Modelling Group
WATER NEW ZEALAND

Modelling Symposium

Challenges in Modelling Energy Losses in Hydraulic Structures

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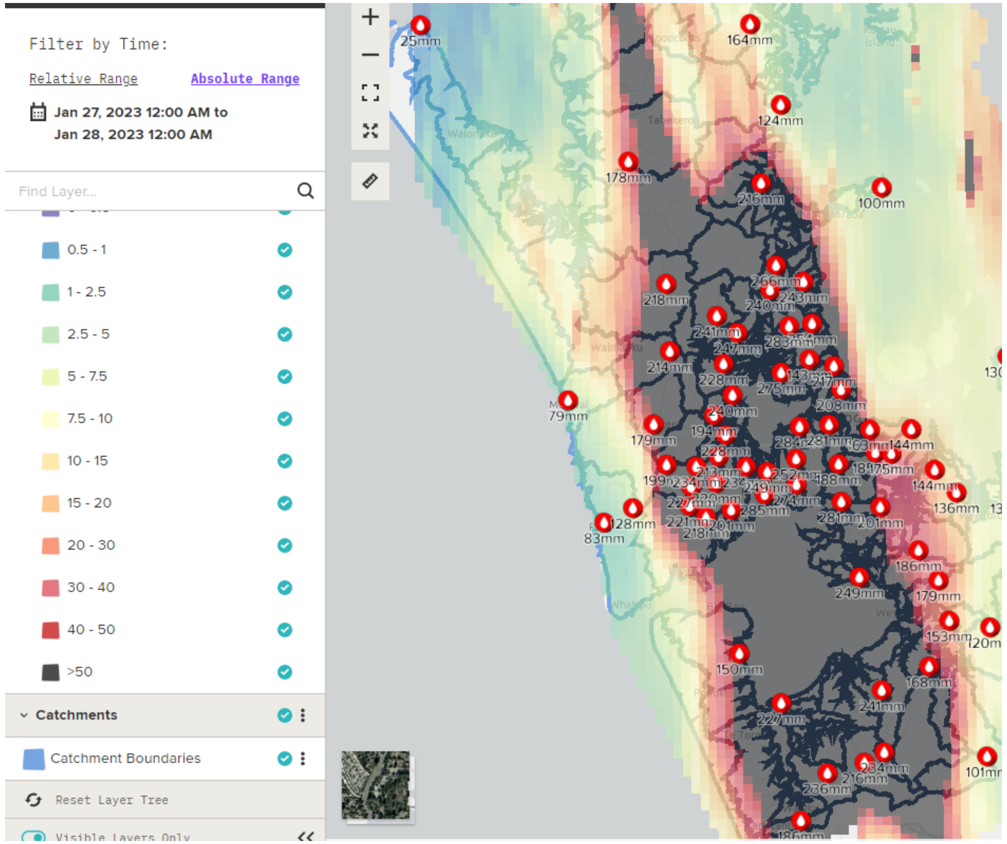
water
NEW ZEALAND
The New Zealand Water & Wastes Association Waiora Aotearoa

Introduction



Introduction

Insurance

Customer Affected

Road damage

Intense Rainfall

Climate Change

Flood Risk

Post event recover

Introduction – Issue Identification

- Climate change
- Increases in both the intensity and variability of rainfall
- Risk of flooding
- Strain on infrastructure

Introduction – Adopted Tool

- Hydraulic drainage network models
- Hydraulic models to evaluate the drainage systems
    - System performance
    - Hazard information
    - Design of new infrastructure
- Drainage network models includes
    - manholes, pipes, culverts, bridges, weirs, and other hydraulic structures
- Auckland Council's modelling project experience
    - Modelling energy losses in hydraulic structures is one of the challenging tasks
    - Experience and recommendations

The Challenge

- Modelling energy losses in hydraulic structures
  - **Why** would it be challenging? – Fact
  - **What** have we experienced? – Examples
  - **What** have we done to overcome the challenges?
    - – Case study
    - – Implication
  - **What** am I trying to emphasis here? – Recommendations

Why would it be challenging

- Energy losses is complicated.

- Energy losses during movement of water is primarily of **two types**

    - Surface friction of the flow boundary

    - Rapid changes in velocity

Why would it be challenging

- Energy loses due to surface friction
    - Manning’s equation - Roughness of the surface based on the surface type

Why would it be challenging

- Energy loses due to surface friction

  - Manning’s equation
    - Roughness of the surface based on the surface type

  - Colebrook-White equation is more preferred
    - When pipe size is smaller than 300mm.

Why would it be challenging

- Energy loses due to Rapid Change in Velocity
- Typical Issues
  - Software limitation on complex structure
  - User knowledge of the software and the structure
  - Study gap with headloss validation

What have we experienced - Examples

- Typical Issues
  - Software limitation on complex structure

What have we experienced – 1. Pipes

- Software limitation on complex structure
  - Ku –the amount of change of flow direction at a manhole

$\Delta h = ku * ks * kv * (v^2/2g)$ (1)

where:

Δh = headloss

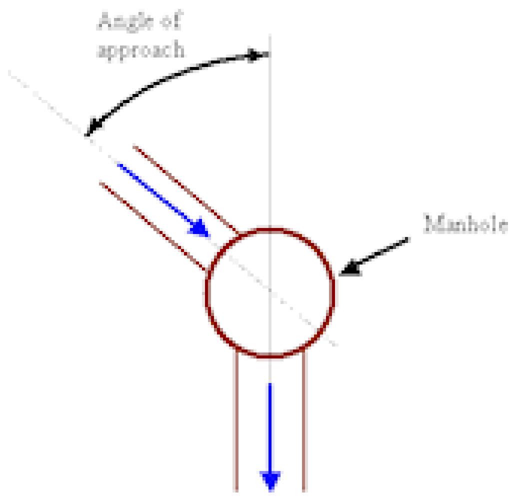
ku = user defined headloss factor

ks = surcharge ratio coefficient

kv = velocity coefficient

v = flow velocity (m/s)

g = acceleration due to gravity (m/s^2)



What have we experienced – 1. Pipes

- Software limitation on complex structure
  - Ku –the amount of change of flow direction at a manhole

$$\Delta h = ku * ks * kv * (v^2/2g)$$

- Level of complexity - Low
  - Inference Tool
  - User define - headloss type
  - **Inference tool calculates Ku based on the angle of approaching**

What have we experienced – 1. Pipes

- Level of complexity - Low
    - **Only 1 incoming and 1 outgoing pipe – Automatically calculated**

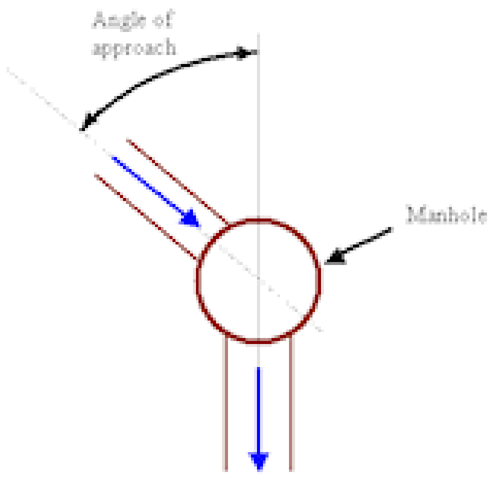


Figure 1 Angle of Approach

What have we experienced – 1. Pipes

- Level of complexity - Complex
  - **More than 1 incoming and outgoing pipe**
- Inference does not deal with this level of complexity.

$$\Delta h = ku * ks * kv * (v^2/2g)$$

Table 1 below presents suggested values of ku for various angles of approach.

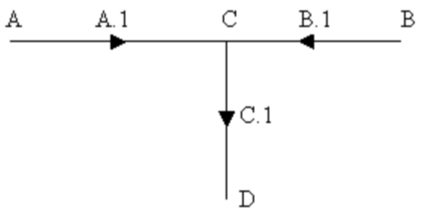


Figure 2 T Junction 1

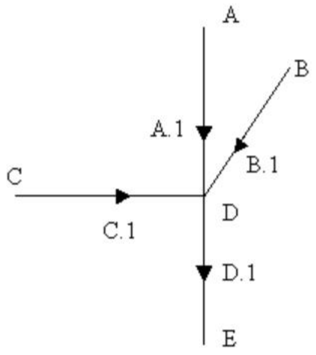


Figure 3 More Complex Junction

Angle of Approach	Ku
30	3.3
60	6.0
90	6.6
>90	8.0

Table 1 Angle of Approach

If a pipe includes several bends then the values of ku should be summed.

What have we experienced – 2. Manholes

- Level complexity – Challenging
- **When there are multiple incoming and outgoing pipe**

What have we experienced – 3. Culvert

- Level complexity – Challenging
- **Is the headloss estimated by the model reliable?**
- **Would schematization make any difference?**

What have we experienced – 4. Bridge

- Level complexity – Challenging
- **Is the headloss estimated by the model reliable?**
- **Would schematization make any difference?**

What have we experienced

- Typical issues
  - Software limitation on complex structure
    - Limitation on user defined QH relationship table
    - Modelling software sometimes does not extrapolate the QH tabulated data and gives inconsistent results during data extrapolation on a rectangular weir modelling

What have we experienced

- **2.** User knowledge of the software and the structure
  - Global Parameter - any box should be checked?

Sim parameters Object Properties (R/O)

Node, conduit and control	
Stay pressurised	☐
Don't linearise conveyance	☐
No. of geometry table entries	15
Use full area for headloss calculations	☐
Inflow is lateral	☐
Bottom of headloss transition	0.000
Top of headloss transition	0.000
Use Villemonte equation	☐
Drop inertia in pressure pipes	☒
Drowned bank linearisation threshold (m)	0.010
Node level affects groundwater infiltration	☒
Weight Manning roughness by n	☐

What have we experienced

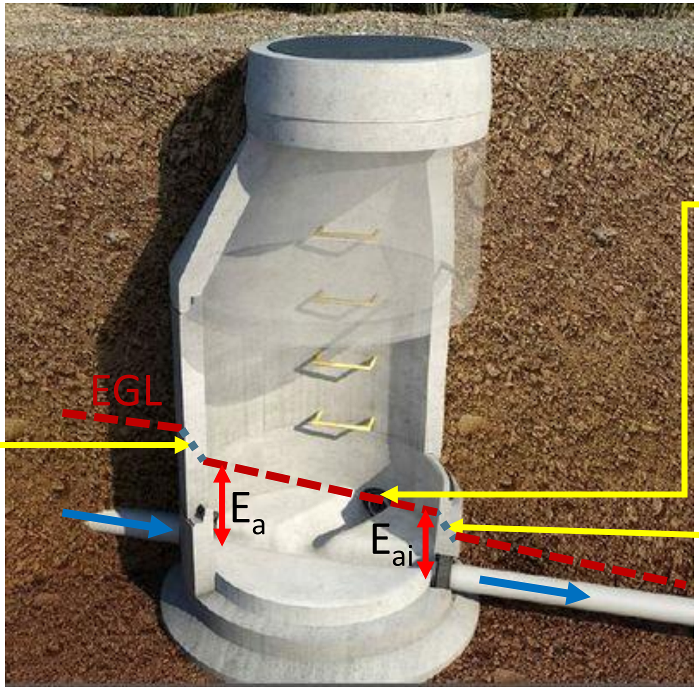
- Typical issues
    - 1. Software limitation on complex structure
    - 2. User knowledge of the software and the structure
    - **3. Study gap with validation of energy loss**
        - All modelling on energy loss are based on theory
        - No monitoring flow **gauges within** the pipe network, creates barrier for energy loss validation

What have we done to overcome the challenges?

- How did we address software limitation?
- How do we know if the energy loss predicted by the model is reasonable?
- Any thoughts on energy loss validation?
- What is recommend based on our experience?

What have we done to overcome the challenges?

- **How did we address software limitation?**
  - Challenging hydraulic structure - Manholes
    - Manual calculation based on First Principle – e.g. HEC 22 Approach



Exit Loss

$H_o = K_O V_i^2 /2g$

K_O = Exit loss coefficient

Additional Loss

$H_a = (C_B + C_P + C_\theta) K_e V_O^2/2g$

C_B = Benching loss coefficient

C_P = Plunging flow loss coefficient

C_θ = Angled Inflow (bend) loss coefficient

Entrance Loss

$H_e = K_e V_O^2/2g$

K_e = Entrance loss coefficient

What have we done to overcome the challenges? – First Principle Approach

- **How did we address software limitation**
  - Challenging hydraulic structure - Manholes
    - Manual calculation based on First Principle – e.g. HEC 22 Approach

Additional Loss

$$Ha = (C_B + C_P + C_\theta) K_e V_O^2/2g$$

C_B = Benching loss coefficient

C_P = Plunging flow loss coefficient

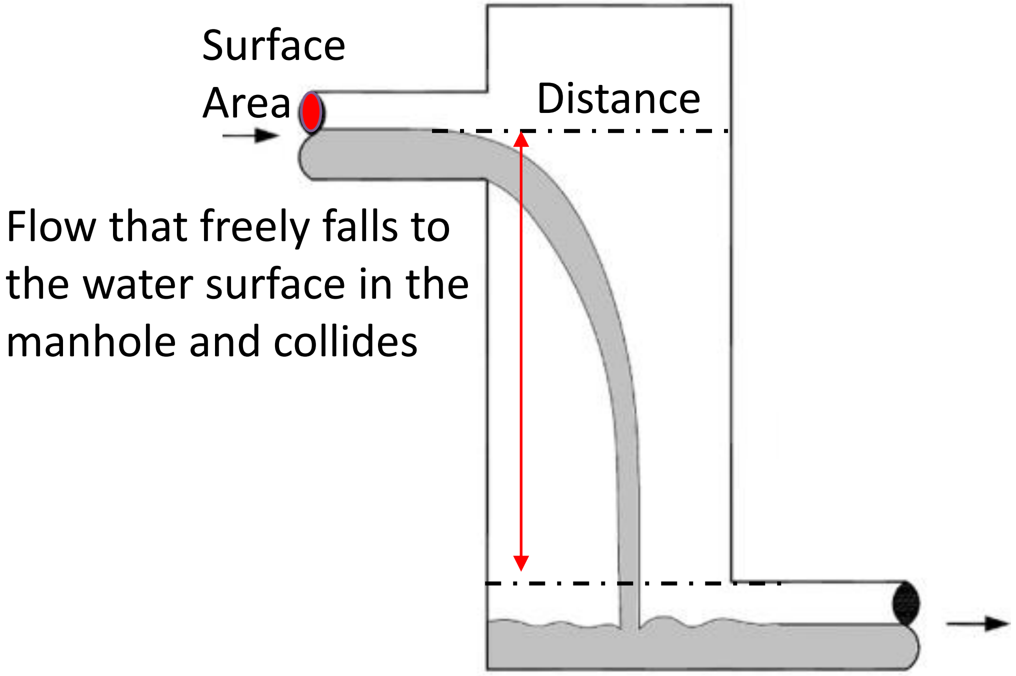
C_θ = Angled Inflow (bend) loss coefficient

Table 7-6. Values for the Coefficient, C_B.

Floor Configuration	Bench Submerged*	Bench Unsubmerged*
Flat (level)	-0.05	-0.05
Depressed	0.0	0.0
Half Benched	-0.05	-0.85
Full Benched	-0.25	-0.93
Improved	-0.60	-0.98

What have we done to overcome the challenges? – First Principle Approach

- **How did we address software limitation**
  - Challenging hydraulic structure - Manholes
    - Manual calculation based on First Principle – e.g. HEC 22 Approach



Additional Loss

$$H_a = (C_B + C_P + C_\theta)\, K_e\, V_O^2/2g$$

C_B = Benching loss coefficient

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What have we done to overcome the challenges? – First Principle Approach

- **How did we address** software limitation
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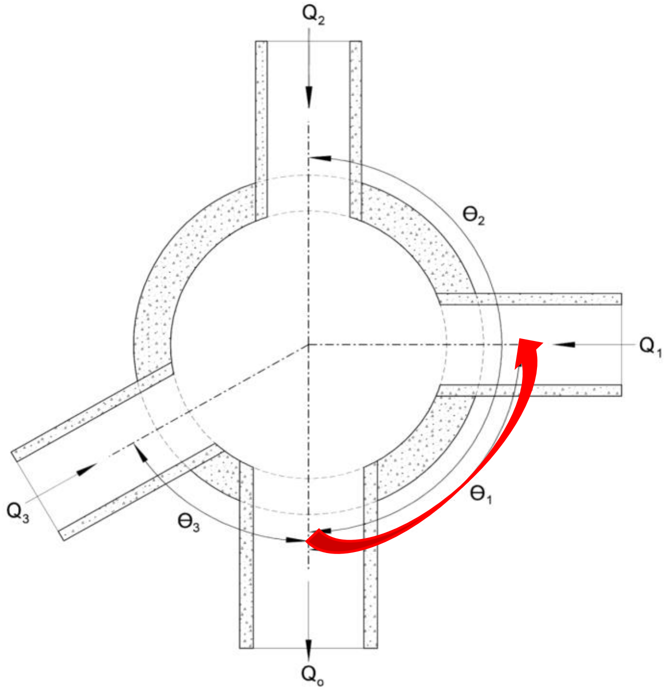

Additional Loss

$Ha = (C_B + C_P + C_\theta)\, K_e\, V_O^2/2g$

C_B = Benching loss coefficient

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What have we done to overcome the challenges? – First Principle Approach

- **How did we address software limitation?**
  - Challenging hydraulic structure - Manholes
    - Manual calculation based on First Principle – e.g. HEC 22 Approach

$$He + Ha = K_e V_O^2/2g + (C_B + C_P + C_\theta)\, K_e V_O^2/2g \quad \text{or} \quad Ke\,(1 + C_B + C_P + C_\theta)\, V_O^2/2g$$

Coefficient	HEC22 Recommended value
Ke Entrance Loss (Contraction)	0.2
Ko Exit Loss (expansion)	0.4

Ke = 0.5 (1 – A/Am)

Ko = (1 – A/Am)² - *limiting values (Am>>A): Ke = 0.5; Ko = 1*

A = cross-sectional area of the pipe

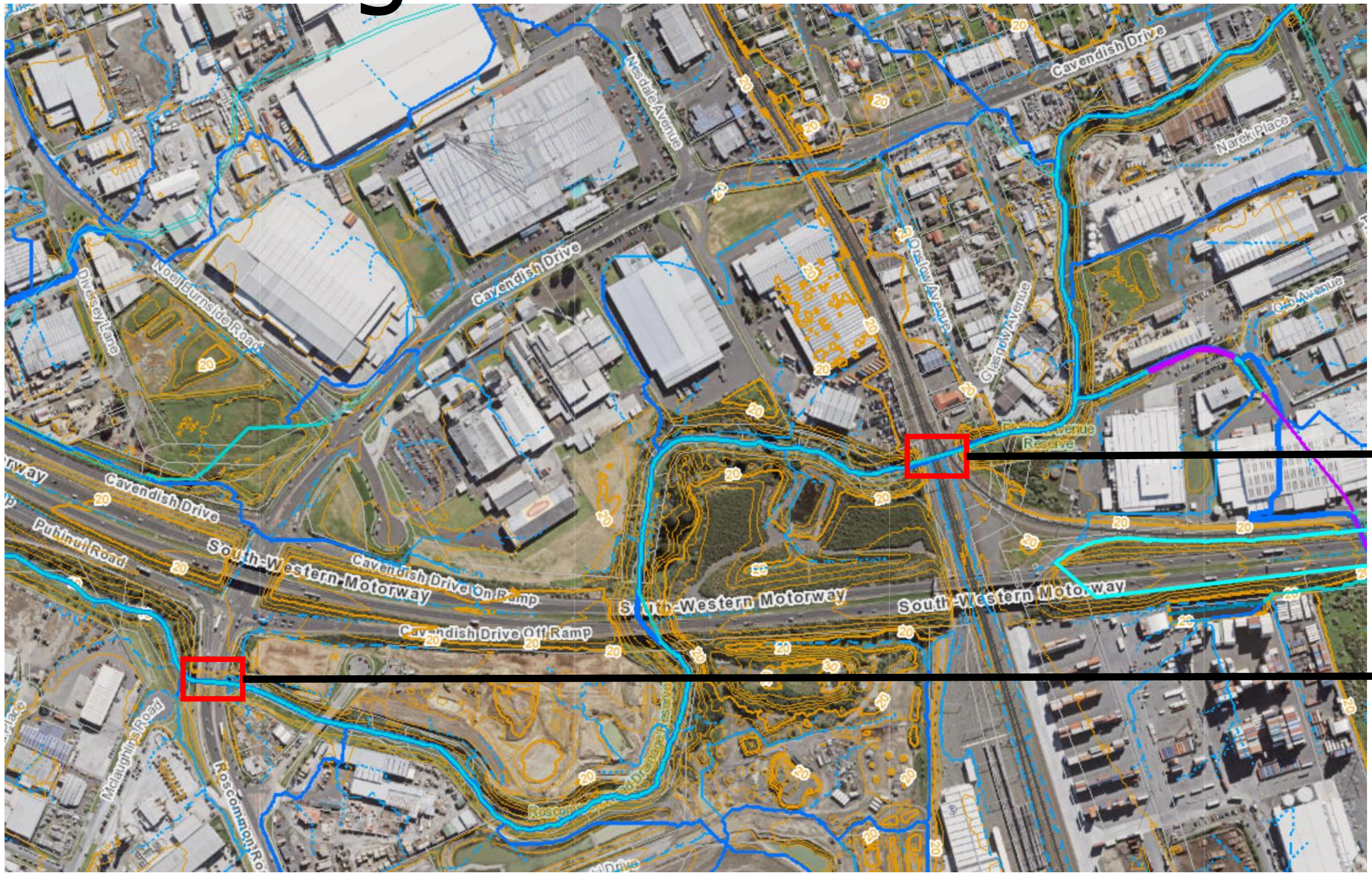
Am = cross-sectional area of the manhole

What have we done to overcome the challenges?

- How did we address software limitation?
  - – Cross check by other software and manual calculation

- How do we know if the energy loss predicted by the model is reasonable?
  - Two examples
    - Culvert
    - Bridge

What have we done to overcome the challenges? – Puhinui Catchment Examples

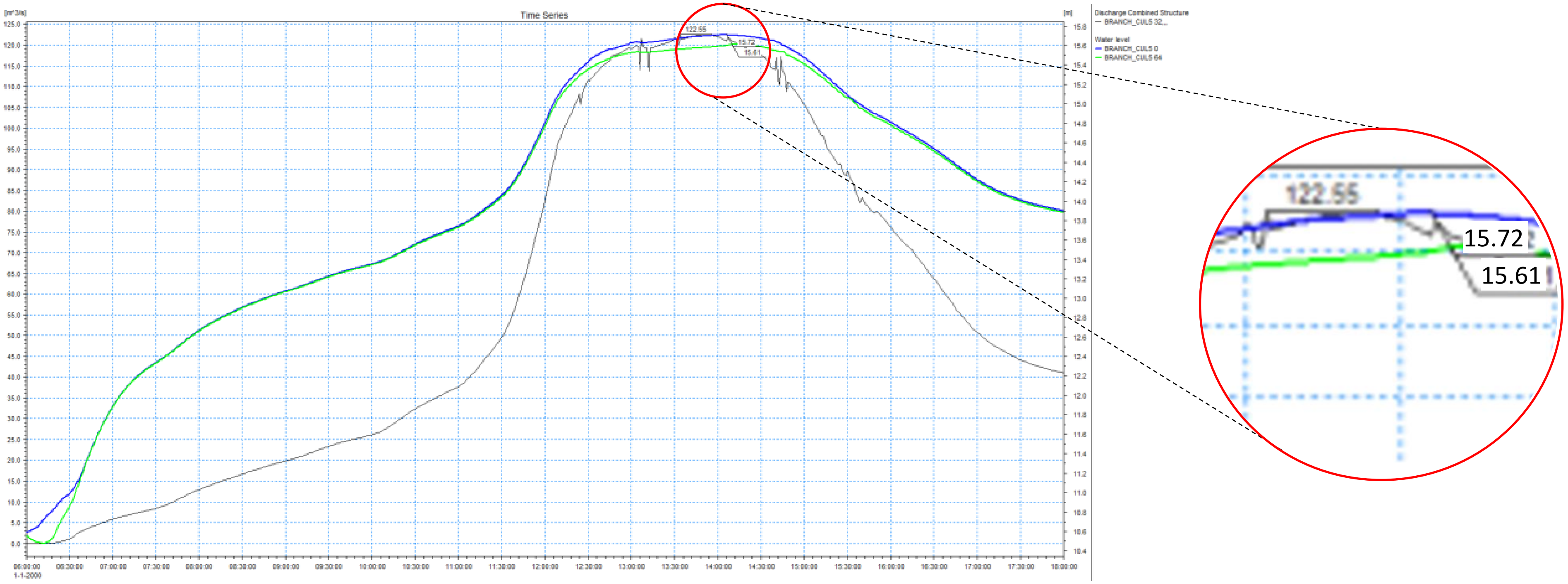


3 parallel rectangular **4.2m x 4.4m** culverts

Roscommon Road Bridge
Width = **32**m
Depth = **5**m

What have we done to overcome the challenges? - Culverts

- **Is the headloss estimated by the model reliable?**
  - **3** parallel rectangular **4.2m x 4.4m** culverts
  - Peak flow = **122.5 m³/s**
  - Modelled headloss = **110mm**



What have we done to overcome the challenges? – Culverts

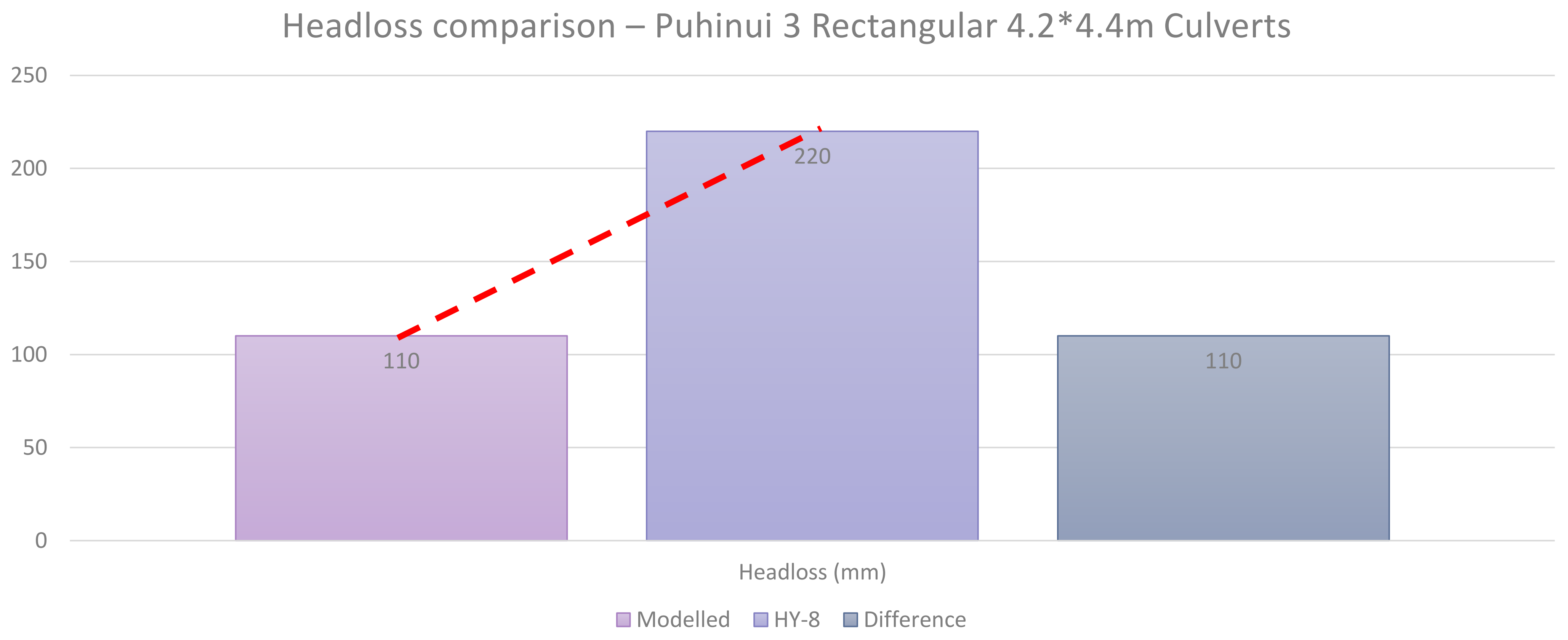
- **Is the headloss estimated by the model reliable?**
  - **3** parallel rectangular **4.2m x 4.4m** culverts
  - Peak flow = **122.5 m³/s**
  - **HY-8 headloss = 220mm**

Tapered Inlet Table - Culvert 1

Total Discharge (cms)	Culvert Discharge (cms)	Headwater Elevation (m)	Inlet Control	Outlet Control	Flow	Crest Control	Face Control	Throat Control	Tailwater Elevation (m)
0.00	0.00	10.71	0.00	0.0	)-NF	0.00	10.90	0.00	10.60
12.25	4.96	12.21	0.80	**1.32**	5-FF	0.00	0.00	0.00	12.21
24.50	12.44	12.91	1.48	**2.02**	5-FF	0.00	0.00	0.00	12.91
36.75	15.16	13.43	1.68	**2.55**	5-FF	0.00	0.00	0.00	13.43
49.00	24.50	13.85	2.33	**3.02**	5-FF	0.00	0.00	0.00	13.85
61.25	19.39	14.24	1.99	**3.36**	5-FF	0.00	0.00	0.00	14.22
73.50	26.11	14.59	2.43	**3.73**	5-FF	0.00	0.00	0.00	14.55
85.75	27.36	14.93	2.51	**4.04**	5-FF	0.00	0.00	0.00	14.85
98.00	31.22	15.24	2.74	**4.35**	4-FF	0.00	0.00	0.00	15.12
110.25	35.13	15.54	2.97	**4.64**	4-FF	0.00	0.00	0.00	15.37
122.50	39.03	15.83	3.19	**4.93**	4-FF	0.00	0.00	0.00	15.61

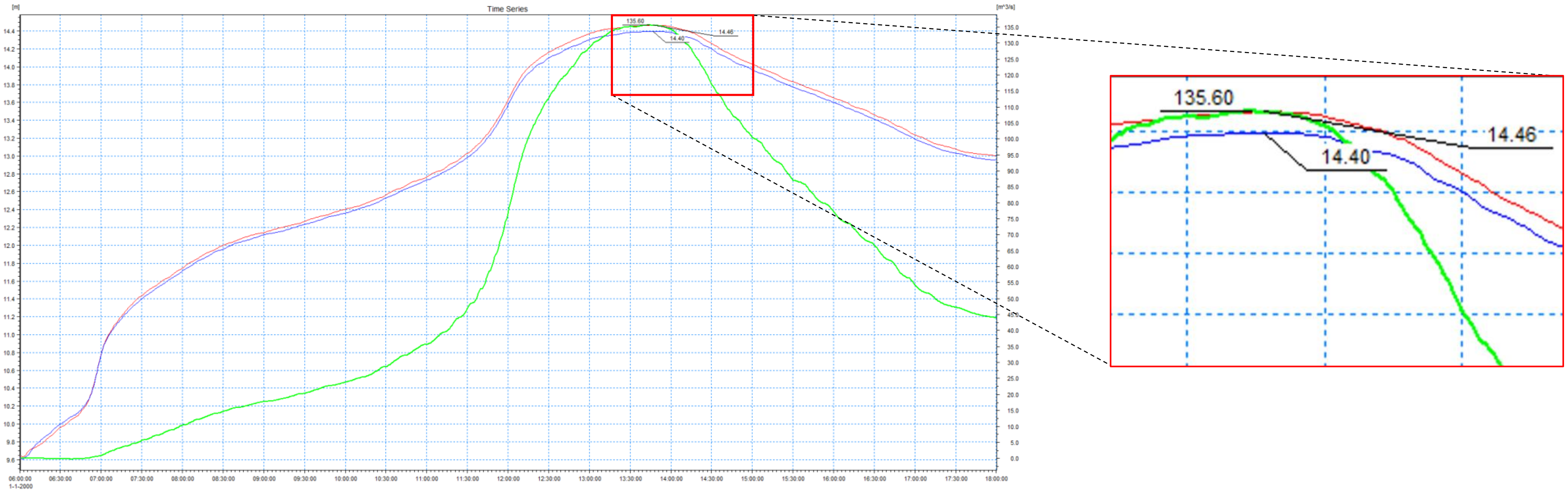
What have we done to overcome the challenges? – Culverts

- **Is the headloss estimated by the model reliable?**



What have we experienced – 4. Bridge

- **Is the headloss estimated by the model reliable?**
  - Roscommon Road Bridge
  - Width = **32**m Depth = **5**m
  - Peak flow = **136 m3/s**
  - Modelled headloss = **60mm**



What have we experienced – 4. Bridge

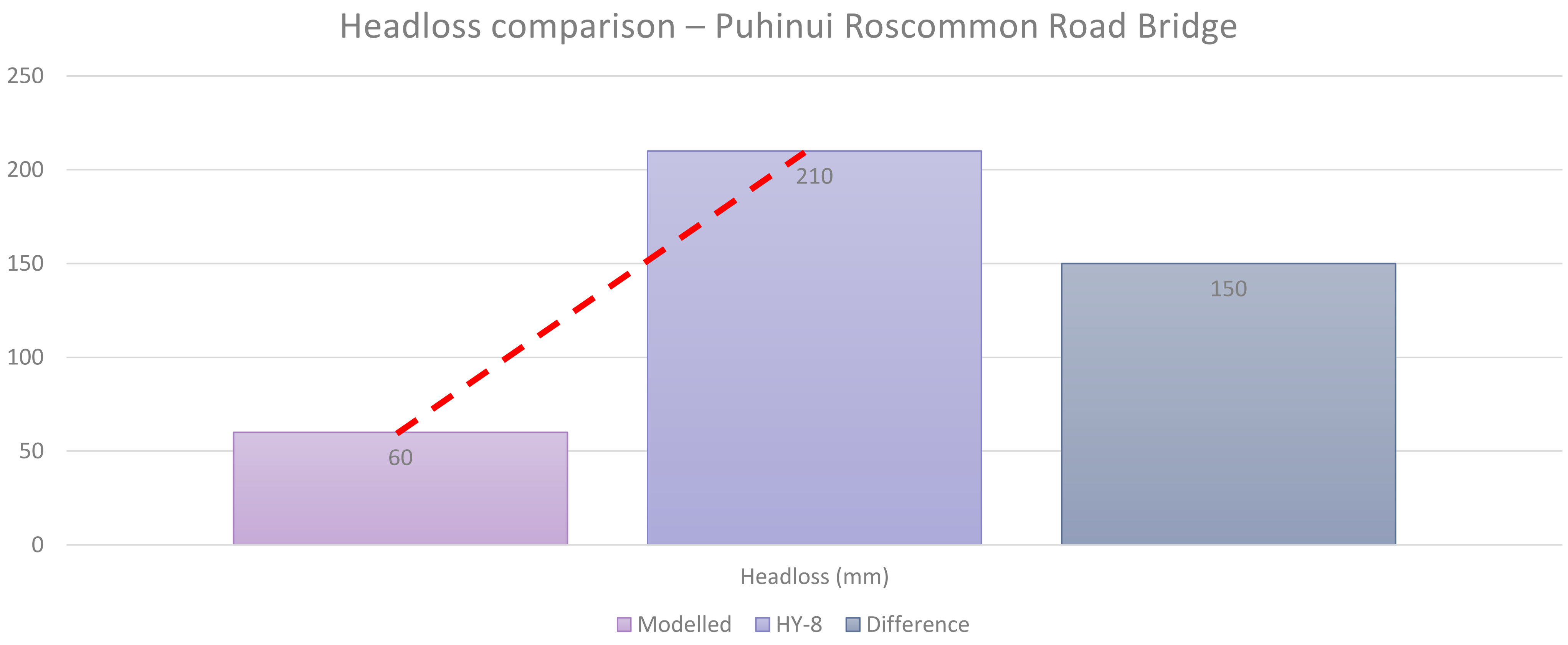
- **Is the headloss estimated by the model reliable?**
  - Width = **32**m Depth = **5**m
  - Peak flow = **136 m3/s**
  - **HY-8 headloss = 210mm**

Tapered Inlet Table - Culvert 2

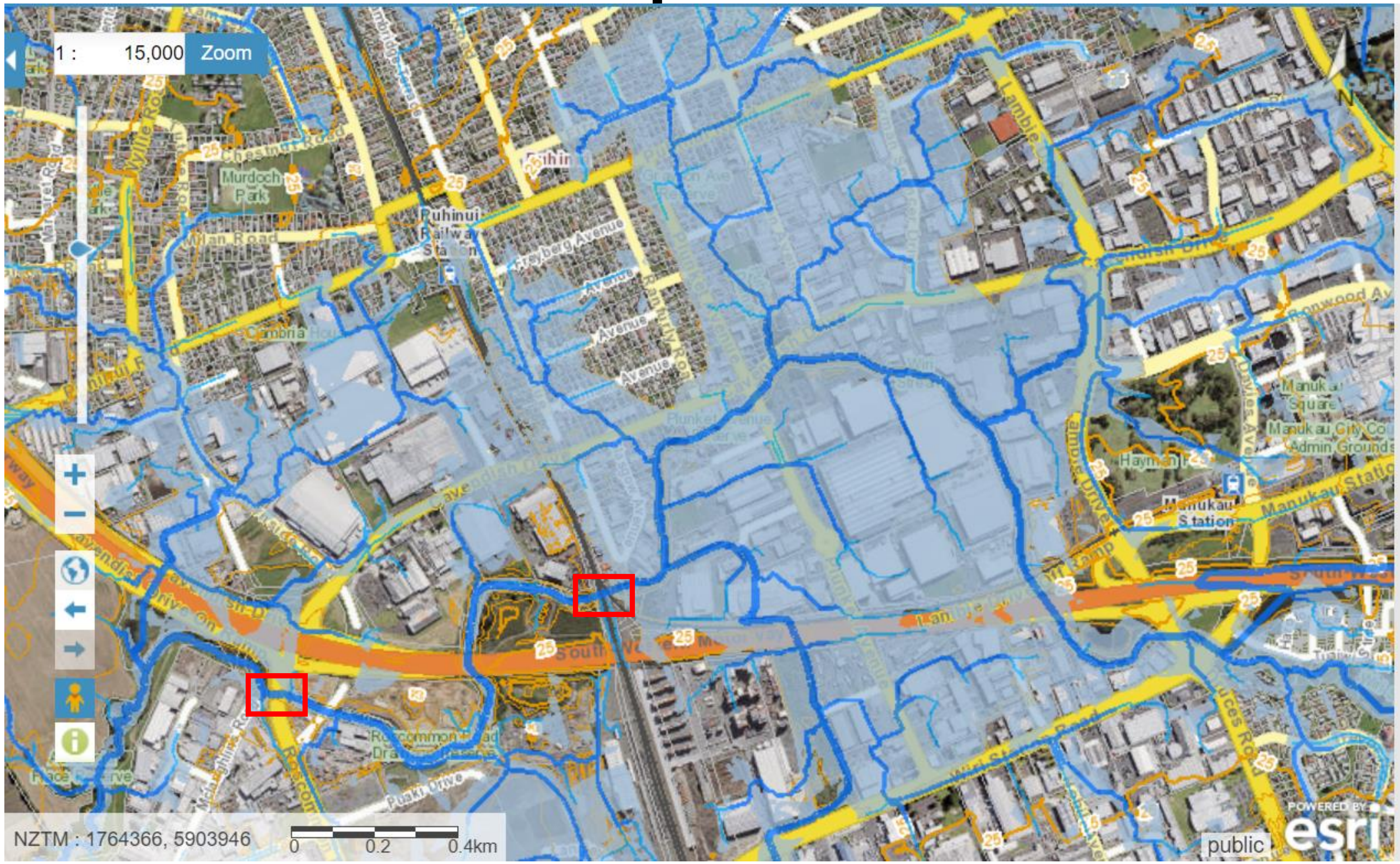
Total Discharge (cms)	Culvert Discharge (cms)	Headwater Elevation (m)	Inlet Control	Outlet Control	Flow	Crest Control	Face Control	Throat Control	Tailwater Elevation (m)
50.00	50.00	14.43	2.02	**4.93**	3-H2	0.00	0.00	0.00	14.40
58.60	58.60	14.44	2.11	**4.94**	3-H2	0.00	0.00	0.00	14.40
67.20	67.20	14.45	2.19	**4.95**	3-H2	0.00	0.00	0.00	14.40
75.80	75.80	14.46	2.26	**4.96**	3-H2	0.00	0.00	0.00	14.40
84.40	84.40	14.48	2.34	**4.98**	3-H2	0.00	0.00	0.00	14.40
93.00	93.00	14.50	2.41	**5.00**	3-H2	0.00	0.00	0.00	14.40
101.60	101.60	14.52	2.48	**5.02**	3-H2	0.00	0.00	0.00	14.40
110.20	110.20	14.54	2.55	**5.04**	3-H2	0.00	0.00	0.00	14.40
118.80	118.80	14.56	2.61	**5.06**	3-H2	0.00	0.00	0.00	14.40
127.40	127.40	14.58	2.68	**5.08**	3-H2	0.00	0.00	0.00	14.40
136.00	136.00	14.61	2.80	**5.11**	3-H2	0.00	0.00	0.00	14.40

What have we experienced – 4. Bridge

- **Is the headloss estimated by the model reliable?**



What is the implication



- 1% Catchment grade
- Under-estimated the upstream head water level
- May under-estimated the floodplain extent
- Impact on flood risk assessment

What have we done to overcome the challenges?

- How did we address software limitation?
  - – Cross check by other software and manual calculation

- How do we know if the energy loss predicted by the model is reasonable?
  - Cross check by other software and manual calculation
  - Keep learning and improving on User knowledge

What have we experienced

- User knowledge of the software and the structure
- Any box should be checked?

Sim parameters Object Properties (R/O)

Node, conduit and control	
Stay pressurised	☐
Don't linearise conveyance	☐
No. of geometry table entries	15
Use full area for headloss calculations	☐
Inflow is lateral	☐
Bottom of headloss transition	0.000
Top of headloss transition	0.000
Use Villemonte equation	☐
Drop inertia in pressure pipes	☒
Drowned bank linearisation threshold (m)	0.010
Node level affects groundwater infiltration	☒
Weight Manning roughness by n	☐

Preissmann slot

What have we done to overcome the challenges?

- Preissmann slot has been assumed to avoid the changes from free surface flow to pressurised flow when pipe is full by adding the artificial slot.

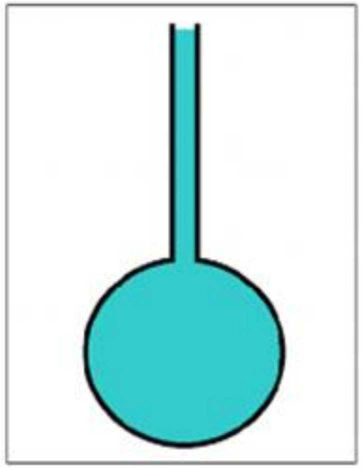
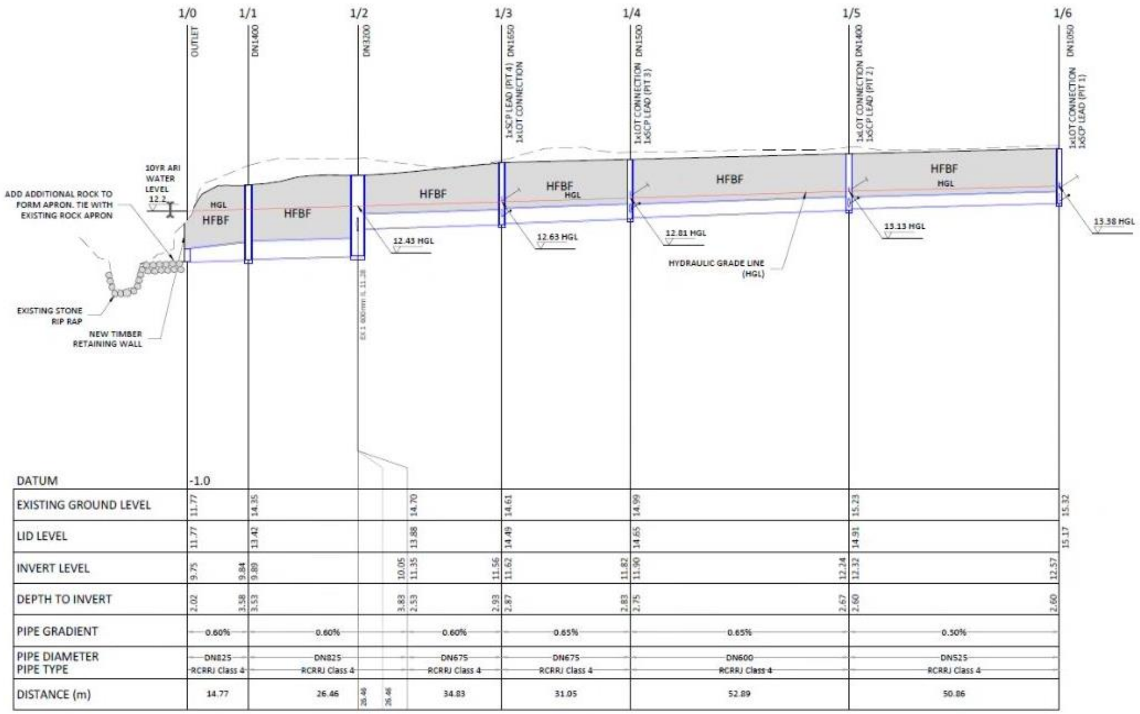


Figure 1: Preissmann slot

- A case study compared the modelled headloss and the headloss calculated by First Principle

What have we done to overcome the challenges?

- Simple long section

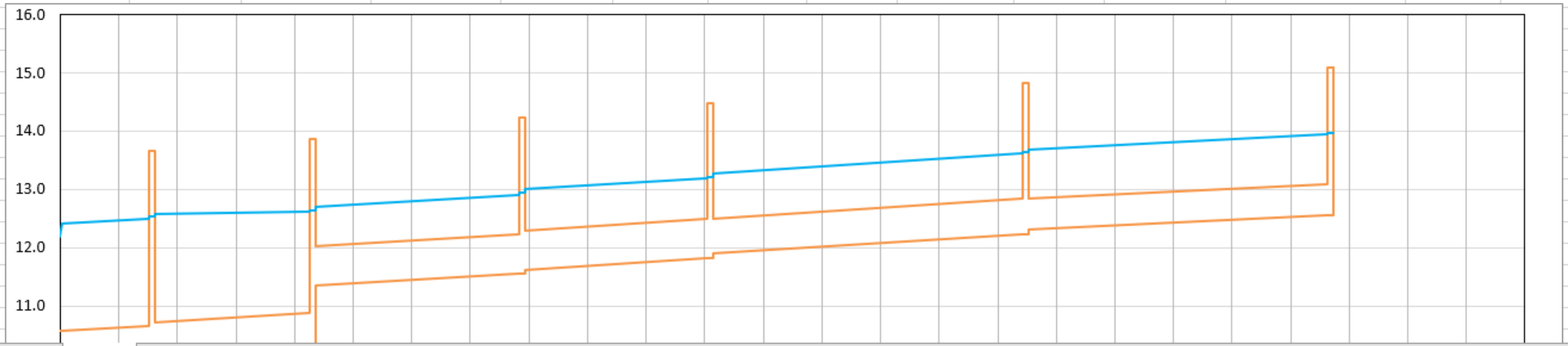


What have we done to overcome the challenges?

- Calculating energy losses by First Principle

Design Hydraulic Grade Line in a Pipeline — **Pipe Full Flow Conditions Only**

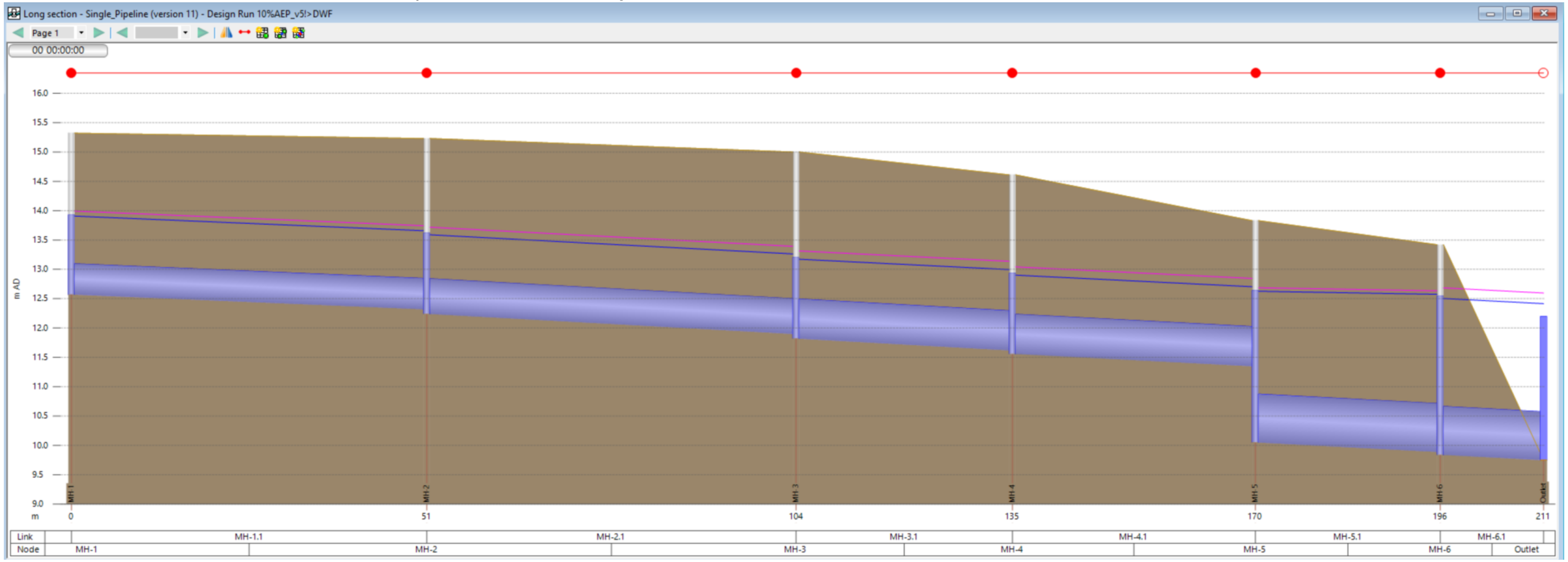
Circular Pipe	Pipe Diameter (m)	Pipe U/S Invert Level (m RL)	Pipe D/S Invert Level (m RL)	Pipe Length (m)	Pipe Roughness	Design Flow (m3/s)	Pipe Full Area (m2)	Pipe Full Velocity (m/s)	Pipe Full Hy Radius	Friction Slope Sf	Friction Loss Hf (m)	Entry Coeff Ki	Entry Loss Hi (m)	Exit Coeff Ko	Exit Loss He (m)
Pipe-6 (MH6 to Outlet)	0.825	9.84	9.75	14.8	0.0133	1.10	0.535	2.058	0.206	0.0061	0.091	0.20	0.043	1.00	0.216
Pipe-5 (MH5 to MH6)	0.825	10.05	9.89	26.5	0.0133	0.63	0.535	1.182	0.206	0.0020	0.054	0.20	0.014	0.40	0.028
Pipe-4 (MH4 to MH5)	0.675	11.56	11.35	34.8	0.0133	0.63	0.358	1.766	0.169	0.0059	0.206	0.20	0.032	0.40	0.064
Pipe-3 (MH3 to MH4)	0.675	11.82	11.62	31.1	0.0133	0.63	0.358	1.766	0.169	0.0059	0.184	0.20	0.032	0.40	0.064
Pipe-2 (MH2 to MH3)	0.600	12.24	11.90	52.9	0.0133	0.48	0.283	1.684	0.150	0.0063	0.333	0.20	0.029	0.40	0.058
Pipe-1 (MH1 to MH2)	0.525	12.57	12.32	50.9	0.0133	0.30	0.216	1.386	0.131	0.0051	0.259	0.20	0.020	0.40	0.039



HGL

What have we done to overcome the challenges?

- Model set up for case study



What have we done to overcome the challenges?

- Comparison between headloss calculated by First Principle and the modelled headloss

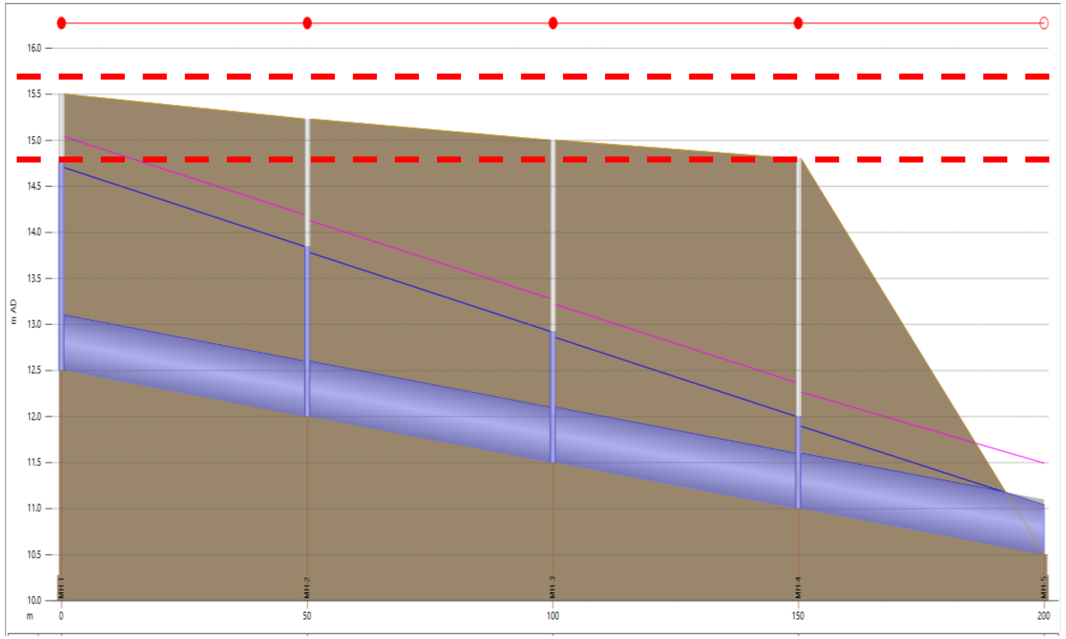
Use full area for headloss calculations ☒

Node ID	Manual Calculated Water Level (mRL)	Modelled Water Level (mRL) – Non Full Area	Difference (m) – Non Full Area	Modelled Water Level (mRL) – Full Area	Difference (m) – Full Area
MH-1	13.96	13.84	0.12	13.93	0.03
MH-2	13.65	13.54	0.11	13.62	0.03
MH-3	13.23	13.14	0.09	13.20	0.03
MH-4	12.95	12.88	0.07	12.93	0.02
MH-5	12.65	12.59	0.06	12.64	0.01
MH-6	12.55	12.51	0.04	12.55	0.00

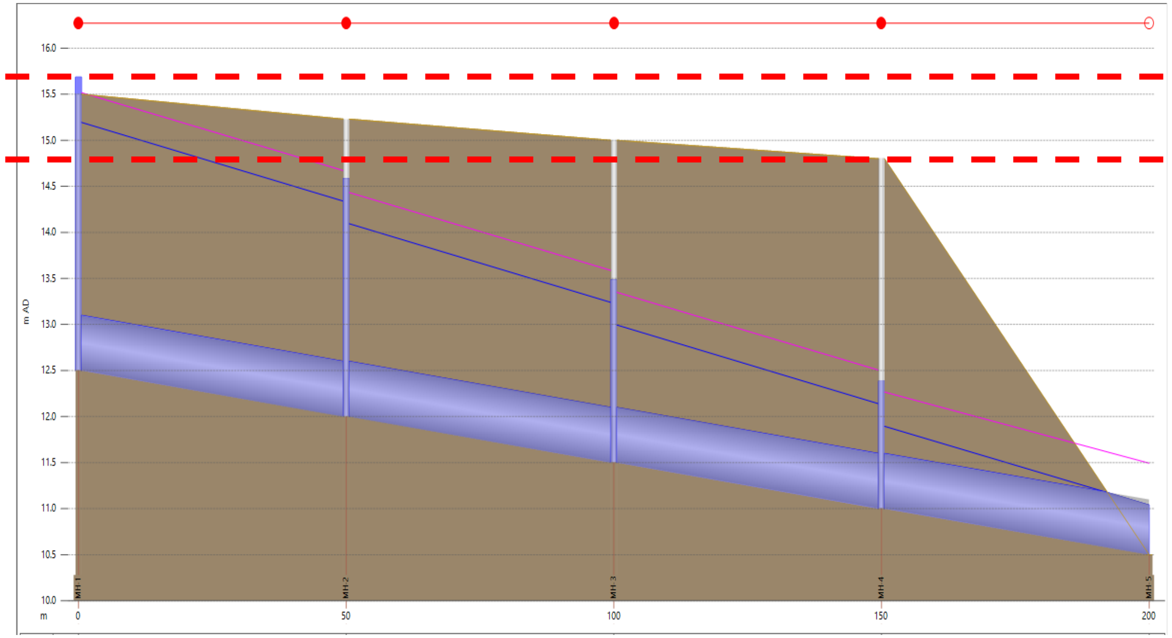
What have we done to overcome the challenges?

- Headloss type would affect on headloss – modelling exercise to quantify

Normal headloss type used



FHWA headloss type used



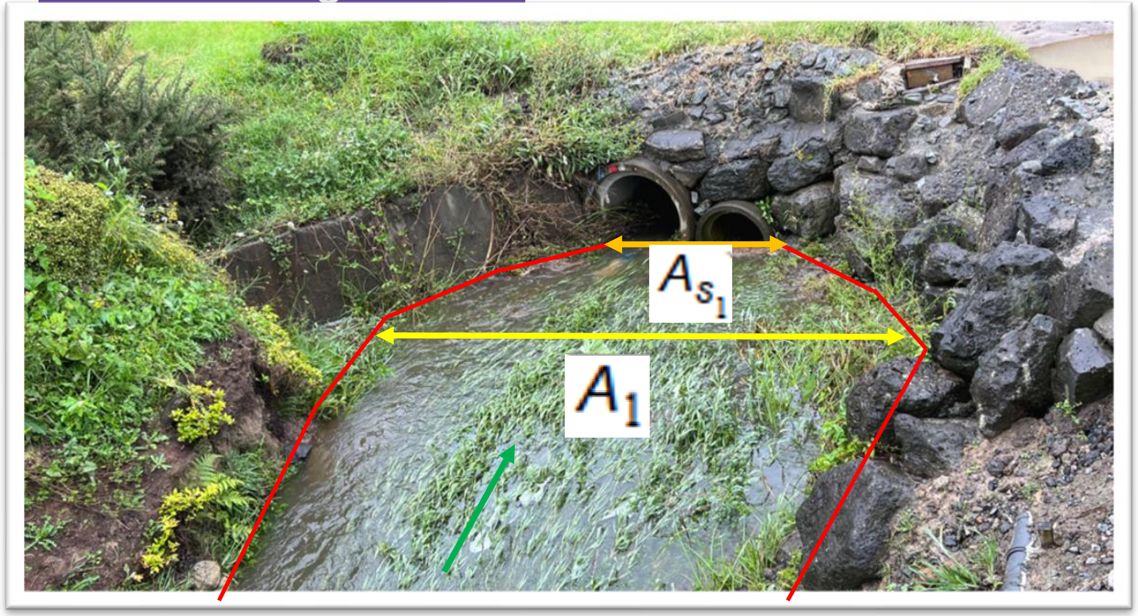
What is the implication

What have we done to overcome the challenges?

- Keep learning and improving on User knowledge
  - Good schematic practice during model build
    - Culvert schematic example – riverbank digitization

Entrance loss $\zeta_1 = \zeta_{in}\left(1 - \frac{A_{s_1}}{A_1}\right)$

Expansion loss $\zeta_1 = \zeta_{out}\left(1 - \frac{A_{s_2}}{A_2}\right)^2$



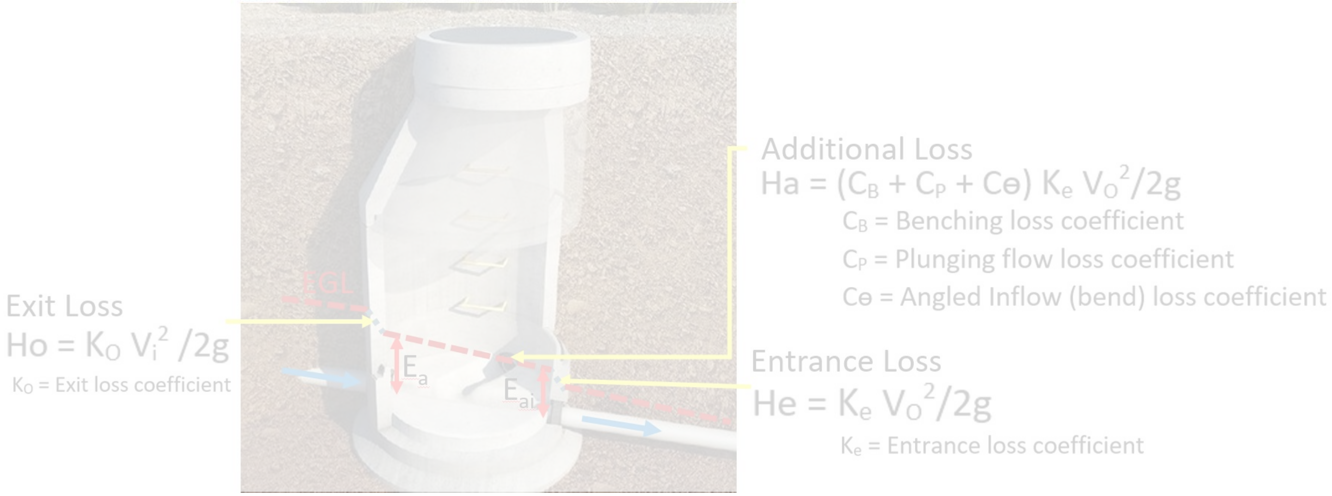
What have we done to overcome the challenges?

- What is recommend based on our experience?
  - Good schematic practice during model build
    - Culvert schematic example– river channel digitization

$$h_o = k_o \left[\frac{V_b^2 - V_{dc}^2}{2g} \right]$$

Summarize - What have we done to overcome the challenges?

- Cross check by other software and manual calculation to address software limitation for challenging hydraulic structures
  - Complex manholes
  - Culverts
  - Bridges



Summarize - What have we done to overcome the challenges?

- Keep learning and improving on user knowledge
  - Global simulation parameter
  - Headloss type selection
  - Proper digitization

No. of geometry table entries	15
Use full area for headloss calculations	☐
Inflow is lateral	☐

Preissmann slot

- Headloss type would affect on headloss – modelling exercise to quantify

Normal headloss type used

FHWA headloss type used

Summarize - What have we done to overcome the challenges?

- Cross check by other software and manual calculation to address software limitation for challenging hydraulic structures
  - Complex manholes
  - Culverts
  - Bridges
- Keep learning and improving on user knowledge
  - Global simulation parameter
  - Headloss type selection
  - Proper digitization
- Any thoughts on energy loss validation?
  - Set up project/case studies where install gauges/ monitoring site within pipe network to collect information

What is recommend based on our experience?

The level of detail to be included in the model

- Purpose driven
  - **Catchment model**
    - Cross checks by manual calculation method and other software for complex structure
    - Calibration
  - **Design detail**
    - Site specific assessment
    - Manual check and other software checks
    - Correct selection of modelling parameters
      - Use Full Area for Headloss Calculation
      - Conservative Headloss Type

Hydraulic Models – Simplified conceptualization

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Thank you!
Questions? Patai?

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