Operational Structure Modelling Using TUFLOW

Phillip Ryan and Dr Shuang Gao

Agenda

Background / Theory

- Why use operational structures
- Common types of control structures
- Design considerations

Case studies

- Tokyo Metro Flood Discharge Pumps, Japan
- The Yolo Bypass Big Notch Project, USA
- River Witham Grand Sluice, UK
- Canal Locks, UK
- Troups Creek Wetland, AUS

Oosterscheldekering, Netherlands

Background

Why operational control structures

Pros

- Ability to achieve outcomes not possible with fixed design

Cons

- Requires ongoing maintenance and testing
- Risk of failure
- Costs
- Complexity

https://rce.webgispublisher.nl/Viewer.aspx?map=Leven%2Dmet%2DWater#

Pumps

Examples

- Flood control
- Irrigation pumps
- Water supply
- Sewage plant

West Closure Sector Gate, New Orleans, USA

https://www.nola.com/

Hand irrigation pump

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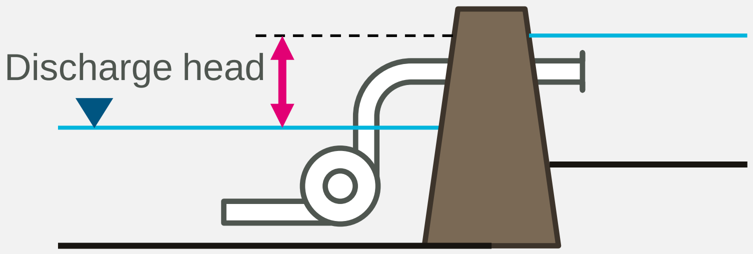
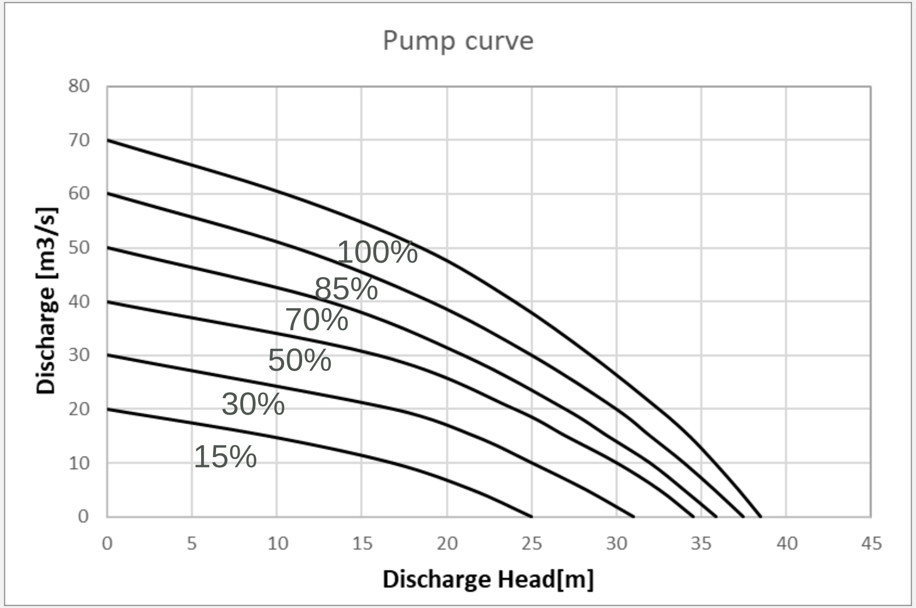
Pumps

Pump Flow

- Constant flow
- Head vs discharge curve
- Head vs discharge curve + operation capacity

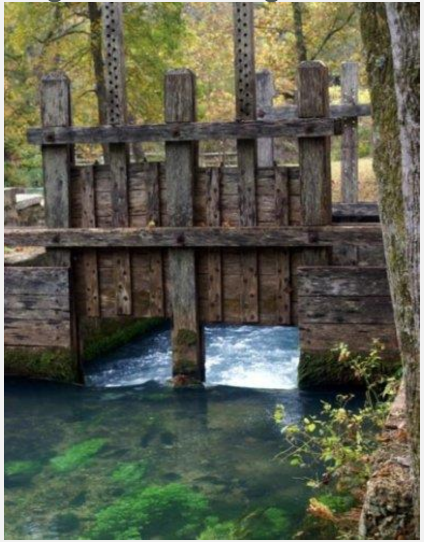




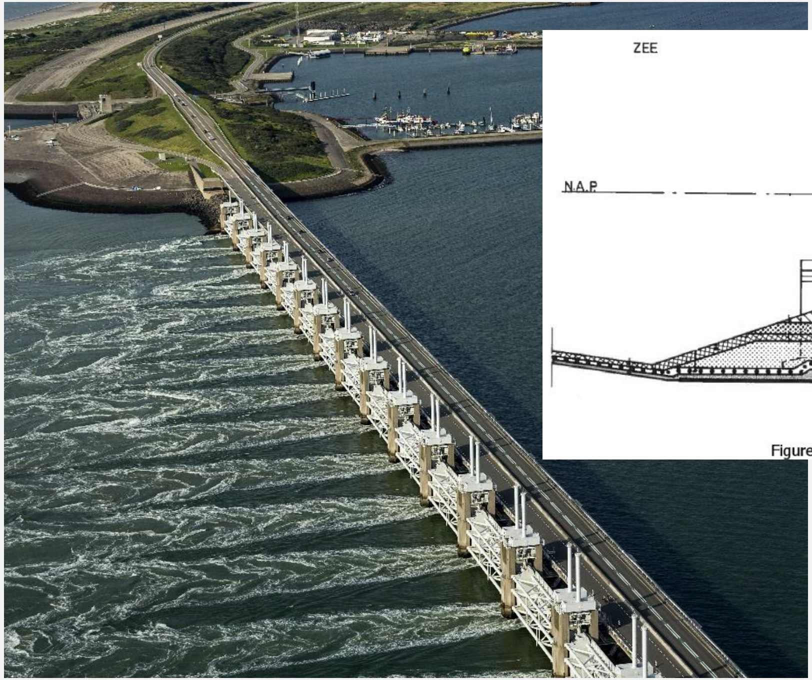
Sluice Gates

Examples

Irrigation sluice gate



Oosterscheldekering, Netherlands



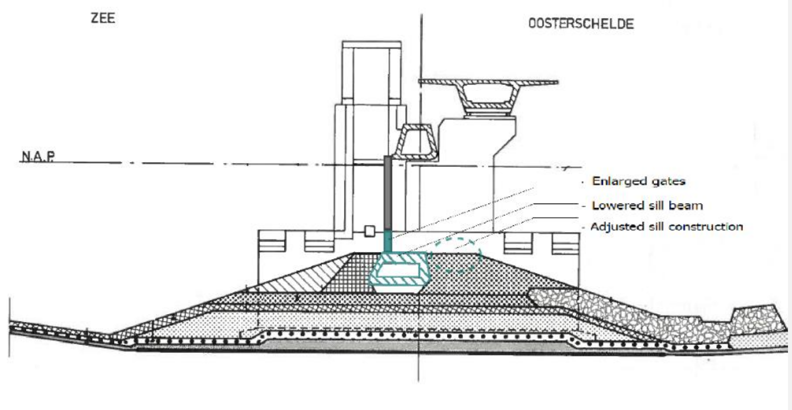


Figure 2: Cross section lowered sill beam alternative

T. V. D. Aart (2015)

Sluice Gates

Sluice Gate Flow

- Free flowing (upstream controlled)

$$Q = C_d W B \sqrt{2 g H_1}$$

Q = Discharge
C_d = Discharge coefficient upstream controlled flow (default = 0.6)
W = Width
B = Height of gate opening above crest level
H_1 = Upstream energy level – Crest level

- Downstream controlled

$$Q = C_s W B \sqrt{2 g \Delta H}$$

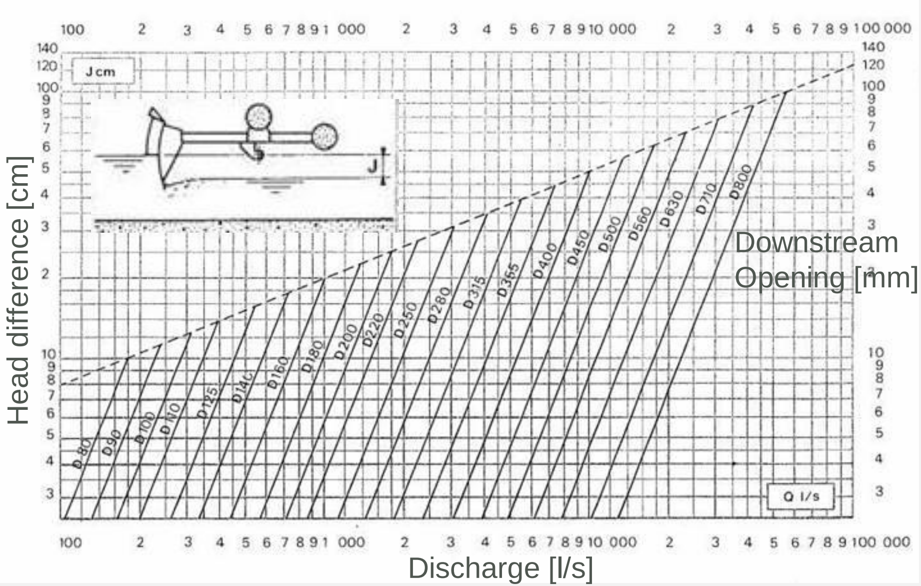
C_s = Submerged discharge coefficient (default = 0.8)
ΔH = Upstream energy level – Downstream level

- Transition

$$Q = C_d W B \sqrt{2 g 3 \Delta H}$$

Or

- Head difference vs discharge at different opening



Submerged Gates (Operational Weirs)

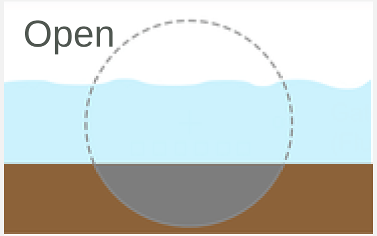
Weir examples:

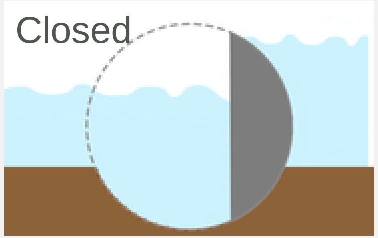
- Weir flow equation with *adjustable* crest height

$$Q = \frac{2}{3} C_f \, C_{sf} \, C_d \, W \sqrt{2g} \, H^{Ex}$$

MOSE flood barrier, Venice (https://www.mosevenezia.eu/mose)

The Thames Barrier (https://www.gov.uk/guidance/the-thames-barrier)





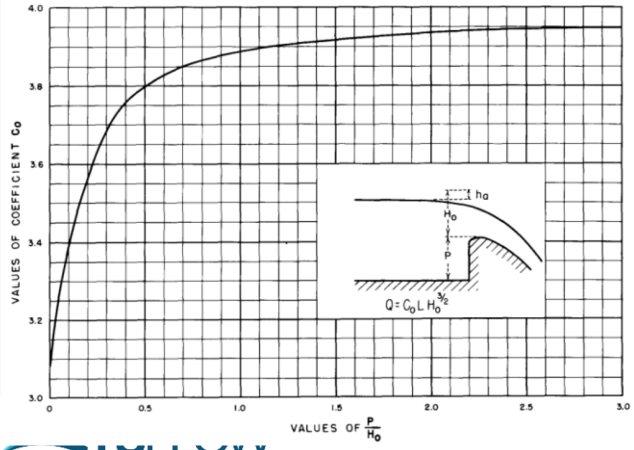
Spillways with Gates

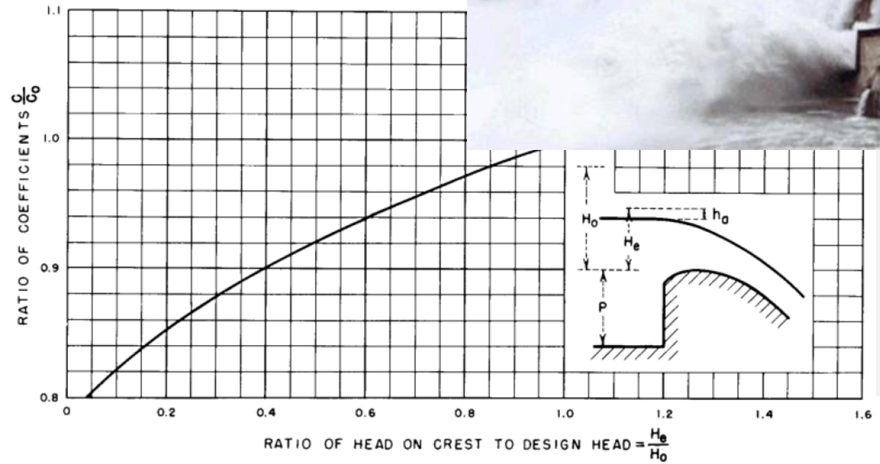
http://fwee.org

Ungated Spillway Flow

“Design of Small Dams” USBR, (1987)

- Discharge coefficient base on design head (H_0) and the crest height above sill (P)
- Adjustment factor based on the actual head (H_e) and design head





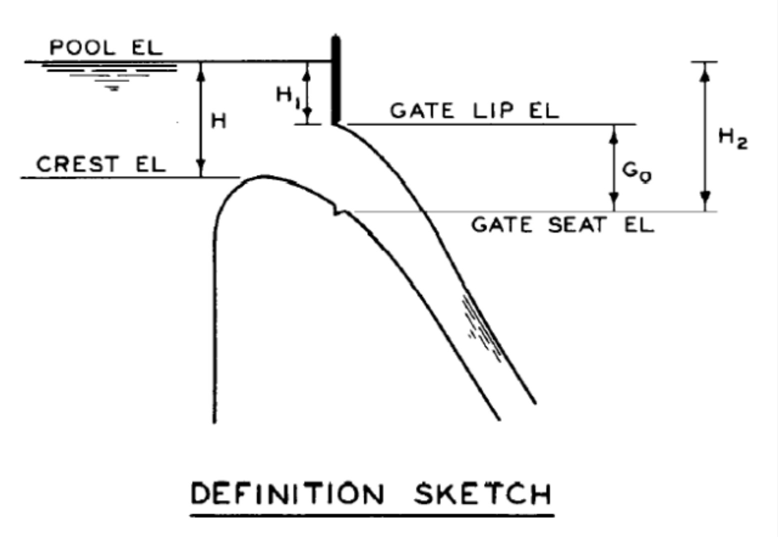
Spillways with Gates

Gated Spillway Flow
(USACE Hydraulic Design Criteria Sheet 312)

- Adjust gated discharge based on ungated discharge:

$$\frac{Q_G}{Q} = \frac{C_G}{C_d}\left(\frac{H_2^{\frac{3}{2}} - H_1^{\frac{3}{2}}}{H^{\frac{3}{2}}}\right)$$

C_G: disgorge coefficient. Default = C_d(ungated discharge coefficient)
H_1, H_2: See diagram on the right



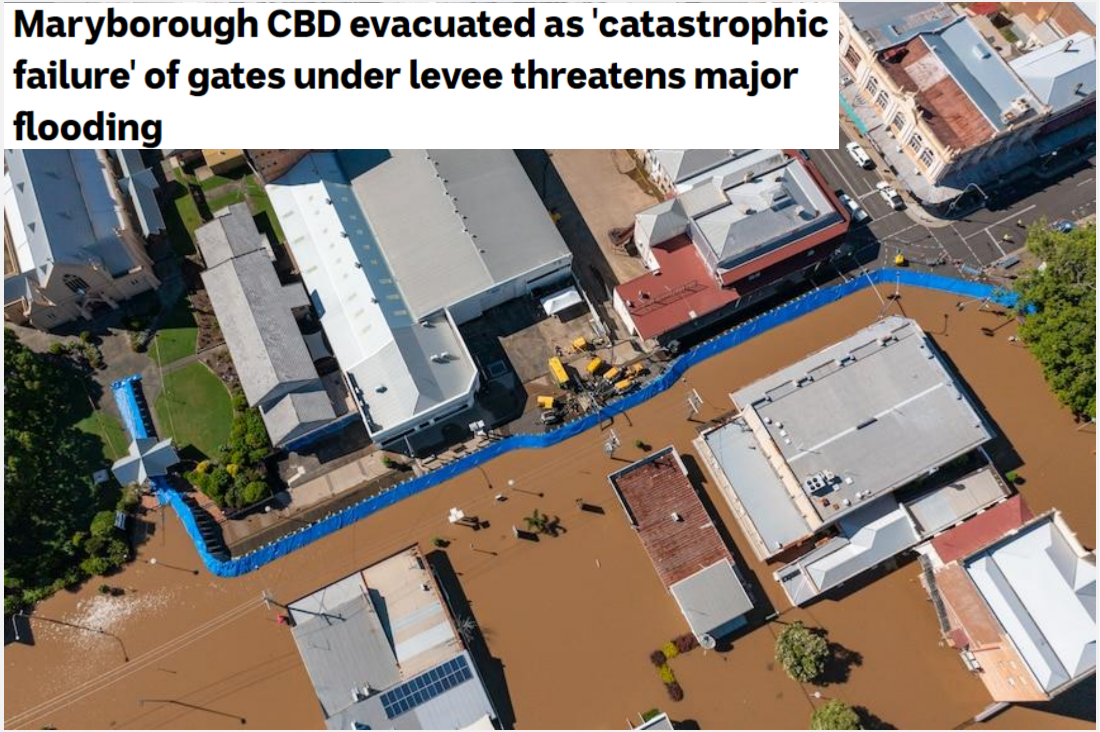
Design considerations

Operation method

- Manual
- Automated
- Combination

Risk based approach

- Likelihood / severity of failure
- Need for redundancy
- Failsafe position



https://www.abc.net.au/news/2022-03-03/flood-levee-saves-businesses/100876222

Example Models

Operational Control File Syntax

- TUFLOW Operational Control File (.toc)
- Database of control structures
- Contains three blocks of information
  - Default settings for structure
  - User defined variables
  - Logic Blocks
- Each structure Type has its own commands

```
!
! OPERATING CONTROL COMMANDS
Define Pump Control == PG_Pump

    ! Default Settings
    Pump Capacity == 11.3
    Pump Operation == OFF
    Period Startup/Shutdown (min) == 10

    ! User Variables
    h_reservoir == H2D 293272, 6178161    ! 2D water level in reservoir

    ! Logic Commands
    If h_reservoir >= 337.4
        Pump Operation == ON
    Else If h_reservoir < 337.2
        Pump Operation == OFF
    Else
        Pump Operation == NO CHANGE
    End IF

End Define


!
! OPERATING CONTROL COMMANDS - DF01
Define Dam Failure Control == DF01

    ! Default Settings
    Period Failure == 0.5
    Period Collapse (s) == 60
```

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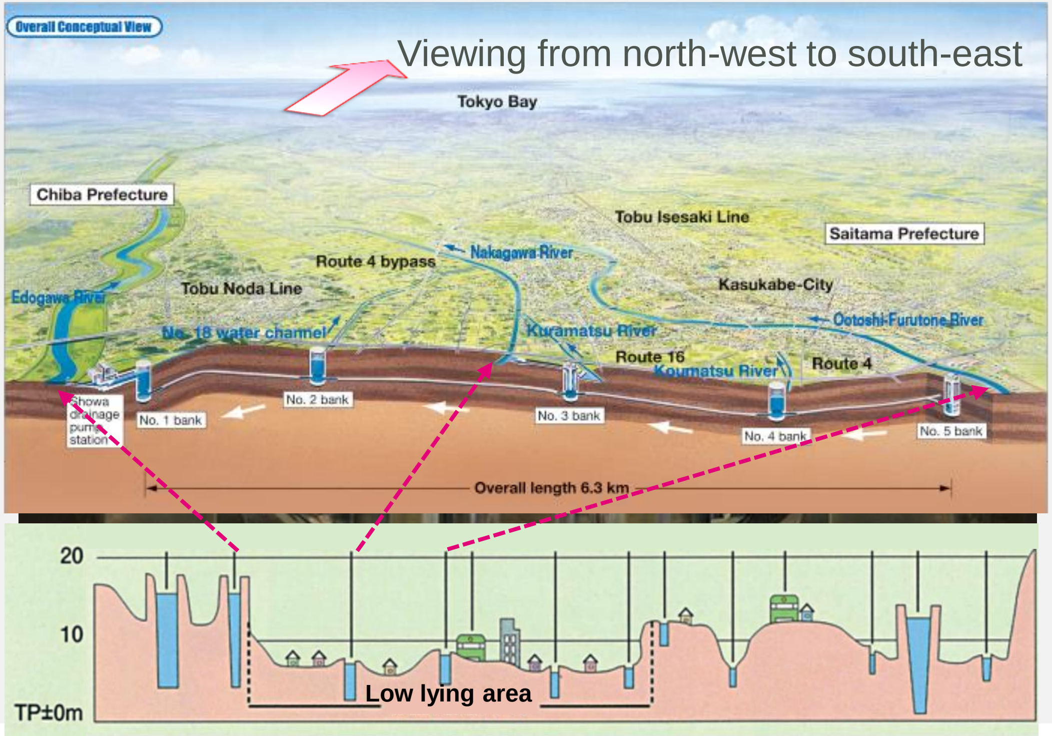
Tokyo Metropolitan Outer Area Underground Discharge Channel
首都圏外郭放水路

Overview

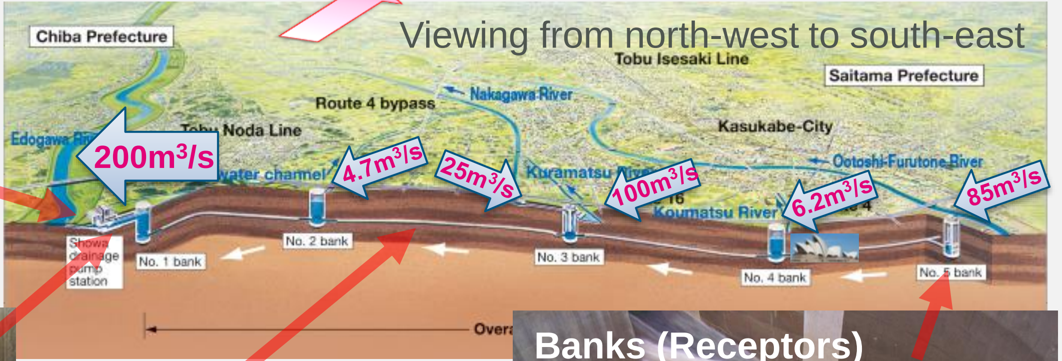


Source: https://www.ktr.mlit.go.jp/edogawa

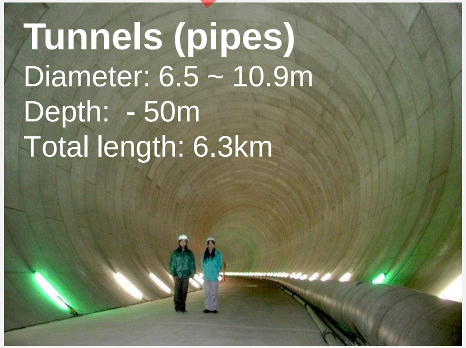
Tokyo Metropolitan Outer Area Underground Discharge Channel
首都圏外郭放水路

Overview

4 Pumps:
Flowrate: 4*50m3/s



Pressure Adjustment Tank (The Underground Shrine)
Length: 177m
Width: 78m
Height: 18m



Tunnels (pipes)
Diameter: 6.5 ~ 10.9m
Depth: - 50m
Total length: 6.3km

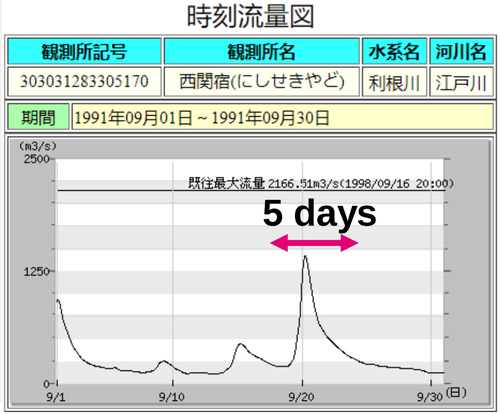
Banks (Receptors)
Height: 69~74.5m
Diameter:
- Bank 1~3: 30m
- Bank 4: 22.5
- Bank 5: 15m

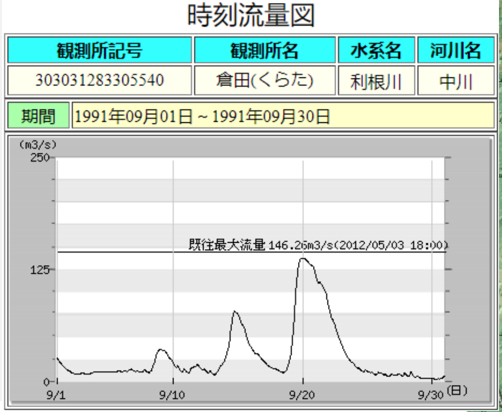
Source: https://www.ktr.mlit.go.jp/edogawa

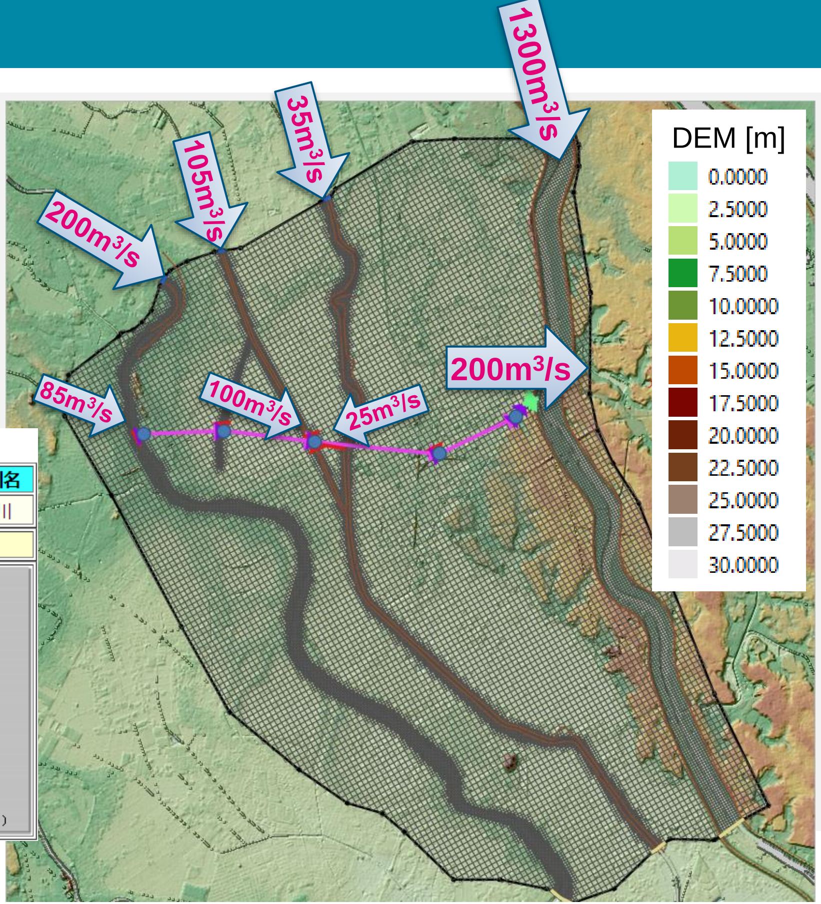
Tokyo Metropolitan Outer Area Underground Discharge Channel
首都圏外郭放水路

Modelling:

- 5m DEM (Geospatial Information Authority of Japan)
- Inflow from the nearest gauge station:
  1991(H3) September Flood caused by Typhoon #18
  (Water Information System by MILT)







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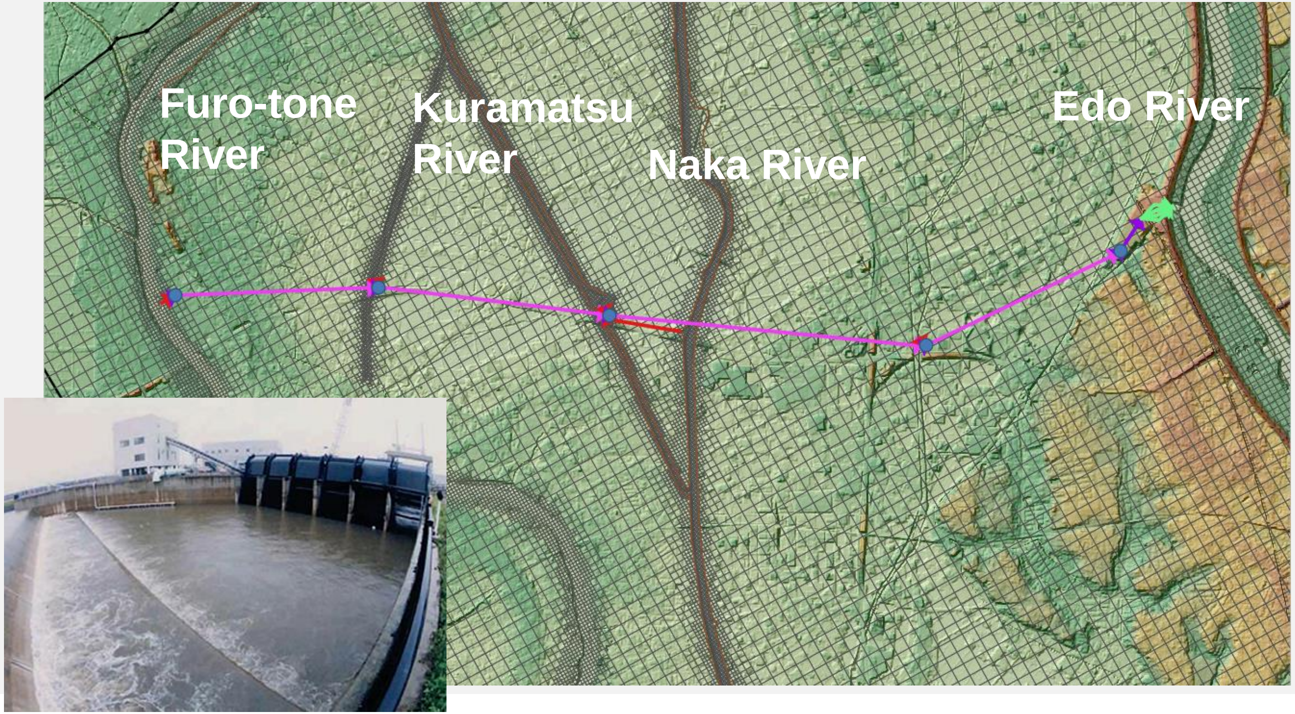
Tokyo Metropolitan Outer Area Underground Discharge Channel
首都圏外郭放水路

Modelling:

- 10m~80m quadtree mesh
- Breaklines at levees
- Tunnels: 1D circular culverts
- Banks: 1D storage nodes
- Inflow to banks: 1D weir



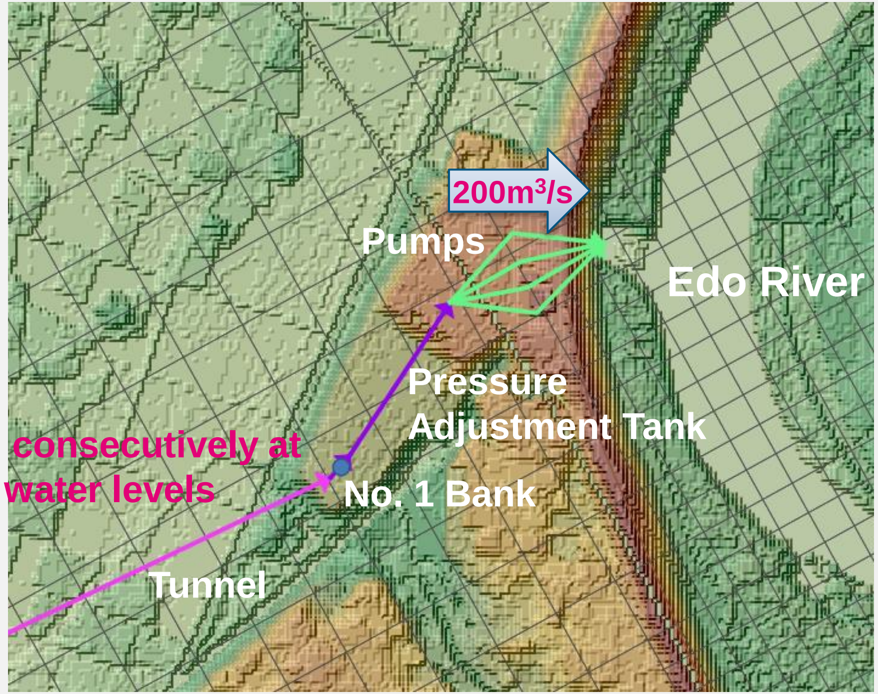
Tokyo Metropolitan Outer Area Underground Discharge Channel
首都圏外郭放水路

Modelling:

- 4 Pumps: **Operational Pumps**

```
Define Pump Control == Pump01

! Default Settings--------------------
   Period Startup/Shutdown (s) == 60
   Pump Capacity == 50.
   Pump Number == 1
   Pump Operation == OFF

! User Variables --------------------
   us_level == HU

! Logic Commands --------------------
   If us_level >= -20
        Pump Operation == ON
   Else
        Pump Operation == OFF
   End If

End Define
```

4 pumps turned on consecutively at different upstream water levels



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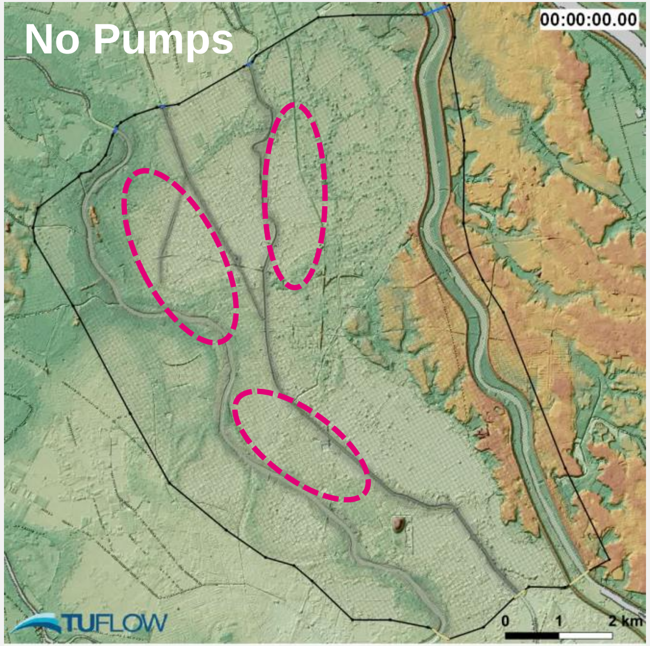
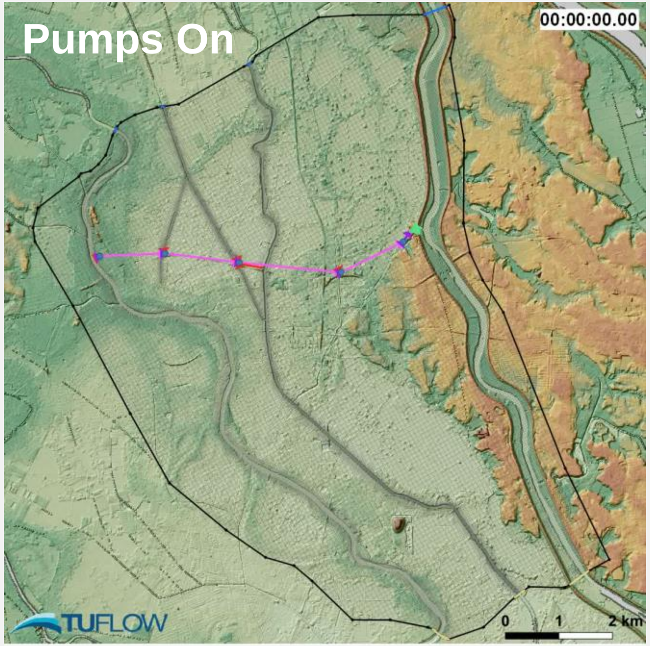
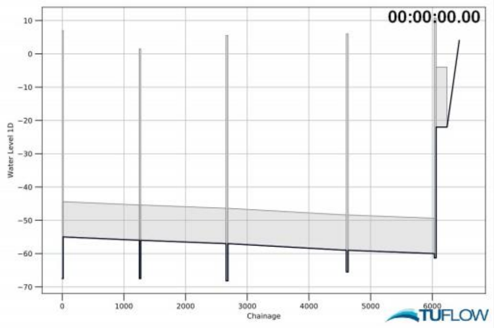
Tokyo Metropolitan Outer Area Underground Discharge Channel
首都圏外郭放水路

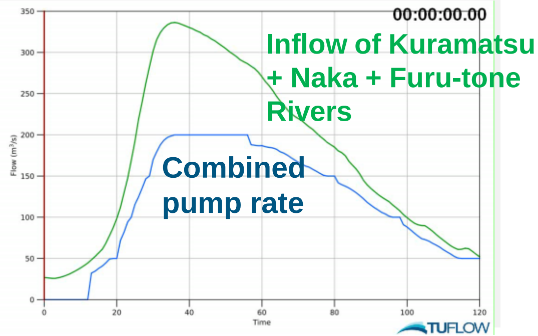
Results:





1D Water Level

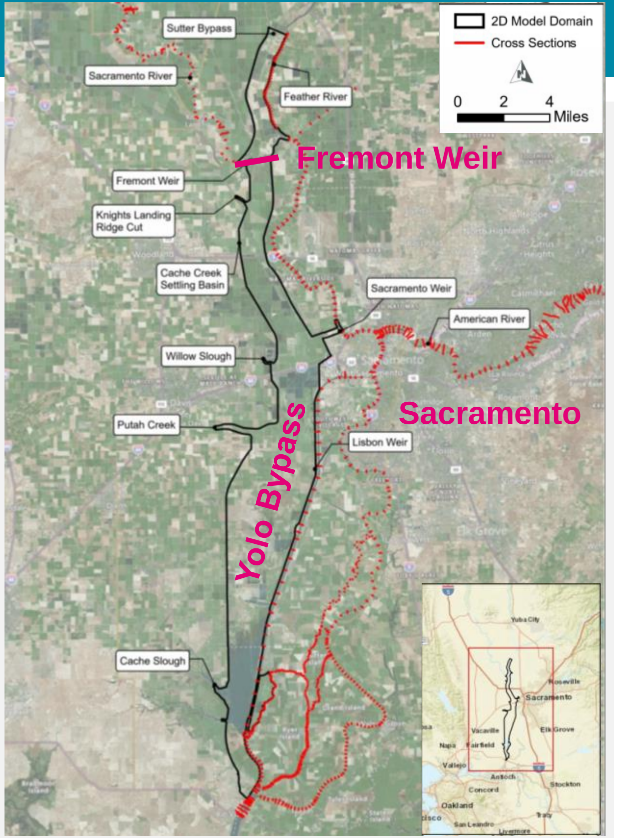




The Yolo Bypass Big Notch Project

Background:

- California Department of Water Resources and the United States Bureau of Reclamation
- 40 miles (64km) long, 3 miles (5km) wide floodwater bypass
- Update to gates at Fremont Weir to allow salmonid get onto the flooded bypass and offer fish passage back to the river
- cbec eco engineering and HDR built 1D/2D TUFLOW model of the project to evaluate benefits and impacts of the project



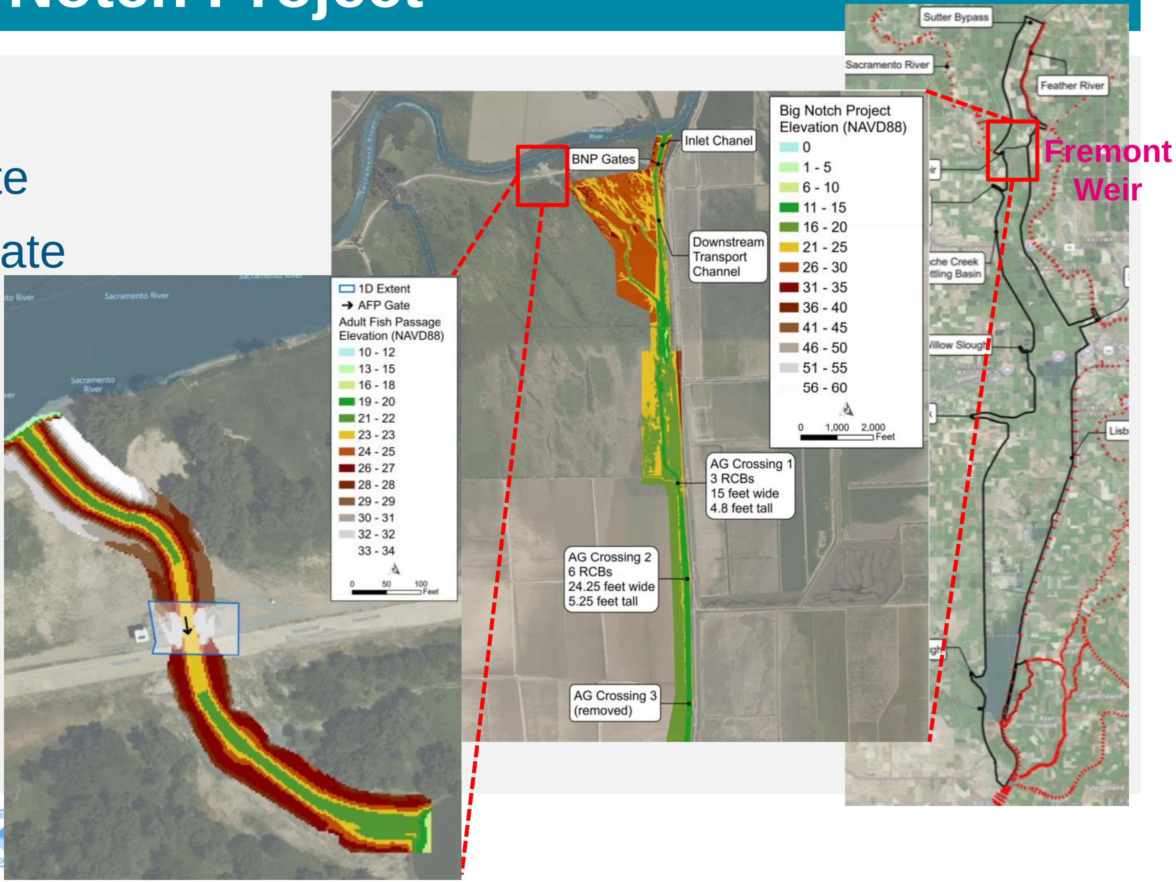
The Yolo Bypass Big Notch Project

Gates:

- Big Notch Project (BNP) Gate
- Adult Fish Passage (AFP) Gate

AFP Gate Operation:

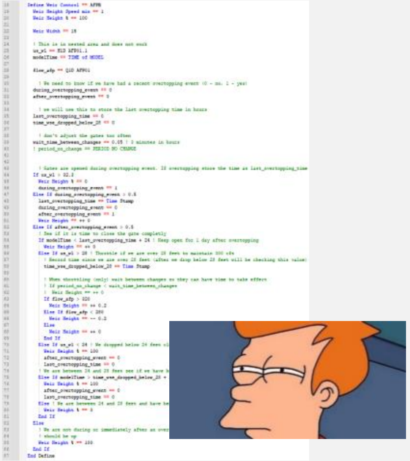
- AFP is opened during an overtopping event and stays open for a period afterwards to provide fish passage
- Limit flow rate for the fish to swim back to the river.



The Yolo Bypass Big Notch Project

Gate Modelling:

- 1D Weir with variable height
- Complicated Logic!!



Key logics:

- Monitor upstream level and flow rate
- H > 32.3ft (overtopping): Open gate completely
- Record the last time it overtopped when water level drops below 32.3ft
- Keep the gate height unchanged for 24hr after the overtopping
- H > 28ft: adjust weir height to keep flow rate between 280~320 cfs
- H < 24ft: Close gate
- H = 24 ~ 28ft: Fully open again (with time restriction)

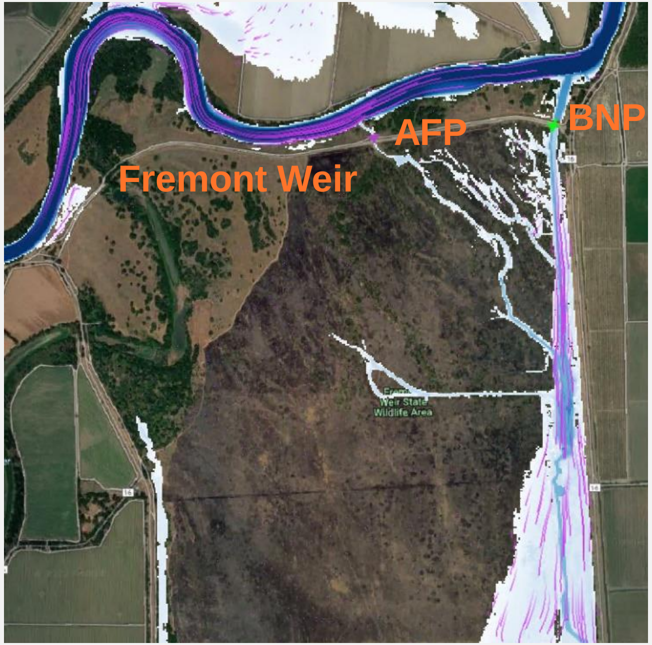
```
us_wl == H1D AFP01.1
modelTime == TIME of MODEL

flow_afp == Q1D AFP01
```

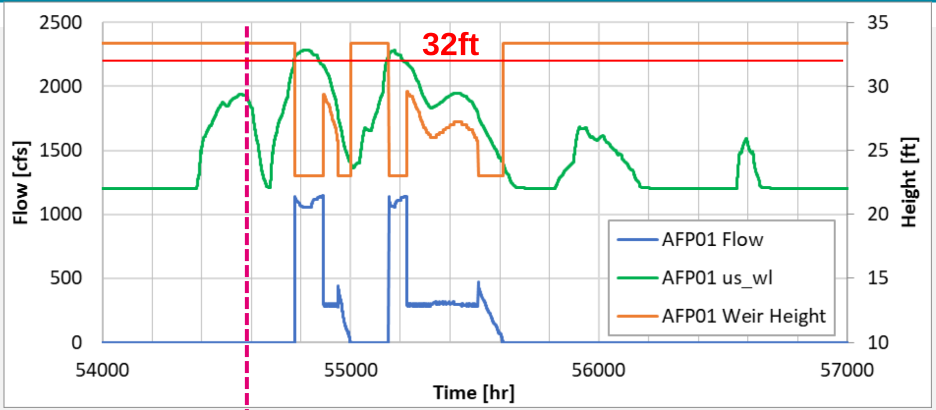
```
If us_wl > 32.3
  Weir Height % == 0
  during_overtopping_event == 1
Else If during_overtopping_event > 0.5
  last_overtopping_time == Time Stamp
  during_overtopping_event == 0
  after_overtopping_event == 1
  Weir Height == ++ 0
Else If after_overtopping_event > 0.5
  ! See if it is time to close the gate complet
  If modelTime < last_overtopping_time + 24 ! K
    Weir Height == ++ 0
  Else If us_wl > 28 ! Throttle if we are over
    ! Record time since we are over 28 feet (af
    time_wse_dropped_below_28 == Time Stamp

    ! When throttling (only) wait between chang
    ! If period_no_change < wait_time_between_c
    !  Weir Height == ++ 0
    If flow_afp > 320
      Weir Height == ++ 0.2
    Else If flow_afp < 280
      Weir Height == -- 0.2
    Else
      Weir Height == ++ 0
    End If
  Else If us_wl < 24 ! We dropped below 24 feet
    Weir Height % == 100
    after_overtopping_event == 0
```

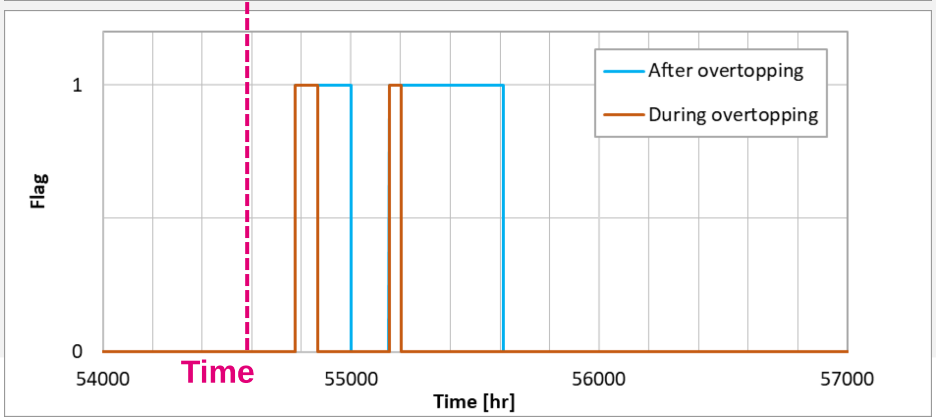
TUFLOW HDR cbec eco engineering DEPARTMENT OF WATER RESOURCES STATE OF CALIFORNIA U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

The Yolo Bypass Big Notch Project

Results: Before Overtopping

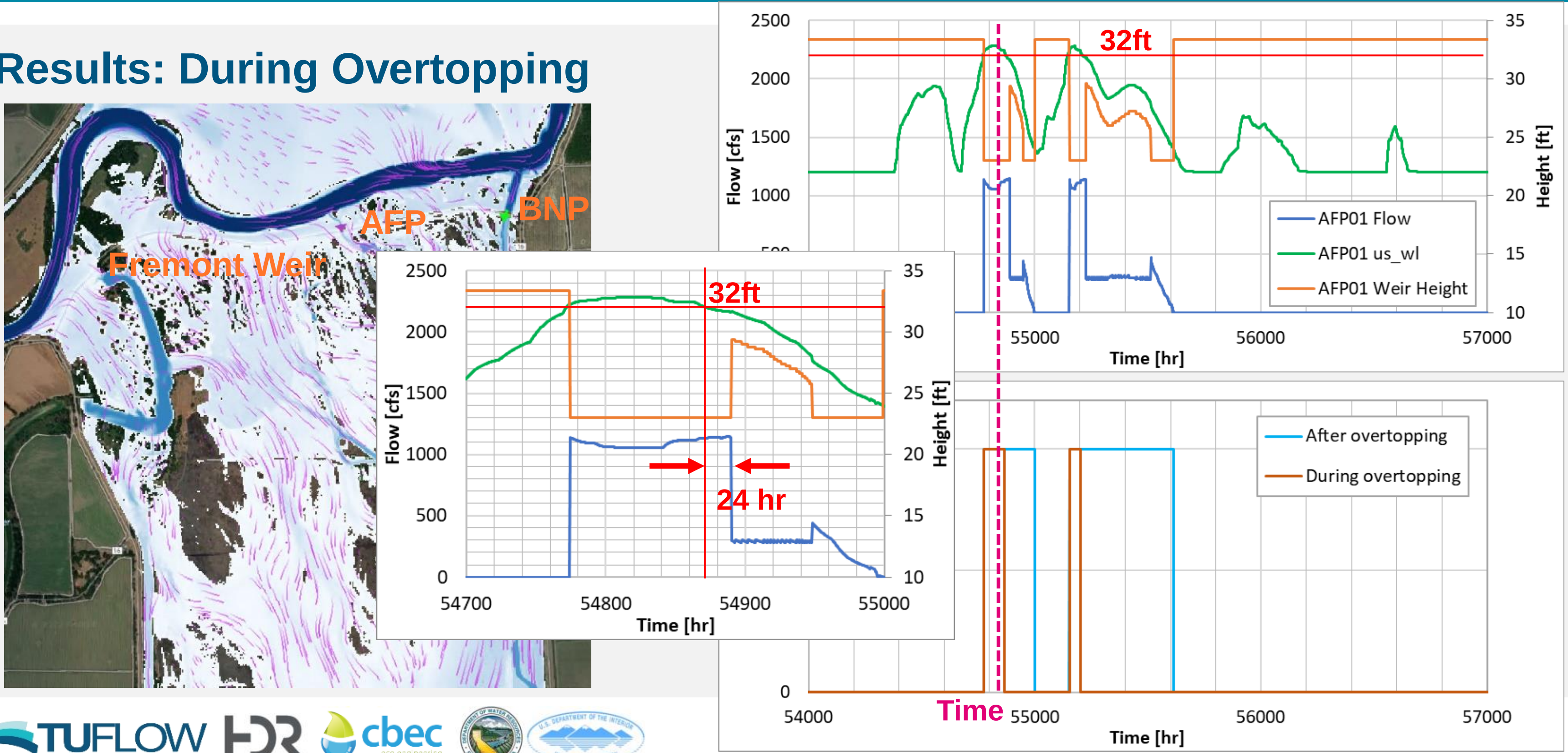






The Yolo Bypass Big Notch Project

Results: During Overtopping



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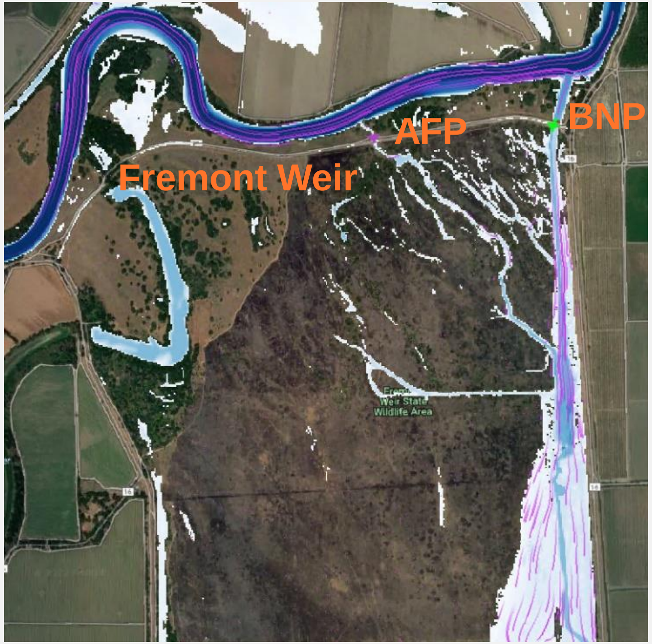
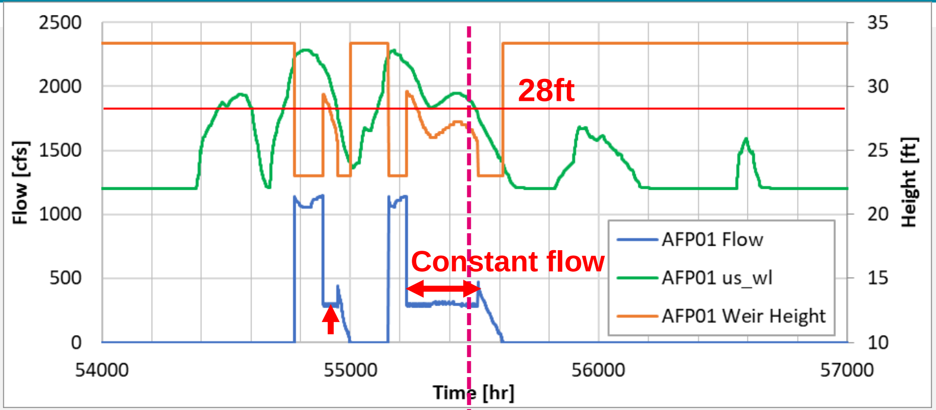
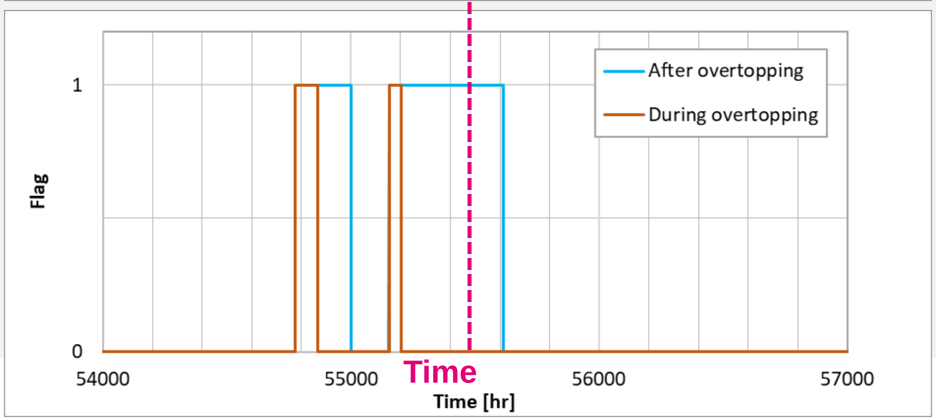
The Yolo Bypass Big Notch Project

Results: After Overtopping







Grand Sluice – Lower Witham

Lower River Witham in Lincolnshire, England

- Naturally marshy wetland
- Legacy of drainage works and embanked watercourses for farming
- Sluices in operation from mid 1100s
- Grand Sluice constructed in 1766
- Large number of sluices / control structures

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Grand Sluice – Lower Witham

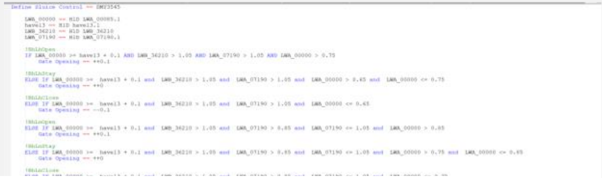
Grand Sluice:

- Most downstream control in River Witham
- 3 Vertical Sluices
- Gravity Outfall
- Automatically controlled based on remote water levels

Grand Sluice – Lower Witham

Complex Control Logic!

- 28 logical conditions
- 4 observatio



```
!BhLhOpen
IF h_upstream >= h_
    Gate Opening ==

!BhLhStay
ELSE IF h_upstream
    Gate Opening ==

!BhLhClose
ELSE IF h_upstream
    Gate Opening ==

!BhLnOpen
ELSE IF h_upstream
    Gate Opening ==

!BhLnStay
ELSE IF h_upstream
    Gate Opening ==

!BhLnClose
ELSE IF h_upstream
    Gate Opening ==
```

```
IF h_upstream >= h_downstream + 0.1
    IF h_bardney > 1.05
        IF h_langrick > 1.05 and  h_upstream > 0.65 and  h_upstream <= 0.75
            Gate Opening == ++0
        ELSE IF h_langrick > 1.05 and  h_upstream <= 0.65
            Gate Opening == --0.1
        ELSE IF h_langrick > 0.85 and  h_langrick <= 1.05 and  h_upstream > 0.85
            Gate Opening == ++0.1
        END IF

    ELSE IF h_bardney > 0.9
        IF h_bardney <= 1.05 and  h_langrick > 1.05 and  h_upstream > 0.85
            Gate Opening == ++0.1
        ELSE IF  h_bardney <= 1.05 and  h_langrick > 1.05 and  h_upstream > 0.75 and  h_upstream <= 0.85
            Gate Opening == ++0
        ELSE IF h_bardney <= 1.05 and  h_langrick > 1.05 and  h_upstream <= 0.75
            Gate Opening == --0.1
        ELSE IF h_bardney <= 1.05 and  h_langrick > 0.85 and  h_langrick <= 1.05 and  h_upstream > 0.95
            Gate Opening == ++0.1
        ELSE IF h_bardney <= 1.05 and  h_langrick > 0.85 and  h_langrick <= 1.05 and  h_upstream > 0.85 and  h_upstream <= 0.95
            Gate Opening == ++0
        ELSE IF h_bardney <= 1.05 and  h_langrick > 0.85 and  h_langrick <= 1.05 and  h_upstream <= 0.85
            Gate Opening == --0.1
        ELSE IF h_bardney <= 1.05 and  h_langrick <= 0.85 and  h_upstream > 1.05
            Gate Opening == ++0.1
    ELSE IF h_bardney <= 0.9
```

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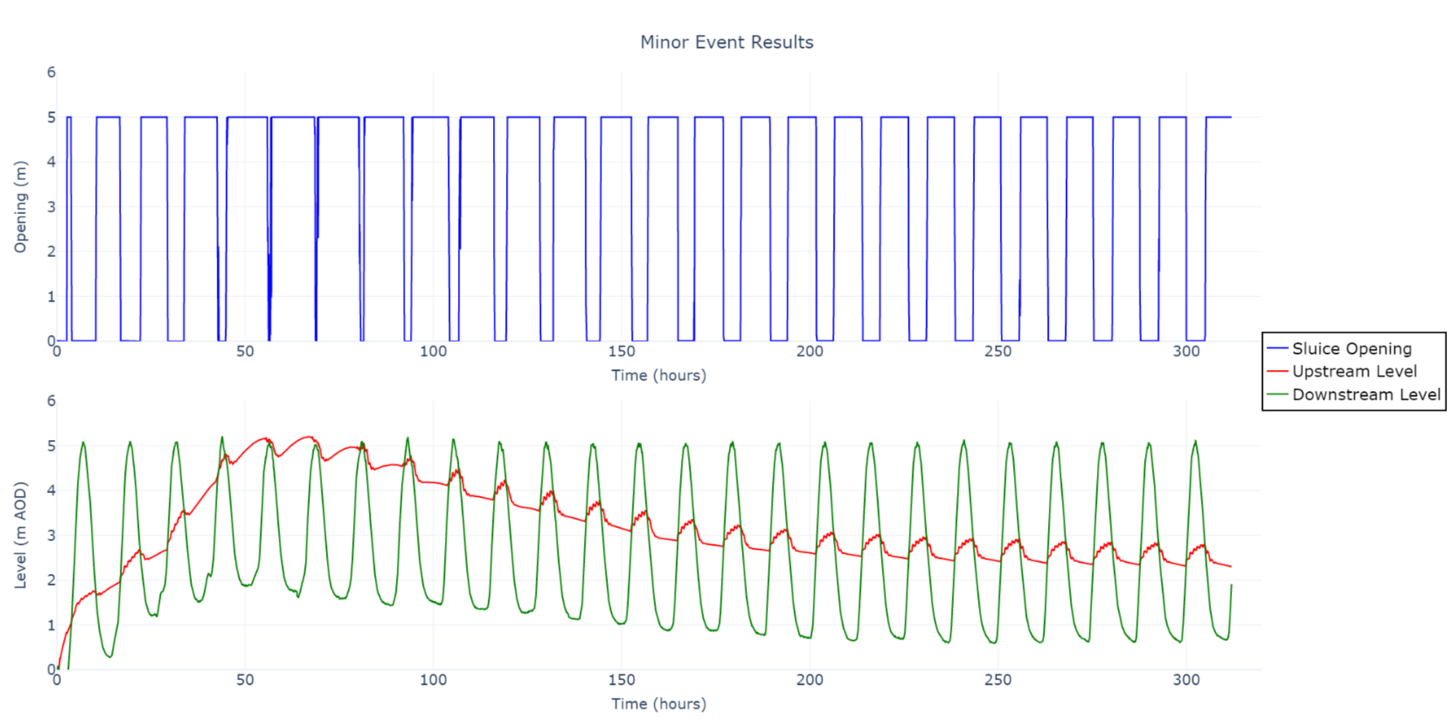
Grand Sluice – Lower Witham

Results



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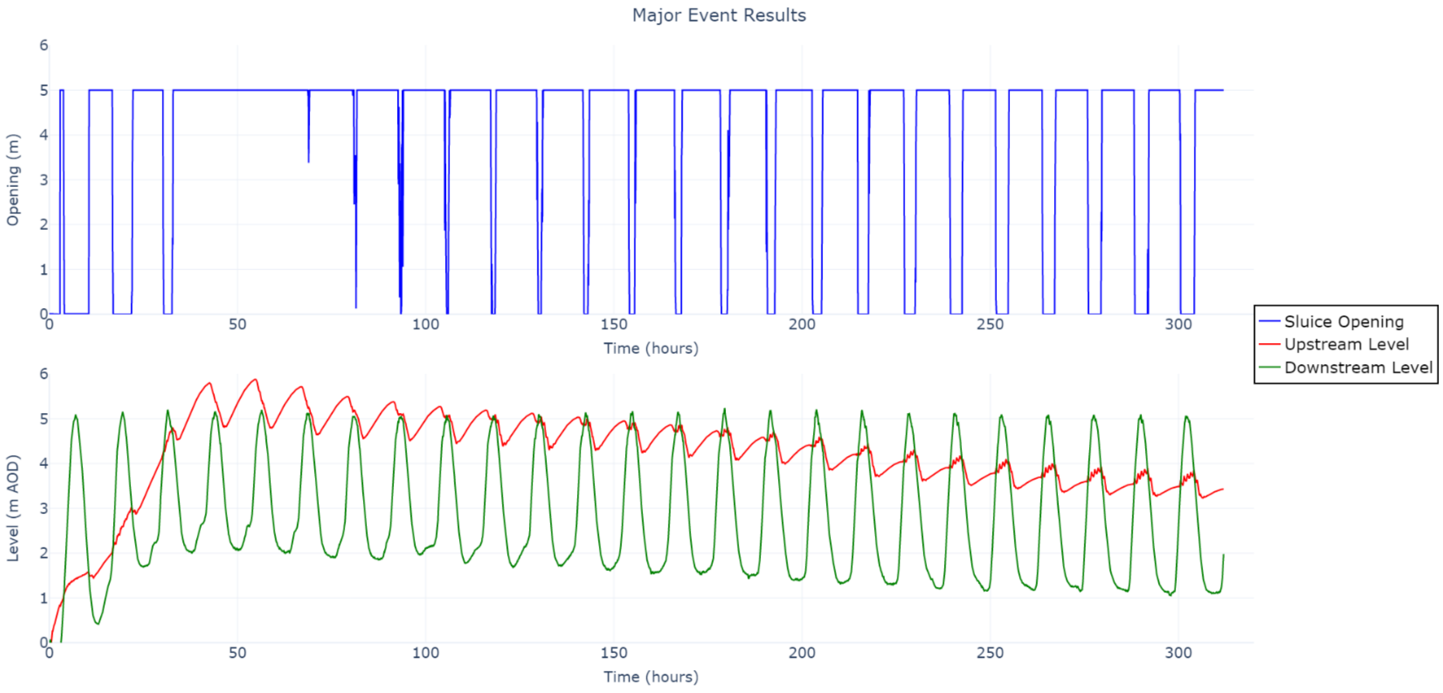
Grand Sluice – Lower Witham

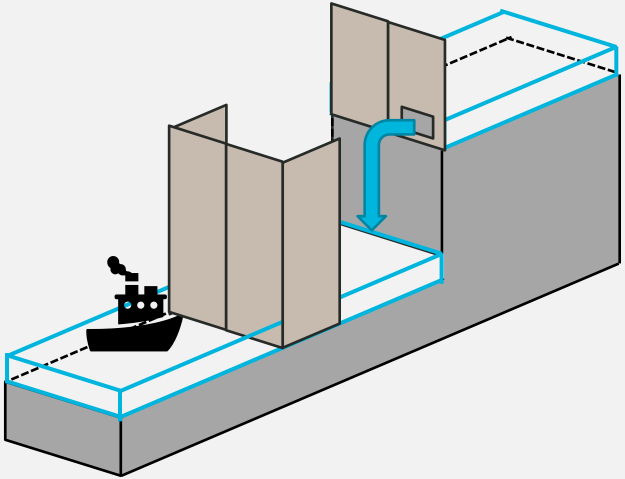
Results



Canal Locks

How it works:

- Gates to lock water
- Sluice gates or culverts to channel water



16 locks at Caen Hill Locks

https://en.wikipedia.org/wiki/Caen_Hill_Locks

Canal Locks

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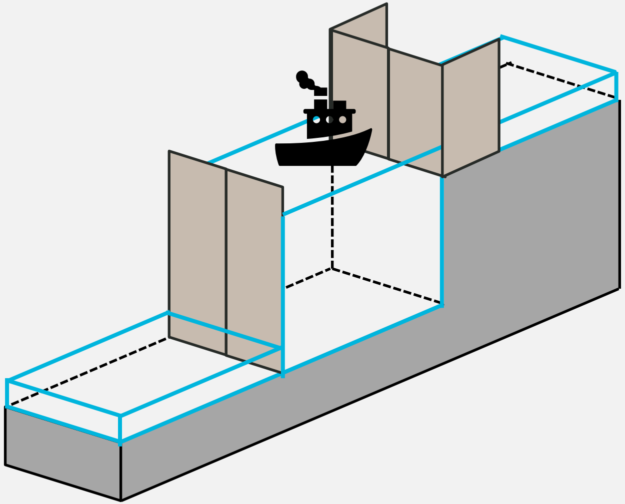

Caen Hill Locks

https://en.wikipedia.org/wiki/Caen_Hill_Locks

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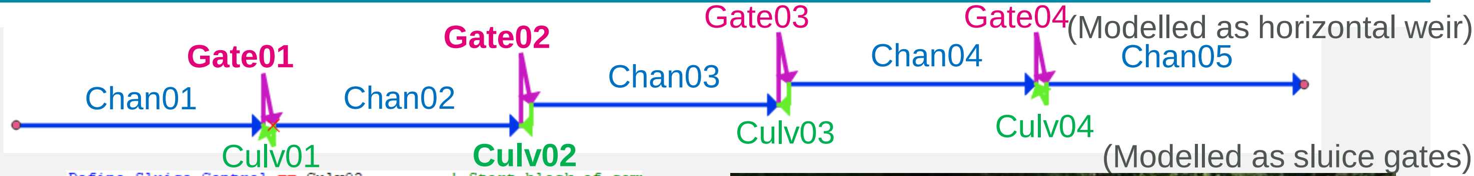
Canal Locks

Modelling:

- Status of upstream gate/culvert
- Make sure upstream gates are closed
- Sluice gates stay open **UNTIL** us/ds are level




```
Define Sluice Control == Culv02          ! Start block of com

! Default Settings----------------------
    Period Opening/Closing (s)   == 10
    Gate Height Fully Open == 0.5
    Gate Opening == Closed
    Cd Gate == 0.6
    Cd Gate Submerged == 0.6

! User Variables -----------------------------------------------
    model_time == Time of Model          ! Set the variable '
    us_level == HU                       ! Set the variable '
    ds_level == HD                       ! Set the variable '
    gate01_width == Weir Width Gate01
    culv01_status == Status Culv01

! Logic Commands ------------------------------------------------
    If model_time > 0.5
        Gate Opening == Closed
    Else If model_time > 0.166667               ! 10 min
        If gate01_width < 0.0001 and culv01_status = Closed
            If us_level >= ds_level + 0.01              ! Close
                Gate Opening == Open
            Else
                Gate Opening == Closed                  ! reduce
            End If
        Else
            Gate Opening == Closed              ! Set the status
        End If
    Else
        Gate Opening == Closed
    End If

End Define
```

$$Q = C_d W B \sqrt{2 g H_1}$$

$$Q = C_s W B \sqrt{2 g \Delta H}$$

Boater's Handbook Video Part 3 – Locks
https://www.youtube.com/watch?v=iKVinUvtVFM

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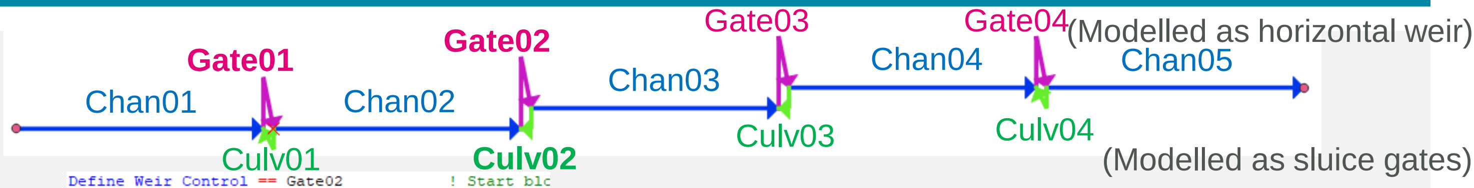
Canal Locks



Modelling:

- Open gates **AFTER** us/ds are level
- Close gates after boat passes (after 5min)

```
Define Weir Control == Gate02                    ! Start blc

! Default Settings---------------------------------------
   Period Opening/Closing (s) == 60      ! (s) Dam f
   Weir Height == 0.0                    ! (m)  Set
   Weir Width  == 0.0                    ! (m)  Set

! User Variables ----------------------------------------
   us_level == HU                        ! Set the v
   ds_level == HD                        ! Set the v
   model_time == Time of Model
   track_time == 0
   opration_start == 0


! Logic Commands ----------------------------------------
   If model_time > 0.333333
      If us_level >= ds_level - 0.01
         If model_time > track_time + 0.0833333
            Weir Width == 0.0                    ! c
         Else
            Weir Width == 5.0                    ! c
            opration_start == 1
         End If
      Else If opration_start = 0
         Weir Width == 0.0                       ! k
         track_time == Time Stamp
      End If
   Else
      Weir Width == 0.0                     ! keep
   End If

End Define                                       ! End block
```

Boater's Handbook Video Part 3 – Locks
https://www.youtube.com/watch?v=iKVinUvtVFM

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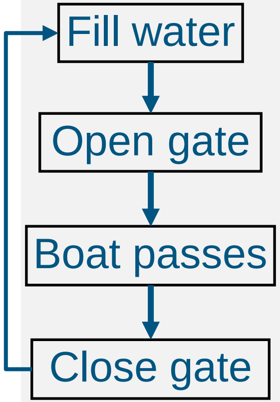
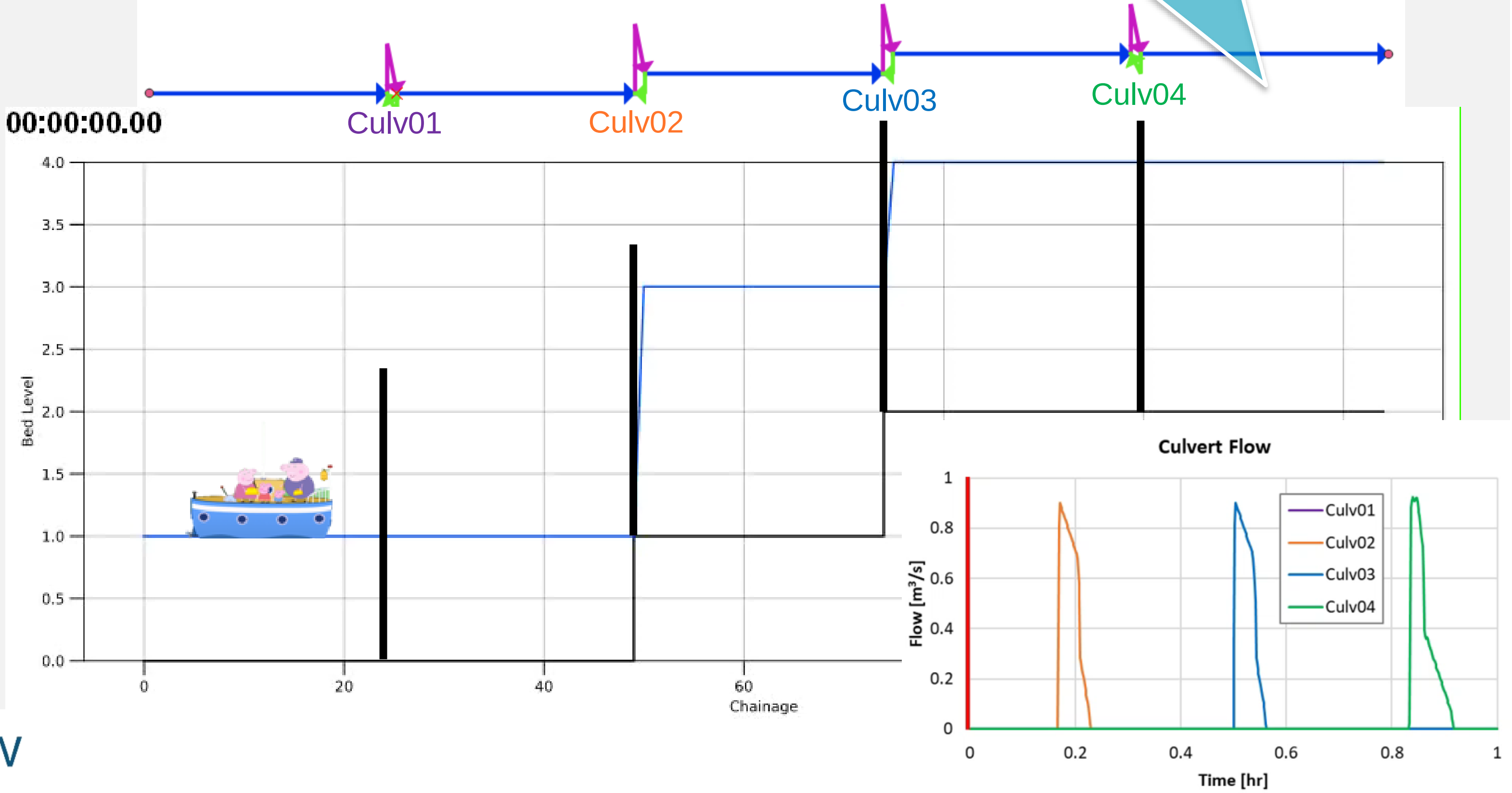
Grandpa Pig's Boat and Canal Locks

I love canal locks.
Everyone loves canal locks.

Results:





Troups Creek Wetland Real-Time Stormwater Control
Monash University / Melbourne Water

Background:

- Constructed wetland for stormwater treatment
- Aquatic plants

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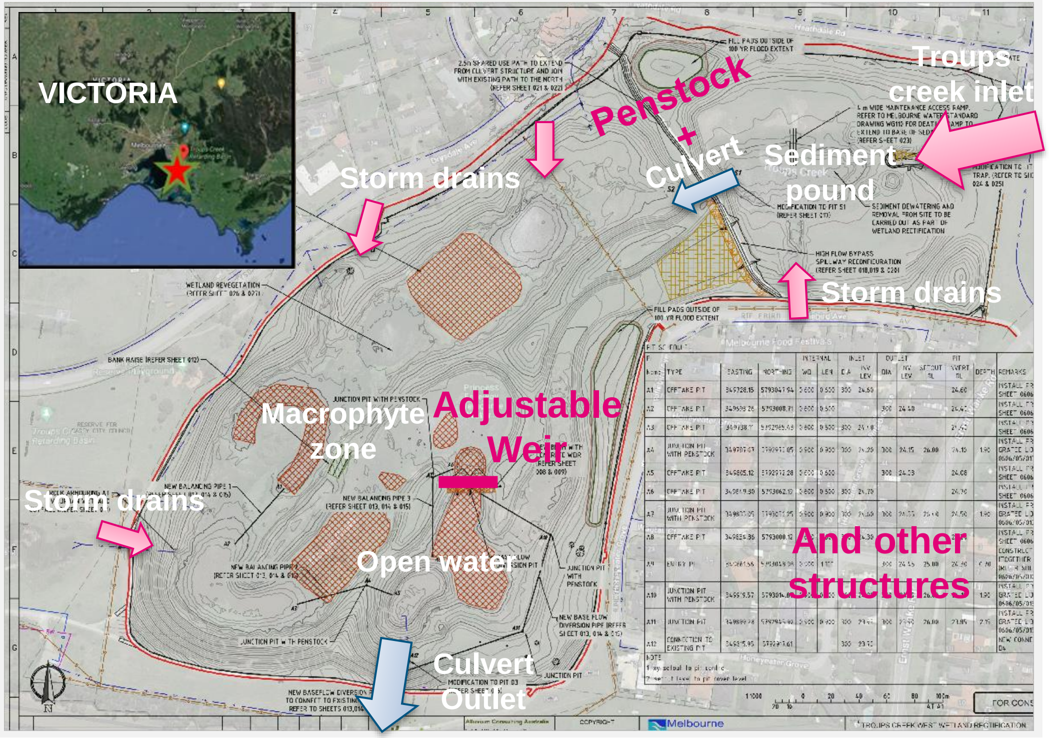
Troups Creek Wetland Real-Time Stormwater Control

Problems with existing wetland:

- Poor treatment efficiency
- High water depth damages aquatic plants

Wetland upgrade:

- Excavation
- Added operational structures to improve water retention time + control water depth



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Troups Creek Wetland Real-Time Stormwater Control

TUFLOW FV Modelling:

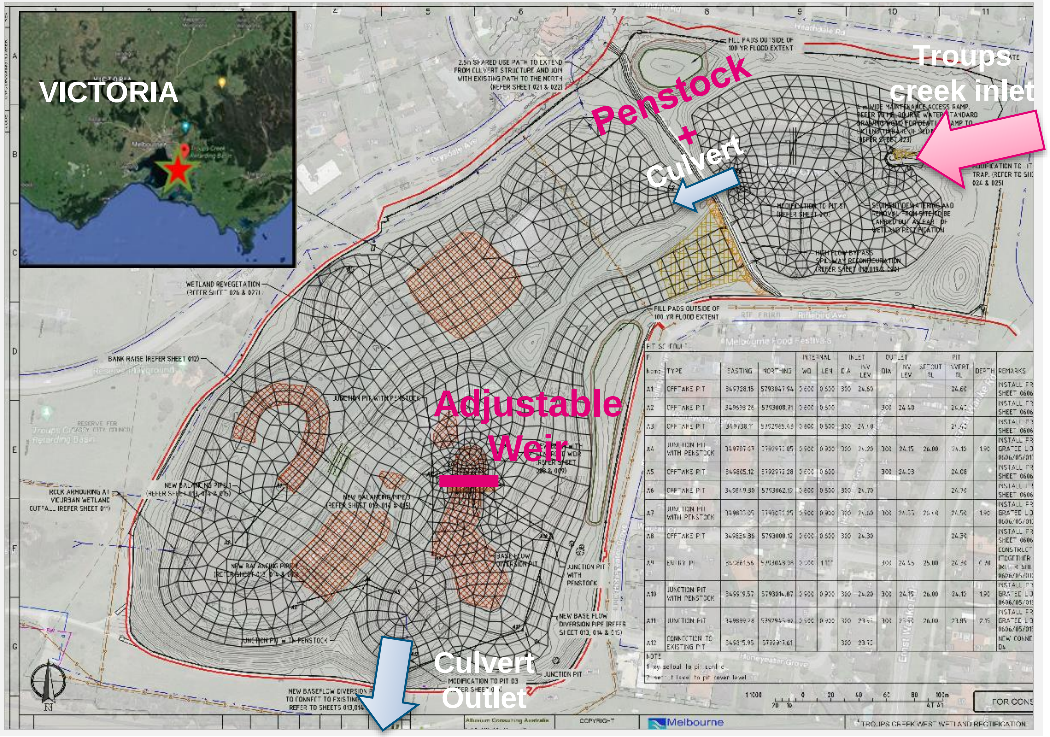
- Hydrodynamic model to evaluate retention time
- 2.5m~10m mesh
- Culvert with adjustable opening
- Weir with adjustable height

Evaluation of “efficiency”:

- Track water “age”
- Pollutant with decay rate K = 0.5 day^{-1}

$$\frac{\partial C}{\partial t} = KC$$

(PhD candidate Xixi to complete the sediment transport and water quality modelling)



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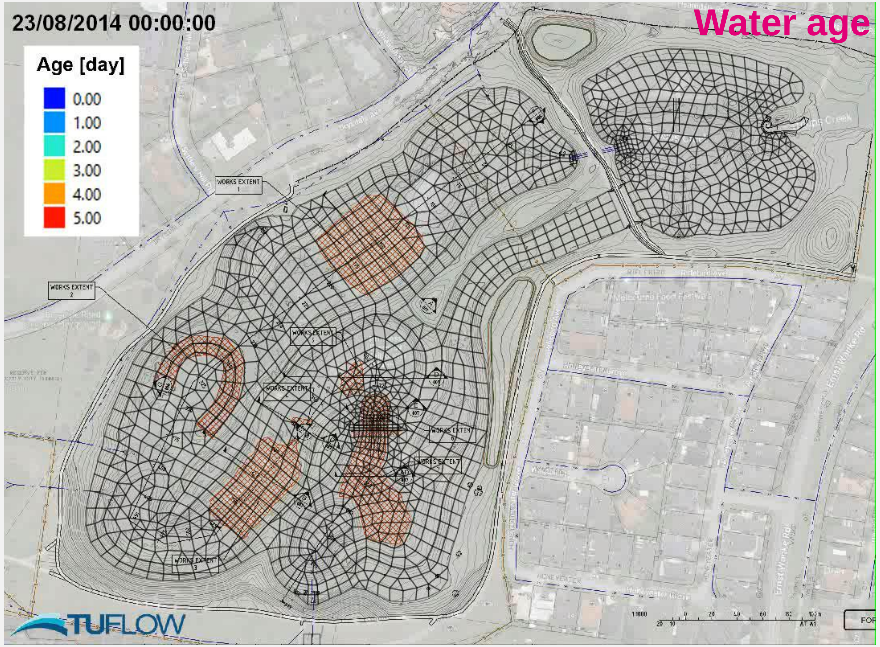
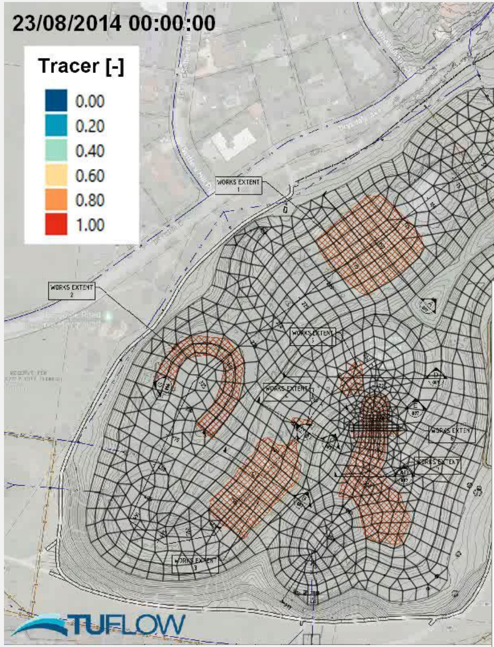
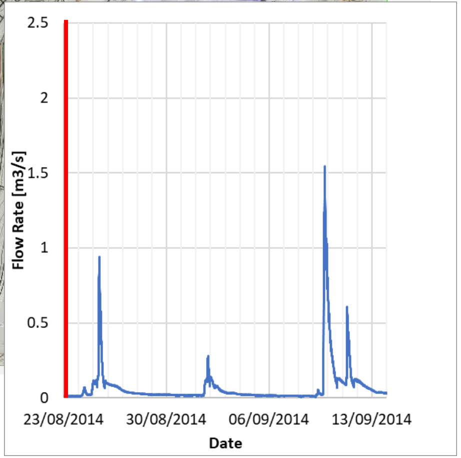
Troups Creek Wetland Real-Time Stormwater Control
Base case

No weir, no structure operation $Age_{n+1} = Age_n + dt$







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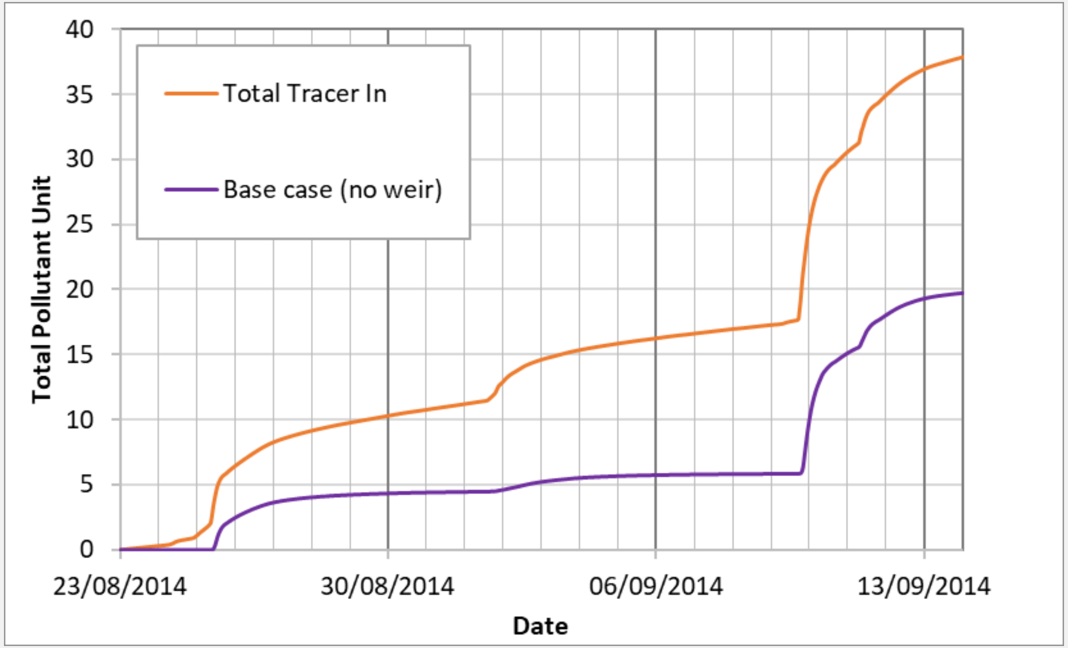
Troups Creek Wetland Real-Time Stormwater Control
Base case

Total Tracer In vs Out:

$$Total\ Tracer\ In = \int Q_{in} C_{in}\, dt$$

$$Total\ Tracer\ Out = \int Q_{out} C_{out}\, dt$$

- Base case (no weir): 49%



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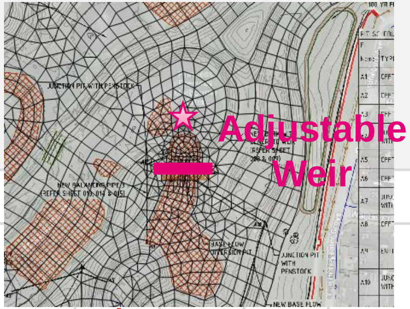
Troups Creek Wetland Real-Time Stormwater Control Case 2

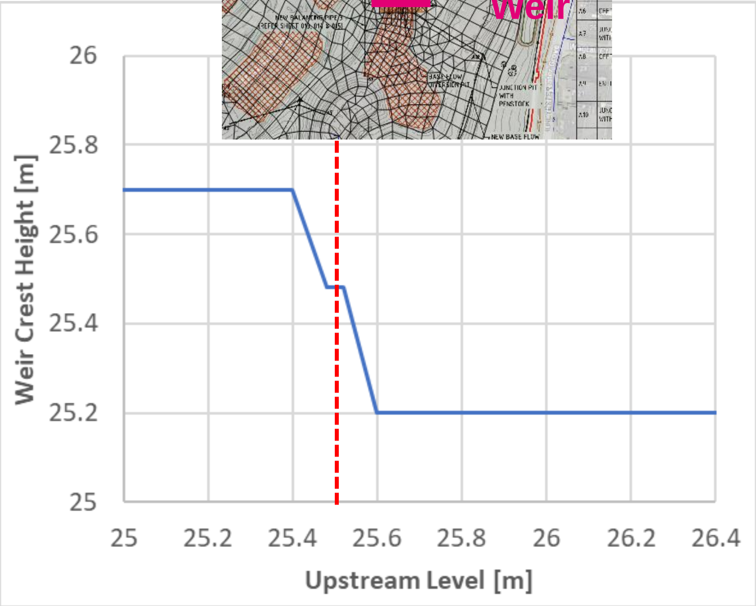
Culvert + Weir used adjusted water level 0.3m higher

- Weir operation based on upstream water level

```
! weir
Structure == Nodestring, 3
    Flux function == Weir
    PROPERTIES == 25.30,0.8! weir elevation(mAHD), weir coefficient

    !Control block. Open or close weir based on upstream WL
    Control == sample_rule                          ! nested control block
        Sample Point == 349862.0, 5793065.2         ! gauge location <x, y>
        Sample Type == WL                           ! Water Level
        Sample dt == 0.166667                       ! 10min
        Control Parameter == Weir_Crest             ! Open or close
        Control Update dt == 0.166667               ! Update structure moveme
        Start Control State == 25.70                ! Start with pump off
        Control file == ..\geo\struct\weir_operation.csv  ! WL vs Weir_Crest
    End Control
End Structure
```





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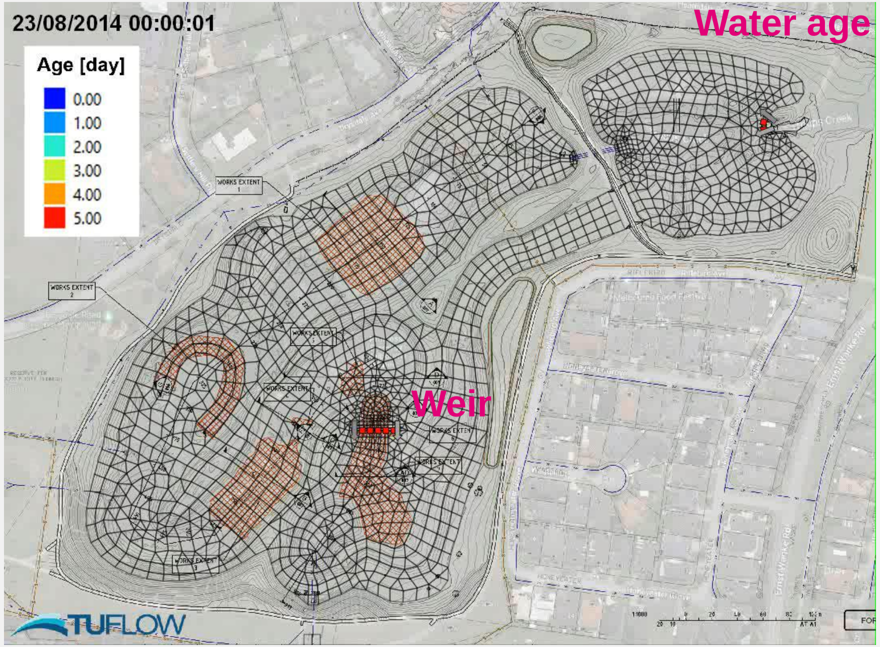
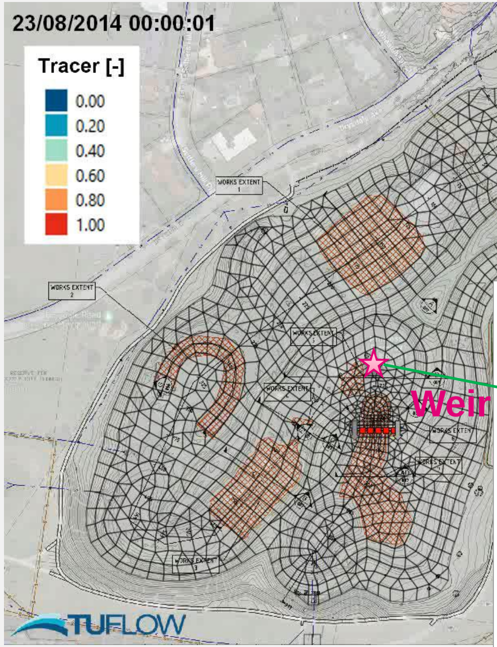
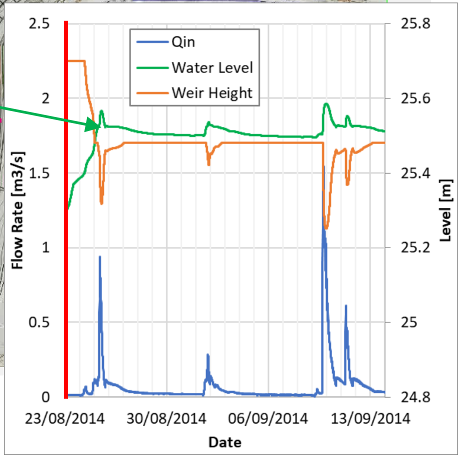
Troups Creek Wetland Real-Time Stormwater Control Case 2

Culvert + Weir







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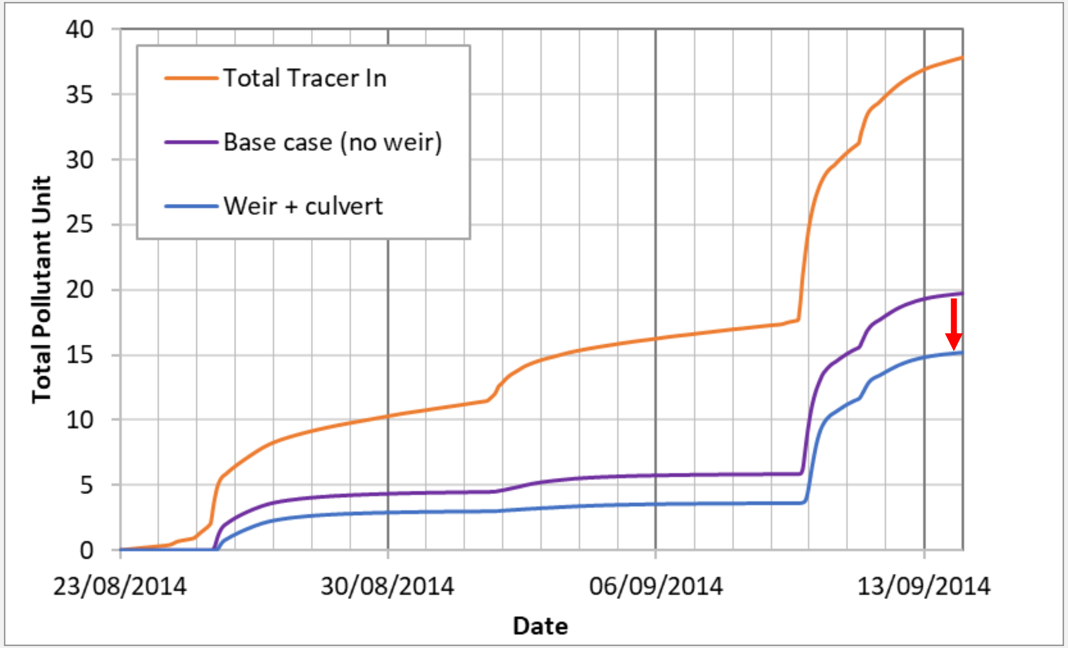
Troups Creek Wetland Real-Time Stormwater Control Case 2

Total Tracer In vs Out:

$$Total\ Tracer\ In = \int Q_{in} C_{in}\, dt$$

$$Total\ Tracer\ Out = \int Q_{out} C_{out}\, dt$$

- Base case (no weir): 49%
- Weir + Culvert: 61%



Troups Creek Wetland Real-Time Stormwater Control Case 3

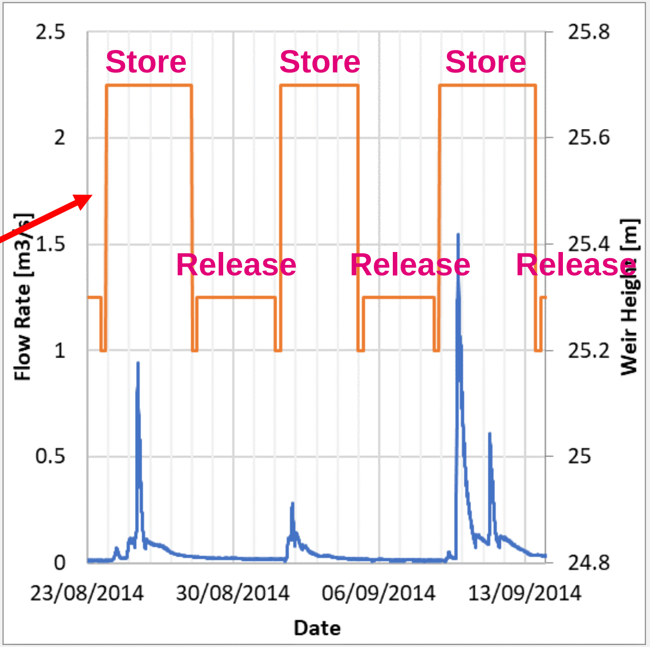
Adjust weir to store and release water

- Weir operation based on predicted rainfall/inflow

  (In modelling: based on timeseries)

```
! weir
Structure == Nodestring, 3
    Flux function == Weir
    PROPERTIES == 25.30,0.8! weir elevation(mAHD), weir coefficient

    !Control block. Open or close weir based on upstream WL
    Control == timeseries                          ! nested control block
        Control Parameter == Weir_Crest             ! Open or close
        Control Update dt == 0.166667               ! Update structure movement
        Start Control State == 25.70                ! Start with pump off
        Control file == ..\geo\struct\weir_tseries.csv  ! Time vs Weir_Crest
    End Control
End Structure
```



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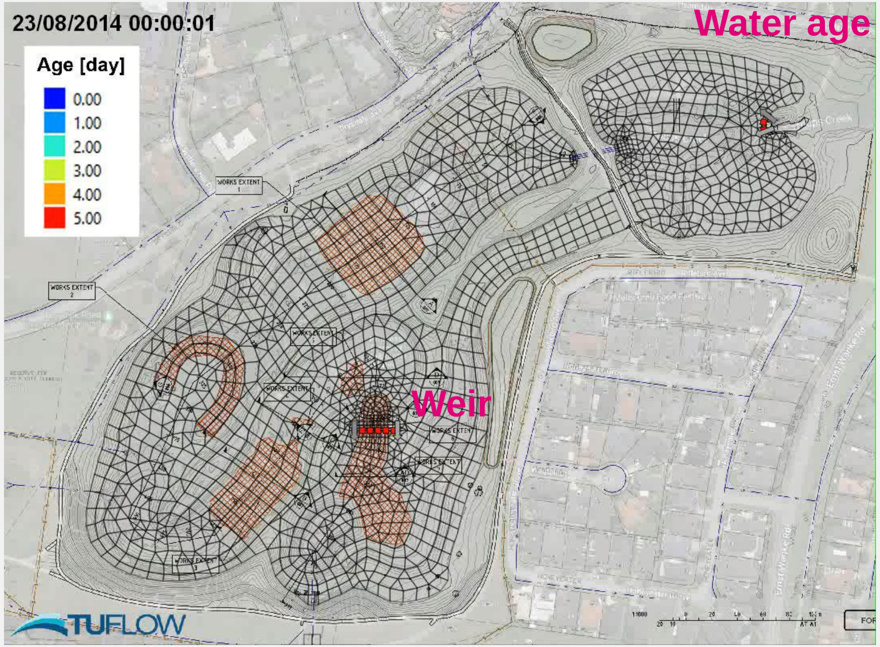
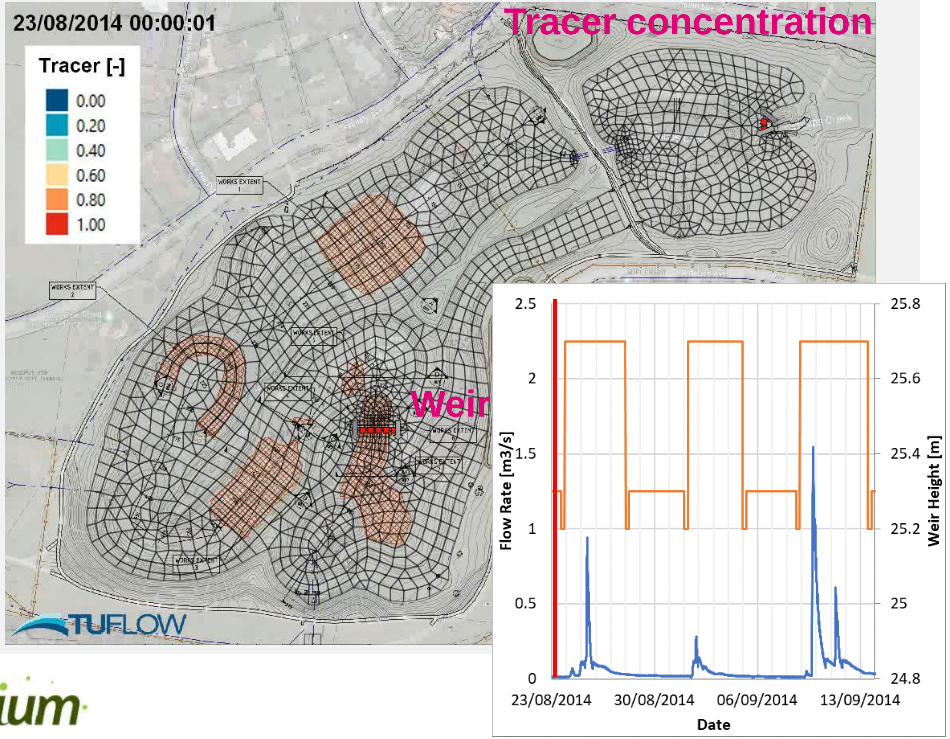
Troups Creek Wetland Real-Time Stormwater Control Case 3

Staged release





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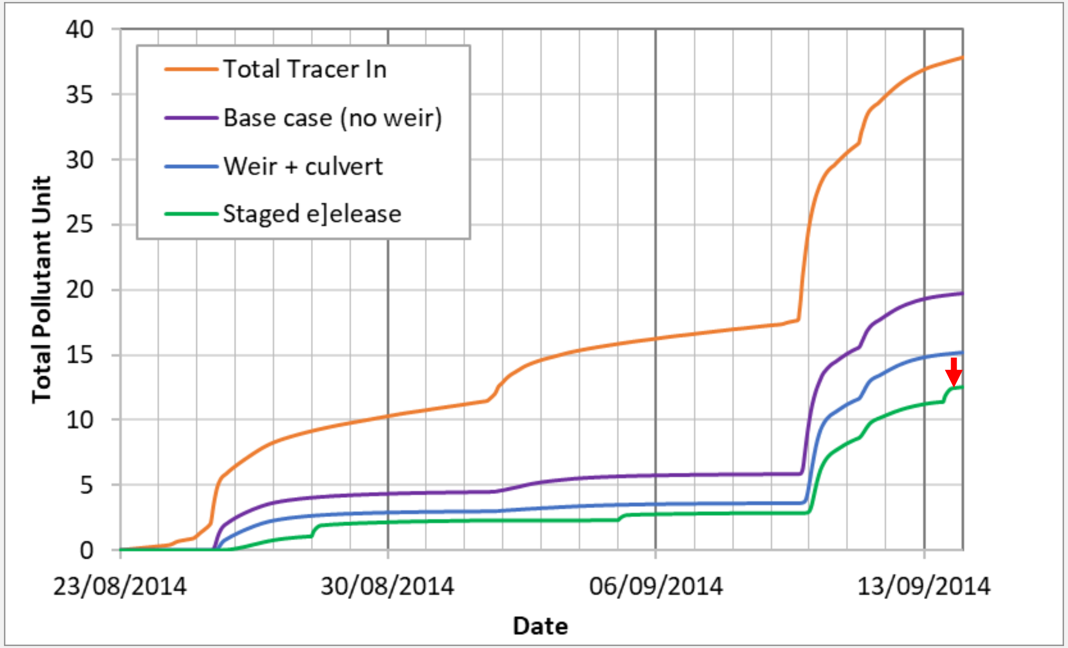
Troups Creek Wetland Real-Time Stormwater Control Case 3

Total Tracer In vs Out:

$$Total\ Tracer\ In \quad = \int Q_{in} C_{in}\, dt$$

$$Total\ Tracer\ Out = \int Q_{out} C_{out}\, dt$$

- Base case (no weir): 49%
- Weir + Culvert: 61%
- Staged release: 67%



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Questions?

```
! Default Settings-----------------------------------
Shop Capacity == 5.      ! Person/shop
Shop Opening == OPEN
! User Variables -----------------------------------
flood_level == H2D<x_coord,y_coord>
! Logic Commands ---------------------------------
If flood_level <= 0
     Shop Opening == OPEN
If flood_level <= 6
     Shop Opening == NO CHANGE
Else
     Shop Opening == …
End If
```

Image of a coffee shop during 2022 Brisbane flood