

The Implementation of Hydraulic Structure Control and Operation in EFDC+ for EEMS 8.4

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1 Introduction

The operation and control of hydraulic structures have been implemented in EFDC+ for EEMS8.4 to simulate the operation of the structures. Two types of structure operation are supported in EFDC+ including operational time series and operational rules.

- With the operational time series, a hydraulic structure is operated during the simulation based on a defined time series of operational state and settings such as gate opening or pumping flow.
- With the operational rules, a hydraulic structure is operated during the simulation based on a set of rules defining how the structure's state and settings are changed

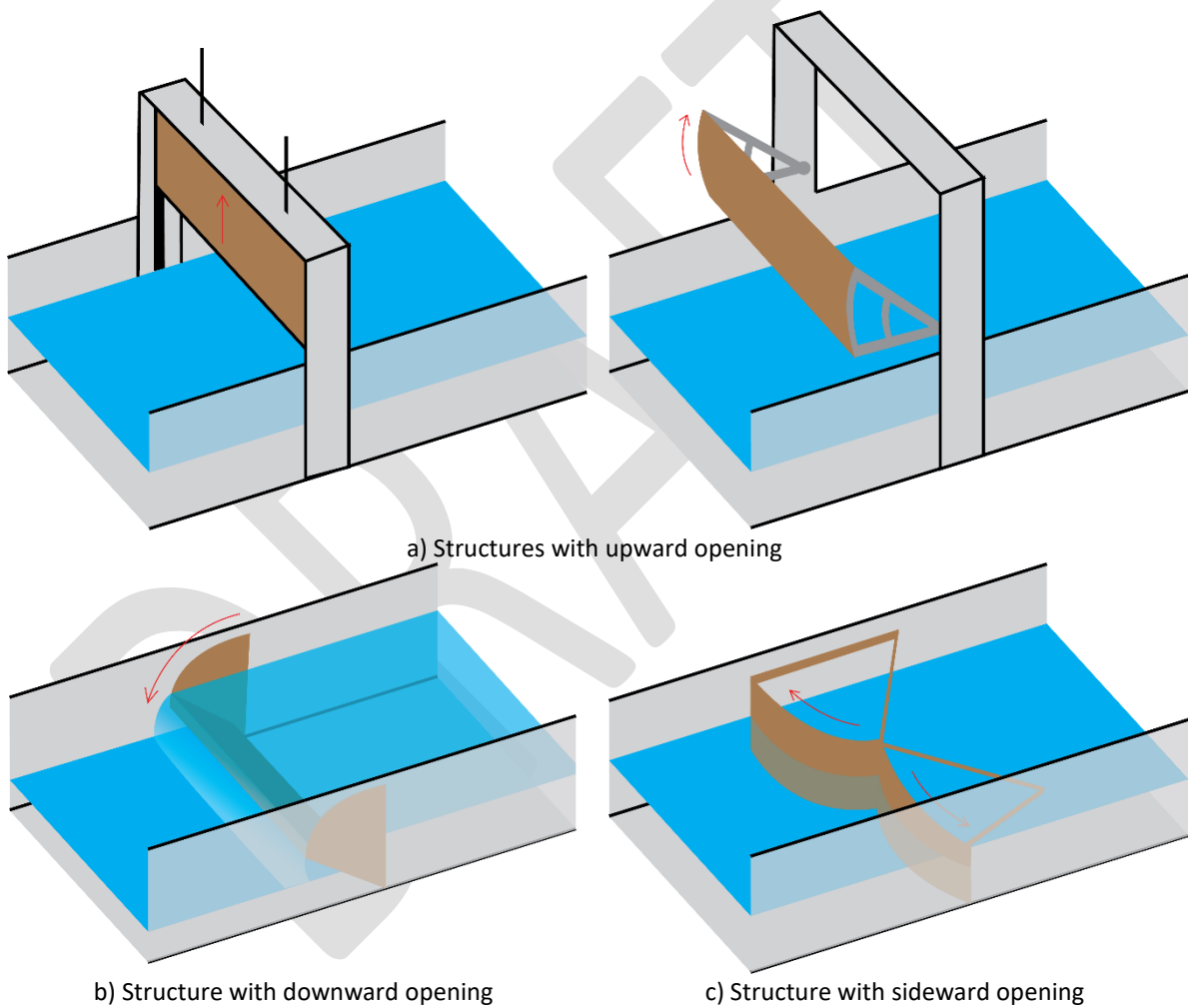


Figure 1: Operation for different types of gate opening is supported in EFDC 8.4

1.1 Changes in EFDC.INP

The operation and control of hydraulic structures in EFDC 8.4 are defined in EFDC.INP cards C23 and C32B.

In C23, two values of NQCTLSER and NQCRULES have been added to the end of the data record as follows

C23	NQSIJ	NQPIJ	NQSER	NQCTL	NQCLT	NHYDST	NQWR	NQWRSR	ISDIQ	NQCTLSER	NQCRULES
-----	-------	-------	-------	-------	-------	--------	------	--------	-------	----------	----------

where

NQCTLSER: is the number of gate opening time-series for hydraulic structure control. If NQCTLSER > 0 then the gate opening time-series will be read from an extra data file QCTLSER.INP.

NQCRULES: is the number of operational rules for hydraulic structure control. If NQCRULES > 0 then the operational rules will be read from an extra data file QCRULES.INP.

When either NQCTLSER > 0 or NQCRULES > 0, an extra card C32B is required with the following parameters

C32B	ITYPE	ID	IQCTL1	JQCTL1	IQCTL2	JQCTL2	STATE	HEIGHT	WIDTH	SILL	NUM	FLOW
------	-------	----	--------	--------	--------	--------	-------	--------	-------	------	-----	------

where

ITYPE: is the type of structure control, can have value as follows

- ITYPE = 0 means uncontrolled structure;
- ITYPE = 1 means the structure is controlled by a time-series of operational parameters (such as gate opening or pump flow);
- ITYPE = 2 means the structure is controlled by operational rules based on upstream water surface elevation;
- ITYPE = 3 means the structure is controlled by operational rules based on the difference of water surface elevations at upstream and downstream locations.

ID: the index of the associated control data

- If ITYPE = 0: this value is set to 0 and is not used for uncontrolled structure;
- If ITYPE = 1: this is the index of the operational time-series in QCTLSER.INP
- If ITYPE > 1: this is the index of the operational rules in QCRULES.INP

IQCTL1, JQCTL1: I and J indices of the upstream reference cell. Default is the same and the location of the structure upstream cell defined in C32. But these can be different with C32.

IQCTL2, JQCTL2: I and J indices of the downstream reference cell. Default is the same and the location of the structure downstream cell defined in C32. But these can be different with C32.

STATE: the initial operation state of the structure at TBEGIN (1 = ON, 0 = OFF)

HEIGHT: the initial opening height (m) of the gate at TBEGIN (for upward opening)

WIDTH: the initial opening width (m) of the gate at TBEGIN (for sideward opening).

SILL: the initial sill level change (m) of the gate at TBEGIN (for downward opening). Default is zero.

NUM: the initial number of opening gates / pumping units (not used, default is one)

FLOW: the initial pumping flow (m3/s) for pumps

With the rule-based withdrawal/return structures, an extra card C33A is added with the following parameters

C33A	ITYPE	IDX	IQCTL1	JQCTL1	IQCTL2	JQCTL2	STATE	FLOW
------	-------	-----	--------	--------	--------	--------	-------	------

where

ITYPE: is the type of structure control, can have value as follows

- ITYPE = 0 means the structure is controlled by a time-series of flow and rising constituents;
- ITYPE = 1 means the structure is controlled by operational rules based on upstream water surface elevation;
- ITYPE = 2 means the structure is controlled by operational rules based on the difference of water surface elevations at upstream and downstream locations.

IDX: index of associated control data

- ITYPE = 0: IDX is the index of the time-series in QWRER.INP
- ITYPE > 0: IDX is index of the rules in QCRULES.INP

IQCTL1: The I index of upstream reference cell

JQCTL1: The J index of upstream reference cell

IQCTL2: The I index of downstream reference cell

JQCTL2: The J index of downstream reference cell

STATE: The initial operation state (1 = ON, 0 = OFF)

FLOW: The initial flow discharge.

1.2 Changes in EE GUI

For hydraulic structure boundary, there is one more dropdown list is added to the input form and labeled as "*Flow Control Type*". The old label "*Flow Control Type*" is renamed to "*Flow Determination Type*". The values of the "*Flow Control Type*" dropdown list and its meaning are as follows

Index	Value	Meaning
1	Uncontrolled Structure	The hydraulic structure is uncontrollable type. The old method of flow computational using lookup table or equation will be used
2	Controlled using Time-Series	The operation of the hydraulic structure is controlled using a time-series which defines the changes with time of gate openings or rating curves
3	Controlled based on Upstream Level	The operation of the hydraulic structure is controlled using control rules defined based on water surface elevation at an upstream location. This location can be different with the upstream cell of the structure.
4	Controlled based on Head Difference	The operation of the hydraulic structure is controlled using control rules defined based on the difference of water surface elevations at two locations upstream and a downstream of the structure. These locations can be different with the upstream and downstream cells of the structure.

1.2.1 Hydraulic Structure Controlled using Time-Series

When the flow control type of "*Controlled using Time-Series*" is selected, the user can select which control time-series will be used for the structure by selecting the corresponding item in the *Time-Series* dropdown list in *Hydraulic Structure Control* group (Figure 2). The user must also set the initial state of the structure at TBEGIN in this group.

The user can click on *Edit* button beside the *Time-Series* dropdown list to edit the control time-series (Figure 3).

Hydraulic Control Structure Boundary Conditions [Equation: Sluice Gate]

Current Boundary Group Information

Number of BC Groups: 3 ID: Gate

Hydraulic Structure Groups: 1 Flow Derived From: Equation: Sluice Gate

Current Group: 3 Time Control: Controlled using Time-Series

Available Rating Curves

Number of Defined Rating Curves: 0

Setting for Current Boundary Cell

Current Cell: 1 Number of Cells: 1

Add Cell Remove Cell Remove All Add by Polyline

Upstream (Outflow) Cell

L: 456 I: 49 J: 17

Bot Elev: 5 Initial Depth: 5

Offset for the Current Cell (HQCTLU, m): 0 Set

Downstream Cell

L: 457 I: 50 J: 17

Bot Elev: 5 Initial Depth: 5

Offset for the Current Cell (HQCTLD, m): 0 Set

Cell Options

Rating Table/Flow Lookup Table

Equation: Gate Edit All

Head Multiplier: 1

Time-variable Hydraulic Structure Control

Table: GATE OPENING Edit All

Boundary Condition Group

Boundary Flow Multiplier: $Q = q(h) (L^2 L^2 / T)$

Cancel OK

Figure 2: GUI for hydraulic structure control using a time-series

Data Series: Hydraulic Control

Series: Number of Series: 1 F Current Series: 1 GATE OPENING Show Params

Title Block Reset Number of Header Lines: 23

* HEIGHT : OPENING HEIGHT (M), FOR UPWARD OPENING
 * WIDTH : OPENING WIDTH (M), FOR SIDEWARD OPENING
 * SILL : SILL LEVEL CHANGE (M), FOR DOWNWARD OPENING
 * UNITS : NUMBER OF GATES/PUMPING UNITS
 * FLOW : FLOW RATE (M3/S), FOR PUMPS
 * IDX : INDEX OF RATING CURVE/LOOKUP TABLE

Precision: Time: 5 Y: 3 # of Points: 35

Time	Height	Width	Sill	Units	Flow	Curve
0.00000	10.000	20.000	0.000	1	0.000	0
0.50000	10.000	20.000	0.000	1	0.000	0
0.54167	0.000	20.000	0.000	1	0.000	0
0.75000	0.000	20.000	0.000	1	0.000	0
0.79167	9.000	20.000	0.000	1	0.000	0
0.83333	10.000	20.000	0.000	1	0.000	0
1.04167	10.000	20.000	0.000	1	0.000	0
1.08333	0.500	20.000	0.000	1	0.000	0
1.12500	0.000	20.000	0.000	1	0.000	0
1.25000	0.000	20.000	0.000	1	0.000	0
1.29167	10.000	20.000	0.000	1	0.000	0
1.58333	10.000	20.000	0.000	1	0.000	0
1.62500	0.000	20.000	0.000	1	0.000	0
1.75000	0.000	20.000	0.000	1	0.000	0
1.79167	10.000	20.000	0.000	1	0.000	0
2.08333	10.000	20.000	0.000	1	0.000	0
2.12500	0.000	20.000	0.000	1	0.000	0
2.29167	0.000	20.000	0.000	1	0.000	0
2.33333	10.000	20.000	0.000	1	0.000	0
2.58333	10.000	20.000	0.000	1	0.000	0
2.62500	1.800	20.000	0.000	1	0.000	0
2.66667	0.000	20.000	0.000	1	0.000	0
2.79167	0.000	20.000	0.000	1	0.000	0
2.83333	3.300	20.000	0.000	1	0.000	0
2.87500	10.000	20.000	0.000	1	0.000	0
3.08333	10.000	20.000	0.000	1	0.000	0
3.12500	8.100	20.000	0.000	1	0.000	0
3.16667	0.000	20.000	0.000	1	0.000	0

Applied to Parameters

Description	Value
Opening Height:	1
Opening Width:	0
Sill Level Change:	0
Number of Units:	0
Flow Discharge:	0
Rating Curve:	0

Cancel OK

View Series: Current More Y Col: -1

Editing Tools: Editing Tools

Apply to Time Operator: + 0 Apply to Y's 1 1 Copy Col 1

Copy Add Delete BreakPt Smooth Convert Check BC's OK Cancel

Figure 3: GUI for editing control time-series

Listser - [d:\Projects\Testing\HSCControl\TidalDrainage\02-ControlTimeSeries\EFDC8.4\qctlser.inp]

File Edit Options Help 48 %

QCTLSEI.INP - OPERATION RULES FOR HYDRAULIC STRUCTURE CONTROL, USE WITH EFDC+ V8.40 AND L

*
 * ITYPE : INPUT TYPE (NOT USED)
 * MQCTLSEI : NUMBER OF DATA ROWS
 * TCQCTLSEI: TIME CONVERSION FACTOR FROM DAYS TO SECONDS
 * TAQCTLSEI: TIME SHIFT
 * ISHEIGHT : USE OPENING HEIGHT?
 * ISWIDTH : USE OPENING WIDTH?
 * ISSILL : USE SILL LEVEL CHANGE?
 * ISUNITS : USE NUMBER OF GATES/PUMPING UNITS?
 * ISFLOW : USE FLOW RATE?
 * ISCURVE : USE RATING CURVES?
 *
 * HEIGHT : OPENING HEIGHT (M), FOR UPWARD OPENING
 * WIDTH : OPENING WIDTH (M), FOR SIDEWARD OPENING
 * SILL : SILL LEVEL CHANGE (M), FOR DOWNWARD OPENING
 * UNITS : NUMBER OF GATES/PUMPING UNITS
 * FLOW : FLOW RATE (M3/S), FOR PUMPS
 * IDX : INDEX OF RATING CURVE/LOOKUP TABLE
 *
 * TIME HEIGHT WIDTH SILL UNITS FLOW IDX
 *
 C ** TIME HEIGHT (M) WIDTH (M) SILL (M) UNITS FLOW (M3/S) IDX
 1 35 86400 0 1 0 0 0 0 0 ! GATE OPENING
 0.00000 10.000 20.000 0.000 1 0.000 0
 0.50000 10.000 20.000 0.000 1 0.000 0
 0.54167 0.000 20.000 0.000 1 0.000 0
 0.75000 0.000 20.000 0.000 1 0.000 0
 0.79167 9.000 20.000 0.000 1 0.000 0
 0.83333 10.000 20.000 0.000 1 0.000 0
 1.04167 10.000 20.000 0.000 1 0.000 0
 1.08333 0.500 20.000 0.000 1 0.000 0

Figure 4: Data format for QCTLSEI.INP

1.2.2 Hydraulic Structure Controlled using Control Rules based on Upstream Level or Head Difference

When the flow control type of "*Controlled based on Upstream Level*" or "*Controlled based on Head Difference*" is selected, the user can select which control rules will be used for the structure by selecting the corresponding item in the *Control Rules* dropdown list in *Hydraulic Structure Control* group (Figure 5). The user must also set the initial state of the structure at TBEGIN in this group.

The user can click on *Edit* button beside the *Control Rules* dropdown list to edit the control rules (Figure 6).

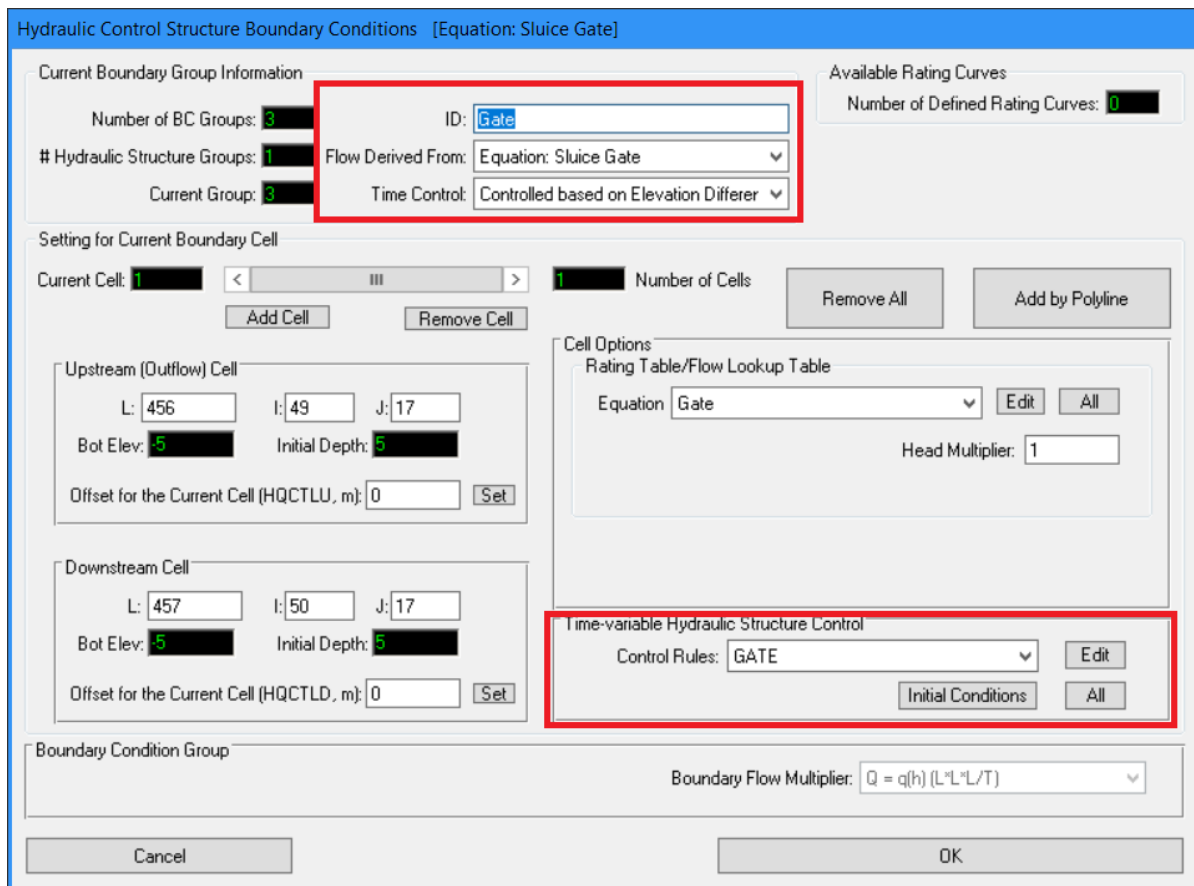


Figure 5: GUI for hydraulic structure control using operational rules

The data columns for control rules in Figure 6 or Figure 7 are as follows

LEVEL: Trigger level (m) of the upstream control or head difference control

STATE: This is to turn on (STATE = 1) or turn off (STATE = 0) the structure operation.

If the current state of the structure is off (STATE = 0) or is closing (STATE = 3 internally) and the control level is higher or equal the turning on trigger level, EFDC will change it state to opening state (STATE = 2 internally) until it reaches the full capacity operation and keeps the state as opened (STATE = 1).

If the current state of the structure is off (STATE = 1) or is opening (STATE = 2 internally) and the control level is lower or equal the turning off trigger level, EFDC will change it state to closing state (STATE = 3 internally) until it reaches the minimum and keeps the state as closed (STATE = 0).

ID

Hydraulic Structure Control Rules

Control Rules

Name: Number of Rules: Current Rule:

Rules Applied For

☒ Opening Height ☐ Opening Width ☐ Sill Level Change

Number of Triggers:

Control Value (m)	State	Height (m)	Rate (m/min.)
0.5	1	10	0.5
0.2	0	0	0.5

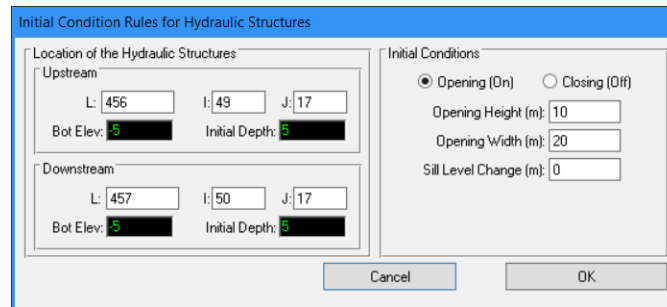
Cancel OK

Figure 6: GUI for editing operational rules

```

Listner - [d:\Projects\Testing\HSControl\TidalDrainage\03-ControlRules\EFDC8.4\QC...
File Edit Options Help 100 %
* QCRULES.INP - OPERATION RULES FOR HYDRAULIC STRUCTURE CONTROL, USE WITH E
*
* ITYPE      : INPUT TYPE (NOT USED)
* MQCTLSER  : NUMBER OF DATA ROWS
* ISHEIGHT   : USE OPENING HEIGHT?
* ISWIDTH    : USE OPENING WIDTH?
* ISSILL     : USE SILL LEVEL CHANGE?
* ISUNITS    : USE NUMBER OF GATES/PUMPING UNITS?
* ISFLOW     : USE FLOW RATE?
* ISCURVE    : USE RATING CURVES?
*
* LEVEL      : THRESHOLD/TRIGGER LEVEL (M)
* STATE      : 0 = OFF, 1 = ON
* HEIGHT     : OPENING HEIGHT (M), FOR UPWARD OPENING
* WIDTH      : OPENING WIDTH (M), FOR SIDEWARD OPENING
* SILL       : SILL LEVEL CHANGE (M), FOR DOWNWARD OPENING
* UNITS      : NUMBER OF GATES/PUMPING UNITS
* FLOW       : FLOW RATE (M3/S), FOR PUMPS
* RATE       : RATE OF OPENING/CLOSING, FOR GATES
* IDX       : INDEX OF RATING CURVE/LOOKUP TABLE
*
* LEVEL STATE HEIGHT WIDTH SILL UNITS FLOW RATE IDX
*
0 2 1 0 0 0 0 0 0 ! Gate
0.500 1 10.00 20.00 0.00 1 0.00 0.500 0
0.200 0 0.00 20.00 0.00 1 0.00 0.500 0
  
```

Figure 7: Data format for QCRULES.INP



Initial Condition Rules for Hydraulic Structures

Location of the Hydraulic Structures:

Upstream: L: 456 I: 49 J: 17 Bot Elev: 5 Initial Depth: 5

Downstream: L: 457 I: 50 J: 17 Bot Elev: 5 Initial Depth: 5

Initial Conditions:

☒ Opening (On) ☐ Closing (Off)

Opening Height (m): 10

Opening Width (m): 20

Sill Level Change (m): 0

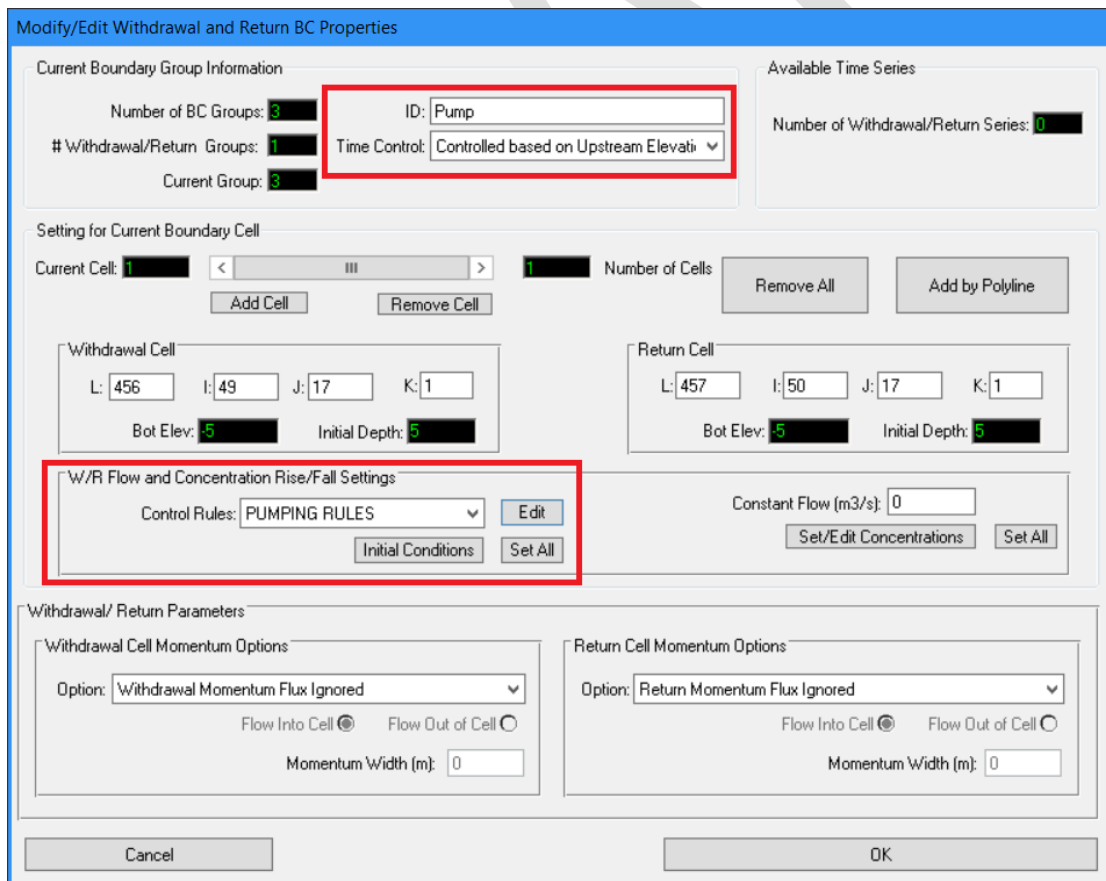
Cancel OK

Figure 8: Initial Conditions for Gate Operation

1.2.3 Withdrawal/Return Structure Controlled using Control Rules based on Upstream Level or Head Difference

When the flow control type of "Controlled based on Upstream Level" or "Controlled based on Head Difference" is selected, the user can select which control rules will be used for the structure by selecting the corresponding item in the *Control Rules* dropdown list in *Hydraulic Structure Control* group (Figure 5). The user must also set the initial state of the structure at TBEGIN in this group.

The user can click on *Edit* button beside the *Control Rules* dropdown list to edit the control rules (Figure 6).



Modify/Edit Withdrawal and Return BC Properties

Current Boundary Group Information:

Number of BC Groups: 3 ID: Pump

Withdrawal/Return Groups: 1 Time Control: Controlled based on Upstream Elevati

Current Group: 3

Available Time Series:

Number of Withdrawal/Return Series: 0

Setting for Current Boundary Cell:

Current Cell: 1 Number of Cells: 1

Add Cell Remove Cell

Withdrawal Cell:

L: 456 I: 49 J: 17 K: 1

Bot Elev: 5 Initial Depth: 5

Return Cell:

L: 457 I: 50 J: 17 K: 1

Bot Elev: 5 Initial Depth: 5

W/R Flow and Concentration Rise/Fall Settings:

Control Rules: PUMPING RULES Edit

Initial Conditions Set All

Constant Flow (m3/s): 0

Set/Edit Concentrations Set All

Withdrawal/ Return Parameters:

Withdrawal Cell Momentum Options:

Option: Withdrawal Momentum Flux Ignored

Flow Into Cell ☒ Flow Out of Cell ☐

Momentum Width (m): 0

Return Cell Momentum Options:

Option: Return Momentum Flux Ignored

Flow Into Cell ☒ Flow Out of Cell ☐

Momentum Width (m): 0

Cancel OK

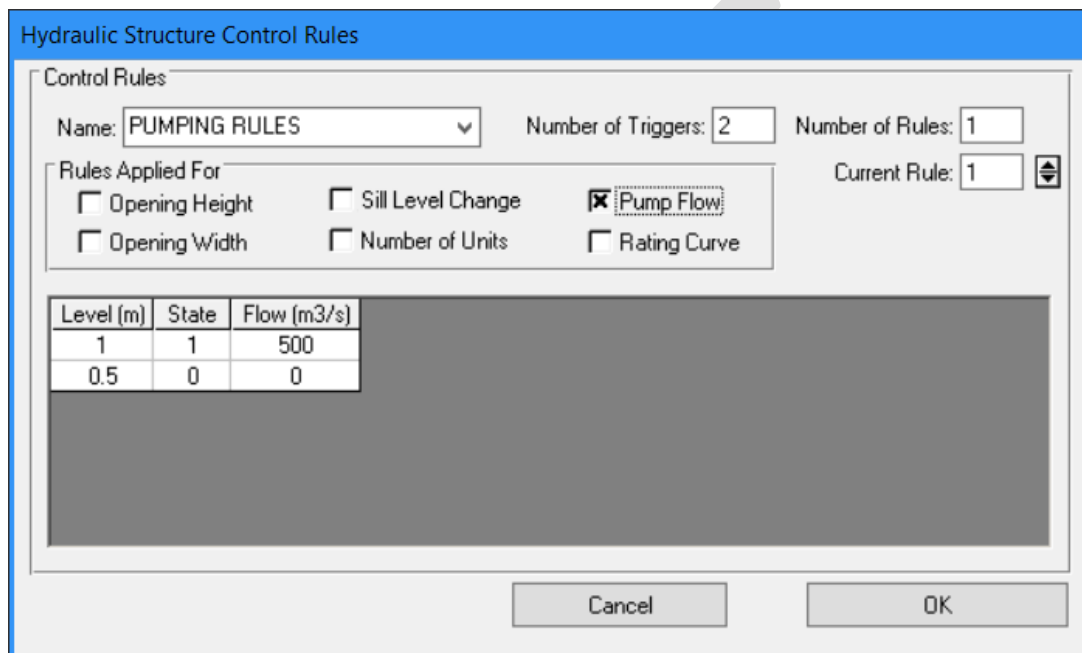
Figure 9: GUI for withdrawal/return Structure structure control using operational rules

The data columns for control rules in Figure 6 or Figure 7 are as follows

LEVEL: Trigger level (m) of the upstream control or head difference control

STATE: This is to turn on (STATE = 1) or turn off (STATE = 0) the structure operation.

FLOW: Flow discharge.



Hydraulic Structure Control Rules

Control Rules

Name: Number of Triggers: Number of Rules:

Rules Applied For

☐ Opening Height ☐ Sill Level Change ☒ Pump Flow

☐ Opening Width ☐ Number of Units ☐ Rating Curve

Current Rule:

Level (m)	State	Flow (m3/s)
1	1	500
0.5	0	0

Cancel OK

Figure 10: GUI for editing operational rules

2 Test Cases

A river and a bay system of 10 km long is connected to the sea by a gate of 20 m wide and 10 m height, bottom elevation of -4 m. The gate is located at RS600 in HEC-RAS and at X=9400 m in EFDC. Upstream boundary condition is river flow and downstream boundary condition is tidal water level fluctuation.

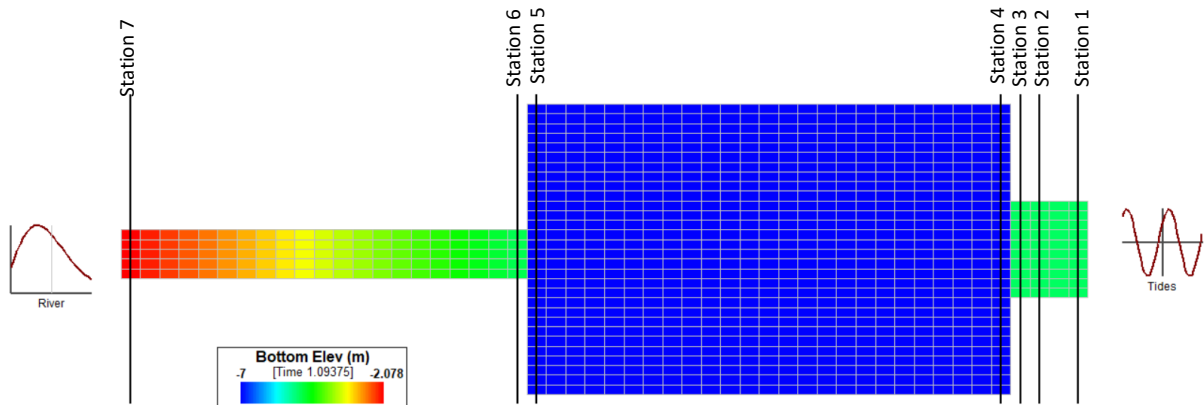


Figure 11: Model Setup in EFDC

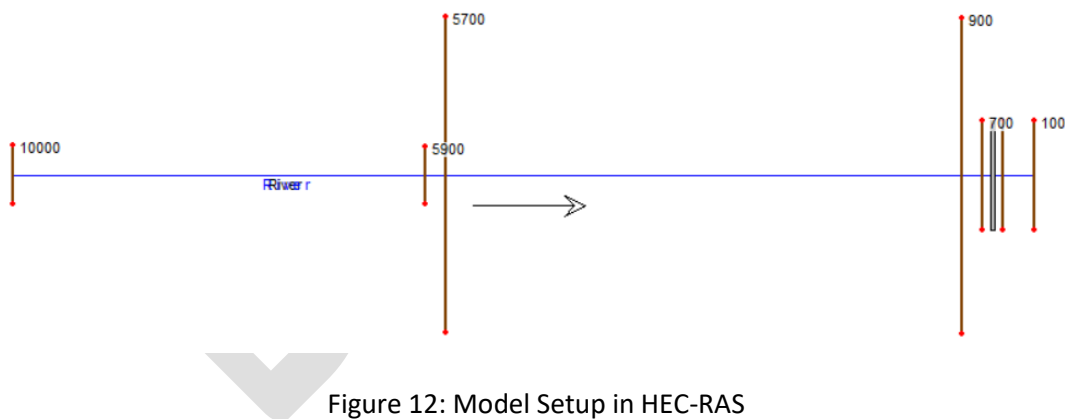


Figure 12: Model Setup in HEC-RAS

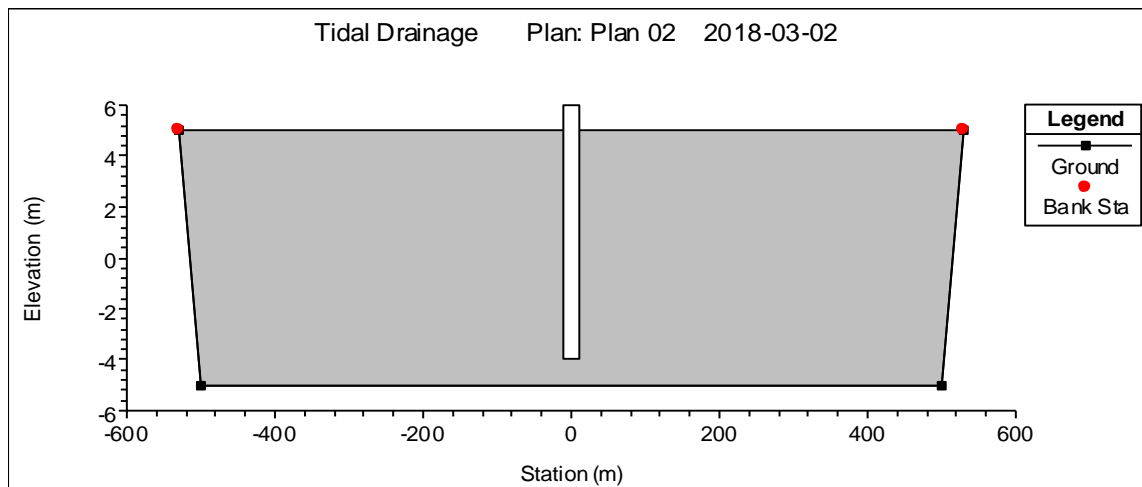


Figure 13: The gate setup in HEC-RAS

Inline Gate Editor

Gate Group: Gate #1

Gate type (or methodology): Sluice

Geometric Properties

Height: 10
Width: 20
Invert: -4
Openings: 1

Centerline Stations

	Station
1	0.
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

Gate Flow

Sluice Gate Flow

Sluice Discharge Coefficient (0.5-0.7): 0.6

Submerged Orifice Flow

Orifice Coefficient (typically 0.8): 0.8

Head Reference: Sill (Invert)

Weir Flow Over Gate Sill (gate out of water)

Weir Shape: Broad Crested

Weir Coefficient: 1.67

OK Cancel Help

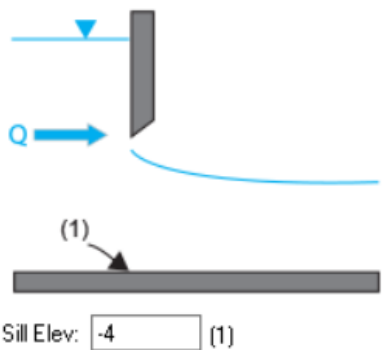
Figure 14: The gate settings in HEC-RAS

Hydraulic Structure Equation Definition Editor

Equation Parameters

Equation ID: Gate

Hydraulic Structure Type: SLUICE GATE ☒ Allow Reverse Flows



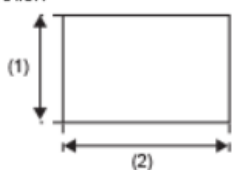
Super-Critical Weir Flow: 1.05

Sub-Critical Weir Flow: 0.61

Free Sluice Flow (Super-Critical): 0.6

Submerged Orifice Flow: 0.8

Cross Section



Height: 10 (1)

Width: 20 (2)

Figure 15: The gate settings in EFDC_Explorer

Table 1: Locations of comparison stations

Station	EFDC X(m)	HEC-RAS RS
Station 1	9900	100
Station 2	9500	500
Station 3	9300	700
Station 4	9100	900
Station 5	4300	5700
Station 6	4100	5900
Station 7	100	9900

2.1 Test 1: Uncontrolled Gate Structures

Path: M:\EFDC_Explorer Modeling System\Testing\EFDC\21 Hystrect\06 Operation\TidalGate\01-Uncontrolled\

This test is to make sure there is no change in the behavior of the uncontrolled structure. The uncontrolled structure in EFDC8.4 should have the same results as in EFDC8.3.

2.1.1 Comparison of water surface elevation

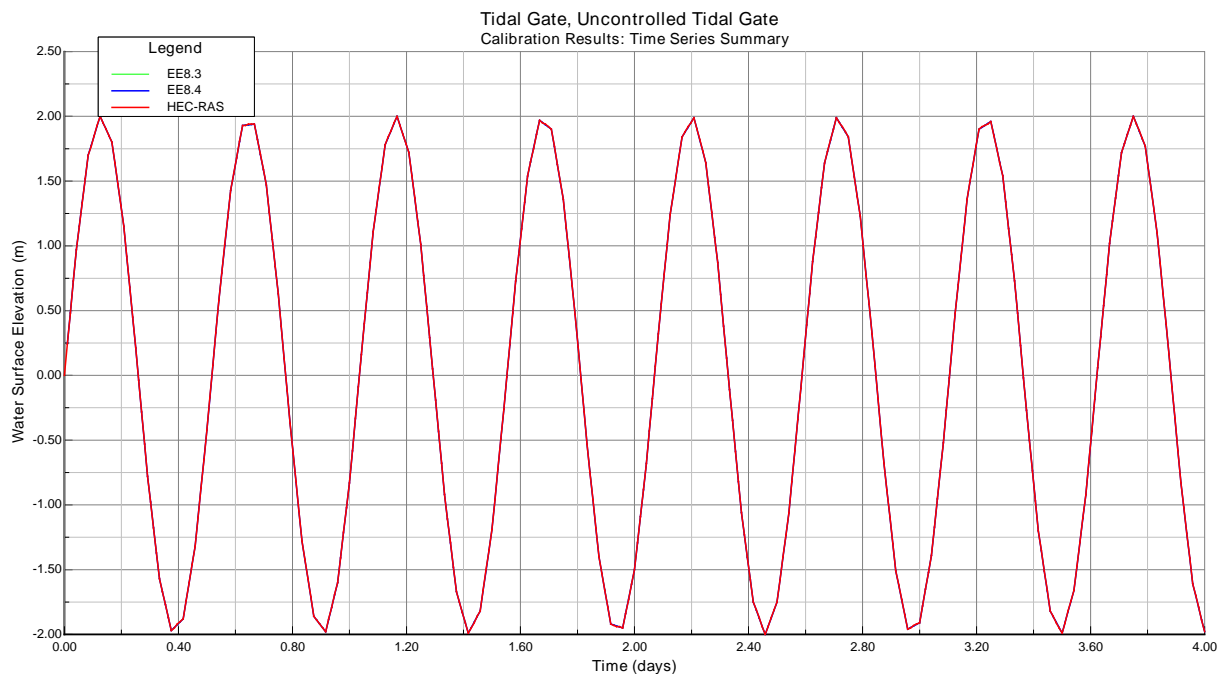


Figure 16: Comparison of water surface elevation at Station 1

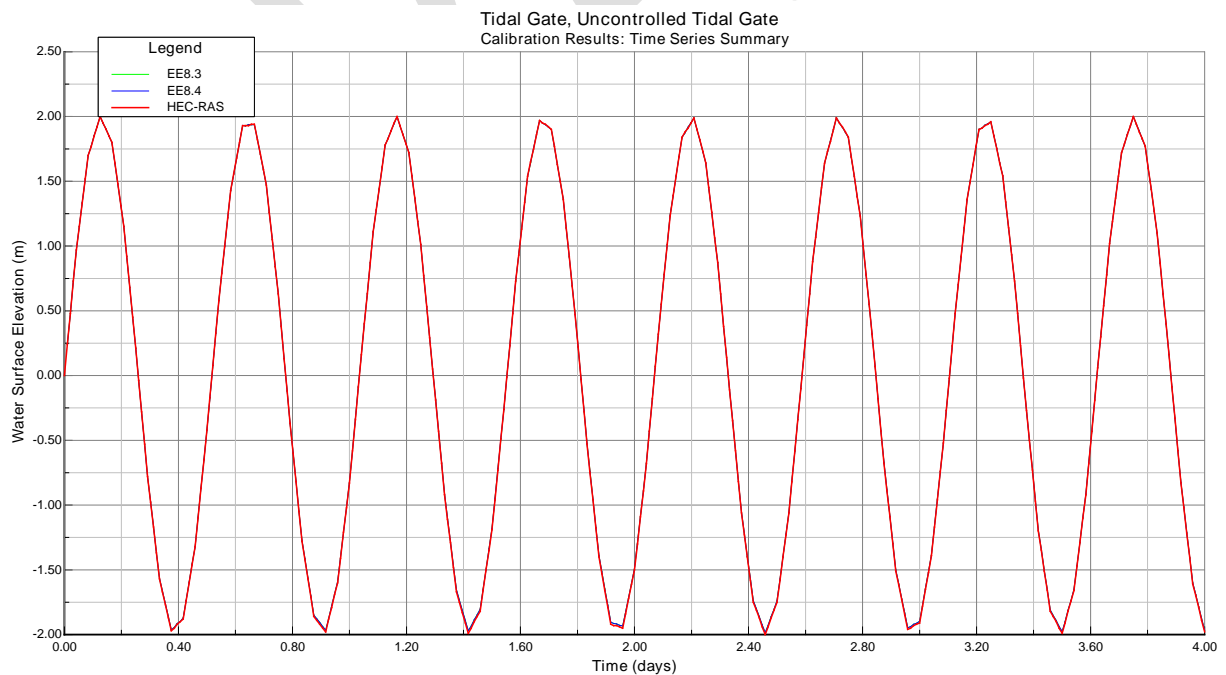


Figure 17: Comparison of water surface elevation at Station 2

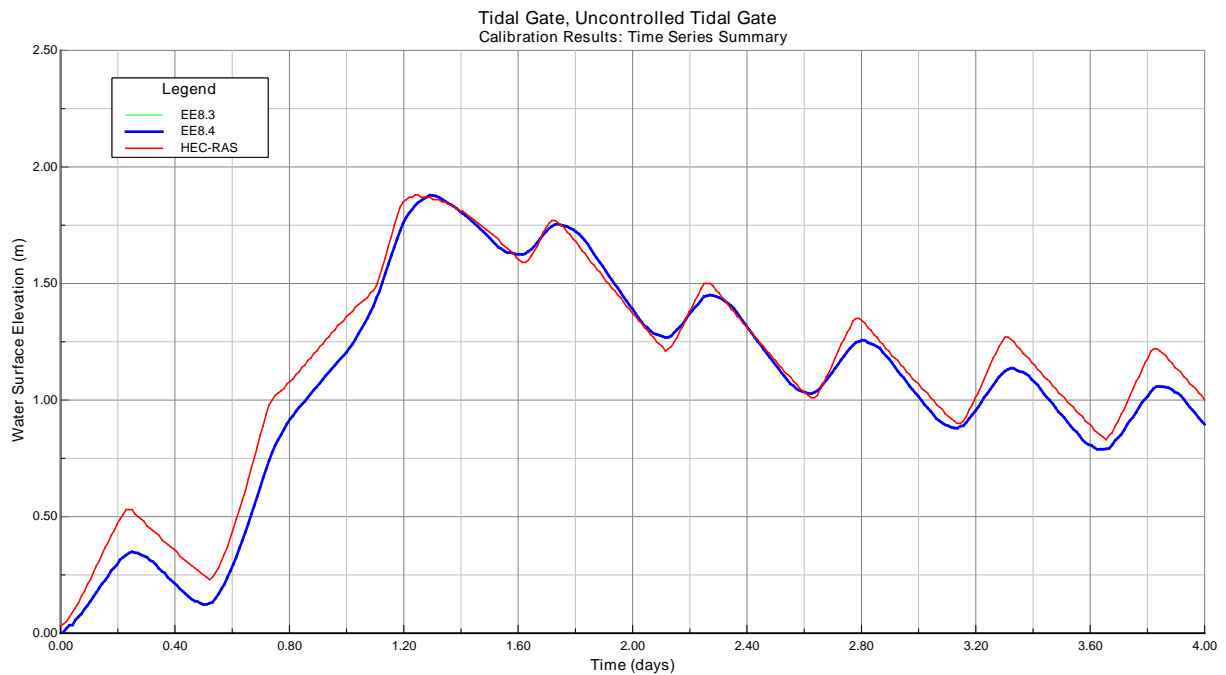


Figure 18: Comparison of water surface elevation at Station 3

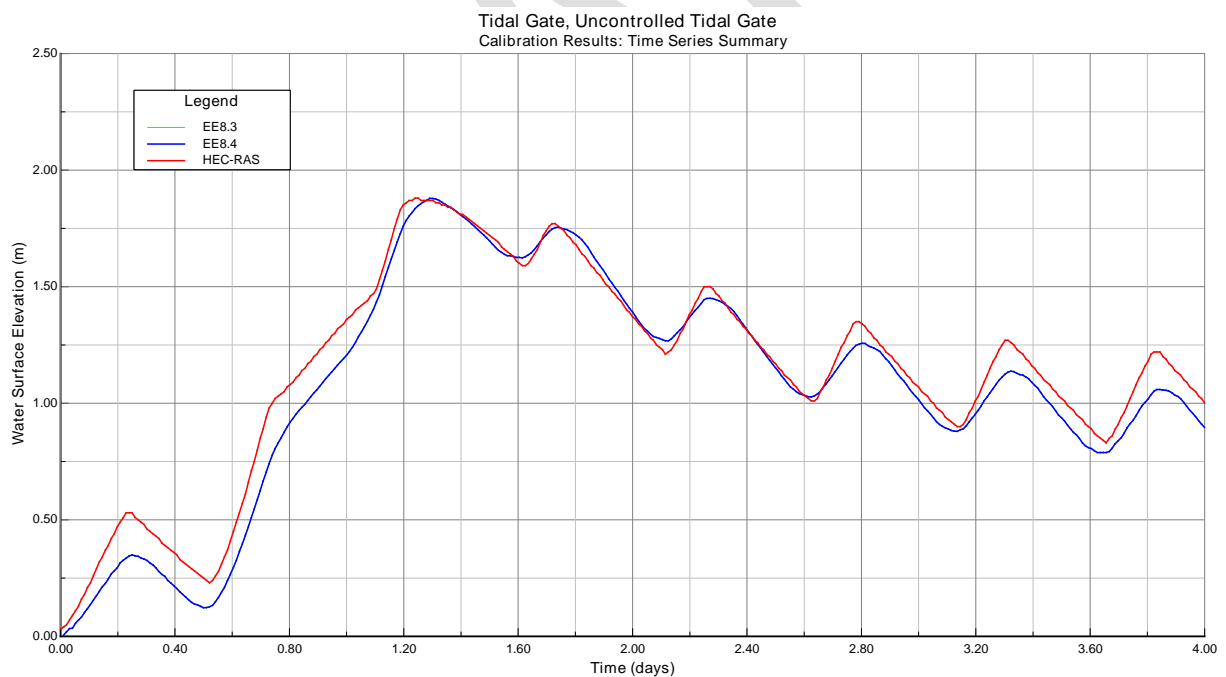


Figure 19: Comparison of water surface elevation at Station 4

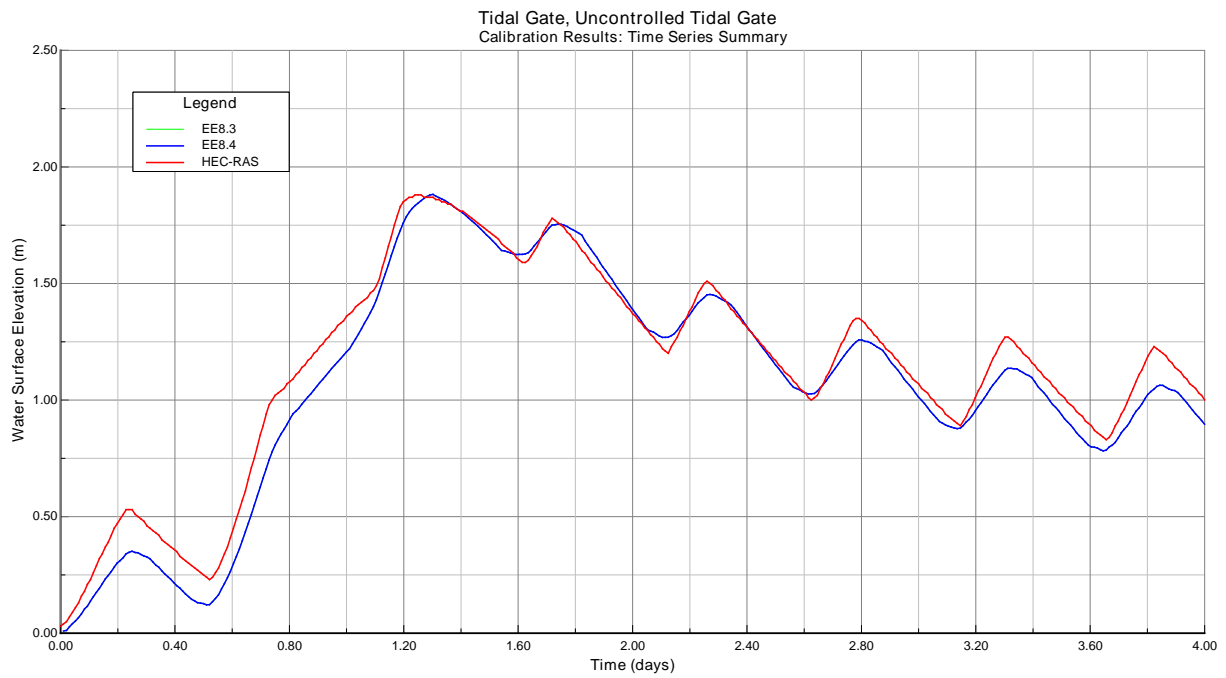


Figure 20: Comparison of water surface elevation at Station 5

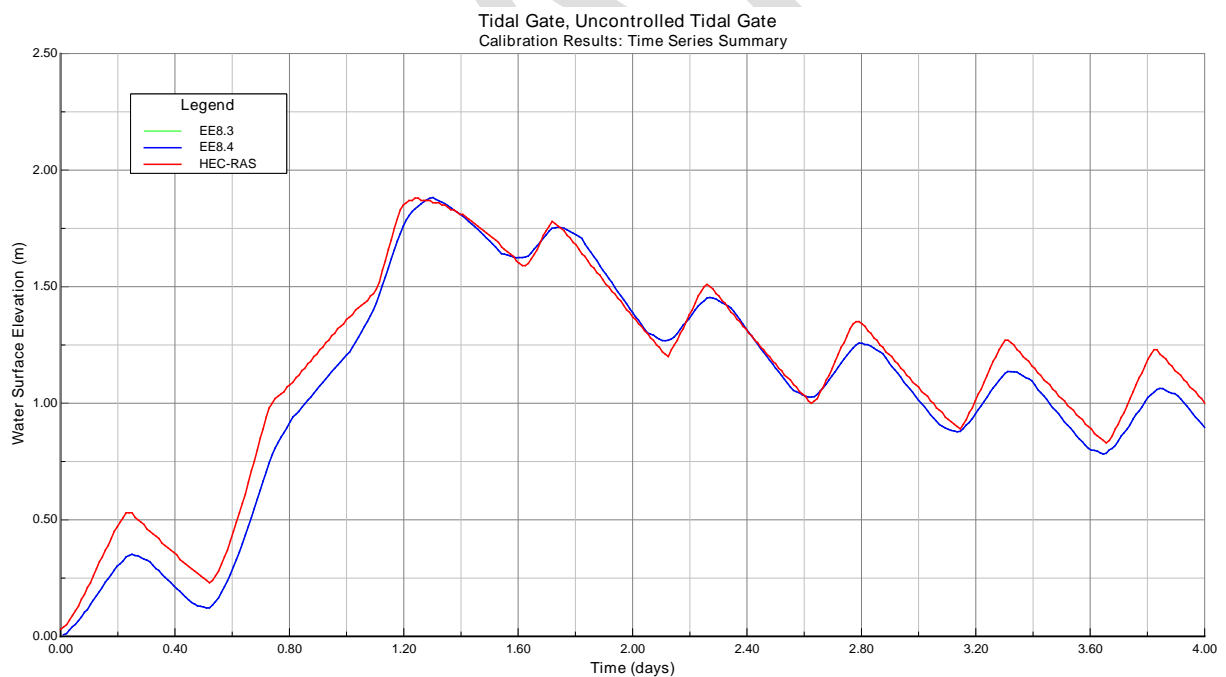


Figure 21: Comparison of water surface elevation at Station 6

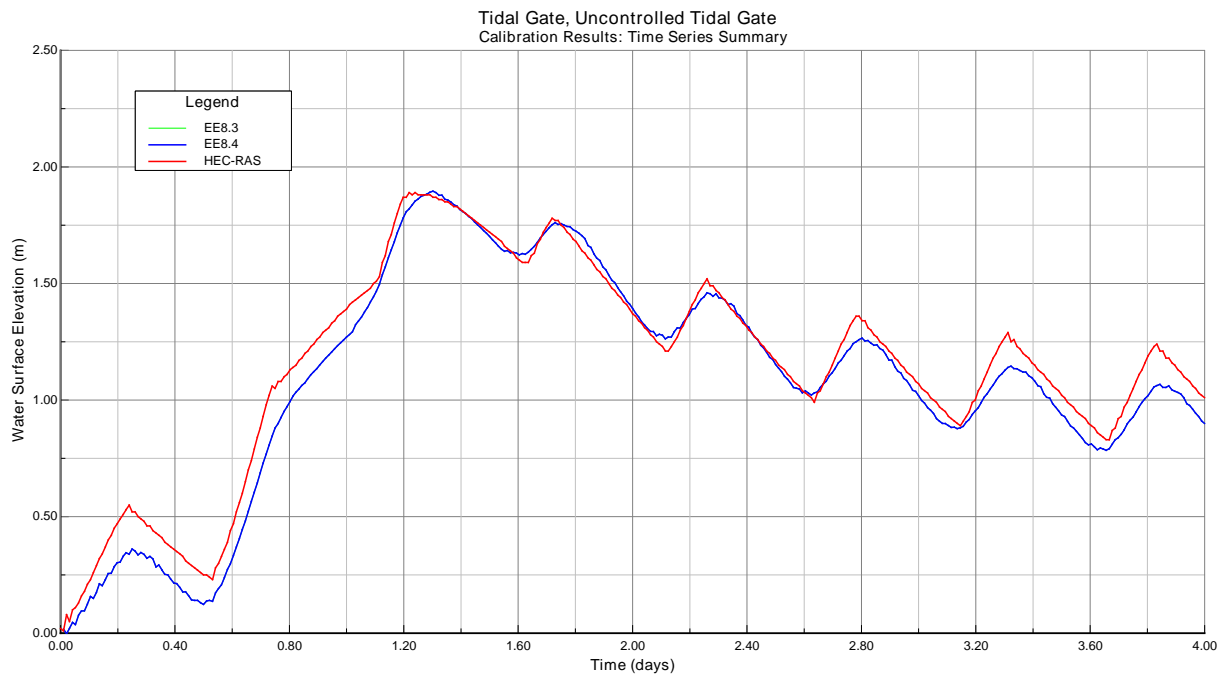


Figure 22: Comparison of water surface elevation at Station 7

2.1.2 Comparison of flow discharge

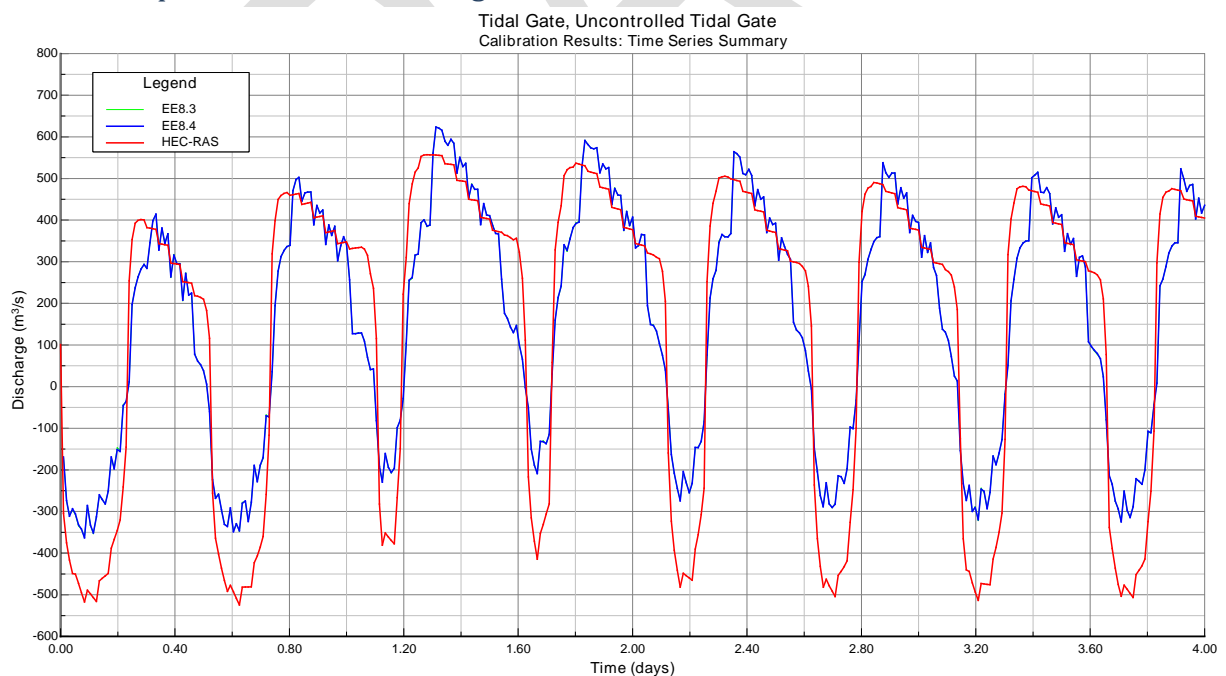


Figure 23: Comparison of flow discharge at Station 1

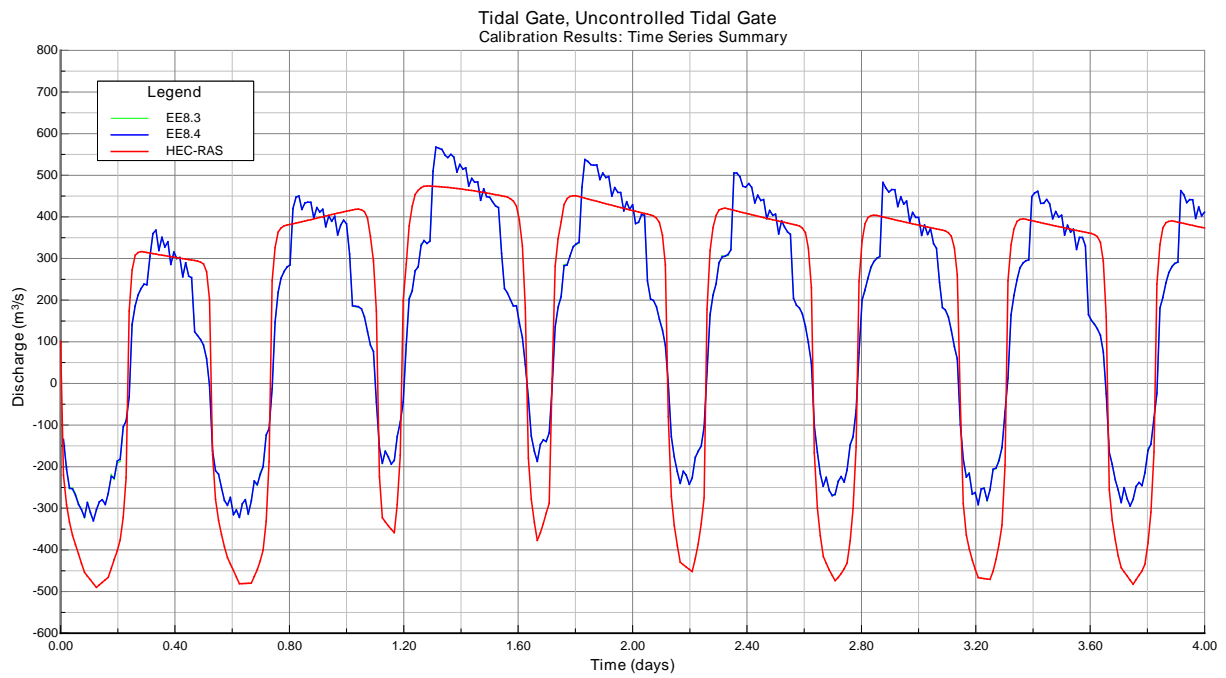


Figure 24: Comparison of flow discharge at Station 2

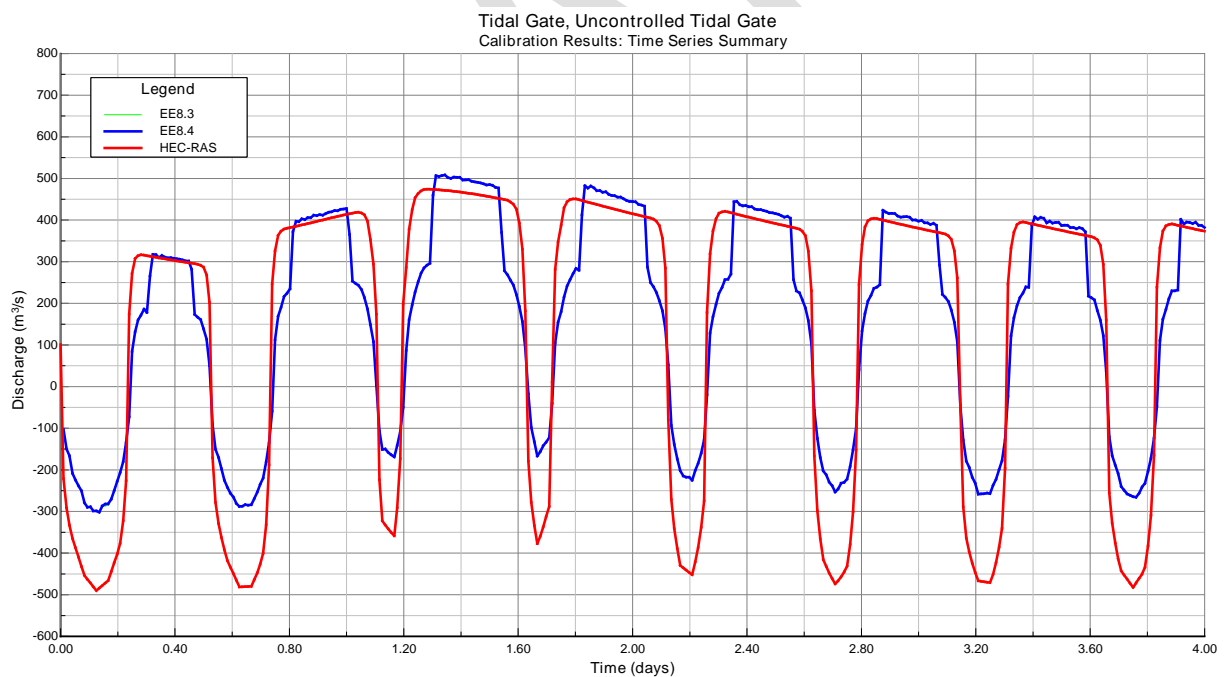


Figure 25: Comparison of flow discharge at Station 3

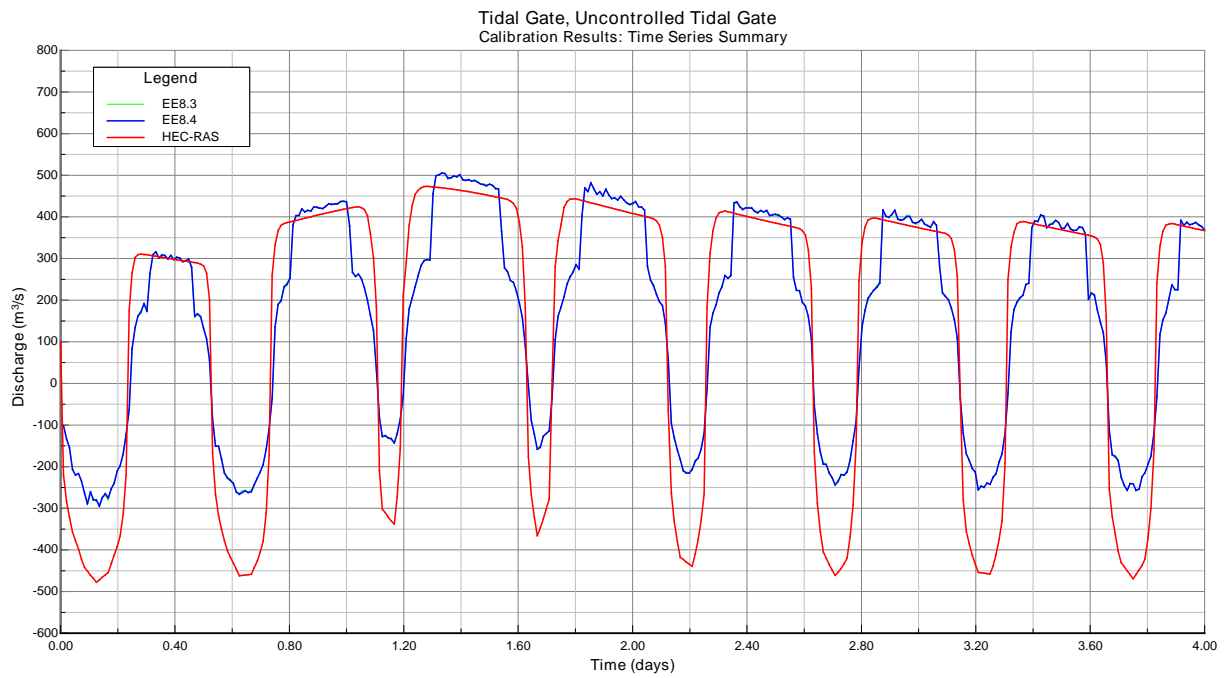


Figure 26: Comparison of flow discharge at Station 4

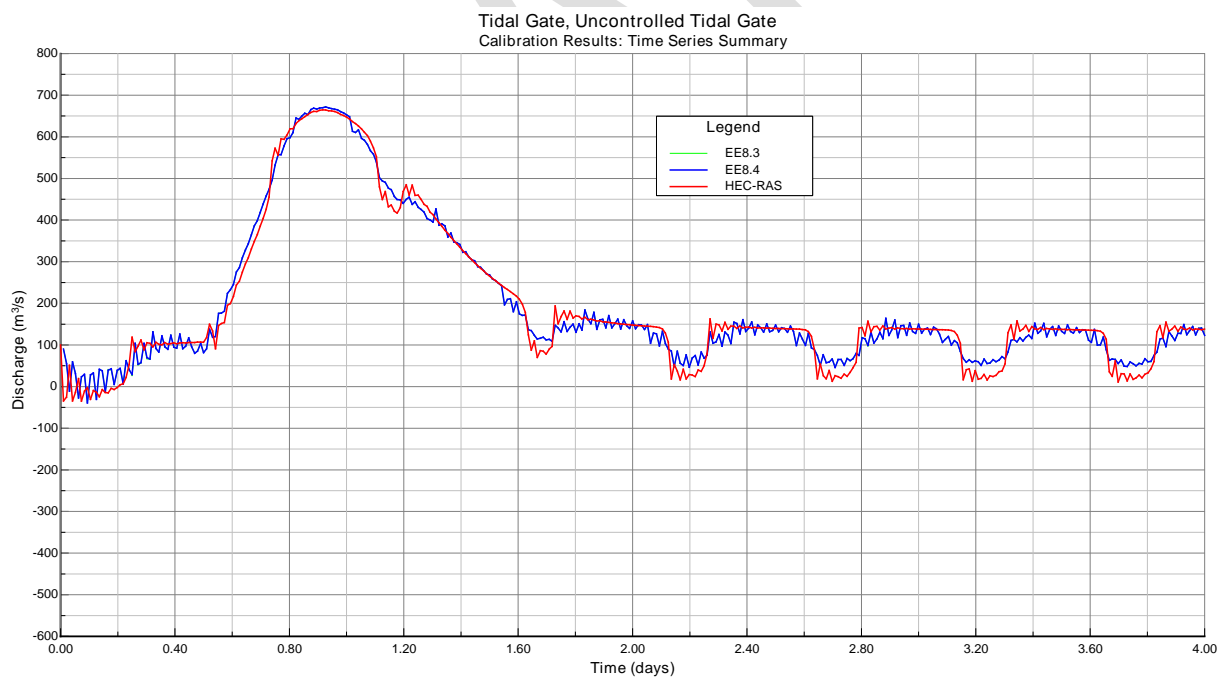


Figure 27: Comparison of flow discharge at Station 5

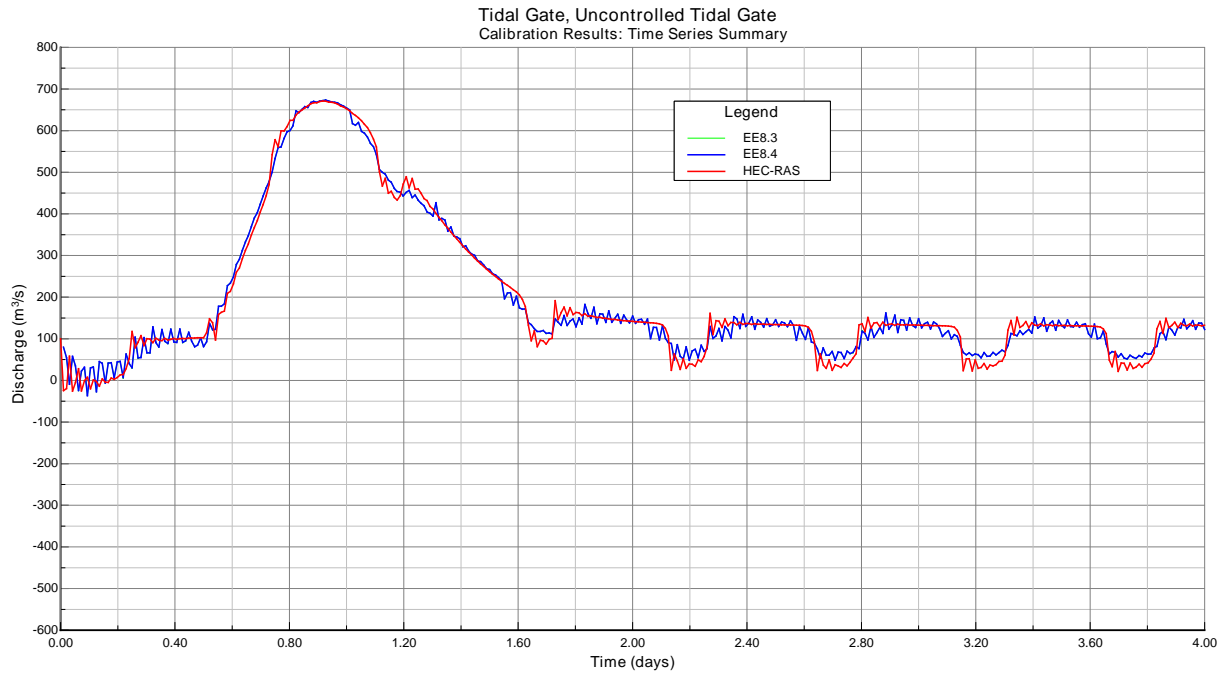


Figure 28: Comparison of flow discharge at Station 6

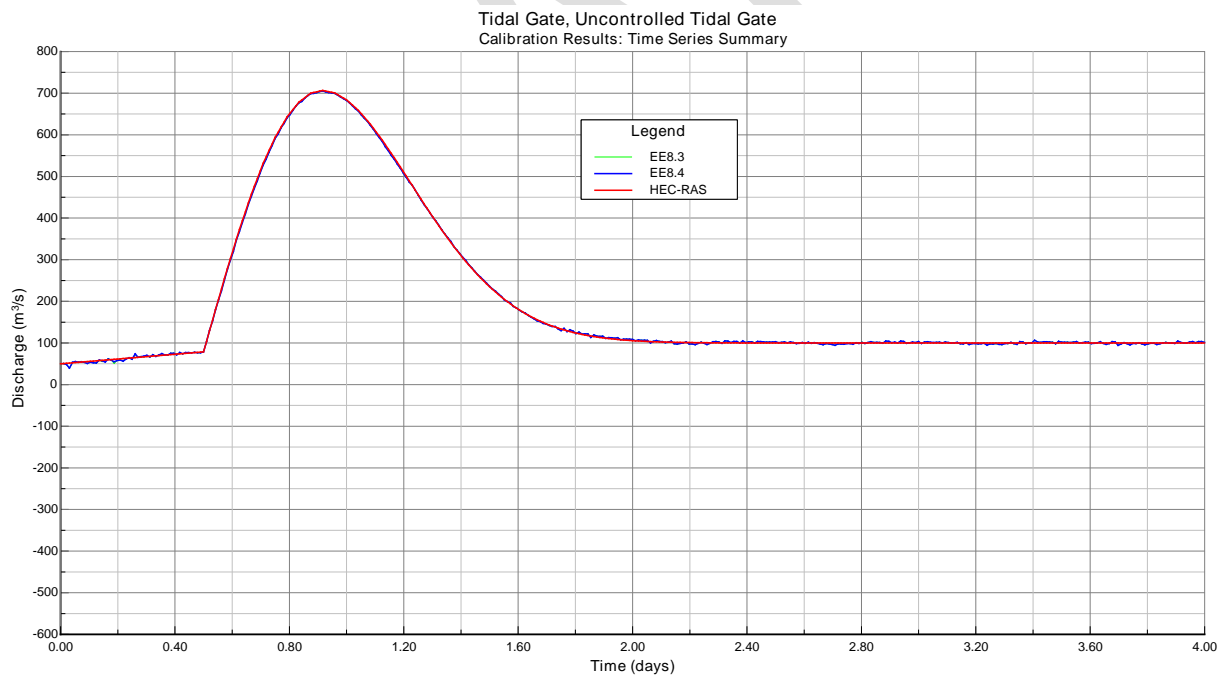


Figure 29: Comparison of flow discharge at Station 7

2.2 Test 2: Gate Structure Controlled using Operational Time Series

Path: M:\EFDC_Explorer Modeling System\Testing\EFDC\21 Hystrcut\06 Operation\TidalGate\02-ControlTimeSeries

This test uses a hydraulic control time-series of gate opening defined in QCTLSER.INP. The model results of EFDC8.4 are compared with HEC-RAS for water surface elevations and flow discharges at the stations.

2.2.1 Comparison of water surface elevation

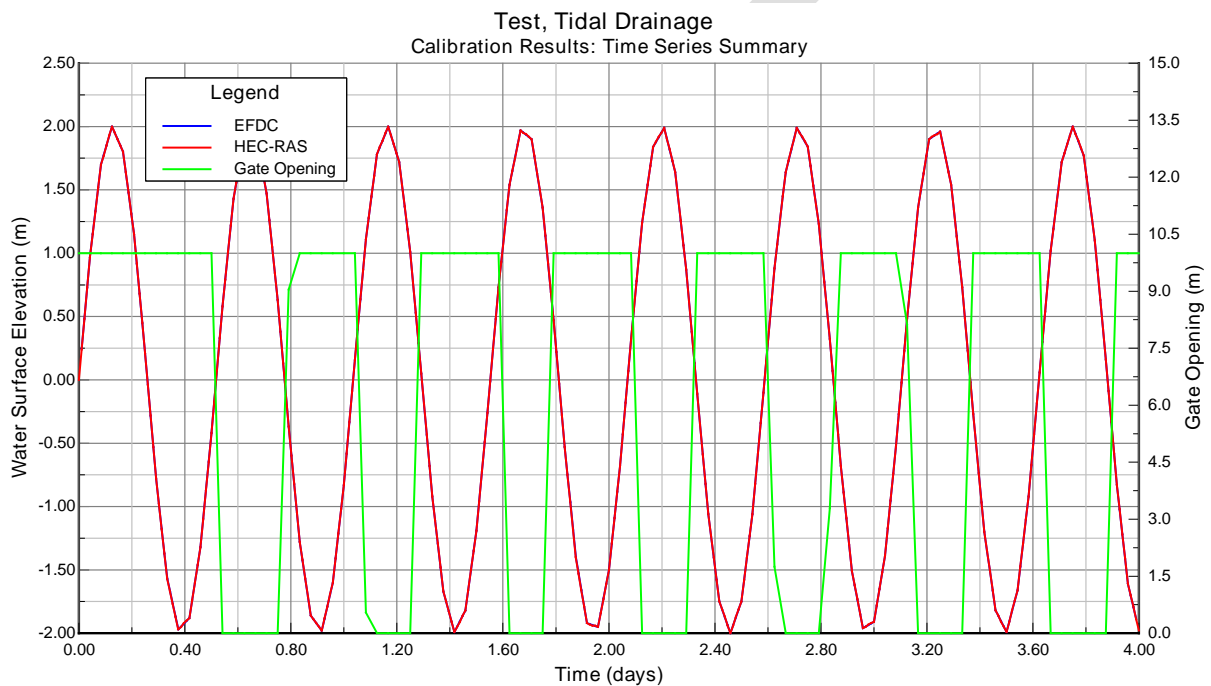


Figure 30: Comparison of water surface elevation at Station 1

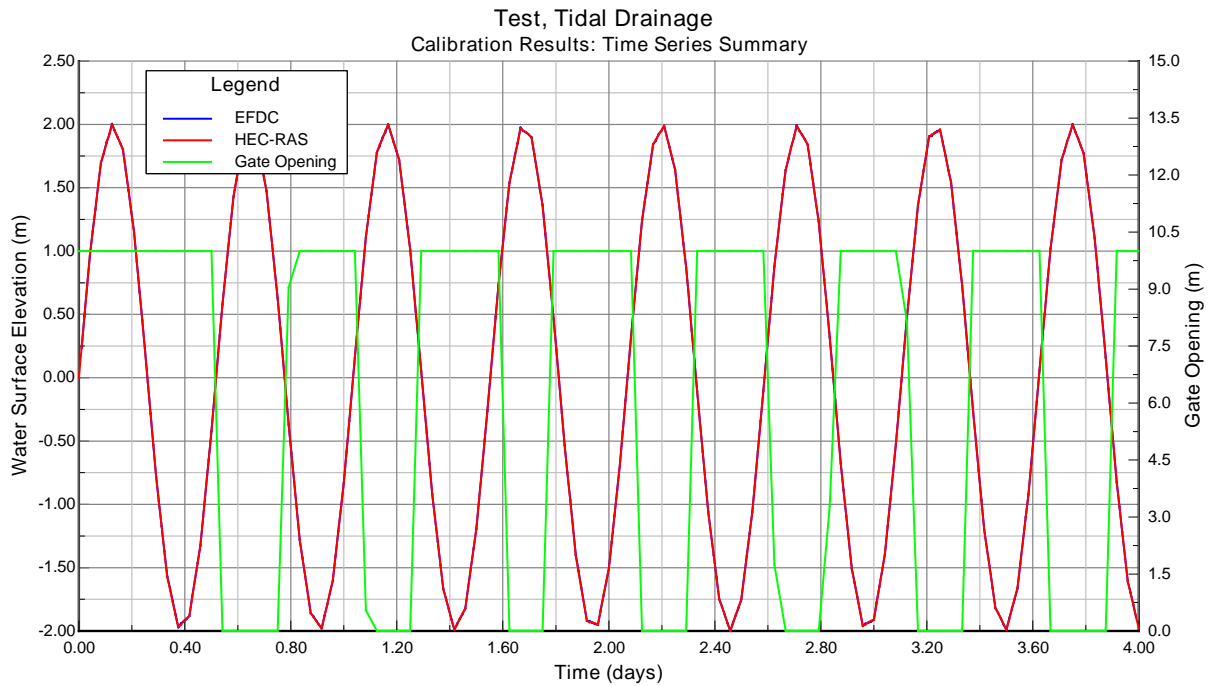


Figure 31: Comparison of water surface elevation at Station 2

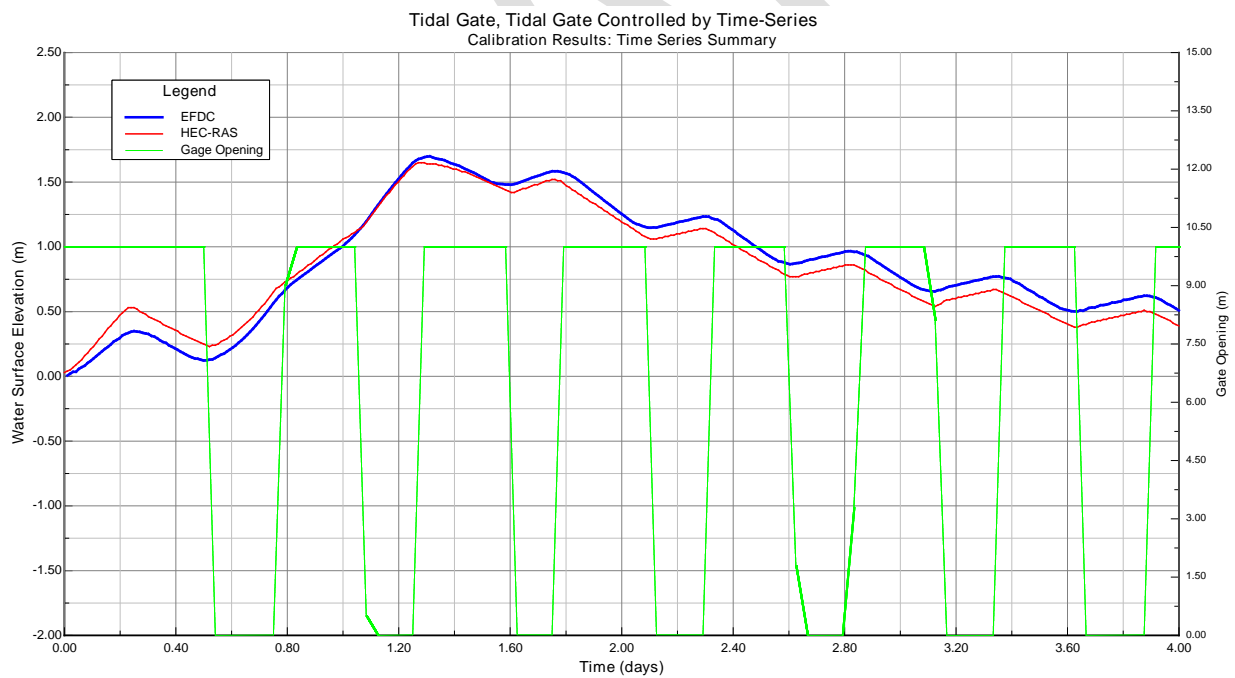


Figure 32: Comparison of water surface elevation at Station 3

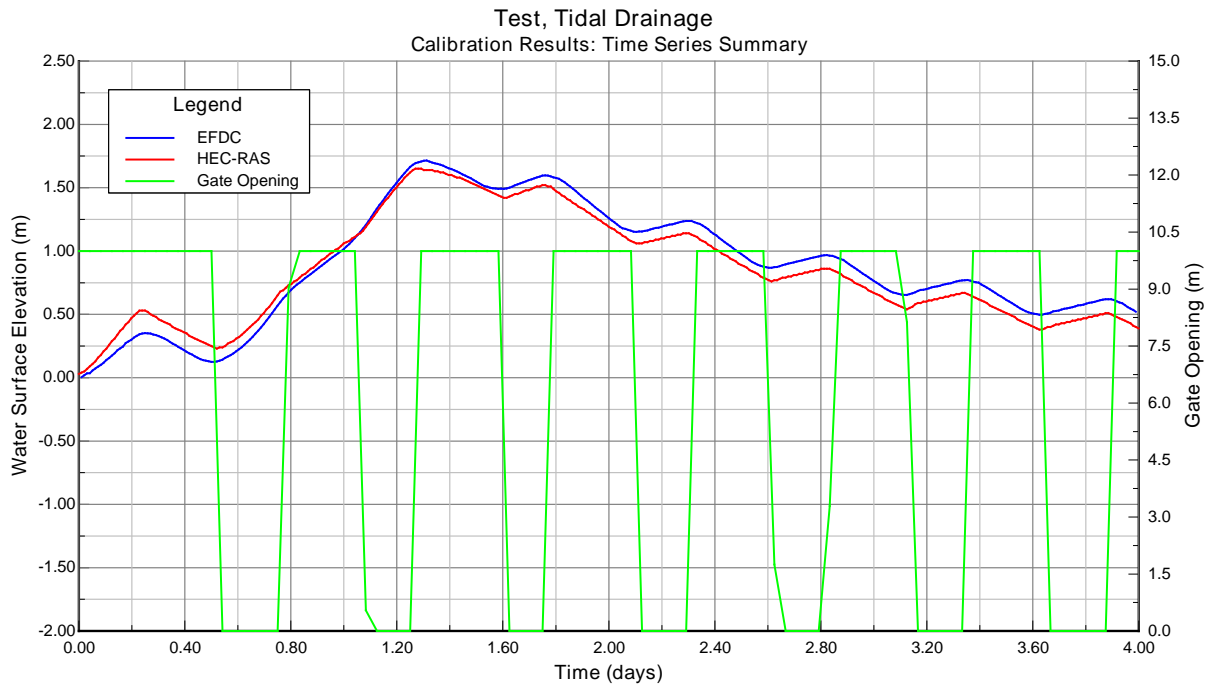


Figure 33: Comparison of water surface elevation at Station 4

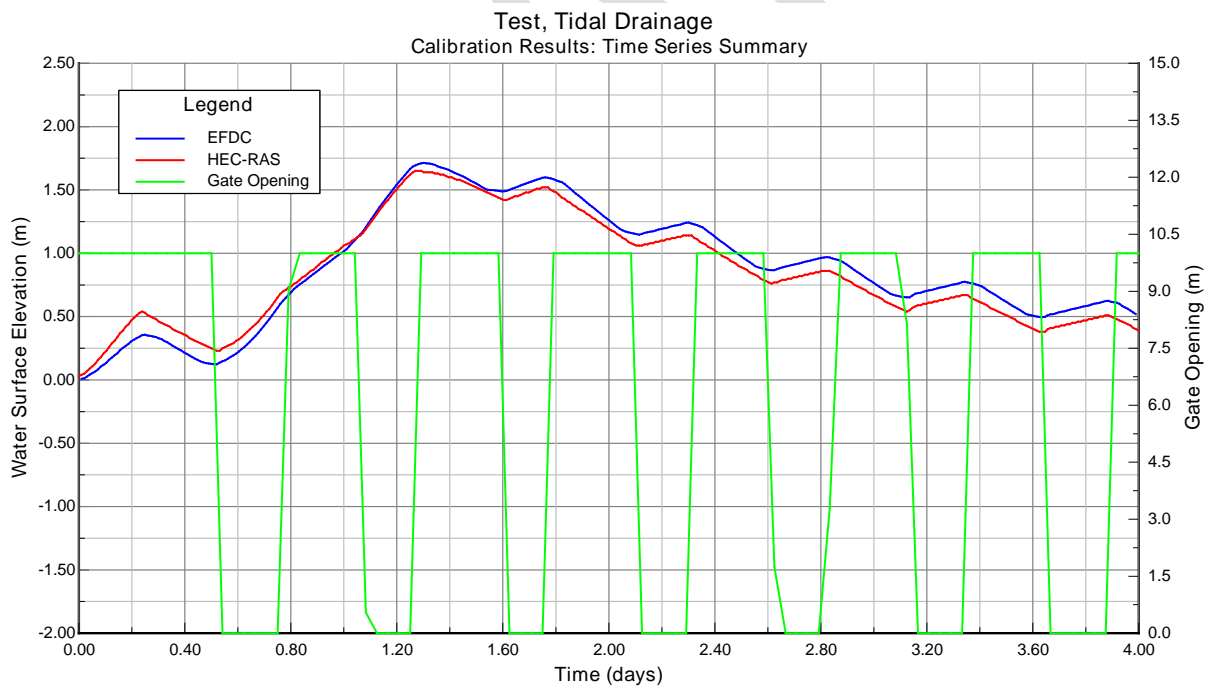


Figure 34: Comparison of water surface elevation at Station 5

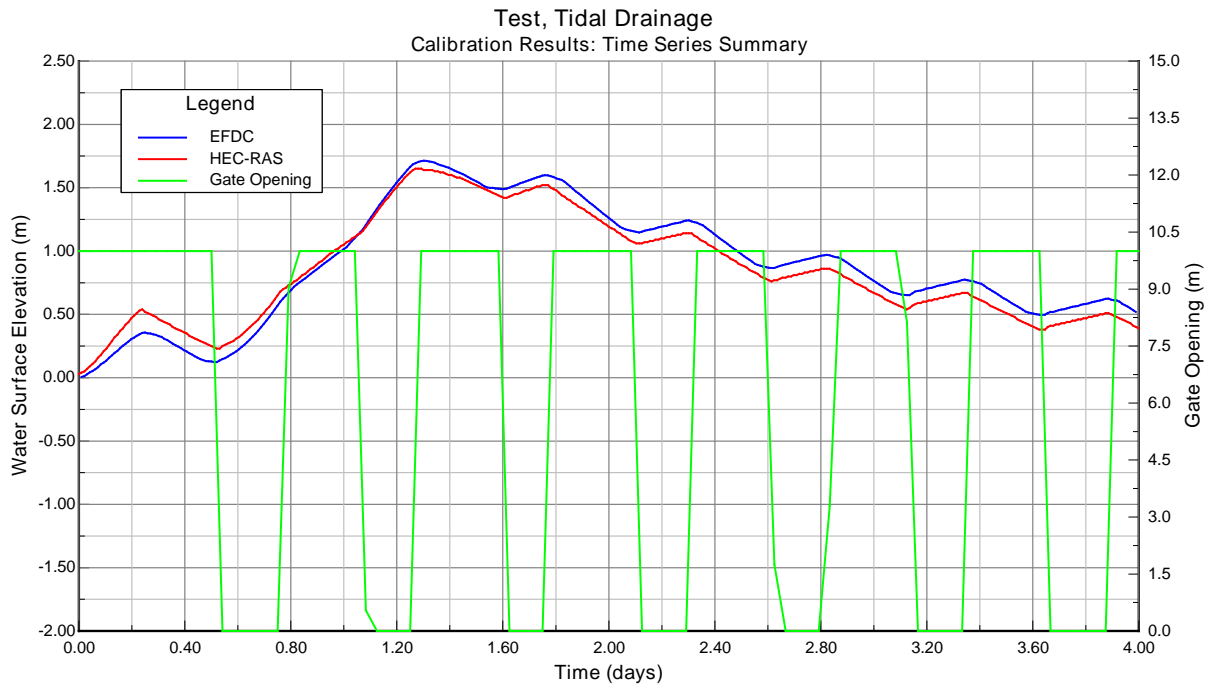


Figure 35: Comparison of water surface elevation at Station 6

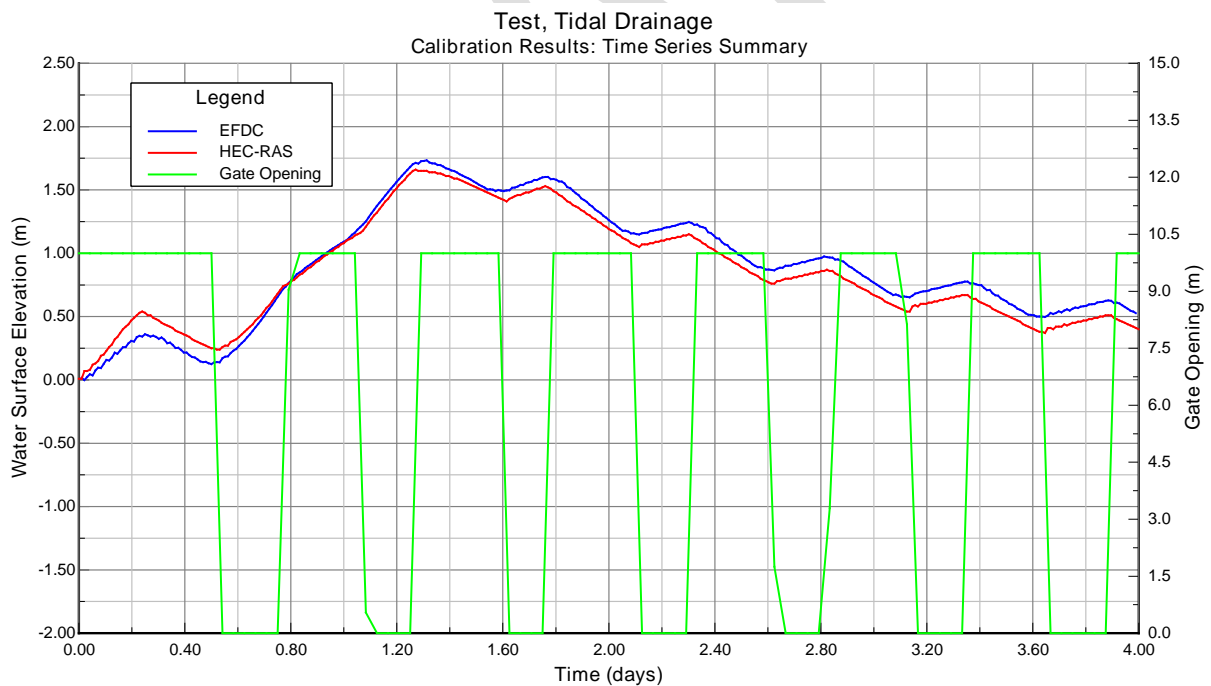


Figure 36: Comparison of water surface elevation at Station 7

2.2.2 Comparison of flow discharge

Flow discharge is extracted and calculated using Flux Tool in EFDC and compared with HEC-RAS

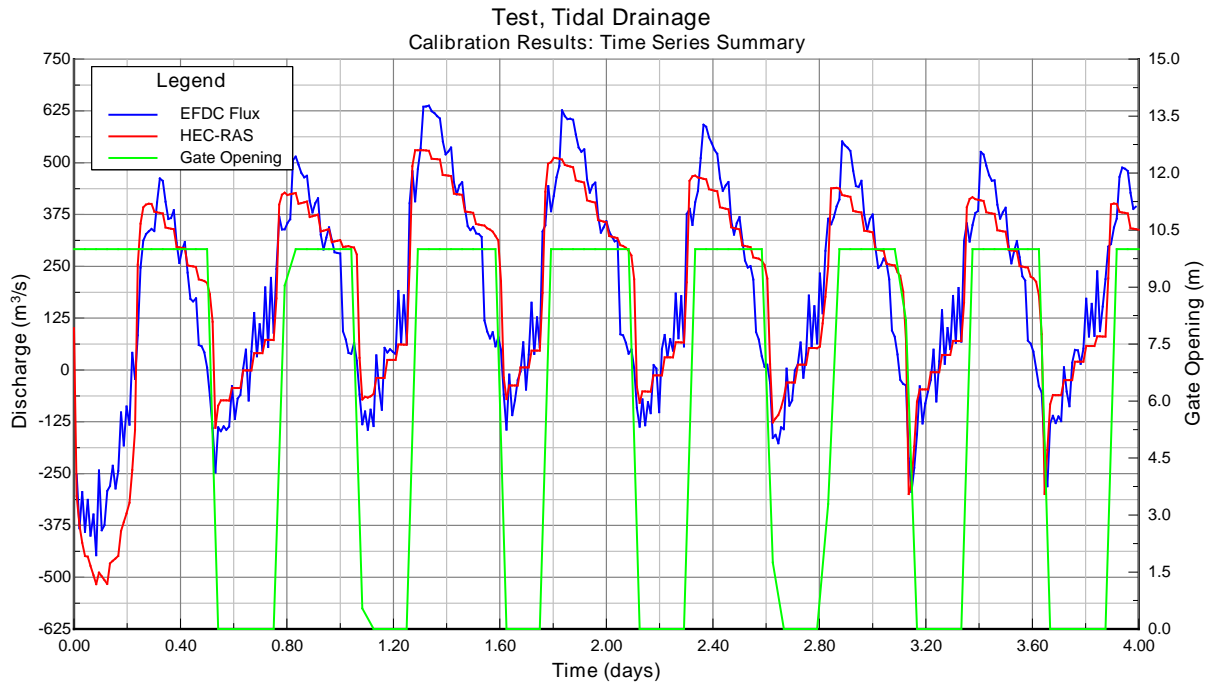


Figure 37: Comparison of flow discharge at Station 1

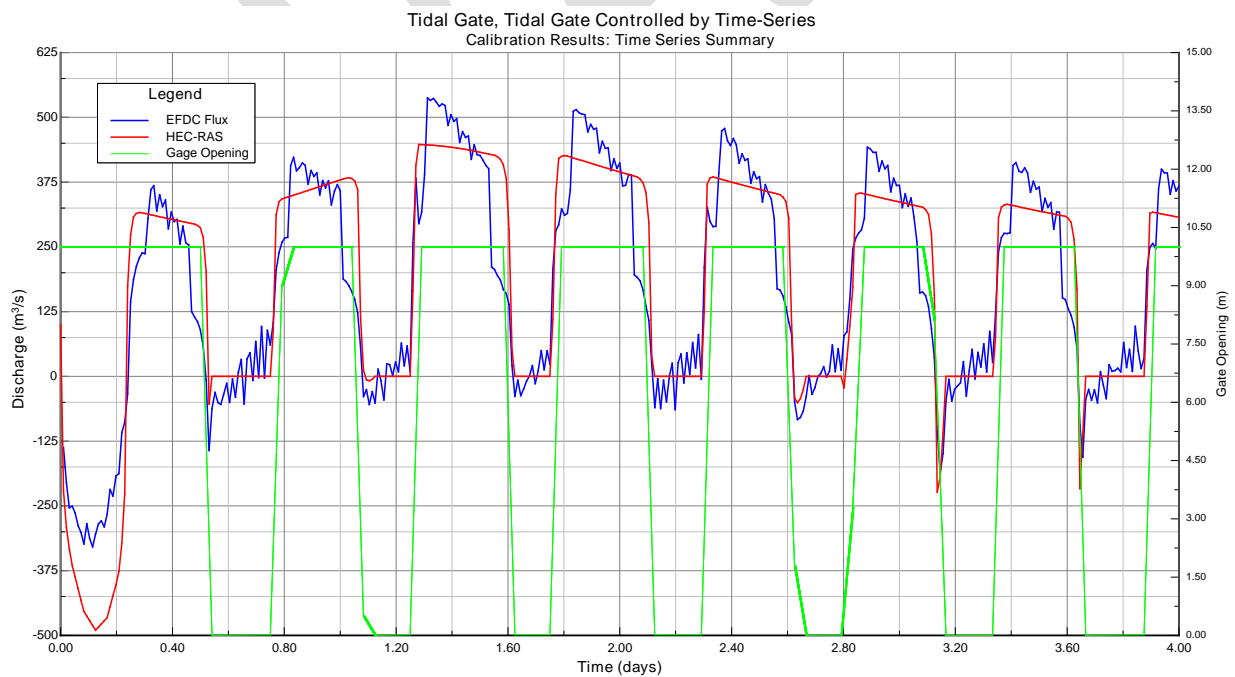


Figure 38: Comparison of water surface elevation at Station 2

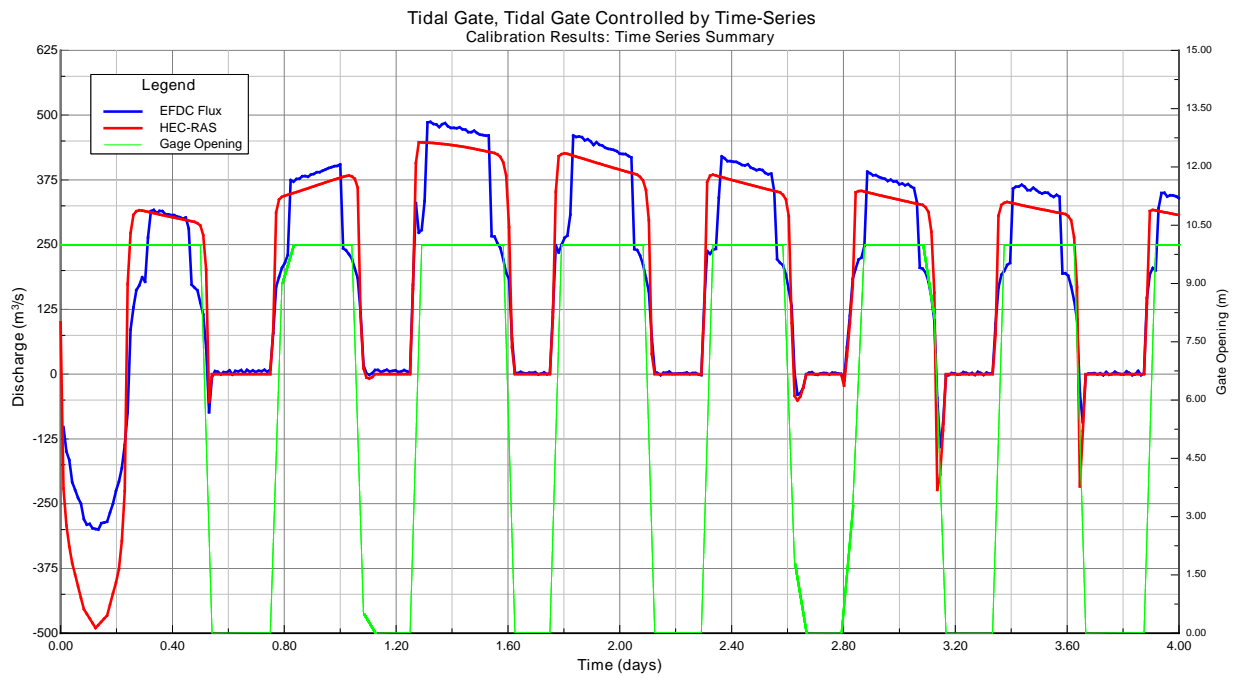


Figure 39: Comparison of water surface elevation at Station 3

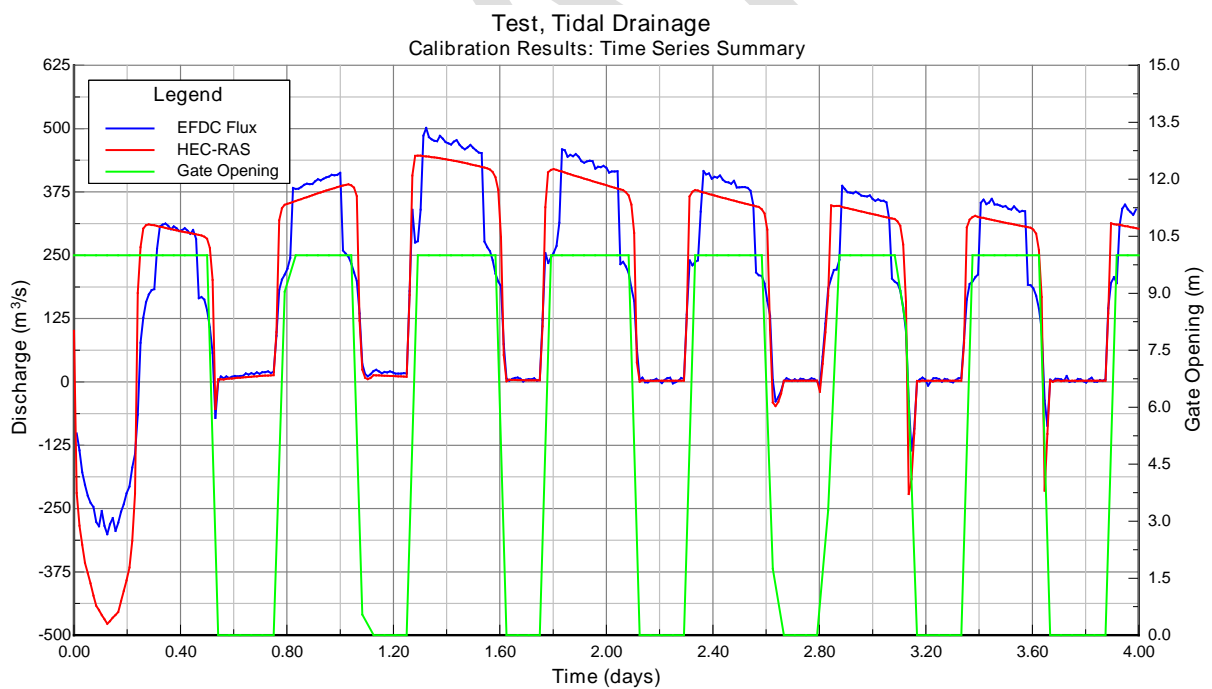


Figure 40: Comparison of water surface elevation at Station 4

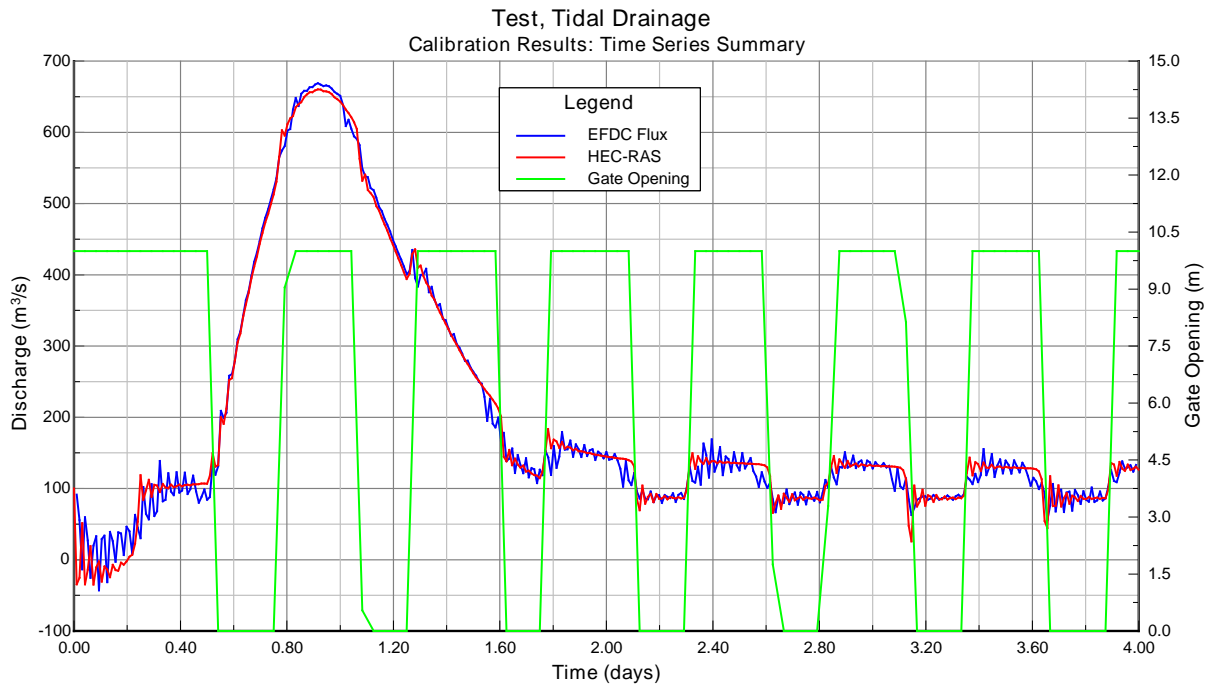


Figure 41: Comparison of water surface elevation at Station 5

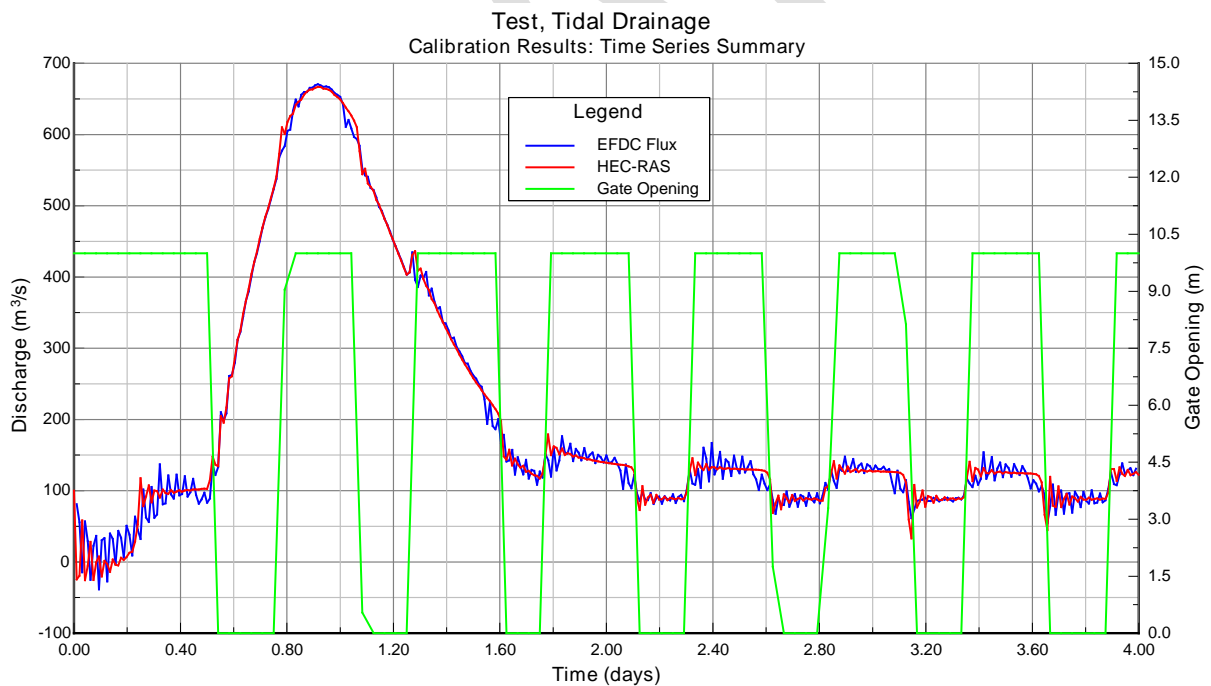


Figure 42: Comparison of water surface elevation at Station 6

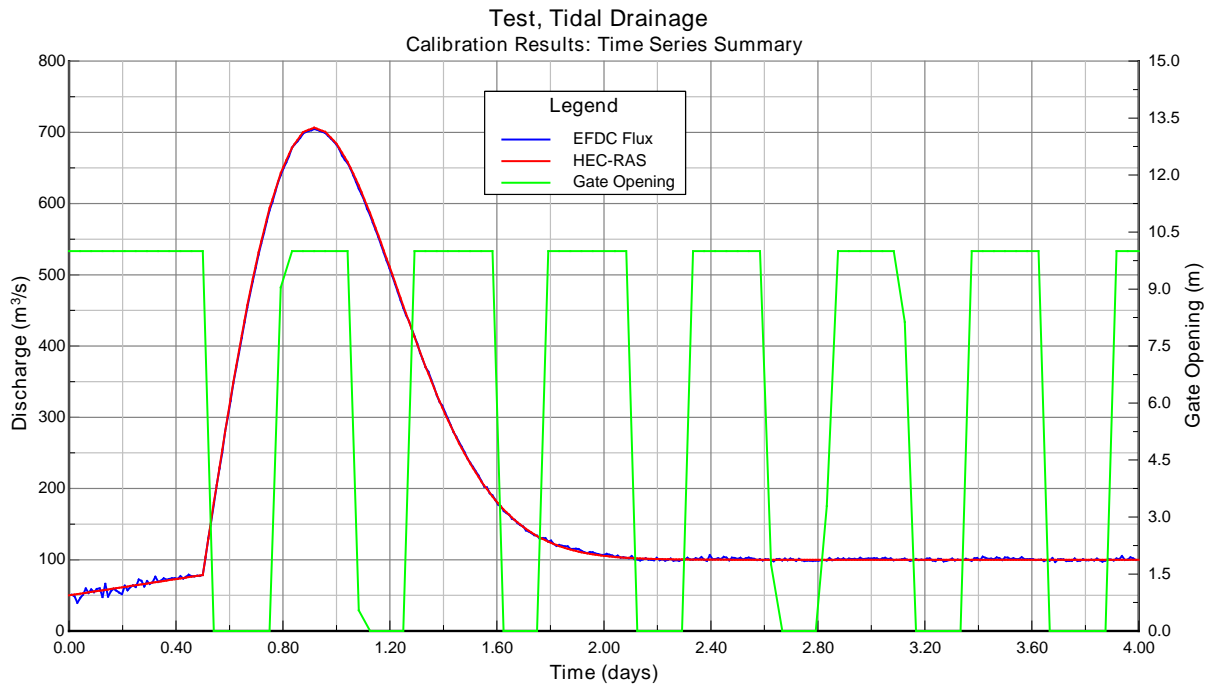


Figure 43: Comparison of water surface elevation at Station 7

2.3 Test 3: Gate Structure Controlled using Operational Rules

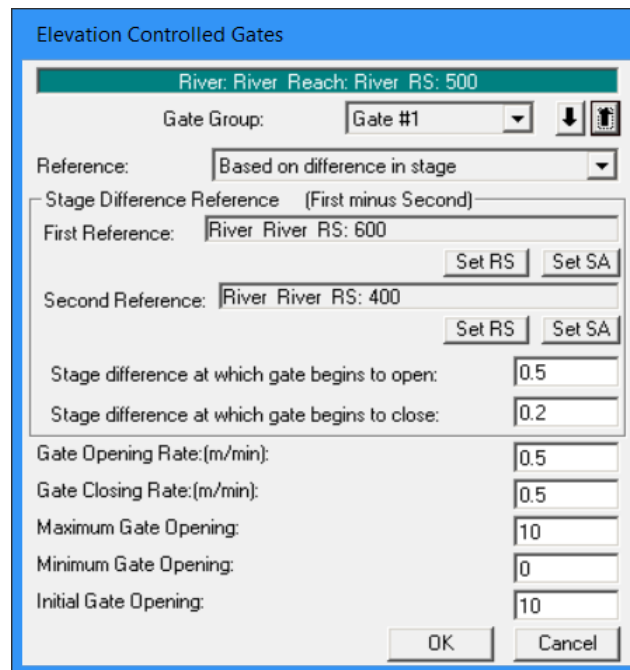
Path: *M:\EFDC_Explorer Modeling System\Testing\EFDC\21 Hystrcut\06 Operation\TidalGate\03-ControlRules*

This test uses a hydraulic control time-series of gate opening defined in QCRULES.INP.

The control rules are defined based on upstream and downstream head difference (Figure 44) as follows:

If the difference between upstream and downstream water surface elevations is greater than or equal to 0.5 meters, the gate is started to open with the opening rate of 0.5 m per minutes until it reaches the maximum opening height of 10 m (completely opened).

If the difference between upstream and downstream water surface elevations is less than or equal to 0.2 meters, the gate is started to close with the closing rate of 0.5 m per minutes until it reaches the minimum opening height of 0 m (completely closed).



Elevation Controlled Gates

River: River Reach: River RS: 500

Gate Group: Gate #1

Reference: Based on difference in stage

Stage Difference Reference (First minus Second)

First Reference: River River RS: 600 Set RS Set SA

Second Reference: River River RS: 400 Set RS Set SA

Stage difference at which gate begins to open: 0.5

Stage difference at which gate begins to close: 0.2

Gate Opening Rate:(m/min): 0.5

Gate Closing Rate:(m/min): 0.5

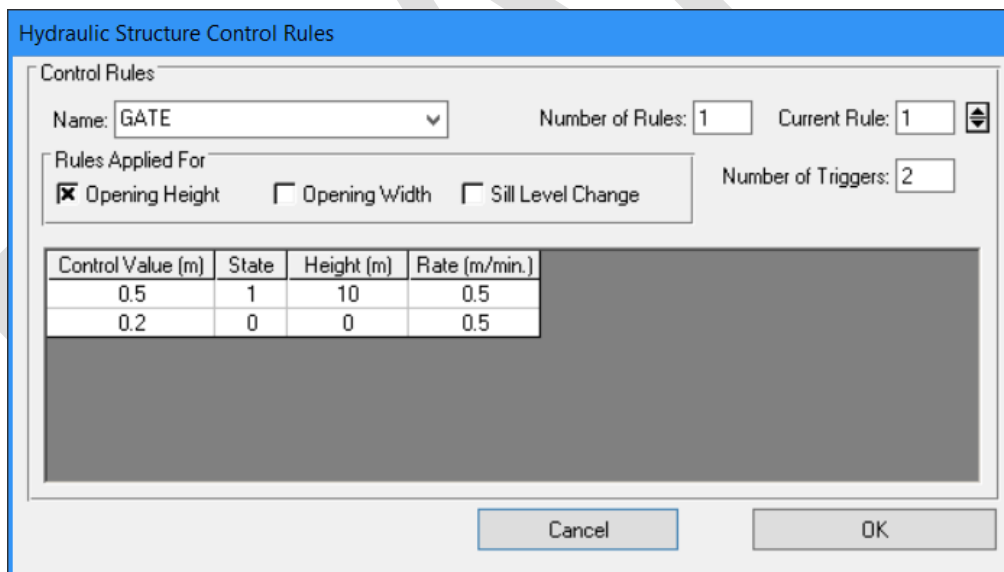
Maximum Gate Opening: 10

Minimum Gate Opening: 0

Initial Gate Opening: 10

OK Cancel

Figure 44: The gate operation rules setup in HEC-RAS



Hydraulic Structure Control Rules

Control Rules

Name: GATE Number of Rules: 1 Current Rule: 1

Rules Applied For

☒ Opening Height ☐ Opening Width ☐ Sill Level Change

Number of Triggers: 2

Control Value (m)	State	Height (m)	Rate (m/min.)
0.5	1	10	0.5
0.2	0	0	0.5

Cancel OK

Figure 45: The gate operation rules setup in EFDC_Explorer

The model results of EFDC8.4 are compared with HEC-RAS for water surface elevations and flow discharges at the stations.

2.3.1 Comparison of water surface elevation

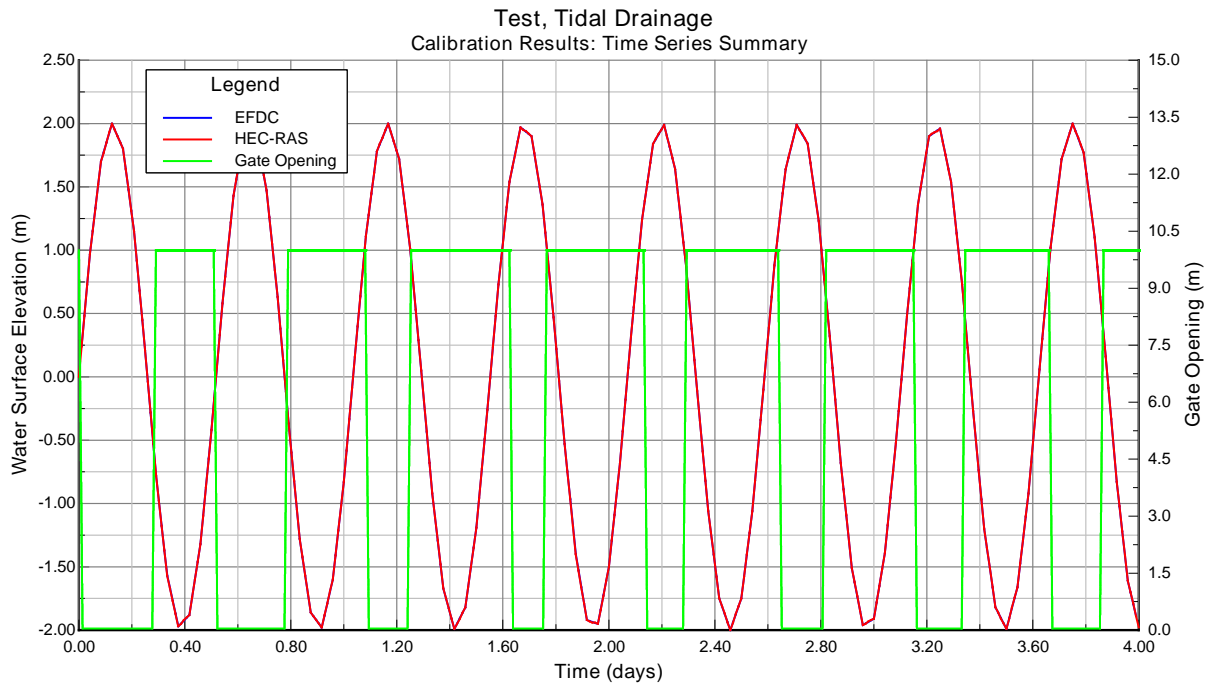


Figure 46: Comparison of water surface elevation at Station 1

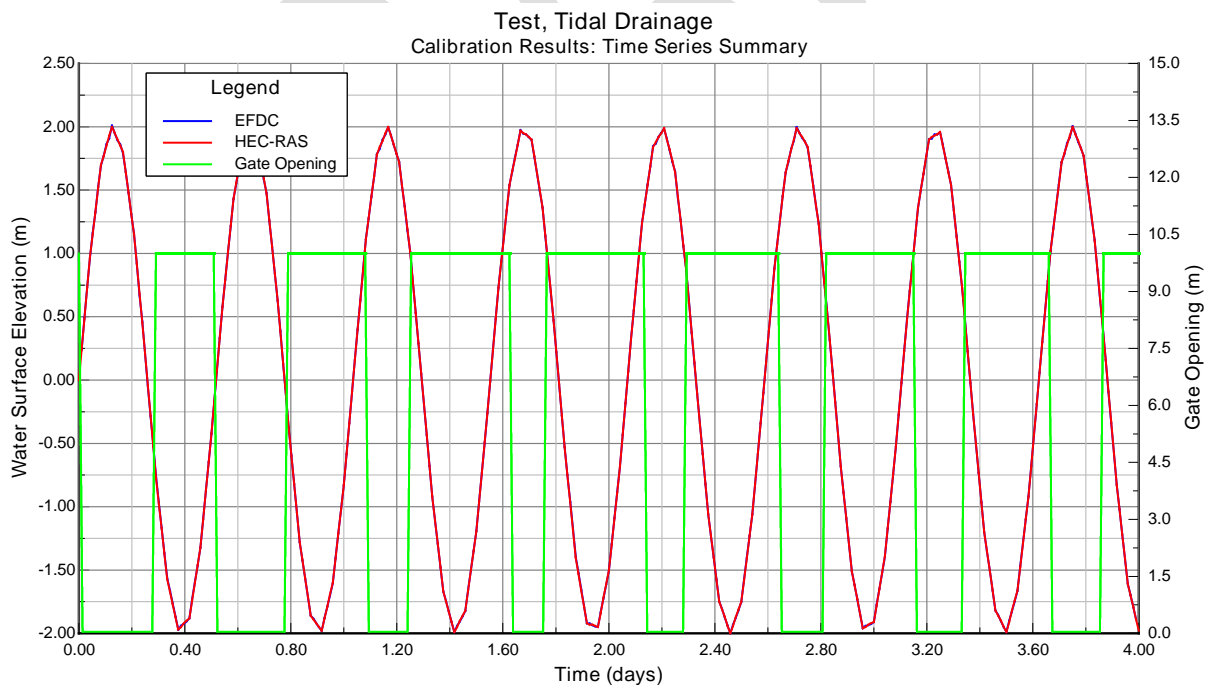


Figure 47: Comparison of water surface elevation at Station 2

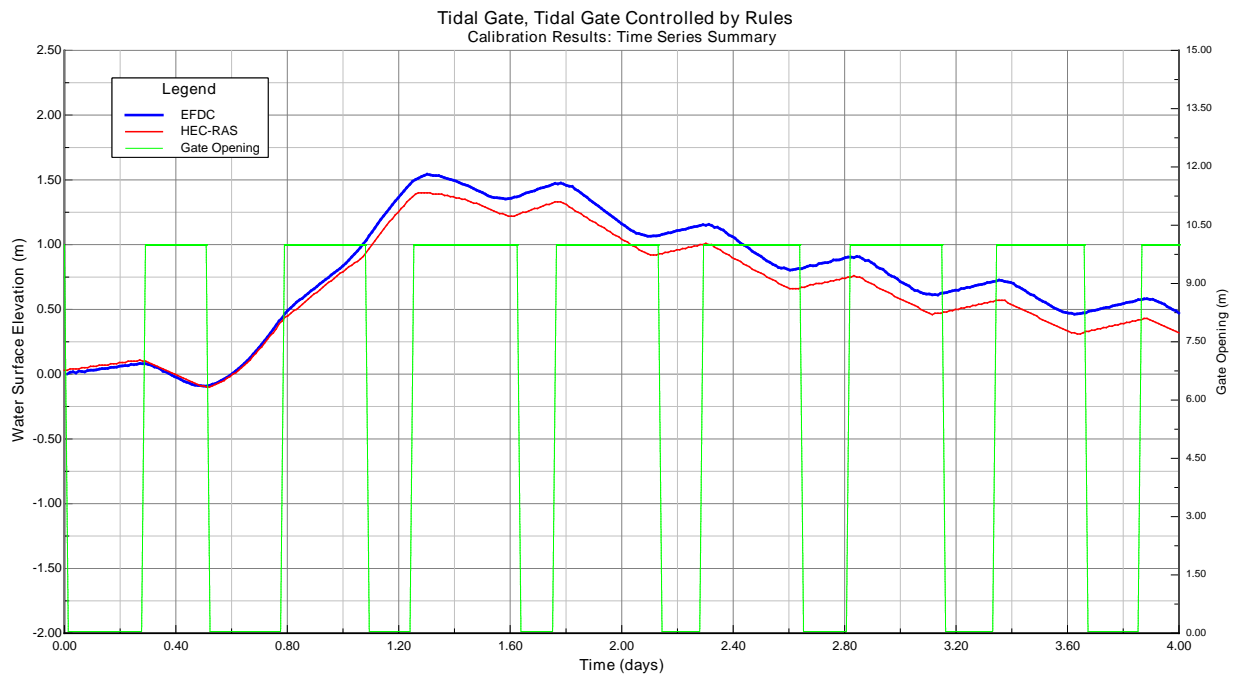


Figure 48: Comparison of water surface elevation at Station 3

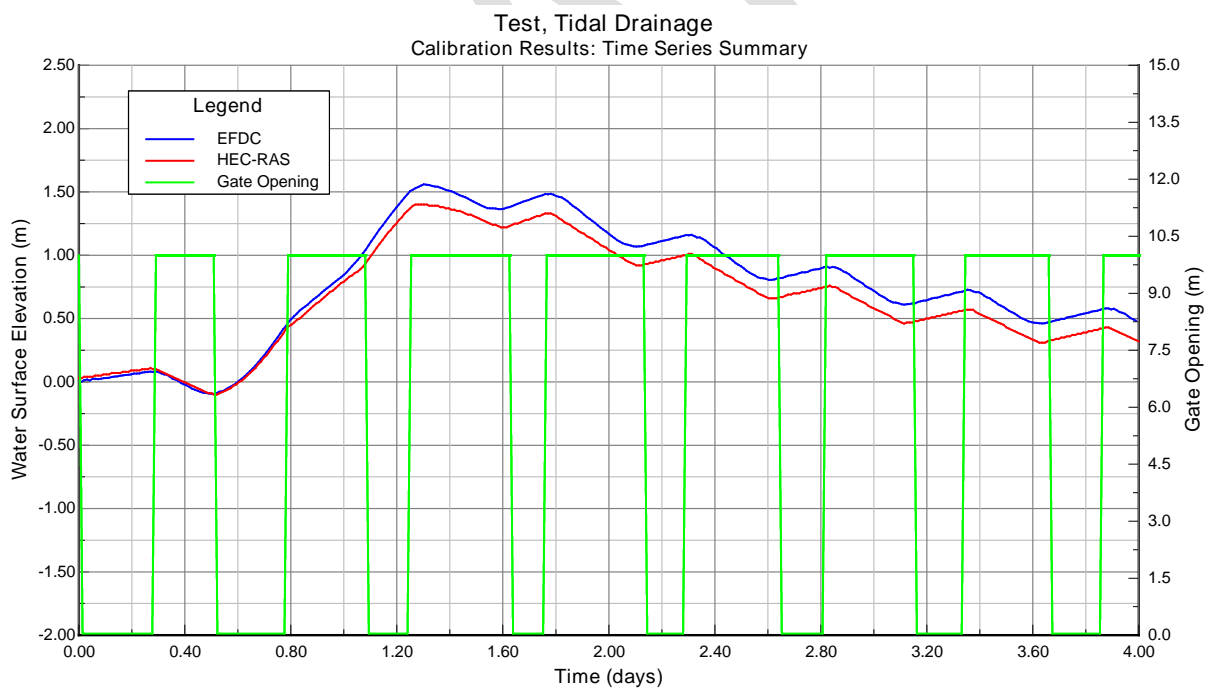


Figure 49: Comparison of water surface elevation at Station 4

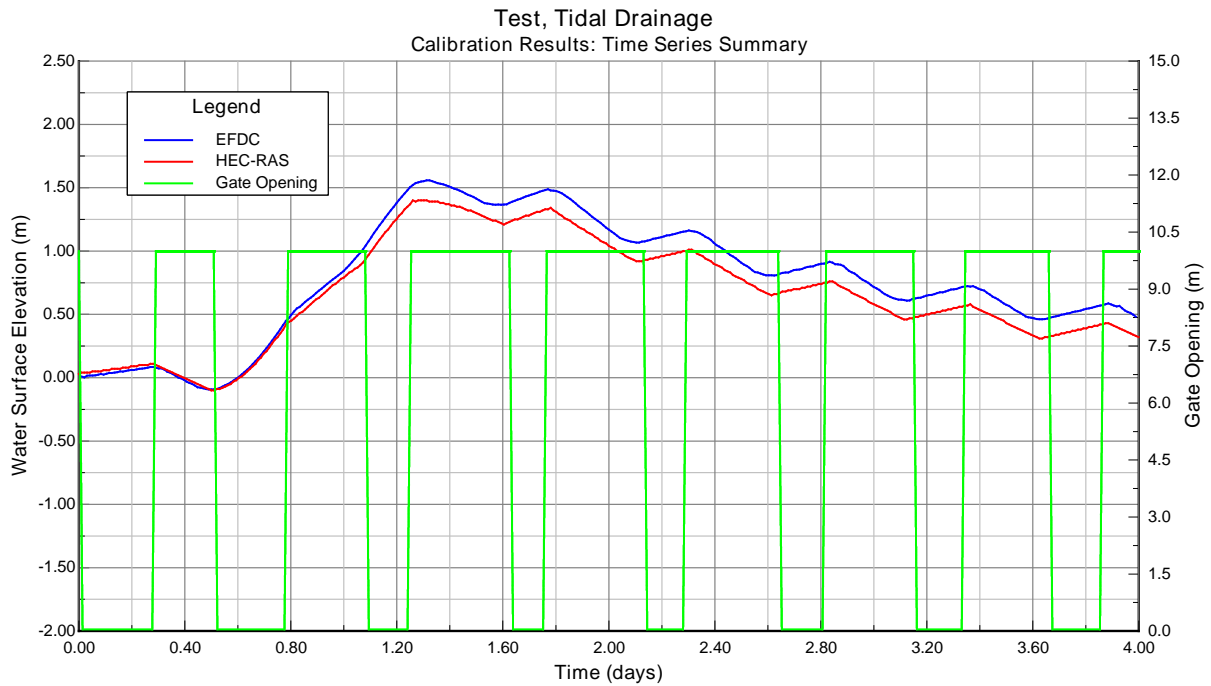


Figure 50: Comparison of water surface elevation at Station 5

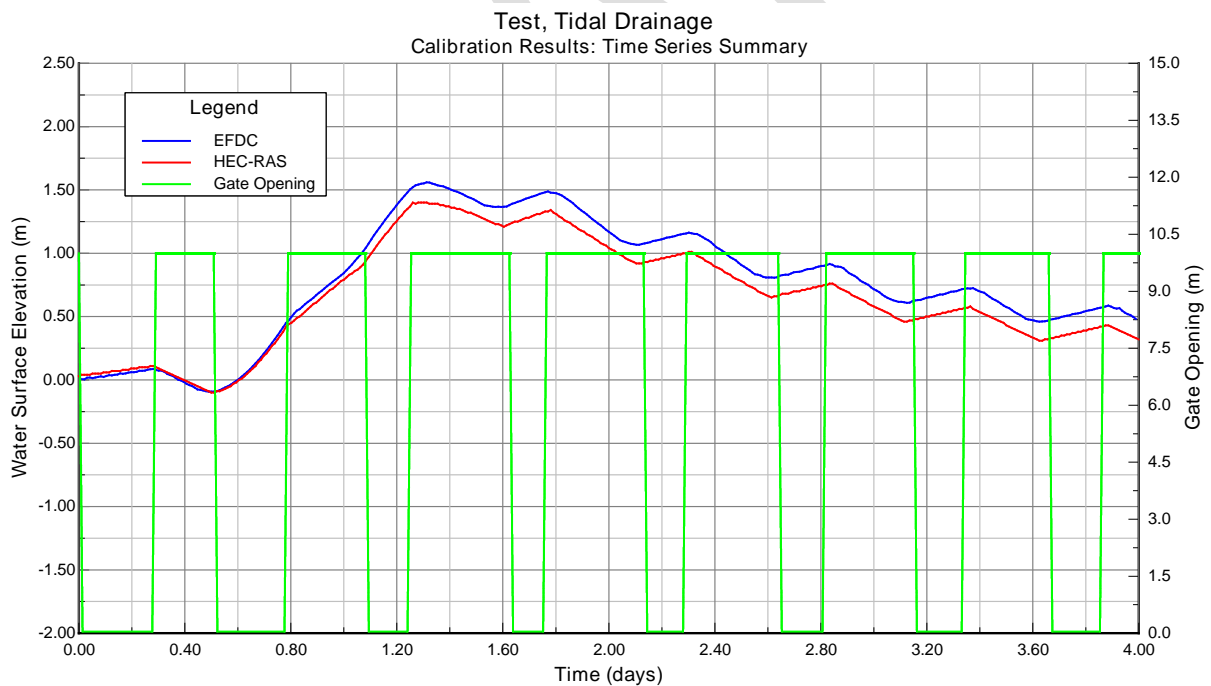


Figure 51: Comparison of water surface elevation at Station 6

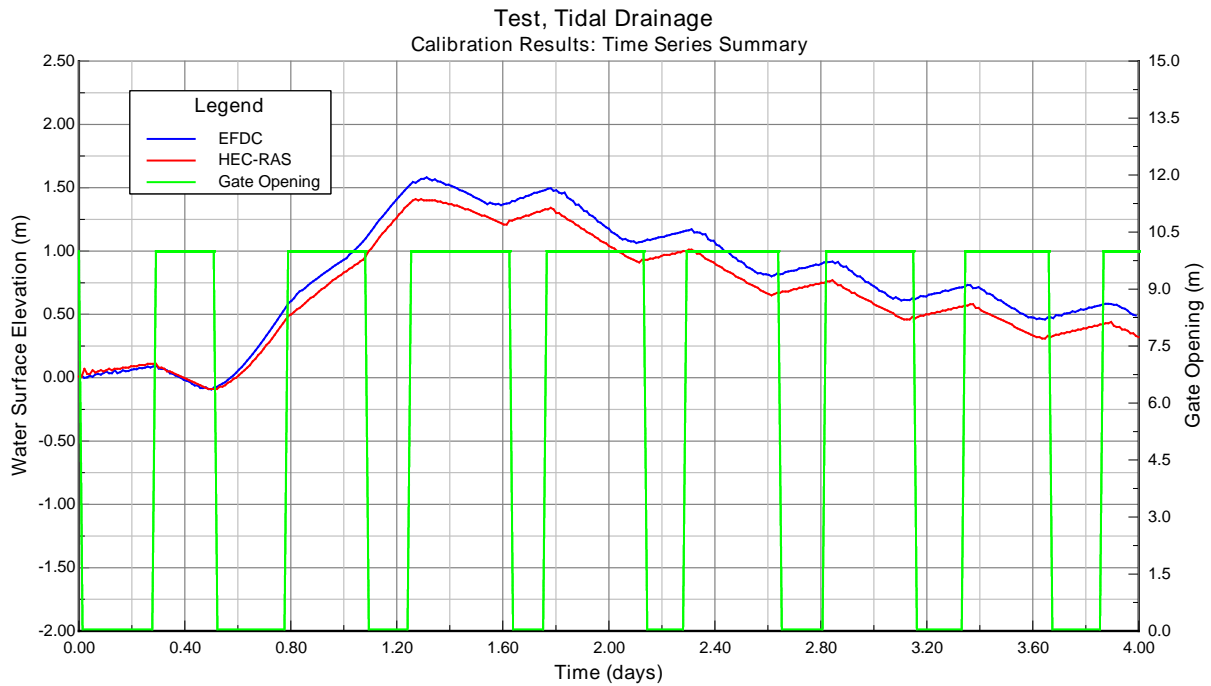


Figure 52: Comparison of water surface elevation at Station 7

2.3.2 Comparison of flow discharge

Flow discharge is extracted and calculated using Flux Tool in EFDC and compared with HEC-RAS

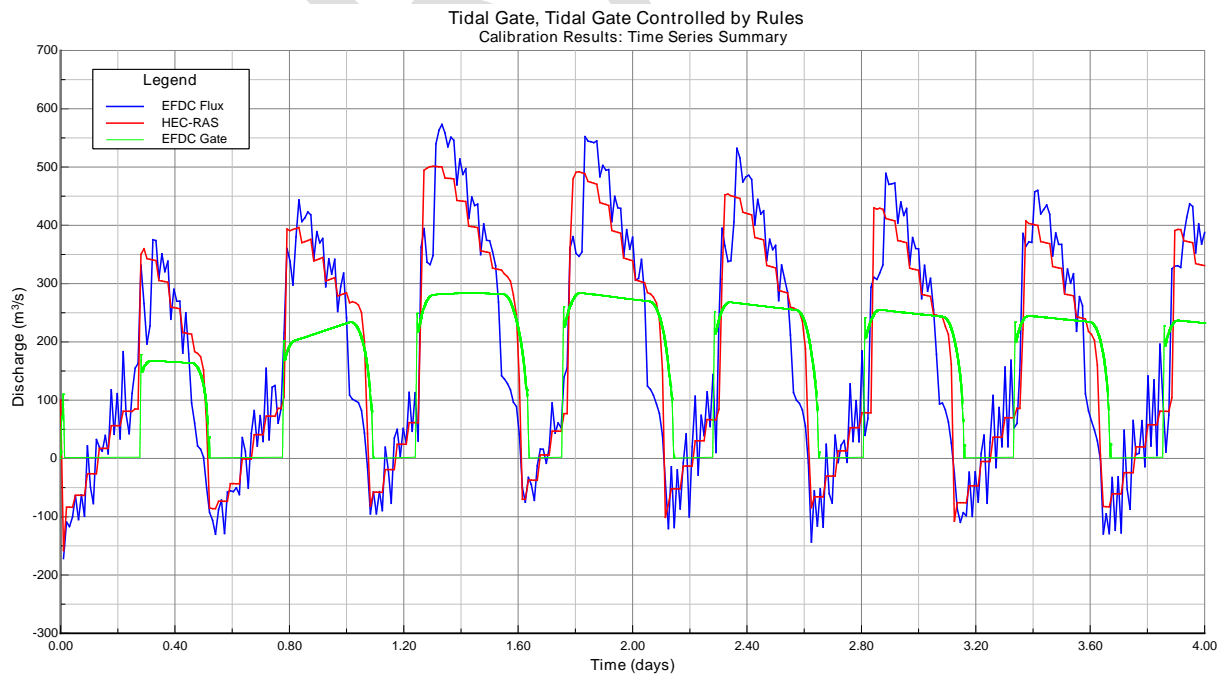


Figure 53: Comparison of flow discharge at Station 1

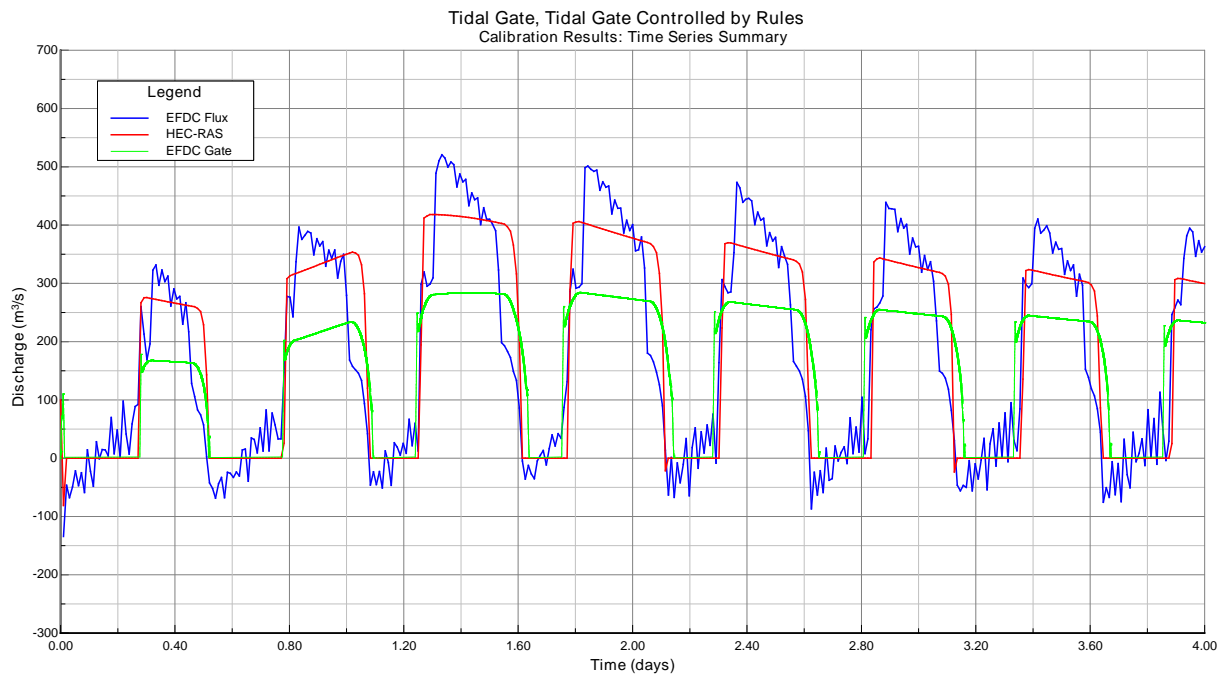


Figure 54: Comparison of water surface elevation at Station 2

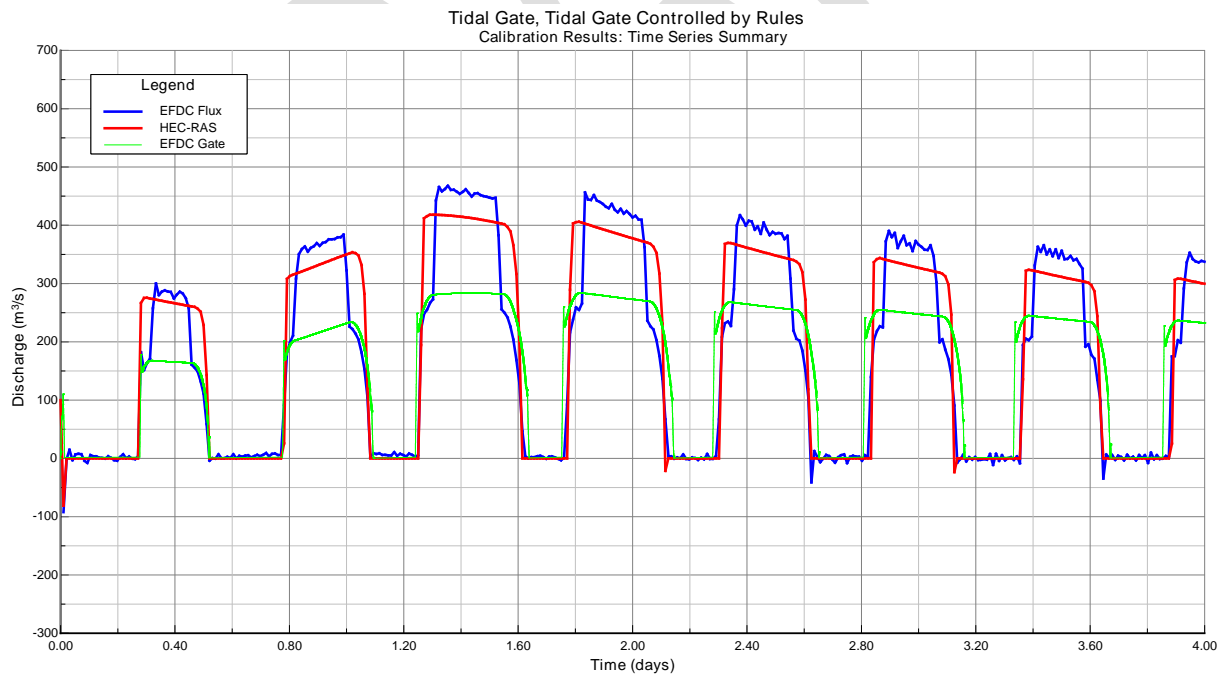


Figure 55: Comparison of water surface elevation at Station 3

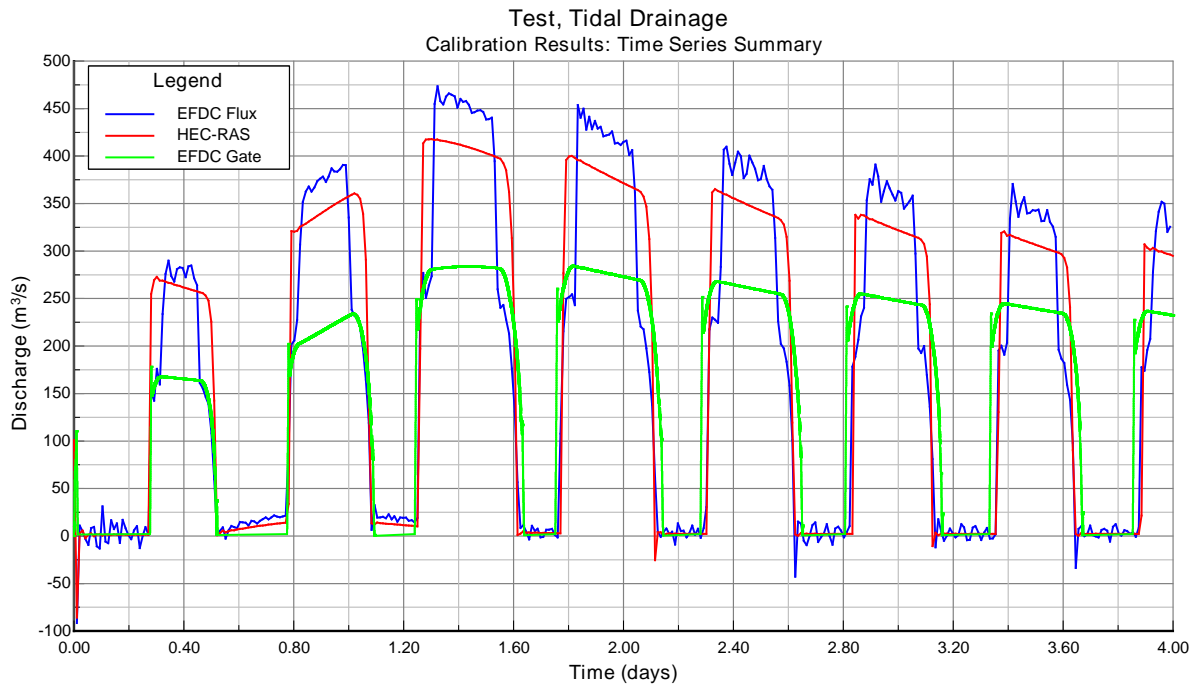


Figure 56: Comparison of water surface elevation at Station 4

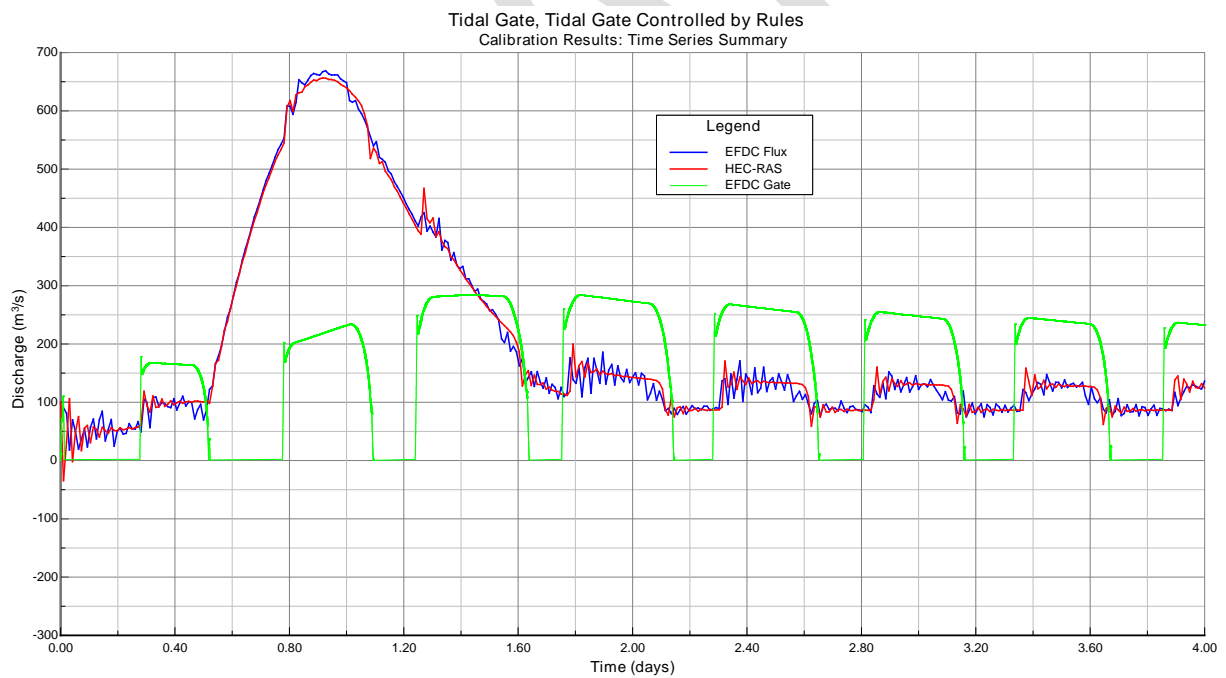


Figure 57: Comparison of water surface elevation at Station 5

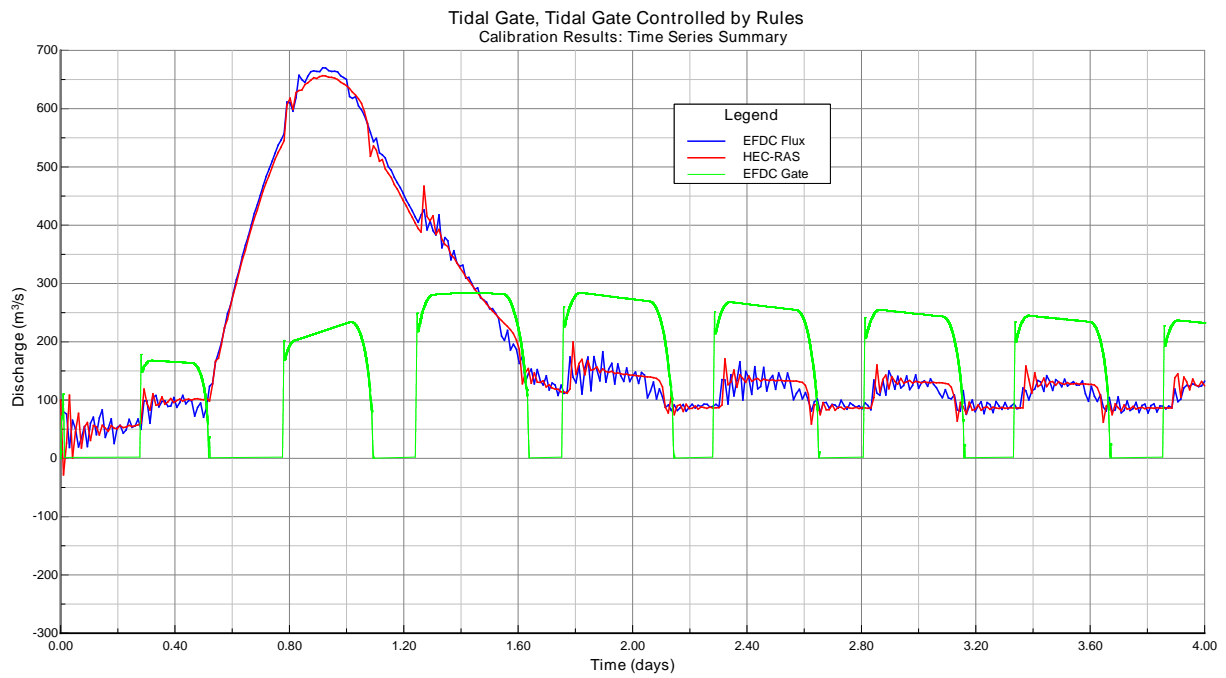


Figure 58: Comparison of water surface elevation at Station 6

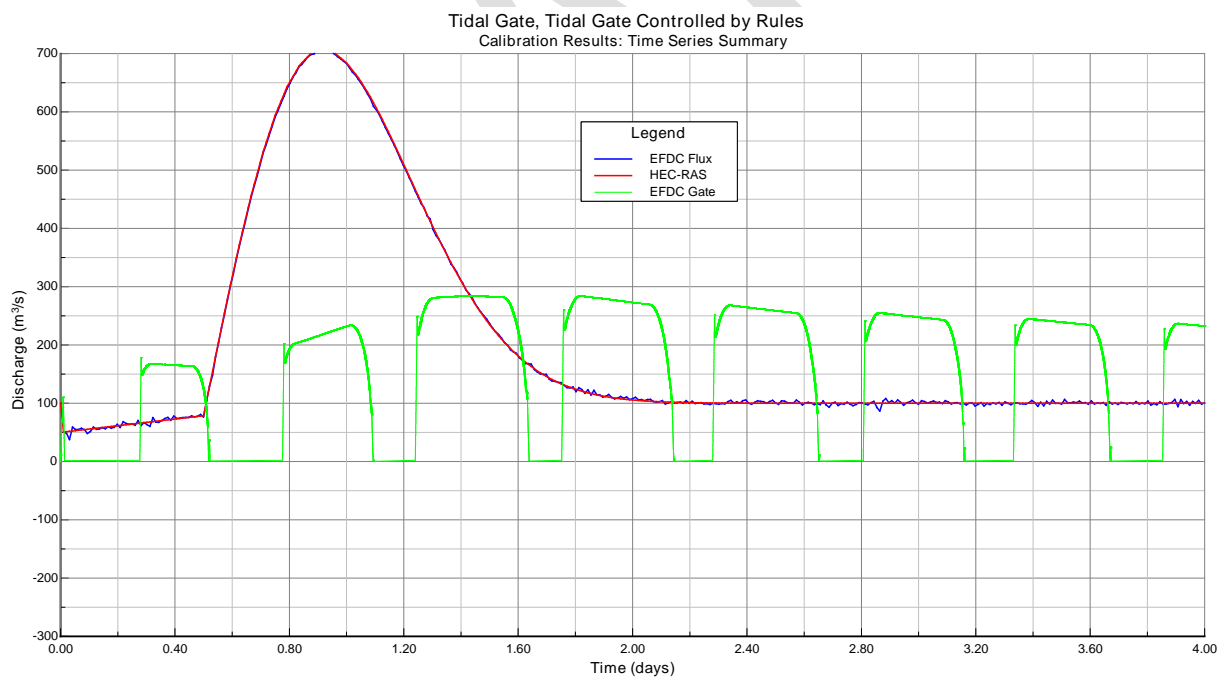


Figure 59: Comparison of water surface elevation at Station 7

2.4 Test 4: Pump Controlled using Operational Rules

Path: M:\EFDC_Explorer Modeling System\Testing\EFDC\21 Hystruct\06 Operation\TidalGate\04-Pump\EFDC8.4\

This test demonstrates the operation of a pumping station based on operation rules with the control philosophy presented in *Pumping Station Design Guidelines*, The Metropolitan Sewer District of Greater Cincinnati (MSDGC), Hamilton County, Ohio, July 2013 (Available at http://www.msdcg.org/downloads/customer_care/forms_and_documents/design/MSDGC_pumping_station_design_guidelines.pdf).

Typical MSDGC pump stations are two pump systems utilizing a local pump control panel to manage the constant speed pumps based on five level settings using float switches or other means.

Figure 60 shows the basic configuration and sequence of operation of the selected level settings.

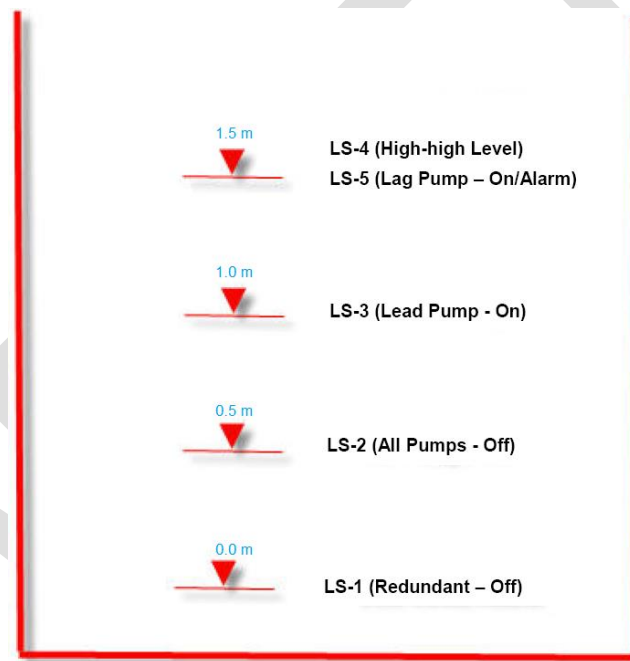


Figure 60: Control Level Settings for Pumping Operation

- When the water level in the wet well reaches LS-3, the lead pump turns ON.
- If the water level continues to rise and reaches LS-5, the lag pump turns ON.
- The lead and/or lag pumps shall continue to run until the water level falls to the LS-2 (All Pumps – Off) level setting.
- LS-1 is a Redundant Off level setting, which will turn off the lead and lag pumps in the event of failure of the LS-2 level device. The LS-1 level shall be set at the pump minimum submergence as required by the pump manufacturer and at least 6-inches below the LS-2 level setting.
- LS-4 provides a high-high level alarm to the station's telemetry system. The LS-4 level is typically set at the same level or slightly higher level as the LS-5 (Lag Pump – On/Alarm) level setting For

in-system pump stations serving separated sewers, LS-5 is recommended to be configured to send out a nominal high water alarm to through the station's telemetry system.

- Other Lag Pumps, if used, will have their 'Lag Pump – On' level set to a level between LS-3 (Lead Pump On) and LS-4 (High-high Level). The other lag pumps-on elevations are dependent on the field condition to avoid influent pipe surcharging as determined by the design engineer.

With Test 4, the control levels are upstream water surface elevations at the reference point (control point) and have values of LS-2 = 0.5 m, LS-3 = 1.0 m and LS-4 = 1.5 m. Depending on the upstream control level the rules are set for the pumping station as follows:

- When the water surface elevation at the reference point is rising equal to above LS-3 = 1.00 m, the lead pump starts to operate with the pumping discharge of 200 m³/s.
- When the water surface elevation at the reference point is rising equal to above LS-4 = 1.50 m, the lag pump starts to operate with the pumping discharge of 200 m³/s. The total discharge of the two pumps is 400 m³/s.
- If the water surface elevation at the reference point drops below LS-2 = 0.50 m, all the pumps will stop.

The pumps are assumed to switch on immediately once the specified water level is reached with no ramp-up of the pumping rate.. Figure 61 and Figure 62 showing the settings for the pumping station using the withdrawal/return boundary conditions in EEMS 8.4. Figure 63 demonstrates the operation of the pumping station.

Modify/Edit Withdrawal and Return BC Properties

Current Boundary Group Information

Number of BC Groups: 8 ID: Pump

Withdrawal/Return Groups: 1 Time Control: Controlled based on Upstream Elevati

Current Group: 8

Available Time Series

Number of Withdrawal/Return Series: 0

Setting for Current Boundary Cell

Current Cell: 1 Number of Cells: 1

Add Cell Remove Cell

Remove All Add by Polyline

Withdrawal Cell

L: 456 I: 49 J: 17 K: 1

Bot Elev: 5 Initial Depth: 5

Return Cell

L: 457 I: 50 J: 17 K: 1

Bot Elev: 5 Initial Depth: 5

W/R Flow and Concentration Rise/Fall Settings

Control Rules: PUMPING RULES Edit

Initial Conditions Set All

Constant Flow (m3/s): 0

Set/Edit Concentrations Set All

Withdrawal/ Return Parameters

Withdrawal Cell Momentum Options

Option: Withdrawal Momentum Flux Ignored

Flow Into Cell ☒ Flow Out of Cell ☐

Momentum Width (m): 0

Return Cell Momentum Options

Option: Return Momentum Flux Ignored

Flow Into Cell ☒ Flow Out of Cell ☐

Momentum Width (m): 0

Cancel OK

Figure 61: The pumping station settings in EFDC_Explorer

Withdrawal and Return Control Rules

Control Rules

Name: PUMPING RULES Number of Rules: 1 Current Rule: 1

Number of Triggers: 3

Control Value (m)	State	Flow Discharge (m3/s)	Rate (m3/s/min.)
1.5	1	400	0
1	1	200	0
0.5	0	0	0

Cancel OK

Figure 62: The pumping operation rules setup in EFDC_Explorer

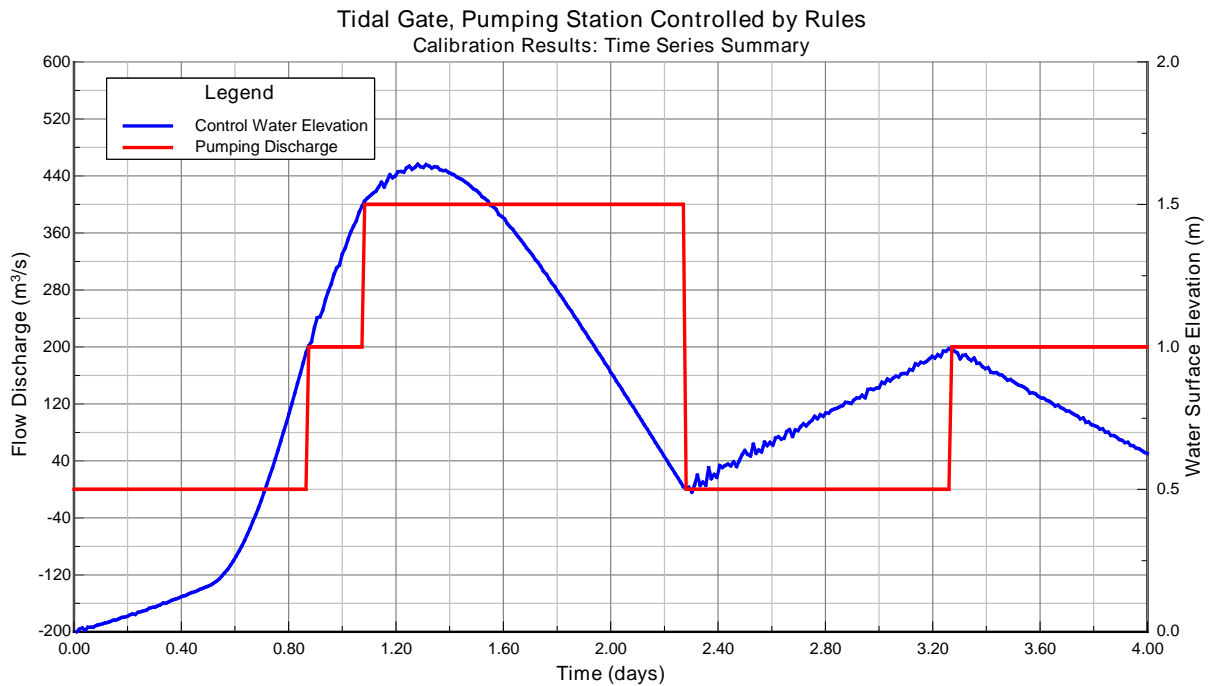


Figure 63: Demonstration of pumping operations.


2.5 Test 5: Pump Controlled using Operational Rules with Rate of Changes

Path: *M:\EFDC_Explorer Modeling System\Testing\EFDC\21 Hystruc\06 Operation\TidalGate\05-PumpWithRate\EFDC8.4*

This test is similar to Test 4 but with a rate of change in operational flow. It is assumed that each pump requires 4 minutes to operate to full capacity as well as to stop completely. So the rate of flow changes is $50 \text{ m}^3/\text{s}$ per minutes. The utilization of the rate of change in withdrawal/return flow is to prevent model instabilities.

Withdrawal and Return Control Rules

Control Rules:

Name: Number of Rules: Current Rule: 

Number of Triggers:

Control Value (m)	State	Flow Discharge (m ³ /s)	Rate (m ³ /s/min.)
1.5	1	400	50
1	1	200	50
0.5	0	0	50

Figure 64: The pumping operation rules setup in EFDC_Explorer

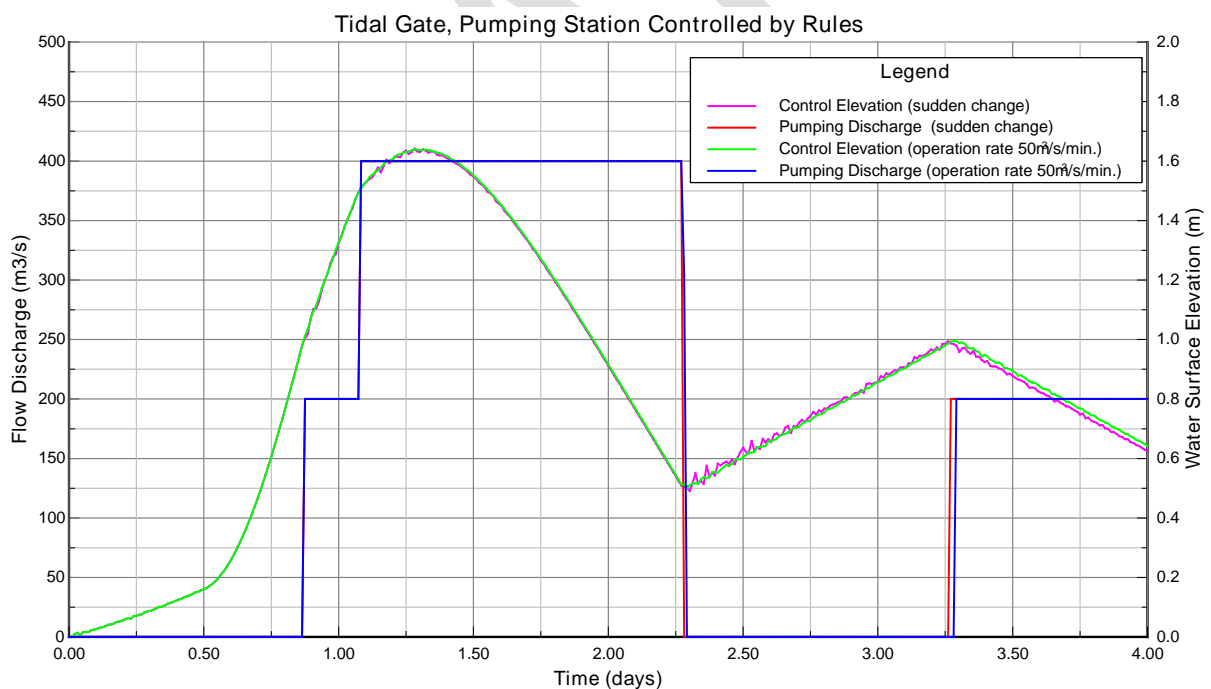


Figure 65: Demonstration of pumping operations.