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Development of a Steady-State River Hydrodynamic and Temperature Model

Based on CE-QUAL-W2

by

Wenwei Xu

A thesis submitted in partial fulfillment of the
requirements for the degree of

Master of Science
in
Civil and Environmental Engineering

Thesis Committee:
Scott A. Wells, Chair
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Portland State University

2014

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Abstract

CE-QUAL-W2 is a 2-D hydrodynamic and water quality model that has been applied to reservoirs, lakes, river systems, and estuaries throughout the world. However, when this model is applied for shallow systems, this model requires a long calculation time to maintain numerical stability, compared to applications of reservoirs or deeper river systems.

To solve this problem, a new hydrodynamic and temperature model was built based on the framework of CE-QUAL-W2 but that allows for steady-state hydrodynamic computations. By calculating the hydrodynamics at steady-state, the time step for stability is relaxed and simulations can proceed at much higher time steps. The rest of the model framework is still used for water quality state variables, in this case, temperature. The algorithm used for computing the water surface elevation is Manning's equation.

This thesis study is one part of the Willamette Water 2100 project (Santelmann et al., 2012), which examines hydrological, ecological, and human factors affecting water scarcity in the Willamette River Basin. This study included three stages: (1) Convert six existing CE-QUAL-W2 V3.1 models into a newer version: CE-QUAL-W2 V3.7. (2) Develop the steady-state model code in FORTRAN. (3) Test the steady-state model on three river systems in the Willamette River Basin at Year 2001 and 2002.

The result proved that the steady-state model could reduce the computing time by 90% for river applications, while predicting dynamic river temperature with high accuracy at a two-minute time scale. This new model will be employed to simulate the future of the

Willamette River System at a decadal or centennial timescales, addressing river temperature concerns and fish habitat issues.

Table of Contents

Abstract	i
Table of Contents	iii
List of Tables	vi
List of Figures	ix
Abbreviations	xxxiii
Chapter 1 Literature Review of River Modeling	1
1.1 Hydrodynamic Models and Temperature Models	1
1.1.1 The Importance of River Temperature Models	1
1.1.2 River Temperature Models Classification	2
1.1.3 Statistically-Based Models Review	2
1.1.4 Physically-Based Models Review	3
1.1.5 Models Review Summary	9
1.2 Willamette Model Using CE-QUAL-W2 V3.1	11
Chapter 2 Converting Willamette River Models from V3.1 to V3.7	13
2.1 Converting all Willamette Models from V3.1 to V3.7	13
2.2 Testing of CE-QUAL-W2 V3.7	14

2.2.1 Lower Willamette River / Columbia River.....	15
2.2.2 Middle Willamette River	44
2.2.3 Upper Willamette River	69
2.2.4 Clackamas River	96
2.2.5 McKenzie River	111
2.2.6 Long Tom River.....	135
2.2.7 Summary and Conclusions	147
Chapter 3 Development of Steady-State Model for Hydrodynamics	151
3.1 New Expectation from River Hydrodynamic and Temperature Model.....	151
3.2 Model Development Theory	152
3.2.1 CE-QUAL-W2 Version 3.7 as the base model	153
3.2.2 Coordinate System and Model Grid	153
3.2.3 Steady-State Hydrodynamic Calculation	157
3.2.4 Dynamic Temperature Calculation	161
3.3 Model Development Process	163
3.4 Converting V3.7 models to Steady-state models	165
3.5 Testing of New Steady State Model Codes	165

3.5.1 Clackamas River	166
3.5.2 McKenzie River	179
3.5.3 Long Tom River	202
Chapter 4 Summary and Conclusions	215
Reference	226
Appendix A: The steady-state model FORTRAN source code	230

List of Tables

Table 1 Comparison of select river temperature models	8
Table 2: Lower Willamette River / Columbia River hydrodynamic calibration statistics, 2001.....	17
Table 3: Lower Willamette River hydrodynamic calibration statistics, 2002	21
Table 4: Willamette River continuous water temperature calibration model-data error statistics, 2001	25
Table 5: Willamette River continuous water temperature calibration model-data error statistics, 2002.....	33
Table 6: Middle Willamette River hydrodynamic calibration statistics, 2001	46
Table 7: Middle Willamette River hydrodynamic calibration statistics, 2002	48
Table 8: Willamette River continuous water temperature calibration model-data error statistics, 2001	50
Table 9: Willamette River continuous water temperature calibration model-data error statistics, 2002.....	65
Table 10: Upper Willamette River hydrodynamic calibration statistics, 2001	71
Table 11: Upper Willamette River hydrodynamic calibration statistics, 2002.....	76
Table 12: Upper Willamette River continuous water temperature calibration model-data error statistics, 2001	82
Table 13: Upper Willamette River continuous water temperature calibration model-data error statistics, 2002	89
Table 14: Clackamas River hydrodynamic calibration statistics, 2001	97
Table 15: Clackamas River hydrodynamic calibration statistics, 2002.....	100

Table 16: Clackamas River continuous water temperature calibration model-data error statistics, 2001	103
Table 17: Clackamas River continuous water temperature calibration model-data error statistics, 2002.....	107
Table 18: McKenzie River hydrodynamic calibration model-data error statistics, 2001	112
Table 19: McKenzie River hydrodynamic calibration model-data error statistics, 2002	116
Table 20: McKenzie River continuous water temperature calibration model-data error statistics, 2001	121
Table 21: McKenzie River continuous water temperature calibration model-data error statistics, 2002.....	128
Table 22 Long Tom River hydrodynamic calibration model-data error statistics, 2001	136
Table 23 Long Tom River hydrodynamic calibration model-data error statistics, 2002	139
Table 24 Long Tom River continuous water temperature calibration model-data error statistics, 2001	142
Table 25 Long Tom River continuous water temperature calibration model-data error statistics, 2002.....	144
Table 26: Comparison of CE-QUAL-W2 Version 3.1 and Version 3.7 temperature predictions accuracy on six river systems.....	148
Table 27: CPU runtime of CE-QUAL-W2 Version 3.7 model at six river systems applications in 2001 and 2002	149
Table 28: Clackamas River hydrodynamic calibration statistics, 2001	167
Table 29: Clackamas River hydrodynamic calibration statistics, 2002.....	170

Table 30: Clackamas River continuous water temperature calibration model-data error statistics, 2001	173
Table 31: Clackamas River continuous water temperature calibration model-data error statistics, 2002.....	176
Table 32: McKenzie River hydrodynamic calibration model-data error statistics, 2001	180
Table 33: McKenzie River hydrodynamic calibration model-data error statistics, 2002	185
Table 34: McKenzie River continuous water temperature calibration model-data error statistics, 2001	190
Table 35: McKenzie River continuous water temperature calibration model-data error statistics, 2002.....	196
Table 36 Long Tom River hydrodynamic calibration model-data error statistics, 2001	203
Table 37 Long Tom River hydrodynamic calibration model-data error statistics, 2002	206
Table 38 Long Tom River continuous water temperature calibration model-data error statistics, 2001	209
Table 39 Long Tom River continuous water temperature calibration model-data error statistics, 2002.....	212
Table 40: Comparison of CE-QUAL-W2 Steady-State Model, CE-QUAL-W2 Version 3.1 and Version 3.7 temperature predictions accuracy on six river systems	216
Table 41: Comparison of CPU runtime of Steady-State Model and CE-QUAL-W2 Version 3.7 model for three river systems applications in 2001 and 2002.....	217
Table 42: McKenzie River continuous water temperature calibration model-data error statistics, 2001. From left to right, the compared models are Version 3.7, steady-state model without re-calibration and steady-state model after calibration.....	221

List of Figures

Figure 1: River systems with delineated watersheds in the Willamette River Basin	12
Figure 2: Lower Willamette / Columbia River model grid.....	16
Figure 3: Willamette River below the Willamette Falls model-data water level comparison, 2001	18
Figure 4: Willamette River at Portland model-data water level comparison, 2001.....	18
Figure 5: Columbia River below Bonneville Dam model-data water level comparison, 2001.....	19
Figure 6 : Columbia River at Vancouver, WA model-data water level comparison, 2001	19
Figure 7: Columbia River at St. Helens, OR model-data water level comparison, 2001 .	20
Figure 8: Columbia River at Beaver Army Terminal model-data flow comparison, 2001	20
Figure 9: Willamette River below the Willamette Falls model-data water level comparison, 2002.....	22
Figure 10: Willamette River at Portland model-data water level comparison, 2002.....	22
Figure 11: Columbia River below Bonneville Dam model-data water level comparison, 2002.....	23
Figure 12: Columbia River at Vancouver, WA model-data water level comparison, 2002	23
Figure 13: Columbia River at St. Helens, OR model-data water level comparison, 2002	24
Figure 14: Columbia River at Beaver Army Terminal model-data flow comparison, 2002	24

Figure 15: Willamette River downstream of the Willamette Falls site A model-data continuous temperature comparison, 2001	26
Figure 16: Willamette River downstream of the Willamette Falls site B continuous model-data temperature comparison, 2001	27
Figure 17: Willamette River at Roehr Waterfront Park (shallow) model-data continuous temperature comparison,	27
Figure 18: Willamette River at Roehr Waterfront Park (deep) model-data continuous temperature comparison, 2001	28
Figure 19: Multnomah Channel downstream of Gilbert River model-data continuous temperature comparison, 2001	28
Figure 20: Columbia River Left Bank at Dodson continuous model-data temperature comparison, 2001	29
Figure 21: Columbia River Right Bank near Skamania model-data continuous temperature comparison, 2001	29
Figure 22: Columbia River at Washougal, WA model-data continuous temperature comparison, 2001	30
Figure 23: Columbia River at RM 122.5 model-data continuous temperature comparison, 2001	30
Figure 24: Columbia River d/s Multnomah Channel model-data continuous temperature comparison, 2001	31
Figure 25: Columbia River at RM 66.8 model-data continuous temperature comparison, 2001	31

Figure 26: Columbia River at Beaver Army Terminal model-data continuous temperature comparison, 2001	32
Figure 27: Willamette River at Roehr Waterfront Park (shallow) model-data continuous temperature comparison, 2002.....	34
Figure 28: Willamette River at Roehr Waterfront Park (deep) model-data continuous temperature comparison, 2002.....	34
Figure 29: Willamette River north of Deer Island (shallow) model-data continuous temperature comparison, 2002.....	35
Figure 30: Willamette River north of Deer Island (deep) model-data continuous temperature comparison, 2002.....	35
Figure 31: Willamette River upstream of Kellog Creek WWTP outfall (shallow) model-data continuous temperature comparison, 2002.....	36
Figure 32: Willamette River upstream of Kellog Creek WWTP outfall (deep) model-data continuous temperature comparison, 2002	36
Figure 33: Willamette River downstream of Kellog Creek WWTP outfall (shallow) model-data continuous temperature comparison, 2002	37
Figure 34: Willamette River downstream of Kellog Creek WWTP outfall (deep) model-data continuous temperature comparison, 2002.....	37
Figure 35: Willamette River at Waverly Country Club model-data continuous temperature comparison, 2002.....	38
Figure 36: Willamette River at Waverly Country Club (QA data set) model-data continuous temperature comparison, 2002	38

Figure 37 : Willamette River at St. Johns Bridge (deep) model-data continuous temperature comparison, 2002.....	39
Figure 38: Willamette River at St. Johns Bridge (shallow) model-data continuous temperature comparison, 2002.....	39
Figure 39: Willamette River upstream of Oregon Steel Mills (shallow) model-data continuous temperature comparison, 2002	40
Figure 40: Willamette River upstream of Oregon Steel Mills (deep) model-data continuous temperature comparison,	40
Figure 41: Columbia River left bank at Dodson, OR model-data continuous temperature comparison, 2002.....	41
Figure 42: Columbia River at Washougal, WA model-data continuous temperature comparison, 2002.....	41
Figure 43: Columbia River downstream of Multnomah Channel (deep) model-data continuous temperature comparison, 2002	42
Figure 44: Columbia River downstream of Multnomah Channel (shallow) model-data continuous temperature comparison, 2002	42
Figure 45: Columbia River at RM 66.8 (deep) model-data continuous temperature comparison, 2002.....	43
Figure 46: Columbia River at RM 66.8 (shallow) model-data continuous temperature comparison, 2002.....	43
Figure 47: Columbia River at Beaver Army Terminal model-data continuous temperature comparison, 2002.....	44
Figure 48: Middle Willamette River Model Grid.....	45

Figure 49: Willamette River at Salem model-data flow comparison, 2001	46
Figure 50: Willamette River at Salem model-data water level comparison, 2001	47
Figure 51: Willamette River at the Willamette Falls model-data water level comparison, 2001.....	47
Figure 52: Willamette River at Salem model-data flow comparison, 2001	48
Figure 53: Willamette River at Salem model-data water level comparison, 2002	49
Figure 54: Willamette River at Newberg model-data water level comparison, 2002	49
Figure 55: Willamette River at the Willamette Falls model-data water level comparison, 2002.....	50
Figure 56: Willamette River at Salem model-data continuous temperature comparison, 2001.....	52
Figure 57: Willamette River at Keizer model-data continuous temperature comparison, 2001.....	52
Figure 58: Willamette River at Willow Lake Treatment Plant model-data continuous temperature comparison, 2001	53
Figure 59: Willamette River at Wheatland Ferry model-data continuous temperature comparison, 2001	53
Figure 60: Willamette River at Eagle Nest A model-data continuous temperature comparison, 2001	54
Figure 61: Willamette River at Eagle Nest B model-data continuous temperature comparison, 2001	54
Figure 62: Willamette River at Coffee Island A model-data continuous temperature comparison, 2001	55

Figure 63: Willamette River at Coffee Island B model-data continuous temperature comparison, 2001	55
Figure 64: Willamette River at San Salvador A model-data continuous temperature comparison, 2001	56
Figure 65: Willamette River at San Salvador B model-data continuous temperature comparison, 2001	56
Figure 66: Willamette River above Ash Island A model-data continuous temperature comparison, 2001	57
Figure 67: Willamette River above Ash Island B model-data continuous temperature comparison, 2001	57
Figure 68: Willamette River at Champoeg Park A model-data continuous temperature comparison, 2001	58
Figure 69: Willamette River at Champoeg Park B model-data continuous temperature comparison, 2001	58
Figure 70: Willamette River at I5 Bridge, Wilsonville model-data continuous temperature comparison, 2001	59
Figure 71: Willamette River upstream of the Molalla River confluence, Power-line A model-data continuous temperature comparison, 2001.	59
Figure 72: Willamette River upstream of the Molalla River confluence, Power-line B model-data continuous temperature comparison, 2001.	60
Figure 73: Willamette River at Canby Ferry B model-data continuous temperature comparison, 2001	60

Figure 74: Willamette River at Powerline A model-data continuous temperature comparison, 2001	61
Figure 75: Willamette River at Powerline A model-data continuous temperature comparison, 2001	61
Figure 76: Willamette River at Tug Dock A model-data continuous temperature comparison, 2001	62
Figure 77: Willamette River at Boathouse A model-data continuous temperature comparison, 2001	62
Figure 78: Willamette River at Forebay B model-data continuous temperature comparison, 2001	63
Figure 79: Willamette River at Log Boom B model-data continuous temperature comparison,	63
Figure 80: Willamette River at Log Boom B model-data continuous temperature comparison,	64
Figure 81: Willamette River at the Willamette Falls model-data continuous temperature comparison, 2001	64
Figure 82: Willamette River at Forebay A model-data continuous temperature comparison, 2001	65
Figure 83: Willamette River at Willow Lake Treatment Plant model-data continuous temperature comparison, 2002	66
Figure 84: Willamette River at Wheatland Ferry model-data continuous temperature comparison, 2002	66

Figure 85: Willamette River at Coffee Island model-data continuous temperature comparison, 2002.....	67
Figure 86: Willamette River upstream of the Yamhill River model-data continuous temperature comparison, 2002.....	67
Figure 87: Willamette River at Newberg model-data continuous temperature comparison, 2002.....	68
Figure 88: Willamette River at I5 Bridge, Wilsonville model-data continuous temperature comparison, 2002.....	68
Figure 89: Willamette River at the Willamette Falls model-data continuous temperature comparison, 2002.....	69
Figure 90: Upper Willamette River Model Grid.....	70
Figure 91: Willamette River at Eugene model-data flow comparison, 2001	72
Figure 92: Willamette River at Eugene model-data water level comparison, 2001	73
Figure 93: Willamette River at Harrisburg model-data flow comparison, 2001	73
Figure 94: Willamette River at Harrisburg model-data water level comparison, 2001	74
Figure 95: Willamette River at Corvallis model-data water level comparison, 2001	74
Figure 969: Willamette River at Albany model-data flow comparison, 2001.....	75
Figure 97: Willamette River at Albany model-data water level comparison, 2001	75
Figure 98: Willamette River at Salem model-data flow comparison, 2001 (gage is 900 m downstream).....	76
Figure 99: Willamette River at Eugene model-data flow comparison, 2002	77
Figure 100: Willamette River at Eugene model-data water level comparison, 2002	78
Figure 101: Willamette River at Harrisburg model-data flow comparison, 2002	78

Figure 102: Willamette River at Harrisburg model-data water level comparison, 2002..	79
Figure 103: Willamette River at Corvallis model-data flow comparison, 2002	79
Figure 104: Willamette River at Corvallis model-data water level comparison, 2002	80
Figure 105: Willamette River at Albany model-data flow comparison, 2002.....	80
Figure 106: Willamette River at Albany model-data water level comparison, 2002	81
Figure 107: Willamette River at Salem model-data flow comparison, 2002 (gage is 900 m downstream).....	81
Figure 108: Upper Willamette River near Springfield model-data continuous temperature comparison, 2001	83
Figure 109: Upper Willamette River above McKenzie River model-data continuous temperature comparison, 2001	83
Figure 110: Upper Willamette River at Harrisburg model-data continuous temperature comparison, 2001	84
Figure 111: Upper Willamette River above Long Tom River model-data continuous temperature comparison, 2001	84
Figure 112: Upper Willamette River at RM 147.4 model-data continuous temperature comparison, 2001	85
Figure 113: Upper Willamette River at RM 142.4 model-data continuous temperature comparison, 2001	85
Figure 114: Upper Willamette River at Corvallis model-data continuous temperature comparison, 2001	86
Figure 115: Upper Willamette River at Albany model-data continuous temperature comparison, 2001	86

Figure 116: Upper Willamette River at Conser Rd model-data continuous temperature comparison, 2001	87
Figure 117: Upper Willamette River at South River Rd model-data continuous temperature comparison, 2001	87
Figure 118: Upper Willamette River above Rickreall Creek model-data continuous temperature comparison, 2001	88
Figure 119: Upper Willamette River at Salem model-data continuous temperature comparison, 2001	88
Figure 120: Upper Willamette River near Springfield model-data continuous temperature comparison, 2002	90
Figure 121: Upper Willamette River above McKenzie River model-data continuous temperature comparison, 2002	90
Figure 122: Upper Willamette River at Harrisburg model-data continuous temperature comparison, 2002	91
Figure 123: Upper Willamette River above Long Tom River model-data continuous temperature comparison, 2002	91
Figure 124: Upper Willamette River at RM 147.4 model-data continuous temperature comparison, 2002	92
Figure 125: Upper Willamette River at RM 142.4 model-data continuous temperature comparison, 2002	92
Figure 126: Upper Willamette River at Corvallis model-data continuous temperature comparison, 2002	93

Figure 127: Upper Willamette River at Albany model-data continuous temperature comparison, 2002.....	93
Figure 128: Upper Willamette River at Conser Rd model-data continuous temperature comparison, 2002.....	94
Figure 129: Upper Willamette River at South River Rd model-data continuous temperature comparison, 2002.....	94
Figure 130: Upper Willamette River above Rickreall Creek model-data continuous temperature comparison, 2002.....	95
Figure 131: Clackamas River model grid.....	96
Figure 132: Clackamas River at Estacada model-data flow comparison, 2001	98
Figure 133: Clackamas River at Estacada model-data water level comparison, 2001	98
Figure 134: Clackamas River near Oregon City model-data flow comparison, 2001	99
Figure 135: Clackamas River near Oregon City model-data water level comparison, 2001	99
Figure 136: Clackamas River at Estacada model-data flow comparison, time step=10s, 2002.....	101
Figure 137: Clackamas River at Estacada model-data flow comparison, time step=5s, 2002.....	101
Figure 138: Clackamas River at Estacada model-data water level comparison, 2002 ...	102
Figure 139: Clackamas River near Oregon City model-data flow comparison, 2002....	102
Figure 140: Clackamas River near Oregon City model-data water level comparison, 2002	103

Figure 141: Clackamas River at Estacada model-data continuous temperature comparison, 2001	104
Figure 142 : Clackamas River at McIver Park model-data continuous temperature comparison, 2001	105
Figure 143: Clackamas River upstream of Eagle Creek model-data continuous temperature comparison, 2001	105
Figure 144 : Clackamas River at Barton model-data continuous temperature comparison, 2001.....	106
Figure 145: Clackamas River at Carver Bridge model-data continuous temperature comparison, 2001	106
Figure 146: Clackamas River at Oregon City model-data continuous temperature comparison, 2001	107
Figure 147: Clackamas River at Estacada model-data continuous temperature comparison, 2002.....	108
Figure 148 : Clackamas River at Rivermill Tailrace model-data continuous temperature comparison, 2002.....	108
Figure 149 : Clackamas River upstream of Eagle Creek model-data continuous temperature comparison, 2002.....	109
Figure 150 : Clackamas River upstream of Clear Creek model-data continuous temperature comparison, 2002.....	109
Figure 151: Clackamas River at Oregon City model-data continuous temperature comparison, 2002.....	110

Figure 152: Clackamas River at Oregon City model-data continuous temperature comparison, 2002	110
Figure 153: McKenzie River model grid.....	111
Figure 154: South Fork McKenzie River below Cougar Dam model-data flow comparison, 2001	112
Figure 155: South Fork McKenzie River below Cougar Dam model-data water level comparison, 2001	113
Figure 156: McKenzie River near Vida model-data flow comparison, 2001	113
Figure 157: McKenzie River near Vida model-data water level comparison, 2001	114
Figure 158: McKenzie River below Leaburg Dam model-data flow comparison, 2001	114
Figure 159: McKenzie River below Leaburg Dam model-data water level comparison, 2001.....	115
Figure 160: McKenzie River near Walterville model-data flow comparison, 2001.....	115
Figure 161: McKenzie River near Walterville model-data water level comparison, 2001	116
Figure 162: South Fork McKenzie River below Cougar Dam model-data flow comparison, 2002.....	117
Figure 163: South Fork McKenzie River below Cougar Dam model-data water level comparison, 2002.....	118
Figure 164: McKenzie River near Vida model-data flow comparison, 2002.....	118
Figure 165: McKenzie River near Vida model-data water level comparison, 2002	119
Figure 166: McKenzie River below Leaburg Dam model-data flow comparison, 2002	119

Figure 167: McKenzie River below Leaburg Dam model-data water level comparison, 2002.....	120
Figure 168: McKenzie River near Walterville model-data flow comparison, 2002.....	120
Figure 169: McKenzie River near Walterville model-data water level comparison, 2002	121
Figure 170: South Fork McKenzie River below Cougar Dam model-data continuous temperature comparison, 2001	122
Figure 171: McKenzie River below Cougar River model-data continuous temperature comparison, 2001	123
Figure 172: McKenzie River near Vida model-data continuous temperature comparison, 2001.....	123
Figure 173: McKenzie River below Leaburg Dam model-data continuous temperature comparison, 2001	124
Figure 174: McKenzie River above the Leaburg tailrace model-data continuous temperature comparison, 2001	124
Figure 175: McKenzie River at Deerborn model-data continuous temperature comparison, 2001	125
Figure 176: McKenzie River near Walterville model-data continuous temperature comparison, 2001	125
Figure 177: McKenzie River above Walterville Tailrace model-data continuous temperature comparison, 2001	126
Figure 178: McKenzie River at Bellinger Landing model-data continuous temperature comparison, 2001	126

Figure 179: Leaburg Canal Intake, upstream end model-data continuous temperature comparison, 2001	127
Figure 180: Leaburg Canal Powerhouse Tailrace, downstream end model-data continuous temperature comparison,.....	127
Figure 181: South Fork McKenzie below Cougar Dam model-data continuous temperature comparison, 2002.....	129
Figure 182: McKenzie River below Cougar River model-data continuous temperature comparison, 2002.....	129
Figure 183: McKenzie River near Vida model-data continuous temperature comparison, 2002.....	130
Figure 184: McKenzie River at Helfrich boat ramp model-data continuous temperature comparison, 2002.....	130
Figure 185: McKenzie River below Leaburg Dam model-data continuous temperature comparison, 2002.....	131
Figure 186: McKenzie River at Deerborn model-data continuous temperature comparison, 2002.....	131
Figure 187: McKenzie River near Walterville model-data continuous temperature comparison, 2002.....	132
Figure 188: McKenzie River at Bellinger Landing model-data continuous temperature comparison, 2002.....	132
Figure 189: McKenzie River above Mohawk River model-data continuous temperature comparison, 2002.....	133

Figure 190: McKenzie River at Coburg Rd model-data continuous temperature comparison, 2002.....	133
Figure 191: Leaburg Canal Intake, upstream end model-data continuous temperature comparison, 2002.....	134
Figure 192: Leaburg Canal Powerhouse Tailrace, downstream end model-data continuous temperature comparison,.....	134
Figure 193: Long Tom River Model Grid	135
Figure 194: Long Tom River near Alvadore model-data flow comparison, 2001	137
Figure 195: Long Tom River near Alvadore model-data water level comparison, 2001	137
Figure 196: Long Tom River at Monroe model-data flow comparison, 2001	138
Figure 197: Long Tom River at Monroe model-data water level comparison, 2001 ..	138
Figure 198 Long Tom River near Alvadore model-data flow comparison, 2002	140
Figure 199 Long Tom River near Alvadore model-data water level comparison, 2002	140
Figure 200 Long Tom River at Monroe model-data flow comparison, 2002.....	141
Figure 201 Long Tom River at Monroe model-data water level comparison, 2002	141
Figure 202 Long Tom River near Alvadore model-data continuous temperature comparison, 2001	142
Figure 203 Long Tom River at RM 19.8 model-data continuous temperature comparison, 2001.....	143
Figure 204 Long Tom River at RM 12.3 model-data continuous temperature comparison, 2001.....	143

Figure 205 Long Tom River at Monroe model-data continuous temperature comparison, 2001.....	144
Figure 206 Long Tom River near Alvadore model-data continuous temperature comparison, 2002.....	145
Figure 207 Long Tom River at RM 19.8 model-data continuous temperature comparison, 2002.....	145
Figure 208 Long Tom River at RM 12.3 model-data continuous temperature comparison, 2002.....	146
Figure 209 Long Tom River at Monroe model-data continuous temperature comparison, 2002.....	146
Figure 210 Long Tom River near mouth model-data continuous temperature comparison, 2002.....	147
Figure 211: Estimated runtime for one year simulation using CE-QUAL-W2 Version 3.7	150
Figure 212: Comparison of river top view in the real world (left) and in the steady-steady model (right)	153
Figure 213: Comparison of river cross-section view in the real world (left) and in the steady-steady model (right).....	154
Figure 214: Comparison of river side view in the real world (left) and in the steady-steady model (right)	154
Figure 215: Example of a loop branch in the real world and in model	156
Figure 216: Flow distribution at the beginning of loop branch	156
Figure 217: An example of transporting flow between branches	157

Figure 218: Flow rate calculation in the Steady-state model.....	158
Figure 219: Water surface elevation smoothing	160
Figure 220: Longitudinal velocity calculation	161
Figure 221: Vertical velocity calculation.....	161
Figure 222: Sketch of heat conservation of a cell.....	163
Figure 223: Steady-State Model testing and refining process flow chart.....	164
Figure 224: Clackamas River at Estacada model-data flow comparison, 2001	167
Figure 225: Clackamas River at Estacada model-data water level comparison, 2001 ...	168
Figure 226: Clackamas River near Oregon City model-data flow comparison, 2001	168
Figure 227: Clackamas River near Oregon City model-data water level comparison, 2001	169
Figure 228: Clackamas River at Estacada model-data flow comparison, 2002	170
Figure 229: Clackamas River at Estacada model-data water level comparison, 2002 ...	171
Figure 230: Clackamas River near Oregon City model-data flow comparison, 2002....	171
Figure 231: Clackamas River near Oregon City model-data water level comparison, 2002	172
Figure 232: Clackamas River at Estacada model-data continuous temperature comparison, 2001	173
Figure 233: Clackamas River at McIver Park model-data continuous temperature comparison, 2001	174
Figure 234: Clackamas River upstream of Eagle Creek model-data continuous temperature comparison, 2001	174

Figure 235: Clackamas River at Barton model-data continuous temperature comparison, 2002.....	175
Figure 236: Clackamas River at Carver Bridge model-data continuous temperature comparison, 2001.....	175
Figure 237: Clackamas River at Oregon City model-data continuous temperature comparison, 2001.....	176
Figure 238: Clackamas River at Estacada model-data continuous temperature comparison, 2002.....	177
Figure 239: Clackamas River upstream of Eagle Creek model-data continuous temperature comparison, 2002.....	177
Figure 240: Clackamas River upstream of Clear Creek model-data continuous temperature comparison, 2002.....	178
Figure 241: Clackamas River at Oregon City model-data continuous temperature comparison, 2002.....	178
Figure 242: South Fork McKenzie River below Cougar Dam model-data flow comparison, 2001.....	180
Figure 243: South Fork McKenzie River below Cougar Dam model-data water level comparison, 2001.....	181
Figure 244: McKenzie River near Vida model-data flow comparison, 2001.....	181
Figure 245: McKenzie River near Vida model-data water level comparison, 2001	182
Figure 246: McKenzie River below Leaburg Dam model-data flow comparison, 2001	182
Figure 247: McKenzie River below Leaburg Dam model-data water level comparison, 2001.....	183

Figure 248: McKenzie River near Walterville model-data flow comparison, 2001.....	183
Figure 249: McKenzie River near Walterville model-data water level comparison, 2001	184
Figure 250: South Fork McKenzie River below Cougar Dam model-data flow comparison, 2002.....	185
Figure 251: South Fork McKenzie River below Cougar Dam model-data water level comparison, 2002.....	186
Figure 252: McKenzie River near Vida model-data flow comparison, 2002.....	186
Figure 253: McKenzie River near Vida model-data water level comparison, 2002	187
Figure 254: McKenzie River below Leaburg Dam model-data flow comparison, 2002	188
Figure 255: McKenzie River below Leaburg Dam model-data water level comparison, 2002.....	188
Figure 256: McKenzie River near Walterville model-data flow comparison, 2002.....	188
Figure 257: McKenzie River near Walterville model-data water level comparison, 2002	189
Figure 258: South Fork McKenzie River below Cougar Dam model-data continuous temperature comparison, 2001.....	190
Figure 259: McKenzie River below Cougar River model-data continuous temperature comparison, 2001	191
Figure 260: McKenzie River near Vida model-data continuous temperature comparison, 2001.....	191
Figure 261: McKenzie River below Leaburg Dam model-data continuous temperature comparison, 2001	192

Figure 262: McKenzie River above the Leaburg tailrace model-data continuous temperature comparison, 2001	192
Figure 263: McKenzie River at Deerborn model-data continuous temperature comparison, 2001	193
Figure 264: McKenzie River near Walterville model-data continuous temperature comparison, 2001	193
Figure 265: McKenzie River above Walterville Tailrace model-data continuous temperature comparison, 2001	194
Figure 266: McKenzie River at Bellinger Landing model-data continuous temperature comparison, 2001	194
Figure 267: Leaburg Canal Intake, upstream end model-data continuous temperature comparison, 2001	195
Figure 268: South Fork McKenzie below Cougar Dam model-data continuous temperature comparison, 2002	196
Figure 269: McKenzie River below Cougar River model-data continuous temperature comparison, 2002	197
Figure 270: McKenzie River near Vida model-data continuous temperature comparison, 2002	197
Figure 271: McKenzie River at Helfrich boat ramp model-data continuous temperature comparison, 2002	198
Figure 272: McKenzie River below Leaburg Dam model-data continuous temperature comparison, 2002	198

Figure 273: McKenzie River at Deerborn model-data continuous temperature comparison, 2002.....	199
Figure 274: McKenzie River near Walterville model-data continuous temperature comparison, 2002.....	199
Figure 275: McKenzie River at Bellinger Landing model-data continuous temperature comparison, 2002.....	200
Figure 276: McKenzie River above Mohawk River model-data continuous temperature comparison, 2002.....	200
Figure 277: McKenzie River at Coburg Rd model-data continuous temperature comparison, 2002.....	201
Figure 278: Leaburg Canal Intake, upstream end model-data continuous temperature comparison, 2002.....	201
Figure 279: Leaburg Canal Powerhouse Tailrace, downstream end model-data continuous temperature comparison, 2002.....	202
Figure 280 Long Tom River near Alvadore model-data flow comparison, 2001	204
Figure 281: Long Tom River near Alvadore model-data water level comparison, 2001	204
Figure 282: Long Tom River at Monroe model-data flow comparison, 2001.....	205
Figure 283: Long Tom River at Monroe model-data water level comparison, 2001	205
Figure 284: Long Tom River near Alvadore model-data flow comparison, 2002	207
Figure 285: Long Tom River near Alvadore model-data water level comparison, 2002	207
Figure 286: Long Tom River at Monroe model-data flow comparison, 2002.....	207
Figure 287: Long Tom River at Monroe model-data water level comparison, 2002	208

Figure 288: Long Tom River near Alvadore model-data continuous temperature comparison, 2001	209
Figure 289: Long Tom River at RM 19.8 model-data continuous temperature comparison, 2001.....	210
Figure 290: Long Tom River at RM 12.3 model-data continuous temperature comparison, 2001.....	210
Figure 291: Long Tom River at Monroe model-data continuous temperature comparison, 2001.....	211
Figure 292: Long Tom River near Alvadore model-data continuous temperature comparison, 2002.....	212
Figure 293: Long Tom River at RM 19.8 model-data continuous temperature comparison, 2002.....	213
Figure 294: Long Tom River at RM 12.3 model-data continuous temperature comparison, 2002.....	213
Figure 295: Long Tom River at Monroe model-data continuous temperature comparison, 2002.....	214
Figure 296: Long Tom River near mouth model-data continuous temperature comparison, 2002.....	214
Figure 297: Comparison of estimated runtime for one year simulation using Steady-State Model and CE-QUAL-W2 Version 3.7	218
Figure 298: Continuous temperature comparison between models (red) VS data (black) at Segment 285 in McKenzie River model, 2001. From top down, the compared models are	

Version 3.7, steady-state model without re-calibration and steady-state model after calibration	220
Figure 299: Side view of the example branch with even grid	222
Figure 300: Side view of the example branch with higher river bed in the middle.....	223
Figure 301: Side view of the example branch with lower river bed in the middle.....	223

Abbreviations

cfs	Cubic Feet Per Second
MAE	Mean absolute error
ME	Mean error
SEE	standard error of estimation
RM	River Mile
RMSE	root-mean-square error

Chapter 1 Literature Review of River Modeling

1.1 Hydrodynamic Models and Temperature Models

1.1.1 The Importance of River Temperature Models

River temperature is one of the most important physical properties that influence aquatic ecosystem health (Poole & Berman, 2001). Most fish species are cold-blooded, and their living is affected by the environmental temperature in a variety of ways. Temperature alters respiration, metabolism, food availability (Metcalf, 1999), and the ease of mobility. Extreme temperature may result in some species experiencing population decline (Elliott, 1981). With climate change, it is more and more important to know the temperature in rivers, which regulation rules and management decisions depend upon.

Specifically for the Pacific Northwest, this area is a natural habitat for many salmon species, and many of them are listed as endangered species, according to the Endangered Species Act (1993). In the Willamette River Basin, endangered species, Chinook salmon, Coho salmon, and Steelhead, give reason for investigation into river temperature.

There are two ways to estimate river temperature: measurement or model predictions. However, temperature measurements only exist in a few locations, and they are usually located on the main-stem of a river and not on other habitat areas. Also, extensive field temperature measurement can take too much time and money. As a result, river temperature models are often built to predict river temperature, and model results are often used as a basis for river management agencies to make management decisions.

1.1.2 River Temperature Models Classification

Basing on the method of how temperature is predicted, river temperature models can be classified into two groups: statistically-based models and physically-based models.

1.1.3 Statistically-Based Models Review

Statistically-based river temperature models are generally built on regression analysis, which relates river temperature to one or more variables in the river systems, for example, air temperature.

Although statistically-based models are easy to build and are not data intensive, they have limitations due to the statistical theories they are based on. First, statistically-based models are generally not able to simulate temperature at a smaller time scale, meaning that they are not able to capture the temperature change dynamics in a day. Instead, generally they can only predict water temperature at a daily or monthly time scale. Second, statistically-based models cannot be adjusted to reflect changes in the system such as new restoration projects or extreme climate changes.

Two statistically-based river temperature models were reviewed for this thesis study. One is in South Africa, where air temperatures data are generally available while river temperature data is not (River-Moore and Lorentz, 2004). River-Moore and Lorentz built a statistically-based model and attempted to simulate hourly water temperature based on hourly air temperature. The model was able to capture the general trend of temperature dynamics in a day, but with MAE up to ± 7 °C for a year-long simulation period. The

River-Moore and Lorentz study also found that the simulated temperature fit observed data better in the upstream of the rivers, and fit not as well in the downstream.

In the second reviewed study, Sahoo et al. (2009) compared three different methods - multiple regression analysis, artificial neural network and chaos non-linear dynamic method – in simulating daily river temperature, and tested these three methods on four rivers. The Sahoo et al. study found that the chaos non-linear dynamic method produced the best result, with the RMSE ranging from 0.8 to 2.5 °C for the daily river temperature over a four year simulation.

1.1.4 Physically-Based Models Review

Physically-based models use governing equations to represent the mechanism of temperature change in a natural environment.

1.1.4.1 Physically-Based Models Classification

Dimensions

Water temperature varies with time as well as in the three dimensions of space. As a result, the governing equations in physically-based temperature modeling are second-order partial differential equations. For river systems, if the variation of temperature in lateral direction is negligible, the governing equations can be simplified to a two-dimensional form; if the variation of temperature in vertical direction is also negligible, the governing equations can be further simplified to a one-dimensional form. Depending on the degree of simplification, physically-based temperature models can be classified into 1, 2, and 3-D models.

For river systems 1-D or 2-D models are applied more frequently, while 3-D models are rarely used. The 3-D models require more detailed boundary conditions, and also require much more time to run. 1-D models are the easiest to build as they require the least input information. However, such models are not able to simulate temperature variation in vertical and lateral directions. On the other hand, 2-D models are somewhere in between 1-D and 3-D models. Decisions on which dimensional models to use should be made based on the hydrodynamic and temperature characteristics of the river system to be modeled.

Steady state vs unsteady state

Steady state is an equilibrium condition which in mathematical terms means that accumulation of the state variable is zero (Chapra, 1997).

In hydrodynamic modeling, steady state assumes that flow conditions reach equilibrium for every time step, so that momentum and turbulence need not to be calculated. By calculating the hydrodynamics at steady-state, the time step for stability is relaxed and simulations can proceed at much higher time steps. However, unsteady state requires the calculation of momentum and turbulence, and the time steps must be smaller.

1.1.4.2 Models Review

Eight existing river temperature models were reviewed in this study. Models were assessed basing on dimensions, hydrodynamic and water quality modeling theory, and example applications. Model characteristics are summarized in Table 1.

QUAL2K

QUAL2K (Chapra, et al. 2008) is a 1-D hydrodynamic and water quality model that simulates flow, temperature and water quality. Velocity and in-stream water depth are simulated at steady state. QUAL2K provides two calculation methods: (1) rating curve, and (2) the Manning formula. The rating curve method use the following empirical equations:

$$\text{Velocity (m/s)} = aQ^b$$

$$\text{Depth (m) or width (m)} = \alpha Q^\beta$$

Where Q = flow rate, m³/s

In the Manning formula, trapezoidal channel shape is used.

Temperature and water quality variables are also simulated at steady state. Although meteorological data and shading data should be input as hourly base, stream temperature result is outputted as daily average temperature, daily maximum temperature and daily minimum temperature.

Von Stackelberg and Neilson (2012) developed a QUAL2K water quality model for Jordan River, Utah. The RMSE of daily average temperature ranges from 0.3 to 1.9 °C.

SNTEMP

SNTEMP (Theurer et al., 1985) is a 1-D stream temperature model. There is no hydrodynamic component in this model, so flow data should be inputted for every time step of simulation. Generally this model runs on a time step of 1 day, and the output is maximum temperature and mean temperature for each time step.

Norton and Bradford (2009) developed a SNTEMP model for Speed River in Ontario, Canada. The simulation period is from June 9 to October 31 in 2004, and the time step is selected as 1 day. HEC-RAS model was applied for the hydraulic simulation. The MAE

for daily mean temperature ranged from 0.2 to 1.0°C, and the MAE for daily maximum temperature ranged from 0.3 to 0.8°C.

CE-QUAL-RIV 1

CE-QUAL-RIV 1 (Environmental Laboratory, 1995) is a 1-D hydrodynamic and water quality model that simulates flow, temperature and water quality. Flow condition is simulated dynamically using St. Venant equations. Heat flux terms included are short-wave radiation, long-wave radiation, evaporation, back radiation of the water, and heat exchange with river bottom.

No example was found in the literature using this model for river temperature modeling.

An unnamed model

Younus et al. (2000) built a 1-D hydrodynamic and stream temperature model specifically for Little Pine Creek in Indiana. Both hydrodynamic and temperature are simulated dynamically. Heat flux terms included are air-water heat exchange, sediment-water heat exchange, lateral heat inflow/outflow, subsurface inflow/outflow, and the interaction between solar radiation and riparian vegetation. The result showed good agreement between modeled temperature and measured stream temperature for every 15 minutes, with the SEE equal to 0.7 °C over a 25-day simulation period.

HEC - RAS

HEC - RAS (Brunner, 2010) is a 1-D unsteady hydrodynamic and water quality model. Water temperature is calculated using the ultimate quickest numerical scheme. Drake et al. (2010) believed that Hydrologic Simulation Program-FORTRAN (HSPF), CE-QUAL-W2 and SNTMP are more accurate and detailed in temperature simulations than HEC-

RAS, but HEC-RAS can be used in cases where hydraulic simulation is critical in temperature and water quality modeling.

Drake et al. (2010) built a HEC – RAS temperature model for Swan Creek in Ontario, Canada, to test the HEC -RAS temperature simulation capability as well as to investigate groundwater flow contribution. In the two-week long simulation, the ME was found to be 0.4°C and 1.0°C for two measurement sites.

Mike 11

Mike 11 (Danish Hydraulics Institute, 1993) is a 1-D hydrodynamic and water quality model. Both hydrodynamic and water quality are simulated dynamically. Temperature is calculated from the difference between solar energy gain and heat radiation (day and night) emission loss. Topographic shading is considered but vegetation shading is not.

Parkinson (2002) developed a Mike 11 model for Snake River from Hells Canyon Dam to just upstream of the confluence with the Clearwater River. Water temperature, dissolved oxygen, nitrogen, and total dissolved gas were simulated in 1984 summer and 2000 fall. The result showed good agreement for temperature simulation, with the MAE for different sites ranging from 0.1 to 0.5°C, and the RMSE ranging from 0.2 to 0.6°C.

Heat Source

Heat Source Version 7.0 (Boyd and Kasper, 2003) is a 1-D hydrodynamic and river temperature model. This modeling methodology and program is maintained by Oregon Department of Environmental Quality. Temperature modeling is based on dynamic topographic and vegetation shading.

Mike 21

Mike 21 (Danish Hydraulics Institute, 1996) is a 2-D hydrodynamic and water quality model. It is a vertical averaged model, and is more suitable for shallow lake systems. The temperature calculation scheme in Mike 21 is similar to the one in Mike 11. Most applications of Mike 21 are found to be water quality models on lake or reservoir systems, or hydrodynamic models on river systems for purposes of flood control.

No example was found in the literature using this model for river temperature modeling.

CE-QUAL-W2 V3.7

CE-QUAL-W2 V3.7 (Cole and Wells, 2011) is a 2-D, laterally averaged hydrodynamic and water quality model. Both hydrodynamic and temperature are simulated dynamically. Heat flux terms that are included are short/ long wave radiation, air-water heat exchange, sediment-water heat exchange, inflow/outflow, dynamic topographic shading and vegetation shading, and ice cover. As temperature influences water density, and accurate hydrodynamic modeling requires accurate water density, temperature calculation is hooked up with hydrodynamic modeling. CE-QUAL-W2 V3.7 provides various options for different hydraulic structures set up, including spillway, weir, gate, withdraw, dam, pipe, etc. Besides, it can be easily applied for fish habitat volume calculation.

Berger et al. (2004) developed a CE-QUAL-W2 V3.1 model for Clackamas River, Oregon for 2001 and 2002. In 2012, this model was converted into CE-QUAL-W2 V3.7, and the modeled river temperature showed good agreement with measured data at six sites along the Clackamas River, with the ME ranging from ± 0.01 to $\pm 0.15^{\circ}\text{C}$, MAE ranging from 0.02 to 0.69°C , and the RMSE ranging from 0.03 to 0.86°C .

Table 1 Comparison of select river temperature models

Model Name	Dimension	Hydrodynamic	Dynamic	Minimum Time	Minimum	Example River	Example Application	Reference
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			Shading	Step	Output Time Step	Application	on Error (°C)	
QUAL2K	1-D	Steady State	No	Less than hourly	Daily	Jordan River, Utah	RMSE (0.3-1.9)	Chapra, et al. 2006
SNTEMP	1-D	Steady State	No	Daily	Daily	Speed River, Ontario, Canada	MAE (0.2-1.0)	Theurer et al., 1985
CE-QUAL-RIV 1	1-D	Unsteady State	No	Less than hourly	Less than hourly	N.A.	N.A.	Environmental Laboratory, 1995
*Unnamed	1-D	Unsteady State	No	Less than hourly	Less than hourly	Little Pine Creek, Indiana	SEE (0.7)	Younus et al., 2000
HEC - RAS	1-D	Unsteady State	No	Less than 1 s	Less than 1 s	Swan Creek, Ontario, Canada	ME (0.4,0.7)	Brunner, 2010
MIKE 11	1-D	Unsteady State	No	Less than 1 s	Less than 1 s	Snake River, Idaho	MAE (0.1-0.5) RMSE (0.2-0.6)	Danish Hydraulics Institute, 1993
Heat Source	1-D	Steady state	Yes	Less than 1 s	Less than 1 s	N.A.	N.A.	Boyd and Kasper, 2003
MIKE 21	2-D	Unsteady State	No	Less than 1 s	Less than 1 s	N.A.	N.A.	Danish Hydraulics Institute, 1996
CE-QUAL-W2 V3.7	2-D	Unsteady State	Yes	Less than 1 s	Less than 1 s	Clackamas River, Oregon	ME (±0.01-±0.15) MAE (0.02-0.69) RMSE (0.03-0.86)	Cole & Wells, 2011

1.1.5 Models Review Summary

Limited by time, this river temperature model review study could not be comprehensive: only a few existing models were reviewed, and only one example application were reviewed for each model. However, this review study still revealed some facts in the river temperature modeling field:

- Statistically-based models are easy to build, but the simulation results are generally not accurate, and models cannot be adjusted to reflect future changes.
- Some of the very popular physically-based models, like QUAL2K, only simulate temperature on daily basis, giving simulation results like daily average temperature, maximum daily temperature. However, continuous temperature is very important for assessing fish species living conditions and making regulation rules.
- 3-D river temperature modeling example could not be found, and 2-D river temperature modeling example could only be found using CE-QUAL-W2.
- According to example applications that were reviewed, both CE-QUAL-W2 model and MIKE 11 model produce accurate continuous temperature simulation.

1.2 Willamette Model Using CE-QUAL-W2 V3.1

In 2004, to assist the Oregon Department of Environmental Quality developing a TMDL for temperature in the Willamette River Basin, river temperature models were built for main stem of Willamette River and all the major tributaries (except Tualatin River where a TMDL already existed). CE-QUAL-W2 Version 3.1 (Cole and Wells, 2002) was chosen as the appropriate model for this system with the following reasons: the ability to model stratified water quality; the ability to model temperature basing on dynamic shading; the ability to various complex hydraulic structures included in the model (Berger et al., 2004); and also very importantly, the fact that many reservoirs within the systems were already modeled with CE-QUAL-W2, which made it easier to prepare input data for river models.

Berger et al. (2004) developed hydrodynamic and water temperature model for Lower Willamette River (including Columbia River from Beaver Army Terminal to Bonneville Dam, and Willamette River from river mouth to RM 26.5), Middle Willamette River (RM 26.5 to RM 85), Upper Willamette River (RM 85 to RM 187), Clackamas River (mouth to RM 26), Long Tom River (mouth to RM 26), McKenzie River (McKenzie River from mouth to RM 56, and South Fork McKenzie River to RM 4), Coast Fork/Middle Fork River (Middle Fork Willamette from mouth to RM 17, Coast Fork Willamette from mouth to RM 30). Figure 1 shows the location of these river systems in the Willamette River Basin. The simulation period varied between models. All models were at least built for the summer of 2001 and 2002, and some models' simulation period also included the spring and fall of those years. These seven models were able to

represent the temperature and hydraulic regime of these river systems. The RMSE for temperature for these models were all less than 1 °C.

Figure 1: River systems with delineated watersheds in the Willamette River Basin

Sullivan and Rounds (2004) built a hydrodynamic and water temperature model for the North Santiam River and the Santiam River. The RMSE of hourly temperature comparison between simulation results and measured data ranged from 0.50 °C to 1.16 °C during the simulation period in 2001 and 2002.

Chapter 2 Converting Willamette River Models from V3.1 to V3.7

2.1 Converting all Willamette Models from V3.1 to V3.7

CE-QUAL-W2 is a public domain and open source code, and it has been updated over the years. By the year 2012, CE-QUAL-W2 was updated to Version 3.7 from Version 3.1 in year 2002 (Cole and Wells, 2011). There were several major differences between Version 3.1 and Version 3.7. Some of the new features included addition of the following new algorithms:

- Suspended solid velocity;
- Zooplankton, macrophyte, and state variables;
- Updated TKE algorithm;
- User-defined roughness height of the water for correction of the vertical velocity wind profile;
- New output format for TECPLOT;
- Updates to NO₃, organic decay rate, and CBOD;
- The ability to specify the number of processors;
- The ability of using automatic selective withdrawal, fish habitat volumes, environmental performance criteria, artificial aeration, and initial water surface and velocity computations;
- The ability to control the interpolation of the maximum time step;

- Slopec as the hydraulic equivalent slope for a river channel;
- The ability to interpolate gate or weir inflow data;
- The ability to specify whether the pipes or pumps are controlled by time series or partially open gate;
- The ability to specify whether the grid is interpreted as rectangular in depth or trapezoidal.

In 2012, six Willamette River System models were converted from CE-QUAL-W2 Version 3.1 to Version 3.7. There were two objectives to convert those models: (1) to test the accuracy and other performance of CE-QUAL-W2 Version 3.7 model; (2) to update and calibrate the Willamette River System models to the current newest version of CE-QUAL-W2.

Converting Willamette River System models from V 3.1 to V 3.7 included: (1) changing the control file, graph file and other files to make the models able to run with the new Version 3.7 executable; (2) adjusting model setting to make the models run through the simulation periods; and (3) re-examine the model calibration to make sure the models calibrated to an acceptable degree.

2.2 Testing of CE-QUAL-W2 V3.7

Six river models within the Willamette River Basin were tested with CE-QUAL-W2 Version 3.7, they were Lower Willamette River/ Columbia River, Middle Willamette River, Upper Willamette River, Clackamas River, McKenzie River, Long Tom River. Attempts have been made to test CE-QUAL-W2 Version 3.7 on Coast Fork/ Middle Fork

Willamette River, North Santiam River and South Santiam River, however due to stability issues and the difficulty to calibrate, together with the limited time available, this work was not attempted. Calibration results of applying CE-QUAL-W2 Version 3.7 on each of the six river systems were described in the following sections.

2.2.1 Lower Willamette River / Columbia River

Introduction

Lower Willamette River / Columbia River model domain includes part of Willamette River: from Willamette Falls (RM 26.8) to Willamette River Mouth (RM 0), and part of Columbia River: from Bonneville Dam (RM 145) to Beaver Army Terminal (RM 53.8). Although Willamette River is not directly connected to the ocean, flow characteristics in Lower Willamette River are strongly influenced by the tide. The model grid is shown in Figure 2.

In the CE-QUAL-W2 Version 3.1 model, a water level boundary condition was set up at Beaver Army Terminal to incorporate tidal fluctuations.

Following the setting up of Version 3.1 model, the CE-QUAL-W2 Version 3.7 model was set up as 2 water bodies, including 13 branches, 462 segments and 28 layers. There were 16 tributaries flowing into the system.

Figure 2: Lower Willamette / Columbia River model grid

Hydrodynamics

Flow rate and water surface elevation was first tested using the original setting in V3.1 model. As the model showed good agreement with data, no further calibrations were conducted.

Year 2001

The hydrodynamic calibration period in 2001 was from July to September. Figure 3 through 8 show the water level and flow comparison between model predictions and measured data. Error statistics are summarized in Table 2. Both the flow and water level

predictions matched well with data at all the sites, and the water level fluctuation due to tidal effect was accurately captured. The root mean square error of flow at Segment 347 was 56.064 m³/s, which was actually very small compared to the flow rate in river which was about 10,000 m³/s.

Table 2: Lower Willamette River / Columbia River hydrodynamic calibration statistics, 2001

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14246900	53.00	347	4208	-43.34	43.439	56.064
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14207770	26.48	2	2976	0.051	0.128	0.192
USGS 14211720	12.70	66	2976	0.027	0.122	0.17
USGS 14128870	144.50	118	5952	0.042	0.091	0.116
USGS 14144700	106.50	223	5952	0.039	0.13	0.169
ACOE SHNO3	85.75	270	7996	0.089	0.116	0.162

Figure 3: Willamette River below the Willamette Falls model-data water level comparison, 2001

Figure 4: Willamette River at Portland model-data water level comparison, 2001

Figure 5: Columbia River below Bonneville Dam model-data water level comparison, 2001

Figure 6 : Columbia River at Vancouver, WA model-data water level comparison, 2001

Figure 7: Columbia River at St. Helens, OR model-data water level comparison, 2001

Figure 8: Columbia River at Beaver Army Terminal model-data flow comparison, 2001

Year 2002

The hydrodynamic calibration period in 2002 was from April to September. Figure 9 through 14 show the water level and flow comparison between model predictions and measured data. Error statistics are summarized in Table 3. The water level was underestimated at high flow period (Julian Day 95-114) for several segments (Segment 2, 66, 223). The reason could be inaccurate segment width at high water levels, or special hydrodynamic phenomenon that was unknown at high flow period. However, during summer and fall when river temperature is more critical, the model was better able to predict the water level.

Table 3: Lower Willamette River hydrodynamic calibration statistics, 2002

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14246900	53.00	347	17446	-14.525	14.874	28.392
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14207770	26.48	2	8352	-0.198	0.224	0.396
USGS 14211720	12.70	66	8352	-0.12	0.141	0.201
USGS 14128870	144.5	118	4175	-0.006	0.114	0.15
USGS 14144700	106.50	223	16704	-0.061	0.115	0.172
ACOE SHNO3	85.75	270	22128	0.035	0.136	0.186

Figure 9: Willamette River below the Willamette Falls model-data water level comparison, 2002

Figure 10: Willamette River at Portland model-data water level comparison, 2002

Figure 11: Columbia River below Bonneville Dam model-data water level comparison, 2002

Figure 12: Columbia River at Vancouver, WA model-data water level comparison, 2002

Figure 13: Columbia River at St. Helens, OR model-data water level comparison, 2002

Figure 14: Columbia River at Beaver Army Terminal model-data flow comparison, 2002

Temperature

Year 2001

Figure 15 through 26 show the continuous temperature comparison between model predictions and measured data. Error statistics are summarized in Table 4. Predicted temperature matched data very well for all the 12 sites with the RMSEs below 0.64 °C. The simulation results were similar with the V3.1 model results; however there were some small differences, with V3.7 better predicting on some sites, and V3.1 better predicting on other sites.

Table 4: Willamette River continuous water temperature calibration model-data error statistics, 2001

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
PGE_2590 A	26.24	2	1426	-0.051	0.256	0.322
PGE_2590 B	26.24	2	1488	-0.232	0.31	0.398
LASAR 26745 Shallow	20.75	33	1488	-0.064	0.371	0.447
LASAR 26745 Deep	20.75	33	1488	-0.011	0.386	0.466
LASAR 26760	11.10	107	160	-0.186	0.222	0.273
USGS4 53651122022200	140.40	134	1488	0.025	0.12	0.168
USGS 453630122021400	140.40	134	1279	0.029	0.061	0.077
USGS 453439122223900	121.75	187	1284	-0.058	0.137	0.169
USGS 14129400 LASAR 26752	121.50	188	2975	-0.042	0.123	0.158
LASAR 26747	85.50	271	163	-0.42	0.423	0.492
LASAR 26754	67.00	314	989	0.463	0.499	0.608
USGS 14246900	53.00	347	5952	-0.074	0.264	0.636

Figure 15: Willamette River downstream of the Willamette Falls site A model-data continuous temperature comparison, 2001

Figure 16: Willamette River downstream of the Willamette Falls site B continuous model-data temperature comparison, 2001

Figure 17: Willamette River at Roehr Waterfront Park (shallow) model-data continuous temperature comparison,

Figure 18: Willamette River at Roehr Waterfront Park (deep) model-data continuous temperature comparison, 2001

Figure 19: Multnomah Channel downstream of Gilbert River model-data continuous temperature comparison, 2001

Figure 20: Columbia River Left Bank at Dodson continuous model-data temperature comparison, 2001

Figure 21: Columbia River Right Bank near Skamania model-data continuous temperature comparison, 2001

Figure 22: Columbia River at Washougal, WA model-data continuous temperature comparison, 2001

Figure 23: Columbia River at RM 122.5 model-data continuous temperature comparison, 2001

Figure 24: Columbia River d/s Multnomah Channel model-data continuous temperature comparison, 2001

Figure 25: Columbia River at RM 66.8 model-data continuous temperature comparison, 2001

Figure 26: Columbia River at Beaver Army Terminal model-data continuous temperature comparison, 2001

Year 2002

Figure 27 through 47 show the continuous temperature comparison between model predictions and measured data. Error statistics are summarized in Table 5. Predicted temperature matched data very well for all the 12 sites with the RMSEs below 0.78°C .

For some sites, there were two series of measured data. These series of data were marked as either “shallow” or “deep”, indicating the different depths where water temperature was measured. These measured temperature data were compared with predicted temperature at the according depth.

The simulation results were similar with the V3.1 model results; however there were some small differences, with V3.7 better predicting on some sites, and V3.1 better predicting on other sites.

Table 5: Willamette River continuous water temperature calibration model-data error statistics, 2002

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
LASAR 26745 Shallow	20.75	33	3370	0.289	0.431	0.543
LASAR 26745 Deep	20.75	33	3370	0.23	0.378	0.474
LASAR 28506 Shallow	18.83	45	3351	0.319	0.43	0.525
LASAR 28506 Deep	18.83	45	3351	-0.178	0.444	0.51
LASAR 28507 Shallow	18.75	46	3351	0.321	0.429	0.523
LASAR 28507 Deep	18.75	46	3351	-0.163	0.4	0.463
LASAR 28508 Shallow	18.59	48	3351	0.373	0.462	0.562
LASAR 28508 Deep	18.59	48	3351	-0.073	0.377	0.431
LASAR 29747	17.38	52	2945	0.229	0.371	0.451
LASAR 29747 QA set	17.38	52	1995	0.172	0.319	0.404
USGS 14211720	12.70	66	8352	0.152	0.361	0.463
LASAR 28765 Shallow	7.14	83	2402	-0.127	0.273	0.341
LASAR 28765 Deep	7.14	83	3351	0.011	0.238	0.293
LASAR 29746 Shallow	3.20	91	3351	-0.015	0.327	0.441
LASAR 29746 Deep	3.20	91	3351	0.183	0.35	0.459
USGS 453630122021400	140.40	134	4176	0.023	0.052	0.074
USGS 453439122223900	121.75	187	4176	-0.036	0.134	0.183
LASAR 26747 Shallow	85.50	271	5296	-0.656	0.667	0.774
LASAR 26747 Deep	85.50	271	5296	-0.172	0.277	0.348
LASAR 26754 Shallow	67.00	314	5299	0.45	0.491	0.578
LASAR 26754 Deep	67.00	314	5299	0.393	0.443	0.532
USGS 14246900	53.00	347	16702	0.01	0.15	0.193

Figure 27: Willamette River at Roehr Waterfront Park (shallow) model-data continuous temperature comparison, 2002

Figure 28: Willamette River at Roehr Waterfront Park (deep) model-data continuous temperature comparison, 2002

Figure 29: Willamette River north of Deer Island (shallow) model-data continuous temperature comparison, 2002

Figure 30: Willamette River north of Deer Island (deep) model-data continuous temperature comparison, 2002

Figure 31: Willamette River upstream of Kellog Creek WWTP outfall (shallow) model-data continuous temperature comparison, 2002

Figure 32: Willamette River upstream of Kellog Creek WWTP outfall (deep) model-data continuous temperature comparison, 2002

Figure 33: Willamette River downstream of Kellog Creek WWTP outfall (shallow) model-data continuous temperature comparison, 2002

Figure 34: Willamette River downstream of Kellog Creek WWTP outfall (deep) model-data continuous temperature comparison, 2002

Figure 35: Willamette River at Waverly Country Club model-data continuous temperature comparison, 2002

Figure 36: Willamette River at Waverly Country Club (QA data set) model-data continuous temperature comparison, 2002

Figure 37 : Willamette River at St. Johns Bridge (deep) model-data continuous temperature comparison, 2002

Figure 38: Willamette River at St. Johns Bridge (shallow) model-data continuous temperature comparison, 2002

Figure 39: Willamette River upstream of Oregon Steel Mills (shallow) model-data continuous temperature comparison, 2002

Figure 40: Willamette River upstream of Oregon Steel Mills (deep) model-data continuous temperature comparison,

Figure 41: Columbia River left bank at Dodson, OR model-data continuous temperature comparison, 2002

Figure 42: Columbia River at Washougal, WA model-data continuous temperature comparison, 2002

Figure 43: Columbia River downstream of Multnomah Channel (deep) model-data continuous temperature comparison, 2002

Figure 44: Columbia River downstream of Multnomah Channel (shallow) model-data continuous temperature comparison, 2002

Figure 45: Columbia River at RM 66.8 (deep) model-data continuous temperature comparison, 2002

Figure 46: Columbia River at RM 66.8 (shallow) model-data continuous temperature comparison, 2002

Figure 47: Columbia River at Beaver Army Terminal model-data continuous temperature comparison, 2002

2.2.2 Middle Willamette River

Introduction

The Middle Willamette River model domain starts from Salem (RM 85.4) and ends at Willamette Falls (RM 26.8). The model was set up as 3 water bodies, including 6 branches, 407 segments and 45 layers. There are 10 tributaries flows into the system. Among the 6 branches, there were loop branches, which represented flow around two islands. The model grid is shown in Figure 48.

Figure 48: Middle Willamette River Model Grid

Hydrodynamics

Flow rate and water surface elevation was first tested using the original setting in V3.1 model. As the model showed good agreement with data, no further calibrations were conducted.

Year 2001

The hydrodynamic calibration period in 2001 was from August to September. Error statistics are summarized in Table 6. Figure 49 through 51 show the water level and flow comparison between model predictions and measured data. Previous research suspected that the water level measurement at Segment 396 was not accurate (Berger, et al., 2004). Despite that, the flow rate and water level predicted by CE-QUAL-W2 Version 3.7 model showed good consistency with data measured.

Table 6: Middle Willamette River hydrodynamic calibration statistics, 2001

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14191000	84.69	5	3096	-0.014	0.149	0.231
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14191000	84.69	5	3096	0.163	0.163	0.163
USGS 14207740	26.81	396	3096	-0.036	0.073	0.099

Figure 49: Willamette River at Salem model-data flow comparison, 2001

Figure 50: Willamette River at Salem model-data water level comparison, 2001

Figure 51: Willamette River at the Willamette Falls model-data water level comparison, 2001

Year 2002

The hydrodynamic calibration period in 2002 was from April to September. Figure 52 through 55 show the water level and flow comparison between model predictions and measured data. There were slightly overestimate in water level for several sites. Error statistics are summarized in Table 7.

Table 7: Middle Willamette River hydrodynamic calibration statistics, 2002

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14191000	84.69	5	8736	-363.979	363.979	467.394
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14191000	84.69	5	8736	0.219	0.219	0.249
USGS 14197900	50.11	246	8736	0.209	0.289	0.38
USGS 14207740	26.81	396	17470	17470	0.141	0.235

Figure 52: Willamette River at Salem model-data flow comparison, 2001

Figure 53: Willamette River at Salem model-data water level comparison, 2002

Figure 54: Willamette River at Newberg model-data water level comparison, 2002

Figure 55: Willamette River at the Willamette Falls model-data water level comparison, 2002

Temperature

Year 2001

Figure 56 through 81 show the continuous temperature comparison between model predictions and measured data. Error statistics are summarized in Table 8. Predicted temperature matched data very well for all the 22 sites with the RMSEs below 0.84 °C.

Table 8: Willamette River continuous water temperature calibration model-data error statistics, 2001

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
USGS 14191000	85.66	5	253	0.008	0.053	0.069
USGS 14192015	82.60	18	2839	0.333	0.479	0.568
LASAR 28255	79.18	40	2951	0.712	0.728	0.832
LASAR 10344	72.63	82	1596	0.632	0.675	0.762

PGE Eagle Nest A	63.95	140	1596	0.484	0.603	0.729
PGE Eagle Nest B	63.95	140	1596	0.436	0.576	0.698
PGE Coffee Island A	61.51	156	1595	0.179	0.569	0.692
PGE Coffee Island B	61.51	156	1596	0.303	0.593	0.721
PGE San Salvador A	55.58	196	1596	0.29	0.591	0.725
PGE San Salvador B	55.58	196	1596	0.298	0.591	0.728
PGE Ash Island A	52.76	228	1596	0.243	0.608	0.76
PGE Ash Island B	52.76	228	1596	0.093	0.597	0.729
PGE Champoeg Dock A	45.21	277	1596	0.034	0.498	0.608
PGE Champoeg Dock B	45.21	277	1596	0.122	0.499	0.619
LASAR 10340	38.94	318	3192	-0.294	0.478	0.587
PGE US Molalla R. A	36.17	336	1577	-0.171	0.478	0.577
PGE US Molalla R. B	36.17	336	1596	-0.088	0.465	0.555
PGE Canby A	34.32	348	1596	0.13	0.47	0.555
PGE Canby B	34.32	348	1596	0.304	0.52	0.621
PGE Powerline A	29.37	380	1548	0.102	0.465	0.562
PGE Powerline B	29.37	380	1548	0.222	0.487	0.596
PGE Tug Dock A	28.61	384	1548	0.33	0.493	0.603
PGE Tug Dock B	28.61	384	1548	0.055	0.426	0.505
PGE Boathouse A	27.27	393	1548	0.005	0.404	0.483
PGE Boathouse B	27.27	393	1548	0.027	0.407	0.488
PGE Forebay A	26.81	396	1516	0.219	0.478	0.594
PGE Forebay B	26.81	396	1517	0.386	0.525	0.667
PGE Log Boom A	26.81	396	1548	0.189	0.483	0.598
PGE Log Boom B	26.81	396	1192	0.33	0.507	0.649
USGS 14207740	28.81	396	2544	0.251	0.486	0.599

Figure 56: Willamette River at Salem model-data continuous temperature comparison, 2001

Figure 57: Willamette River at Keizer model-data continuous temperature comparison, 2001

Figure 58: Willamette River at Willow Lake Treatment Plant model-data continuous temperature comparison, 2001

Figure 59: Willamette River at Wheatland Ferry model-data continuous temperature comparison, 2001

Figure 60: Willamette River at Eagle Nest A model-data continuous temperature comparison, 2001

Figure 61: Willamette River at Eagle Nest B model-data continuous temperature comparison, 2001

Figure 62: Willamette River at Coffee Island A model-data continuous temperature comparison, 2001

Figure 63: Willamette River at Coffee Island B model-data continuous temperature comparison, 2001

Figure 64: Willamette River at San Salvador A model-data continuous temperature comparison, 2001

Figure 65: Willamette River at San Salvador B model-data continuous temperature comparison, 2001

Figure 66: Willamette River above Ash Island A model-data continuous temperature comparison, 2001

Figure 67: Willamette River above Ash Island B model-data continuous temperature comparison, 2001

Figure 68: Willamette River at Champoeg Park A model-data continuous temperature comparison, 2001

Figure 69: Willamette River at Champoeg Park B model-data continuous temperature comparison, 2001

Figure 70: Willamette River at I5 Bridge, Wilsonville model-data continuous temperature comparison, 2001

Figure 71: Willamette River upstream of the Molalla River confluence, Power-line A model-data continuous temperature comparison, 2001.

Figure 72: Willamette River upstream of the Molalla River confluence, Power-line B model-data continuous temperature comparison, 2001.

Figure 73: Willamette River at Canby Ferry B model-data continuous temperature comparison, 2001.

Figure 74: Willamette River at Powerline A model-data continuous temperature comparison, 2001

Figure 75: Willamette River at Powerline A model-data continuous temperature comparison, 2001

Figure 76: Willamette River at Tug Dock A model-data continuous temperature comparison, 2001

Figure 77: Willamette River at Boathouse A model-data continuous temperature comparison, 2001

Figure 78: Willamette River at Forebay B model-data continuous temperature comparison, 2001

Figure 79: Willamette River at Log Boom B model-data continuous temperature comparison,

Figure 80: Willamette River at Log Boom B model-data continuous temperature comparison,

Figure 81: Willamette River at the Willamette Falls model-data continuous temperature comparison, 2001

Year 2002

Figure 82 through 89 show the continuous temperature comparison between model predictions and measured data. Error statistics are summarized in Table 9. Predicted temperature matched data very well for all the 8 sites with the RMSEs below 0.93 °C.

Table 9: Willamette River continuous water temperature calibration model-data error statistics, 2002

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
USGS 14192015	82.60	18	8784	-0.355	0.454	0.553
LASAR 28255	79.18	40	3202	0.019	0.382	0.501
LASAR 10344	72.63	82	3207	0.04	0.425	0.542
DEQ Coffee Island	61.51	156	3110	0.279	0.716	0.928
LASAR 30525	55.30	197	3109	-0.255	0.491	0.612
USGS 14197900	50.11	246	8736	0.056	0.536	0.681
LASAR 10340	38.94	318	5393	-0.284	0.622	0.769
USGS 14207740	28.81	396	8734	-0.198	0.51	0.638

Figure 82: Willamette River at Forebay A model-data continuous temperature comparison, 2001

Figure 83: Willamette River at Willow Lake Treatment Plant model-data continuous temperature comparison, 2002

Figure 84: Willamette River at Wheatland Ferry model-data continuous temperature comparison, 2002

Figure 85: Willamette River at Coffee Island model-data continuous temperature comparison, 2002

Figure 86: Willamette River upstream of the Yamhill River model-data continuous temperature comparison, 2002

Figure 87: Willamette River at Newberg model-data continuous temperature comparison, 2002

Figure 88: Willamette River at I5 Bridge, Wilsonville model-data continuous temperature comparison, 2002

Figure 89: Willamette River at the Willamette Falls model-data continuous temperature comparison, 2002

2.2.3 Upper Willamette River

Introduction

Upper Willamette River model domain includes the upstream part of Willamette River main stem, which starts from RM 185.2 and ends at RM 85.4. The model was set up as 9 water bodies including 13 branches, with 667 segments and 45 layers. There are 14 tributaries flows into the reach. The model grid is shown in Figure 90.

Figure 90: Upper Willamette River Model Grid

Hydrodynamics

In the original set up in V3.1 model, AX (longitudinal eddy viscosity, m^2/s) and DX (longitudinal eddy diffusivity, m^2/s) were at the magnitude of 50, which was derived from dye study. However, the Version 3.7 model suffered stability issues with these parameters being set to so big. These two parameters were assigned to 1.0. Further calibration was conducted by changing manning friction coefficients. The calibrated model showed better hydrodynamic predictions result for year 2001 than year 2002. The reason was that calibration was first conducted for year 2001. Although there was a

potential for further model improvement, the calibration was conducted until hydrodynamic and temperature results were acceptable.

Year 2001

The hydrodynamic calibration period in 2001 was from June to September. Figure 91 through 98 show the water level and flow comparison between model predictions and measured data. The figures showed that flow predictions matched well with data. Error statistics are summarized in Table 10.

Overall, model predicted flow rate and water surface elevation showed good agreement with measured data, except for water level predictions at segment 352. However, the measured data indicated the same water level for over 100 days, which raised suspect about the accuracy of this data. As a result, water level calibration for segment 352 was conducted mainly basing on data in Year 2002.

Table 10: Upper Willamette River hydrodynamic calibration statistics, 2001

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
ACOE EUGO3	182.45	19	4983	0.222	0.497	0.718
USGS 14166000	161.98	156	4992	-0.241	0.501	0.7
ACOE CORO3	132.32	352	1728	Quality of data is questionable		
USGS 14174000	120.11	434	4634	0.17	0.933	1.516
USGS 14191000	84.70	665	4678	0.011	0.450	0.562
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
ACOE EUGO3	182.45	19	4983	0.008	0.022	0.028
USGS 14166000	161.98	156	4992	0.007	0.007	0.012

ACOE CORO3	132.32	352	Flow data is not available			
USGS 14174000	120.11	434	4634	-0.004	0.013	0.021
USGS 14191000	84.70	665	5040	Not appropriate comparison, 1 km downstream of model grid

Figure 91: Willamette River at Eugene model-data flow comparison, 2001

Figure 92: Willamette River at Eugene model-data water level comparison, 2001

Figure 93: Willamette River at Harrisburg model-data flow comparison, 2001

Figure 94: Willamette River at Harrisburg model-data water level comparison, 2001

Figure 95: Willamette River at Corvallis model-data water level comparison, 2001

Figure 969: Willamette River at Albany model-data flow comparison, 2001

Figure 97: Willamette River at Albany model-data water level comparison, 2001

Figure 98: Willamette River at Salem model-data flow comparison, 2001 (gage is 900 m downstream)

Year 2002

The hydrodynamic calibration period in 2002 was from May to October. Figure 99 through 107 show the water level and flow comparison between model predictions and measured data. The figures showed that flow predictions matched well with data. Error statistics are summarized in Table 11.

Table 11: Upper Willamette River hydrodynamic calibration statistics, 2002

Gage ID	RM	Model Segment	Number of Comparisons	Flow		
				ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
ACOE EUGO3	182.45	19	8289	0.266	0.586	2.649
USGS 14166000	161.98	156	8399	0.027	1.237	6.948
ACOE CORO3	132.32	352	15701	0.611	1.18	10.378
USGS 14174000	120.11	434	8399	0.993	1.694	15.265
USGS 14191000	84.70	665*	5758	0.081	0.987	1.650

Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
ACOE EUGO3	182.45	19	8289	0.073	0.073	0.076
USGS 14166000	161.98	156	8399	-0.131	0.14	0.156
ACOE CORO3	132.32	352	15701	0.106	0.106	0.118
USGS 14174000	120.11	434	8399	0.026	0.028	0.075
USGS 14191000	84.70	665*	5760	Not appropriate comparison, 1 km downstream of model grid

Figure 99: Willamette River at Eugene model-data flow comparison, 2002

Figure 100: Willamette River at Eugene model-data water level comparison, 2002

Figure 101: Willamette River at Harrisburg model-data flow comparison, 2002

Figure 102: Willamette River at Harrisburg model-data water level comparison, 2002

Figure 103: Willamette River at Corvallis model-data flow comparison, 2002

Figure 104: Willamette River at Corvallis model-data water level comparison, 2002

Figure 105: Willamette River at Albany model-data flow comparison, 2002

Figure 106: Willamette River at Albany model-data water level comparison, 2002

Figure 107: Willamette River at Salem model-data flow comparison, 2002 (gage is 900 m downstream)

Temperature

Year 2001

Figure 108 through 119 show the continuous temperature comparison between model predictions and measured data. Error statistics are summarized in Table 12. Predicted temperature matched data very well for all the 12 sites with the RMSEs below 0.88 °C.

Table 12: Upper Willamette River continuous water temperature calibration model-data error statistics, 2001

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
LASAR 10359	185.3	2	5040	0.004	0.034	0.048
LASAR 28723	177.7	53	2362	-0.223	0.464	0.593
USGS 14166000	162.0	156	5040	0.135	0.659	0.782
LASAR 26755	151.6	227	5040	0.332	0.647	0.803
LASAR 26753	147.4	255	5040	0.444	0.698	0.877
LASAR 26772	142.4	287	5040	0.317	0.708	0.861
LASAR 10353	135.2	334	2520	0.169	0.514	0.654
USGS 14174000	120.2	434	2179	-0.129	0.408	0.519
LASAR 10349	113.9	476	4967	-0.005	0.498	0.638
LASAR 10347	96.9	589	4958	-0.213	0.476	0.59
LASAR 28254	88.9	643	2520	0.063	0.606	0.791
USGS 14191000	84.7	666	600	0.139	0.46	0.562

Figure 108: Upper Willamette River near Springfield model-data continuous temperature comparison, 2001

Figure 109: Upper Willamette River above McKenzie River model-data continuous temperature comparison, 2001

Figure 110: Upper Willamette River at Harrisburg model-data continuous temperature comparison, 2001

Figure 111: Upper Willamette River above Long Tom River model-data continuous temperature comparison, 2001

Figure 112: Upper Willamette River at RM 147.4 model-data continuous temperature comparison, 2001

Figure 113: Upper Willamette River at RM 142.4 model-data continuous temperature comparison, 2001

Figure 114: Upper Willamette River at Corvallis model-data continuous temperature comparison, 2001

Figure 115: Upper Willamette River at Albany model-data continuous temperature comparison, 2001

Figure 116: Upper Willamette River at Conser Rd model-data continuous temperature comparison, 2001

Figure 117: Upper Willamette River at South River Rd model-data continuous temperature comparison, 2001

Figure 118: Upper Willamette River above Rickreall Creek model-data continuous temperature comparison, 2001

Figure 119: Upper Willamette River at Salem model-data continuous temperature comparison, 2001

Year 2002

Figure 120 through 130 show the continuous temperature comparison between model predictions and measured data. Error statistics are summarized in Table 13. Predicted temperature matched data very well for all the 10 sites with the RMSEs below 0.73 °C.

Table 13: Upper Willamette River continuous water temperature calibration model-data error statistics, 2002

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
LASAR 10359	185.3	2	5761	0.009	0.141	0.17
LASAR 28723	177.7	53	4152	-0.163	0.515	0.647
USGS 14166000	162.0	156	8303	-0.373	0.591	0.717
LASAR 26755	151.6	227	5959	-0.403	0.485	0.601
LASAR 26753	147.4	255	5955	-0.222	0.422	0.534
LASAR 26772	142.4	287	4077	-0.393	0.537	0.658
LASAR 10353	135.2	334	4063	-0.317	0.469	0.581
USGS 14174000	120.2	434	8303	-0.493	0.569	0.729
LASAR 10349	113.9	476	5993	-0.447	0.501	0.628
LASAR 10347	96.9	589	5665	-0.401	0.439	0.536
LASAR 28254	88.9	643	2688	-0.425	0.543	0.689

Figure 120: Upper Willamette River near Springfield model-data continuous temperature comparison, 2002

Figure 121: Upper Willamette River above McKenzie River model-data continuous temperature comparison, 2002

Figure 122: Upper Willamette River at Harrisburg model-data continuous temperature comparison, 2002

Figure 123: Upper Willamette River above Long Tom River model-data continuous temperature comparison, 2002

Figure 124: Upper Willamette River at RM 147.4 model-data continuous temperature comparison, 2002

Figure 125: Upper Willamette River at RM 142.4 model-data continuous temperature comparison, 2002

Figure 126: Upper Willamette River at Corvallis model-data continuous temperature comparison, 2002

Figure 127: Upper Willamette River at Albany model-data continuous temperature comparison, 2002

Figure 128: Upper Willamette River at Conser Rd model-data continuous temperature comparison, 2002

Figure 129: Upper Willamette River at South River Rd model-data continuous temperature comparison, 2002

Figure 130: Upper Willamette River above Rickreall Creek model-data continuous temperature comparison, 2002

2.2.4 Clackamas River

Introduction

Clackamas River is a right-bank tributary of Willamette River. Following the original set up in Clackamas River V3.1 model, Clackamas River V3.7 model was built from Rivermill Reservoir (RM 22.6) to the river's confluence with the Willamette River (RM 0). The model consists of 2 branches, 149 segments, and 40 layers. The model grid is shown in Figure 131.

Clackamas River V3.7 model calibration period is from April 1 to September 30 in 2001 and from April 1 to October in 2002.

Figure 131: Clackamas River model grid

Hydrodynamics

Flow rate and water surface elevation was first tested using the original setting in V3.1 model. As the model showed good agreement with data, no further calibrations were conducted.

Year 2001

Figure 132 through 135 show the water level and flow comparison between model predictions and measured data. Error statistics are summarized in Table 14.

The flow predictions matched well with data for the both sites. For the water level at segment 2, however, the model over estimated at high flow conditions, and under estimated at low flow conditions. The 1-meter layer depth might result in coarse bathymetry and led this problem to occur. Similar problem existed in V3.1 model, but was not as severe as in V3.7 model.

Table 14: Clackamas River hydrodynamic calibration statistics, 2001

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14210000	22.22	2	8664	0.021	0.564	1.169
USGS 14211010	2.41	133	5380	-0.004	1.213	2.192
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14210000	22.22	2	8664	-0.314	0.539	0.619
USGS 14211010	2.41	133	5380	-0.078	0.098	0.11

Figure 132: Clackamas River at Estacada model-data flow comparison, 2001

Figure 133: Clackamas River at Estacada model-data water level comparison, 2001

Figure 134: Clackamas River near Oregon City model-data flow comparison, 2001

Figure 135: Clackamas River near Oregon City model-data water level comparison, 2001

Year 2002

The hydrodynamic calibration period in 2002 was from April to September. Figure 136 through 140 show the water level and flow comparison between model predictions and measured data. Error statistics are summarized in Table 15.

The model predicted rapidly changing flow rate in two periods in 2002 at Estacada (Segment 2), and resulted in oscillation of flow curve in Figure 136. This was caused by stability issues. The time step at these two unstable periods was 10s. Time step was then decreased to 5s, and the stability issues disappeared.

Table 15: Clackamas River hydrodynamic calibration statistics, 2002

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14210000	22.22	2	8679	-0.148	0.573	2.65
USGS 14211010	2.41	133	8649	7.131	8.736	17.662
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14210000	22.22	2	8664	0.198	0.341	0.391
USGS 14211010	2.41	133	8687	0.244	0.245	0.338

Figure 136: Clackamas River at Estacada model-data flow comparison, time step=10s, 2002

Figure 137: Clackamas River at Estacada model-data flow comparison, time step=5s, 2002

Figure 138: Clackamas River at Estacada model-data water level comparison, 2002

Figure 139: Clackamas River near Oregon City model-data flow comparison, 2002

Figure 140: Clackamas River near Oregon City model-data water level comparison, 2002

Temperature

Year 2001

Figure 141 through 146 show the continuous temperature comparison between model predictions and measured data. Error statistics are summarized in Table 16. Predicted temperature matched data very well for all the 6 sites with the RMSEs below 1.04 °C.

Table 16: Clackamas River continuous water temperature calibration model-data error statistics, 2001

Site ID	RM	Model Segment	Continuous Temperature			RMSE, °C
			Number of Comparisons	ME, °C	AME, °C	
USGS 14210000	22.22	2	3831	0.005	0.015	0.024
PGE CRMCIV	20.64	12	3934	0.2	0.563	0.784
PGE CRUPEC	16.30	41	4379	0.282	0.735	0.923
PGE CRBART	13.25	60	3852	-0.001	0.734	0.888
PGE CRATCB	8.11	93	4306	0.07	0.778	0.955
PGE CRATOC	2.41	133	4379	-0.087	0.823	1.033

Figure 141: Clackamas River at Estacada model-data continuous temperature comparison, 2001

Figure 142 : Clackamas River at McIver Park model-data continuous temperature comparison, 2001

Figure 143: Clackamas River upstream of Eagle Creek model-data continuous temperature comparison, 2001

Figure 144 : Clackamas River at Barton model-data continuous temperature comparison, 2001

Figure 145: Clackamas River at Carver Bridge model-data continuous temperature comparison, 2001

Figure 146: Clackamas River at Oregon City model-data continuous temperature comparison, 2001

Year 2002

Figure 147 through 152 show the continuous temperature comparison between model predictions and measured data. Error statistics are summarized in Table 17. Predicted temperature matched data very well for all the 3 sites with the RMSEs below 0.72 °C.

Table 17: Clackamas River continuous water temperature calibration model-data error statistics, 2002

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
USGS 14210000	22.22	2	8687	0.008	0.016	0.027
LASAR 30439	16.30	41	1309	-0.287	0.348	0.429
USGS 14211010	2.41	133	4922	-0.416	0.577	0.713

Figure 147: Clackamas River at Estacada model-data continuous temperature comparison, 2002

Figure 148 : Clackamas River at Rivermill Tailrace model-data continuous temperature comparison, 2002

Figure 149 : Clackamas River upstream of Eagle Creek model-data continuous temperature comparison, 2002

Figure 150 : Clackamas River upstream of Clear Creek model-data continuous temperature comparison, 2002

Figure 151: Clackamas River at Oregon City model-data continuous temperature comparison, 2002

Figure 152: Clackamas River at Oregon City model-data continuous temperature comparison, 2002

2.2.5 McKenzie River

Introduction

McKenzie River model domain includes South Fork McKenzie River from Cougar Reservoir and McKenzie River. Blue River was treated as a tributary into the system. Leaburg Canal and Walterville Canal were included in the system as loop branches. The model was set up as 7 water bodies including 7 branches, 474 segments and 23 layers. There are 13 tributaries flows into the systems. The model grid is shown in Figure 153.

Figure 153: McKenzie River model grid

Hydrodynamics

Flow rate and water surface elevation was first tested using the original setting in V3.1 model. As the model showed good agreement with data, no further calibrations were conducted.

Year 2001

The McKenzie River calibration period in 2001 was from April to September. Figure 154 through 161 show the water level and flow comparison between model predictions and

measured data. The figures showed that flow predictions matched well with data. Error statistics are summarized in Table 18.

Table 18: McKenzie River hydrodynamic calibration model-data error statistics, 2001

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14159500	60.39	4	7008	0	0.025	0.076
USGS 14162500	44.56	108	7008	-0.019	0.264	0.424
USGS 14163150	34.11	177	7008	-0.033	0.208	0.487
USGS 14163900	24.97	240	6996	-0.051	0.313	0.619
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14159500	60.39	4	7008	-0.006	0.026	0.036
USGS 14162500	44.56	108	7008	-0.088	0.088	0.092
USGS 14163150	34.11	177	7008	-0.026	0.026	0.033
USGS 14163900	24.97	240	6996	0.159	0.159	0.162

Figure 154: South Fork McKenzie River below Cougar Dam model-data flow comparison, 2001

Figure 155: South Fork McKenzie River below Cougar Dam model-data water level comparison, 2001

Figure 156: McKenzie River near Vida model-data flow comparison, 2001

Figure 157: McKenzie River near Vida model-data water level comparison, 2001

Figure 158: McKenzie River below Leaburg Dam model-data flow comparison, 2001

Figure 159: McKenzie River below Leaburg Dam model-data water level comparison, 2001

Figure 160: McKenzie River near Walterville model-data flow comparison, 2001

Figure 161: McKenzie River near Waltherville model-data water level comparison, 2001

Year 2002

The McKenzie River calibration period in 2002 was from April to October. Figure 162 through 169 show the water level and flow comparison between model predictions and measured data. The figures showed that flow predictions matched well with data. Error statistics are summarized in Table 19.

Table 19: McKenzie River hydrodynamic calibration model-data error statistics, 2002

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14159500	60.39	4	10175	0.003	0.046	0.295
USGS 14162500	44.56	108	10174	-0.029	0.54	1.365
USGS 14163150	34.11	177	10174	-0.053	0.957	2.273
USGS 14163900	24.97	240	10174	-0.073	1.293	4.511
Water Level						

Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14159500	60.39	4	10175	0.057	0.097	0.162
USGS 14162500	44.56	108	10174	-0.001	0.128	0.164
USGS 14163150	34.11	177	10174	-0.1	0.1	0.136
USGS 14163900	24.97	240	10174	0.117	0.118	0.156

Figure 162: South Fork McKenzie River below Cougar Dam model-data flow comparison, 2002

Figure 163: South Fork McKenzie River below Cougar Dam model-data water level comparison, 2002

Figure 164: McKenzie River near Vida model-data flow comparison, 2002

Figure 165: McKenzie River near Vida model-data water level comparison, 2002

Figure 166: McKenzie River below Leaburg Dam model-data flow comparison, 2002

Figure 167: McKenzie River below Leaburg Dam model-data water level comparison, 2002

Figure 168: McKenzie River near Walterville model-data flow comparison, 2002

Figure 169: McKenzie River near Waltherville model-data water level comparison, 2002

Temperature

Year 2001

Figure 170 through 180 show the McKenzie River continuous temperature comparison between model predictions and measured data in 2001. Error statistics are summarized in Table 20. Predicted temperature matched data very well for all the 11 sites with the RMSEs below 1.0 °C.

Table 20: McKenzie River continuous water temperature calibration model-data error statistics, 2001

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
USGS 14159500	60.39	4	6982	0.065	0.109	0.164
LASAR 26770	50.99	65	6638	-0.399	0.594	0.673
USGS 14162500	44.56	108	7104	-0.425	0.531	0.618
LASAR 25610	35.72	167	5711	-0.445	0.739	0.89

LASAR 25612	30.38	203	5715	-0.259	0.741	0.884
LASAR 26758	28.45	215	4678	-0.341	0.673	0.822
USGS 14163900	24.97	240	3284	-0.365	0.607	0.763
LASAR 25614	17.90	285	5709	-0.266	0.629	0.757
LASAR 26757	15.61	299	4825	-0.444	0.636	0.79
LASAR 25611	35.78	402	5712	-0.389	0.685	0.817
LASAR 25613	30.27	431	5714	-0.508	0.723	0.87

Figure 170: South Fork McKenzie River below Cougar Dam model-data continuous temperature comparison, 2001

Figure 171: McKenzie River below Cougar River model-data continuous temperature comparison, 2001

Figure 172: McKenzie River near Vida model-data continuous temperature comparison, 2001

Figure 173: McKenzie River below Leaburg Dam model-data continuous temperature comparison, 2001

Figure 174: McKenzie River above the Leaburg tailrace model-data continuous temperature comparison, 2001

Figure 175: McKenzie River at Deerborn model-data continuous temperature comparison, 2001

Figure 176: McKenzie River near Walterville model-data continuous temperature comparison, 2001

Figure 177: McKenzie River above Waltherville Tailrace model-data continuous temperature comparison, 2001

Figure 178: McKenzie River at Bellinger Landing model-data continuous temperature comparison, 2001

Figure 179: Leaburg Canal Intake, upstream end model-data continuous temperature comparison, 2001

Figure 180: Leaburg Canal Powerhouse Tailrace, downstream end model-data continuous temperature comparison,

Year 2002

Figure 181 through 192 show the McKenzie River continuous temperature comparison between model predictions and measured data in 2002. Error statistics are summarized in Table 21. Predicted temperature matched data very well for all the 12 sites with the RMSEs below 0.96 °C.

Table 21: McKenzie River continuous water temperature calibration model-data error statistics, 2002

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
USGS 14159500	60.39	4	10271	0.035	0.098	0.15
LASAR 26770	50.99	65	5856	-0.134	0.324	0.397
USGS 14162500	44.56	108	10270	0.333	0.403	0.507
LASAR 28504	40.74	132	3385	0.345	0.406	0.509
LASAR 25610	35.72	167	5668	0.284	0.644	0.803
LASAR 26758	28.45	215	5666	0.164	0.666	0.81
USGS 14163900	24.97	240	10270	0.167	0.521	0.662
LASAR 26757	15.61	299	4870	0.011	0.437	0.551
LASAR 29645	10.40	333	5857	-0.048	0.534	0.654
LASAR 10376	3.38	378	5715	0.079	0.508	0.628
LASAR 25611	35.78	402	5669	0.403	0.654	0.831
LASAR 25613	30.27	431	5667	0.314	0.764	0.954

Figure 181: South Fork McKenzie below Cougar Dam model-data continuous temperature comparison, 2002

Figure 182: McKenzie River below Cougar River model-data continuous temperature comparison, 2002

Figure 183: McKenzie River near Vida model-data continuous temperature comparison, 2002

Figure 184: McKenzie River at Helfrich boat ramp model-data continuous temperature comparison, 2002

Figure 185: McKenzie River below Leaburg Dam model-data continuous temperature comparison, 2002

Figure 186: McKenzie River at Deerborn model-data continuous temperature comparison, 2002

Figure 187: McKenzie River near Waltherville model-data continuous temperature comparison, 2002

Figure 188: McKenzie River at Bellinger Landing model-data continuous temperature comparison, 2002

Figure 189: McKenzie River above Mohawk River model-data continuous temperature comparison, 2002

Figure 190: McKenzie River at Coburg Rd model-data continuous temperature comparison, 2002

Figure 191: Leaburg Canal Intake, upstream end model-data continuous temperature comparison, 2002

Figure 192: Leaburg Canal Powerhouse Tailrace, downstream end model-data continuous temperature comparison,

2.2.6 Long Tom River

Introduction

The Long Tom River domain starts from Fern Ridge Dam at RM 23.7 and ends at its confluence with the Willamette River. The model was set up as 1 water body including 14 branches, with 187 segments and 22 layers. The model grid is shown in Figure 193. There were no tributaries flows into the system. Several spillways/weirs/dams were added in Version 3.1 model to represent the natural stone barriers along the upstream section of the river.

Figure 193: Long Tom River Model Grid

Hydrodynamics

The flow calibration was done in Version 3.1, in which distributed tributaries were added to compensate the lacking of tributary inflow data. While calibrating water level, Manning's friction coefficient and hydraulic equivalent slope were chosen to be the calibration parameters. It was found out that by delicately adjusting Manning's friction coefficient and hydraulic equivalent slope, calculation time can be greatly reduced.

Year 2001

The hydrodynamic calibration period in 2001 was from June to October. Figure 194 through 197 show the water level and flow comparison between model predictions and measured data. Error statistics are summarized in Table 22.

The flow predictions result matched well with data for the both sites. For water level, at segment 2, however, the model over estimated at high flow conditions, and under estimated at low flow conditions. The 1-meter layer depth might result in coarse bathymetry and led this problem to occur. Similar problem existed in V3.1 model, but was not as severe as in V3.7 model.

Table 22 Long Tom River hydrodynamic calibration model-data error statistics, 2001

Flow						
Gage ID	RM	Model Segment	Sample size, N	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14169000	23.47	2	5760	0	0.003	0.012
USGS 14170000	6.86	134	5559	0.026	0.109	0.138
Water Level						
Gage ID	RM	Model Segment	Sample size, N	ME, m	AME, m	RMSE, m
USGS 14169000	23.47	2	5760	-0.048	0.049	0.052
USGS 14170000	6.86	134	5559	-0.099	0.099	0.099

Figure 194: Long Tom River near Alvadore model-data flow comparison, 2001

Figure 195: Long Tom River near Alvadore model-data water level comparison, 2001

Figure 196: Long Tom River at Monroe model-data flow comparison, 2001

Figure 197: Long Tom River at Monroe model-data water level comparison, 2001

Year 2002

The hydrodynamic calibration period in 2002 was from April to October. Figure 198 through 201 show the water level and flow comparison between model predictions and measured data. Error statistics are summarized in Table 23. Both the simulated flow and water level matched well with data.

Table 23 Long Tom River hydrodynamic calibration model-data error statistics, 2002

Flow						
Gage ID	RM	Model Segment	Sample size, N	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14169000	23.47	2	8688	0.002	0.007	0.077
USGS 14170000	6.86	134	8688	-0.246	0.325	0.595
Water Level						
Gage ID	RM	Model Segment	Sample size, N	ME, m	AME, m	RMSE, m
USGS 14169000	23.47	2	8688	-0.029	0.046	0.058
USGS 14170000	6.86	134	8688	-0.074	0.075	0.078

Figure 198 Long Tom River near Alvadore model-data flow comparison, 2002

Figure 199 Long Tom River near Alvadore model-data water level comparison, 2002

Figure 200 Long Tom River at Monroe model-data flow comparison, 2002

Figure 201 Long Tom River at Monroe model-data water level comparison, 2002

Temperature

Year 2001

Figure 202 through 205 show the continuous temperature comparison between model predictions and measured data. Error statistics are summarized in Table 24. The current calibration result had the RMSEs below 1.3 °C. Overall the model captured the temperature dynamics well.

Table 24 Long Tom River continuous water temperature calibration model-data error statistics, 2001

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMS, °C
USGS 14169000	23.47	2	2622	0.002	0.029	0.036
LASAR 26749	17.75	55	5808	0.031	0.849	1.037
LASAR 26750	12.71	95	5808	0.764	1.019	1.259
USGS14170000	6.86	134	2616	0.254	0.717	0.889

Figure 202 Long Tom River near Alvadore model-data continuous temperature comparison, 2001

Figure 203 Long Tom River at RM 19.8 model-data continuous temperature comparison, 2001

Figure 204 Long Tom River at RM 12.3 model-data continuous temperature comparison, 2001

Figure 205 Long Tom River at Monroe model-data continuous temperature comparison, 2001

Year 2002

Figure 206 through 210 show the continuous temperature comparison between model predictions and measured data. Error statistics are summarized in Table 25. The current calibration result had the RMSEs below 1.3 °C.

Table 25 Long Tom River continuous water temperature calibration model-data error statistics, 2002

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMS, °C
USGS 14169000	23.47	2	8688	0.001	0.041	0.052
LASAR 26749	17.75	55	5922	-0.496	0.757	0.899
LASAR 26750	12.71	95	5884	0.155	0.558	0.721
USGS14170000	6.86	134	8688	-0.107	0.779	0.997
LASAR 29644	0.91	176	5882	0.003	0.981	1.234

Figure 206 Long Tom River near Alvadore model-data continuous temperature comparison, 2002

Figure 207 Long Tom River at RM 19.8 model-data continuous temperature comparison, 2002

Figure 208 Long Tom River at RM 12.3 model-data continuous temperature comparison, 2002

Figure 209 Long Tom River at Monroe model-data continuous temperature comparison, 2002

Figure 210 Long Tom River near mouth model-data continuous temperature comparison, 2002

2.2.7 Summary and Conclusions

Accuracy

The continuous model-data error statistics of the Version 3.1 models and Version 3.7 models are summarized in Table 26. The testing results showed improved accuracy when Lower Willamette River was converted to Version 3.7 and similar or slightly degraded accuracy on other river applications when they were converted. Because of the limited time that was spent on calibration, most of the six river models still had a potential for further calibration and improvement in accuracy. CE-QUAL-W2 Version 3.7 has the equivalent ability as Version 3.1 to achieve high-accuracy temperature predictions.

When setting the river models with the old calibration parameters in Version 3.1, most models produce the same or similar result, in which cases no further calibration was conducted. However, there were a few locations where Version 3.7 water level results did not show agreement with field measured data. Oftentimes, Version 3.1 water level results showed similar results at those locations. The water level prediction inaccuracy was resulted from insufficiency of river cross-section data.

Table 26: Comparison of CE-QUAL-W2 Version 3.1 and Version 3.7 temperature predictions accuracy on six river systems

River System Name	Simulation Period		Continuous Temperature RMSE Range °C	
			CE-QUAL-W2 Version 3.1	CE-QUAL-W2 Version 3.7
Lower Willamette	2001	63 days	0.16-0.76	0.08-0.64
	2002	182 days	0.09-0.81	0.07-0.78
Middle Willamette	2001	66 days	0.07-0.81	0.07-0.83
	2002	66 days	0.48-0.85	0.50-0.93
Upper Willamette	2001	105 days	0.05-0.81	0.05-0.88
	2002	175 days	0.16-0.74	0.17-0.73
Clackamas River	2001	183 days	0.03-0.86	0.02-1.03
	2002	183 days	0.03-0.68	0.03-0.71
McKenzie River	2001	148 days	0.16-0.99	0.16-0.89
	2002	214 days	0.16-0.76	0.15-0.95
Long Tom River	2001	123 days	0.04-1.07	0.04-1.26
	2002	183 days	0.05-1.16	0.05-1.23

Stability

Stability issues occurred at all the six river models except Lower Willamette River. The models suffered stability issues were characterized with one or more of the following features: very low flow rate (as low as 1.0 m³/s in some cases), dramatically changing flow rate at flood events or reservoir operations, complex branch connections and hydraulic structures, steep slope where segments easily dry up, complex and uneven

underwater topography. To solve this problem, four techniques were applied to make the model run:

- Reducing the maximum time step and time step fraction.
- Smoothing the branch bathymetry by even the river bed and adjusting widths.
- Delicately adjusting Slopec (the hydraulic equivalent slope) for different branches to reach a best working Slopec combination.
- Adjusting Manning's friction coefficients.

Although the presented six rivers were able to run through the simulation periods in 2001 and 2002, these models were not stable and might not run through another year. The reduced time step also resulted in the reduction of calculation speed, which was presented below.

Speed

The CPU runtime of CE-QUAL-W2 Version 3.7 model at six river systems applications are summarized in Table 27. The runtime the two simulation years were different because the flow conditions were different in different years so the time steps were different.

Table 27: CPU runtime of CE-QUAL-W2 Version 3.7 model at six river systems applications in 2001 and 2002

River System Name	Simulation Period		CPU Runtime (minutes)
			CE-QUAL-W2 version 3.7
Lower Willamette	2001	63 days	5.57
	2002	182 days	17.31
Middle Willamette	2001	66 days	59.8
	2002	66 days	28.4
Upper Willamette	2001	105 days	133.3
	2002	175 days	137.0
Clackamas River	2001	183 days	17.6

	2002	183 days	26.0
McKenzie River	2001	148 days	99.8
	2002	214 days	159.7
Long Tom River	2001	123 days	4.84
	2002	183 days	7.21

Based on the CPU runtime for the two simulation periods in year 2001 and 2002, runtime for one year simulation was estimated and summarized in Figure 211. Middle Willamette River, Upper Willamette River and McKenzie River were the three rivers that took the longest time to run for one year, with runtime over 200 minutes.

Figure 211: Estimated runtime for one year simulation using CE-QUAL-W2 Version 3.7

In summary, the CE-QUAL-W2 Version 3.7 has the ability to predict continuous river temperature accurately; however, it suffers some stability issues and runs slowly, especially for rivers with steep slope.

Chapter 3 Development of Steady-State Model for Hydrodynamics

3.1 New Expectation from River Hydrodynamic and Temperature Model

With the recent advances of research on climate change, it becomes possible to look into the future of watersheds and water bodies. Willamette Water 2100 is a five year project in which faculty from Oregon State University, the University of Oregon and Portland State University are cooperating with each other, and trying to evaluate how climate change, population growth and economic growth will change water in the Willamette River Basin. An integrated model framework incorporated Geographic Information System, hydrologic models, ecological models, socio-economic models, and a decision-making model.

One of the research tasks is to model the hydrodynamics and temperature in the Willamette River in the future, using input information from climate change models, hydrologic models and other models. The modeling results will assist protecting endangered species and also provide data for management decision making.

Since hydrodynamic and water temperature models for the whole Willamette River System are already developed, it is logical to use these existing models for the Willamette Water 2100 project. However, to simulate the river systems on a decadal or centennial timescale, it would take too long, for either CE-QUAL-W2 Version 3.7 or Version 3.1 to

run the models. Besides, the stability issues with CE-QUAL-W2 may cause difficulties during low-flow periods. As a result, the existing river models with CE-QUAL-W2 cannot be directly used for the Willamette Water 2100 Project.

To summarize, a hydrodynamic and water temperature model is needed to simulate the Willamette River Systems. The expectations from this model includes:

- Running fast,
- High accuracy of hydrodynamic and water temperature predictions,
- Ability to model temperature basing on dynamic shading,
- Including various hydraulic structures,
- Preferably having a smooth connection with many of the reservoir models within the basin that utilizes CE-QUAL-W2 Version 3.7,
- Ability to model stratified water quality.

3.2 Model Development Theory

To meet the current project requirement, and also to meet future challenge of expanding the capacity and scope of water quality models, a new river hydrodynamic and temperature model was built based on existing water quality models. The new model was built based on CE-QUAL-W2 Version 3.7. This new model uses steady-state methods to calculate water level and velocity, and uses existing CE-QUAL-W2 code to calculate dynamic temperature. By calculating the hydrodynamics at steady-state, the time step for stability is relaxed and simulations can proceed at much longer time steps. The rest of the model framework is still used for water quality state variables, such as temperature.

3.2.1 CE-QUAL-W2 Version 3.7 as the base model

The model theory and general description of CE-QUAL-W2 can be found in Section 1.1.4. The changes over different versions of CE-QUAL-W2 are described in Section 2.1.

3.2.2 Coordinate System and Model Grid

For most parts, the steady-state model uses the same coordinate system and model grid set up as CE-QUAL-W2 Version 3.7. The steady-state model is also a 2-D lateral averaged model. Figure 212 through Figure 214 show the comparison of a river top view, cross-section view, and side view in the real world (on the left) and in the model (on the right).

Figure 212: Comparison of river top view in the real world (left) and in the steady-state model (right)

Figure 213: Comparison of river cross-section view in the real world (left) and in the steady-steady model (right)

Figure 214: Comparison of river side view in the real world (left) and in the steady-steady model (right)

The modeled system is described with:

- **Cell:** the smallest unit in the model. It is a rectangular cubic, within which temperature is assumed to be a single value. A common dimension of a cell in the steady-state model would be 250-meters long, 5-meter wide, and 1-meter tall. On the right side of Figure 213, each rectangular represent a cell.
- **Segment:** includes several cells laying over each other. In the steady-state model, longitudinal velocity is the same within one segment. The right side of Figure 213 represents a segment.
- **Branch:** includes several segments. Branch is usually a representation of a river or part of a river. All the segments under one branch share the same slope and

hydraulic equivalent slope. However, Manning's friction coefficient is differentiated among segments.

- **Water body:** may include one or more branch(s). All the segments within one water body share the same top layer during calculation, as a result branches with very different bottom elevation should be separated into different water bodies.

Hydraulic Structures

The model is able to model a variety of hydraulic structures, including spillways, weirs, gates, pipes, pumps, withdraws, dam outflow.

Tributary and Distributed Tributary

CE-QUAL-W2 provides the flexibility to specify inflow from tributaries and distributed tributaries are distributed evenly from top layer to bottom layer. The steady state model does not support users to specify which layer tributaries enters, or distribute tributary flow according to density. Under Tributary Inflow Placement (TRIB PLACE), DISTR should be used for all tributaries.

Loop branch

Loop branches were used to represent flow around an island. In the code, loop branch was defined as a branch that is connected to a main branch by internal head boundary conditions at both ends. Figure 215 shows an example of a loop branch in the real world. Based on the way loop branches were defined in the code, loop branch and main branch should be in the same water body, and loop branch should be defined after its main

branch in the control file. Besides, additional tributaries should not be defined at the same segment of UHS(JB) or DHS(JB)+1.

Figure 215: Example of a loop branch in the real world and in model

Flow in loop branch and main branch is determined by applying Manning's equation in both branches, as is shown in Figure 216. Bisection (Press et al., 1992) is employed to find a water level at which the flow rate at two branches sum up to the flow rate in the upstream adjacent segment.

Figure 216: Flow distribution at the beginning of loop branch

During calibration, the friction coefficient of the first segment in loop branch can be calibrated together with the connected main branch segment to ensure that the right amount of water flows into loop branch. At the end of loop branch, the friction coefficient can be deliberately raised to a high value to represent the resistance when loop branch flows back into main branch.

Branch and water body connections

At the connection between different branches, flow and heat should be conserved transporting from upstream to downstream. As the downstream bottom layer and upstream bottom layer are not necessarily at the same elevation, there are several different scenarios to transport flow and heat to downstream. Figure 217 shows an example of dividing flow in a cell to cells in the downstream branch.

Figure 217: An example of transporting flow between branches

3.2.3 Steady-State Hydrodynamic Calculation

The steady-state hydrodynamic calculation method already exists in CE-QUAL-W2 Version 3.7. CE-QUAL-W2 Version 3.7 uses this method to estimate the initial water level and velocity at the first time step, so that simulation can start with estimated initial water level and velocity, instead of inputted initial condition. The steady-state model uses the same method to calculate hydrodynamics, but for every time step of simulation.

In every time step of steady-state hydrodynamic calculation, flow in each model segment is first estimated. Inflow, outflow, flow from upstream, tributary, distributaries, withdraws are all considered. Precipitation and evaporation as sources/sinks for flow balance are considered in CE-QUAL-W2 V3.7, but not in CE-QUAL-W2 steady-state model. This will not influence hydrodynamic calculation, as distributed tributaries are often used to make up flow data deficiency.

Figure 218: Flow rate calculation in the Steady-state model

Second, with estimated flow data, water level in each segment is solved from Manning's normal depth equation:

$$Q_i = \frac{1}{n_i} A_i R_{hi}^{2/3} S_i^{1/2}$$

Where

Q_i is the flow rate at segment i,

n_i is the Manning's friction coefficient for segment i,

A_i is the wetted cross-section area of segment i,

R_{hi} is the hydraulic radius of segment i,

S_i is the slope of the branch (in calculation, SLOPEC is used).

Hydraulic radius R_{hi} is calculated from:

$$R_{hi} = \frac{A_i}{P_i}$$

Where

P_i is the wetted perimeter of segment i.

Because A_i and P_i are functions of water level, Manning's normal depth equation cannot be directly solved. In CE-QUAL-W2 Version 3.7, the method of bisection (Press et al., 1992) is used to find normal depth.

Third, water level is first smoothed out within branches, then within the whole river system. Smoothing is basically replacing upstream water level with downstream water level when the former is smaller than the later one. Smoothing ensures downstream obstacles able to hold water in the upstream, and reduces inaccuracy resulted from uneven water surface.

Figure 219: Water surface elevation smoothing

Fourth, average velocity is calculated in every segment, using

$$U_{avg i} = \frac{Q_i}{A_i}$$

$U_{avg i}$ is the average velocity of segment i. This velocity is later assigned to every active layer of the segment.

Figure 220: Longitudinal velocity calculation

Last, vertical velocity is calculated for each layer to make sure the amount of water that enters a cell equals the amount of water that leaves a cell.

Figure 221: Vertical velocity calculation

3.2.4 Dynamic Temperature Calculation

Unlike hydrodynamics, temperature is estimated at unsteady-state; in other words, temperature at each time step is assumed to be related to temperature at earlier time steps.

The governing equation for temperature predictions is conservation of heat:

$$\frac{\partial B\Phi}{\partial t} + \frac{\partial UB\Phi}{\partial x} + \frac{\partial WB\Phi}{\partial z} - \frac{\partial (BD_x \frac{\partial \Phi}{\partial x})}{\partial x} - \frac{\partial (BD_z \frac{\partial \Phi}{\partial z})}{\partial z} = r_\Phi B$$

Where

B is channel width,

t is time,

x and z are the two dimensions,

U and W are velocity in x and z,

Φ is temperature,

D_x and D_z are the dispersion coefficients in x and z,

r_Φ is sources and sinks of heat.

Dispersion coefficients D_x and D_z are input into the model. Figure 222 shows the theory of the temperature calculation governing equation in the steady-state model. To put things simple, the above equation is basically saying that the temperature change in a cell equals to the heat budget change due to flow, heat sources and sink. Heat sources and sinks include: short/ long wave radiation with dynamic topographic shading and vegetation shading, air-water heat exchange, sediment-water heat exchange. Ice formation and ice cover exists in CE-QUAL-W2 Version 3.7, but it was not tested in the steady-state model yet, so for ice covered rivers the model should be used with caution.

Figure 222: Sketch of heat conservation of a cell

The temperature calculation governing equation is solved using numerical method. There are 3 transport solution schemes available in CE-QUAL-W2: Upwind, Quickest, and Ultimate quickest. THETA is a parameter that allows user to specify how much percentage of implicit scheme is employed, with 0 indicating the numerical scheme is totally explicit, and 1 indicating totally implicit. Ultimate quickest numerical scheme together with THETA set to 0.55 is found to be most accurate in CE-QUAL-W2 model. The same setting is employed in the steady-state model for temperature predictions.

3.3 Model Development Process

The model development process can be separated into two stages: (1) building the steady-state model prototype, and (2) constantly refining the prototype.

The first stage focused on putting steady-state hydrodynamics and dynamic temperature calculation together. The hydrodynamic calculation module was replaced with Manning's equation, which calculates water level and velocity at steady state. After that, effort was focused on making the manning's equation properly connect with other parts within the code, and to make code run without errors.

The second stage focused on the correctness of the code. As was shown in Figure 223, the model development process involved a lot of testing and refining of the prototype. Clackamas River was relatively simple compared to other river systems, so it was chosen to be the first river system to be tested with the new code. For debugging purposes, an ideal state was created, where the temperature of all the inflow from upstream and tributaries were set to 20 °C, and all the heat exchange activities were neglected. As a result, temperature in every cell and every segment should be 20 °C if the code is correct. All the real world models were first tested at this ideal state before real world cases were tested and calibrated.

Model Testing and Refining Process

Figure 223: Steady-State Model testing and refining process flow chart

3.4 Converting V3.7 models to Steady-state models

Most parts of the model setting up for CE-QUAL-W2 steady-state model is identical to the setting up for CE-QUAL-W2 V3.7. The procedures to convert an existing Version 3.7 model to steady-state include:

- In the control file (“W2_con.npt”), initial water surface elevation calculation (INITUWL) must be turned to “ON” to make sure that the executable (w2_ivf32-11.11.exe) is able to run.
- In the control file (“W2_con.npt”), precipitation should be turned off, as the steady-state model is not developed incorporating precipitation data.
- In the control file (“W2_con.npt”), a new coefficient named “DMZ” should be added under the card “Hydraulic coefficients”. DMZ specifies the vertical diffusion coefficient for each water body.

After make these changes, paste the steady-state executable into the work dictionary folder. The executable should be able to run when it is double clicked. Now the maximum time step can be set to a bigger value, for example 120 seconds.

The remaining work would be re-calibrated to ensure accurate prediction. Manning’s friction coefficient, the equivalent slope are generally chosen as calibration parameters.

In Chapter 4, an example case shows what if an existing Version 3.7 model is converted to steady-state without re-calibration.

3.5 Testing of New Steady State Model Codes

Three river models within the Willamette River System were tested with the New Steady State Model Codes, they were: Clackamas River, McKenzie River, Long Tom River. Attempts have been made to convert and calibrate Middle Willamette River model and Upper Willamette River model to steady-state model, but the calibration work is still going on. For Lower Willamette/ Columbia River model, because flow characteristics in Lower Willamette River and Columbia River are strongly influenced by tides, and the steady-state model does not have the ability to simulate the tidal effects, the Lower Willamette River / Columbia River model is not converted to steady-state.

The calibration results of the three tested river models were presented with details in the following sections.

3.5.1 Clackamas River

Hydrodynamics

Manning's friction coefficient and hydraulic equivalent slope were the only two parameters used to calibrate the model.

Year 2001

Clackamas River hydrodynamic model-data error statistics in 2001 are summarized in Table 28. Figure 224 through 227 show the flow rate and water level comparison at different sites. The model was overestimating water level at high flow period and underestimating water level at low flow period. Similar result appeared in Version 3.1 and Version 3.7 model. Finer bathymetry data would be needed to solve this problem.

Table 28: Clackamas River hydrodynamic calibration statistics, 2001

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14210000	22.22	2	8664	0.034	0.402	0.95
USGS 14211010	2.41	133	5380	-0.04	1.372	1.989
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14210000	22.22	2	8664	0.547	0.57	0.621
USGS 14211010	2.41	133	5380	0.224	0.242	0.265

Figure 224: Clackamas River at Estacada model-data flow comparison, 2001

Figure 225: Clackamas River at Estacada model-data water level comparison, 2001

Figure 226: Clackamas River near Oregon City model-data flow comparison, 2001

Figure 227: Clackamas River near Oregon City model-data water level comparison, 2001

Year 2002

Clackamas River hydrodynamic model-data error statistics in 2002 are summarized in Table 29. Figure 228 through 231 show the flow rate and water level comparison at different sites. The model experienced the same problem for water level at segment 2 in 2002 as in 2001. Another problem was that the model was overestimating the water level at peak flow, which occurred at Julia Day 97. This would be the first problem to look at if there were more time for calibration.

Table 29: Clackamas River hydrodynamic calibration statistics, 2002

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14210000	22.22	2	8687	0.015	0.35	1.119
USGS 14211010	2.41	133	8687	6.977	8.057	12.454
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14210000	22.22	2	8687	-0.013	0.289	0.292
USGS 14211010	2.41	133	8687	0.112	0.117	0.257

Figure 228: Clackamas River at Estacada model-data flow comparison, 2002

Figure 229: Clackamas River at Estacada model-data water level comparison, 2002

Figure 230: Clackamas River near Oregon City model-data flow comparison, 2002

Figure 231: Clackamas River near Oregon City model-data water level comparison, 2002

Temperature

Year 2001

Clackamas River continuous water temperature calibration model-data error statistics in 2001 are summarized in Table 30. Figure 232 through 237 show the continuous temperature comparison at different sites. The current calibration result had the RMSEs below 1.1 °C.

Table 30: Clackamas River continuous water temperature calibration model-data error statistics, 2001

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
USGS 14210000	22.22	2	3831	0.002	0.017	0.024
PGE CRMCIV	20.64	12	3934	0.191	0.564	0.784
PGE CRUPEC	16.30	41	4331	0.253	0.716	0.899
PGE CRBART	13.25	60	3852	-0.029	0.75	0.914
PGE CRATCB	8.11	93	4258	0.022	0.77	0.952
PGE CRATOC	2.41	133	4331	-0.152	0.807	1.01

Figure 232: Clackamas River at Estacada model-data continuous temperature comparison, 2001

Figure 233: Clackamas River at McIver Park model-data continuous temperature comparison, 2001

Figure 234: Clackamas River upstream of Eagle Creek model-data continuous temperature comparison, 2001

Figure 235: Clackamas River at Barton model-data continuous temperature comparison, 2002

Figure 236: Clackamas River at Carver Bridge model-data continuous temperature comparison, 2001

Figure 237: Clackamas River at Oregon City model-data continuous temperature comparison, 2001

Year 2002

Clackamas River continuous water temperature calibration model-data error statistics in 2002 are summarized in Table 31. Figure 238 through 241 show the continuous temperature comparison at different sites. The current calibration result had the RMSEs below 1.1 °C.

Table 31: Clackamas River continuous water temperature calibration model-data error statistics, 2002

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
USGS 14210000	22.22	2	8687	0.007	0.014	0.024
LASAR 30439	16.30	41	1309	-0.314	0.368	0.466
LASAR 30515	8.20	92	1307	-0.382	0.644	0.775
USGS 14211010	2.41	133	4922	-0.493	0.862	1.065

Figure 238: Clackamas River at Estacada model-data continuous temperature comparison, 2002

Figure 239: Clackamas River upstream of Eagle Creek model-data continuous temperature comparison, 2002

Figure 240: Clackamas River upstream of Clear Creek model-data continuous temperature comparison, 2002

Figure 241: Clackamas River at Oregon City model-data continuous temperature comparison, 2002

3.5.2 McKenzie River

Hydrodynamics

Manning's friction coefficient and hydraulic equivalent slope were the only two parameters used to calibrate the model.

Year 2001

McKenzie River hydrodynamic model-data error statistics in 2001 are summarized in Table 32. Figure 242 through 249 show the flow rate and water level comparison at different sites. Overall, the Steady-State model was able to predict both flow rate and water level very well. For segment 240, the model was overestimating the water level. This was because water level during the simulation period fell into one single layer, and only by adjusting friction coefficient the water level could not be gotten for the whole simulation period. More accurate bathymetry data would be needed to get the right water level. As the water temperature results were acceptable, further calibration was not conducted.

Table 32: McKenzie River hydrodynamic calibration model-data error statistics, 2001

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14159500	60.39	4	7008	0	0.01	0.028
USGS 14162500	44.56	108	7008	-0.054	0.358	0.872
USGS 14163150	34.11	177	7008	-0.115	0.709	1.457
USGS 14163900	24.97	240	6996	-0.187	1.210	2.253
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14159500	60.39	4	7008	0.086	0.086	0.109
USGS 14162500	44.56	108	7008	-0.016	0.017	0.019
USGS 14163150	34.11	177	7008	0.011	0.021	0.027
USGS 14163900	24.97	240	6996	0.216	0.217	0.219

Figure 242: South Fork McKenzie River below Cougar Dam model-data flow comparison, 2001

Figure 243: South Fork McKenzie River below Cougar Dam model-data water level comparison, 2001

Figure 244: McKenzie River near Vida model-data flow comparison, 2001

Figure 245: McKenzie River near Vida model-data water level comparison, 2001

Figure 246: McKenzie River below Leaburg Dam model-data flow comparison, 2001

Figure 247: McKenzie River below Leaburg Dam model-data water level comparison, 2001

Figure 248: McKenzie River near Walterville model-data flow comparison, 2001

Figure 249: McKenzie River near Waltherville model-data water level comparison, 2001

Year 2002

McKenzie River hydrodynamic model-data error statistics in 2002 are summarized in Table 33. Figure 250 through 257 show the flow rate and water level comparison at different sites. Overall, the Steady-State model was able to predict both flow rate and water level well. As hydrodynamic calibration was conducted first for year 2001 and then tested on year 2002, simulation results in year 2002 was not as good as year 2001. Continuous water level at Segment 4, Segment 177, and Segment 240 were either overestimating or underestimating estimating. However, as the calibration as a whole was acceptable, calibration was not further conducted.

Table 33: McKenzie River hydrodynamic calibration model-data error statistics, 2002

Flow						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14159500	60.39	4	10271	0.009	0.147	0.596
USGS 14162500	44.56	108	10270	-0.149	1.289	3.884
USGS 14163150	34.11	177	10270	-0.244	2.406	6.402
USGS 14163900	24.97	240	10270	-0.367	3.802	10.039
Water Level						
Gage ID	RM	Model Segment	Number of Comparisons	ME, m	AME, m	RMSE, m
USGS 14159500	60.39	4	10271	0.148	0.185	0.299
USGS 14162500	44.56	108	10270	-0.007	0.026	0.044
USGS 14163150	34.11	177	10270	-0.055	0.06	0.107
USGS 14163900	24.97	240	10270	0.204	0.205	0.228

Figure 250: South Fork McKenzie River below Cougar Dam model-data flow comparison, 2002

Figure 251: South Fork McKenzie River below Cougar Dam model-data water level comparison, 2002

Figure 252: McKenzie River near Vida model-data flow comparison, 2002

Figure 253: McKenzie River near Vida model-data water level comparison, 2002

Figure 254: McKenzie River below Leaburg Dam model-data flow comparison, 2002

Figure 255: McKenzie River below Leaburg Dam model-data water level comparison, 2002

Figure 256: McKenzie River near Walterville model-data flow comparison, 2002

Figure 257: McKenzie River near Waltherville model-data water level comparison, 2002

Temperature

Year 2001

McKenzie River continuous water temperature calibration model-data error statistics in 2001 are summarized in Table 34. Figure 258 through 267 show the continuous temperature comparison at different sites. The current calibration result had the RMSEs below 0.89°C .

Table 34: McKenzie River continuous water temperature calibration model-data error statistics, 2001

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
USGS 14159500	60.39	4	6982	0.062	0.112	0.163
LASAR 26770	50.99	65	6638	-0.396	0.591	0.67
USGS 14162500	44.56	108	7104	-0.424	0.53	0.616
LASAR 25610	35.72	167	5711	-0.443	0.737	0.886
LASAR 25612	30.38	203	5715	-0.258	0.74	0.882
LASAR 26758	28.45	215	4678	-0.34	0.671	0.819
USGS 14163900	24.97	240	3284	-0.365	0.606	0.761
LASAR 25614	17.90	285	5709	-0.265	0.629	0.757
LASAR 26757	15.61	299	4825	-0.443	0.635	0.789
LASAR 25611	35.78	402	5712	-0.387	0.682	0.813
LASAR 25613	30.27	431	5714	-0.507	0.721	0.867

Figure 258: South Fork McKenzie River below Cougar Dam model-data continuous temperature comparison, 2001

Figure 259: McKenzie River below Cougar River model-data continuous temperature comparison, 2001

Figure 260: McKenzie River near Vida model-data continuous temperature comparison, 2001

Figure 261: McKenzie River below Leaburg Dam model-data continuous temperature comparison, 2001

Figure 262: McKenzie River above the Leaburg tailrace model-data continuous temperature comparison, 2001

Figure 263: McKenzie River at Deerborn model-data continuous temperature comparison, 2001

Figure 264: McKenzie River near Walterville model-data continuous temperature comparison, 2001

Figure 265: McKenzie River above Waltherville Tailrace model-data continuous temperature comparison, 2001

Figure 266: McKenzie River at Bellinger Landing model-data continuous temperature comparison, 2001

Figure 267: Leaburg Canal Intake, upstream end model-data continuous temperature comparison, 2001

Year 2002

McKenzie River continuous water temperature calibration model-data error statistics in 2001 are summarized in Table 35. Figure 268 through 279 show the continuous temperature comparison at different sites. The current calibration result had the RMSEs below 0.79 °C.

Table 35: McKenzie River continuous water temperature calibration model-data error statistics, 2002

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMSE, °C
USGS 14159500	60.39	4	10175	0.042	0.119	0.176
LASAR 26770	50.99	65	5856	-0.171	0.295	0.361
USGS 14162500	44.56	108	10174	0.326	0.395	0.498
LASAR 28504	40.74	132	3385	0.329	0.392	0.49
LASAR 25610	35.72	167	5668	0.262	0.597	0.75
LASAR 26758	28.45	215	5666	0.15	0.606	0.746
USGS 14163900	24.97	240	10174	0.159	0.48	0.616
LASAR 26757	15.61	299	4870	0.015	0.407	0.517
LASAR 29645	10.40	333	5857	-0.026	0.516	0.648
LASAR 10376	3.38	378	5715	0.088	0.453	0.57
LASAR 25611	35.78	402	5669	0.379	0.608	0.779
LASAR 25613	30.27	431	5667	0.227	0.623	0.784

Figure 268: South Fork McKenzie below Cougar Dam model-data continuous temperature comparison, 2002

Figure 269: McKenzie River below Cougar River model-data continuous temperature comparison, 2002

Figure 270: McKenzie River near Vida model-data continuous temperature comparison, 2002

Figure 271: McKenzie River at Helfrich boat ramp model-data continuous temperature comparison, 2002

Figure 272: McKenzie River below Leaburg Dam model-data continuous temperature comparison, 2002

Figure 273: McKenzie River at Deerborn model-data continuous temperature comparison, 2002

Figure 274: McKenzie River near Walterville model-data continuous temperature comparison, 2002

Figure 275: McKenzie River at Bellinger Landing model-data continuous temperature comparison, 2002

Figure 276: McKenzie River above Mohawk River model-data continuous temperature comparison, 2002

Figure 277: McKenzie River at Coburg Rd model-data continuous temperature comparison, 2002

Figure 278: Leaburg Canal Intake, upstream end model-data continuous temperature comparison, 2002

Figure 279: Leaburg Canal Powerhouse Tailrace, downstream end model-data continuous temperature comparison, 2002

3.5.3 Long Tom River

In Long Tom River CE-QUAL-W2 version 3.1 model, there is a side branch that represent an irrigation channel. This side branch was connected to the system with a lateral gate in the upstream, and an internal head boundary in the downstream.

In the current calibrated steady-state model, this side branch was deleted. The code which enable a side branch is connected to a main branch with a dynamic pump is underdevelopment. In the future study, this side branch should be added back to the model grid.

Hydrodynamics

Adjustment of spillway bottom elevation was performed to all the spillways to calibrate water level. Manning's friction coefficient and hydraulic equivalent slope were also adjusted.

Year 2001

Long Tom River hydrodynamic model-data error statistics in 2001 are summarized in Table 36. Figure 280 through 283 show the flow rate and water level comparison at different sites. The Steady-State model was able to predict both flow rate and water level very well.

Table 36 Long Tom River hydrodynamic calibration model-data error statistics, 2001

Flow						
Gage ID	RM	Model Segment	Sample size, N	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14169000	23.47	2	5760	0	0.003	0.012
USGS 14170000	6.86	134	5559	0.053	0.126	0.178
Water Level						
Gage ID	RM	Model Segment	Sample size, N	ME, m	AME, m	RMSE, m
USGS 14169000	23.47	2	5760	-0.014	0.019	0.024
USGS 14170000	6.86	134	5559	-0.024	0.025	0.026

Figure 280 Long Tom River near Alvadore model-data flow comparison, 2001

Figure 281: Long Tom River near Alvadore model-data water level comparison, 2001

Figure 282: Long Tom River at Monroe model-data flow comparison, 2001

Figure 283: Long Tom River at Monroe model-data water level comparison, 2001

Year 2002

Long Tom River hydrodynamic model-data error statistics in 2002 are summarized in Table 37. Figure 284 through 287 show the flow rate and water level comparison at different sites. The Steady-State model was able to predict both flow rate and water level very well.

Table 37 Long Tom River hydrodynamic calibration model-data error statistics, 2002

Flow						
Gage ID	RM	Model Segment	Sample size, N	ME, m ³ /s	AME, m ³ /s	RMSE, m ³ /s
USGS 14169000	23.47	2	8688	0.003	0.008	0.076
USGS 14170000	6.86	134	8688	-0.209	0.389	0.679
Water Level						
Gage ID	RM	Model Segment	Sample size, N	ME, m	AME, m	RMSE, m
USGS 14169000	23.47	2	8688	0.005	0.019	0.046
USGS 14170000	6.86	134	8688	0	0.02	0.03

Figure 284: Long Tom River near Alvadore model-data flow comparison, 2002

Figure 285: Long Tom River near Alvadore model-data water level comparison, 2002

Figure 286: Long Tom River at Monroe model-data flow comparison, 2002

Figure 287: Long Tom River at Monroe model-data water level comparison, 2002

Temperature

Year 2001

Long Tom River continuous water temperature calibration model-data error statistics in 2001 are summarized in Table 38. Figure 288 through 291 show the continuous temperature comparison at different sites. The current calibration result had the RMSEs below 0.95°C , which was better than both the current Version 3.1 calibration results and the Version 3.7 calibration results.

Table 38 Long Tom River continuous water temperature calibration model-data error statistics, 2001

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMS, °C
USGS 14169000	23.47	2	2622	0.002	0.029	0.036
LASAR 26749	17.75	55	5808	-0.006	0.782	0.95
LASAR 26750	12.71	95	5808	0.288	0.712	0.914
USGS14170000	6.86	134	2616	0.129	0.667	0.815

Figure 288: Long Tom River near Alvadore model-data continuous temperature comparison, 2001

Figure 289: Long Tom River at RM 19.8 model-data continuous temperature comparison, 2001

Figure 290: Long Tom River at RM 12.3 model-data continuous temperature comparison, 2001

Figure 291: Long Tom River at Monroe model-data continuous temperature comparison, 2001

Year 2002

Long Tom River continuous water temperature calibration model-data error statistics in 2001 are summarized in Table 39. Figure 292 through 296 show the continuous temperature comparison at different sites. The current calibration result had the maximum RMSE 1.295 °C, which was similar to maximum RMSE in the current Version 3.1 calibration results (1.16 °C) and the maximum RMSE in the Version 3.7 calibration result (1.23 °C).

Table 39 Long Tom River continuous water temperature calibration model-data error statistics, 2002

Site ID	RM	Model Segment	Continuous Temperature			
			Number of Comparisons	ME, °C	AME, °C	RMS, °C
USGS 14169000	23.47	2	8688	0	0.041	0.052
LASAR 26749	17.75	55	5922	-0.457	0.786	0.951
LASAR 26750	12.71	95	5884	-0.445	0.562	0.724
USGS14170000	6.86	134	8688	-0.382	0.758	0.913
LASAR 29644	0.91	176	5882	-0.26	1.044	1.295

Figure 292: Long Tom River near Alvadore model-data continuous temperature comparison, 2002

Figure 293: Long Tom River at RM 19.8 model-data continuous temperature comparison, 2002

Figure 294: Long Tom River at RM 12.3 model-data continuous temperature comparison, 2002

Figure 295: Long Tom River at Monroe model-data continuous temperature comparison, 2002

Figure 296: Long Tom River near mouth model-data continuous temperature comparison, 2002

Chapter 4 Summary and Conclusions

This research presents (1) the conversion of Willamette River systems from CE-QUAL-W2 Version 3.1 to Version 3.7, (2) the development of a new hydrodynamic and temperature model which is based on CE-QUAL-W2 Version 3.7, and (3) testing of the new model.

In the first part of the research, six river models within the Willamette River Basin were converted from CE-QUAL-W2 Version 3.1 to Version 3.7. CE-QUAL-W2 Version 3.7 was proven to have the equivalent ability as Version 3.1 to achieve high-accuracy results of flow rate, water surface elevation and temperature on river applications, with the RMSE for continuous temperature model-data comparison below 1 °C for five out of the six river models. This research also found out that both CE-QUAL-W2 Version 3.1 and Version 3.7 ran relatively slow (up to several hours) for these six river models.

In the second part of the research, a new hydrodynamic and temperature model was developed based on CE-QUAL-W2 Version 3.7. The hydrodynamic calculation module was replaced with steady-state calculation methods. Water level was estimated using Manning's normal depth equation. Temperature was calculated using the same methods applied in CE-QUAL-W2 Version 3.7.

In the third part of the research, the newly developed model was tested on five river models in the Willamette River Basin. The calibration work is still ongoing for Middle Willamette River model and Upper Willamette River model, so only results from three river models are presented. This new model is assessed from the following three aspects:

Accuracy

The continuous model-data error statistics of the Version 3.1 models, Version 3.7 models and steady-state models are summarized in Table 40. The steady-state models produced results similar to Version 3.1 models and Version 3.7 models. The increase in continuous model-data temperature RMSE did not exceed 0.2 °C. Sometimes the RMSE was smaller in the steady-state models than in Version 3.1 models and Version 3.7 models. The steady-state model has similar ability as the Version 3.1 and Version 3.7 models to achieve high-accuracy temperature predictions.

Table 40: Comparison of CE-QUAL-W2 Steady-State Model, CE-QUAL-W2 Version 3.1 and Version 3.7 temperature predictions accuracy on six river systems

River System Name	Simulation Period		Continuous Temperature RMSE Range °C		
			CE-QUAL-W2 Version 3.1	CE-QUAL-W2 Version 3.7	CE-QUAL-W2 Steady-State
Clackamas River	2001	183 days	0.03-0.86	0.02-1.03	0.02-1.01
	2002	183 days	0.03-0.68	0.03-0.71	0.02-1.07
McKenzie River	2001	148 days	0.16-0.99	0.16-0.89	0.16-0.89
	2002	214 days	0.16-0.76	0.15-0.95	0.18-0.78
Long Tom River	2001	123 days	0.04-1.07	0.04-1.26	0.04-0.95
	2002	183 days	0.05-1.16	0.05-1.23	0.05-1.30

Stability

Compared to the Version 3.7 models that are described in Chapter 2, the steady-state models are much more stable. The length of time step is no longer limited by stability issues with the hydrodynamics calculation, but only limited by stability issues with the temperature calculation. The maximum time steps in the three tested steady-state models

ranged from 120 seconds to 180 seconds. The minimum time steps were generally set to 20 seconds which were used during flood events.

Speed

The CPU runtime of the steady-state model and Version 3.7 model for three river applications are summarized in Table 41. The estimated runtime for one year simulation using the steady-state model and Version 3.7 model is compared in Figure 297. The steady-state model is able to reduce computing time by up to 96%.

Table 41: Comparison of CPU runtime of Steady-State Model and CE-QUAL-W2 Version 3.7 model for three river systems applications in 2001 and 2002

River System Name	Simulation Period		CPU Runtime (minutes)		Time Reduced by Fraction
			CE-QUAL-W2 version 3.7	Steady-state model	
Clackamas River	2001	183 days	17.6	1.7	90%
	2002	183 days	26.0	4.26	84%
McKenzie River	2001	148 days	99.8	4.44	96%
	2002	214 days	159.7	7.0	96%
Long Tom River	2001	123 days	4.84	1.91	61%
	2002	183 days	7.21	4.33	40%

Figure 297: Comparison of estimated runtime for one year simulation using Steady-State Model and CE-QUAL-W2 Version 3.7

In summary, this new steady-state model is accurate, stable and fast. It not only meets the Willamette Water 2100 project requirements, but also has a great potential to be applied on other rivers around the world and to address river temperature concerns and fish habitat issues.

List of recommendations for future study

(1) Convert an existing CE-QUAL-W2 Version 3.7 model to steady-state model

The detailed procedures to convert an existing CE-QUAL-W2 Version 3.7 model to steady-state model are described in Section 3.4.

It is easy to make changes in the control file to enable the steady-state executable to run, however re-calibration can be challenging for a new user. What if an existing Version 3.7 model is converted to steady-state without re-calibration? Figure 298 and Table 42 compared the results from Version 3.7, the steady-state model without re-calibration and the steady-state model after calibration. From Figure 298, the differences between results are not evident, because the temperature fluctuation during a day is bigger than difference between models. However, from Table 42, it is clear that without re-calibration the steady-state model results are not as accurate as the Version 3.7 model results, or the calibrated steady-state model results. The RMSE for continuous temperature model-data comparisons can reach 1.3 °C in the un-calibrated steady-state model, while the RMSE is below 0.9 °C in both calibrated Version 3.7 model and calibrated steady-state model.

Figure 298: Continuous temperature comparison between models (red) VS data (black) at Segment 285 in McKenzie River model, 2001. From top down, the compared models are Version 3.7, steady-state model without re-calibration and steady-state model after calibration

Table 42: McKenzie River continuous water temperature calibration model-data error statistics, 2001. From left to right, the compared models are Version 3.7, steady-state model without re-calibration and steady-state model after calibration

Site ID	RM	Model Segment	Continuous Temperature RMSE, °C		
			Version 3.7	steady-state model without re-calibration	steady-state model after calibration
USGS 14159500	60.39	4	0.164	0.117	0.163
LASAR 26770	50.99	65	0.673	0.741	0.67
USGS 14162500	44.56	108	0.618	0.75	0.616
LASAR 25610	35.72	167	0.89	1.273	0.886
LASAR 25612	30.38	203	0.884	1.301	0.882
LASAR 26758	28.45	215	0.822	1.157	0.819
USGS 14163900	24.97	240	0.763	0.969	0.761
LASAR 25614	17.90	285	0.757	0.902	0.757
LASAR 26757	15.61	299	0.79	0.909	0.789
LASAR 25611	35.78	402	0.817	1.201	0.813
LASAR 25613	30.27	431	0.87	1.232	0.867

(2) Vertical diffusion coefficient

The current steady-state model has a problem with vertical diffusion. Giving this coefficient a value instead of zero resulted in inaccurate temperature prediction. However, setting this coefficient to zero means that there is no vertical diffusion between layers which is not true. The problem should be examined in future study.

(3) The effects of irregularity in the grid

In the steady-state model, as Manning's equation assumes steady flow, the water level is higher at segments with narrower width or higher river bed than the surrounding segments. However in the real world, critical flow condition may occur at segments with smaller cross-sections, where longitudinal velocity is bigger than velocity at regular cross-section and water level is accordingly lower.

The following three scenarios show how the steady-state model deals with irregularity in the model grid. The slope of the three-segment branch is 0.00001. Segment length is 250 meters, and layer thickness is 1 meter.

In the first scenario, the three segments have the same cross-section shape. The side view of this branch is shown in Figure 299. Given a specific flow rate, the water surface elevations in the three segments are very close to each other.

Figure 299: Side view of the example branch with even grid

In the second scenario, all other conditions are the same as the first scenario except that second segment have a higher river bed, as is shown in Figure 300. This results in a higher water surface elevation in the second segment. Because of the smoothing algorithm, the water surface elevation in the first segment is equal to the second segment.

Figure 300: Side view of the example branch with higher river bed in the middle

In the third scenario, all other conditions are the same as the first scenario except that second segment has a lower river bed, as is shown in Figure 301. The water surface elevation in the second segment is equal to the third segment.

Figure 301: Side view of the example branch with lower river bed in the middle

(4) Explore new smoothing algorithm for branches with small slope or slope equals zero

First, the steady-state model has issues when the small slope (e.g., slope=0.00001) and uneven underwater topography coexist. As is shown in the example above, a segment with narrow width or high river bed may raise up the water level upstream.

Second, the steady-state model would not work with branches where slope equals zero because Manning's equation calculates water level basing on slope.

To solve the two problems above, a new smoothing algorithm is needed. The smoothing algorithm used in the current steady-state model is described in Section 3.2.3. The new smoothing algorithm may fit a polynomial for a long section of segments.

(5) Codes to ensure stability

It was noticed in the steady-state model that even when the model encountered stability issues and the predicted temperature output was not a number ("NaN"), the model was still running. Some codes should be written to ensure a warning when the model encountered stability issues.

(6) Season and time step

All the three river systems have only been tested for part of the year. Most of the system simulation periods include summer and some include spring and fall, but none of them include winter.

In winter and spring, flow rate is generally higher than the rest of the year in the Pacific Northwest, and time steps should be considerably smaller so that the calculation can be stable. Special attention should be paid to search for potential stability problems in the future simulation.

(7) Water quality modules

As long as the steady-state model is able to model flow rate, water level and temperature, the next step would be adding the water quality modeling capacity to this model. CE-QUAL-W2 Version 3.7 is able to model 34 water quality constituents. Information about water quality should be gathered, so that the water quality constituents that need to be included in the model can be determined.

(8) Use team based approach to new model development

New model development is a challenging endeavor. It takes much time and effort to construct a new model with several complicated and interrelated parts, and it takes even more time and effort to make the model sound and robust. Team based approach is used by industries for new product development. This approach integrates different individuals' intelligence and perspective toward problem solving. There is a potential to utilize team based approach to develop new models in universities.

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Appendix A: The steady-state model FORTRAN source code

w2_37_win.f90

```
! CE-QUAL-W2 computations
INTEGER(4) FUNCTION CE_QUAL_W2 (DLG)

! IVF/CVF specific code

USE DFLOGM; USE MSCLIB; USE DFWIN, RENAMED => DLT;

!DEC$ATTRIBUTES STDCALL :: ce_qual_w2
!DEC$ATTRIBUTES REFERENCE :: Dlg
USE IFPORT          ! to get current working directory
USE MAIN
USE GLOBAL;   USE NAMESC; USE GEOMC; USE LOGICC; USE PREC; USE SURFHE; USE KINETIC;
USE SHADEC; USE EDDY
USE STRUCTURES; USE TRANS; USE TVDC; USE SELWC; USE GDAYC; USE SCREENC; USE TDGAS;
USE RSTART
USE MACROPHYTEC; USE POROSITYC; USE ZOOPLANKTONC
USE INITIALVELOCITY; USE ENVIRPMOD
USE BIOENERGETICS
! include "omp_lib.h"    ! OPENMP directive to adjust the # of processors TOGGLE FOR DEBUG

IMPLICIT NONE

EXTERNAL RESTART_OUTPUT
TYPE (DIALOG) :: DLG
INTEGER      :: RESULT, KTMAX
REAL        :: DEPTH, XAREA, WSURF !XAREA WX5/23/13

!*****
!*****
!**                               **
!***** Task 1: Inputs *****
!*****
!*****

INTEGER(4) length, istatus
character*255 dirc
! call omp_set_num_threads(4) ! set # of processors to NPROC Moved to INPUT subroutine

CALL GET_COMMAND_ARGUMENT(1,DIRC,LENGTH,ISTATUS)
DIRC=TRIM(DIRC)

! IF(ISTATUS.NE.0)WRITE(*,*)'GET_COMMAND_ARGUMENT FAILED: STATUS=',ISTATUS

IF(LENGTH /= 0)THEN
  ISTATUS=CHDIR(DIRC)
  SELECT CASE(ISTATUS)
    CASE(2) ! ENOENT
      WRITE(*,*)'The directory does not exist:',DIRC
    CASE(20) ! ENOTDIR
      WRITE(*,*)'This is not a directory:', DIRC
    CASE(0) ! NO ERROR
  END SELECT
ENDIF
```

```

MODDIR = FILE$CURDRIVE      ! GET CURRENT DIRECTORY
LENGTH = GETDRIVEDIRQQ(MODDIR)

! open ancillary control file for fish bioenergetics !mlm bioexp
BIOEXP = .FALSE.           ! INITIALIZE LOGICAL VARIABLE THIS IS READ IN THE CONTROL FILE
OPEN (1222,FILE='W2_con_anc.npt',status='old', IOSTAT=I)
IF (I /= 0) THEN
  FISHBIO = .FALSE.
ELSE
  FISHBIO = .TRUE.
END IF
IF(FISHBIO)THEN
  DO II = 1,16
    READ(1222,'(A8)') BIOC ! DUMMY VARIABLE AT THIS POINT FIX THIS
  END DO
ENDIF

! Open control file
IOPENFISH=0
OPEN (CON,FILE=CONFN,STATUS='OLD',IOSTAT=I)
IF (I /= 0) THEN
  TEXT = 'Could not open w2_con.npt'
  GO TO 240
END IF

CALL INPUT
RESTART_IN = RSIC == '  ON'.OR. RESTART_PUSHED
! Restart data
IF (RESTART_PUSHED) RSIFN = 'rso.opt'

JDAY = TMSTRT
IF (RESTART_IN) THEN
  VERT_PROFILE = .FALSE.
  LONG_PROFILE = .FALSE.
  OPEN (RSI,FILE=RSIFN,FORM='UNFORMATTED',STATUS='OLD')
  READ (RSI) NIT, NV, KMIN, IMIN, NSPRF, CMBRT, ZMIN, IZMIN, START, CURRENT
  READ (RSI) DLTDP, SNPDP, TSRDP, VPLDP, PRFPD, CPLDP, SPRDP, RSODP, SCRDP, FLXDP,
WDODP
  READ (RSI) JDAY, ELTM, ELTMF, DLT, DLTAV, DLTS, MINDLT, JDMIN, CURMAX
  READ (RSI) NXTMSN, NXTMTS, NXTMPR, NXTMCP, NXTMVP, NXTMRS, NXTMSC, NXTMSP,
NXTMFL, NXTMWD
  READ (RSI) VOLIN, VOLOUT, VOLUH, VOLDH, VOLPR, VOLTRB, VOLDT, VOLWD, VOLEV,
VOLSBR, VOLTR, VOLSR
  READ (RSI) TSSEV, TSSPR, TSSTR, TSSDT, TSSWD, TSSIN, TSSOUT, TSSS, TSSB, TSSICE
  READ (RSI) TSSUH, TSSDH, TSSUH2, TSSDH2, CSSUH2, CSSDH2, VOLUH2, VOLDH2, QUH1
  READ (RSI) ESB, ETBR, EBRI
  READ (RSI) Z, SZ, ELWS, SAVH2, SAVHR, H2
  READ (RSI) KTWB, KTI, SKTI, SBKT
  READ (RSI) ICE, ICETH, CUF, QSUM
  READ (RSI) U, W, SU, SW, AZ, SAZ, DLTLM
  READ (RSI) T1, T2, C1, C2, C1S, EPD, SED, KFS, CSSK
  READ (RSI) SEDC, SEDN, SEDP, ZOO, CD ! mlm 10/06
  READ (RSI) sdkv ! cb 11/30/06
  read (rsi) tke ! sw 10/4/07
  if(envirpc == '  ON')THEN

```

```

allocate(cc_e(NCT),c_int(NCT),c_top(NCT),cd_e(NDC),cd_int(NDC),cd_top(NDC),c_avg(NCT),cd_avg(NDC),cn_e(
NCT),cdn_e(NDC))
cc_e=' '
c_int=0.0
c_top=0.0
cd_e=' '
cd_int=0.0
cd_top=0.0
c_avg=0.0
cd_avg=0.0
cn_e=0.0
cdn_e=0.0
NAC_E=0
NACD_E=0
open(CONE,file='w2_envirprf.npt',status='old')
READ (CONE,'(/8X,I8)') numclass
Read (CONE,'(/8x,2(5x,a3,f8.3,f8.3))') VEL_VPR, VEL_INT, VEL_TOP,TEMP_VPR,TEMP_INT,TEMP_TOP
READ (CONE,'(/(8X,(5X,A3,F8.0,F8.0)))') (CC_E(JC), C_INT(JC), C_TOP(JC), JC=1,NCT)
READ (CONE,'(/(8X,(5X,A3,F8.0,F8.0)))') (CD_E(JD),CD_INT(JD), CD_TOP(JD), JD=1,NDC)
close(CONE)

DO JC=1,NCT
IF (CC_E(JC).EQ.' ON') THEN
NAC_E = NAC_E+1
CN_E(NAC_E) = JC
END IF
End DO
DO JD=1,NDC
IF (CD_E(JD).EQ.' ON') THEN
NACD_E = NACD_E+1
CDN_E(NACD_E) = JD
END IF
End DO

allocate
(c_cnt(NCT),cd_cnt(NDC),c_class(NCT,numclass),cd_class(NDC,numclass),c_tot(NCT),cd_tot(NDC),t_class(numcla
ss),v_class(numclass),c_sum(NCT),cd_sum(NDC))
allocate (conc_c(NCT,numclass),conc_cd(NDC,numclass))

READ(RSI)T_CLASS,V_CLASS,C_CLASS,CD_CLASS,T_TOT,T_CNT,SUMVOLT,V_CNT,V_TOT,C_TOT,C_C
NT,CD_TOT,CD_CNT

ENDIF
IF(NPI > 0)READ(RSI)YS,VS,VST,YST,DTP,QOLD
CLOSE (RSI)
ENDIF
CE_QUAL_W2 = 1
CALL INIT

DO JW=1,NWB
DO JB=BS(JW),BE(JW)
DO I=US(JB),DS(JB)
! E(I)=EROUGH(JW)
DZ(:,I)=DZM(JW)
ENDDO
ENDDO
ENDDO
!WX 11/27/2012

```



```

! determining initial horizontal velocities and water levels
once_through=.true.
IF(inituwl == ' ON')init_vel=.true.
if(.not. restart_in)then
  if(init_vel)then
    allocate (qssi(imx),loop_branch(nbr),elwss(imx),uavg(imx))
    elwss=elws
    call initial_water_level
!   deALLOCATE (ESTR,WSTR,QSTR,KTSW,KBSW,SINKC,POINT_SINK,QNEW)
!   deALLOCATE (ESTR,WSTR,QSTR,KTSW,KBSW,SINKC,POINT_SINK,QNEW,tavg, tavgw)
    b=bsave
    call initgeom
    call initcond !WX 5/7/13
    call initial_u_velocity
    open(999,file='init_wl_u_check.dat',status='unknown')
    write(999,(' i elws_calc qssi u depth elws_init'))
    DO JW=1,NWB
      DO JB=BS(JW),BE(JW)
        IU = CUS(JB)
        ID = DS(JB)
        do i=iu,id
          depth=elws(i)-el(kbi(i)+1,i)
          write(999,'(i8,f8.3,f8.2,f8.3,2f8.2)')i,elws(i),qssi(i),u(kt,i),depth,elwss(i)
        end do
      end do
    end do
    close(999)
    !deallocate (qssi,loop_branch,elwss) WX 11/29/12
  end if
end if
! DEALLOCATE (ESTRT,KBSWT,KTSWT,WSTRT,SINKCT)
! end w2-ressim

IF (.NOT. RESTART_IN) THEN
  LINE = CTIME(1:2)/' ':'/CCTIME(3:4)/' ':'/CCTIME(5:6)
  RESULT = DLGSET (DLG,STARTING_TIME,TRIM(LINE))
time
  RESULT = DLGSET (DLG,STATUS,'Executing')
  CURRENT = 0.0
ELSE
  CALL CPU_TIME (CURRENT)
END IF

CALL OUTPUTINIT
IF (RESTART_IN) THEN
  DO JW=1,NWB
    IF (SCREEN_OUTPUT(JW))CALL SCREEN_UPDATE(DLG)
  ENDDO
ENDIF
! ngraph=0
! DO JH=1,NHY
! IF (HYDRO_PLOT(JH))ngraph=ngraph+1
! END DO
! DO JC=1,NCT
! IF (CONSTITUENT_PLOT(JC)) ngraph=ngraph+1
! END DO
! DO JD=1,NDC
! IF (DERIVED_PLOT(JD))ngraph=ngraph+1
! END DO

```

!Display starting

!Display execution status

```

! CALL GRAPH(ngraph)
! DO JH=1,NHY
!     IF (HYDRO_PLOT(JH)) CALL GRAPH_OPEN (JH,HYD(:,JH), HNAME(JH),
HYMIN(JH),HYMAX(JH),1.0, LNAME(JH))
! END DO
! DO JC=1,NCT
!     IF (CONSTITUENT_PLOT(JC)) CALL GRAPH_OPEN (JH+JC,C2(:,JC), CNAME(JC), CMIN(JC),
CMAX(JC), CMULT(JC), LNAME(JH+JC))
! END DO
! DO JD=1,NDC
!     IF (DERIVED_PLOT(JD)) CALL GRAPH_OPEN
(JH+JC+JD,CD(:,JD),CDNAME(JD),CDMIN(JD),CDMAX(JD),CDMULT(JD),LNAME(JH+JC+JD))
! END DO
! INITIALIZE_GRAPH = .FALSE.

```

```

IF (.NOT. RESTART_IN) CALL CPU_TIME (START)

```

```

if (macrophyte_on.and.constituents) call porosity
IF(SELECTC == ' ON')CALL SELECTIVEINIT ! new subroutine for selecting water temperature target
IF(AERATEC == ' ON'.and. oxygen_demand)CALL AERATE

```

```

!*****
!*****
!** Task 2: Calculations **
!*****
!*****

```

```

DO WHILE (.NOT. END_RUN.AND. .NOT. STOP_PUSHED)
  IF (JDAY >= NXTVD) CALL READ_INPUT_DATA (NXTVD)
  CALL INTERPOLATE_INPUTS
  DLTVD = (NXTVD-JDAY)*DAY
  DLT = MIN(DLT,DLTVD+1.0)
  DLTS1 = DLT
  IF (DLT <= DLTVD+0.999) THEN
    DLTS = DLT
  ELSE
    KLOC = 1
    ILOC = 1
  END IF

```

```

210 continue ! timestep violation entry point
IF(SELECTC == ' ON')CALL SELECTIVE ! new subroutine for selecting water temperature target
! IF(NIT/=0) THEN
! CALL initial_water_level !WX 11/11/2012
! END IF
CALL initial_water_level !WX 11/11/2012
!CALL initial_u_velocity !WX 1/14/2013

```

```

CALL HYDROINOUT
!***** Surface elevations: Z calculation from ELWS
!*****
DO JW=1,NWB
  KT = KTWB(JW)
  DO JB=BS(JW),BE(JW)
    IU = CUS(JB)
    ID = DS(JB)
    DO I=IU,ID ! WX 2/28/13
      DO WHILE (EL(KTI(I),I) > ELWS(I))
        KTI(I) = KTI(I)+1
      END DO
    END DO
  END DO
END DO

```

```

      KTI(I) = MAX(KTI(I)-1,2)
      KTMAX = MAX(2,KTI(I))
      KTWB(JW) = MAX(KTMAX,KTWB(JW))

      Z(I) = (EL(KT,I)-ELWS(I))/COSA(JB)
      ZMIN(JW) = MAX(ZMIN(JW),Z(I))
    END DO
  END DO
END DO
!*****
!*****
!**                               Task 2.2: Hydrodynamic calculations                               **
!*****
!*****

      DO JW=1,NWB
      KT = KTWB(JW)
      DO JB=BS(JW),BE(JW)
      IU = CUS(JB)
      ID = DS(JB)

!*****
!*****
!**                               Task 2.2.1: Boundary concentrations, temperatures, and densities                               **
!*****
!*****

      IUT = IU
      IDT = ID
      IF (UP_FLOW(JB)) THEN
      IF (.NOT. INTERNAL_FLOW(JB)) THEN
      DO K=KT,KB(IU)
      IF (QIND(JB)+QINSUM(JB).GT.0.0) THEN
      TIN(JB) = (TINSUM(JB) + *QINSUM(JB)+TIND(JB)
      *QIND(JB))/(QIND(JB)+QINSUM(JB))
      CIN(CN(1:NAC),JB) =
      MAX((CINSUM(CN(1:NAC),JB)*QINSUM(JB)+CIND(CN(1:NAC),JB)*QIND(JB))/(QIND(JB)+QINSUM(JB)),&
      0.0)
      T1(K,IU-1) = TIN(JB)
      T2(K,IU-1) = TIN(JB)
      C1S(K,IU-1,CN(1:NAC)) = CIN(CN(1:NAC),JB)
      QIN(JB) = QIND(JB)+QINSUM(JB)
      ELSE
      QIN(JB) = 0.0
      TIN(JB) = TIND(JB)
      T1(K,IU-1) = TIND(JB)
      T2(K,IU-1) = TIND(JB)
      C1S(K,IU-1,CN(1:NAC)) = CIND(CN(1:NAC),JB)
      END IF
      END DO
      ELSE IF (.NOT. DAM_INFLOW(JB)) THEN
      IF (JBUH(JB) >= BS(JW) .AND. JBUH(JB) <= BE(JW)) THEN
      TIN(JB) = T1(KT,UHS(JB))
      CIN(CN(1:NAC),JB) = MAX(C1S(KT,UHS(JB),CN(1:NAC)),0.0)
      FORALL(K=KT:KB(IU)) !DO K=KT,KB(IU)
      T1(K,IU-1) = T1(K,UHS(JB))
      T2(K,IU-1) = T1(K,UHS(JB))
      C1S(K,IU-1,CN(1:NAC)) = C1S(K,UHS(JB),CN(1:NAC))
      C1(K,IU-1,CN(1:NAC)) = C1S(K,UHS(JB),CN(1:NAC))
      C2(K,IU-1,CN(1:NAC)) = C1S(K,UHS(JB),CN(1:NAC))
      !TC 08/03/04

```

```

END FORALL          !DO
ELSE
  CALL UPSTREAM_WATERBODY
  TIN(JB)           = T1(KT,IU-1)
  CIN(CN(1:NAC),JB) = MAX(C1(KT,IU-1,CN(1:NAC)),0.0)
END IF
ELSE
  TIN(JB)           = TINSUM(JB)
  QIN(JB)           = QINSUM(JB)
  CIN(CN(1:NAC),JB) = MAX(CINSUM(CN(1:NAC),JB),0.0)
  DO K=KT,KB(ID)
    T1(K,IU-1)       = TIN(JB)
    T2(K,IU-1)       = TIN(JB)
    C1S(K,IU-1,CN(1:NAC)) = CIN(CN(1:NAC),JB)
  END DO
END IF
END IF
IF (DN_FLOW(JB)) THEN
  DO K=KT,KB(ID)
    T1(K,ID+1)       = T2(K,ID)
    T2(K,ID+1)       = T2(K,ID)
    C1S(K,ID+1,CN(1:NAC)) = C1S(K,ID,CN(1:NAC))
  END DO
END IF
IF (UP_HEAD(JB)) THEN
  IUT = IU-1
  IF (UH_INTERNAL(JB)) THEN
    IF (JBUH(JB) >= BS(JW) .AND. JBUH(JB) <= BE(JW)) THEN
      DO K=KT,KB(IUT)
        RHO(K,IUT)    = RHO(K,UHS(JB))
        T1(K,IUT)     = T2(K,UHS(JB))
        T2(K,IUT)     = T2(K,UHS(JB))
        C1S(K,IUT,CN(1:NAC)) = C1S(K,UHS(JB),CN(1:NAC))
        C1(K,IUT,CN(1:NAC)) = C1S(K,UHS(JB),CN(1:NAC))
        C2(K,IUT,CN(1:NAC)) = C1S(K,UHS(JB),CN(1:NAC))
      END DO
    ELSE
      CALL UPSTREAM_WATERBODY
    END IF
    DO K=KT,KB(IUT)
      RHO(K,IUT) = DENSITY(T2(K,IUT),DMAX1(TDS(K,IUT),0.0D0),DMAX1(TISS(K,IUT),0.0D0))
    END DO
  ELSE IF (UH_EXTERNAL(JB)) THEN
    DO K=KT,KB(IUT)
      RHO(K,IUT)    = DENSITY(TUH(K,JB),DMAX1(TDS(K,IUT),0.0D0),DMAX1(TISS(K,IUT),0.0D0))
      T1(K,IUT)     = TUH(K,JB)
      T2(K,IUT)     = TUH(K,JB)
      C1S(K,IUT,CN(1:NAC)) = CUH(K,CN(1:NAC),JB)
      C1(K,IUT,CN(1:NAC)) = CUH(K,CN(1:NAC),JB)
      C2(K,IUT,CN(1:NAC)) = CUH(K,CN(1:NAC),JB)
    END DO
  END IF
END IF
IF (DN_HEAD(JB)) THEN
  IDT = ID+1
  IF (DH_INTERNAL(JB)) THEN
    IF (JBDH(JB) >= BS(JW) .AND. JBDH(JB) <= BE(JW)) THEN
      DO K=KT,KB(IDT)
        RHO(K,IDT)    = RHO(K,DHS(JB))
        T1(K,IDT)     = T2(K,DHS(JB))

```

```

      T2(K,IDT)      = T2(K,DHS(JB))
      C1S(K,IDT,CN(1:NAC)) = C1S(K,DHS(JB),CN(1:NAC))
      C1(K,IDT,CN(1:NAC)) = C1S(K,DHS(JB),CN(1:NAC))
      C2(K,IDT,CN(1:NAC)) = C1S(K,DHS(JB),CN(1:NAC))
    END DO
  ELSE
    CALL DOWNSTREAM_WATERBODY
  END IF
  DO K=KT,KB(ID)
    RHO(K,IDT) = DENSITY(T2(K,IDT),DMAX1(TDS(K,IDT),0.0D0),DMAX1(TISS(K,IDT),0.0D0))
  END DO
  ELSE IF (DH_EXTERNAL(JB)) THEN
    DO K=KT,KB(IDT)
      RHO(K,IDT)      = DENSITY(TDH(K,JB),DMAX1(TDS(K,IDT),0.0D0),DMAX1(TISS(K,IDT),0.0D0))
      T1(K,IDT)      = TDH(K,JB)
      T2(K,IDT)      = TDH(K,JB)
      C1S(K,IDT,CN(1:NAC)) = CDH(K,CN(1:NAC),JB)
      C1(K,IDT,CN(1:NAC)) = CDH(K,CN(1:NAC),JB)
      C2(K,IDT,CN(1:NAC)) = CDH(K,CN(1:NAC),JB)
    END DO
  END IF
END IF

!!*****
***** !WX 11/11/2012
!!**                               **
***** Task 2.2.2: Momentum terms *****
*****

!
!!***** Density pressures
!
!   DO I=IUT,IDT
!     DO K=KT,KB(I)
!       P(K,I) = P(K-1,I)+RHO(K,I)*G*H(K,JW)*COSA(JB)
!     END DO
!   END DO
!
!!***** Horizontal density gradients
!
!   DO I=IUT,IDT-1
!     HDG(KT,I) = DLXRHO(I)*(BKT(I)+BKT(I+1))*0.5D0*H(KT,JW)*(P(KT,I+1)-P(KT,I))
!     DO K=KT+1,KBMIN(I)
!       HDG(K,I) = DLXRHO(I)*BHR2(K,I)*((P(K-1,I+1)-P(K-1,I))+P(K,I+1)-P(K,I))
!     END DO
!   END DO
!
!!***** Adjusted wind speed and surface wind shear drag coefficient
!
!   DO I=IU-1,ID+1
!     WIND10(I) = WIND(JW)*WSC(I)*DLOG(10.0D0/Z0(JW))/DLOG(WINDH(JW)/Z0(JW))   ! older version
z0=0.01      ! SW 11/28/07
!     FETCH(I) = FETCHD(I,JB)
!     IF (COS(PHI(JW)-PHI0(I)) < 0.0) FETCH(I) = FETCHU(I,JB)
!     IF (FETCH(I) <= 0.0) FETCH(I) = DLX(I)
!     IF (FETCH_CALC(JW)) THEN
!       ZB      = 0.8D0*DLOG(FETCH(I)*0.5D0)-1.0718D0
!       WIND10(I) = WIND10(I)*(5.0D0*ZB+4.6052D0)/(3.0D0*ZB+9.2103D0)
!     END IF
!
!     IF(WIND10(I) >= 15.0)THEN          ! SW 1/19/2008

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```

!      CZ(I) = 0.0026D0
!      ELSEIF(WIND10(I) >= 4.0) THEN
!      CZ(I) = 0.0005D0*DSQRT(WIND10(I))
!      ELSEIF(WIND10(I) >= 0.5) THEN
!      CZ(I) = 0.0044D0*WIND10(I)**(-1.15D0)
!      ELSE
!      CZ(I) = 0.01D0
!      ENDIF
!
!!      CZ(I) = 0.0
!!      IF (WIND10(I) >= 1.0) CZ(I) = 0.0005*SQRT(WIND10(I))
!!      IF (WIND10(I) >= 4.0) CZ(I) = 0.0005*SQRT(WIND10(I))
!!      IF (WIND10(I) >= 15.0) CZ(I) = 0.0026
!      END DO
!
!!***** Longitudinal and lateral surface wind shear and exponential decay
!
!      DO I=IUT,IDT-1
!      WSHX(I) = CZ(I)*WIND10(I)**2*RHOA/RHOW* DCOS(PHI(JW)-PHI0(I))* ICESW(I)
!      WSHY(I) = CZ(I)*WIND10(I)**2*RHOA/RHOW*DABS(DSIN(PHI(JW)-PHI0(I)))*ICESW(I)
!      WWT = 0.0
!      IF (WIND10(I) /= 0.0) WWT = 6.95D-2*(FETCH(I)**0.233D0)*WIND10(I)**0.534D0
!      DFC = -8.0D0*PI*PI/(G*WWT*WWT+NONZERO)
!      DO K=KT,KBMIN(I)
!      DECAY(K,I) = DEXP(DMAX1(DFC*DEPTHB(K,I),-30.0D0))
!      END DO
!
!!***** Branch inflow lateral shear and friction
!
!      DO JJB=1,NBR
!      IF (I == UHS(JJB) .AND. .NOT. INTERNAL_FLOW(JJB)) THEN
!      BETABR = (PHI0(I)-PHI0(US(JJB)))
!      IF (JJB >= BS(JW) .AND. JJB <= BE(JW)) THEN
!      DO K=KT,KBMIN(I)
!      IF (U(K,US(JJB)) < 0.0) THEN
!      UXBR(K,I) = UXBR(K,I)+ABS(U(K,US(JJB)))*DCOS(BETABR) *VOLUH2(K,JJB)/(DLT*DLX(I))
!      UYBR(K,I) = UYBR(K,I) +ABS(DSIN(BETABR))*ABS(VOLUH2(K,JJB))/DLT
!      END IF
!      END DO
!      ELSE
!      CALL UPSTREAM_BRANCH
!      END IF
!      END IF
!      IF (I == DHS(JJB)) THEN
!      BETABR = (PHI0(I)-PHI0(DS(JJB)))
!      IF (I == US(JB) .AND. UHS(JB) /= DS(JJB)) THEN
!      IF (JJB >= BS(JW) .AND. JJB <= BE(JW)) THEN
!      DO K=KT,KBMIN(I)
!      IF (U(K,DS(JJB)) >= 0.0) THEN
!      UXBR(K,I) = UXBR(K,I)+U(K,DS(JJB))* DCOS(BETABR) *VOLDH2(K,JJB)/(DLT*DLX(I))
!      UYBR(K,I) = UYBR(K,I) +ABS(DSIN(BETABR))*VOLDH2(K,JJB)/DLT
!      END IF
!      END DO
!      ELSE
!      CALL DOWNSTREAM_BRANCH
!      END IF
!      ELSE IF (I /= US(JB)) THEN
!      IF (JJB >= BS(JW) .AND. JJB <= BE(JW)) THEN
!      DO K=KT,KBMIN(I)
!      IF (U(K,DS(JJB)) >= 0.0) THEN

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```

!          UXBR(K,I) = UXBR(K,I)+U(K,DS(JJB))* DCOS(BETABR) *VOLDH2(K,JJB)/(DLT*DLX(I))
!          UYBR(K,I) = UYBR(K,I)          +ABS(DSIN(BETABR))*VOLDH2(K,JJB)/DLT
!      END IF
!      END DO
!      ELSE
!          CALL DOWNSTREAM_BRANCH
!      END IF
!      END IF
!      END IF
!      END DO
!      DO K=KT,KBMIN(I)
!          FRICBR(K,I) = (FI(JW)/8.0D0)*RHO(K,I)*(UYBR(K,I)/(DLX(I)*H2(K,I)))**2
!      END DO
!  END DO
!
!!***** Vertical eddy viscosities/diffusivities
!      FIRSTI(JW) = IUT
!          LASTI(JW) = IDT
!      DO I=IUT,IDT-1
!          CALL CALCULATE_AZ
!          IF (KBMIN(I) <= KT+1 .AND. KB(I) > KBMIN(I)) THEN
!              AZ(KBMIN(I),I) = AZMIN
!              DZ(KBMIN(I),I) = DZMIN
!          END IF
!      END DO
!      IF (AZC(JW) == ' TKE'.OR.AZC(JW) == ' TKE1') THEN
!          AZT(:,IDT-1) = AZ(:,IDT-1)
!          DO I=IUT,IDT-2
!              DO K=KT,KBMIN(I)
!                  AZT(K,I) = 0.5*(AZ(K,I)+AZ(K,I+1))
!              END DO
!              AZ(KBMIN(I),I) = AZMIN      !SG 10/4/07 SW 10/4/07
!          END DO
!          AZ(KT:KMX-1,IUT:IDT-1)=AZT(KT:KMX-1,IUT:IDT-1)
!      END IF
!      DO JWR=1,NIW
!          IF (WEIR_CALC) AZ(KTWR(JWR)-1:KBWR(JWR),IWR(1:NIW)) = 0.0
!      END DO
!
!!***** Average eddy diffusivities
!
!      IF(AZC(JW) /= ' TKE'.AND.AZC(JW) /= ' TKE1')THEN
!          DZ(KT:KB(IDT)-1,IDT) = DZT(KT:KB(IDT)-1,IDT-1)  ! DZT is only used for non-TKE algorithms
!      ELSE
!          DZ(KT:KB(IDT)-1,IDT) = DZ(KT:KB(IDT)-1,IDT-1)
!      ENDIF
!      DO I=IUT,IDT-1
!          DO K=KT,KB(I)-1
!              IF (K >= KBMIN(I)) THEN
!                  IF (KB(I-1) >= KB(I) .AND. I /= IUT) THEN
!                      DZ(K,I) = DZ(K,I-1)
!                  ELSE
!                      DZ(K,I) = DZMIN
!                  END IF
!              ELSE
!                  IF(AZC(JW) /= ' TKE'.AND.AZC(JW) /= ' TKE1')THEN
!                      IF(I == IUT)THEN      ! SW 10/20/07
!                          DZ(K,I)=DZT(K,I)
!                      ELSE

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```

!          DZ(K,I) = (DZT(K,I)+DZT(K,I-1))*0.5D0      ! SW 10/20/07 (DZT(K,I)+DZT(K+1,I))*0.5 ! FOR
NON-TKE ALGORITHMS, AVERAGE DZ FROM EDGES TO CELL CENTERS
!          ENDIF
!          ENDIF
!          END IF
!          END DO
!          END DO
!
!! Hypolimnetic aeration
!
!          IF(AERATEC == '  ON' .and. oxygen_demand)CALL DZAERATE
!
!!***** Density inversions
!
!          DO I=IUT,IDT
!            DO K=KT,KB(I)-1
!              DZQ(K,I) = MIN(1.0D-2,DZ(K,I))              !MIN(1.0E-4,DZ(K,I)) No reason to limit DZ in
rivers/estuaries-used in ULTIMATE scheme
!              IF (RHO(K,I) > RHO(K+1,I)) DZ(K,I) = DZMAX
!            END DO
!          END DO
!
!!***** Wind, velocity, and bottom shear stresses @ top and bottom of cell
!
!          SB(:,IUT:IDT-1) = 0.0
!          DO I=IUT,IDT-1
!            ST(KT,I) = WSHX(I)*BR(KTI(I),I)
!            DO K=KT+1,KBMIN(I)
!              ST(K,I) = WSHX(I)*DECAY(K-1,I)*BR(K,I)
!              IF (.NOT. IMPLICIT_VISC(JW)) ST(K,I) = ST(K,I)+AZ(K-1,I)*(BR(K-1,I)+BR(K,I))*0.5D0*(U(K-1,I)-
U(K,I))/((AVH2(K-1,I)    &
!                  +AVH2(K-1,I+1))*0.5D0)
!            END DO
!            GC2 = 0.0
!            IF (FRIC(I) /= 0.0) GC2 = G/(FRIC(I)*FRIC(I))
!
!            HRAD=BHR2(KT,I)/(BR(KTI(I),I)-BR(KT+1,I)+2.0D0*AVHR(KT,I))
!            IF(MACROPHYTE_ON.AND.MANNINGS_N(JW))THEN
!              CALL MACROPHYTE_FRICTION(HRAD,FRIC(I),EFFRIC,KT,I)
!              GC2=G*EFFRIC*EFFRIC/HRAD**0.3333333D0
!            ELSE IF(.NOT.MACROPHYTE_ON.AND.MANNINGS_N(JW))THEN
!              GC2=G*FRIC(I)*FRIC(I)/HRAD**0.3333333D0
!            END IF
!            IF (ONE_LAYER(I)) THEN
!              SB(KT,I) = ST(KT+1,I)+GC2*(BR(KTI(I),I)+2.0D0*AVHR(KT,I))*U(KT,I)*DABS(U(KT,I))
!            ELSE
!              SB(KT,I) = GC2*(BR(KTI(I),I)-BR(KT+1,I)+2.0D0*AVHR(KT,I))*U(KT,I)*DABS(U(KT,I))
!            DO K=KT+1,KBMIN(I)-1
!              HRAD=(BHR2(K,I)/(BR(K,I)-BR(K+1,I)+2.0D0*H(K,JW)))
!              IF(MACROPHYTE_ON.AND.MANNINGS_N(JW))THEN
!                CALL MACROPHYTE_FRICTION(HRAD,FRIC(I),EFFRIC,K,I)
!                GC2=G*EFFRIC*EFFRIC/HRAD**0.3333333D0
!              ELSE IF(.NOT.MACROPHYTE_ON.AND.MANNINGS_N(JW))THEN
!                GC2=G*FRIC(I)*FRIC(I)/HRAD**0.3333333D0
!              END IF
!              SB(K,I) = GC2*(BR(K,I)-BR(K+1,I)+2.0D0*H(K,JW))*U(K,I)*DABS(U(K,I))
!            END DO
!            IF (KT /= KBMIN(I)) THEN
!              HRAD=(BHR2(KBMIN(I),I)/(BR(KBMIN(I),I)+2.0D0*H(KBMIN(I),JW)))
!              IF(MACROPHYTE_ON.AND.MANNINGS_N(JW))THEN

```



```

!      CALL MACROPHYTE_FRICTION(HRAD,FRIC(I),EFFRIC,KBMIN(I),I)
!      GC2=G*EFFRIC*EFFRIC/HRAD**0.3333333D0
!      ELSE IF(.NOT.MACROPHYTE_ON.AND.MANNINGS_N(JW))THEN
!      GC2=G*FRIC(I)*FRIC(I)/HRAD**0.3333333D0
!      END IF
!
!      IF (KBMIN(I) /= KB(I)) THEN
!
!                               SB(KBMIN(I),I)  =  GC2*(BR(KBMIN(I),I)-
BR(KBMIN(I)+1,I)+2.0D0*H2(K,I))*U(KBMIN(I),I)*DABS(U(KBMIN(I),I))
!      ELSE
!      SB(KBMIN(I),I) = GC2*(BR(KBMIN(I),I)+2.0D0*H2(K,I))*U(KBMIN(I),I)*DABS(U(KBMIN(I),I))
!      END IF
!      END IF
!      END IF
!      DO K=KT,KBMIN(I)-1
!      SB(K,I) = SB(K,I)+ST(K+1,I)
!      END DO
!
!      SB(KBMIN(I),I)  =  SB(KBMIN(I),I)+WSHX(I)*DECAY(KBMIN(I),I)*(BR(KBMIN(I)-
1,I)+BR(KBMIN(I),I))*0.5D0
!      END DO
!
!!***** Horizontal advection of momentum
!
!      DO I=IU,ID-1
!      DO K=KT,KBMIN(I)
!      UDR  = (1.0D0+DSIGN(1.0D0,(U(K,I)+U(K,I+1))*0.5D0))*0.5D0
!      UDL  = (1.0D0+DSIGN(1.0D0,(U(K,I)+U(K,I-1))*0.5D0))*0.5D0
!      ADMX(K,I) = (BH2(K,I+1)*(U(K,I+1)+U(K,I))*0.5D0*(UDR*U(K,I)+(1.0-UDR)*U(K,I+1))-
BH2(K,I)*(U(K,I)+U(K,I-1))) &
!      *0.5D0*(UDL*U(K,I-1)+(1.0D0-UDL)*U(K,I)))/DLXR(I)
!      END DO
!      END DO
!
!!***** Horizontal dispersion of momentum
!
!      DO I=IU,ID-1
!      DO K=KT,KBMIN(I)
!      DM(K,I) = AX(JW)*(BH2(K,I+1)*(U(K,I+1)-U(K,I))/DLX(I+1)-BH2(K,I)*(U(K,I)-U(K,I-
1))/DLX(I))/DLXR(I)
!      END DO
!      END DO
!
!!***** Vertical advection of momentum
!
!      DO I=IU,ID-1
!      DO K=KT,KB(I)-1
!      AB  = (1.0D0+DSIGN(1.0D0,(W(K,I+1)+W(K,I))*0.5D0))*0.5D0
!      ADMZ(K,I) = (BR(K,I)+BR(K+1,I))*0.5D0*(W(K,I+1)+W(K,I))*0.5D0*(AB*U(K,I)+(1.0-AB)*U(K+1,I))
!      END DO
!      END DO
!
!!***** Gravity force due to channel slope
!
!      DO I=IU-1,ID
!      GRAV(KT,I) = AVHR(KT,I)*(BKT(I)+BKT(I+1))*0.5D0*G*SINAC(JB)
!      DO K=KT+1,KB(I)
!      GRAV(K,I) = BHR2(K,I)*G*SINAC(JB)
!      END DO
!      END DO
!

```

```

!!*****
*****
!!** Task 2.2.3: Water surface elevation **
!!*****
*****
!
!!***** Tridiagonal coefficients
!
! BHRHO(IU-1:ID+1) = 0.0D0; D(IU-1:ID+1) = 0.0D0; F(IU-1:ID+1) = 0.0D0
! DO I=IU,ID-1
! DO K=KT,KBMIN(I)
! BHRHO(I) = BHRHO(I)+(BH2(K,I+1)/RHO(K,I+1)+BH2(K,I)/RHO(K,I))
! END DO
! DO K=KT,KB(I)
! D(I) = D(I)+(U(K,I)*BHR2(K,I)-U(K,I-1)*BHR2(K,I-1)-QSS(K,I)+(UXBR(K,I)-UXBR(K,I-1))*DLT)
! F(I) = F(I)+(-SB(K,I)+ST(K,I)-ADMX(K,I)+DM(K,I)-HDG(K,I)+GRAV(K,I))
! END DO
! END DO
!
!!***** Boundary tridiagonal coefficients
!
! D(IU) = 0.0D0
! DO K=KT,KB(IU)
! D(IU) = D(IU)+(U(K,IU)*BHR2(K,IU)-QSS(K,IU))+UXBR(K,IU)*DLT
! END DO
! IF (DN_FLOW(JB)) THEN
! DO K=KT,KB(ID)
! D(ID) = D(ID)-U(K,ID-1)*BHR2(K,ID-1)-QSS(K,ID)+(UXBR(K,ID)-UXBR(K,ID-1))*DLT+QOUT(K,JB)
! END DO
! END IF
! IF (UP_HEAD(JB)) THEN
! DO K=KT,KBMIN(IU-1)
! BHRHO(IU-1) = BHRHO(IU-1)+(BH2(K,IU)/RHO(K,IU)+BH2(K,IU-1)/RHO(K,IU-1))
! END DO
! DO K=KT,KB(IU)
! D(IU) = D(IU)-U(K,IU-1)*BHR2(K,IU-1)
! F(IU-1) = F(IU-1)-(-SB(K,IU-1)+ST(K,IU-1)+HDG(K,IU-1)-GRAV(K,IU-1))
! END DO
! END IF
! IF (DN_HEAD(JB)) THEN
! DO K=KT,KBMIN(ID)
! BHRHO(ID) = BHRHO(ID)+(BH2(K,ID+1)/RHO(K,ID+1)+BH2(K,ID)/RHO(K,ID))
! END DO
! DO K=KT,KB(ID)
! D(ID) = D(ID)+(U(K,ID)*BHR2(K,ID)-U(K,ID-1)*BHR2(K,ID-1)-QSS(K,ID))+UXBR(K,ID)-UXBR(K,ID-1))*DLT
! F(ID) = F(ID)+(-SB(K,ID)+ST(K,ID)-HDG(K,ID)+GRAV(K,ID))
! END DO
! END IF
! END DO
! END DO
DO JW=1,NWB
KT = KTWB(JW)
DO JB=BS(JW),BE(JW)
IU = CUS(JB)
ID = DS(JB)
!ELWS(IU-1) = ELWS(IU) !wx 2/28/13 !MOVE TO INITWL
!ELWS(ID+1) = ELWS(ID)
IF (INTERNAL_FLOW(JB) .AND. .NOT. DAM_INFLOW(JB)) THEN !TC
08/03/04

```

```

!     QIN(JB) = 0.0D0
!     DO K=KTWB(JWUH(JB)),KB(UHS(JB))
!         QIN(JB) = QIN(JB)+U(K,UHS(JB))*BHR2(K,UHS(JB))
!                                     !wx 2/13/13
!     END DO
!     QIN(JB) = QSSI(UHS(JB))    !!!!!this is wrong,need to find the upstream jb wx
!     !!!!!maybe here qssi should be directly used, because qin maybe lead back into calculation, and result in
mistakes.
!     END IF
!     IF (UP_FLOW(JB)) D(IU) = D(IU)-QIN(JB)
!
!!***** Surface elevations: Z calculation from ELWS
!!*****
!     DO I=IU,ID                                     ! WX 2/28/13
!         Z(I) = (EL(KT,I)-ELWS(I))/COSA(JB)
!         ZMIN(JW) = MAX(ZMIN(JW),Z(I))
!
!         DO WHILE (EL(KTI(I),ID+1) > ELWS(I)) ! "I" instead of "ID+1"
!             KTI(I) = KTI(I)+1
!         END DO
!
!         KTI(I) = MAX(KTI(I)-1,2)
!         KTMAX = MAX(2,KTI(I))
!         KTWB(JW) = MAX(KTMAX,KTWB(JW))
!     END DO
!
!!***** Boundary surface elevations
!
!     IF (UH_INTERNAL(JB)) THEN
!         Z(IU-1) = ((-EL(KTWB(JWUH(JB)),UHS(JB))+Z(UHS(JB))*COSA(JBUH(JB)))+EL(KT,IU-
1)+SINA(JB)*DLXR(IU-1))/COSA(JB)
!         ELWS(IU-1) = EL(KT,IU-1)-Z(IU-1)*COSA(JB)
!         KTI(IU-1) = 2
!         DO WHILE (EL(KTI(IU-1),IU-1) > ELWS(IU-1))
!             KTI(IU-1) = KTI(IU-1)+1
!         END DO
!         KTI(IU-1) = MAX(KTI(IU-1)-1,2)
!     END IF
!     IF (UH_EXTERNAL(JB)) Z(IU-1) = (EL(KT,IU-1)-(ELUH(JB)+SINA(JB)*DLX(IU)*0.5D0))/COSA(JB)
!     IF (DH_INTERNAL(JB)) THEN
!         Z(ID+1) = ((-EL(KTWB(JWDH(JB)),DHS(JB))+Z(DHS(JB))*COSA(JBDH(JB)))+EL(KT,ID+1))/COSA(JB)
!         ELWS(ID+1) = EL(KT,ID+1)-Z(ID+1)*COSA(JB)
!         KTI(ID+1) = 2
!         DO WHILE (EL(KTI(ID+1),ID+1) > ELWS(ID+1))
!             KTI(ID+1) = KTI(ID+1)+1
!         END DO
!         KTI(ID+1) = MAX(KTI(ID+1)-1,2)
!         IF (KTI(ID+1) > KB(ID)) THEN ! IF (KTI(ID+1) >= KB(ID)) THEN !wx 6/3/13
!             Z(ID+1) = Z(ID)-SLOPE(JB)*DLX(ID)/2.0D0
!             ELWS(ID+1) = EL(KT,ID+1)-Z(ID+1)*COSA(JB)
!             KTI(ID+1) = 2
!             DO WHILE (EL(KTI(ID+1),ID+1) > ELWS(ID+1))
!                 KTI(ID+1) = KTI(ID+1)+1
!             END DO
!             KTI(ID+1) = MAX(KTI(ID+1)-1,2)
!         END IF
!     END IF
!     IF (DH_EXTERNAL(JB)) Z(ID+1) = (EL(KT,ID+1)-(ELDH(JB)-SINA(JB)*DLX(ID)*0.5D0))/COSA(JB)
!
!!***** Implicit water surface elevation solution
!

```

```

!   FORALL(I=IU:ID)           !DO I=IU,ID
!   A(I) = -RHO(KT,I-1)*G*COSA(JB)*DLT*DLT* BHRHO(I-1)*0.5D0/DLXR(I-1)
!   C(I) = -RHO(KT,I+1)*G*COSA(JB)*DLT*DLT* BHRHO(I) *0.5D0/DLXR(I)
!   V(I) = RHO(KT,I) *G*COSA(JB)*DLT*DLT*(BHRHO(I) *0.5D0/DLXR(I)+BHRHO(I-1)*0.5D0/DLXR(I-
1))+DLX(I)*BI(KT,I)
!   D(I) = DLT*(D(I)+DLT*(F(I)-F(I-1)))+DLX(I)*BI(KT,I)*Z(I)
!   END FORALL           !DO
!   IF (UP_HEAD(JB)) D(IU) = D(IU)-A(IU)*Z(IU-1)
!   IF (DN_HEAD(JB)) D(ID) = D(ID)-C(ID)*Z(ID+1)
!   BTA(IU) = V(IU)
!   GMA(IU) = D(IU)
!   DO I=IU+1,ID
!   BTA(I) = V(I)-A(I)/BTA(I-1)*C(I-1)
!   GMA(I) = D(I)-A(I)/BTA(I-1)*GMA(I-1)
!   END DO
!   Z(ID) = GMA(ID)/BTA(ID)
!   DO I=ID-1,IU,-1
!   Z(I) = (GMA(I)-C(I)*Z(I+1))/BTA(I)
!   END DO
!

```

!***** Boundary water surface elevations

```

!   IF (UP_FLOW(JB) .AND. .NOT. HEAD_FLOW(JB)) Z(IU-1) = Z(IU)
!   IF (UP_FLOW(JB) .AND. HEAD_FLOW(JB)) Z(IU-1) = (-
EL(KTWB(JWUH(JB)),UHS(JB))+Z(UHS(JB))*COSA(JBUH(JB))+EL(KT,IU-1) &
+SINA(JBUH(JB))*DLXR(IU-1))/COSA(JBUH(JB))
!   IF (DN_FLOW(JB)) Z(ID+1) = Z(ID)
!   IF (DN_FLOW(JB)) THEN           !WX 6/18/13
!   Z(ID+1) = Z(ID)
!   ELWS(ID+1) = EL(KT,ID+1)-Z(ID+1)*COSA(JB)
!   END IF

```

!*****UPDATE KTI OF IU-1 & ID+1

```

!   IU-1
!   DO WHILE (EL(KTI(IU-1),IU-1) > EL(KT,IU-1)-Z(IU-1)*COSA(JB))
!
!   KTI(IU-1) = KTI(IU-1)+1
!   END DO
!
!   KTI(IU-1) = MAX(KTI(IU-1)-1,2)
!   ID+1
!   DO WHILE (EL(KTI(ID+1),ID+1) > EL(KT,ID+1)-Z(ID+1)*COSA(JB))
!   KTI(ID+1) = KTI(ID+1)+1
!   END DO
!
!   KTI(ID+1) = MAX(KTI(ID+1)-1,2)

```

!***** Updated surface layer and geometry

```

!   IF (.NOT. TRAPEZOIDAL(JW)) THEN           !SW 07/16/04
!   DO I=IU-1,ID+1
!   IF (EL(KT,I)-Z(I)*COSA(JB) > EL(KTI(I),I)) THEN
!   DO WHILE ( EL(KT,I)-Z(I)*COSA(JB) > EL(KTI(I),I) .AND. KTI(I) /= 2)
!   Z(I) = (EL(KT,I)-EL(KTI(I),I)-(EL(KT,I)-EL(KTI(I),I)-Z(I)*COSA(JB))*(B(KTI(I),I)/B(KTI(I)-
1,I)))/COSA(JB)
!
!   IF(MACROPHYTE_ON)THEN

```

```

        KTIP=KTI(I)
!C KEEPING TRACK IF COLUMN KTI HAS MACROPHYTES
        IF(KTIP.GT.2)KTICOL(I)=.FALSE.
        END IF

        KTI(I) = MAX(KTI(I)-1,2)
        END DO
        ELSE IF (EL(KT,I)-Z(I)*COSA(JB) < EL(KTI(I)+1,I)) THEN
        DO WHILE (EL(KT,I)-Z(I)*COSA(JB) < EL(KTI(I)+1,I) .AND. KTI(I) < KB(I))      ! sw 7/18/11
            Z(I) = (EL(KT,I)-EL(KTI(I)+1,I)-(EL(KT,I)-EL(KTI(I)+1,I)-
Z(I)*COSA(JB)))*(B(KTI(I),I)/B(KTI(I)+1,I)))/COSA(JB)
            KTI(I) = KTI(I)+1
            IF(MACROPHYTE_ON)KTICOL(I)=.TRUE.
            IF (KTI(I) >= KB(I)) EXIT
        END DO
!       KTI(I) = MAX(KTI(I)-1,2)      ! WX 2/28/13
        END IF
        BI(KT:KB(I),I) = B(KT:KB(I),I)
        BI(KT,I) = B(KTI(I),I)
        H1(KT,I) = H(KT,JW)-Z(I)
        AVH1(KT,I) = (H1(KT,I)+H1(KT+1,I))*0.5D0
        IF (KT == KTI(I) .OR. KTI(I) >= KB(I)) THEN
            BH1(KT,I) = B(KT,I)*H1(KT,I)
        ELSE
            BH1(KT,I) = BI(KT,I)*(EL(KT,I)-Z(I)*COSA(JB)-EL(KTI(I)+1,I))/COSA(JB)
        END IF
        DO K=KTI(I)+1,KT
            BH1(KT,I) = BH1(KT,I)+BNEW(K,I)*H(K,JW) !BNEW(K,I)*H(K,JW) ! SW 1/23/06
        END DO
        BKT(I) = BH1(KT,I)/H1(KT,I)
        IF(KBI(I) < KB(I))BKT(I)=BH1(KT,I)/(H1(KT,I)-(EL(KBI(I)+1,I)-EL(KB(I)+1,I))) ! SW 1/23/06
        VOL(KT,I) = BH1(KT,I)*DLX(I)
        END DO
        DO I=IU-1,ID
            AVHR(KT,I) = H1(KT,I) + (H1(KT,I+1) - H1(KT,I))/(0.5D0*(DLX(I)+DLX(I+1)))*0.5D0*DLX(I)
!SW 07/29/04 (H1(KT,I+1) + H1(KT,I))*0.5
            IF(KBI(I) < KB(I))AVHR(KT,I)=(H1(KT,I)-(EL(KBI(I)+1,I)-EL(KB(I)+1,I))) &
                + (H1(KT,I+1)-(EL(KBI(I)+1,I+1)-EL(KB(I)+1,I+1))) - H1(KT,I)+(EL(KBI(I)+1,I)&
                -EL(KB(I)+1,I)))/(0.5D0*(DLX(I)+DLX(I+1)))*0.5D0*DLX(I) ! SW 1/23/06
            BHR1(KT,I) = BH1(KT,I)+(BH1(KT,I+1)-BH1(KT,I))/(0.5D0*(DLX(I)+DLX(I+1)))*0.5D0*DLX(I)
!SW 07/29/04 (BH1(KT,I+1)+BH1(KT,I))*0.5
        END DO
        AVHR(KT,ID+1) = H1(KT,ID+1)
        BHR1(KT,ID+1) = BH1(KT,ID+1)
        DLVOL(JB) = 0.0
        ELSE      !SW 07/16/04
        DO I=IU-1,ID+1
            BI(KT:KB(I),I) = B(KT:KB(I),I)
            CALL GRID_AREA2
            H1(KT,I) = H(KT,JW)-Z(I)
            AVH1(KT,I) = (H1(KT,I)+H1(KT+1,I))*0.5
            CALL GRID_AREA1 (EL(KT,I)-Z(I),EL(KT+1,I),BH1(KT,I),BI(KT,I))
            BKT(I) = BH1(KT,I)/H1(KT,I)
            if(kbi(i) < kb(i))bkt(i)=bh1(kt,i)/(h1(kt,i)-(el(kbi(i)+1,i)-el(kb(i)+1,i))) ! SW 1/23/06
            VOL(KT,I) = BH1(KT,I)*DLX(I)
        END DO
        DO I=IU-1,ID
            AVHR(KT,I) = H1(KT,I) + (H1(KT,I+1) - H1(KT,I))/(0.5D0*(DLX(I)+DLX(I+1)))*0.5D0*DLX(I)
!SW 07/29/04
            if(kbi(i) < kb(i))avhr(kt,i)=(h1(kt,i)-(el(kbi(i)+1,i)-el(kb(i)+1,i))) &

```

```

      +(H1(KT,I+1)-(el(kbi(i)+1,i+1)-el(kb(i)+1,i+1)) -H1(KT,I)+(el(kbi(i)+1,i)&
      -el(kb(i)+1,i)))/(0.5D0*(DLX(I)+DLX(I+1)))*0.5D0*DLX(I) ! SW 1/23/06
      BHR1(KT,I) = BH1(KT,I)+(BH1(KT,I+1)-BH1(KT,I))/(0.5*(DLX(I)+DLX(I+1)))*0.5*DLX(I)
!SW 07/29/04
      END DO
      AVHR(KT,ID+1) = H1(KT,ID+1)
      BHR1(KT,ID+1) = BH1(KT,ID+1)
      DLVOL(JB) = 0.0
      END IF
!
      ELWS(CUS(JB):DS(JB)+1) = EL(KT,CUS(JB):DS(JB)+1)-Z(CUS(JB):DS(JB)+1)*COSA(JB)
!WX 3/3/13
      DO I=IU,ID
      DLVOL(JB) = DLVOL(JB)+(BH1(KT,I)-BH2(KT,I))*DLX(I)
      IF (KT == 2 .AND. H1(KT,I) > H(2,JW) .AND. .NOT. SURFACE_WARNING) THEN
        WRITE (WRN,'(A,I0,A,F0.3)') 'Water surface is above the top of layer 2 in segment ',I,' at day ',JDAY
        WARNING_OPEN = .TRUE.
        SURFACE_WARNING = .TRUE.
      END IF
      END DO

      IF(MACROPHYTE_ON)THEN
!C IF DEPTH IN KTI LAYER BECOMES GREATER THAN THRESHOLD, SETTING
!C MACROPHYTE CONC. IN KTI COLUMN TO INITIAL CONC.
      DO I=IU,ID
        DEPKTI=ELWS(I)-EL(KTI(I)+1,I)

!***** MACROPHYTES, SETTING CONC. OF MACROPHYTES IN NEW COLUMNS TO
!***** INITIAL CONCENTRATION IF COLUMN DEPTH IS GREATER THAN 'THRKTI'
      IF(.NOT.KTICOL(I).AND.DEPKTI.GE.THRKTI)THEN
        KTICOL(I)=.TRUE.
        JT=KTI(I)
        MACT(JT,KT,I)=0.0
        DO M=1,NMC
          MACRC(JT,KT,I,M)=MACWBCI(JW,M)
          COLB=EL(KTI(I)+1,I)
          COLDEP=ELWS(I)-COLB
          MACRM(JT,KT,I,M)=MACWBCI(JW,M)*COLDEP*CW(JT,I)*DLX(I)
          MACT(JT,KT,I)=MACT(JT,KT,I)+MACWBCI(JW,M)
          MACMBRT(JB,M) = MACMBRT(JB,M)+MACRM(JT,KT,I,M)
        END DO
      END IF

!***** MACROPHYTES, WHEN COLUMN DEPTH IS LESS THAN 'THRKTI', ZEROING OUT CONC.
      IF(KTICOL(I).AND.DEPKTI.LT.THRKTI)THEN
        KTICOL(I)=.FALSE.
        JT=KTI(I)
        MACT(JT,KT,I)=0.0
        DO M=1,NMC
          MACMBRT(JB,M) = MACMBRT(JB,M)-MACRM(JT,KT,I,M)
          MACRC(JT,KT,I,M)=0.0
          MACRM(JT,KT,I,M)=0.0
        END DO
      END IF
      END DO
      END IF

```

```

!!*****
*****

```

!!**

Task 2.2.4: Longitudinal velocities

**

```

!!*****
*****
!
!   IUT = IU
!   IDT = ID
!   IF (UP_HEAD(JB)) IUT = IU-1
!   IF (DN_HEAD(JB)) IDT = ID+1
!
!!***** Pressures
!
!   DO I=IUT,IDT
!   DO K=KT,KB(I)
!     P(K,I) = P(K-1,I)+RHO(K,I)*G*H1(K,I)*COSA(JB)
!   END DO
! END DO
!
!!***** Horizontal pressure gradients
!
!   DO I=IUT,IDT-1
!   HPG(KT,I) = DLXRHO(I)*(BKT(I)+BKT(I+1))*0.5D0*(H1(KT,I+1)*P(KT,I+1)-H1(KT,I)*P(KT,I))
!   DO K=KT+1,KBMIN(I)
!     HPG(K,I) = DLXRHO(I)*BHR2(K,I)*((P(K-1,I+1)-P(K-1,I))+P(K,I+1)-P(K,I))
!   END DO
! END DO
!
!!*****Horizontal velocity
!   IF (SLOPE(JB) > 0.0 .AND. .NOT. LOOP_BRANCH(JB)) THEN
!     DO I=IU,ID
!!       WSURF=ELWS(I)
!       XAREA=0.0
!       DO K=KT,KBMIN(I)    !KBI(I) SW 5/21/13
!         XAREA = XAREA + BHR1(K,I)
!       END DO
!       UAVG(I)=QSSI(I)/XAREA
!       DO K=KT,KBMIN(I)    ! change KB to KBMIN
!         U(K,I)=UAVG(I)
!       END DO
!     END DO
!
!       !WSURF=ELWS(IU)           ! nEEDS REFINEMENT FOR CASES WHERE A TRIB ENTERS
!WX 4/11/13
!   ! CALL XSECTIONAL_AREA(WSURF,XAREA)
!   ! UAVG(IU)=QSSI(IU)/XAREA
!!   DO K=KT,KBMIN(IU-1) ! change KB to KBMIN
!!     U(K,IU-1)=UAVG(IU)
!!   END DO
!!   DO K=KT,KBMIN(ID+1) ! change KB to KBMIN
!!     U(K,ID+1)=UAVG(ID)
!!   END DO
!
!   END IF

IF (SLOPE(JB) > 0.0) THEN    ! .AND. .NOT. LOOP_BRANCH(JB) !wx 8/24/13
DO I=IU,ID
  WSURF=ELWS(I)
!  CALL XSECTIONAL_AREA2(WSURF,XAREA)
  CALL XSECTIONAL_AREA4(WSURF,XAREA)
  UAVG(I)=QSSI(I)/XAREA
  DO K=KT,KBMIN(I) ! change KB to KBMIN
    U(K,I)=UAVG(I)
  
```

```

        END DO
    END DO

    I=IU          !set i=iu so that there will not be error at the end of branch (exceeding imax)  WX 6/12/13
    WSURF=ELWS(I)
!    CALL XSECTIONAL_AREA2(WSURF,XAREA)
!    CALL XSECTIONAL_AREA4(WSURF,XAREA)
    UAVG(IU)=QSSI(IU)/XAREA
    DO K=KT,KBMIN(IU-1) ! change KB to KBMIN
        U(K,IU-1)=UAVG(IU)
    END DO

!WSURF=ELWS(IU)          ! nEEEDS REFINEMENT FOR CASES WHERE A TRIB ENTERS          !WX
4/11/13
!    CALL XSECTIONAL_AREA(WSURF,XAREA)
!    UAVG(IU)=QSSI(IU)/XAREA
!    DO K=KT,KBMIN(IU-1) ! change KB to KBMIN
!        U(K,IU-1)=UAVG(IU)
!    END DO
!    DO K=KT,KBMIN(ID+1) ! change KB to KBMIN
!        U(K,ID+1)=UAVG(ID)
!    END DO

END IF

!***** Boundary horizontal velocities

IF (UP_FLOW(JB)) THEN
    IF (.NOT. HEAD_FLOW(JB)) THEN
        QINF(:,JB) = 0.0
        IF (PLACE_QIN(JW)) THEN

!***** Inflow layer

            K = KT
            SSTOT = 0.0
            DO JC=NSSS,NSSE
                SSTOT = SSTOT+CIN(JC,JB)
            END DO
            RHOIN = DENSITY(TIN(JB),DMAX1(CIN(1,JB),0.0D0),DMAX1(SSTOT,0.0D0))
            DO WHILE (RHOIN > RHO(K,IU) .AND. K < KB(IU))
                K = K+1
            END DO
            KTQIN(JB) = K
            KBQIN(JB) = K

!***** Layer inflows

            VQIN = QIN(JB)*DLT
            VQINI = VQIN
            QINFR = 1.0
            INCR = -1
            DO WHILE (QINFR > 0.0D0)
                V1 = VOL(K,IU)
                IF (K <= KB(IU)) THEN
                    IF (VQIN > 0.5D0*V1) THEN
                        QINF(K,JB) = 0.5D0*V1/VQINI
                        QINFR = QINFR-QINF(K,JB)
                        VQIN = VQIN-QINF(K,JB)*VQINI
                    IF (K == KT) THEN

```



```

        K = KBQIN(JB)
        INCR = 1
    END IF
ELSE
    QINF(K,JB) = QINFR
    QINFR = 0.0D0
END IF
IF (INCR < 0) KTQIN(JB) = K
IF (INCR > 0) KBQIN(JB) = MIN(KB(IU),K)
K = K+INCR
ELSE
    QINF(KT,JB) = QINF(KT,JB)+QINFR
    QINFR = 0.0D0
END IF
END DO
ELSE
    KTQIN(JB) = KT
    KBQIN(JB) = KB(IU)
    BHSUM = 0.0D0
    DO K=KT,KB(IU)
        BHSUM = BHSUM+BH1(K,IU)
    END DO
    DO K=KT,KB(IU)
        QINF(K,JB) = BH1(K,IU)/BHSUM
    END DO
END IF
DO K=KT,KB(IU)
    ! !WX 4/6/13
    U(K,IU-1) = QINF(K,JB)*QIN(JB)/BHR1(K,IU-1)
END DO
ELSE
    KTQIN(JB) = KT
    KBQIN(JB) = KB(IU)
    IF (JBUH(JB) <= BE(JW) .AND. JBUH(JB) >= BS(JW)) THEN
        DO K=KT,KB(IU)
            U(K,IU-1) = U(K,UHS(JB))*BHR1(K,UHS(JB))/BHR1(K,IU-1)
        END DO
    ELSE
        CALL UPSTREAM_VELOCITY
    END IF
END IF
IF (DN_FLOW(JB)) THEN
    DO K=KT,KB(ID)
        U(K,ID) = QOUT(K,JB)/BHR1(K,ID)
    END DO
END IF
IF (UP_HEAD(JB)) THEN
    XAREA = 0.0
    DO K=KT,KBMIN(IU-1)
        !WX 6/17/13
        ! U(K,IU-1) = (BHR2(K,IU-1)*U(K,IU-1)+DLT*(-SB(K,IU-1)+ST(K,IU-1)-HPG(K,IU-1)+GRAV(K,IU-1)))/BHR1(K,IU-1)
        XAREA = XAREA + BHR1(K,IU-1)
    END DO
    UAVG(IU-1) = QSSI(IU)/XAREA
    DO K=KT,KBMIN(IU-1)
        !WX 6/17/13
        U(K,IU-1) = UAVG(IU-1)
    END DO
END IF
IF (DN_HEAD(JB)) THEN
    XAREA = 0.0

```

```

DO K=KT,KBMIN(ID)      !KB(ID+1)      !is this a problem? id or id+1? 5/28/13
  !U(K,ID) = (BHR2(K,ID)*U(K,ID)+DLT*(-SB(K,ID)+ST(K,ID)-HPG(K,ID)+GRAV(K,ID)))/BHR1(K,ID)
  XAREA = XAREA + BHR1(K,ID)
END DO
UAVG(ID) = QSSI(ID)/XAREA
DO K=KT,KBMIN(ID)      !WX 6/17/13
  U(K,ID) = UAVG(ID)    !WX 6/17/13
END DO
END IF

!!***** Horizontal velocities
!
! DO I=IU,ID-1
!   DO K=KT,KBMIN(I)
!     U(K,I) = (BHR2(K,I)*U(K,I))/BHR1(K,I)+(DLT*(-SB(K,I)+ST(K,I)-ADMZ(K,I)+ADMZ(K-1,I)-
ADMX(K,I)+DM(K,I)-HPG(K,I)+GRAV(K,I)&
!       +UXBR(K,I)/H2(K,I)))/BHR1(K,I)
!     IF (INTERNAL_WEIR(K,I)) U(K,I) = 0.0D0
!   END DO
! END DO
!
!!***** Implicit vertical eddy viscosity
!
! IF (IMPLICIT_VISC(JW)) THEN
!   AT = 0.0D0; CT = 0.0D0; VT = 0.0D0; DT = 0.0D0
!   DO I=IUT,IDT-1
!     DO K=KT,KBMIN(I)      !KB(I) SW 10/7/07
!       AT(K,I) = -DLT/BHR1(K,I)*AZ(K-1,I)*(BHR1(K-1,I)/AVHR(K-1,I)+BR(K,I)) /((AVH1(K-1,I)+AVH1(K-
1,I+1))
!       CT(K,I) = -DLT/BHR1(K,I)*AZ(K,I) *(BHR1(K,I) /AVHR(K,I) +BR(K+1,I))/(AVH1(K,I)
+AVH1(K,I+1))
!       VT(K,I) = 1.0D0-AT(K,I)-CT(K,I)
!       DT(K,I) = U(K,I)
!     END DO
!     CALL TRIDIAG(AT(:,I),VT(:,I),CT(:,I),DT(:,I),KT,KBMIN(I),KMX,U(:,I))
!   END DO
! END IF
!
!!***** Corrected horizontal velocities
!
! IF (UP_HEAD(JB)) THEN
!   IS = ID
!   IE = IU-1
!   INCR = -1
!   Q(IS) = 0.0D0
!   DO K=KT,KB(ID)
!     Q(IS) = Q(IS)+U(K,IS)*BHR1(K,IS)
!   END DO
!   QSSUM(IS) = 0.0D0
!   DO K=KT,KB(IS)
!     QSSUM(IS) = QSSUM(IS)+QSS(K,IS)
!   END DO
! ELSE
!   IS = IU-1
!   IE = ID
!   INCR = 1
!   IF (DN_FLOW(JB)) IE = ID-1
!   Q(IS) = 0.0D0
!   DO K=KT,KB(IU)
!     Q(IS) = Q(IS)+U(K,IS)*BHR1(K,IS)

```

```

!     END DO
!     END IF
!     QC(IS) = Q(IS)
!     DO I=IS+INCR,IE,INCR
!         QSSUM(I) = 0.0D0
!         DO K=KT,KB(I)
!             QSSUM(I) = QSSUM(I)+QSS(K,I)
!         END DO
!         BHRSUM = 0.0D0
!         Q(I) = 0.0D0
!         DO K=KT,KBMIN(I)
!             IF (.NOT. INTERNAL_WEIR(K,I)) THEN
!                 BHRSUM = BHRSUM+BHR1(K,I)
!                 Q(I) = Q(I)+U(K,I)*BHR1(K,I)
!             END IF
!         END DO
!         IF (UP_HEAD(JB)) THEN
!             QC(I) = QC(I+1)+(BH1(KT,I+1)-BH2(KT,I+1))*DLX(I+1)/DLT-QSSUM(I+1)
!         ELSE
!             QC(I) = QC(I-1)-(BH1(KT,I) -BH2(KT,I)) *DLX(I) /DLT+QSSUM(I)
!         END IF
!         DO K=KT,KBMIN(I)
!             IF (INTERNAL_WEIR(K,I)) THEN
!                 U(K,I) = 0.0D0
!             ELSE
!                 U(K,I) = U(K,I)+(QC(I)-Q(I))/BHRSUM
!                 IF (Q(I) /= 0.0) QERR(I) = (Q(I)-QC(I))/Q(I)*100.0
!             END IF
!         END DO
!     END DO
!     END DO

!***** Head boundary flows

IF (UP_HEAD(JB)) QUH1(KT:KB(IU-1),JB) = U(KT:KB(IU-1),IU-1)*BHR1(KT:KB(IU-1),IU-1)
IF (DN_HEAD(JB)) QDH1(KT:KB(ID+1),JB) = U(KT:KB(ID+1),ID) *BHR1(KT:KB(ID+1),ID)

!** tributary and distributed tributary flow distribution. This QTRF calculated below is for both TRIB and DTR
!WX 8/17/13
      DO I=CUS(JB),DS(JB)
        BHSUM = 0.0
        DO K=KTWB(JW),KB(I)
          BHSUM = BHSUM+BHR1(K,I)
        END DO
        DO K=KTWB(JW),KB(I)
          QTRF(K,I) = BHR1(K,I)/BHSUM
        END DO
      END DO
!** CALCULATE QSS FOR TRIBUTARIES AND DISTRIBUTED TRIBUTARIES      !WX 8/18/13
!** tributary
      IF (TRIBUTARIES)THEN
        DO JT=1,JTT
          IF (JB==JBTR(JT)) THEN
            I= MAX(ITR(JT),IU)
            DO K=KTWB(JW),KB(I)
              QSS(K,I) = QSS(K,I)+QTR(JT)*QTRF(K,I)
            END DO
          END IF
        END DO
      END IF

```

```

! ** distributed tributary
  IF (DIST_TRIBS(JB)) THEN
    DO I=IU,ID
      QDT(I) = QDTR(JB)/REAL(ID-IU+1)
      DO K=KTWB(JW),KB(I)
        QSS(K,I) = QSS(K,I)+QDT(I)*QTRF(K,I)
      END DO
    END DO
  ELSE
    DO I=IU,ID      !ZERO DISTRIBUTED FLOWS ARE CALCULATED SO THAT QDT CAN BE
DIRECTLY USED IN LOOP BRANCH FLOW
      QDT(I) = 0.0
    END DO
  END IF

! ** LOOP BRANCH FLOW      !WX 8/25/13 CALCULATE QSS FOR LOOP BRANCH, SO THAT
VERTICAL VELOCITY IS RIGHT
  IF (LOOP_BRANCH(JB)) THEN
    I=UHS(JB)
    DO K=KTWB(JW),KB(I)
      QSS(K,I) =QSS(K,I)-QSSI(US(JB))*QTRF(K,I)
    END DO

    I=DHS(JB)
    DO K=KTWB(JW),KB(I)
      QSS(K,I) =QSS(K,I)+QSSI(DS(JB))*QTRF(K,I)
    END DO
  END IF
END DO      !wx 11/10/2013 seprate vertical velocity and others into 2 loop
END DO

!*****
*****
! **      Task 2.2.5: Vertical velocities      **
!*****
*****
DO JW=1,NWB      !wx 11/10/2013 seprate vertical velocity and others into 2 loop
  KT = KTWB(JW)
  DO JB=BS(JW),BE(JW)
    IU = CUS(JB)
    ID = DS(JB)
    DO I=IU,ID
      DO K=KB(I)-1,KT,-1
        WT1 = W(K+1,I)*BB(K+1,I)
        WT2 = (BHR(K+1,I)*U(K+1,I)-BHR(K+1,I-1)*U(K+1,I)-QSS(K+1,I))/DLX(I)
        W(K,I) = (WT1+WT2)/BB(K,I)
      END DO
    END DO
  END DO
!!**  WHEN THERE IS LOOP BRANCH, VERTICAL VELOCITY IN MAIN BRANCH IS CALCULATED
EARLIER THAN QSS calculated, so correction of vertical v is needed
!  IF (LOOP_BRANCH(JB)) THEN      !WX 8/26/13
!    I=UHS(JB)
!    DO K=KB(I)-1,KT,-1
!      W(K,I)=0.0
!    END DO
!    I=DHS(JB)
!    DO K=KB(I)-1,KT,-1
!      W(K,I)=0.0
!    END DO
!  END IF

```

```

        END DO
    END DO

! ** for the first time step, BH2 is set to equal BH1, so that the numerical calculation can be steady
    IF (NIT == 0) THEN                !WX 5/18/13
        BH2=BH1
    END IF

!
!!*****
*****
!!**                                Task 2.2.6: Autosteppping                                **
!!*****
*****
!
! DO JW=1,NWB
!     KT = KTWB(JW)
!     DO JB=BS(JW),BE(JW)
!         DO I=CUS(JB),DS(JB)
!
!             IF(DLTADD(JW)==' ON'.and.ABS(H1(KT,I)-H2(KT,I))/H2(KT,I) > 0.5)THEN
!                 WRITE (WRN, '(A,F0.3,A,I0,A,F0.3/3(A,F0.3),a,i10,a)') 'Computational warning |h1-h2/h2>0.25 on Julian
day = ',JDAY,' at segment ',I,' timestep DLT= ',DLT,&
!                 ' Water surface deviation [Z,m] = ',Z(I),' H1 layer thickness(m) = ',H1(KT,I),' H2 layer
thickness(m)=' ,h2(kt,i),' Iteration[NIT]=' ,nit,' DLT reduced'
!                 WARNING_OPEN = .TRUE.
!                 IF(H1(KT,I)>0.0)THEN
!                     CURMAX=DLT*0.5
!                 ELSE
!                     CURMAX=DLTMIN
!                 ENDIF
!                 GO TO 220
!
!             ELSEIF (H1(KT,I) < 0.0) THEN
!                 WRITE (WRN, '(A,F0.3,A,I0/4(A,F0.3))') 'Computational warning at Julian day = ',JDAY,' at segment
',I,'timestep = ',DLT,&
!                 ' water surface deviation [Z] = ',Z(I),' m layer thickness = ',H1(KT,I),' m'
!                 WARNING_OPEN = .TRUE.
!                 IF (DLT > DLTMIN) THEN
!                     WRITE (WRN, '(A,I0/2(A,F0.3),A,I0)') 'Negative surface layer thickness in segment ',I,' time step reduced to
', &
!                     DLTMIN,' s on day ',JDAY,' at iteration ',NIT
!                 WARNING_OPEN = .TRUE.
!                 CURMAX = DLTMIN
!                 GO TO 220
!                 ELSE
!                     WRITE (W2ERR, '(A,F0.3/A,I0)') 'Unstable water surface elevation on day ',JDAY,'negative surface layer
thickness '// &
!                     'using minimum timestep at iteration ',NIT
!                     WRITE (W2ERR, '(A)') 'Segment, Surface layer thickness, m, Flow m3/s, U(KT,I) m/s, ELWS, m'
!                     DO II=MAX(CUS(JB),I-3),MIN(DS(JB),I+3)
!                         WRITE (W2ERR, '(T4,I3,T19,F10.2,t37,f10.2,1x,f10.2,2x,f10.2)') II,H1(KT,II),QC(II),U(KT,II),ELWS(II)
! SW 7/13/10
!                     END DO
!                     TEXT = 'Runtime error - see w2.err'
!                     ERROR_OPEN = .TRUE.
!                     GO TO 230
!                 END IF
!             END IF
!         END DO
!     END DO
!     DO I=CUS(JB),DS(JB)

```

```

!      IF (VISCOSITY_LIMIT(JW)) TAU1 = 2.0*MAX(AX(JW),DXI(JW))/(DLX(I)*DLX(I))
!      IF (CELERITY_LIMIT(JW)) CELRTY = SQRT((ABS(RHO(KB(I),I)-
RHO(KT,I))/1000.0*G*DEPTHB(KBI(I),I)*0.5) ! SW 1/23/06
!      DO K=KT,KB(I)
!      IF (VISCOSITY_LIMIT(JW) .AND. .NOT. IMPLICIT_VISC(JW)) TAU2 =
2.0*AZ(K,I)/(H1(K,JW)*H1(K,JW))
!      QTOT(K,I) = (ABS(U(K,I))*BHR1(K,I)+ABS(U(K,I-1))*BHR1(K,I-1)+(ABS(W(K,I))*BB(K,I)+ABS(W(K-
1,I))*BB(K-1,I))*DLX(I) &
!      +DLX(I)*ABS(BH2(K,I)-BH1(K,I))/DLT+ABS(QSS(K,I)))*0.5
!      DLTCAL = 1.0/((QTOT(K,I)/BH1(K,I)+CELRTY)/DLX(I)+TAU1+TAU2+NONZERO)
!      IF (DLTCAL < CURMAX) THEN
!      KLOC = K
!      ILOC = I
!      CURMAX = DLTCAL
!      IF (DLTFF*CURMAX < MINDLT) THEN
!      KMIN = K
!      IMIN = I
!      END IF
!      END IF
!      END DO
!      END DO
!      END DO
!      END DO
!
!!** Restore timestep dependent variables and restart calculations
!
!220 CONTINUE
! IF (CURMAX < DLT .AND. DLT > DLTMIN) THEN
!   DLT = DLTFF*CURMAX
!   IF (DLT <= DLTMIN) THEN
!     WRITE (WRN,'(A,F0.3/A,F0.3,A)') 'Computational warning at Julian day = ',JDAY,' timestep = ',DLT,' sec:
DLT<DLTMIN set DLT=DLTMIN'
!     WARNING_OPEN = .TRUE.
!     DLT = DLTMIN
!   END IF
!   NV = NV+1
!   Z = SZ
!   U = SU
!   W = SW
!   AZ = SAZ
!   AVH2 = SAVH2
!   AVHR = SAVHR
!   KTI = SKTI
!   BKT = SBKT
!   QSS = 0.0
!   SB = 0.0
!   DLTS = DLT
!
!   do jw=1,nwb ! SW 8/25/05
!   do jb=bs(jw),be(jw)
!   do i=us(jb)-1,ds(jb)+1
!     VOL(KTWB(JW),I) = BH2(KTWB(JW),I)*DLX(I)
!     BI(KTWB(JW),I) = B(KTI(I),I)
!   end do
!   end do
!   end do
!
!   CURMAX = DLTMAXX/DLTFF
!   IF (PIPES) THEN

```

```

!   YS = YSS
!   VS = VSS
!   VST = VSTS
!   YST = YSTS
!   DTP = DTPS
!   QOLD = QOLDS
!   END IF

```

```

!***** Macrophytes

```

```

DO JW=1,NWB
DO M=1,NMC
IF (MACROPHYTE_CALC(JW,M)) THEN
KT = KTWB(JW)
DO JB=BS(JW),BE(JW)
DO I=CUS(JB),DS(JB)
DO K=KT,KB(I)
MAC(K,I,M)=SMAC(K,I,M)
IF(KTICOL(I))THEN
JT=KTI(I)
ELSE
JT=KTI(I)+1
END IF
JE=KB(I)
DO J=JT,JE
MACRC(J,K,I,M)=SMACRC(J,K,I,M)
MACRM(J,K,I,M)=SMACRM(J,K,I,M)
END DO
END DO
END DO
END IF
END DO
END DO

!GO TO 210          !WX 11/29/12
!END IF            !WX 11/12/2012
!DLTLIM(KMIN,IMIN) = DLTLIM(KMIN,IMIN)+1.0

```

```

!** Layer bottom and middle depths

```

```

DO JW=1,NWB
DO JB=BS(JW),BE(JW)
DO I=CUS(JB)-1,DS(JB)
DEPTHB(KTWB(JW),I) = H1(KTWB(JW),I)
DEPTHM(KTWB(JW),I) = H1(KTWB(JW),I)*0.5
if(kbi(i) < kb(i) .and. (el(kbi(i)+1,i)-el(kb(i)+1,i)) < h1(ktwb(jw),i))then ! SW 7/22/10 if h1 < elev diff this
means depth is below the bottom - if we ignore that the run will continue but if dpethb is negative it will bomb in
computing DECAY
depthb(ktwb(jw),i)=(h1(ktwb(jw),i)-(el(kbi(i)+1,i)-el(kb(i)+1,i))) ! SW 1/23/06
depthm(ktwb(jw),i)=(h1(ktwb(jw),i)-(el(kbi(i)+1,i)-el(kb(i)+1,i)))*0.5
endif
DO K=KTWB(JW)+1,KMX
DEPTHB(K,I) = DEPTHB(K-1,I)+ H1(K,I)
DEPTHM(K,I) = DEPTHM(K-1,I)+(H1(K-1,I)+H1(K,I))*0.5
END DO
END DO
END DO
END DO

```

```

CALL temperature

```

IF (CONSTITUENTS) CALL wqconstituents

CALL LAYERADDSUB

if(error_open)go to 230

CALL BALANCES

CALL UPDATE

if(restart_in)then
 if(iopenfish==0)nxtmts=jday
endif

IF (JDAY.GE.NXTMTS.OR.JDAY.GE.TSRD(TSRDP+1).or.nit==1) THEN ! OUTPUT AT FREQUENCY OF
TSR FILES

IF(HABTATC == ' ON')CALL FISHHABITAT(iopenfish) ! OUTPUT AT

FREQUENCY OF TSR FILES

IF(AERATEC == ' ON'.and.oxygen_demand)CALL AERATEOUTPUT

IF(RESTART_IN)IOPENFISH=1

IF(ENVIRPC == ' ON')CALL ENVIRP

iopenfish=1

ENDIF ! OUTPUT AT FREQUENCY OF TSR FILES

CALL OUTPUTA

!**** Screen output

DO JW=1,NWB

 IF (SCREEN_OUTPUT(JW)) THEN

 IF (JDAY >= NXTMSC(JW).OR.JDAY >= SCRDP(SCRDP(JW)+1,JW)) THEN

 IF (JDAY >= SCRDP(SCRDP(JW)+1,JW)) THEN

 SCRDP(JW) = SCRDP(JW)+1

 NXTMSC(JW) = SCRDP(SCRDP(JW),JW)

 ENDIF

 KT = KTWB(JW)

 NXTMSC(JW) = NXTMSC(JW)+SCRF(SCRDP(JW),JW)

 CALL SCREEN_UPDATE (DLG)

 CALL DATE_AND_TIME (CDATE,CCTIME)

 ! DO JH=1,NHY

 ! IF (HYDRO_PLOT(JH)) CALL GRAPH_UPDATE (JH,HYD(:,JH), HNAME(JH), HYMIN(JH),1.0,
 LNAME(JH))

 ! END DO

 ! DO JC=1,NCT

 ! IF (CONSTITUENT_PLOT(JC)) CALL GRAPH_UPDATE (JH+JC,C2(:,JC), CNAME(JC), CMIN(JC),
 CMULT(JC), LNAME(JH+JC))

 ! END DO

 ! DO JD=1,NDC

 ! IF (DERIVED_PLOT(JD)) CALL GRAPH_UPDATE
 (JH+JC+JD,CD(:,JD),CDNAME(JD),CDMIN(JD),CDMULT(JD),LNAME(JH+JC+JD))

 ! END DO

 ENDIF

 ENDIF

END DO

END DO ! END OF MAIN DO WHILE LOOP

230 CONTINUE

IF (STOP_PUSHED) THEN

 TEXT = 'Execution stopped at '//CCTIME(1:2)//'://CCTIME(3:4)//'://CCTIME(5:6)//' on
 '//CDATE(5:6)//'//CDATE(7:8)//' &


```

//CDATE(3:4)
CALL RESTART_OUTPUT ('rso.opt')
END IF

IOPENFISH=3
IF(ENVIRPC == " ON")CALL ENVIRP
IF(HABTATC == " ON")call fishhabitat(iopenfish)
PERFORMANCE
CALL ENDSIMULATION

240 CONTINUE
! CALL DEALLOCATE_GRAPH

IF(CLOSEC==' ON' .AND. END_RUN)THEN
CALL EXITDIALOG(DLG,TEXT)
ELSE
CALL STOP_W2 (DLG,TEXT)
ENDIF
RETURN
END FUNCTION CE_QUAL_W2
! FINAL OUTPUT FOR ENVIR

```

init-u-elws.f90

```
!*****
!*****
!**  SUBROUTINE INITIAL WATER LEVEL  **
!*****
!*****

subroutine initial_water_level

USE MAIN
USE GLOBAL;   USE NAMESC; USE GEOMC; USE LOGICC; USE PREC; USE SURFHE; USE KINETIC;
USE SHADEC; USE EDDY
  USE STRUCTURES; USE TRANS; USE TVDC;  USE SELWC; USE GDAYC; USE SCREENC; USE TDGAS;
USE RSTART
USE MACROPHYTEC; USE POROSITYC; USE ZOOPLANKTONC
USE INITIALVELOCITY
IMPLICIT NONE
EXTERNAL RESTART_OUTPUT
INTEGER :: JBU,JBD, JJW
REAL :: QGATE,WSUP,BRLEN,WLSLOPE,DIST, WLDIFF
REAL :: QLOOP1, QLOOP2

LOOP_BRANCH=.FALSE.

! estimating initial flows in each segment
  QSSI=0.0

! first considering specified flows: upstream inflows, tributaries, distributed tribs, structural withdrawals and
withdrawals
  DO JW=1,NWB
    KT = KTWB(JW)
    DO JB=BS(JW),BE(JW)
      IU = CUS(JB)
      ID = DS(JB)
      DO I=IU,ID
        !      IF(I == IU .AND. UP_FLOW(JB))THEN                                !wx 2/13/13
        IF(I == IU .AND. UHS(JB)==0)THEN
          QSSI(I)=QIND(JB)+QSSI(I)                                !WX 7/6/13
        END IF
      END DO
    END DO
  END DO

! if downstream of structure
  !IF (i == iu .and. UHS(JB) < 0) then
  IF (I == IU .AND. DAM_INFLOW(JB)) THEN  ! CB 4/27/2011
    DO JJW=1,NWB
      DO JJB=BS(JJW),BE(JJW)
        IF(DS(JJB) == ABS(UHS(JB)))THEN
          DO JS=1,NSTR(JJB)
            QSSI(I)=QSSI(I)+QSTR(JS,JJB)
          END DO
        END IF
      END DO
    END DO
  END IF

  IF (TRIBUTARIES) THEN
    DO JT=1,NTR
      IF(ITR(JT) == I)QSSI(I)=QSSI(I)+QTR(JT)
    END DO
  END IF
  IF (DIST_TRIBS(JB)) THEN
```

```

      QSSI(I)=QSSI(I)+QDTR(JB)/REAL(ID-IU+1)      ! SINCE INITIAL WL UNKNOWN, DISTRIBUTING
FLOW EVENLY BTW. SEGS.
      END IF
      IF (WITHDRAWALS) THEN
        DO JWD=1,NWD
          IF(IWD(JWD) == I)QSSI(I)=QSSI(I)-QWD(JWD)
        END DO
      END IF
      IF(I == ID)THEN
        DO JS=1,NSTR(JB)
          QSSI(I)=QSSI(I)-QSTR(JS,JB)
        END DO
      END IF
    END DO
  END DO
END DO

! INCLUDING FLOWS WITHIN BRANCH UPSTEAM OF SEGMENT
DO JW=1,NWB
  KT = KTWB(JW)
  DO JB=BS(JW),BE(JW)
    IU = CUS(JB)
    ID = DS(JB)
    DO I=IU+1,ID
      QSSI(I)=QSSI(I)+QSSI(I-1)
    END DO
  END DO
END DO

DO JW=1,NWB
  KT = KTWB(JW)
  DO JB=BS(JW),BE(JW)
    IU = CUS(JB)
    ID = DS(JB)
    DO I=IU,ID
      ! DETERMINING IF SEGMENT IS DOWNSTREAM INTERNAL HEAD BOUNDARY OF ANOTHER
      *UPSTREAM* BRANCH, AND ADDING FLOW TO SEGMENT AND SEGMENTS DOWNSTREAM
      DO JJW=1,NWB
        DO JJB=BS(JJW),BE(JJW)
          IF(DHS(JJB) == I)THEN
            DO II=I,ID
              QSSI(II)=QSSI(II)+QSSI(DS(JJB))
            END DO
          END IF
        END DO
      END DO
    END DO
  END DO
  ! DETERMINING IF SEGMENT IS DOWNSTREAM OF SPILLWAY BELOW ANOTHER BRANCH
  DO JS=1,NSP
    IF(ESP(JS) < EL(2,I))THEN ! DISREGARDING IF CREST ABOVE GRID
      IF(I == IDSP(JS))THEN
        DO II=I,ID
          QSSI(II)=QSSI(II)+QSSI(IUSP(JS))
        END DO
      END IF
    END IF
  END DO
  ! DETERMINING IF SEGMENT IS DOWNSTREAM OF GATE BELOW ANOTHER BRANCH
  DO JG=1,NGT
    IF(EGT(JG) < EL(2,I))THEN ! DISREGARDING IF CREST ABOVE GRID
      IF(I == IDGT(JG))THEN

```

```

        IF(DYNGTC(JG) == ' FLOW')THEN
            QGATE = BGT(JG)
            DO II=I,ID
                QSSI(II)=QSSI(II)+QGATE
            END DO
        ELSE
            DO II=I,ID
                QSSI(II)=QSSI(II)+QSSI(IUGT(JG))
            END DO
        END IF
    END IF
END IF
END DO
END DO
END DO
END DO

```

! DETERMINING IF BRANCH IS A SECONDARY BRANCH THAT LOOPS AROUND AN ISLAND WITH
INTERNAL HEAD BOUNDARIES AT UPSTREAM AND DOWNSTREAM BC
! ATTACHED TO A SINGLE BRANCH

```

DO JW=1,NWB
    KT = KTWB(JW)
    DO JB=BS(JW),BE(JW)
        IF(UH_INTERNAL(JB) .AND. DH_INTERNAL(JB))THEN
            DO JJW=1,NWB
                DO JJB=BS(JJW),BE(JJW)
                    IF(UHS(JB) > US(JJB) .AND. UHS(JB) < DS(JJB))THEN
                        JBU=JJB
                    END IF
                END DO
            END DO
        END DO
        DO JJW=1,NWB
            DO JJB=BS(JJW),BE(JJW)
                IF(DHS(JB) > US(JJB) .AND. DHS(JB) < DS(JJB))THEN      !WX 7/8/13
                    JBD=JJB
                END IF
            END DO
        END DO
        LOOP_BRANCH(JB) = JBU == JBD
        IF(LOOP_BRANCH(JB))THEN      !WX 8/23/13

            CALL LOOP_FLOW_DIVIDE(JBU, QSSI(UHS(JB)-1), QLOOP1, QLOOP2)

            ! recalculate flow in the main branch
            DO II=UHS(JB),DHS(JB)-1
                QSSI(II)=QSSI(II)-QSSI(UHS(JB)-1)+QLOOP1
            END DO

            ! recalculate flow in the loop branch
            DO II=US(JB),DS(JB)
                QSSI(II)=QSSI(II)+QLOOP2
            END DO
            QIN(JB)=QSSI(US(JB))      !FOR THE PURPOSE OF SCR OUTPUT
            TIN(JB)=T2(KTWB(JW),US(JB))

        END IF
    END IF
END DO
END DO

```

! GIVEN ESTIMATED FLOWS FOR EACH SEGMENT, ESTIMATING WL WITH NORMAL DEPTH EQUATION

```
DO JW=1,NWB
  KT = KTWB(JW)
  DO JB=BS(JW),BE(JW)
! ONLY CONSIDERING BRANCHES WITH SLOPES > 0
    IF (SLOPE(JB) > 0.0 .AND. .NOT. LOOP_BRANCH(JB))THEN
      IU = CUS(JB)
      ID = DS(JB)
      DO I=IU,ID
        CALL NORMAL_DEPTH(QSSI(I))
      END DO
    END IF
  END DO
END DO
```

! SMOOTHING WATER SURFACE ELEVATIONS, FIRST WITHIN BRANCHES

```
DO JW=1,NWB
  KT = KTWB(JW)
  DO JB=BS(JW),BE(JW)
    IU = CUS(JB)
    ID = DS(JB)
    IF (DH_EXTERNAL(JB)) ELWS(ID) = ELDH(JB)+SINA(JB)*DLX(ID)    !WX 7/11/13    make sure
! downstream tide is considered
    IF (SLOPE(JB) > 0.0 .AND. .NOT. LOOP_BRANCH(JB))THEN
      DO I=ID-1,IU,-1
        IF(ELWS(I+1) > ELWS(I))THEN
          ELWS(I) = ELWS(I+1)
        END IF
      END DO
    END IF
  END DO
END DO
```

! SMOOTHING WATER SURFACE ELEVATIONS AT INTERNAL HEAD BOUNDARIES

```
DO JW=1,NWB
  KT = KTWB(JW)
  DO JB=BS(JW),BE(JW)
    IF (SLOPE(JB) > 0.0 .AND. .NOT. LOOP_BRANCH(JB) .AND. DH_INTERNAL(JB))THEN
      IU = CUS(JB)
      ID = DS(JB)
      IF(ELWS(DHS(JB)) > ELWS(ID))THEN
        ELWS(ID)=ELWS(DHS(JB))
        DO I=ID-1,IU,-1
          IF(ELWS(I+1) > ELWS(I))THEN
            ELWS(I) = ELWS(I+1)
          END IF
        END DO
      END IF
    END IF
  END DO
END DO
```

! IF SPILLWAY OR GATE AT DOWNSTREAM END OF BRANCH, MAKING SURE WATER LEVEL IS ABOVE CREST ELEVATION

```
DO JW=1,NWB
  KT = KTWB(JW)
```

```

DO JB=BS(JW),BE(JW)
! IF (SLOPE(JB) > 0.0 .AND. .NOT. LOOP_BRANCH(JB) .AND. NSTR(JB) == 0)THEN !wx 10/29/13
  IF (SLOPE(JB) > 0.0 .AND. .NOT. LOOP_BRANCH(JB))THEN
    IU = CUS(JB)
    ID = DS(JB)
! SPILLWAYS
    DO JS=1,NSP
      IF(ESP(JS) < EL(2,ID))THEN ! DISREGARDING IF CREST ABOVE GRID !WX 10/30/13
        EL(2,I)>>EL(2,ID)
        IF(ID == IUSP(JS))THEN
          WSUP=ESP(JS)+(QSSI(ID)/A1SP(JS))*(1.0/B1SP(JS)) ! ESTIMATING UPSTREAM WS ELEV
          IF(ELWS(ID) < WSUP)THEN
            IF(IDSP(JS) .NE. 0)THEN ! CB 8/10/10
              IF(ELWS(IDSP(JS)) > WSUP) WSUP = ELWS(IDSP(JS)) ! CHECKING TO SEE IF DOWNSTREAM
WS ELEVATION ISN'T ALREADY 'HIGH'
            END IF ! CB 8/10/10
            ELWS(ID)=WSUP !WX 10/30/13 CHANGED POSTION WITH THE LINE ABOVE
            DO I=ID-1,IU,-1
              IF(ELWS(I+1) > ELWS(I))THEN
                ELWS(I) = ELWS(I+1)
              END IF
            END DO
          END IF
        END IF
      END IF
    END DO
! GATES
    DO JG=1,NGT
      IF(EGT(JG) < EL(2,I) .AND. DYNGTC(JG) .NE. ' FLOW')THEN ! DISREGARDING IF CREST ABOVE
GRID
        IF(ID == IUGT(JG))THEN
          IF(DYNGTC(JG) == ' B')THEN
            WSUP=EGT(JG)+(QSSI(ID)/(A1GT(JG)*BGT(JG)**G1GT(JG)))*(1.0/B1GT(JG))
          END IF
          IF(DYNGTC(JG) == ' ZGT')THEN
            WSUP=EGT(JG)+(QSSI(ID)/A1GT(JG))*(1.0/B1GT(JG))
          END IF
          IF(ELWS(ID) < WSUP)THEN
! IF(ELWS(IDSP(JS)) > WSUP) WSUP = ELWS(IDSP(JS)) ! CHECKING TO SEE IF DOWNSTREAM
WS ELEVATION ISN'T ALREADY 'HIGH'
! IF(IDGT(JG).NE.0)THEN
! IF(ELWS(IDGT(JG)) > WSUP) WSUP = ELWS(IDGT(JG)) !WX 08/20/13 UNLIKE A
SPILLWAY,ELEVATION UPSTREAM A GATE CAN BE LOWER THAN DOWNSTREAM
            ELWS(ID)=WSUP
! END IF
            DO I=ID-1,IU,-1
              IF(ELWS(I+1) > ELWS(I))THEN
                ELWS(I) = ELWS(I+1)
              END IF
            END DO
          END IF
        END IF
      END IF
    END DO
! SMOOTHING WATER LEVEL AROUND LOOP BRANCHES !&ELWS(IU-1) ELWS(ID+1) !WX 4/11/13
    DO JW=1,NWB

```

```

KT = KTWB(JW)
DO JB=BS(JW),BE(JW)
  IU = CUS(JB)
  ID = DS(JB)
  IF (LOOP_BRANCH(JB))THEN
    WLDIFF=ELWS(UHS(JB))-ELWS(UHS(JB))
    BRLEN=0.0
    DO I=IU,ID
      BRLEN=BRLEN+DLX(I)
    END DO
    WLSLOPE=WLDIFF/BRLEN
    DIST=DLX(IU)/2.0
    ELWS(IU)=ELWS(UHS(JB))-WLSLOPE*DIST
    DO I=IU+1,ID
      DIST=DIST+(DLX(I-1)+DLX(I))/2.0
      ELWS(IU)=ELWS(UHS(JB))-WLSLOPE*DIST
    END DO
  END IF
  ! ELWS(IU-1) = ELWS(IU)+SLOPE(JB)*DLX(IU)/2.0      !WX 5/21/13
  ! ELWS(ID+1) = ELWS(ID)-SINA(JB)*(DLX(ID)+DLX(ID+1))/2.0    !WX 5/21/13
END DO
END DO

RETURN
END SUBROUTINE INITIAL_WATER_LEVEL

!*****
!*****
!**      SUBROUTINE LOOP_FLOW_DIVIDE      **
!*****
!*****

!*****WX 8/23/13      SUBROUTINE TO CALCULATE Q1 & Q2 FOR MAIN STEM AND LOOP
BRANCH RESPECTIVELY

SUBROUTINE LOOP_FLOW_DIVIDE(JBU1, FLOW, QLOOP1, QLOOP2)

USE GLOBAL; USE GEOMC; USE EDDY; USE LOGICC; USE MAIN, ONLY: KBI

!  INTEGER, PARAMETER ::JMAX=40
REAL(R8)  :: FLOW
REAL :: X1, X2, FUNCVAL1, FUNCVAL2, XACC, FMID, FUNC1, RTBIS, DX, XMID
REAL :: QLOOP1, QLOOP2, WSURF2, DEPTH2, XAREA2, WPER2, HRAD2, FMANN2
REAL :: WSURF1, DEPTH1, XAREA1, WPER1, HRAD1, FMANN1
INTEGER :: JJ,J, JBU1, JMAX

! FIRST, BRACKETING ROOT
X1=0.0001
X2=1.0
JMAX=50
CALL MANNINGS_EQN2(JBU1, FLOW,X1,FUNCVAL1)
CALL MANNINGS_EQN2(JBU1, FLOW,X2,FUNCVAL2)

DO JJ=1,JMAX
  IF(FUNCVAL1*FUNCVAL2 > 0.0)THEN
    IF(ABS(FUNCVAL1) < ABS(FUNCVAL2))THEN
      X1=X1/2.0
      CALL MANNINGS_EQN2(JBU1, FLOW,X1,FUNCVAL1)
    ELSE
      X2=X2+1.5*(X2-X1)

```

```

        CALL MANNINGS_EQN2(JBU1, FLOW,X2,FUNCVAL2)
      END IF
    ELSE
      EXIT
    END IF
  END DO

! FINDING ROOT BY BISECTION
  XACC=0.0005
  CALL MANNINGS_EQN2(JBU1, FLOW,X2,FMID)
  CALL MANNINGS_EQN2(JBU1, FLOW,X1,FUNC1)
! IF(FUNC1*FMID.GE.0.) PAUSE 'ROOT MUST BE BRACKETED IN RTBIS'
  IF(FUNC1.LT.0.)THEN
    RTBIS=X1
    DX=X2-X1
  ELSE
    RTBIS=X2
    DX=X1-X2
  ENDIF
  DO J=1,JMAX
    DX=DX*.5
    XMID=RTBIS+DX
    CALL MANNINGS_EQN2(JBU1, FLOW,XMID,FMID)
    IF(FMID.LE.0.)RTBIS=XMID
    IF(ABS(DX).LT.XACC .OR. FMID.EQ.0.)THEN
      ! calculate qloop1 & qloop2, basing on water level
      I=UHS(JB)
      WSURF1=RTBIS+EL(KBI(I)+1,I)
      CALL XSECTIONAL_AREA(WSURF1,XAREA1,KTTOP1)
      DEPTH1=RTBIS
      WPER1=0.5*(B(KBI(I),I)+B(KTTOP1,I))+2.0*DEPTH1
      HRAD1=XAREA1/WPER1
      IF(MANNINGS_N(JW))THEN
        FMANN1=FRIC(I)
      ELSE
        FMANN1=HRAD1**0.16666667/FRIC(I)
      END IF
      QLOOP1=XAREA1*HRAD1**0.6667*SLOPE(JBU1)**0.5/FMANN1

      I=US(JB)
      WSURF2=WSURF1
      CALL XSECTIONAL_AREA(WSURF2,XAREA2,KTTOP2)
      DEPTH2=WSURF2-EL(KBI(I)+1,I)
      WPER2=0.5*(B(KBI(I),I)+B(KTTOP2,I))+2.0*DEPTH2
      HRAD2=XAREA2/WPER2
      IF(MANNINGS_N(JW))THEN
        FMANN2=FRIC(I)
      ELSE
        FMANN2=HRAD2**0.16666667/FRIC(I)
      END IF
      QLOOP2=XAREA2*HRAD2**0.6667*SLOPE(JB)**0.5/FMANN2

      RETURN
    END IF
  END DO
! PAUSE 'TOO MANY BISECTIONS IN RTBIS'
END SUBROUTINE LOOP_FLOW_DIVIDE

!*****
*****

```



```

!**      SUBROUTINE NORMAL_DEPTH**
!*****
*****

SUBROUTINE NORMAL_DEPTH(FLOW)

USE GLOBAL; USE GEOMC ; USE MAIN, ONLY: KBI

INTEGER, PARAMETER ::JMAX=40
REAL(R8)  :: FLOW
REAL :: X1, X2, FUNCVAL1, FUNCVAL2, XACC, FMID, FUNC1, RTBIS, DX, XMID
INTEGER :: JJ,J

! FIRST, BRACKETING ROOT
X1=0.001
X2=1.0
CALL MANNINGS_EQN(FLOW,X1,FUNCVAL1)
CALL MANNINGS_EQN(FLOW,X2,FUNCVAL2)

DO JJ=1,JMAX
  IF(FUNCVAL1*FUNCVAL2 > 0.0)THEN
    IF(ABS(FUNCVAL1) < ABS(FUNCVAL2))THEN
      X1=X1/2.0
      CALL MANNINGS_EQN(FLOW,X1,FUNCVAL1)
    ELSE
      X2=X2+1.5*(X2-X1)
      CALL MANNINGS_EQN(FLOW,X2,FUNCVAL2)
    END IF
  ELSE
    EXIT
  END IF
END DO

! FINDING ROOT BY BISECTION
XACC=0.01
CALL MANNINGS_EQN(FLOW,X2,FMID)
CALL MANNINGS_EQN(FLOW,X1,FUNC1)
! IF(FUNC1*FMID.GE.0.) PAUSE 'ROOT MUST BE BRACKETED IN RTBIS'
IF(FUNC1.LT.0.)THEN
  RTBIS=X1
  DX=X2-X1
ELSE
  RTBIS=X2
  DX=X1-X2
ENDIF
DO J=1,JMAX
  DX=DX*.5
  XMID=RTBIS+DX
  CALL MANNINGS_EQN(FLOW,XMID,FMID)
  IF(FMID.LE.0.)RTBIS=XMID
  IF(ABS(DX).LT.XACC .OR. FMID.EQ.0.)THEN
    ELWS(I)=RTBIS+EL(KBI(I)+1,I)      !CB 4/5/13 !WX 6/12/13
    RETURN
  END IF
END DO
! PAUSE 'TOO MANY BISECTIONS IN RTBIS'
END SUBROUTINE NORMAL_DEPTH

```

```

!*****
*****
!**      SUBROUTINE MANNINGS EQUATION      **
!*****
*****

```

```

SUBROUTINE MANNINGS_EQN(FLOW,DEPTH,FUNCVALUE)

```

```

USE GLOBAL; USE GEOMC; USE EDDY; USE LOGICC; USE MAIN, ONLY: KBI

```

```

REAL(R8) :: FLOW
REAL    :: WSURF, DEPTH, XAREA, WPER, HRAD, FMANN, FUNCVALUE

```

```

!  WSURF=EL(KB(I)-1,I)+DEPTH
WSURF=EL(KBI(I)+1,I)+DEPTH ! CB 7/7/10      !KBMIN WX 6/12/13
CALL XSECTIONAL_AREA(WSURF,XAREA,KTTOP)
WPER=0.5*(B(KBI(I),I)+B(KTTOP,I))+2.0*DEPTH
HRAD=XAREA/WPER
IF(MANNINGS_N(JW))THEN
  FMANN=FRIC(I)
ELSE
  FMANN=HRAD**0.16666667/FRIC(I)
END IF
FUNCVALUE=FLOW-XAREA*HRAD**0.6667*SLOPE(JB)**0.5/FMANN

```

```

RETURN
END SUBROUTINE MANNINGS_EQN

```

```

!*****
*****
!**      SUBROUTINE MANNINGS EQUATION 2      **
!*****
*****

```

```

!*****used to determine loop branch flow rate, only used in SUBROUTINE LOOP_FLOW_DIVIDE !wx
8/23/13

```

```

SUBROUTINE MANNINGS_EQN2(JBU1, FLOW,DEPTH1,FUNCVALUE) !depth is the depth of main branch

```

```

USE GLOBAL; USE GEOMC; USE EDDY; USE LOGICC; USE MAIN, ONLY: KBI

```

```

REAL(R8) :: FLOW
REAL    :: WSURF1, DEPTH1, XAREA1, WPER1, HRAD1, FMANN1, FUNCVALUE
REAL    :: WSURF2, DEPTH2, XAREA2, WPER2, HRAD2, FMANN2
INTEGER :: KTTOP1, KTTOP2, JBU1

```

```

!FOR SEGMENT UHS(JB)
I=UHS(JB)
WSURF1=EL(KBI(I)+1,I)+DEPTH1
CALL XSECTIONAL_AREA(WSURF1,XAREA1,KTTOP1)
WPER1=0.5*(B(KBI(I),I)+B(KTTOP1,I))+2.0*DEPTH1
HRAD1=XAREA1/WPER1
IF(MANNINGS_N(JW))THEN
  FMANN1=FRIC(I)
ELSE
  FMANN1=HRAD1**0.16666667/FRIC(I)
END IF

```

```

!FOR SEGMENT US(JB)
I=US(JB)
WSURF2=WSURF1
CALL XSECTIONAL_AREA(WSURF2,XAREA2,KTTOP2)

```

```

DEPTH2=WSURF2-EL(KBI(I)+1,I)
WPER2=0.5*(B(KBI(I),I)+B(KTTOP2,I))+2.0*DEPTH2
HRAD2=XAREA2/WPER2
IF(MANNINGS_N(JW))THEN
  FMANN2=FRIC(I)
ELSE
  FMANN2=HRAD**0.16666667/FRIC(I)
END IF

FUNCVALUE=FLOW-XAREA1*HRAD1**0.6667*SLOPE(JBU1)**0.5/FMANN1-
XAREA2*HRAD2**0.6667*SLOPE(JB)**0.5/FMANN2

RETURN
END SUBROUTINE MANNINGS_EQN2

!*****
*****
!**      SUBROUTINE CROSS SECTIONAL AREA      **
!*****
*****

SUBROUTINE XSECTIONAL_AREA(WSURF,XAREA,KTTOP)                                !USED FOR WATER
LEVEL CALCULATION

USE GLOBAL; USE GEOMC; USE MAIN; USE INITIALVELOCITY

REAL :: XAREA, WSURF ! KTTOP   SW 4/5/13
INTEGER :: KTTOP

!  KTTOP = 2
DO K=2,KMX-1
  IF(EL(K,I) < WSURF)THEN
    KTTOP=K-1
    EXIT
  END IF
  KTTOP=K   ! CB 8/10/10
END DO
!  DO WHILE (EL(KTTOP,I) > WSURF)
!    KTTOP = KTTOP+1
!  END DO
XAREA=(WSURF-EL(KTTOP+1,I)) * BSAVE(KTTOP,I)
DO K=KTTOP+1,KBI(I)          !KBMIN  WX 6/12/13
  XAREA = XAREA+BSAVE(K,I)*H(K,JW)
END DO

RETURN
END SUBROUTINE XSECTIONAL_AREA

!*****
*****
!**      SUBROUTINE CROSS SECTIONAL AREA 2      **NOT USED
!**
!*****
*****

SUBROUTINE XSECTIONAL_AREA2(WSURF,XAREA)

USE GLOBAL; USE GEOMC; USE MAIN; USE INITIALVELOCITY
IMPLICIT NONE
REAL :: XAREA, XAREA1,XAREA2, WSURF ! KTTOP   SW 4/5/13

```

```

      INTEGER :: KTTOP1, KTTOP2

!   KTTOP = 2
      DO K=2,KMX-1
        IF(EL(K,I) < WSURF)THEN
          KTTOP1=K-1
          EXIT
        END IF
        KTTOP1=K   ! CB 8/10/10
      END DO
      DO K=2,KMX-1
        IF(EL(K,I+1) < elws(i+1))THEN
          KTTOP2=K-1
          EXIT
        END IF
        KTTOP2=K   ! CB 8/10/10
      END DO
!   DO WHILE (EL(KTTOP,I) > WSURF)
!     KTTOP = KTTOP+1
!   END DO
      XAREA1=(WSURF-EL(KTTOP1+1,I)) / COSA(JB) * BSAVE(KTTOP1,I)   !       XAREA1=(WSURF-
EL(KTTOP1+1,I)) * BSAVE(KTTOP1,I)
      XAREA2=(ELWS(I+1)-EL(KTTOP2+1,I+1)) / COSA(JB) * B(KTTOP2,I+1) !       XAREA2=(ELWS(I+1)-
EL(KTTOP2+1,I+1)) * BSAVE(KTTOP2,I+1)
      XAREA=XAREA1 +(XAREA2 -XAREA1)/(0.5*(DLX(I)+DLX(I+1)))*0.5*DLX(I)
      DO K=KTTOP1+1,KBMIN(I)   !KBI(I) SW 5/21/13
        XAREA = XAREA+BH(K,I) +(BH(K,I+1) -BH(K,I))/(0.5*(DLX(I)+DLX(I+1)))*0.5*DLX(I)
      END DO
!     BHR(K,I) = BH(K,I) +(BH(K,I+1) -BH(K,I))/(0.5*(DLX(I)+DLX(I+1)))*0.5*DLX(I)
      RETURN
    END SUBROUTINE XSECTIONAL_AREA2
!*****
!*****
!**          S U B R O U T I N E   C R O S S   S E C T I O N A L   A R E A   3          ***NOT USED
!**
!*****
!*****

SUBROUTINE XSECTIONAL_AREA3(XAREA)

  USE GLOBAL; USE GEOMC; USE MAIN; USE INITIALVELOCITY
  IMPLICIT NONE
  REAL :: XAREA, XAREA1,XAREA2, WSURF ! KTTOP   SW 4/5/13

  XAREA=0.0
  DO K=KT,KBMIN(I)   !KBI(I) SW 5/21/13
    XAREA = XAREA + BHR1(K,I)
  END DO
!   BHR(K,I) = BH(K,I) +(BH(K,I+1) -BH(K,I))/(0.5*(DLX(I)+DLX(I+1)))*0.5*DLX(I)
  RETURN
  END SUBROUTINE XSECTIONAL_AREA3
!*****
!*****
!**          S U B R O U T I N E   C R O S S   S E C T I O N A L   A R E A   4          **
!*****
!*****

SUBROUTINE XSECTIONAL_AREA4(WSURF,XAREA)                                !USED FOR VELOCITY
CALCULATION

```

```

USE GLOBAL; USE GEOMC; USE MAIN; USE INITIALVELOCITY
IMPLICIT NONE
REAL :: XAREA, XAREA1, XAREA2, WSURF ! KTTOP SW 4/5/13
INTEGER :: KTTOP1, KTTOP2

! KTTOP = 2
!***find the tope layer of i and i+1 that have water: kttop2, kttop2
DO K=2, KMX-1
  IF(EL(K,I) < WSURF) THEN
    KTTOP1=K-1
    EXIT
  END IF
  KTTOP1=K ! CB 8/10/10
END DO
DO K=2, KMX-1
  IF(EL(K,I+1) < elws(i+1)) THEN
    KTTOP2=K-1
    EXIT
  END IF
  KTTOP2=K ! CB 8/10/10
END DO
! DO WHILE (EL(KTTOP,I) > WSURF)
! KTTOP = KTTOP+1
! END DO

XAREA1=(WSURF-EL(KTTOP1+1,I)) / COSA(JB) * BSAVE(KTTOP1,I) ! XAREA1=(WSURF-
EL(KTTOP1+1,I)) * BSAVE(KTTOP1,I)
DO K=KTTOP1+1, KT
  XAREA1=XAREA1+H(K,JW) * BNEW(K,I)
END DO

XAREA2=(ELWS(I+1)-EL(KTTOP2+1,I+1)) / COSA(JB) * B(KTTOP2,I+1) ! XAREA2=(ELWS(I+1)-
EL(KTTOP2+1,I+1)) * BSAVE(KTTOP2,I+1)
DO K=KTTOP2+1, KT
  XAREA2=XAREA2+H(K,JW) * BNEW(K,I+1)
END DO

XAREA=XAREA1 +(XAREA2 -XAREA1)/(0.5*(DLX(I)+DLX(I+1)))*0.5*DLX(I)
DO K=KT+1, KBMIN(I) !KBI(I) SW 5/21/13
  XAREA = XAREA+BH(K,I) +(BH(K,I+1) -BH(K,I))/(0.5*(DLX(I)+DLX(I+1)))*0.5*DLX(I)
END DO
! BHR(K,I) = BH(K,I) +(BH(K,I+1) -BH(K,I))/(0.5*(DLX(I)+DLX(I+1)))*0.5*DLX(I)
RETURN
END SUBROUTINE XSECTIONAL_AREA4
!*****
!*****
!** SUBROUTINE INITIAL HORIZONTAL VELOCITY **
!*****
!*****

SUBROUTINE INITIAL_U_VELOCITY

USE GLOBAL; USE GEOMC
USE INITIALVELOCITY

REAL :: XAREA !, WSURF
INTEGER :: K

DO JW=1, NWB
  KT = KTWB(JW)

```

```

DO JB=BS(JW),BE(JW)
IF (SLOPE(JB) > 0.0 .AND. .NOT. LOOP_BRANCH(JB)) THEN
IU = CUS(JB)
ID = DS(JB)
DO I=IU,ID
WSURF=ELWS(I)
CALL XSECTIONAL_AREA2(WSURF,XAREA)
! DO K=KT,KBMIN(I) !KBI(I) SW 5/21/13
! XAREA = XAREA + BHR1(K,I)
! END DO
UAVG(I)=QSSI(I)/XAREA
DO K=KT,KBMIN(I) ! change KB to KBMIN
U(K,I)=UAVG(I)
END DO
END DO

! WSURF=ELWS(IU) ! NEEDS REFINEMENT FOR CASES WHERE A TRIB ENTERS !WX
4/11/13 I=IU !set i=iu so that there will not be error at the end of branch (exceeding imax) WX 6/12/13
WSURF=ELWS(I)
CALL XSECTIONAL_AREA2(WSURF,XAREA)
UAVG(IU)=QSSI(IU)/XAREA
DO K=KT,KBMIN(IU-1) ! change KB to KBMIN
U(K,IU-1)=UAVG(IU)
END DO
! DO K=KT,KBMIN(ID+1) ! change KB to KBMIN
! U(K,ID+1)=UAVG(ID)
! END DO

END IF
END DO
END DO

RETURN
END SUBROUTINE INITIAL_U_VELOCITY

```

hydroinout.F90

SUBROUTINE HYDROINOUT

USE MAIN

USE GLOBAL; USE NAMESC; USE GEOMC; USE LOGICC; USE PREC; USE SURFHE; USE KINETIC;
USE SHADEC; USE EDDY

USE STRUCTURES; USE TRANS; USE TVDC; USE SELWC; USE GDAYC; USE SCREENC; USE TDGAS;
USE RSTART

USE MACROPHYTEC; USE POROSITYC; USE ZOOPLANKTONC ; USE INITIALVELOCITY

IMPLICIT NONE

EXTERNAL RESTART_OUTPUT

INTEGER :: JBU, JBD, JLAT, JWU

REAL(R8) :: ELW, CGAS, TM, VPTG, DTVL, RHOTR, VQTR, VQTRI, QTRFR, AKB, FW

REAL(R8) :: TSUM, QSUM

!*****

!** Task 2.1: Hydrodynamic sources/sinks **
!*****

QINSUM = 0.0; TINSUM = 0.0; CINSUM = 0.0; UXBR = 0.0; UYBR = 0.0

DO JW=1,NWB

KT = KTWB(JW)

DO JB=BS(JW),BE(JW)

IU = CUS(JB)

ID = DS(JB)

TSUM = 0.0; CSUM = 0.0; QSUM(JB) = 0.0; QOUT(:,JB) = 0.0; TOUT(JB)=0.0; COUT(:,JB)=0.0

!***** Densities

DO I=IU-1,ID+1

DO K=KT,KB(I)

TISS(K,I) = 0.0

DO JS=1,NSS

TISS(K,I) = TISS(K,I)+SS(K,I,JS)

END DO

RHO(K,I) = DENSITY(T2(K,I),DMAX1(TDS(K,I),0.0D0),DMAX1(TISS(K,I),0.0D0))

END DO

END DO

! v3.5 deleted pumpback code from v3.2

DO JS=1,NSTR(JB)

IF (QSTR(JS,JB) /= 0.0) THEN

CALL DOWNSTREAM_WITHDRAWAL (JS)

END IF

END DO

DO K=KT,KB(ID)

QSUM(JB) = QSUM(JB) + QOUT(K,JB)

TSUM = TSUM + QOUT(K,JB)*T2(K,ID)

CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QOUT(K,JB)*C2(K,ID,CN(1:NAC))

END DO

IF (QSUM(JB) /= 0.0) THEN

TOUT(JB) = TSUM / QSUM(JB)

COUT(CN(1:NAC),JB) = CSUM(CN(1:NAC))/QSUM(JB)

END IF

IF (QSUM(JB) /= 0.0 .AND. DAM_OUTFLOW(JB)) THEN

TINSUM(JBDAM(JB)) = (TSUM + QINSUM(JBDAM(JB))*TINSUM(JBDAM(JB)))

/(QSUM(JB) &
+ QINSUM(JBDAM(JB)))

!TC 08/03/04

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      CINSUM(CN(1:NAC),JBDAM(JB))
(CSUM(CN(1:NAC))+QINSUM(JBDAM(JB))*CINSUM(CN(1:NAC),JBDAM(JB)))/(QSUM(JB)      &
      +QINSUM(JBDAM(JB)))
      QINSUM(JBDAM(JB))      = QINSUM(JBDAM(JB))+QSUM(JB)
      END IF
      END DO
      END DO
      ILAT = 0
      JWW = NWD
      withdrawals = jww > 0
      JTT = NTR
      tributaries = jtt > 0
      JSS = NSTR
      IF (SPILLWAY) THEN
      ! CALL SPILLWAY_FLOW
      DO JS=1,NSP

!***** Positive flows
      QSP(JS)=QSSI(IUSP(JS))  ! SW

      JLAT = 0
      JBU = JBUSP(JS)
      JBD = JBDSP(JS)
      IF (QSP(JS) >= 0.0) THEN
      IF (LATERAL_SPILLWAY(JS)) THEN
      !
      JLAT = 1
      JWW = JWW+1
      IWD(JWW) = IUSP(JS)
      QWD(JWW) = QSP(JS)
      KTWD(JWW) = KTUSP(JS)
      KBWD(JWW) = KBUSP(JS)
      EWD(JWW) = ESP(JS)
      JBWD(JWW) = JBU
      I = MAX(CUS(JBWD(JWW)),IWD(JWW))
      JB = JBWD(JWW)
      JW = JWUSP(JS)
      KT = KTWB(JW)
      CALL LATERAL_WITHDRAWAL (JWW)
      DO K=KTW(JWW),KBW(JWW)
      QSS(K,I) = QSS(K,I)-QSW(K,JWW)
      END DO
      ELSE
      JSS(JBU) = JSS(JBU)+1
      KTSW(JSS(JBU),JBU) = KTUSP(JS)
      KBSW(JSS(JBU),JBU) = KBUSP(JS)
      JB = JBU
      POINT_SINK(JSS(JBU),JBU) = .TRUE.
      ID = IUSP(JS)
      QSTR(JSS(JBU),JBU) = QSP(JS)
      ESTR(JSS(JBU),JBU) = ESP(JS)
      KT = KTWB(JWUSP(JS))
      JW = JWUSP(JS)
      CALL DOWNSTREAM_WITHDRAWAL(JSS(JBU))
      ! moved code
      QSUM(JB) = 0.0; TSUM = 0.0; CSUM = 0.0
      DO K=KT,KB(ID)
      QSUM(JB) = QSUM(JB)+QOUT(K,JB)
      TSUM = TSUM+QOUT(K,JB)*T2(K,ID)
      DO JC=1,NAC

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      IF (CN(JC)==NDO .AND. CAC(NDO) == '    ON' .AND. GASSPC(JS) == '    ON' .AND. QSP(JS) >
0.0) THEN      ! MM 5/21/2009
      T2R4=T2(K,ID)
      CGAS=C2(K,ID,CN(JC))
      CALL TOTAL DISSOLVED GAS (PALT(ID),0,JS,T2R4,CGAS)
      CSUM(CN(JC)) = CSUM(CN(JC))+QOUT(K,JB)*CGAS
      ELSE
      CSUM(CN(JC)) = CSUM(CN(JC))+QOUT(K,JB)*C2(K,ID,CN(JC))
      END IF
    END DO
  END DO
  IF (QSUM(JB) /= 0.0) THEN
    TOUT(JB)      = TSUM      /QSUM(JB)
    COUT(CN(1:NAC),JB) = CSUM(CN(1:NAC))/QSUM(JB)
  END IF
! moved code
  IF (IDSP(JS) /= 0 .AND. US(JBD) == IDSP(JS)) THEN
    QSUMM = 0.0; TSUM = 0.0; CSUM = 0.0
    DO K=KT,KB(ID)
      QSUMM = QSUMM+QNEW(K)
      TSUM = TSUM+QNEW(K)*T2(K,ID)
      DO JC=1,NAC
        IF (CN(JC)==NDO .AND. CAC(NDO) == '    ON' .AND. GASSPC(JS) == '    ON' .AND. QSP(JS) >
0.0) THEN      ! MM 5/21/2009
          T2R4=T2(K,ID)
          CGAS=C2(K,ID,CN(JC))
          CALL TOTAL DISSOLVED GAS (PALT(ID),0,JS,T2R4,CGAS)
          CSUM(CN(JC)) = CSUM(CN(JC))+QNEW(K)*CGAS
          ELSE
          CSUM(CN(JC)) = CSUM(CN(JC))+QNEW(K)*C2(K,ID,CN(JC))
          END IF
        END DO
      END DO
      IF (QSUMM /= 0.0) THEN
        TINSUM(JBD)      = (TSUM      +QINSUM(JBD)*TINSUM(JBD))      /(QSUMM+QINSUM(JBD))
        CINSUM(CN(1:NAC),JBD)
(CSUM(CN(1:NAC))+QINSUM(JBD)*CINSUM(CN(1:NAC),JBD))/(QSUMM+QINSUM(JBD))
        QINSUM(JBD)      = QINSUM(JBD)+QSUMM
      END IF
    END IF
    !
    ! QSUM(JB) = 0.0; TSUM = 0.0; CSUM = 0.0
    ! DO K=KT,KB(ID)
    !   QSUM(JB) = QSUM(JB)+QOUT(K,JB)
    !   TSUM = TSUM+QOUT(K,JB)*T2(K,ID)
    !   DO JC=1,NAC
    !     IF (CN(JC)==NDO .AND. CAC(NDO) == '    ON' .AND. GASSPC(JS) == '    ON' .AND. QSP(JS) >
0.0) THEN      ! MM 5/21/2009
    !       T2R4=T2(K,ID)
    !       CGAS=C2(K,ID,CN(JC))
    !       CALL TOTAL DISSOLVED GAS (PALT(ID),0,JS,T2R4,CGAS)
    !       CSUM(CN(JC)) = CSUM(CN(JC))+QOUT(K,JB)*CGAS
    !       ELSE
    !       CSUM(CN(JC)) = CSUM(CN(JC))+QOUT(K,JB)*C2(K,ID,CN(JC))
    !       END IF
    !     END DO
    !   END DO
    !   IF (QSUM(JB) /= 0.0) THEN
    !     TOUT(JB)      = TSUM      /QSUM(JB)
    !     COUT(CN(1:NAC),JB) = CSUM(CN(1:NAC))/QSUM(JB)
    !   END IF
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!   END IF
!   IF (IDSP(JS) /= 0) THEN
ELSEIF (IDSP(JS) /= 0) THEN
!   IF (US(JBD) /= IDSP(JS) .OR. HEAD_FLOW(JBD) .OR. UP_HEAD(JBD)) THEN
      JTT      = JTT+1
      QTR(JTT)  = QSP(JS)
      ITR(JTT)  = IDSP(JS)
      PLACE_QTR(JTT) = PDSPC(JS) == ' DENSITY'
      SPECIFY_QTR(JTT) = PDSPC(JS) == ' SPECIFY'
      IF (SPECIFY_QTR(JTT)) THEN
        ELTRT(JTT) = ETDSP(JS)
        ELTRB(JTT) = EBDSP(JS)
      END IF
      JBTR(JTT) = JBD
!   IF (JLAT == 1) THEN
!     CSUM(CN(1:NAC)) = 0.0; TSUM = 0.0; QSUMM = 0.0
!     DO K=KTW(JWW),KBW(JWW)
!       QSUMM      = QSUMM      +QSW(K,JWW)
!       TSUM       = TSUM       +QSW(K,JWW)*T2(K,IWD(JWW))
!       CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QSW(K,JWW)*C2(K,IWD(JWW),CN(1:NAC))
!     END DO
!     IF(QSUMM == 0.0)THEN
!       TTR(JTT)=0.0
!       CTR(:,JTT)=0.0
!     ELSE
!       TTR(JTT) = TSUM/QSUMM
!       DO JC=1,NAC
!         CTR(CN(JC),JTT) = CSUM(CN(JC))/QSUMM
!         IF (CN(JC) == NDO .AND. GASSPC(JS) == ' ON' .AND. QSP(JS) > 0.0) THEN
!           TDG_SPILLWAY(JWW,JS) = .TRUE.
!           CALL TOTAL_DISSOLVED_GAS (PALT(ITR(JTT)),0,JS,TTR(JTT),CTR(CN(JC),JTT))
!         END IF
!       END DO
!     ENDIF
!   ELSE
      TTR(JTT) = TOUT(JB)
      DO JC=1,NAC
        CTR(CN(JC),JTT) = COUT(CN(JC),JB)
        IF (CN(JC) == NDO .AND. GASSPC(JS) == ' ON' .AND. QSP(JS) > 0.0) THEN
          CALL TOTAL_DISSOLVED_GAS (PALT(ITR(JTT)),0,JS,TTR(JTT),CTR(CN(JC),JTT))
        END IF
      END DO
!   END IF
!   ELSE IF (LATERAL_SPILLWAY(JS)) THEN
!     TSUM = 0.0; QSUMM = 0.0; CSUM = 0.0
!     ILAT(JWW) = 1
!     DO K=KTW(JWW),KBW(JWW)
!       QSUMM      = QSUMM      +QSW(K,JWW)
!       TSUM       = TSUM       +QSW(K,JWW)*T2(K,IWD(JWW))
!       CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QSW(K,JWW)*C2(K,IWD(JWW),CN(1:NAC))
!     END DO
!     TINSUM(JBD)      = (TINSUM(JBD)      *QINSUM(JBD)+TSUM)      /(QSUMM+QINSUM(JBD))
!     CINSUM(CN(1:NAC),JBD) =
(CINSUM(CN(1:NAC),JBD)*QINSUM(JBD)+CSUM(CN(1:NAC)))/(QSUMM+QINSUM(JBD))
!     QINSUM(JBD)      = QSUMM      +QINSUM(JBD)
!     ELSE IF (CAC(NDO) == ' ON' .AND. GASSPC(JS) == ' ON' .AND. QSP(JS) > 0.0) THEN
!       TDG_SPILLWAY(JWW,JS) = .TRUE.
!     END IF
!   END IF
!   ELSE IF (QSP(JS) < 0.0) THEN

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JTT      = JTT+1
JWW      = JWW+1
IWD(JWW) = IDSP(JS)
ITR(JTT) = IUSP(JS)
QTR(JTT) = -QSP(JS)
QWD(JWW) = -QSP(JS)
KTWD(JWW) = KTDSP(JS)
KBWD(JWW) = KBDSP(JS)
EWD(JWW) = ESP(JS)
PLACE_QTR(JTT) = PUSPC(JS) == ' DENSITY'
SPECIFY_QTR(JTT) = PUSPC(JS) == ' SPECIFY'
IF (SPECIFY_QTR(JTT)) THEN
  ELTRT(JTT) = ETUSP(JS)
  ELTRB(JTT) = EBUSP(JS)
END IF
JBTR(JTT) = JBU
JBWD(JWW) = JBD
I      = MAX(CUS(JBWD(JWW)),IWD(JWW))
JB     = JBWD(JWW)
JW     = JWDSP(JS)
KT     = KTWB(JW)
CALL LATERAL_WITHDRAWAL (JWW)
DO K=KTW(JWW),KBW(JWW)
  QSS(K,I) = QSS(K,I)-QSW(K,JWW)
END DO
IF (IDSP(JS) /= 0) THEN
  TSUM = 0.0; QSUMM = 0.0; CSUM = 0.0
  DO K=KTW(JWW),KBW(JWW)
    QSUMM      = QSUMM      +QSW(K,JWW)
    TSUM       = TSUM       +QSW(K,JWW)*T2(K,IWD(JWW))
    CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QSW(K,JWW)*C2(K,IWD(JWW),CN(1:NAC))
  END DO
  TTR(JTT) = TSUM/QSUMM
  DO JC=1,NAC
    CTR(CN(JC),JTT) = CSUM(CN(JC))/QSUMM
    IF (CN(JC) == NDO .AND. GASSPC(JS) == '  ON' .AND. QSP(JS) > 0.0) THEN
      TDG_SPILLWAY(JWW,JS) = .TRUE.
      CALL TOTAL_DISSOLVED_GAS (PALT(I),0,JS,TTR(JTT),CTR(CN(JC),JTT))
    END IF
  END DO
  ELSE IF (CAC(NDO) == '  ON' .AND. GASSPC(JS) == '  ON' .AND. QSP(JS) > 0.0) THEN
    TDG_SPILLWAY(JWW,JS) = .TRUE.
  END IF
END IF
END DO
END IF
IF (PUMPS) THEN
  DO JP=1,NPU
    JLAT = 0
    JWU = JWUPU(JP)
    JBU = JBUPU(JP)
    JBD = JBDPU(JP)
    IF (LATERAL_PUMP(JP)) THEN
      ELW = EL(KTWB(JWU),IUPU(JP))-Z(IUPU(JP))*COSA(JBU)
      JWW = JWW+1
      JBWD(JWW) = JBU
      IWD(JWW) = IUPU(JP)
    ELSE
      ELW = EL(KTWB(JWU),IUPU(JP))-Z(IUPU(JP))*COSA(JBU)-SINA(JBU)*DLX(IUPU(JP))*0.5
      JSS(JBU) = JSS(JBU)+1
    END IF
  END DO
END IF

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END IF
IF (JDAY >= ENDFPU(JP)) PUMPON(JP) = .FALSE.
IF (JDAY >= STRTPU(JP) .AND. JDAY < ENDFPU(JP)) THEN
! CB 1/13/06

IF (ELW <= EOFFPU(JP)) PUMPON(JP) = .FALSE.
IF (ELW > EOFFPU(JP) .AND. QPU(JP) > 0.0) THEN
! CB 1/13/06
IF (ELW >= EONPU(JP)) PUMPON(JP) = .TRUE.
IF (PUMPON(JP)) THEN
IF (LATERAL_PUMP(JP)) THEN
JLAT = 1
QWD(JWW) = QPU(JP)
KTWD(JWW) = KTPU(JP)
KBWD(JWW) = KBPU(JP)
EWD(JWW) = EPU(JP)
I = MAX(CUS(JBWD(JWW)),IWD(JWW))
JB = JBWD(JWW)
JW = JWU
KT = KTWD(JW)
CALL LATERAL_WITHDRAWAL (JWW)
DO K=KTW(JWW),KBW(JWW)
QSS(K,I) = QSS(K,I)-QSW(K,JWW)
END DO
ELSE

KTSW(JSS(JBU),JBU) = KTPU(JP)
KBSW(JSS(JBU),JBU) = KBPU(JP)
JB = JBU
POINT_SINK(JSS(JBU),JBU) = .TRUE.
ID = IUPU(JP)
QSTR(JSS(JBU),JBU) = QPU(JP)
ESTR(JSS(JBU),JBU) = EPU(JP)
KT = KTWD(JWU)
JW = JWU
CALL DOWNSTREAM_WITHDRAWAL (JSS(JBU))
IF (IDPU(JP) /= 0 .AND. US(JBD) == IDPU(JP)) THEN
QSUMM = 0.0; TSUM = 0.0; CSUM = 0.0
DO K=KT,KB(ID)
QSUMM = QSUMM + QNEW(K)
TSUM = TSUM + QNEW(K)*T2(K,ID)
CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QNEW(K)*C2(K,ID,CN(1:NAC))
END DO
IF (QSUMM /= 0.0) THEN
TINSUM(JBD) = (TSUM +TINSUM(JBD))
*QINSUM(JBD))/(QSUMM+QINSUM(JBD))
CINSUM(CN(1:NAC),JBD) =
(CSUM(CN(1:NAC))+CINSUM(CN(1:NAC),JBD)*QINSUM(JBD))/(QSUMM+QINSUM(JBD))
QINSUM(JBD) = QINSUM(JBD) +QSUMM
END IF
END IF
QSUM(JB) = 0.0; TSUM = 0.0; CSUM = 0.0
DO K=KT,KB(ID)
QSUM(JB) = QSUM(JB) +QOUT(K,JB)
TSUM = TSUM +QOUT(K,JB)*T2(K,ID)
CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QOUT(K,JB)*C2(K,ID,CN(1:NAC))
END DO
IF (QSUM(JB) /= 0.0) THEN
TOUT(JB) = TSUM /QSUM(JB)
COUT(CN(1:NAC),JB) = CSUM(CN(1:NAC))/QSUM(JB)
END IF
END IF
END IF

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!***** Positive flows

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JLAT = 0
JBU = JBUPI(JP)
JBD = JBDPI(JP)
IF (QPI(JP) >= 0.0) THEN
  IF (LATERAL_PIPE(JP)) THEN
    JLAT = 1
    JWW = JWW+1
    IWD(JWW) = IUPI(JP)
    QWD(JWW) = QPI(JP)
    KTWD(JWW) = KTUPI(JP)
    KBWD(JWW) = KBUPI(JP)
    EWD(JWW) = EUPI(JP)
    JBWD(JWW) = JBU
    I = MAX(CUS(JBWD(JWW)),IWD(JWW))
    JB = JBWD(JWW)
    JW = JWUPI(JP)
    KT = KTWB(JW)
    CALL LATERAL_WITHDRAWAL (JWW)
    DO K=KTW(JWW),KBW(JWW)
      QSS(K,I) = QSS(K,I)-QSW(K,JWW)
    END DO
  ELSE
    JSS(JBU) = JSS(JBU)+1
    KTSW(JSS(JBU),JBU) = KTDPI(JP)
    KBSW(JSS(JBU),JBU) = KBDPI(JP)
    JB = JBU
    POINT_SINK(JSS(JBU),JBU) = .TRUE.
    ID = IUPI(JP)
    QSTR(JSS(JBU),JBU) = QPI(JP)
    ESTR(JSS(JBU),JBU) = EUPI(JP)
    KT = KTWB(JWUPI(JP))
    JW = JWUPI(JP)
    CALL DOWNSTREAM_WITHDRAWAL(JSS(JBU))
    IF (IDPI(JP) /= 0 .AND. US(JBD) == IDPI(JP)) THEN
      QSUMM = 0.0; TSUM = 0.0; CSUM = 0.0
      DO K=KT,KB(ID)
        QSUMM = QSUMM + QNEW(K)
        TSUM = TSUM + QNEW(K)*T2(K,ID)
        CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QNEW(K)*C2(K,ID,CN(1:NAC))
      END DO
      IF (QSUMM /= 0.0) THEN
        TINSUM(JBD) = (TSUM + QINSUM(JBD)*TINSUM(JBD)) / (QSUMM+QINSUM(JBD))
        CINSUM(CN(1:NAC),JBD) =
(CSUM(CN(1:NAC))+QINSUM(JBD)*CINSUM(CN(1:NAC),JBD))/(QSUMM+QINSUM(JBD))
        QINSUM(JBD) = QINSUM(JBD) + QSUMM
      END IF
    END IF
    QSUM(JB) = 0.0; TSUM = 0.0; CSUM = 0.0
    DO K=KT,KB(ID)
      QSUM(JB) = QSUM(JB) + QOUT(K,JB)
      TSUM = TSUM + QOUT(K,JB)*T2(K,ID)
      CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QOUT(K,JB)*C2(K,ID,CN(1:NAC))
    END DO
    IF (QSUM(JB) /= 0.0) THEN
      TOUT(JB) = TSUM / QSUM(JB)
      COUT(CN(1:NAC),JB) = CSUM(CN(1:NAC))/QSUM(JB)
    END IF
  END IF

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IF (IDPI(JP) /= 0) THEN
  IF (US(JBD) /= IDPI(JP) .OR. HEAD_FLOW(JBD) .OR. UP_HEAD(JBD)) THEN
    JTT      = JTT+1
    QTR(JTT) = QPI(JP)
    ITR(JTT) = IDPI(JP)
    PLACE_QTR(JTT) = PDPIC(JP) == ' DENSITY'
    SPECIFY_QTR(JTT) = PDPIC(JP) == ' SPECIFY'
    IF (SPECIFY_QTR(JTT)) THEN
      ELTRT(JTT) = ETDPI(JP)
      ELTRB(JTT) = EBDPI(JP)
    END IF
    JBTR(JTT) = JBD
    IF (JLAT == 1) THEN
      TSUM = 0.0; QSUMM = 0.0; CSUM(CN(1:NAC)) = 0.0
      DO K=KTW(JWW),KBW(JWW)
        QSUMM      = QSUMM      +QSW(K,JWW)
        TSUM       = TSUM       +QSW(K,JWW)*T2(K,IWD(JWW))
        CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QSW(K,JWW)*C2(K,IWD(JWW),CN(1:NAC))
      END DO
      TTR(JTT)      = TSUM      /QSUMM
      CTR(CN(1:NAC),JTT) = CSUM(CN(1:NAC))/QSUMM
    ELSE
      TTR(JTT)      = TOUT(JB)
      CTR(CN(1:NAC),JTT) = COUT(CN(1:NAC),JB)
    END IF
  ELSE
    IF (LATERAL_PIPE(JP)) THEN
      TSUM = 0.0; QSUMM = 0.0; CSUM = 0.0
      ILAT(JWW) = 1
      JB = JBD
      DO K=KTW(JWW),KBW(JWW)
        QSUMM      = QSUMM      +QSW(K,JWW)
        TSUM       = TSUM       +QSW(K,JWW)*T2(K,IWD(JWW))
        CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QSW(K,JWW)*C2(K,IWD(JWW),CN(1:NAC))
      END DO
      TINSUM(JB)      = (TINSUM(JB)      *QINSUM(JB)+TSUM)      /(QSUMM+QINSUM(JB))
      CINSUM(CN(1:NAC),JB)
      (CINSUM(CN(1:NAC),JB)*QINSUM(JB)+CSUM(CN(1:NAC)))/(QSUMM+QINSUM(JB)) =
      QINSUM(JB)      = QSUMM      +QINSUM(JB)
    END IF
  END IF
END IF
ELSE
  JTT      = JTT+1
  JWW      = JWW+1
  IWD(JWW) = IDPI(JP)
  ITR(JTT) = IUPI(JP)
  QTR(JTT) = -QPI(JP)
  QWD(JWW) = -QPI(JP)
  KTWD(JWW) = KTDPI(JP)
  KBWD(JWW) = KBDPI(JP)
  EWD(JWW) = EDPI(JP)
  PLACE_QTR(JTT) = PUPIC(JP) == ' DENSITY'
  SPECIFY_QTR(JTT) = PUPIC(JP) == ' SPECIFY'
  IF (SPECIFY_QTR(JTT)) THEN
    ELTRT(JTT) = ETUPI(JP)
    ELTRB(JTT) = EBUPI(JP)
  END IF
  JBTR(JTT) = JBU
  JBWD(JWW) = JBD

```

```

I      = MAX(CUS(JBWD(JWW)),IWD(JWW))
JB      = JBWD(JWW)
JW      = JWDPI(JP)
KT      = KTWB(JW)
CALL LATERAL_WITHDRAWAL (JWW)
DO K=KTW(JWW),KBW(JWW)
  QSS(K,I) = QSS(K,I)-QSW(K,JWW)
END DO
IF (IDPI(JP) /= 0) THEN
  TSUM = 0.0; QSUMM = 0.0; CSUM = 0.0
  DO K=KTW(JWW),KBW(JWW)
    QSUMM      = QSUMM      +QSW(K,JWW)
    TSUM       = TSUM       +QSW(K,JWW)*T2(K,IWD(JWW))
    CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QSW(K,JWW)*C2(K,IWD(JWW),CN(1:NAC))
  END DO
  TTR(JTT)      = TSUM      /QSUMM
  CTR(CN(1:NAC),JTT) = CSUM(CN(1:NAC))/QSUMM
END IF
END IF
END DO
END IF
IF (GATES) THEN
!  CALL GATE_FLOW xxxx must set flow rate !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
  DO JG=1,NGT

!***** Positive flows
    QGT(JG)=QSSI(IUGT(JG)) ! sw

    JLAT = 0
    JBU = JBUGT(JG)
    JBD = JBDGT(JG)
    IF (QGT(JG) >= 0.0) THEN
      IF (LATERAL_GATE(JG)) THEN
!        JLAT = 1
        JWW = JWW+1
        IWD(JWW) = IUGT(JG)
        QWD(JWW) = QGT(JG)
        KTWD(JWW) = KTUGT(JG)
        KBWD(JWW) = KBUGT(JG)
        EWD(JWW) = EGT(JG)
        IF(DYNGTC(JG) == ' ZGT' .AND. GT2CHAR == 'EGT2ELEV')THEN          ! SW 2/25/11
          IF(EGT2(JG) /= 0.0)THEN
            EWD(JWW) = EGT2(JG)
          ENDIF
        ENDIF
        JBWD(JWW) = JBU
        I      = MAX(CUS(JBWD(JWW)),IWD(JWW))
        JW      = JWUGT(JG)
        JB      = JBWD(JWW)
        KT      = KTWB(JW)
        CALL LATERAL_WITHDRAWAL (JWW)
        DO K=KTW(JWW),KBW(JWW)
          QSS(K,I) = QSS(K,I)-QSW(K,JWW)
        END DO
        IF (IDGT(JG) /= 0) THEN
          CSUM(CN(1:NAC)) = 0.0; TSUM = 0.0; QSUMM = 0.0
          JTT = JTT+1          ! SW 4/1/09
          QTR(JTT) = QGT(JG)          ! SW 4/1/09
          ITR(JTT) = IDGT(JG)          ! SW 4/1/09
          PLACE_QTR(JTT) = PDGTC(JG) == 'DENSITY' ! SW 4/1/09
        END IF
      END IF
    END IF
  END DO

```



```

SPECIFY_QTR(JTT) = PDGTC(JG) == 'SPECIFY' ! SW 4/1/09
IF (SPECIFY_QTR(JTT)) THEN ! SW 4/1/09
  ELTRT(JTT) = ETDGT(JG) ! SW 4/1/09
  ELTRB(JTT) = EBDGT(JG) ! SW 4/1/09
END IF
JBTR(JTT) = JBD ! SW 4/1/09
DO K=KTW(JWW),KBW(JWW)
  QSUMM = QSUMM +QSW(K,JWW)
  TSUM = TSUM +QSW(K,JWW)*T2(K,IWD(JWW))
  CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QSW(K,JWW)*C2(K,IWD(JWW),CN(1:NAC))
END DO
IF(QSUMM==0.0)THEN
  TTR(JTT)=0.0
  CTR(:,JTT)=0.0
ELSE
  TTR(JTT) = TSUM/QSUMM
DO JC=1,NAC
  CTR(CN(JC),JTT) = CSUM(CN(JC))/QSUMM
  IF (CN(JC) == NDO .AND. GASGTC(JG) == ' ON' .AND. QGT(JG) > 0.0) THEN
    TDG_GATE(JWW,JG) = .TRUE.
    CALL TOTAL DISSOLVED GAS (PALT(ID),1,JG,TTR(JTT),CTR(CN(JC),JTT))
  END IF
END DO
ENDIF
ELSE IF (CAC(NDO) == ' ON' .AND. GASGTC(JG) == ' ON' .AND. QGT(JG) > 0.0) THEN
  TDG_GATE(JWW,JG) = .TRUE.
END IF
ELSE
  JSS(JBU) = JSS(JBU)+1
  KTSW(JSS(JBU),JBU) = KTUGT(JG)
  KBSW(JSS(JBU),JBU) = KBUGT(JG)
  JB = JBU
  POINT_SINK(JSS(JBU),JBU) = .TRUE.
  ID = IUGT(JG)
  ESTR(JSS(JBU),JBU) = EGT(JG)
  IF(DYNGTC(JG) == ' ZGT' .AND. GT2CHAR == 'EGT2ELEV')THEN ! SW 2/25/11
    IF(EGT2(JG) /= 0.0)THEN
      ESTR(JSS(JBU),JBU) = EGT2(JG)
    ENDIF
  ENDIF
  QSTR(JSS(JBU),JBU) = QGT(JG)
  KT = KTWB(JWUGT(JG))
  JW = JWUGT(JG)
  CALL DOWNSTREAM_WITHDRAWAL (JSS(JBU))
! moved code section from below
  QSUM(JB) = 0.0; TSUM = 0.0; CSUM = 0.0
  DO K=KT,KB(ID)
    QSUM(JB) = QSUM(JB)+QOUT(K,JB)
    TSUM = TSUM+QOUT(K,JB)*T2(K,ID)
  DO JC=1,NAC
    IF (CN(JC) == NDO .AND. CAC(NDO) == ' ON' .AND. GASGTC(JG) == ' ON' .AND. QGT(JG) >
0.0) THEN ! MM 5/21/2009
      T2R4=T2(K,ID)
      CGAS=C2(K,ID,CN(JC)) ! MM 5/21/2009
      CALL TOTAL DISSOLVED GAS (PALT(ID),1,JG,T2R4,CGAS)
      CSUM(CN(JC)) = CSUM(CN(JC))+QOUT(K,JB)*CGAS
    ELSE
      CSUM(CN(JC)) = CSUM(CN(JC))+QOUT(K,JB)*C2(K,ID,CN(JC))
    END IF
  END DO

```

```

END DO
IF (QSUM(JB) /= 0.0) THEN
  TOUT(JB) = TSUM / QSUM(JB)
  COUT(CN(1:NAC),JB) = CSUM(CN(1:NAC))/QSUM(JB)
END IF
! end code moved section
IF (IDGT(JG) /= 0 .AND. US(JBD) == IDGT(JG)) THEN
  QSUMM = 0.0
  TSUM = 0.0
  CSUM = 0.0
  DO K=KT,KB(ID)
    QSUMM = QSUMM+QNEW(K)
    TSUM = TSUM+QNEW(K)*T2(K,ID)
    DO JC=1,NAC
      IF (CN(JC) == NDO .AND. CAC(NDO) == ' ON' .AND. GASGTC(JG) == ' ON' .AND. QGT(JG) >
0.0) THEN ! MM 5/21/2009
        T2R4=T2(K,ID)
        CGAS=C2(K,ID,CN(JC)) ! MM 5/21/2009
        CALL TOTAL DISSOLVED GAS(PALT(ID),1,JG,T2R4,CGAS)
        CSUM(CN(JC)) = CSUM(CN(JC))+QNEW(K)*CGAS
      ELSE
        CSUM(CN(JC)) = CSUM(CN(JC))+QNEW(K)*C2(K,ID,CN(JC))
      END IF
    END DO
  END DO
  IF (QSUMM /= 0.0) THEN
    TINSUM(JBD) = (TSUM + QINSUM(JBD)*TINSUM(JBD)) / (QSUMM+QINSUM(JBD))
    CINSUM(CN(1:NAC),JBD) =
(CSUM(CN(1:NAC))+QINSUM(JBD)*CINSUM(CN(1:NAC),JBD))/(QSUMM+QINSUM(JBD))
    QINSUM(JBD) = QINSUM(JBD) + QSUMM
  END IF
! END IF
! QSUM(JB) = 0.0; TSUM = 0.0; CSUM = 0.0
! DO K=KT,KB(ID)
! QSUM(JB) = QSUM(JB)+QOUT(K,JB)
! TSUM = TSUM+QOUT(K,JB)*T2(K,ID)
! DO JC=1,NAC
! IF (CN(JC) == NDO .AND. CAC(NDO) == ' ON' .AND. GASGTC(JG) == ' ON' .AND. QGT(JG) >
0.0) THEN ! MM 5/21/2009
! T2R4=T2(K,ID)
! CGAS=C2(K,ID,CN(JC)) ! MM 5/21/2009
! CALL TOTAL DISSOLVED GAS (PALT(ID),1,JG,T2R4,CGAS)
! CSUM(CN(JC)) = CSUM(CN(JC))+QOUT(K,JB)*CGAS
! ELSE
! CSUM(CN(JC)) = CSUM(CN(JC))+QOUT(K,JB)*C2(K,ID,CN(JC))
! END IF
! END DO
! END DO
! IF (QSUM(JB) /= 0.0) THEN
! TOUT(JB) = TSUM / QSUM(JB)
! COUT(CN(1:NAC),JB) = CSUM(CN(1:NAC))/QSUM(JB)
! END IF
! END IF
! IF (IDGT(JG) /= 0) THEN
ELSEIF (IDGT(JG) /= 0) THEN
! IF (US(JBD) /= IDGT(JG) .OR. HEAD_FLOW(JBD) .OR. UP_HEAD(JBD)) THEN
JTT = JTT+1
QTR(JTT) = QGT(JG)
ITR(JTT) = IDGT(JG)
PLACE_QTR(JTT) = PDGTC(JG) == ' DENSITY'

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SPECIFY_QTR(JTT) = PDGTC(JG) == ' SPECIFY'
IF (SPECIFY_QTR(JTT)) THEN
  ELTRT(JTT) = ETDGT(JG)
  ELTRB(JTT) = EBDGT(JG)
END IF
JBTR(JTT) = JBD
! IF (JLAT == 1) THEN
!   CSUM(CN(1:NAC)) = 0.0; TSUM = 0.0; QSUMM = 0.0
!   DO K=KTW(JWW),KBW(JWW)
!     QSUMM      = QSUMM      +QSW(K,JWW)
!     TSUM       = TSUM       +QSW(K,JWW)*T2(K,IWD(JWW))
!     CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QSW(K,JWW)*C2(K,IWD(JWW),CN(1:NAC))
!   END DO
!   TTR(JTT) = TSUM/QSUMM
!   DO JC=1,NAC
!     CTR(CN(JC),JTT) = CSUM(CN(JC))/QSUMM
!     IF (CN(JC) == NDO .AND. GASGTC(JG) == ' ON' .AND. QGT(JG) > 0.0) THEN
!       TDG_GATE(JWW,JG) = .TRUE.
!       CALL TOTAL DISSOLVED GAS (PALT(ID),1,JG,TTR(JTT),CTR(CN(JC),JTT))
!     END IF
!   END DO
! ELSE
  TTR(JTT) = TOUT(JB)
  DO JC=1,NAC
    CTR(CN(JC),JTT) = COUT(CN(JC),JB)
    IF (CN(JC) == NDO .AND. GASGTC(JG) == ' ON' .AND. QGT(JG) > 0.0) THEN
      CALL TOTAL DISSOLVED GAS (PALT(ID),0,JS,TTR(JTT),CTR(CN(JC),JTT))
    END IF
  END DO
! END IF
ELSE IF (CAC(NDO) == ' ON' .AND. GASGTC(JG) == ' ON' .AND. QGT(JG) > 0.0) THEN
  TDG_GATE(JWW,JG) = .TRUE.
! ELSE IF (LATERAL_GATE(JG)) THEN
!   TSUM = 0.0; QSUMM = 0.0; CSUM = 0.0
!   ILAT(JWW) = 1
!   DO K=KTW(JWW),KBW(JWW)
!     QSUMM      = QSUMM      +QSW(K,JWW)
!     TSUM       = TSUM       +QSW(K,JWW)*T2(K,IWD(JWW))
!     CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QSW(K,JWW)*C2(K,IWD(JWW),CN(1:NAC))
!   END DO
!   JB      = JBD
!   TINSUM(JB) = (TINSUM(JB) *QINSUM(JB)+TSUM) /((QSUMM+QINSUM(JB))
!   CINSUM(CN(1:NAC),JB) =
(CINSUM(CN(1:NAC),JB)*QINSUM(JB)+CSUM(CN(1:NAC)))/(QSUMM+QINSUM(JB))
!   QINSUM(JB) = QSUMM+QINSUM(JB)
! END IF
END IF
ELSE IF (QGT(JG) < 0.0) THEN
  JTT = JTT+1
  JWW = JWW+1
  IWD(JWW) = IDGT(JG)
  ITR(JTT) = IUGT(JG)
  QTR(JTT) = -QGT(JG)
  QWD(JWW) = -QGT(JG)
  KTWD(JWW) = KTDGT(JG)
  KBWD(JWW) = KBDGT(JG)
  EWD(JWW) = EGT(JG)
  PLACE_QTR(JTT) = PUGTC(JG) == ' DENSITY'
  SPECIFY_QTR(JTT) = PUGTC(JG) == ' SPECIFY'
  IF (SPECIFY_QTR(JTT)) THEN

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```

    ELTRT(JTT) = ETUGT(JG)
    ELTRB(JTT) = EBUGT(JG)
END IF
JBTR(JTT) = JBU
JBWD(JWW) = JBD
I      = MAX(CUS(JBWD(JWW)),IWD(JWW))
JW     = JWDGT(JG)
JB     = JBWD(JWW)
KT     = KTWB(JW)
CALL LATERAL_WITHDRAWAL (JWW)
DO K=KTW(JWW),KBW(JWW)
    QSS(K,I) = QSS(K,I)-QSW(K,JWW)
END DO
IF (IDGT(JG) /= 0) THEN
    CSUM(CN(1:NAC)) = 0.0; TSUM = 0.0; QSUMM = 0.0
    DO K=KTW(JWW),KBW(JWW)
        QSUMM      = QSUMM      +QSW(K,JWW)
        TSUM       = TSUM       +QSW(K,JWW)*T2(K,IWD(JWW))
        CSUM(CN(1:NAC)) = CSUM(CN(1:NAC))+QSW(K,JWW)*C2(K,IWD(JWW),CN(1:NAC))
    END DO
    TTR(JTT) = TSUM/QSUMM
    DO JC=1,NAC
        CTR(CN(JC),JTT) = CSUM(CN(JC))/QSUMM
        IF (CN(JC) == NDO .AND. GASGTC(JG) == '    ON' .AND. QGT(JG) > 0.0) THEN
            TDG_GATE(JWW,JG) = .TRUE.
            CALL TOTAL DISSOLVED GAS (PALT(ID),1,JG,TTR(JTT),CTR(CN(JC),JTT))
        END IF
    END DO
ELSE IF (CAC(NDO) == '    ON' .AND. GASGTC(JG) == '    ON' .AND. QGT(JG) > 0.0) THEN
    TDG_GATE(JWW,JG) = .TRUE.
END IF
END IF
END DO
END IF
tributaries = jtt > 0
withdrawals = jww > 0

DO JW=1,NWB
    KT = KTWB(JW)
    DO JB=BS(JW),BE(JW)
        IU = CUS(JB)
        ID = DS(JB)
        IF (EVAPORATION(JW)) THEN
            EVBR(JB) = 0.0
            DO I=IU,ID
                FW = AFW(JW)+BFW(JW)*WIND2(I)**CFW(JW)
                IF (RH_EVAP(JW)) THEN
                    EA = EXP(2.3026*(7.5*TDEW(JW)/(TDEW(JW)+237.3)+0.6609))
                    ES = EXP(2.3026*(7.5*T2(KT,I)/(T2(KT,I)+237.3)+0.6609))
                    IF (TDEW(JW) < 0.0) EA = EXP(2.3026*(9.5*TDEW(JW)/(TDEW(JW)+265.5)+0.6609))
                    IF (T2(KT,I) < 0.0) ES = EXP(2.3026*(9.5*T2(KT,I)/(T2(KT,I)+265.5)+0.6609))
                    TAIRV = (TAIR(JW)+273.0)/(1.0-0.378*EA/760.0)
                    DTV = (T2(KT,I)+273.0)/(1.0-0.378*ES/760.0)-TAIRV
                    DTVL = 0.0084*WIND2(I)**3
                    IF (DTV < DTVL) DTV = DTVL
                    FW = (3.59*DTV**0.3333333+4.26*WIND2(I))
                END IF
                TM = (T2(KT,I)+TDEW(JW))*0.5
                VPTG = 0.35+0.015*TM+0.0012*TM*TM
            END DO
        END IF
    END DO
END DO

```

```

      EV(I) = VPTG*(T2(KT,I)-TDEW(JW))*FW*BI(KT,I)*DLX(I)/2.45E9
      IF (EV(I) < 0.0 .OR. ICE(I)) EV(I) = 0.0
      QSS(KT,I) = QSS(KT,I)-EV(I)
      EVBR(JB) = EVBR(JB)+EV(I)
    END DO
  END IF
  IF (PRECIPITATION(JW)) THEN
    QPRBR(JB) = 0.0
    DO I=IU,ID
      QPR(I) = PR(JB)*BI(KT,I)*DLX(I)
      QPRBR(JB) = QPRBR(JB)+QPR(I)
      QSS(KT,I) = QSS(KT,I)+QPR(I)
    END DO
  END IF
  !       IF (TRIBUTARIES) THEN                                !WX 08/18/13   !THIS PIECE OF CODE IS MOVED TO
W2_37_WIN.F90 LINE1238
  !       DO JT=1,JTT
  !
  !!***** Inflow fractions
  !
  !       IF (JB == JBTR(JT)) THEN
  !         I = MAX(ITR(JT),IU)
  !         QTRF(KT:KB(I),JT) = 0.0
  !         IF (PLACE_QTR(JT)) THEN
  !
  !!***** Inflow layer
  !
  !         SSTOT = 0.0
  !         DO J=NSSS,NSSE
  !           SSTOT = SSTOT+CTR(J,JT)
  !         END DO
  !         RHOTR = DENSITY(TTR(JT),CTR(NTDS,JT),SSTOT)
  !         K = KT
  !         DO WHILE (RHOTR > RHO(K,I) .AND. K < KB(I))
  !           K = K+1
  !         END DO
  !         KTTR(JT) = K
  !         KBTR(JT) = K
  !
  !!***** Layer inflows
  !
  !         VQTR = QTR(JT)*DLT
  !         VQTRI = VQTR
  !         QTRFR = 1.0
  !         INCR = -1
  !         DO WHILE (QTRFR > 0.0)
  !           IF (K <= KB(I)) THEN
  !             V1 = VOL(K,I)
  !             IF (VQTR > 0.5*V1) THEN
  !               QTRF(K,JT) = 0.5*V1/VQTRI
  !               QTRFR = QTRFR-QTRF(K,JT)
  !               VQTR = VQTR-QTRF(K,JT)*VQTRI
  !               IF (K == KT) THEN
  !                 K = KBTR(JT)
  !                 INCR = 1
  !               END IF
  !             ELSE
  !               QTRF(K,JT) = QTRFR
  !               QTRFR = 0.0
  !             END IF
  !           END IF

```

```

!       IF (INCR < 0) KTTR(JT) = K
!       IF (INCR > 0) KBTR(JT) = MIN(KB(I),K)
!       K = K+INCR
!     ELSE
!       QTRF(KT,JT) = QTRF(KT,JT)+QTRFR
!       QTRFR      = 0.0
!     END IF
!   END DO
! ELSE
!   IF (SPECIFY_QTR(JT)) THEN
!     KTTR(JT) = 2
!     DO WHILE (EL(KTTR(JT),I) > ELTRT(JT))
!       KTTR(JT) = KTTR(JT)+1
!     END DO
!     KBTR(JT) = KMX-1
!     DO WHILE (EL(KBTR(JT),I) < ELTRB(JT))
!       KBTR(JT) = KBTR(JT)-1
!     END DO
!   ELSE
!     KTTR(JT) = KT
!     KBTR(JT) = KB(I)
!   END IF
!   KTTR(JT) = MAX(KT,KTTR(JT))
!   KBTR(JT) = MIN(KB(I),KBTR(JT))
!   IF (KBTR(JT) < KTTR(JT)) KBTR(JT) = KTTR(JT)
!   BHSUM = 0.0
!   DO K=KTTR(JT),KBTR(JT)
!!     BHSUM = BHSUM+BH2(K,I)
!     BHSUM = BHSUM+BH1(K,I)          !WX 8/17/13
!   END DO
!   DO K=KTTR(JT),KBTR(JT)
!!     QTRF(K,JT) = BH2(K,I)/BHSUM
!     QTRF(K,JT) = BH1(K,I)/BHSUM    !WX 8/17/13
!   END DO
!   END IF
!   DO K=KTTR(JT),KBTR(JT)
!     QSS(K,I) = QSS(K,I)+QTR(JT)*QTRF(K,JT)
!   END DO
!   END IF
!   END DO
!   END IF
!   IF (DIST_TRIBS(JB)) THEN
!!     AKBR = 0.0          !WX 7/8/13 AS the way flow is added and tss is added for distributed is different,
I recommend
!!     DO I=IU,ID          !to go with the simple way.
!!       AKBR = AKBR+BI(KT,I)*DLX(I)
!!     END DO
!     DO I=IU,ID
!!       QDT(I) = QDTR(JB)*BI(KT,I)*DLX(I)/AKBR
!       QDT(I) = QDTR(JB)/REAL(ID-IU+1)
!       QSS(KT,I) = QSS(KT,I)+QDT(I)
!     END DO
!   END IF
!   IF (WITHDRAWALS) THEN
!     DO JWD=1,NWD
!       IF (JB == JBWD(JWD)) THEN
!         I = MAX(CUS(JBWD(JWD)),IWD(JWD))
!         CALL LATERAL_WITHDRAWAL (JWD)
!         DO K=KTW(JWD),KBW(JWD)
!           QSS(K,I) = QSS(K,I)-QSW(K,JWD)

```

```

        END DO
    END IF
END DO
END IF
IF (UH_INTERNAL(JB).AND. .NOT. LOOP_BRANCH(JB)) THEN    !add the criteria of not loop branch.
because loop_branch qss(uhs(jb) is calcaulted in w2_37_win
    IF (UHS(JB) /= DS(JBUH(JB)) .OR. DHS(JBUH(JB)) /= US(JB)) THEN
        IF (JBUH(JB) >= BS(JW) .AND. JBUH(JB) <= BE(JW)) THEN
            DO K=KT,KB(IU-1)
                QSS(K,UHS(JB)) = QSS(K,UHS(JB))-VOLUH2(K,JB)/DLT
            END DO
        ELSE
            CALL UPSTREAM_FLOW
        END IF
    END IF
END IF
IF (DH_INTERNAL(JB).AND. .NOT. LOOP_BRANCH(JB)) THEN    !add the criteria of not loop branch. WX
11/11/13
    IF (DHS(JB) /= US(JBDH(JB)) .OR. UHS(JBDH(JB)) /= DS(JB)) THEN
        IF (JBDH(JB) >= BS(JW) .AND. JBDH(JB) <= BE(JW)) THEN
            DO K=KT,KB(ID+1)
                QSS(K,CDHS(JB)) = QSS(K,CDHS(JB))+VOLDH2(K,JB)/DLT
            END DO
        ELSE
            CALL DOWNSTREAM_FLOW
        END IF
    END IF
END IF
END DO
END DO

```

!** Compute tributary contribution to cross-shear

```

IF (TRIBUTARIES) THEN
    DO JW=1,NWB
        DO JB=BS(JW),BE(JW)
            DO JT=1,JTT
                IF (JB == JBTR(JT)) THEN
                    I = MAX(CUS(JB),ITR(JT))
                    DO K=KTWB(JW),KBMIN(I)
                        UYBR(K,I) = UYBR(K,I)+ABS(QTR(JT))*QTRF(K,JT)
                    END DO
                END IF
            END DO
        END DO
    END DO
END IF

```

```

return
end subroutine hydroinout

```

temperature.F90

```
subroutine temperature

USE MAIN
USE GLOBAL;   USE NAMESC; USE GEOMC; USE LOGICC; USE PREC; USE SURFHE; USE KINETIC;
USE SHADEC; USE EDDY
USE STRUCTURES; USE TRANS; USE TVDC;   USE SELWC; USE GDAYC; USE SCREENC; USE
TDGAS; USE RSTART
USE MACROPHYTEC; USE POROSITYC; USE ZOOPLANKTONC; USE INITIALVELOCITY, ONLY: QSSI
USE INITIALVELOCITY
IMPLICIT NONE
EXTERNAL RESTART_OUTPUT

REAL RN1
INTEGER ::JLOOP !WX 8/25/13

DO JW=1,NWB
  KT = KTWB(JW)
  IF (.NOT. NO_HEAT(JW)) THEN
    IF (.NOT. READ_RADIATION(JW)) CALL SHORT_WAVE_RADIATION (JDAY)
    IF (TERM_BY_TERM(JW)) THEN ! SW 1/25/05
      IF(TAIR(JW).GE.5.0)THEN
        RANLW(JW) = 5.31D-13*(273.15D0+TAIR(JW))**6*(1.0D0+0.0017D0*CLOUD(JW)**2)*0.97D0
      ELSE
        RANLW(JW) = 5.62D-8*(273.15D0+TAIR(JW))**4*(1.0D0-0.261D0*DEXP(-7.77D-
4*TAIR(JW)**2))*(1.0D0+0.0017D0*CLOUD(JW)**2)*0.97D0
      ENDIF
    ENDIF
  END IF
  DO JB=BS(JW),BE(JW)
    IU = CUS(JB)
    ID = DS(JB)

    !***** Heat exchange

    IF (.NOT. NO_HEAT(JW)) THEN
      DO I=IU,ID
        IF (DYNAMIC_SHADE(I)) CALL SHADING

        !***** Surface

        IF (.NOT. ICE(I)) THEN
          IF (TERM_BY_TERM(JW)) THEN
            CALL SURFACE_TERMS (T2(KT,I))
            RS(I) = SRON(JW)*SHADE(I)
            RN(I) = RS(I)+RANLW(JW)-RB(I)-RE(I)-RC(I)
            HEATEX = RN(I)/RHOWCP*BI(KT,I)*DLX(I)
          ELSE
            CALL EQUILIBRIUM_TEMPERATURE
            HEATEX = (ET(I)-T2(KT,I))*CSHE(I)*BI(KT,I)*DLX(I)
          END IF
          TSS(KT,I) = TSS(KT,I)+HEATEX
          TSSS(JB) = TSSS(JB)+HEATEX*DLT
          SROOUT = (1.0D0-BETA(JW))*(SRON(JW)*SHADE(I)/RHOWCP)*BI(KT,I)*DLX(I)*DEXP(-
GAMMA(KT,I)*DEPTHB(KT,I))
          TSS(KT,I) = TSS(KT,I)-SROOUT
          TSSS(JB) = TSSS(JB)-SROOUT*DLT
          IF(KT == KB(I))THEN ! SW 4/18/07
            SROSED = SROOUT*TSEDF(JW)
          END IF
        END IF
      END DO
    END IF
  END DO
END DO
```



```

ELSE
SROSED = SROOUT*(1.0D0-BI(KT+1,I)/BI(KT,I))*TSEDF(JW)
ENDIF
TSS(KT,I) = TSS(KT,I)+SROSED
TSSS(JB) = TSSS(JB)+SROSED*DLT
SROIN = SROOUT*B(KT+1,I)/BI(KT,I)
DO K=KT+1,KB(I)
SROOUT = SROIN*DEXP(-GAMMA(K,I)*(H1(K,I)))
SRONET = SROIN-SROOUT
IF(K /= KB(I))THEN ! SW 1/18/08
SROSED = SROOUT*(1.0D0-BI(K+1,I)/BI(K,I))*TSEDF(JW)
ELSE
SROSED = SROOUT*TSEDF(JW)
ENDIF
TSS(K,I) = TSS(K,I)+SRONET+SROSED
TSSS(JB) = TSSS(JB)+(SRONET+SROSED)*DLT
SROIN = SROOUT*B(K+1,I)/BI(K,I)
END DO
END IF

!***** Sediment/water

DO K=KT,KB(I)
IF(K==KB(I))THEN ! SW 4/18/07
TFLUX = CBHE(JW)/RHOWCP*(TSED(JW)-T2(K,I))*BI(K,I)*DLX(I)
ELSE
TFLUX = CBHE(JW)/RHOWCP*(TSED(JW)-T2(K,I))*(BI(K,I)-BI(K+1,I))*DLX(I)
ENDIF
TSS(K,I) = TSS(K,I)+TFLUX
TSSB(JB) = TSSB(JB)+TFLUX*DLT
END DO
END DO

!***** Ice cover

IF (ICE_CALC(JW)) THEN
! HIA = 0.2367*CSHE(I)/5.65E-8 ! SW 10/20/09 Duplicate line of code
DO I=IU,ID
ALLOW_ICE(I) = .TRUE.
IF (T2(KT,I) > ICET2(JW)) ALLOW_ICE(I) = .FALSE. ! RC/SW 4/28/11
DO K=KT,KB(I) ! RC 4/28/11: no reason to loop over all layers
IF (T2(K,I) > ICET2(JW)) ALLOW_ICE(I) = .FALSE.
END DO
END DO
! ICE_IN(JB) = .TRUE. ! RC/SW 4/28/11 eliminate ICE_IN
! DO I=IU,ID
! IF (ICETH(I) < ICEMIN(JW)) ICE_IN(JB) = .FALSE.
! END DO
DO I=IU,ID
IF(SALT_WATER(JW))THEN ! SW/RC 4/28/11
IF(TDS(KT,I) < 35.)THEN
RIMT = -0.0545*TDS(KT,I) ! REGRESSION FOR TDS BETWEEN 0 AND 35
PPT
ELSE
RIMT=-0.31462-0.04177*TDS(KT,I)-0.000166*TDS(KT,I)*TDS(KT,I) ! REGRESSION EQN FOR
TDS>35 PPT
ENDIF
ELSE
RIMT=0.0
ENDIF

```



```

        TFLUX = 2.392D-7*HWI(JW)*(RIMT-T2(KT,I))*BI(KT,I)*DLX(I)
        TSS(KT,I) = TSS(KT,I)+TFLUX
        TSSICE(JB) = TSSICE(JB)+TFLUX*DLT
    END IF
END IF

!***** Ice thickness

        ICETH(I) = ICETH(I)+ICETHU+ICETH1+ICETH2
        IF (ICETH(I) < ICE_TOL) ICETH(I) = 0.0D0
!       IF (WINTER .AND. (.NOT. ICE_IN(JB))) THEN          ! RC 4/28/11 No reason for this
!           IF (.NOT. ALLOW_ICE(I)) ICETH(I) = 0.0
!       END IF
        ICE(I) = ICETH(I) > 0.0
        IF (ICE(I)) THEN ! 3/27/08 SW
            ICESW(I) = 0.0
        ELSE
            ICESW(I) = 1.0
        ENDIF
        ICETHU = 0.0
        ICETH1 = 0.0
        ICETH2 = 0.0
        IF (ICETH(I) < ICE_TOL .AND. ICETH(I) > 0.0) ICETH(I) = ICE_TOL
        ELSE ! IF no ice the preceding time step
            IF (TERM_BY_TERM(JW)) CALL EQUILIBRIUM_TEMPERATURE ! SW 10/20/09 Must call
this first otherwise ET and CSHE are 0
            HIA = 0.2367D0*CSHE(I)/5.65D-8 ! JM 11/08 convert SI units of m/s to English
(btu/ft2/d/F) and then back to SI W/m2/C
!           ICETH(I) = MAX(0.0,ICETH(I)+DLT*((RIMT-ET(I))/(ICETH(I)/RK1+1.0/HIA)-(T2(KT,I)-
RIMT))/RHOIRL1)
            ICETH(I) = MAX(0.0,ICETH(I)+DLT*((RIMT-ET(I))/(ICETH(I)/RK1+1.0D0/HIA)-
HWI(JW)*(T2(KT,I)-RIMT))/RHOIRL1) ! SW 10/20/09 Revised missing HWI(JW)
            ICE(I) = ICETH(I) > 0.0
            ICESW(I) = 1.0
            IF (ICE(I)) THEN
!               TFLUX = 2.392E-7*(RIMT-T2(KT,I))*BI(KT,I)*DLX(I)
                TFLUX = 2.392D-7*HWI(JW)*(RIMT-T2(KT,I))*BI(KT,I)*DLX(I) ! SW 10/20/09 Revised
missing HWI(JW)
                TSS(KT,I) = TSS(KT,I)+TFLUX
                TSSICE(JB) = TSSICE(JB)+TFLUX*DLT
                ICESW(I) = 0.0
            END IF
        END IF
    END DO
END IF
END IF

!***** Heat sources/sinks and total inflow/outflow

        IF (EVAPORATION(JW)) THEN
            DO I=IU,ID
                TSS(KT,I) = TSS(KT,I)-EV(I)*T2(KT,I)
                TSSEV(JB) = TSSEV(JB)-EV(I)*T2(KT,I)*DLT
                VOLEV(JB) = VOLEV(JB)-EV(I) *DLT
            END DO
        END IF
        IF (PRECIPITATION(JW)) THEN
            DO I=IU,ID
!               TSS(KT,I) = TSS(KT,I)+QPR(I)*TPR(JB)
!               TSSPR(JB) = TSSPR(JB)+QPR(I)*TPR(JB)*DLT

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!      VOLPR(JB) = VOLPR(JB)+QPR(I)      *DLT
DO K=KTWB(JW),KB(I)                      !WX 8/22/13 distribute precipitation to all layers
  TSS(K,I) = TSS(K,I)+TPR(JB)*QPR(I)*QTRF(K,I)
  TSSPR(JB) = TSSPR(JB)+TPR(JB)*QPR(I)*QTRF(K,I)*DLT
  VOLPR(JB) = VOLPR(JB)+QPR(I)*DLT
END DO
END DO
END IF
IF (TRIBUTARIES) THEN
DO JT=1,JTT
  IF (JB == JBTR(JT)) THEN
    I = ITR(JT)
    IF (I < CUS(JB)) I = CUS(JB)
    DO K=KTWB(JW),KB(I)
      IF (QTR(JT) < 0) THEN
        TSS(K,I) = TSS(K,I) +T2(K,I)*QTR(JT)*QTRF(K,I)
        TSSTR(JB) = TSSTR(JB)+T2(K,I)*QTR(JT)*QTRF(K,I)*DLT
      ELSE
        TSS(K,I) = TSS(K,I) +TTR(JT)*QTR(JT)*QTRF(K,I)
        TSSTR(JB) = TSSTR(JB)+TTR(JT)*QTR(JT)*QTRF(K,I)*DLT
      END IF
    END DO
    VOLTRB(JB) = VOLTRB(JB)+QTR(JT)*DLT
  END IF
END DO
END IF
IF (DIST_TRIBS(JB)) THEN
DO I=IU,ID                      !WX 7/8/13 ! DO I=IU,ID !because for seg iu, qdt is already included in
inflow,IU+1 !WX 8/18/13 CHANGE BACK TO IU
  DO K=KTWB(JW),KB(I)
    IF (QDT(I) < 0) THEN
      TSS(K,I) = TSS(K,I)+T2(K,I)*QDT(I)*QTRF(K,I)
      TSSDT(JB) = TSSDT(JB)+T2(K,I)*QDT(I)*QTRF(K,I)*DLT
    ELSE
      TSS(K,I) = TSS(K,I)+TDTR(JB)*QDT(I)*QTRF(K,I)
      TSSDT(JB) = TSSDT(JB)+TDTR(JB)*QDT(I)*QTRF(K,I)*DLT
    END IF
    VOLDT(JB) = VOLDT(JB)+QDT(I)*DLT
  END DO
END DO
END IF
IF (WITHDRAWALS) THEN
DO JWD=1,JWW
  IF (QWD(JWD) /= 0.0) THEN
    IF (JB == JBWD(JWD)) THEN
      I = MAX(CUS(JBWD(JWD)),IWD(JWD))
      DO K=KTW(JWD),KBW(JWD)
        TSS(K,I) = TSS(K,I) -T2(K,I)*QSW(K,JWD)
        TSSWD(JB) = TSSWD(JB)-T2(K,I)*QSW(K,JWD)*DLT
      END DO
      VOLWD(JB) = VOLWD(JB)-QWD(JWD)*DLT
    END IF
  END IF
END DO
END IF
IF (UP_FLOW(JB)) THEN
DO K=KT,KB(IU)
  IF (.NOT. HEAD_FLOW(JB)) THEN
    TSS(K,IU) = TSS(K,IU)+QINF(K,JB)*QIN(JB)*TIN(JB)
    TSSIN(JB) = TSSIN(JB)+QINF(K,JB)*QIN(JB)*TIN(JB)*DLT
  
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ELSE
  IF (U(K,IU-1) >= 0.0) THEN
    TSS(K,IU) = TSS(K,IU)+U(K,IU-1)*BHR1(K,IU-1)*T1(K,IU-1)
    TSSIN(JB) = TSSIN(JB)+U(K,IU-1)*BHR1(K,IU-1)*T1(K,IU-1)*DLT
  ELSE
    TSS(K,IU) = TSS(K,IU)+U(K,IU-1)*BHR1(K,IU-1)*T1(K,IU)
    TSSIN(JB) = TSSIN(JB)+U(K,IU-1)*BHR1(K,IU-1)*T1(K,IU)*DLT
  END IF
END IF
END DO
VOLIN(JB) = VOLIN(JB)+QIN(JB)*DLT
END IF
IF (DN_FLOW(JB)) THEN
  DO K=KT,KB(ID)
    TSS(K,ID) = TSS(K,ID) -QOUT(K,JB)*T2(K,ID+1)
    TSSOUT(JB) = TSSOUT(JB)-QOUT(K,JB)*T2(K,ID+1)*DLT
    VOLOUT(JB) = VOLOUT(JB)-QOUT(K,JB) *DLT
  END DO
END IF
IF (UP_HEAD(JB)) THEN
  DO K=KT,KB(IU)
    IUT = IU
    IF (QUH1(K,JB) >= 0.0) IUT = IU-1
    TSSUH1(K,JB) = T2(K,IUT)*QUH1(K,JB)
    TSS(K,IU) = TSS(K,IU)+TSSUH1(K,JB)
    TSSUH(JB) = TSSUH(JB)+TSSUH1(K,JB)*DLT
    VOLUH(JB) = VOLUH(JB)+QUH1(K,JB) *DLT
  END DO
END IF
IF (UH_INTERNAL(JB).AND. .NOT. LOOP_BRANCH(JB)) THEN
  IF (UHS(JB) /= DS(JBUH(JB)) .OR. DHS(JBUH(JB)) /= US(JB)) THEN
    IF (JBUH(JB) >= BS(JW) .AND. JBUH(JB) <= BE(JW)) THEN
      DO K=KT,KB(IU-1)
        TSS(K,UHS(JB)) = TSS(K,UHS(JB)) -TSSUH2(K,JB)/DLT
        TSSUH(JBUH(JB)) = TSSUH(JBUH(JB))-TSSUH2(K,JB)
        VOLUH(JBUH(JB)) = VOLUH(JBUH(JB))-VOLUH2(K,JB)
      END DO
    ELSE
      CALL UPSTREAM_CONSTITUENT(T2,TSS)
      DO K=KT,KB(IU-1)
        TSSUH(JBUH(JB)) = TSSUH(JBUH(JB))-TSSUH2(K,JB)
        VOLUH(JBUH(JB)) = VOLUH(JBUH(JB))-VOLUH2(K,JB)
      END DO
    END IF
  END IF
END IF
IF (DN_HEAD(JB)) THEN
  DO K=KT,KB(ID+1)
    IDT = ID+1
    IF (QDH1(K,JB) >= 0.0) IDT = ID
    TSSDH1(K,JB) = T2(K,IDT)*QDH1(K,JB)
    TSS(K,ID) = TSS(K,ID)-TSSDH1(K,JB)
    TSSDH(JB) = TSSDH(JB)-TSSDH1(K,JB)*DLT
    VOLDH(JB) = VOLDH(JB)-QDH1(K,JB) *DLT
  END DO
END IF
IF (DH_INTERNAL(JB).AND. .NOT. LOOP_BRANCH(JB)) THEN
  IF (DHS(JB) /= US(JBDH(JB)) .OR. UHS(JBDH(JB)) /= DS(JB)) THEN
    IF (JBDH(JB) >= BS(JW) .AND. JBDH(JB) <= BE(JW)) THEN
      DO K=KT,KB(ID+1)

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!WX 8/26/13

!WX 8/26/13

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TSS(K,CDHS(JB)) = TSS(K,CDHS(JB))+TSSDH2(K,JB)/DLT
TSSDH(JBDH(JB)) = TSSDH(JBDH(JB))+TSSDH2(K,JB)
VOLDH(JBDH(JB)) = VOLDH(JBDH(JB))+VOLDH2(K,JB)
END DO
ELSE
CALL DOWNSTREAM_CONSTITUENT(T2,TSS)
DO K=KT,KB(ID+1)
TSSDH(JBDH(JB)) = TSSDH(JBDH(JB))+TSSDH2(K,JB)
VOLDH(JBDH(JB)) = VOLDH(JBDH(JB))+VOLDH2(K,JB)
END DO
END IF
END IF
END IF
IF (LOOP_BRANCH(JB))THEN      !WX 8/24/13      !tss is already calculated in UH_INTERNAL(JB)
& DH_INTERNAL(JB)
DO JLOOP=BS(JW),BE(JW)
IF (UHS(JB)>US(JLOOP).AND. UHS(JB)<DS(JLOOP))THEN
EXIT
END IF
END DO
! WX 11/10/13 LOOP BRANCH flow and temperature should go into QSS and TSS. The previous method
will not work because tss should not depend on temperature difference. Relations should be physical
! There can be problems when there is distributed flow in the loop branch, then qloop1 should be used instead
of qssi(us(jb))
I=UHS(JB)      !at the beginning of loop branch
DO K=KTWB(JW),KB(I)
TSS(K,I) =TSS(K,I)-T2(K,I)*QSSI(US(JB))*QTRF(K,I)
END DO
I=DHS(JB)      !at the end of loop branch
!first, calculate all the sum of tss at the end of loop branch. Then, assign TSSLOOP to each layer
TSSLOOP(DS(JB))=0.0
DO K=KTWB(JW), KB(DS(JB))
TSSLOOP(DS(JB)) =TSSLOOP(DS(JB))+T2(K,DS(JB))*U(K,DS(JB))*BHR1(K,DS(JB))
END DO
DO K=KTWB(JW),KB(I)
TSS(K,I) =TSS(K,I)+TSSLOOP(DS(JB))*QTRF(K,I)
END DO
! IF (QDT(UHS(JB))>0.0) THEN      !IF THERE IS POSITIVE DISTRIBUTED FLOW, USE TDTR()
! I=UHS(JB)
! DO K=KTWB(JW),KB(I)
! TSS(K,I) =TSS(K,I)+T2(K,I)*U(K,I)*BHR1(K,I)-T2(K,I-1)*U(K,I-1)*BHR1(K,I-1)-
TDTR(JLOOP)*QDT(I)*QTRF(K,I) !tss is calculated from the differences of
! END DO
! I=DHS(JB)
! DO K=KTWB(JW),KB(I)
! TSS(K,I) =TSS(K,I)+T2(K,I)*U(K,I)*BHR1(K,I)-T2(K,I-1)*U(K,I-1)*BHR1(K,I-1)-
TDTR(JLOOP)*QDT(I)*QTRF(K,I)
! END DO
! ELSE      !IF DISTRIBUTED FLOW IS NOT POSITIVE, USE T2(K,I)
! I=UHS(JB)
! DO K=KTWB(JW),KB(I)
! TSS(K,I) =TSS(K,I)+T2(K,I)*U(K,I)*BHR1(K,I)-T2(K,I-1)*U(K,I-1)*BHR1(K,I-1)-
T2(K,I)*QDT(I)*QTRF(K,I)
! END DO
! I=DHS(JB)
! DO K=KTWB(JW),KB(I)
! TSS(K,I) =TSS(K,I)+T2(K,I)*U(K,I)*BHR1(K,I)-T2(K,I-1)*U(K,I-1)*BHR1(K,I-1)-
T2(K,I)*QDT(I)*QTRF(K,I)
! END DO
! END IF

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        END IF
    END DO
END DO

!** Temperature transport

DO JW=1,NWB
    KT = KTWB(JW)
    DO JB=BS(JW),BE(JW)
        IU = CUS(JB)
        ID = DS(JB)
        COLD => HYD(:,4)
        CALL HORIZONTAL_MULTIPLIERS1
        CALL VERTICAL_MULTIPLIERS1
        CALL HORIZONTAL_MULTIPLIERS
        CALL VERTICAL_MULTIPLIERS
        CNEW => T1(:,)
        SSB => TSS(:,)
        SSK => CSSB(:,1)
        CALL HORIZONTAL_TRANSPORT
        DO I=IU,ID
            AT(:,I) = 0.0D0; CT(:,I) = 0.0D0; VT(:,I) = 0.0D0; DT(:,I) = 0.0D0
            FORALL(K=KT:KB(I)) !DO K=KT,KB(I)
                AT(K,I) = -DLT/BH1(K,I)*(BB(K-1,I)*(DZ(K-1,I)/AVH1(K-1,I)+THETA(JW)*0.5D0*W(K-1,I)))
                CT(K,I) = DLT/BH1(K,I)*(BB(K,I)*(THETA(JW)*0.5D0*W(K,I)-DZ(K,I)/AVH1(K,I)))
                VT(K,I) = 1.0D0+DLT/BH1(K,I)*(BB(K,I)*(DZ(K,I)/AVH1(K,I)+THETA(JW)*0.5D0*W(K,I))+BB(K-
1,I)*(DZ(K-1,I)/AVH1(K-1,I) &
                    -THETA(JW)*0.5D0*W(K-1,I)))
                DT(K,I) = CNEW(K,I)
            END FORALL
            CALL TRIDIAG(AT(:,I),VT(:,I),CT(:,I),DT(:,I),KT,KB(I),KMX,CNEW(:,I))
        END DO
    END DO
END DO

END SUBROUTINE TEMPERATURE

```