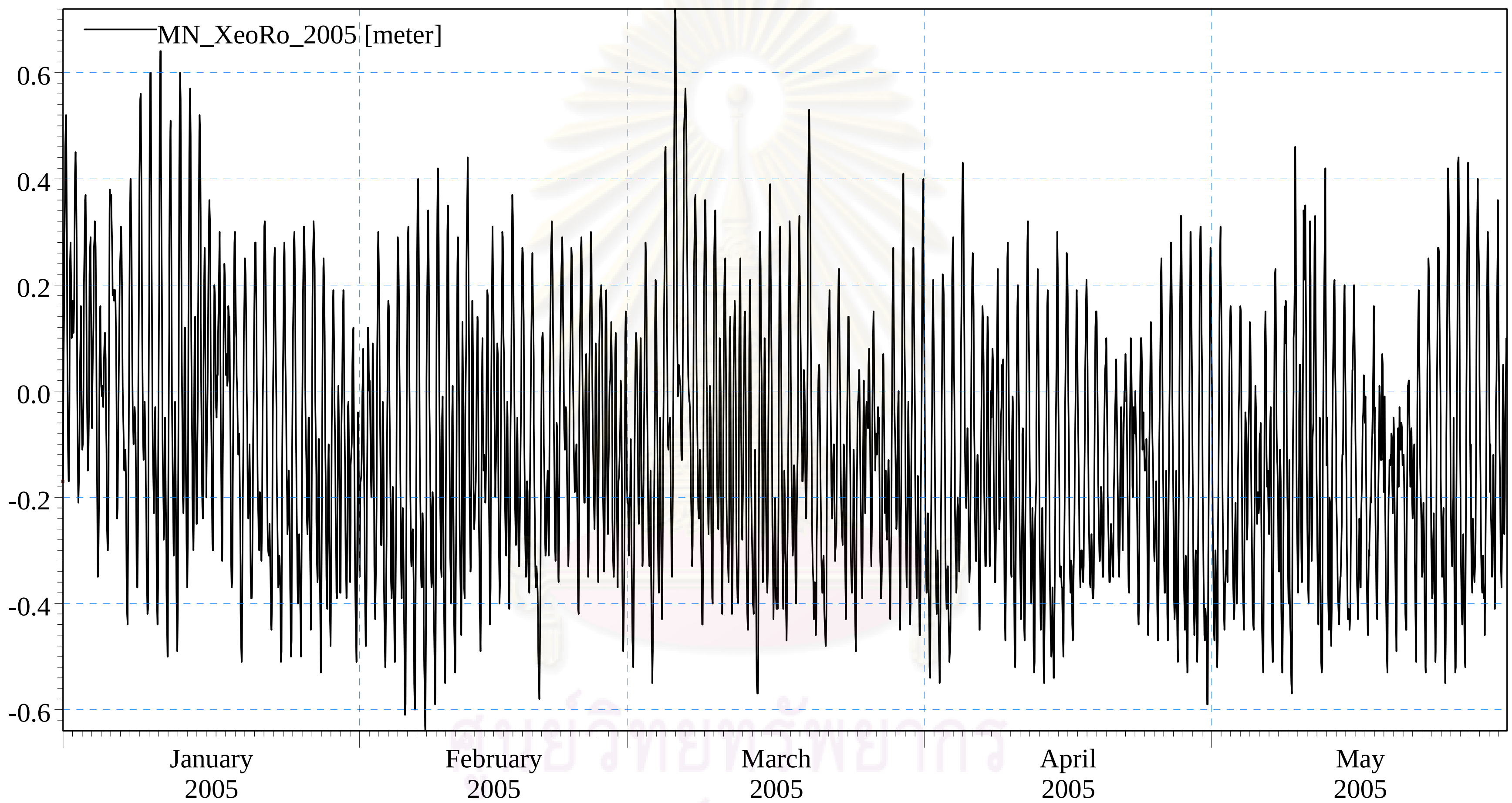


Figure F. 19. Boundary Condition (Water Level) at Xeo Ro in 2005

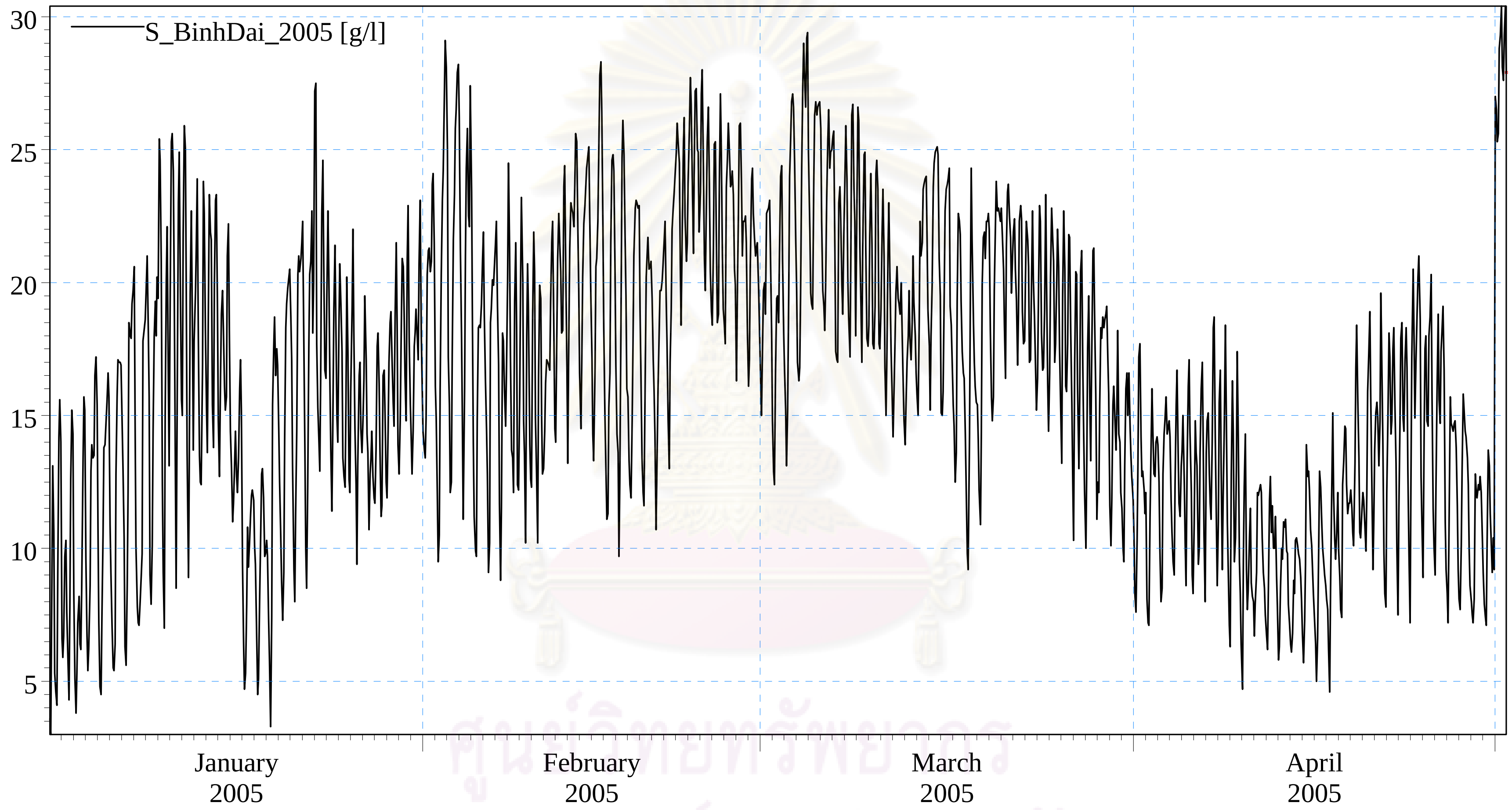


Figure F. 20. Boundary Condition (Salt Concentration) at Binh Dai Station in 2005

142

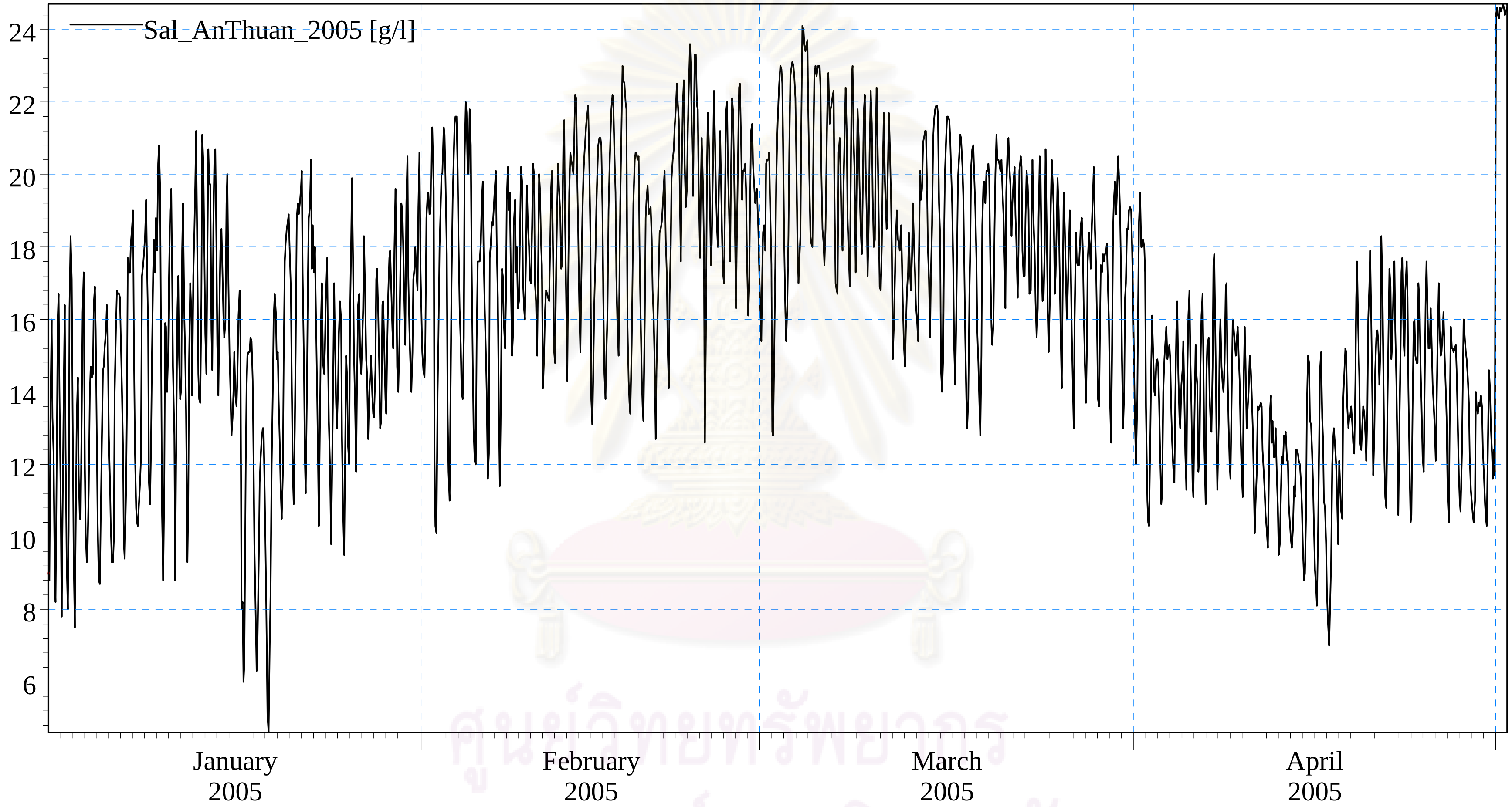


Figure F. 21. Boundary Condition (Salt Concentration) at An Thuan Station in 2005

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

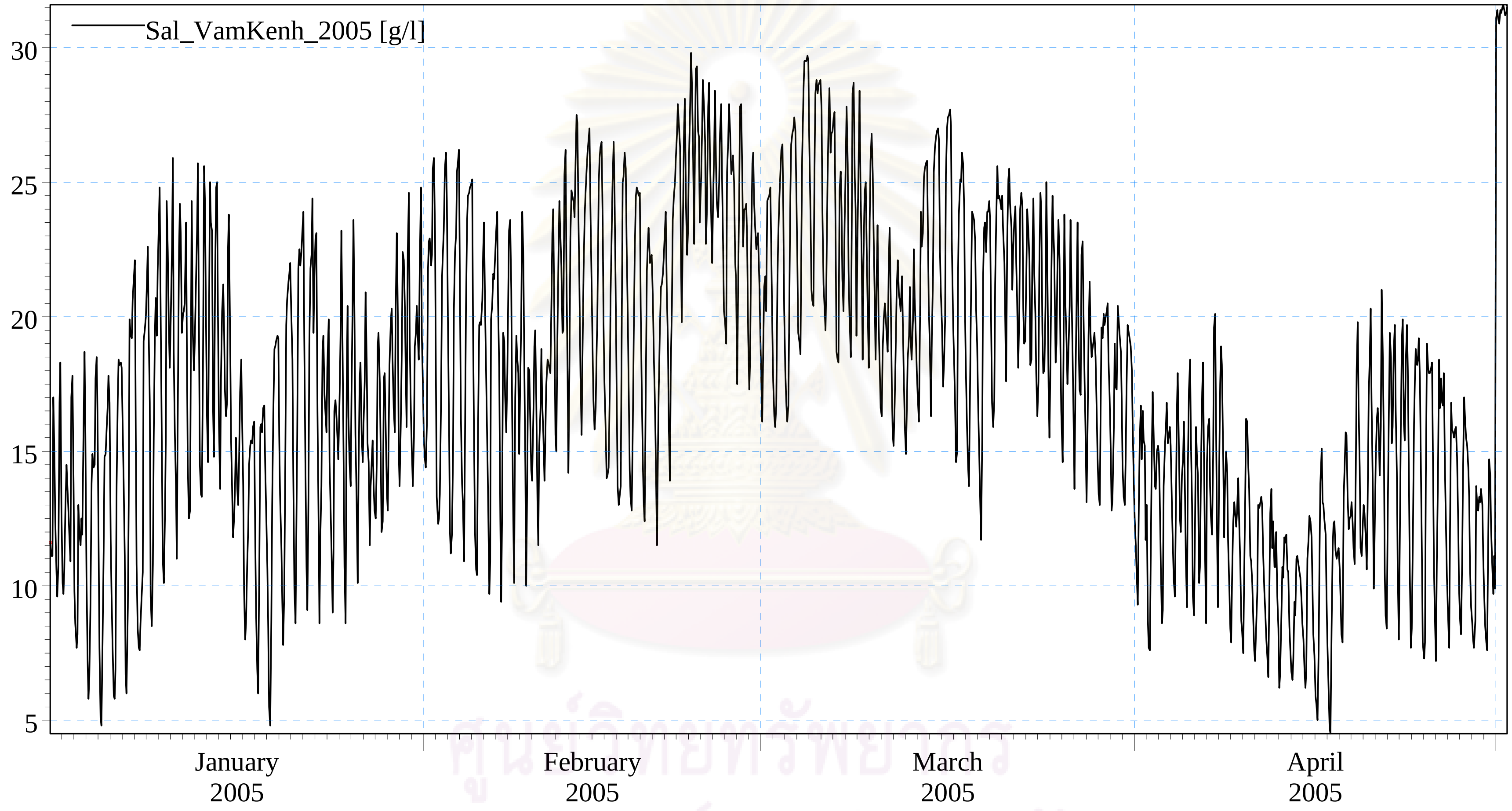


Figure F. 22. Boundary Condition (Salt Concentration) at Vam Kenh Station in 2005

144

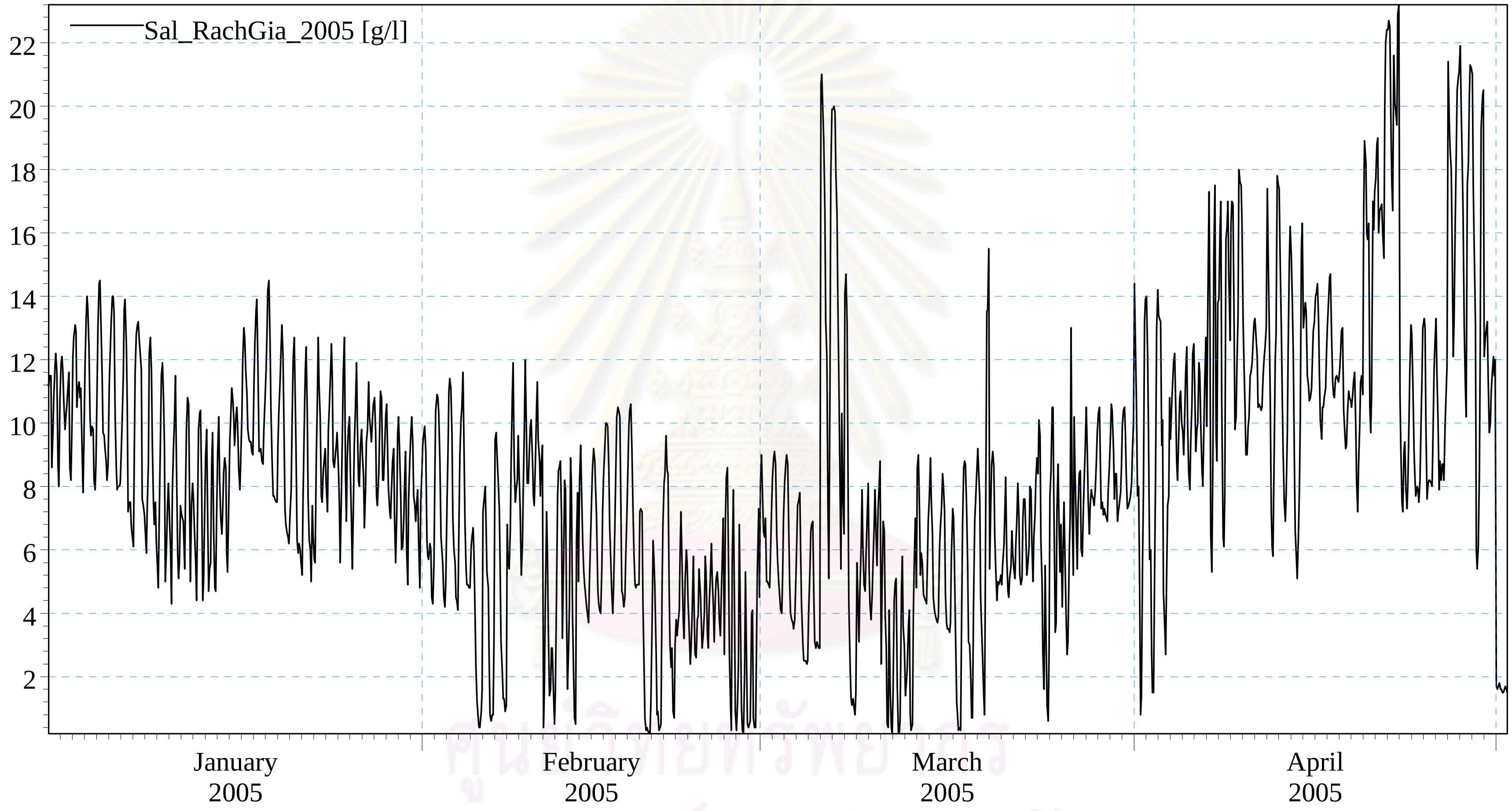


Figure F. 23. Boundary Condition (Salt Concentration) at Rach Gia Station in 2005

145

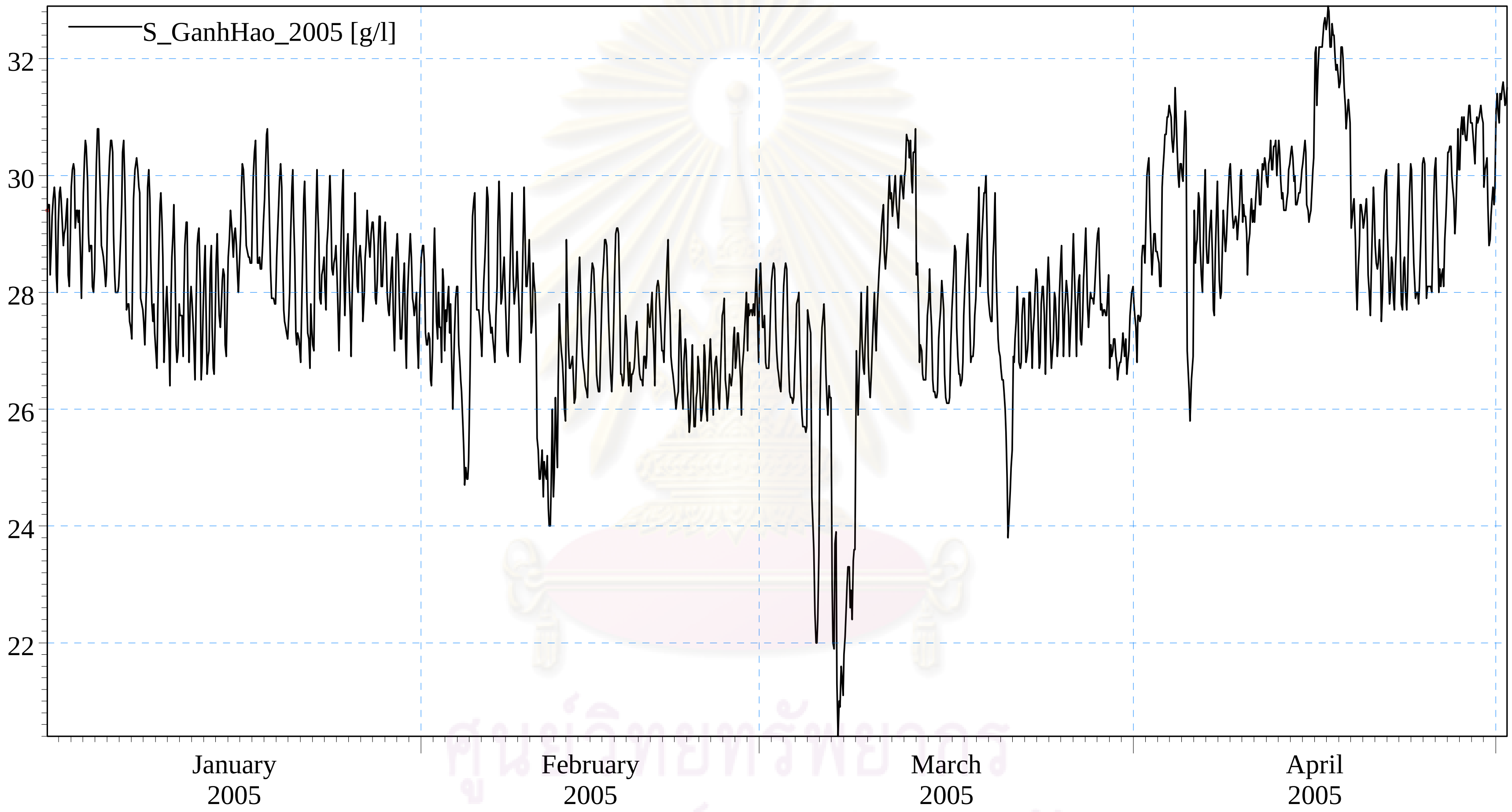


Figure F. 24. Boundary Condition (Salt Concentration) at Ganh Hao Station in 2005

146

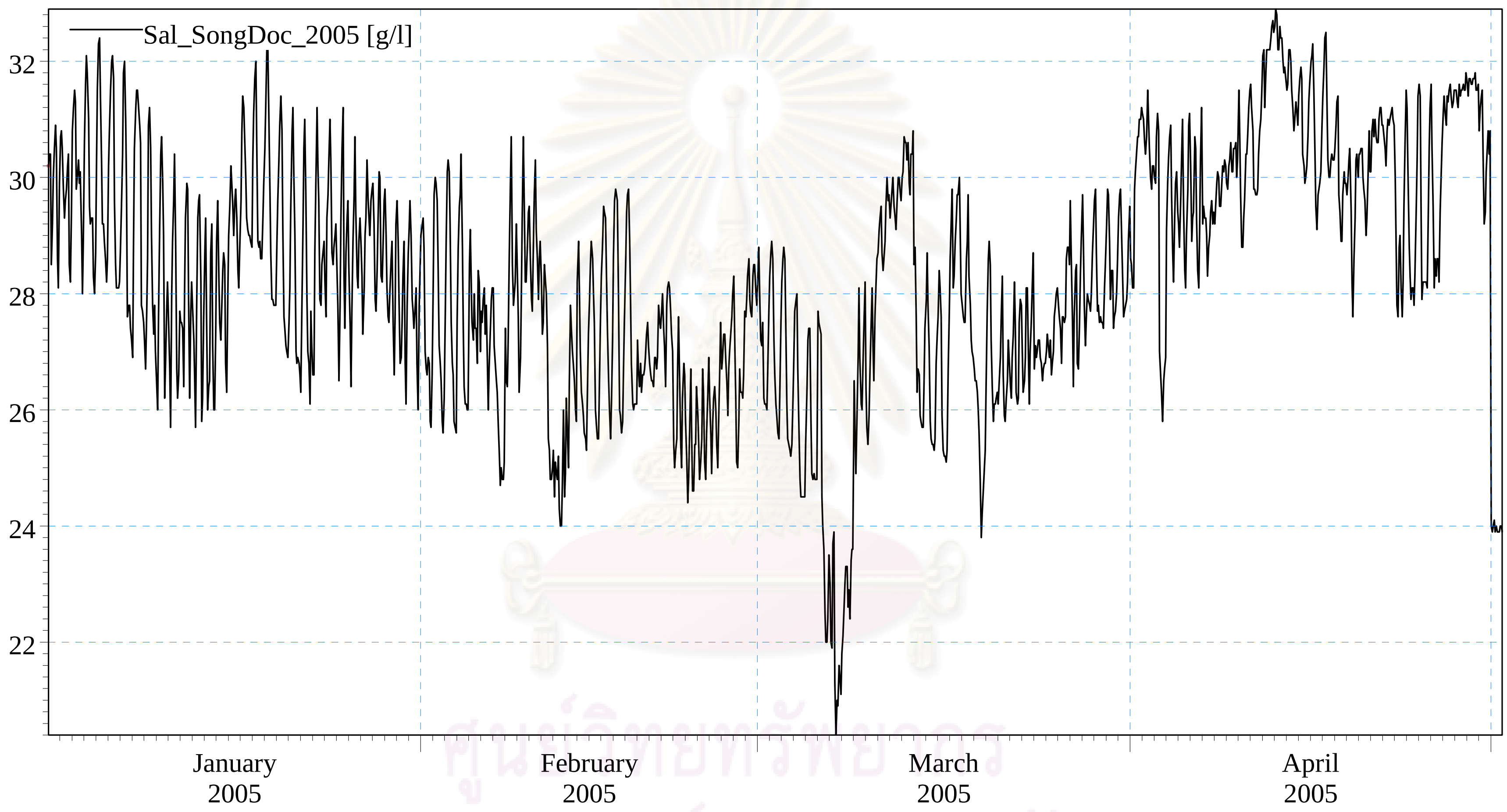


Figure F. 25. Boundary Condition (Salt Concentration) at Song Doc Station in 2005

147

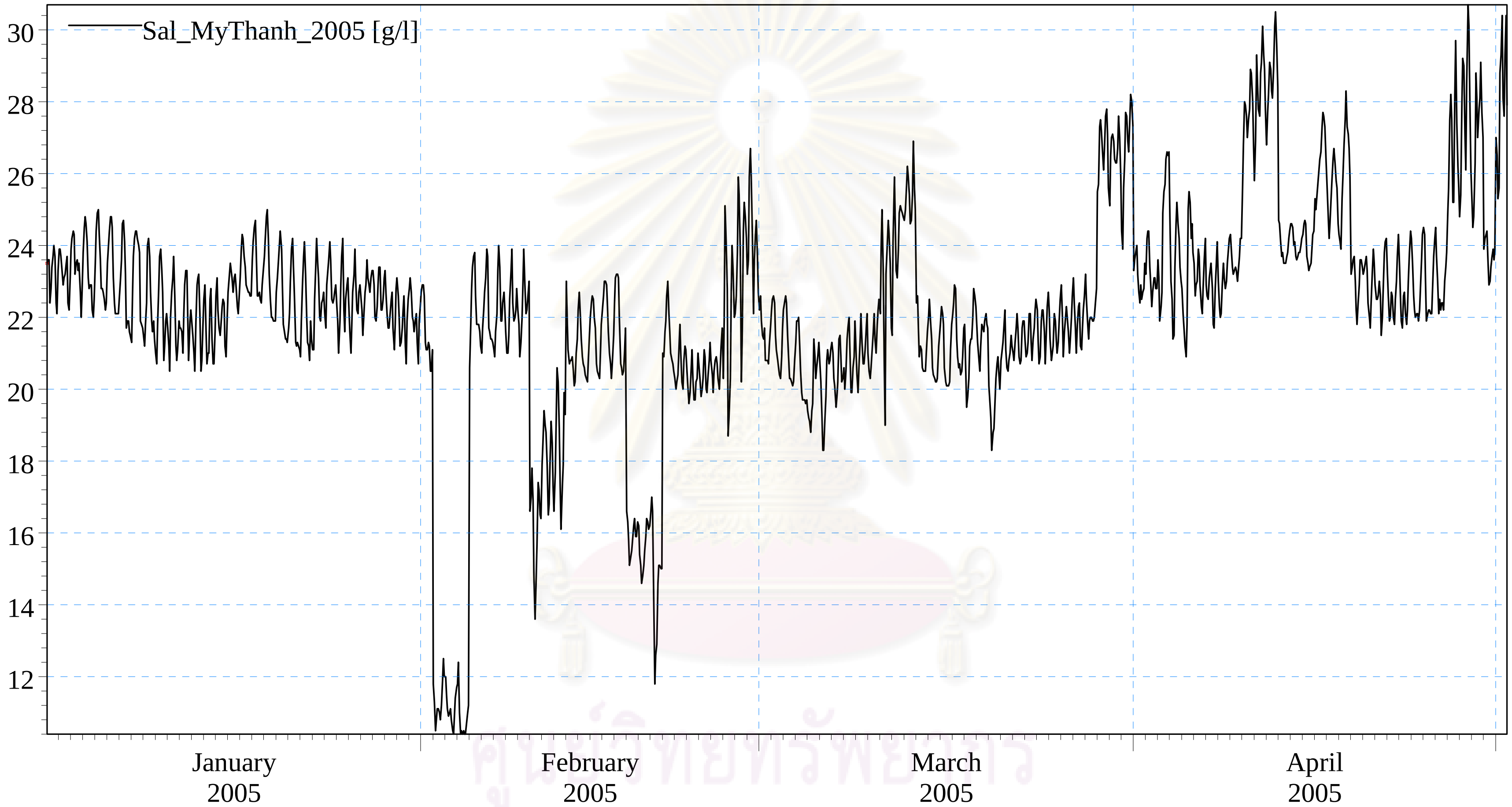


Figure F. 26. Boundary Condition (Salt Concentration) at My Thanh Station in 2005

148

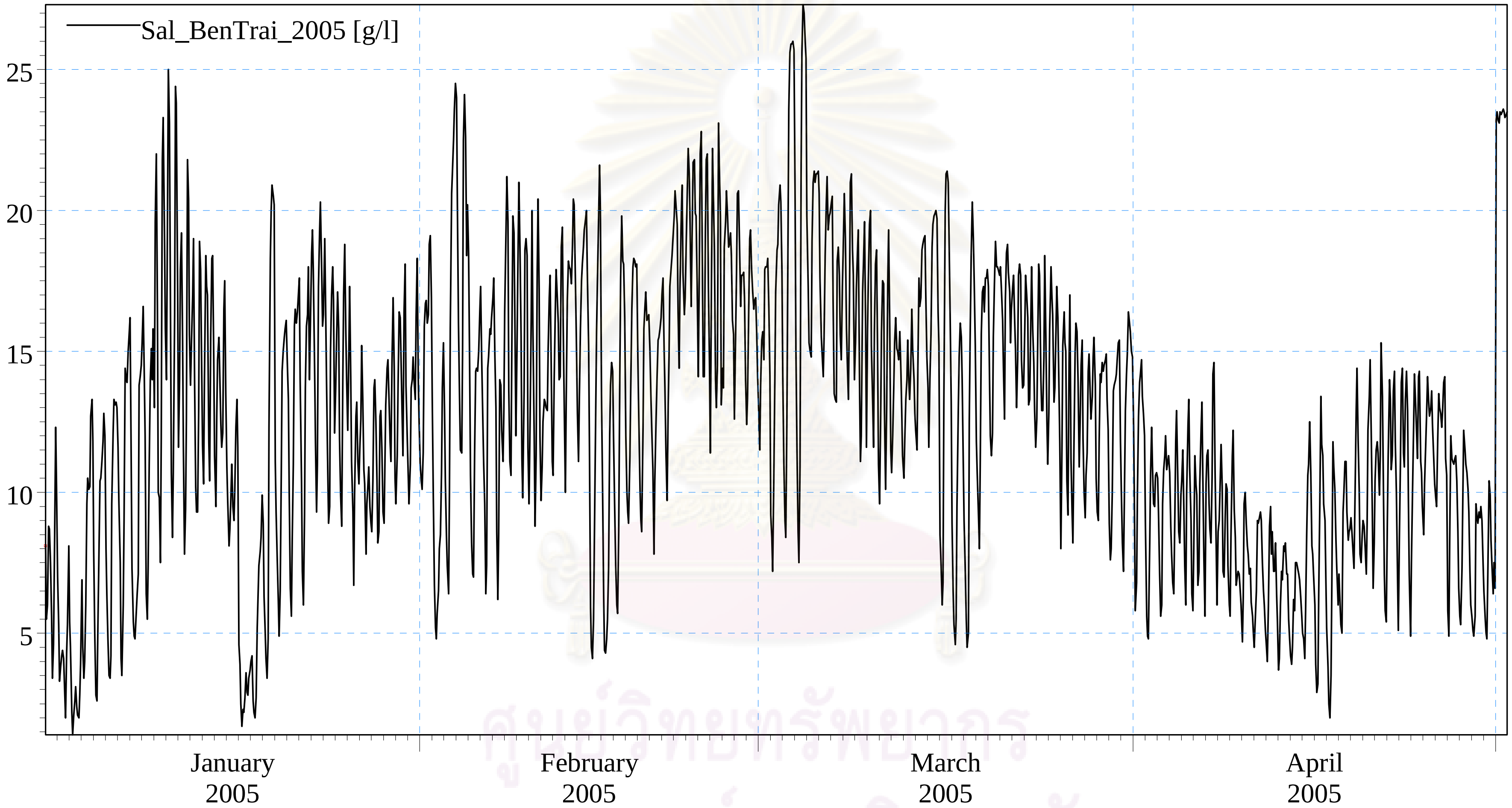


Figure F. 27. Boundary Condition (Salt Concentration) at Ben Trai Station in 2005

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

149

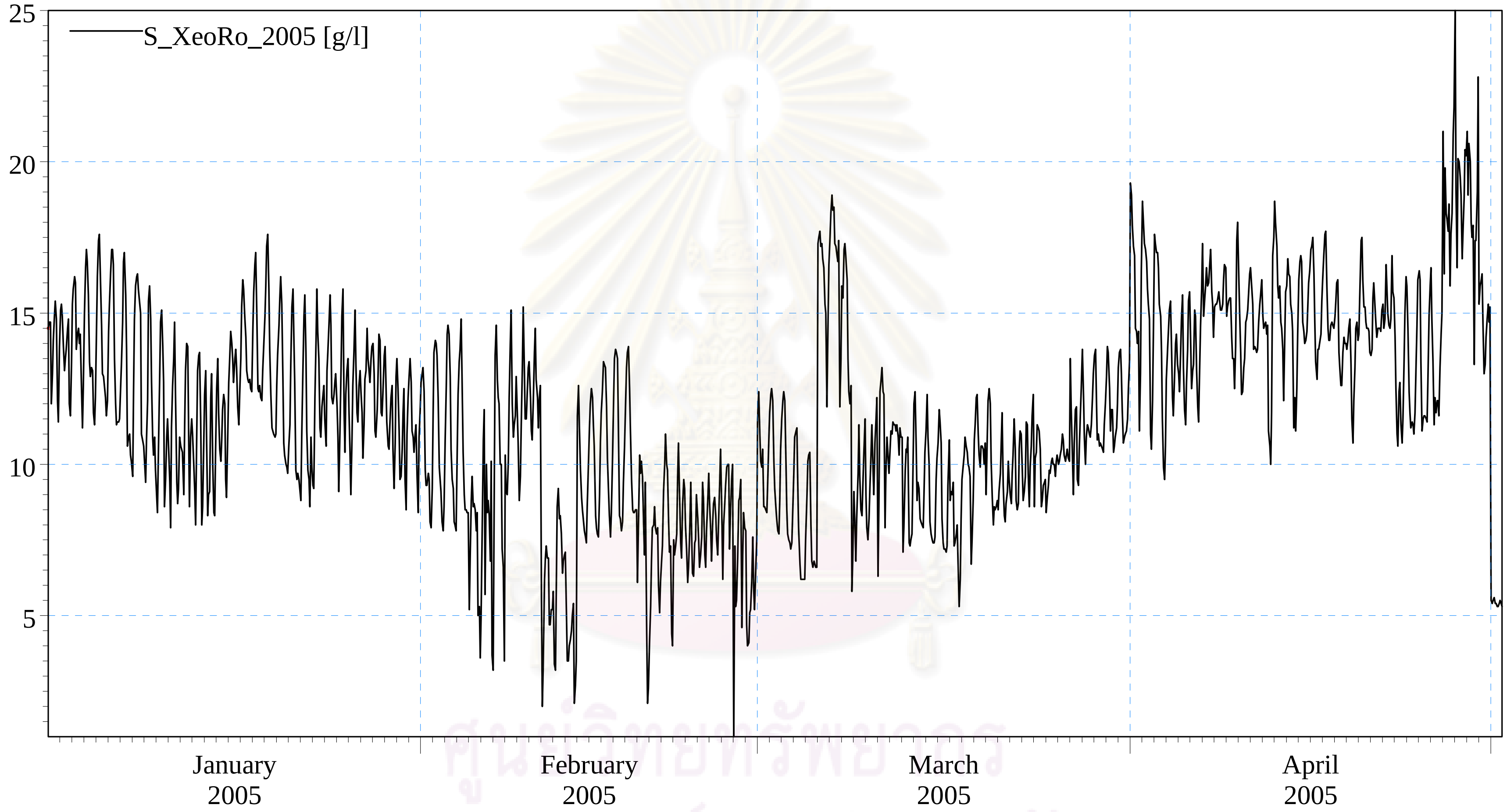


Figure F. 28. Boundary Condition (Salt Concentration) at Xeo Ro Station in 2005

150

APPENDIX G

Manning Coefficient for Model

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

River name	Chainage	Manning'n Coefficient Coeffient	River name	Chainage	Manning'n Coefficient Coeffient	River name	Chainage	Manning'n Coefficient Coeffient
2-9_down	0	0.02	Bacdongcanal	27960	0.025	Basi_cr	0	0.02
2-9_down	10900	0.02	Bachnguucreck	0	0.025	Basi_cr	12315	0.02
2-9_up	0	0.02	Bachnguucreck	44216	0.028	Basi_cr	23782	0.02
2-9_up	6773	0.02	Bactrang	0	0.02	Batri_creck1	0	0.02
AB_KSo6_1	0	0.028	Bactrang	10603	0.02	Batri_creck1	5900	0.02
AB_KSo6_1	10900	0.028	Balairiver	0	0.017	Batricreck2	0	0.02
AB_Kso6_2	0	0.028	Balairiver	68896	0.017	Batricreck2	18762	0.02
AB_Kso6_2	6400	0.028	Baodinh-creck	0	0.02	Bayhapriver	0	0.026
AB_Kso6_3	0	0.028	Baodinh-creck	25737	0.018	Bayhapriver	46000	0.02
AB_Kso6_3	3900	0.025	Baoke_canal	0	0.02	Ben_Luc	0	0.022
Anbinhcanal	0	0.018	Baoke_canal	29365	0.02	Ben_Luc	31884	0.022
Anbinhcanal	30254	0.02	BARAIKENH12	14500	0.02	Benke-canal	0	0.02
Anphong_Myhoa1	0	0.018	BARAIKENH12	27700	0.02	Benke-canal	13570	0.02
Anphong_Myhoa1	44161	0.02	BARAIKENH12	28000	0.02	Bentreriver	0	0.02
Anphong_Myhoa2	0	0.023	BARAIKENH12	55700	0.02	Bentreriver	11410	0.02
Anphong_Myhoa2	25370	0.02	BaRinh_TaLim	0	0.028	Bien30-4	0	0.022
Bacdongcanal	0	0.025	BaRinh_TaLim	9900	0.028	Bien30-4	1000	0.022

River name	Chainage	Manning'n Coefficient Coeffient	River name	Chainage	Manning'n Coefficient Coeffient	River name	Chainage	Manning'n Coefficient Coeffient
BienCaiCung	0	0.022	Ca_Gau	14039	0.022	CAIBEO	20000	0.02
BienCaiCung	0	0.022	Cagua_canal	0	0.02	Caicai_creck	0	0.02
BienChuaPhat	0	0.022	Cagua_canal	20269	0.02	Caicai_creck	18180	0.02
BienChuaPhat	0	0.022	Caibat_1	0	0.02	Caicungcanal	0	0.028
Bongcung1	0	0.017	Caibat_1	8495	0.02	Caicungcanal	12652	0.028
Bongcung1	14037	0.02	Caibat_2	0	0.02	CaiDoiVam	0	0.025
Bongcungcreck	0	0.017	Caibat_2	9038	0.02	CaiDoiVam	21200	0.025
Bongcungcreck	17163	0.02	Caibat_3	0	0.025	Caihop	0	0.03
Bonglot_cr	0	0.02	Caibat_3	6000	0.023	Caihop	20071	0.03
Bonglot_cr	12313	0.02	Caibat_3	19550	0.023	Cailon2	0	0.025
BTNEARDON1	0	0.02	Caibe	0	0.018	Cailon2	14200	0.05
BTNEARDON1	6000	0.04	Caibe	11450	0.018	Cailonriver	14800	0.022
BTNEARDON2	0	0.04	CaiBe1	0	0.025	Cailonriver	37988	0.018
BTNEARDON2	8645	0.02	CaiBe1	1700	0.025	CaiOanh	0	0.025
Bungtruong	0	0.02	CaiBe2	0	0.025	CaiOanh	12800	0.025
Bungtruong	15381	0.02	CaiBe2	4390	0.025	Caisancanal	0	0.02
Ca_Gau	0	0.022	CAIBEO	0	0.02	Caisancanal	55424	0.02

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

153

River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient
Caisao_cr	0	0.02	Cay_Kho	0	0.022	CL_Rua	0	0.022
Caisao_cr	31256	0.02	Cay_Kho	8788	0.022	CL_Rua	6210	0.022
Caitac-creck	0	0.02	ChauHung1	0	0.025	Clchai	0	0.022
Caitac-creck	9278	0.02	ChauHung1	8655	0.025	Clchai	5100	0.022
CaiTrau	0	0.025	CH-CC5	0	0.025	CM-BL-Ntho	8400	0.035
CaiTrau	33864	0.025	CH-CC5	4979	0.025	CM-BL-Ntho	83800	0.035
Caitrau-Daingai	0	0.025	Chetsay_canal1	0	0.02	Cochien_nv1	0	0.02
Caitrau-Daingai	77309	0.025	Chetsay_canal1	3326	0.02	Cochien_nv1	16500	0.02
CaiXe	0	0.025	CHOBUNG	0	0.02	Cochien-nv2	0	0.02
CaiXe	12300	0.025	CHOBUNG	17198	0.02	Cochien-nv2	13000	0.02
Can_Giuoc	0	0.025	Chogaocanal	0	0.02	Cochienriver	0	0.02
Can_Giuoc	11477	0.025	Chogaocanal	23212	0.02	Cochienriver	23000	0.02
Canchong	0	0.02	ChuVang1	0	0.025	Cochienriver	36500	0.023
Canchong	11032	0.02	ChuVang1	6300	0.025	Cochienriver	39000	0.025
CaoLanhR	0	0.018	ChuVang2	0	0.025	Cochienriver	41000	0.023
CaoLanhR	22200	0.018	ChuVang2	3800	0.025	Cochienriver	72900	0.02
Cau_Kenh	0	0.025	CL_Pho	0	0.04	COCO	0	0.018
Cau_Kenh	1570	0.025	CL_Pho	7067	0.03	COCO	31360	0.018

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

154

River name	Chainage	Manning’n Coefficient	River name	Chainage	Manning’n Coefficient	River name	Chainage	Manning’n Coefficient
Coco-Baclieu	0	0.025	daingai	0	0.02	Dong_Nai	93112	0.035
Coco-Baclieu	30100	0.025	daingai	16709	0.02	Dong_Tranh	0	0.05
CoCoRiver	0	0.025	DaMDoiriver	0	0.026	Dong_Tranh	9045	0.05
CoCoRiver	26600	0.025	DaMDoiriver	51000	0.026	Dong_Tranh	11000	0.035
Conect-river	0	0.03	Dan_Xay	0	0.05	Dong_Tranh	24653	0.035
Conect-river	8400	0.03	Dan_Xay	3750	0.05	DongCungCanal	0	0.026
CongNghiep	0	0.025	Dinh_Ba	0	0.05	DongCungCanal	27780	0.026
CongNghiep	9770	0.025	Dinh_Ba	15500	0.05	Dongtiencanal	0	0.018
CS_KS1	0	0.025	Dinh_Ba	16500	0.03	Dongtiencanal	36000	0.018
CS_KS1	5070	0.025	Dinh_Ba	25406	0.025	Dongtiencanal	39400	0.025
CS_KS2	0	0.025	Dong_Nai	0	0.018	Dongtiencanal	44250	0.025
CS_KS2	4960	0.025	Dong_Nai	48000	0.018	Duongvanduong	0	0.025
Cuadairiver	0	0.022	Dong_Nai	49000	0.02	Duongvanduong	20000	0.022
Cuadairiver	14500	0.02	Dong_Nai	50924.3	0.025	Duongvanduong	28000	0.025
Cuadairiver	16000	0.02	Dong_Nai	54000	0.035	Duongvanduong	30310	0.025
Cuadairiver	37000	0.02	Dong_Nai	58878	0.04	Ganhhaoriver	0	0.035
Cualonriver	0	0.03	Dong_Nai	59940	0.04	Ganhhaoriver	32000	0.035
Cualonriver	44782	0.02	Dong_Nai	88875	0.035	Ganhhaoriver	48000	0.017

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient
GiongTromR	0	0.02	HangMai	0	0.026	Hauriver	180750	0.025
GiongTromR	32800	0.02	HangMai	16400	0.026	Hauriver	194000	0.025
GOCAT-HOCLUU	0	0.02	Hauriver	0	0.023	Hauriver	212000	0.022
GOCAT-HOCLUU	24854	0.02	Hauriver	109000	0.023	Hauriver	239000	0.022
GoCongR	0	0.02	Hauriver	111000	0.0275	Hauriver	245000	0.025
GoCongR	10800	0.02	Hauriver	118700	0.0275	Hauriver	275200	0.022
Hamgiang	0	0.02	Hauriver	119000	0.03	Hauriver	317400	0.02
Hamgiang	14641	0.02	Hauriver	126000	0.03	HAURIVER_109R	0	0.03
HAMLUONG_12500R	0	0.025	Hauriver	128000	0.03	HAURIVER_109R	10000	0.03
HAMLUONG_12500R	13500	0.025	Hauriver	134000	0.026	Hauriver171r	0	0.025
HAMLUONG_33500L	0	0.025	Hauriver	137000	0.023	Hauriver171r	5000	0.025
HAMLUONG_33500L	4900	0.025	Hauriver	149000	0.023	Hauriver194r	0	0.025
HAMLUONG_51500L	0	0.022	Hauriver	153000	0.035	Hauriver194r	18000	0.025
HAMLUONG_51500L	7000	0.02	Hauriver	156150	0.03	Hauriver218r	0	0.02
Hamluongriver	0	0.022	Hauriver	156650	0.035	Hauriver218r	10000	0.02
Hamluongriver	40000	0.022	Hauriver	167000	0.03	Hauriver245l	0	0.025
Hamluongriver	40500	0.02	Hauriver	168200	0.025	Hauriver245l	17935	0.025
Hamluongriver	71600	0.02	Hauriver	171571	0.025	Hauriver256l	0	0.025

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

156

River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient
hauriver256L	14930	0.025	Huyensu1	8688	0.025	KBAYXA	12859	0.02
hauriver265L	0	0.025	Huyensu2	0	0.026	KBUIMOI-1	0	0.02
hauriver265L	4000	0.025	Huyensu2	10223	0.03	KBUIMOI-1	7000	0.02
HDONGTUONG	0	0.02	Huyensu3	2800	0.03	KBUIMOI-2	0	0.02
HDONGTUONG	14600	0.02	Huyensu3	11000	0.026	KBUIMOI-2	5000	0.02
HGiang3_1	0	0.026	K307-1	0	0.02	KDABIEN	0	0.04
HGiang3_1	7000	0.026	K307-1	10000	0.02	KDABIEN	9900	0.04
HGiang3_2	0	0.026	K307-2	0	0.02	KDUONGTHIET-1	0	0.04
HGiang3_2	11060	0.026	K307-2	9640	0.02	KDUONGTHIET-1	4100	0.04
HGiang3_3	0	0.026	K7THUOC	303.242	0.02	KDUONGTHIET-2	0	0.02
HGiang3_3	10500	0.026	K7THUOC	25400	0.02	KDUONGTHIET-2	4025	0.02
HOABINHCANAL	0	0.026	KBACDONGCU	0	0.04	KDUONGTHIET-3	0	0.02
HOABINHCANAL	21338	0.026	KBACDONGCU	16025	0.04	KDUONGTHIET-3	7570	0.033
Hong_ngu	0	0.018	KBAKYBATRATG	0	0.02	Kengchongmy	0	0.026
Hong_ngu	43900	0.02	KBAKYBATRATG	16077	0.02	Kengchongmy	49686	0.026
Hophongcanal	0	0.035	KBANGLOITG	0	0.02	Kenh_ChuaPhat	0	0.03
Hophongcanal	17500	0.035	KBANGLOITG	9379	0.02	Kenh_ChuaPhat	11000	0.03
Huyensu1	0	0.025	KBAYXA	0	0.02	Kenh_KH9	0	0.02

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

157

River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient
Kenh_KH9	55176	0.02	Kenh30-4	27406	0.026	Kenhdoi	6650	0.022
Kenh12	0	0.03	Kenh3-2	0	0.02	Kenhdtm22	0	0.02
Kenh12	14200	0.03	Kenh3-2	21052	0.02	Kenhdtm22	1790	0.02
Kenh2/9_1	0	0.02	Kenh32Bien	0	0.02	Kenhdtm406	0	0.02
kenh2/9_1	2578	0.02	Kenh32Bien	9800	0.02	Kenhdtm406	3205	0.02
Kenh2/9_2	0	0.02	Kenh61	0	0.025	Kenhdtm518	0	0.02
Kenh2/9_2	6000	0.02	Kenh61	45940	0.025	Kenhdtm518	15400	0.02
Kenh2/9_3	0	0.02	Kenh79_1	0	0.023	Kenhdtm705	0	0.02
Kenh2/9_3	4000	0.02	Kenh79_1	26250	0.023	Kenhdtm705	4745	0.02
Kenh2/9_4	0	0.02	Kenh79_2	0	0.023	KenhKT1_1	0	0.026
Kenh2/9_4	9000	0.02	Kenh79_2	7220	0.023	KenhKT1_1	36700	0.026
Kenh2/9_5	0	0.02	Kenhchacbang	0	0.023	KenhKT1_2	0	0.026
Kenh2/9_5	8000	0.02	Kenhchacbang	3060	0.023	KenhKT1_2	9100	0.026
Kenh28-down	0	0.018	Kenhchacbang	10000	0.03	KenhNoiThotNotTest	0	0.026
Kenh28-down	16706	0.018	Kenhchacbang	31161	0.03	KenhNoiThotNotTest	4000	0.026
Kenh28-up	0	0.018	KenhCRU	0	0.018	KENHSO10	0	0.018
Kenh28-up	7253	0.018	KenhCRU	11130	0.018	KENHSO10	25910	0.02
Kenh30-4	0	0.026	Kenhdoi	0	0.022	KENHSO1-1	0	0.02

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

158

River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient
KENHSO1-1	8000	0.02	Kenhtg67	13310	0.02	Kratie-pnompenh	204606	0.026
KENHSO1-2	8000	0.02	Kenhthotnot	0	0.02	KRTHMUOI-TTHANH-1	0	0.067
KENHSO1-2	21100	0.02	Kenhthotnot	69511	0.02	KRTHMUOI-TTHANH-1	10095	0.067
KENHSO1-3	21100	0.02	KENHTIEN97_HAU94	0	0.03	KTANCONGSINH1-1	0	0.02
KENHSO1-3	31096	0.02	KENHTIEN97_HAU94	12000	0.03	KTANCONGSINH1-1	6760	0.02
KENHSO5-1	0	0.02	KH1_canal	0	0.026	KTANCONGSINH1-2	0	0.02
KENHSO5-1	19311	0.02	KH1_canal	61724	0.026	KTANCONGSINH1-2	3095	0.02
KENHSO5-2	0	0.02	KH6_canal	0	0.02	KTANCONGSINH1-3	0	0.02
KENHSO5-2	6445	0.02	KH6_canal	66672	0.02	KTANCONGSINH1-3	12120	0.018
KENHSO7	0	0.02	KH8-canal	0	0.02	KTANCONGSINH2-1	0	0.02
KENHSO7	17975	0.02	KH8-canal	53602	0.02	KTANCONGSINH2-1	6660	0.02
KenhSoKhong	0	0.026	KimQuyK	0	0.026	KTANCONGSINH2-2	0	0.02
KenhSoKhong	22700	0.026	KimQuyK	3537	0.026	KTANCONGSINH2-2	1480	0.02
KENHTCH-CD	0	0.012	KimQuyR	0	0.026	KTANCONGSINH2-3	0	0.02
KENHTCH-CD	11000	0.012	KimQuyR	14700	0.026	KTANCONGSINH2-3	2415	0.02
KENHTG618	0	0.02	Kratie-pnompenh	0	0.035	KTANCONGSINH2-4	0	0.02
KENHTG618	11680	0.02	Kratie-pnompenh	110000	0.035	KTANCONGSINH2-4	4500	0.02
Kenhtg67	0	0.02	Kratie-pnompenh	112000	0.026	KTANCONGSINH2-6	0	0.02

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

River name	Chainage	Manning’n Coefficient	River name	Chainage	Manning’n Coefficient	River name	Chainage	Manning’n Coefficient
Maytuc	0	0.02	NAMTHON	0	0.018	NgonCLon	0	0.025
Maytuc	8300	0.02	NAMTHON	17265	0.018	NgonCLon	59050	0.025
MK157_L	0	0.02	Nangmaucanal	0	0.026	NGUYENTANTHANHCANAL	0	0.02
MK157_L	6830	0.02	Nangmaucanal	54000	0.026	NGUYENTANTHANHCANAL	18459	0.018
Mk175l	0	0.022	NangRen	0	0.026	Nguyenvantiep_down	0	0.02
Mk175l	4400	0.022	NangRen	26095	0.026	Nguyenvantiep_down	26000	0.02
Mocaycanal	0	0.02	NangRenR	0	0.026	Nguyenvantiep-up	0	0.018
Mocaycanal	14446	0.02	NangRenR	12200	0.026	Nguyenvantiep-up	33400	0.02
Muong_Chuoi	0	0.022	Ngahau	0	0.03	NGVANTIEPB-2	8000	0.02
Muong_Chuoi	2639	0.022	Ngahau	18540	0.03	NGVANTIEPB-2	26800	0.02
Mythanhriver	0	0.026	NganDua-BacLieu 2	0	0.025	Nha_Be	0	0.03
Mythanhriver	35261	0.026	NganDua-BacLieu 2	27000	0.026	Nha_Be	5145	0.03
Myvan	0	0.02	Ngandua-Baclieu1	0	0.025	Nha_Be	6089	0.03
Myvan	13920	0.02	Ngandua-Baclieu1	14990	0.025	Nha_Be	8474	0.03
N9-1	0	0.04	Ngangcanal	0	0.018	Nhanh_Dua	0	0.05
N9-1	3955	0.04	Ngangcanal	13000	0.018	Nhanh_Dua	3129	0.05
N9-2	0	0.018	Ngangcanal	14000	0.02	Nhanhdua_bs	0	0.04
N9-2	6908	0.018	Ngangcanal	33492	0.02	Nhanhdua_bs	3256	0.04

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

160

River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient
NinhThanhLoi	0	0.026	Onglon_vcd1	0	0.025	PhuHiep4	0	0.02
NinhThanhLoi	18000	0.026	Onglon_vcd1	1620	0.025	PhuHiep4	11265	0.018
No_1canal	0	0.026	OngNhuR	0	0.026	PHUOCLONG-VINHMY	0	0.026
No_1canal	24362	0.026	OngNhuR	21100	0.026	PHUOCLONG-VINHMY	18470	0.026
NTL 5000	0	0.035	OngThuocR	0	0.026	Phuocxuyencanal	0	0.018
NTL 5000	5426	0.035	OngThuocR	18300	0.026	Phuocxuyencanal	27000	0.018
Nuocman1	0	0.026	Phosinhcanal1	0	0.026	Phuocxuyencanal	27500	0.03
Nuocman1	14385	0.026	Phosinhcanal1	16000	0.026	Phuocxuyencanal	34000	0.03
Nuocman2	0	0.026	Phosinhcanal2	0	0.026	Phuocxuyencanal	75179	0.03
Nuocman2	4673	0.026	Phosinhcanal2	13783	0.026	Phuthanh1	0	0.02
Omoncanal	0	0.02	Phu_Xuan	0	0.022	Phuthanh1	6963	0.02
Omoncanal	37000	0.02	Phu_Xuan	9888	0.022	Phuthanh2	0	0.02
Ong_Con	0	0.03	PhuHiep1	0	0.02	Phuthanh2	8530	0.018
Ong_Con	10232	0.03	PhuHiep1	6772	0.02	Phuthanh3	0	0.02
Ong_Lon	0	0.025	PhuHiep2	0	0.02	Phuthanh3	9100	0.02
Ong_Lon	42428	0.02	PhuHiep2	5251	0.02	PreyVeng	0	0.025
ONGCHUONG	0	0.02	PhuHiep3	0	0.02	PreyVeng	50400	0.025
ONGCHUONG	19900	0.02	PhuHiep3	7415	0.02	PreyVengT	0	0.022

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

161

River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient
PreyVengT	125300	0.022	Rach_tra	38519	0.022	RXeoQuao	6200	0.026
PThanhTay1	0	0.026	Rach_vang	0	0.022	Sai_Gon	0	0.025
PThanhTay1	8500	0.026	Rach_vang	9605	0.022	Sai_Gon	109729	0.025
PThanhTay2	0	0.026	Rachgia-Hatien	0	0.026	Sai_Gon	112309	0.025
PThanhTay2	10400	0.026	Rachgia-Hatien	12498	0.026	Sai_Gon	126750	0.035
QLNhuGia	0	0.026	RachRuong1	0	0.026	Sai_Gon	143692	0.035
QLNhuGia	16700	0.026	RachRuong1	12700	0.026	SaKeo	0	0.026
Quanlophunghiep	0	0.022	Rachtieudua	0	0.026	SaKeo	11800	0.026
Quanlophunghiep	4600	0.023	Rachtieudua	42080	0.026	Santenoy_1	0	0.026
Quanlophunghiep	27000	0.023	Rachtram-mybinh	0	0.02	Santenoy_1	10252	0.026
Quanlophunghiep	46245	0.028	Rachtram-mybinh	58375	0.02	Santenoy_2	0	0.026
Quanlophunghiep	74954	0.028	RACHTRANGTRAM	0	0.026	Santenoy_2	7000	0.026
Quanlophunghiep	115237	0.03	RACHTRANGTRAM	11490	0.026	Santenoy_3	0	0.026
Rach_Chiec	0	0.022	RachXeoChit	23500	0.026	Santenoy_3	8500	0.026
Rach_Chiec	6655	0.025	RachXeoChit	104500	0.026	Sarai-3	0	0.02
Rach_Doi	0	0.022	RHO	0	0.018	Sarai-3	6700	0.02
Rach_Doi	9321	0.022	RHO	4943	0.02	Sarai-4	0	0.02
Rach_Tra	0	0.022	RXeoQuao	0	0.026	Sarai-4	18000	0.018

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

162

River name	Chainage	Manning’n Coefficient	River name	Chainage	Manning’n Coefficient	River name	Chainage	Manning’n Coefficient
Saraicanal	0	0.02	SoaiRap_EXT	10000	0.025	T5&T6-1	9224	0.02
Saraicanal	11500	0.02	SOGREAH1963	0	0.02	T5&T6-2	0	0.02
SCaiBe	0	0.026	SOGREAH1963	10000	0.02	T5&T6-2	11646	0.02
SCaiBe	14926	0.026	SongDamChim	0	0.026	T7-1	0	0.02
SCAIBEO	0	0.022	SongDamChim	31300	0.026	T7-1	7912	0.02
SCAIBEO	12570	0.022	Songdoc	0	0.028	T7-2	0	0.02
Sg_Dua	0	0.022	Songdoc	44000	0.02	T7-2	10572	0.02
Sg_Dua	5000	0.03	Songtrang	0	0.02	Tacvan	0	0.026
Sg_Dua	11732	0.022	Songtrang	7292	0.02	Tacvan	8293	0.026
Sg_Tac	0	0.022	T1&T2-1	0	0.02	TaKeo	0	0.035
Sg_Tac	12978	0.022	T1&T2-1	5325	0.02	TaKeo	76100	0.035
SNhuGia	0	0.026	T1&t2-2	0	0.02	TamThuoc1	0	0.026
SNhuGia	11600	0.026	T1&t2-2	6500	0.02	TamThuoc1	7800	0.026
Soai_Rap	0	0.025	T3&T4-1	0	0.02	TamThuoc2	0	0.026
Soai_Rap	10000	0.025	T3&T4-1	7500	0.02	TamThuoc2	11200	0.026
Soai_Rap	15000	0.023	T3&T4-2	0	0.02	TamThuoc3	0	0.026
Soai_Rap	39615.5	0.023	T3&T4-2	8726	0.02	TamThuoc3	8400	0.026
SoaiRap_EXT	0	0.025	T5&T6-1	0	0.02	Tan_Uyen	0	0.022

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

163

River name	Chainage	Manning’n Coefficient	River name	Chainage	Manning’n Coefficient	River name	Chainage	Manning’n Coefficient
Tan_Uyen	6815	0.022	Thaurau-tanlap	22480	0.02	THSON	9600	0.023
TanLap	0	0.026	ThiBuongR	0	0.026	Thuthuacreck	0	0.02
TanLap	10100	0.026	ThiBuongR	18600	0.026	Thuthuacreck	10063	0.02
TanPhuoc	0	0.026	ThoMaiCanal	0	0.026	Tienriver	0	0.025
TanPhuoc	7900	0.026	ThoMaiCanal	23500	0.026	Tienriver	56000	0.026
Tanphuoc_canal	0	0.026	Thongnhat_canal	0	0.02	Tienriver	60000	0.026
Tanphuoc_canal	15934	0.026	Thongnhat_canal	25885	0.02	Tienriver	92000	0.026
TANTHANH	0	0.02	Thongnhat1	0	0.02	Tienriver	96000	0.03
TANTHANH	7968	0.02	Thongnhat1	5702	0.02	Tienriver	97000	0.033
Tanthanh_logach_down	0	0.02	Thongnhat-1	0	0.02	Tienriver	101060	0.035
Tanthanh_logach_down	31734	0.02	Thongnhat-1	3229	0.02	Tienriver	106000	0.035
Tanthanh_logach_up	0	0.02	Thongnhat2	0	0.02	Tienriver	110500	0.035
Tanthanh_logach_up	21400	0.02	Thongnhat2	5961	0.02	Tienriver	113000	0.035
TANTHANH2	0	0.02	Thongnhat-5	0	0.02	Tienriver	122000	0.035
TANTHANH2	9657	0.02	Thongnhat-5	10800	0.02	Tienriver	123000	0.0325
Than_nong	0	0.02	ThotNotN	0	0.026	Tienriver	126000	0.03
Than_nong	20922	0.02	ThotNotN	25300	0.026	Tienriver	126500	0.03
Thaurau-tanlap	0	0.02	THSON	0	0.023	Tienriver	131000	0.0275

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

164

River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient
Travinh	0	0.02	Vamcodong	127900	0.025	Vungliem_creck	12430	0.02
Travinh	16125	0.02	Vamcodong	130000	0.02	WestVamco	0	0.018
Trem_tremriver	0	0.022	Vamcodong	150077	0.02	WestVamco	16000	0.018
Trem_tremriver	76861	0.028	VamCoTay_CPC	0	0.021	WestVamco	17000	0.018
TuanTuc	0	0.026	VamCoTay_CPC	70000	0.021	WestVamco	18000	0.05
TuanTuc	9730	0.026	Vamnao	0	0.03	WestVamco	24400	0.04
Tuhaicanal	0	0.02	Vamnao	16600	0.03	WestVamco	30100	0.02
Tuhaicanal	26214	0.02	Vamnao	18000	0.025	WestVamco	42000	0.02
TuThuong-Canal	0	0.025	Vamnao	27200	0.025	WestVamco	48600	0.0225
TuThuong-Canal	53900	0.025	Vinhan_canal	0	0.02	WestVamco	52000	0.06
TVanThoi	0	0.026	Vinhan_canal	14812	0.02	WestVamco	62000	0.06
TVanThoi	32310	0.026	VinhBinh	0	0.02	WestVamco	72000	0.06
Vam_Sat	0	0.022	VinhBinh	10500	0.02	WestVamco	81100	0.0375
Vam_Sat	27253	0.022	Vinhkimcanal	0	0.02	WestVamco	90000	0.02
Vambuon	0	0.02	Vinhkimcanal	16524	0.02	WestVamco	102300	0.035
Vambuon	17215	0.02	Vinhloc1	0	0.026	WestVamco	129200	0.03
Vamcodong	0	0.025	Vinhloc1	20000	0.026	WestVamco	130200	0.025
Vamcodong	124577	0.025	Vungliem_creck	0	0.02	WESTVAMCO	159190	0.025

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

165

River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient
XangChim1	0	0.026	ZZZ_CHCC1	0	0.03	ZZZ_KenhGiuaBL3	0	0.03
XangChim1	5000	0.026	ZZZ_CHCC1	5300	0.03	ZZZ_KenhGiuaBL3	1346	0.03
XangChim2	0	0.026	ZZZ_CHCC3	0	0.03	ZZZ_KenhHK10	0	0.03
XangChim2	8040	0.026	ZZZ_CHCC3	2566	0.03	ZZZ_KenhHK10	5900	0.03
Xanocanal	0	0.02	ZZZ_CHCP1	0	0.03	ZZZ_KenhHKx	0	0.03
Xanocanal	63180	0.02	ZZZ_CHCP1	3330	0.03	ZZZ_KenhHKx	2234	0.03
XeoCan	0	0.026	ZZZ_CHCP4	0	0.03	ZZZ_KenhHoaDong	0	0.03
XeoCan	10500	0.026	ZZZ_CHCP4	5571	0.03	ZZZ_KenhHoaDong	8103	0.03
XeoNhao1	0	0.026	ZZZ_CPNM4	0	0.03	ZZZ_KenhHocRang	0	0.03
XeoNhao1	9700	0.026	ZZZ_CPNM4	8626	0.03	ZZZ_KenhHocRang	10418	0.03
XeoNhao2	0	0.026	ZZZ_KenhAnDien1	0	0.03	ZZZ_KenhHuyenKe3	0	0.03
XeoNhao2	7200	0.026	ZZZ_KenhAnDien1	3619	0.03	ZZZ_KenhHuyenKe3	9534	0.03
XeoNhao3	0	0.026	ZZZ_KenhGiongMe	0	0.03	ZZZ_KenhNgangBL1	0	0.03
XeoNhao3	4500	0.026	ZZZ_KenhGiongMe	8973	0.03	ZZZ_KenhNgangBL1	8309	0.03
XeoQuaoR	0	0.026	ZZZ_KenhGiongTra	0	0.03	ZZZ_KenhNgangBL2	0	0.03
XeoQuaoR	6500	0.026	ZZZ_KenhGiongTra	9283	0.03	ZZZ_KenhNgangBL2	10241	0.03
ZZZ_BLCM	0	0.03	ZZZ_KenhGiuaBL2	0	0.03	ZZZ_KenhNgangBL3	0	0.03
ZZZ_BLCM	13505	0.03	ZZZ_KenhGiuaBL2	818	0.03	ZZZ_KenhNgangBL3	6736	0.03

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

166

River name	Chainage	Manning'n Coefficient	River name	Chainage	Manning'n Coefficient
ZZZ_KenhNoiCH	0	0.03	ZZZ_KenhTraiMuon2	752	0.03
ZZZ_KenhNoiCH	720	0.03	ZZZ_KenhTruongDien	0	0.03
ZZZ_KenhOngTa	0	0.03	ZZZ_KenhTruongDien	9644	0.03
ZZZ_KenhOngTa	4728	0.03	ZZZ_KenhTruongSon1	0	0.03
ZZZ_KenhSo3BL	0	0.03	ZZZ_KenhTruongSon1	8481	0.03
ZZZ_KenhSo3BL	2348	0.03	ZZZ_KenhTruongSon2	0	0.03
ZZZ_KenhSo4BL	0	0.03	ZZZ_KenhTruongSon2	10374	0.03
ZZZ_KenhSo4BL	1857	0.03	ZZZ_KenhTuBuu	0	0.03
ZZZ_KenhThaoLac	0	0.03	ZZZ_KenhTuBuu	16173	0.03
ZZZ_KenhThaoLac	3430	0.03	ZZZ_RachCaiHuu	0	0.03
ZZZ_KenhTraiMuoi1	0	0.03	ZZZ_RachCaiHuu	8085	0.03
ZZZ_KenhTraiMuoi1	1408	0.03	ZZZ_RachCayBong2	0	0.03
ZZZ_KenhTraiMuoi3	0	0.03	ZZZ_RachCayBong2	8005	0.03
ZZZ_KenhTraiMuoi3	3293	0.03	ZZZ_RachCayGiang	0	0.03
ZZZ_KenhTraiMuon2	0	0.03	ZZZ_RachCayGiang	7929	0.03

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

167

APPENDIX H

Advection-Dispersion Coefficient for Model

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

River Name	Chainage	AD Coefficient	Exponent	Minimum AD Coefficient	Maximum AD Coefficient
Balairiver	0	500	0	0	700
Balairiver	68896	500	0	0	700
Cochien_nv1	0	500	0	0	700
Cochien_nv1	16500	500	0	0	700
Cochien-nv2	0	500	0	0	700
Cochien-nv2	13000	500	0	0	700
Cochienriver	0	500	0	0	700
Cochienriver	72900	500	0	0	700
Cuadairiver	0	500	0	0	700
Cuadairiver	37000	500	0	0	700
Dong_Nai	66560	100	0	0	700
Dong_Nai	93112	300	0	0	700
HAMLUONG_12500R	0	500	0	0	700
HAMLUONG_12500R	13500	500	0	0	700
HAMLUONG_33500L	0	500	0	0	700
HAMLUONG_33500L	4900	500	0	0	700
HAMLUONG_51500L	0	500	0	0	700
HAMLUONG_51500L	7000	500	0	0	700

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

169

River Name	Chainage	AD Coefficient	Exponent	Minimum AD Coefficient	Maximum AD Coefficient
Hamluongriver	0	500	0	0	700
Hamluongriver	71600	500	0	0	700
Long_Tau	0	500	0	0	700
Long_Tau	42832	500	0	0	700
Nha_Be	0	300	0	0	700
Nha_Be	8474	500	0	0	700
SAI_GON	85000	50	0	0	700
SAI_GON	131007	75	0	0	700
SAI_GON	143692	100	0	0	700
Soai_Rap	0	500	0	0	700
Soai_Rap	39615.5	500	0	0	700
SoaiRap_EXT	0	500	0	0	700
SoaiRap_EXT	10000	500	0	0	700
THSON	0	500	0	0	700
THSON	9600	500	0	0	700
Tienriver	251750	100	0	0	700
Tienriver	268500	500	0	0	700
Tienriver	326000	500	0	0	700

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

170

River Name	Chainage	AD Coefficient	Exponent	Minimum AD Coefficient	Maximum AD Coefficient
Vamcodong	70000	75	0	0	700
Vamcodong	129000	100	0	0	700
Vamcodong	150077	125	0	0	700
WestVamco	0	75	0	0	700
WestVamco	17600	100	0	0	700
WestVamco	51000	150	0	0	700
WestVamco	97500	200	0	0	700
WestVamco	130200	225	0	0	700
WestVamco	142560	250	0	0	700
WestVamco	159190	300	0	0	700
Hauriver	317400	500	0	0	700
Hauriver	277200	500	0	0	700
Trande	0	500	0	0	700
Trande	35130	500	0	0	700
Hauriver	265000	300	0	0	700
Hauriver256l	14930	500	0	0	700
Hauriver256l	0	250	0	0	700
Hauriver245l	17935	300	0	0	700
Hauriver245l	0	150	0	0	700
Hauriver	239000	100	0	0	700
Hauriver	212000	50	0	0	700

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

171

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

APPENDIX I

Comparison of Salinity Concentration between Simulation and Observation Result

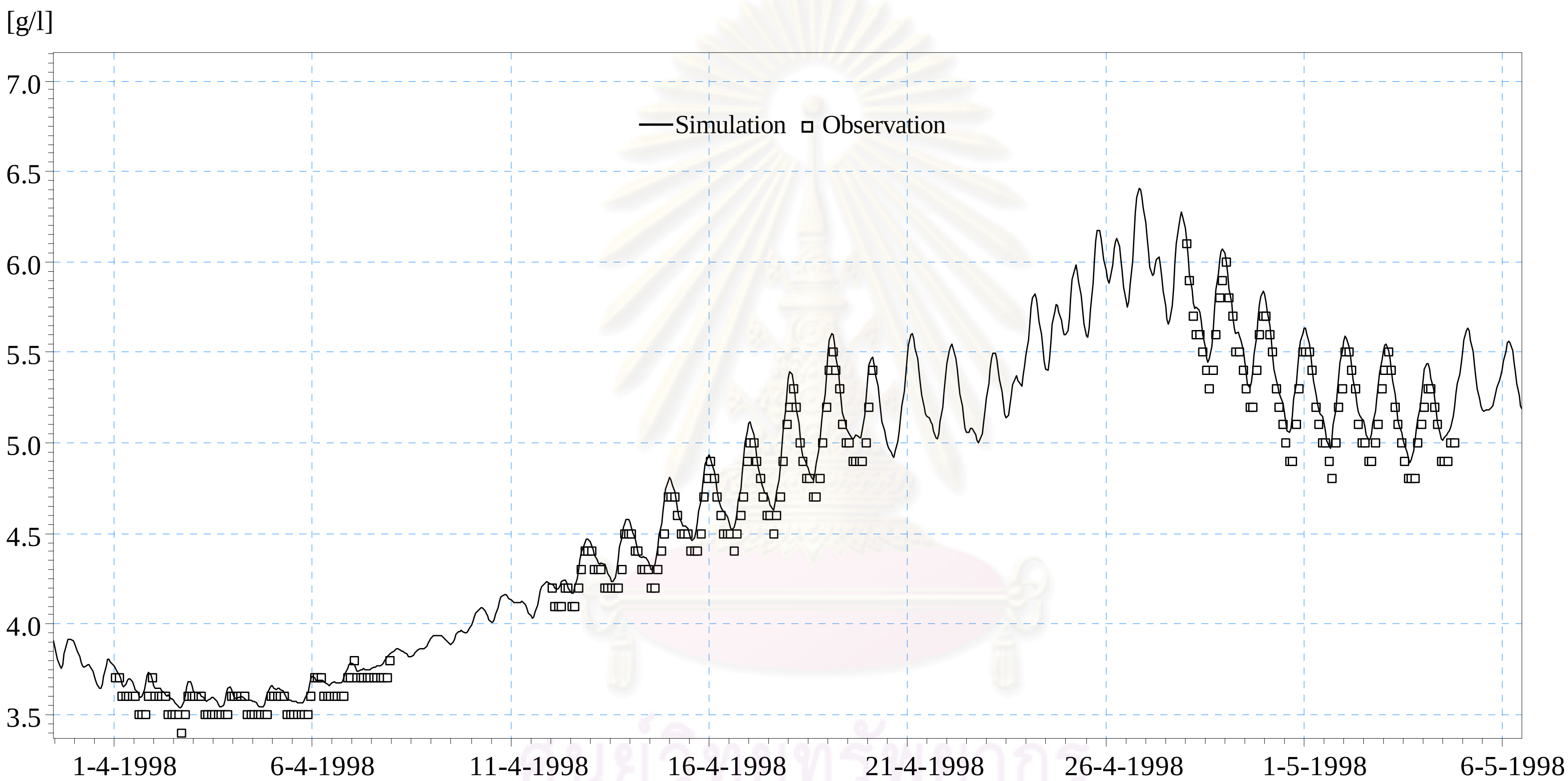


Figure I. 1. Comparison of Salinity Concentration between Simulation and Observation Result at Go Quao Station in 1998

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

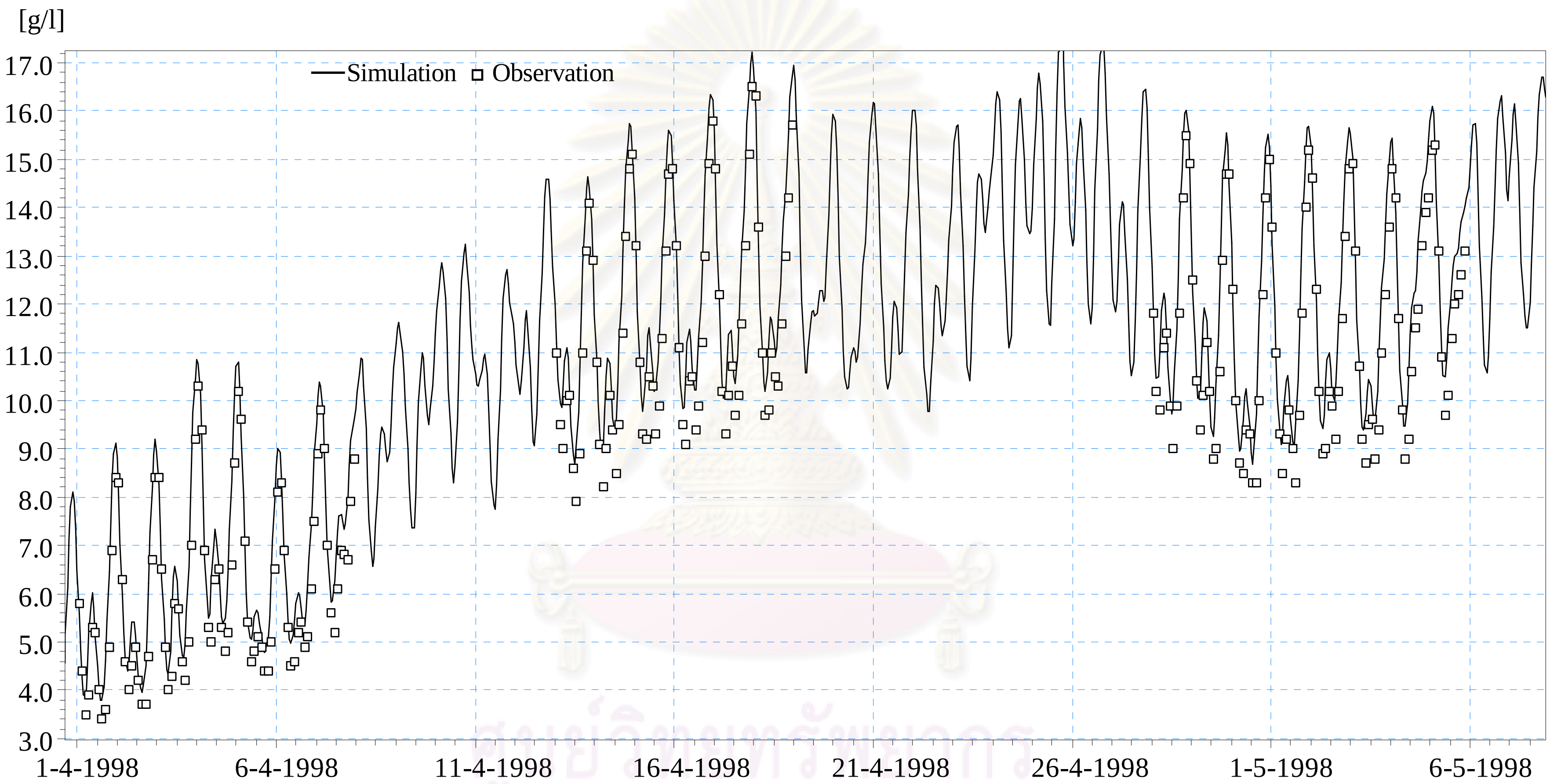


Figure I. 2. Comparison of Salinity Concentration between Simulation and Observation Result at Cai Lon Station in 1998

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

174

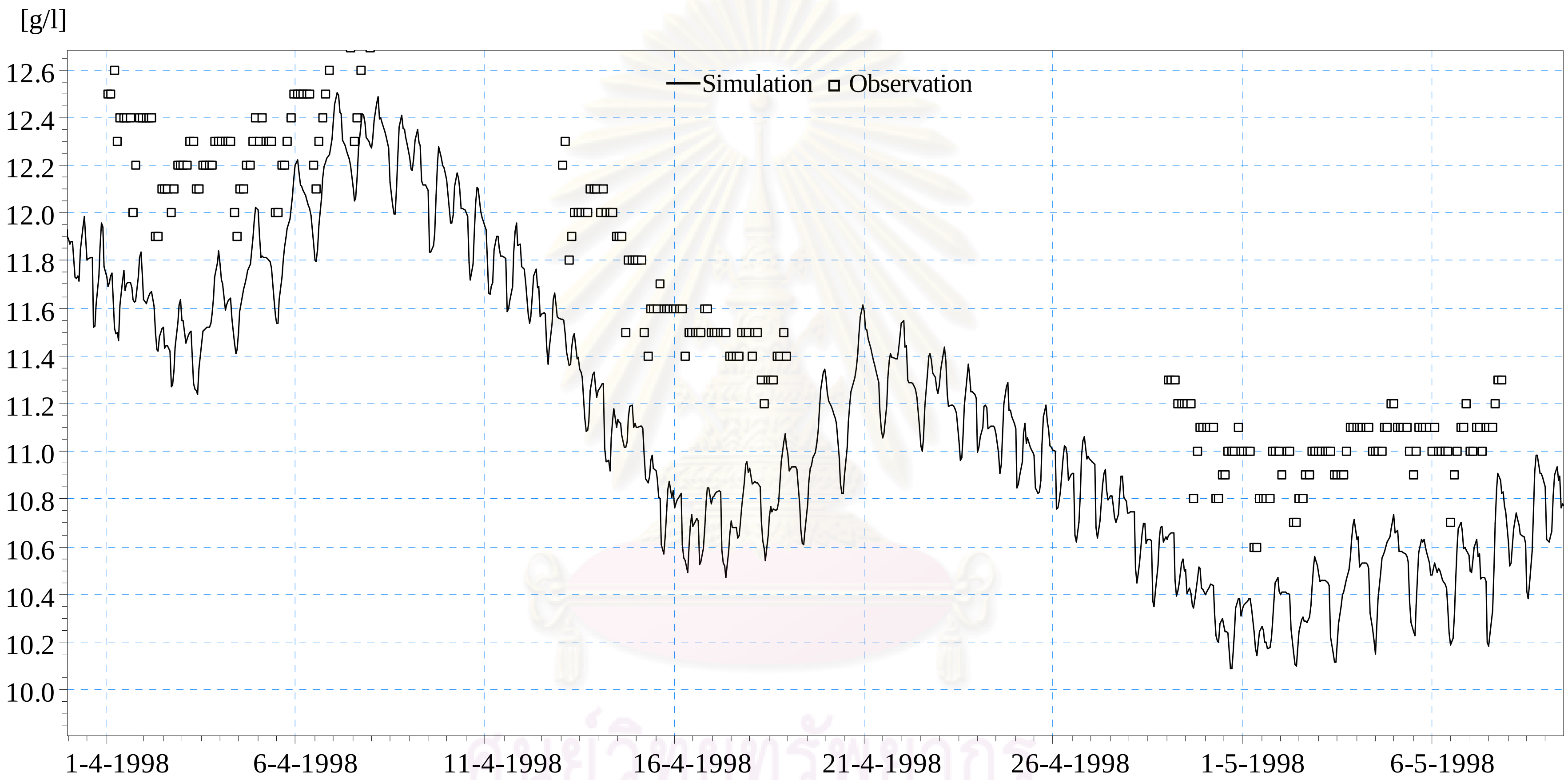


Figure I. 3. Comparison of Salinity Concentration between Simulation and Observation Result at Quan Lo-Phung Hiep Station in 1998

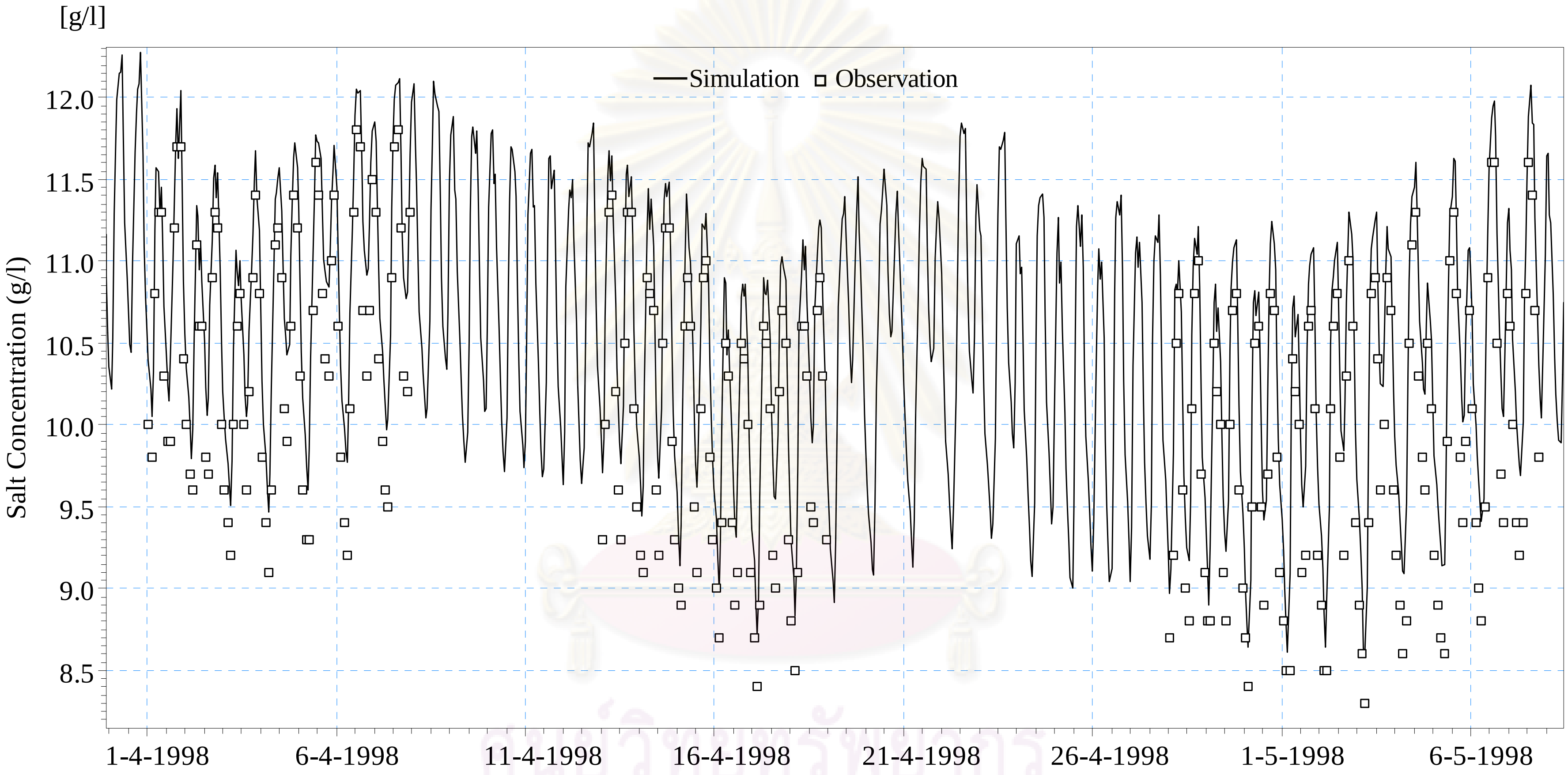


Figure I. 4. Comparison of Salinity Concentration between Simulation and Observation Result at Soc Trang Station in 1998

176

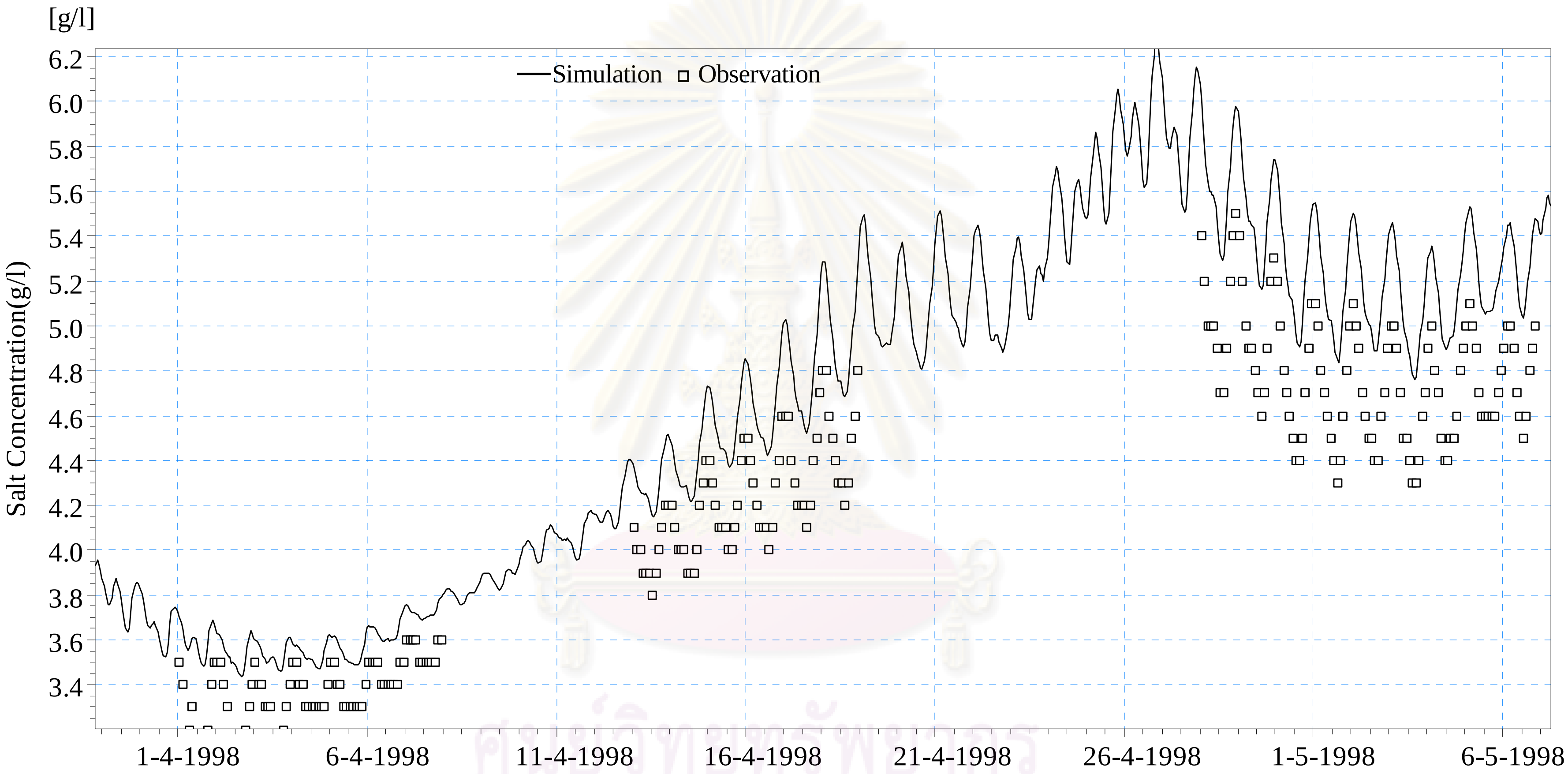


Figure I. 5. Comparison of Salinity Concentration between Simulation and Observation Result at Vi Thanh Station in 1998

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

177

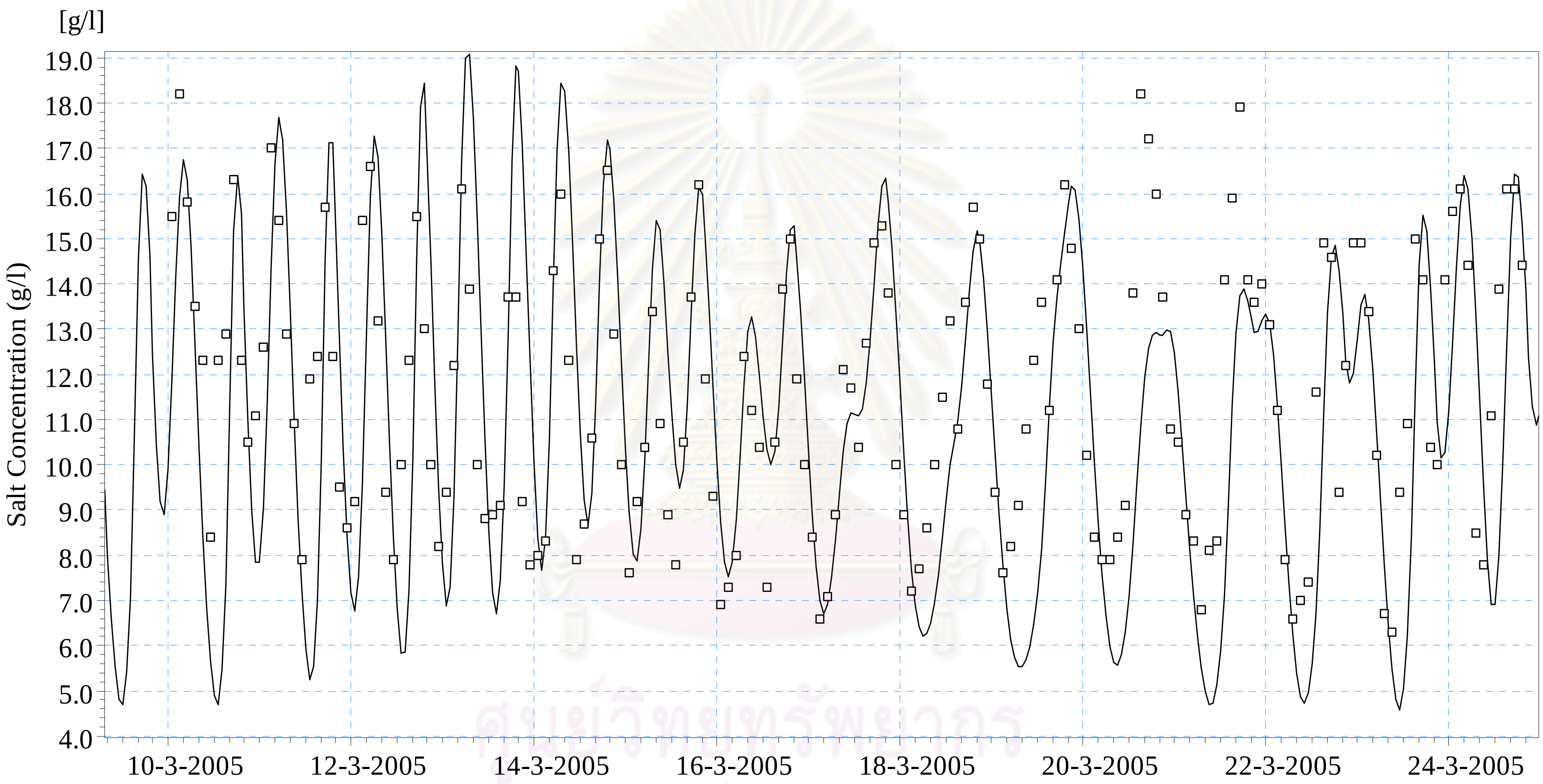


Figure I. 6. Comparison of Salinity Concentration between Simulation and Observation Result at Tra Kha Station in 2005

178

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

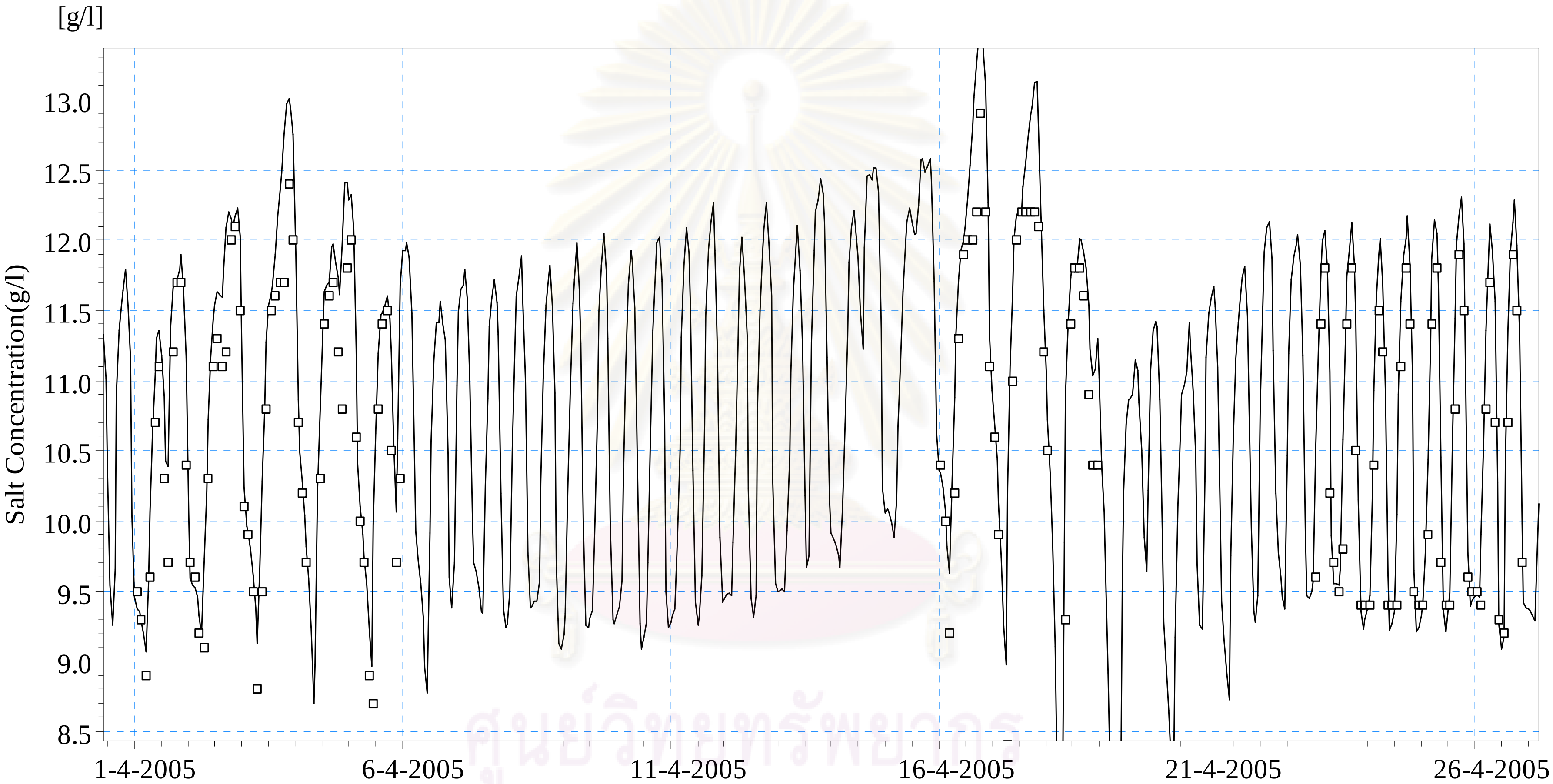


Figure I. 7. Comparison of Salinity Concentration between Simulation and Observation Result at Soc Trang Station in 2005

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

179

APPENDIX J

Salinity Distribution along the Mekong River Estuaries

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

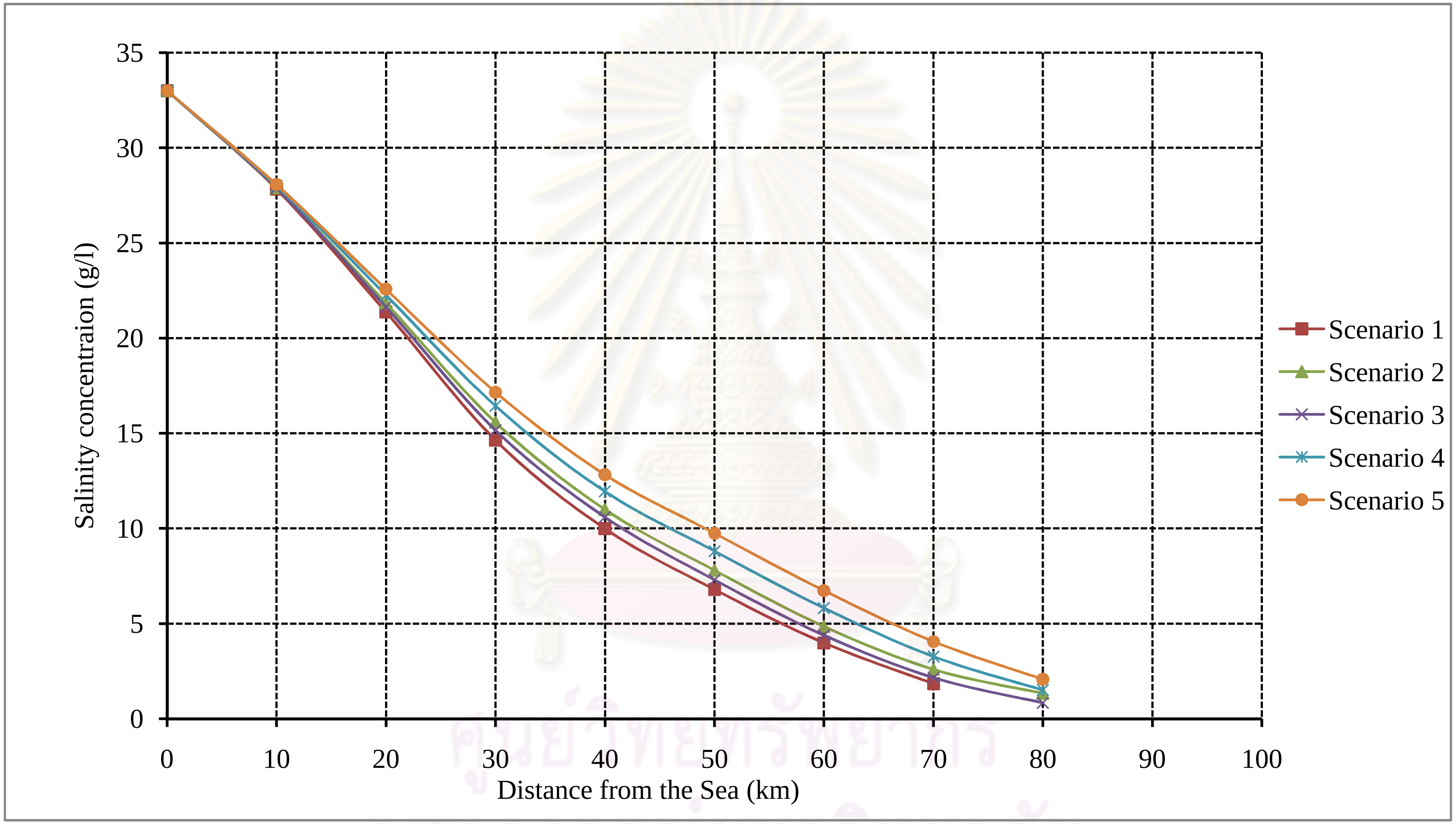


Figure J. 1. Salinity Distribution along the Dinh An Branch

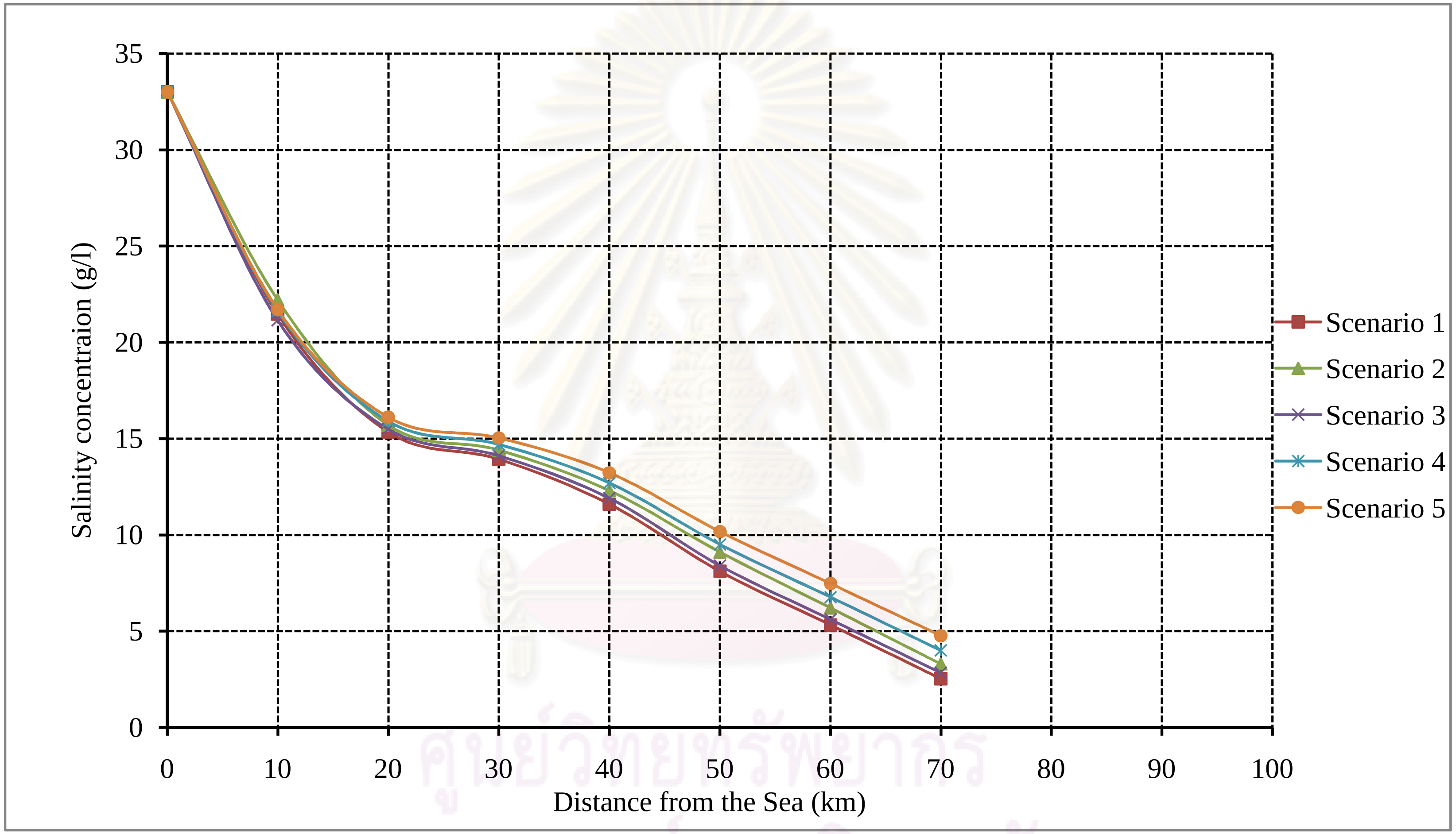


Figure J. 2. Salinity Distribution along the Ham Luong Branch

182

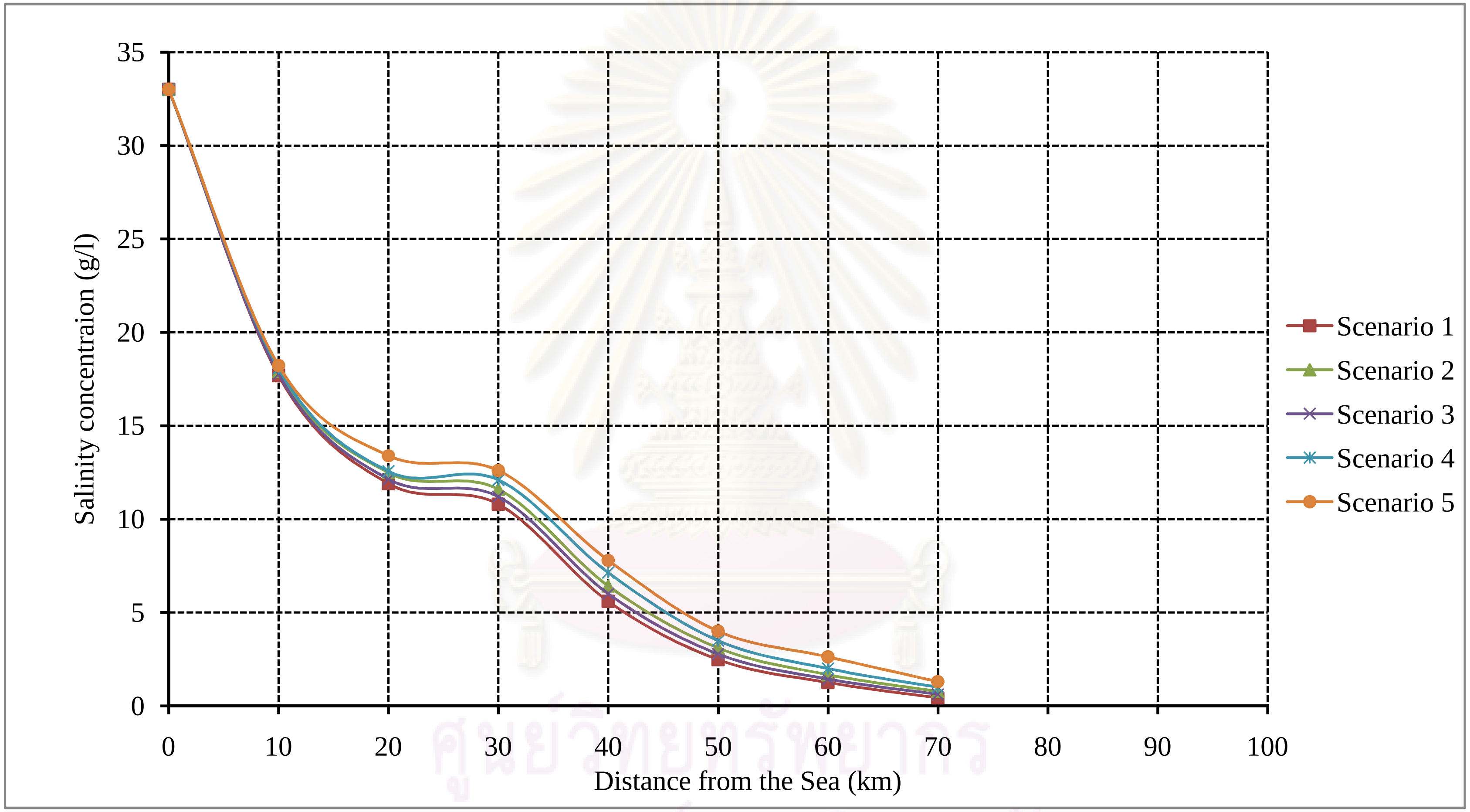


Figure J. 3. Salinity Distribution along the Co Chien Branch

183

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

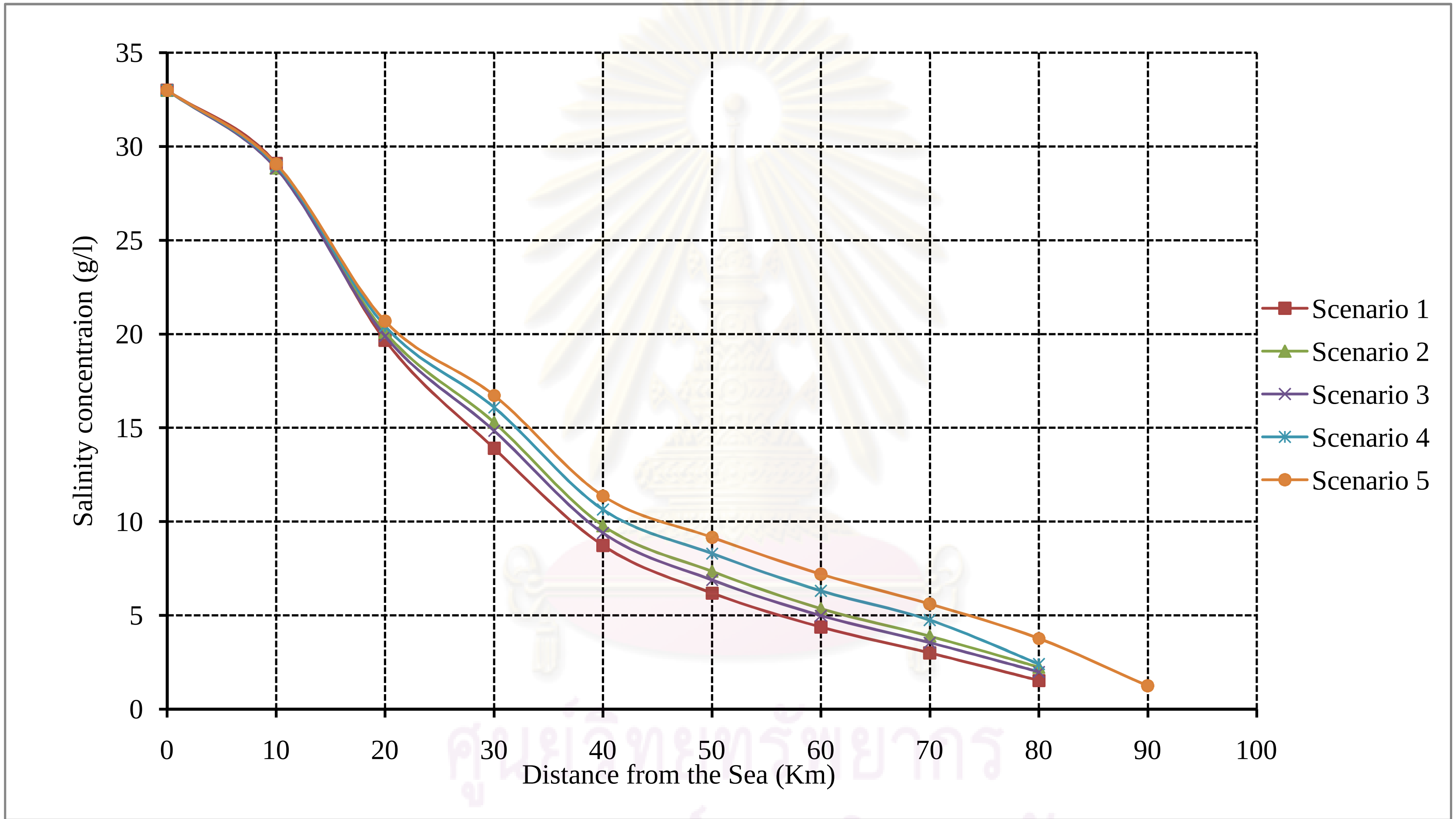


Figure J. 4. Salinity Distribution along the Tieu Branch

184

BIOGRAPHY

Tran Quoc Dat was born in Vinh Long, Vietnam in June 1984 in a family of four children. His father is Tran Van Tu and his mother is Nguyen Thi Cam Thu.

He got two bachelor' degrees on Hydraulic Engineering and Civil engineering in 2007 at Can Tho University, Vietnam. During the time studying, he experienced a part- time job as an engineer for Kien Cuong Limited Construction Company. As a student, he also carried out a student research project on Win-up Fin modeling. In September 2007, he started his professional career as a lecturer at College of Technology, Cantho University. He teaches Pump and Pumping station, Hydraulic practices, Fluid Mechanics and Concrete. Besides teaching, he attended several field works such as water sampling for Integrated Water Resources Management project, soil sampling and analyzing for Center for Verifying and Construction Consultants of Can Tho University.

In June 2009, he received Graduate Scholarship from Chulalongkorn University which formally admitted him to study Master Degree in Infrastructure in Civil Engineering at Chulalongkorn University. After studying, he will go back to Vietnam to continue teaching and doing research at the College of Technology, Cantho University.

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย