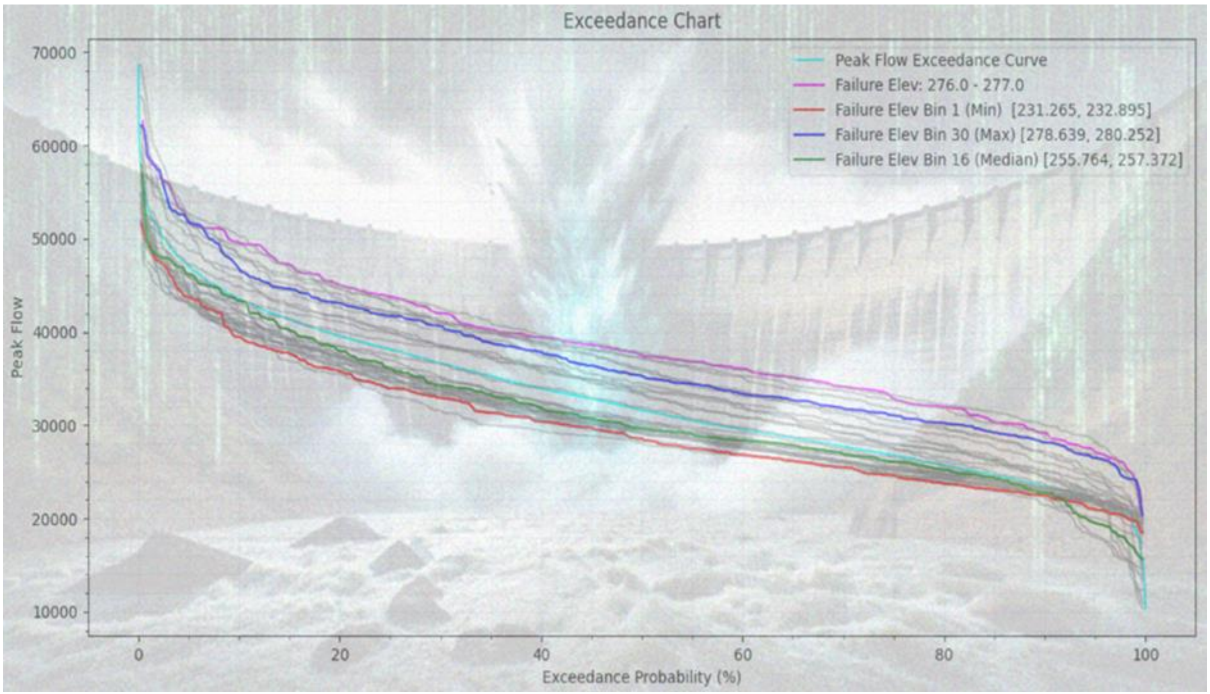
Breach Hydro

Water Balance Suite for Stochastic Dam Break Analysis



Breacher Current Version: 2024-01-beta.01
Breacher Post: breacher_post_2024-01-beta_01_setup

February 2024

Forward Hydro Pty Ltd **ABN 62 664 280 693**

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About This Manual

Welcome to the comprehensive manual for Breach Hydro, a software suit including Breacher and Breacher-Post, water balance and analysis engines for the 2024-01-beta.01 release. This document is designed to guide users through the features, functionalities, application, and validation of the software, which is developed to predict and analyse the outcomes of potential dam break scenarios.

Additional content relating to Breacher and Breacher-Post is also available on the Forward Hydro website.

For all feedback and suggestions, please email admin@forwardhydro.com.au. While we look to further improve Breacher, to provide a useful dam break tool for the broader industry, this feedback will be invaluable.

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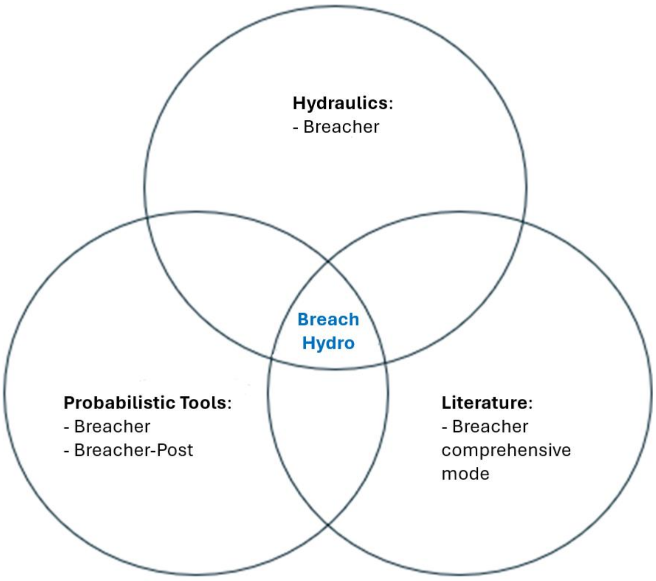
1 What is Breach Hydro?

Included in Breach Hydro is a water balance model, Breacher, validated to replicate the breach progression and outflow hydrograph of the HEC-RAS dam break solver. Breacher has been developed to be a text file based solver, simulated with batch (.bat) files to allow for rapid simulations, with benchmarks typically between 0.01 to 0.05 seconds per run on low performance laptops and modelling machines.

Within Breacher is a command to trigger a "Comprehensive" assessment, this allows for the simulation to be compared to a historical dam breach dataset (Azmi and Thomson, 2024) and parameters from common literature (i.e. Froehlich, Hooshyaripor, Xu & Zhang and Azmi &Thomson's work on breach width, time, and peak flow).

Also included in the suite is Breacher-Post, a windows based application to allow for reviewing and performing analytics on Breacher results. Ultimately this is to help the user with decision making around suitable parameters and uncertainties / confidence ranges.



There's a multitude of reasons why Breach Hydro has been developed and a water balance modelling approach chosen. The key reasons are:

- Dam break modelling and selecting the probable hydrograph shape and peak carries substantial uncertainty. Just performing a handful of simulations in a hydrodynamic model isn't adequate for quantifying uncertainty and the impact this has on results.
- Running many hydrodynamic models often isn't practical given simulation times, instabilities, set up time and post-processing results. A water balance model allows for ease of setting up and running 1,000 to 100,000 simulations in a short duration.
- HEC-RAS is arguably the most peer reviewed and industry adopted software package for dam break modelling. Replicating breach progression, hydrograph shape and peak flows from HEC-RAS demonstrates the tool adopts similar breach assumptions.
- From our experience working with consultants and asset owners, everyone has their own "unique" spreadsheet, modelling assumptions or approach, creating widely different results for the same dam. As a tool for a comprehensive, user friendly stochastic assessment hasn't existed, the industry has struggled to establish consistent best practices.
- Continuing the above point, it shouldn't come as a surprise that the outcome of a dam failure or consequence assessment is beholden to the modeller and errors (technical or judgement) that could be made during the modelling process. For asset owners this is a significant concern as errors could lead to an underestimate of risk, and potentially loss of life. Alternatively, the modeller could be "overly cautious" with their assumptions leading to costly maintenance for assets that pose lower risk to what's been recommended.
- A tool that performs the dam break, compares to literature and historical events (Breacher) and performs the analytics on the results (Breacher-Post) will allow for a consistent approach and replicable result. There is enough flexibility built into Breacher to allow for modellers to still exercise their own judgement, as with each dam, characteristics and risk are unique with the modellers judgement being critical.

2 List of Variables and Inputs

All variables in the Breacher control file are shown in Table 1, please note Breacher is currently only available in System International (Metric System) units.

Table 1 List of Variables and Inputs

Inputs	Notes
Failure_Type	Options are **“SDF”** for sunny day failure and **“FFS”** for flood failure scenario. Selecting SDF sets inflow as 0 for the full simulation duration while FFS triggers the dbase inflow file.
Timestep	Simulation timestep in **seconds**. Timestep can form part of a sensitivity test by randomising it between two values [x, y]
Start_Time	Simulation start time in **hours**
End_Time	Simulation end time in **hours**
Calc_Precision	**Number of decimal places** during each operation, for example calculating outflow rate or storage level, occurring in each time increment of the water balance model. Reducing the number of decimals solves can reduce run times for large simulations, but this can also reduce model accuracy
Breach_Mode	Options are **“Comprehensive”** to compare Breacher calculations to historical dams (Azmi and Thomson, 2024) and common breach parameter literature, or **“Manual”** to turn this feature off.
Breach_Output	Options are **“Summary”** for a simulation run that only writes to the summary file, and **“Detailed”** to output hydrographs, water levels and other typical outputs as a .csv.
Total_Simulations	Number of simulations to be run. It’s common to run a single (**1**) simulation in Comprehensive model to initially estimate feasible breach parameters, then many (i.e. **10000**) with typical inputs randomised
BC_Inflow	Location of an inflow (.csv) file. Note, inflow time is in **hours** and flow rate in **m^3/s**. Example file: **"inflow.csv”**
inflow_name	Name of the inflow column in the inflow csv file. Example: **“Inflow”**
BC_Elev_Storage	Location of an elevation-storage (.csv) file. Note, elevation is a relative level (RL) in **meters** and storage is in **10^3 m^3** similarly to HEC-RAS. Example file: **"elev_storage.csv".** **It’s recommended the max height and storage in elev_storage.csv be set above the Failure_WSL, and lowest height and storage be set below Breach_Base.**
BC_Elev_Outflow	Location of elevation outflow (.csv) file. Useful when needing to account for outflow structure rating curves, where elevation is a relative level (RL) **datum in meters** and outflow is in **m^3/s**
BC_Breach_Progression	Location of breach progression curve (.csv) where breach where Time_Fraction should **start at 0 and end at 1**, and Breach_Fraction the same. By default the file provided is a sine function, similarly to HEC-RAS. Example file: **"breach_progression.csv"**
BC_Flow_Tailwater	Options are **“None”** or an outflow rate (**m^3/s**) and elevation (relative level **datum in meters**) file (.csv) Example: **"flow_tailwater.csv"**
Top_of_dam	Top of the dam, or dam crest, as a relative level (RL) **datum in meters**
Breach_Time	Time taken for the breach to complete in **hours**
Initial_Storage	Initial storage elevation in the dam, as a relative level (RL) **datum in meters**
Failure_WSL	Water level when dam failure commences, as a relative level (RL) **datum in meters**
Failure_Elev	Elevation where the failure commences, as a relative level (RL) **datum in meters**. If this elevation is set at or above Top_of_dam, the failure mode is assumed as overtopping, if below Top_of_dam it’s assumed as piping
Breach_Base	The bottom most elevation where embankment material cannot erode further. This is commonly assumed as the embankment toe or lower, as a relative level (RL) **datum in meters**
Side_Slope	Slope of the breach walls during the failure as **H:1V** A typical breaching side slope of 0.5 (a range of zero to 1 for earthen/rockfll dams) is set as recommended by USACE (2014).
Breach_Bot_Width	Final bottom width in **meters** of the dam breach on completion
Weir_Cd	Weir coefficient of discharge, **typically between 1.1 to 1.8**, but extreme values can be plausible. See (Azmi and Thomson, 2024) for more information.
Orifice_Cd	Orifice coefficient of discharge, **typically between 0.2 to 0.6**, but extreme values can be plausible. See (Azmi and Thomson, 2024) for more information.
Dam_Crest_Width	If "Comprehensive" is turned on in Breach_Mode, dam crest in **meters**.
Z1	If "Comprehensive" is turned on in Breach_Mode, Slope of upstream dam face (**H:V**)
Z2	If "Comprehensive" is turned on in Breach_Mode, Slope of downstream dam face (**H:V**)
Dam_Type	If "Comprehensive" is turned on in Breach_Mode, options are **"Core_wall"**, **"Concrete_Faced"**, **"Zoned_Fill"** or **"Homogeneous"**. See (Azmi and Thomson, 2024) for more information.
Dam_Erodibility	If "Comprehensive" is turned on in Breach_Mode, Options are **"Low"**, **"Medium"** or **"High"**, see (Azmi and Thomson, 2024) for more information. Dam erodibility is highly subjective and the use of “Low” erodibility to inform on breach parameters should be used with extreme caution.

3 Breacher Commands and Simulation

3.1 Breacher Command File and Batch File

Included with Breacher and Breacher-Post are example set up files. Dam and breach parameters are specified in the Breacher command file and run by “calling” the command file and the Breacher executable with a batch file. See Figure 1 and Figure 2.

It’s recommended to save the Breacher executable to the following path: "C:\BREACHER\2024-01-beta.01\breacher.exe"

```
# SIMULATION CONTROL COMMANDS
Project_Name = ""
Failure_Type = "SDF"                          # "SDF" for sunny day failure or "FFS" for flood failure scenario
Timestep = 10                                 # seconds
Start_Time = 0                                # hours
End_Time = 2                                  # hours
Calc_Precision = 3                            # decimals solved
Breach_Mode = "Comprehensive"             # "Comprehensive" to calculate historical dams or literature, "Manual" to turn off
Breach_Output = "Summary"                     # "Summary" to only write summary file, "Detailed" outputs all calculations
Total_Simulations = 10000                     # Number of simulations to run, useful for probabilitic modelling
#
# INPUT BC_DBASE
BC_Inflow = "inflow.csv"                      # dam inflow csv
inflow_name = "Inflow"                        # inflow column in the dam inflow csv
BC_Elev_Storage = "elev_storage.csv"          # dam elevation-storage csv, storage is in 10^3 m3
BC_Elev_Outflow = "elev_outflow.csv"          # dam elevation-outflow (ie spillway rating curve) csv
BC_Breach_Progression = "breach_progression.csv"  # optional custom breach progression curve (ie linear, sine, non-linear)
BC_Flow_Tailwater = "None"                    # "flow_tailwater.csv" or "None"
#
# BREACH PARAMETERS
Top_of_dam = 290.26                           # Top of dam (RL)
Breach_Time = [0.65, 2.96]                    # breach time in hours
Initial_Storage = 280.26                      # initial storage elevation at the dam
Failure_WSL = 280.26                          # water surface level for failure commencement
Failure_Elev = [276, 277]                     # elevation for failure commencement[231.26, 280.26]
Breach_Base = 231.26                          # elevation at base of breach  231.26
Side_Slope = 0.4                              # H:1V
Breach_Bot_Width = [85, 160]                  # breach bottom with in meters [85, 160] 101 replicates zhong
Weir_Cd = [1.1, 1.8]                          # weir coefficient of discharge for the breach
Orifice_Cd = [0.4, 0.6]                       # orifice coefficient of discharge for the breach
#
# COMPREHENSIVE PARAMETERS - If "Comprehensive" is turned on in Breach_Mode
Dam_Crest_Width = 7                     # Dam crest width
Z1 = 0.444                              # Slope of US dam face Z1 (H:V)
Z2 = 0.444                              # Slope of DS dam face Z2 (H:V)
Dam_Type = "Homogeneous"                # Options are "Core_wall", "Concrete_Faced", "Zoned_Fill" or "Homogeneous"
Dam_Erodibility = "Medium"              # Options are "Low", "Medium" or "High"
```

Figure 1 Breacher Command File

Run_Breacher.bat

```
Set Breacher="C:\BREACHER\2024-01-beta.01\breacher.exe"
set bcf="C:\Users\ExampleUser\Projects\ExampleProject\breacher\runs\ExampleSite.py"
%Breacher% %bcf%
```

Figure 2 Breacher Batch File

3.2 Workflow

The water balance model’s workflow for Breacher is shown in Figure 3.

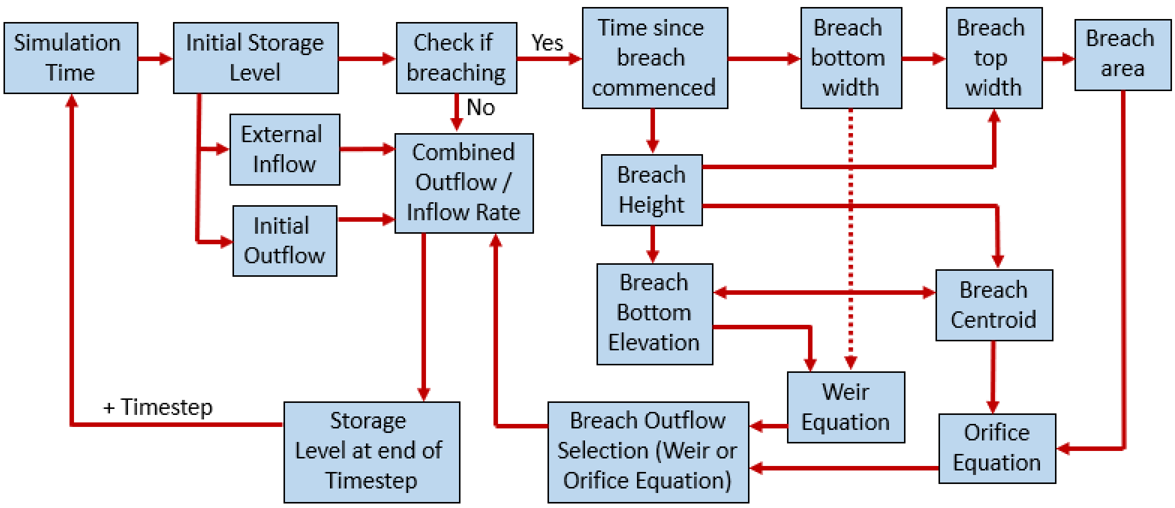


Figure 3 Breacher Workflow

3.3 Types of Dam Failures

Within the command file, options are **"SDF"** for sunny day failure and **"FFS"** for flood failure scenario. Selecting SDF sets inflow as 0 for the full simulation duration while FFS triggers the dbase inflow file.

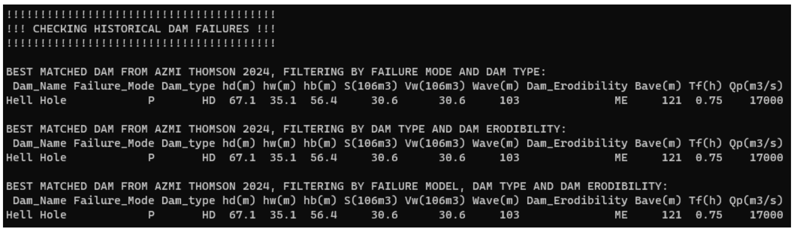
Breacher has generally been setup with the intended use for water dams, modelling of non-newtonian dams requires substantial engineering judgement and often specialist tools (i.e. CFD and/or lab studies). For non-newtonian breaks, understanding of the site specific rheological properties, density and solid content, consolidation behaviour, permeability and unique characteristics of the site need to be considered.

3.4 Simulation Controls

3.4.1 Comprehensive Mode

Comprehensive mode can be triggered with the following command: Breach_Mode = " Comprehensive "

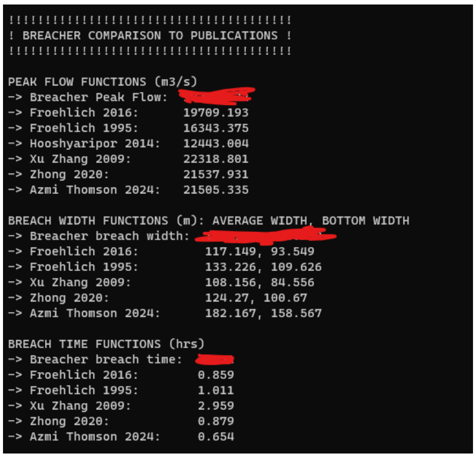
Comprehensive mode uses the dam characteristics in the command file to look up the dam with the closest match in (Azmi and Thomson, 2024). The focus of this lookup is predominantly height of breach (hb) and volume of water (Vw). It's recommended to sensitivity test this lookup by changing inputs like Dam_Type and Dam_Erodibility to see if others match.



```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!! CHECKING HISTORICAL DAM FAILURES !!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

BEST MATCHED DAM FROM AZMI THOMSON 2024, FILTERING BY FAILURE MODE AND DAM TYPE:
 Dam_Name Failure_Mode Dam_type hd(m) hw(m) hb(m) S(106m3) Vw(106m3) Wave(m) Dam_Erodibility Bave(m) Tf(h) Qp(m3/s)
Hell Hole            P       HD  67.1  35.1  56.4      30.6      30.6     103              ME     121  0.75    17000

BEST MATCHED DAM FROM AZMI THOMSON 2024, FILTERING BY DAM TYPE AND DAM ERODIBILITY:
 Dam_Name Failure_Mode Dam_type hd(m) hw(m) hb(m) S(106m3) Vw(106m3) Wave(m) Dam_Erodibility Bave(m) Tf(h) Qp(m3/s)
Hell Hole            P       HD  67.1  35.1  56.4      30.6      30.6     103              ME     121  0.75    17000

BEST MATCHED DAM FROM AZMI THOMSON 2024, FILTERING BY FAILURE MODEL, DAM TYPE AND DAM ERODIBILITY:
 Dam_Name Failure_Mode Dam_type hd(m) hw(m) hb(m) S(106m3) Vw(106m3) Wave(m) Dam_Erodibility Bave(m) Tf(h) Qp(m3/s)
Hell Hole            P       HD  67.1  35.1  56.4      30.6      30.6     103              ME     121  0.75    17000
```

Figure 4 Comprehensive Mode – Comparison to Historical Dam Failures

Secondly, Comprehensive Mode also compares inputs and results from the command file to common literature. Average width from the literature is translated to bottom width with the side slope specified in the control file, it should be noted publications on breach parameters and peak flow (ie Froehlich's work) often specify side slope too. It may be beneficial to the Breacher modeller to review the relevant literature for their associated side slopes and other assumptions and limitations prior to selecting breach parameters.



```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! BREACHER COMPARISON TO PUBLICATIONS !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

PEAK FLOW FUNCTIONS (m3/s)
-> Breacher Peak Flow: [redacted]
-> Froehlich 2016:      19709.193
-> Froehlich 1995:      16343.375
-> Hooshyaripor 2014:   12443.004
-> Xu Zhang 2009:       22318.801
-> Zhong 2020:          21537.931
-> Azmi Thomson 2024:   21505.335

BREACH WIDTH FUNCTIONS (m): AVERAGE WIDTH, BOTTOM WIDTH
-> Breacher breach width: [redacted]
-> Froehlich 2016:         117.149, 93.549
-> Froehlich 1995:         133.226, 109.626
-> Xu Zhang 2009:          108.156, 84.556
-> Zhong 2020:             124.27, 100.67
-> Azmi Thomson 2024:      182.167, 158.567

BREACH TIME FUNCTIONS (hrs)
-> Breacher breach time: [redacted]
-> Froehlich 2016:        0.859
-> Froehlich 1995:        1.011
-> Xu Zhang 2009:         2.959
-> Zhong 2020:            0.879
-> Azmi Thomson 2024:     0.654
```

Figure 5 Comprehensive Mode – Comparison to Common Literature

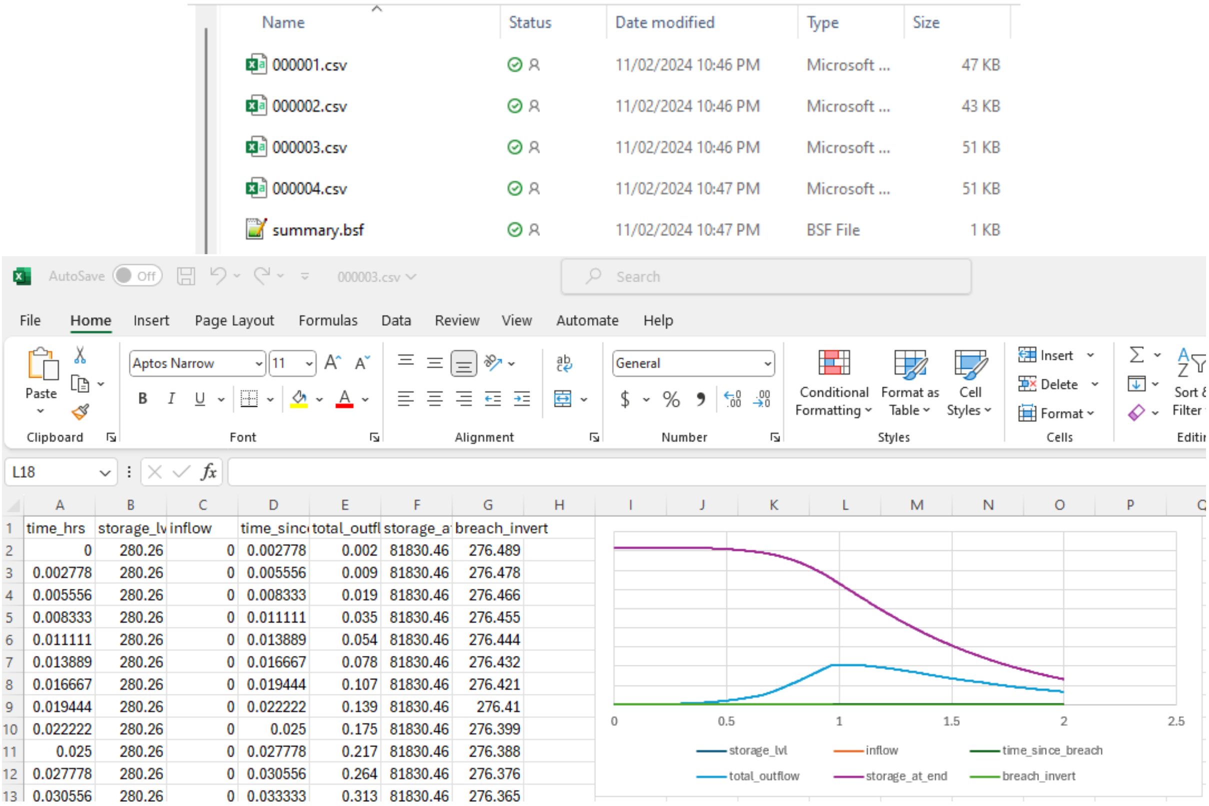
Comprehensive mode shouldn't be used to define a definitive range of breach parameters, rather a plausible range subject to the modellers own judgement. Often the site modelled will be an outlier to those in the historical databases used to develop the literature parameter equations.

Concerns have also been raised about the use of (Xu and Zhang, 2009), see (Azmi and Thomson, 2024). (Xu and Zhang, 2009) have been included in Breacher's comprehensive assessment due to consideration around erodibility and availability in HEC-RAS. Dam erodibility is highly subjective and the use of "Low" erodibility to inform on breach parameters should be used with extreme caution.

3.4.2 Detailed Output Mode

Detailed output mode can be triggered with the following command: Breach_Output = "Detailed"

Turning on this command allows for writing storage level, outflow and other outputs from the Breacher simulation for each simulated event. Caution should be used when turning this on for a lot of events as, for example, running 10,000 simulations with this turned on will create 10,000 files. Turning this command off and running large quantities of simulations will still write critical outputs (ie peak flow) to the summary.bsf file.



Name	Date modified	Type	Size
000001.csv	11/02/2024 10:46 PM	Microsoft ...	47 KB
000002.csv	11/02/2024 10:46 PM	Microsoft ...	43 KB
000003.csv	11/02/2024 10:46 PM	Microsoft ...	51 KB
000004.csv	11/02/2024 10:47 PM	Microsoft ...	51 KB
summary.bsf	11/02/2024 10:47 PM	BSF File	1 KB

time_hrs	storage_lv	inflow	time_sinc	total_outfl	storage_a	breach_invert
0	280.26	0	0.002778	0.002	81830.46	276.489
0.002778	280.26	0	0.005556	0.009	81830.46	276.478
0.005556	280.26	0	0.008333	0.019	81830.46	276.466
0.008333	280.26	0	0.011111	0.035	81830.46	276.455
0.011111	280.26	0	0.013889	0.054	81830.46	276.444
0.013889	280.26	0	0.016667	0.078	81830.46	276.432
0.016667	280.26	0	0.019444	0.107	81830.46	276.421
0.019444	280.26	0	0.022222	0.139	81830.46	276.41
0.022222	280.26	0	0.025	0.175	81830.46	276.399
0.025	280.26	0	0.027778	0.217	81830.46	276.388
0.027778	280.26	0	0.030556	0.264	81830.46	276.376
0.030556	280.26	0	0.033333	0.313	81830.46	276.365

Figure 6 Detailed Output Mode – Files wrote (top), File Content (Bottom)

3.4.3 Breach Parameters

All parameters required for a simulation, without turning on Comprehensive Mode, are shown in Figure 7.

[x, y] indicates a lower and upper value for a parameter to be randomly chosen**. It's important to check there isn't overlap between parameter ranges that do not make sense, for example Breach_Base above Top_of_Dam, as this could create unusual results.**

```
#
# BREACH PARAMETERS
Top_of_dam = 280                              # Top of dam (RL)
Breach_Time = [0.5, 1.5]                      # breach time in hours
Initial_Storage = 279                         # initial storage elevation at the dam
Failure_WSL = 279.5                           # water surface level for failure commencement
Failure_Elev = [250, 281]                     # elevation for failure commencement
Breach_Base = 240                             # elevation at base of breach
Side_Slope = [0.5, 1.0]                       # H:1V
Breach_Bot_Width = [50, 100]                  # breach bottom with in meters
Weir_Cd = [1.1, 1.8]                          # weir coefficient of discharge for the breach
Orifice_Cd = [0.25, 0.6]                      # orifice coefficient of discharge for the breach
#
```

Figure 7 Command File – Breach Parameters

3.4.4 Databases (dbase)

Databases required for a simulation, without turning on Comprehensive Mode, are shown in Figure 8.

It's recommended the headers and format in the templates provided be retained, to reduce the risk of model errors. Where inflow is not required, inflow rates can be set as 0.

It's recommended the max height and storage in elev_storage.csv be set above the Failure_WSL, and lowest height and storage be set below Breach_Base.

```
# ____________________________________________________________________________
# INPUT BC_DBASE
BC_Inflow = "inflow.csv"                                # dam inflow csv
inflow_name = "Inflow"                                  # inflow column in the dam inflow csv
BC_Elev_Storage = "elev_storage.csv"                    # dam elevation-storage csv, storage is in 10^3 m3
BC_Elev_Outflow = "elev_outflow.csv"                    # dam elevation-outflow (ie spillway rating curve) csv
BC_Breach_Progression = "breach_progression.csv"        # optional custom breach progression curve (ie linear, sine, non-linear)
BC_Flow_Tailwater = "None"                              # "flow_tailwater.csv" or "None"
# ____________________________________________________________________________
```

[redacted] > ··· Projects > [redacted] > breacher > dbase

Sort · View · ···

Name	Status	Date modified	Type	Size
breach_progression.csv		16/04/2023 9:48 PM	Microsoft Excel C...	1 KB
elev_outflow.csv		8/02/2024 11:15 PM	Microsoft Excel C...	1 KB
elev_storage.csv		8/02/2024 11:16 PM	Microsoft Excel C...	1 KB
flow_tailwater.csv		8/02/2024 11:11 PM	Microsoft Excel C...	1 KB
inflow.csv		27/07/2023 3:26 PM	Microsoft Excel C...	4 KB

Figure 8 Breacher Workflow

3.4.5 Comprehensive Parameters

Extra parameters required for a simulation, when turning on Comprehensive Mode, are shown in Figure 9.

```
# ____________________________________________________________________________
# COMPREHENSIVE PARAMETERS - If "Comprehensive" is turned on in Breach_Mode
Dam_Crest_Width = 7                     # Dam crest width
Z1 = 0.444                              # Slope of US dam face Z1 (H:V)
Z2 = 0.444                              # Slope of DS dam face Z2 (H:V)
Dam_Type = "Homogeneous"                # Options are "Core_wall", "Concrete_Faced", "Zoned_Fill" or "Homogeneous"
Dam_Erodibility = "Medium"              # Options are "Low", "Medium" or "High"
```

Figure 9 Comprehensive Mode – Breach Parameters

3.5 Summary Files

3.5.1 Breacher Summary File (summary.bsf)

All model runs, regardless of the output type or mode, write a summary of results to a file in the results folder called "summary.bsf". It's recommended to delete or save a copy of this file when performing a new task with Breacher (ie refining breach parameter ranges) as each run will just add another line to this file, and polluting results could impact the analysis in Breacher-Post.

G9 fx

	A	B	C	D	E	F	G	H	I	J	K
1	It_Nu	Initial_Storage	Failure_WSL	Failure_Elev	Breach_Base	Side_Slope	Breach_Bot_Width	Weir_Cd	Orifice_Cd	Breach_Time	Peak_Flow
2	1	280.26	280.26	276.5	231.26	0.4	93.55	1.45	0.5	1.01	39603.418
3	2	280.26	280.26	276.5	231.26	0.4	158.57	1.45	0.5	0.654	61591.581
4	3	280.26	280.26	276.5	246.2	0.4	89.1	1.45	0.5	1.32	20688.794
5	4	280.26	280.26	276.5	246.2	0.4	136.8	1.45	0.5	1.15	29255.693

Figure 10 Breacher Summary File Example

3.5.2 Breacher Comprehensive Summary File (summary_comprehensive.bsf)

When Comprehensive mode is turned on, a second file "summary_comprehensive.bsf" is created, with additional detail from the literature comparison part of the Breacher simulation.

Q24

	It_Nu	Initial_Storage	Failure_WSL	Failure_Elev	Breach_Base	Side_Slope	Breach_Bot_Width	Weir_Cd	Orifice_Cd	Breach_Time	Breacher_Peak_Flow	froehlich_2016_peak_flow	froehlich_1995_peak_flow	hooshyaripor_2014_peak_flow
2	1	280.26	280.26	233.193	231.26	0.4	123.114	1.281	0.426	1.92	26930.393	19709.193	16343.375	12443.004
3	2	280.26	280.26	256.837	231.26	0.4	155.871	1.219	0.483	2.929	13724.072	19709.193	16343.375	12443.004
4	3	280.26	280.26	257.327	231.26	0.4	101.227	1.514	0.439	2.84	146.175	19709.193	16343.375	12443.004
5	4	280.26	280.26	239.884	231.26	0.4	92.764	1.679	0.437	0.912	61893.237	19709.193	16343.375	12443.004
6	5	280.26	280.26	240.827	231.26	0.4	129.458	1.682	0.417	0.882	83158.414	19709.193	16343.375	12443.004
7	6	280.26	280.26	277.764	231.26	0.4	130.634	1.384	0.57	1.662	70484.255	19709.193	16343.375	12443.004
8	7	280.26	280.26	262.403	231.26	0.4	151.036	1.607	0.516	0.824	91721.922	19709.193	16343.375	12443.004
9	8	280.26	280.26	240.225	231.26	0.4	109.834	1.279	0.588	1.394	56654.574	19709.193	16343.375	12443.004
10	9	280.26	280.26	250.614	231.26	0.4	153.116	1.149	0.456	1.511	68814.815	19709.193	16343.375	12443.004
11	10	280.26	280.26	237.506	231.26	0.4	91.707	1.206	0.471	2.082	1.108	19709.193	16343.375	12443.004
12	11	280.26	280.26	277.348	231.26	0.4	122.556	1.759	0.423	2.904	0.055	19709.193	16343.375	12443.004
13	12	280.26	280.26	243.868	231.26	0.4	141.574	1.471	0.531	1.856	79902.314	19709.193	16343.375	12443.004

15	It_Nu	xu_zhang_2009_peak_flow	zhong_2020_peak_flow	_2024_peak_flow	froehlich_2016_breach_width	froehlich_1995_breach_width	9_breach_width	zhong_2020_breach_width	_2024_breach_width	froehlich_2016_breach_time	froehlich_1995_breach_time	xu_zhang_2009_breach_time	zhong_2020_breach_time	_2024_breach_time
16	1	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
17	2	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
18	3	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
19	4	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
20	5	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
21	6	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
22	7	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
23	8	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
24	9	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
25	10	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
26	11	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654
27	12	22318.801	21537.931	21505.335	117.149	133.226	108.156	124.27	182.167	0.859	1.011	2.959	0.879	0.654

Figure 11 Breacher Comprehensive Summary File Example

4 Breacher-Post

4.1 Purpose

Included in the suite is Breacher-Post, a windows based application to allow for reviewing and performing analytics on Breacher results. Ultimately this is to help the user with decision making around suitable parameters and uncertainties / confidence ranges.

Five (5) methods for cutting the data from the summary.bsf have been included in Breacher-Post. To import the data, just click "Import BSF file" and select the summary file.

Once the chart required has been toggled on (ticked) and variables and inputs allocated, click "Generate files" to generate the chosen charts.

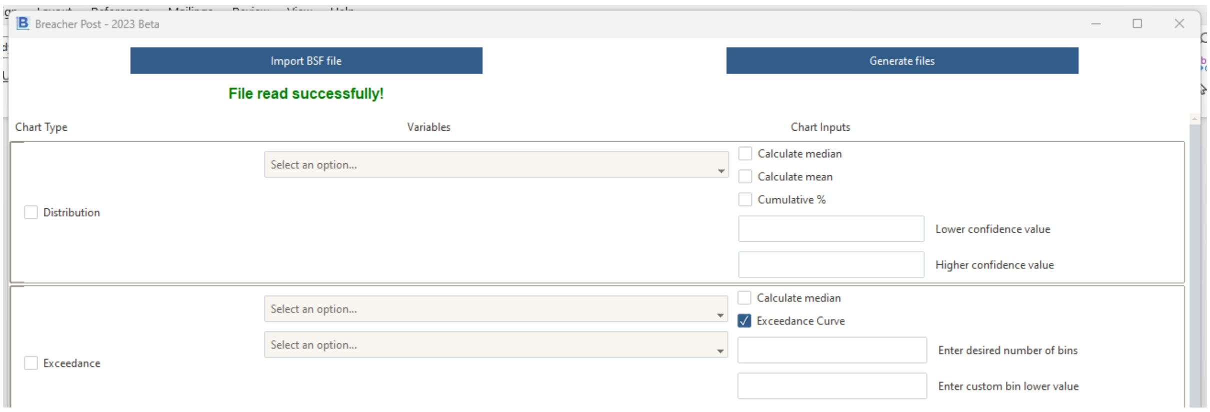


Figure 12 Breacher-Post Application

4.2 Detailed Plot

Detailed plot has been provided as a quick method for checking the simulated runs when ***Breach_Output = "Detailed"*** is triggered in Breacher. Detailed Plot reads the summary.bsf file and loads all csv runs that are listed in the file. Example shown in Figure 13.

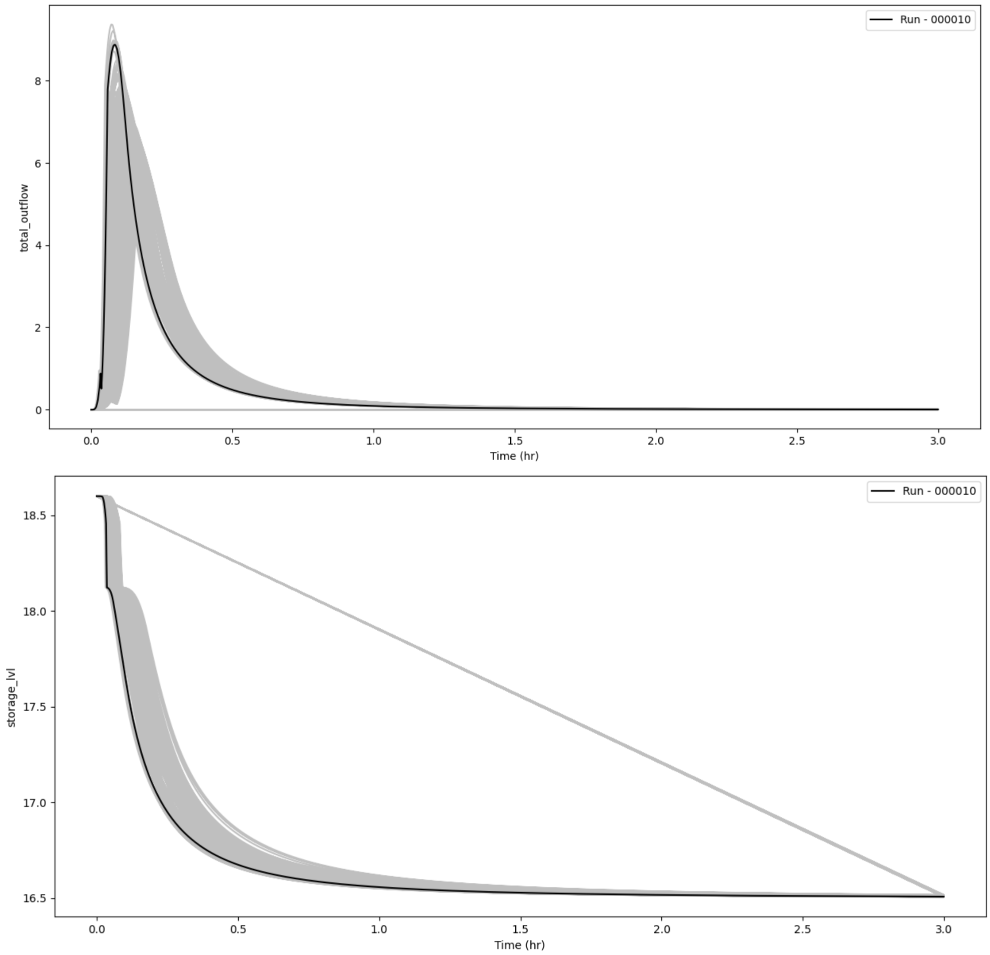


Figure 13 Breacher-Post – Detailed Plot of Outflow Hydrograph (top) and Change to Storage (bottom)

4.3 Distribution Plots

Distribution plots have been provided as a quick method for checking peak flow variation and for the user to check if parameter randomisation (ie breach bottom width) has been performed correctly.

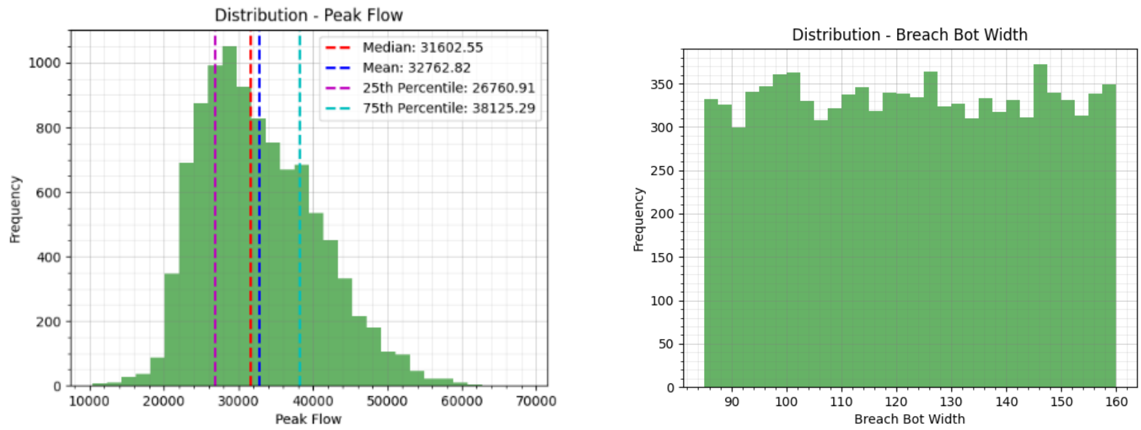


Figure 14 Breacher-Post – Distribution Plots

4.4 Exceedance Plots

Exceedance plots are useful tools for estimating critical parameters where relationships to peak flow aren't directly correlated. For example, many guidelines in Australia suggest choosing a failure elevation that produces the highest peak flow, using exceedance plots at elevation increments allows identifying the failure elevation that has a higher peak flow magnitude to others. Figure 15 shows the dam being assessed has a critical failure elevation between RL 276 to 277.

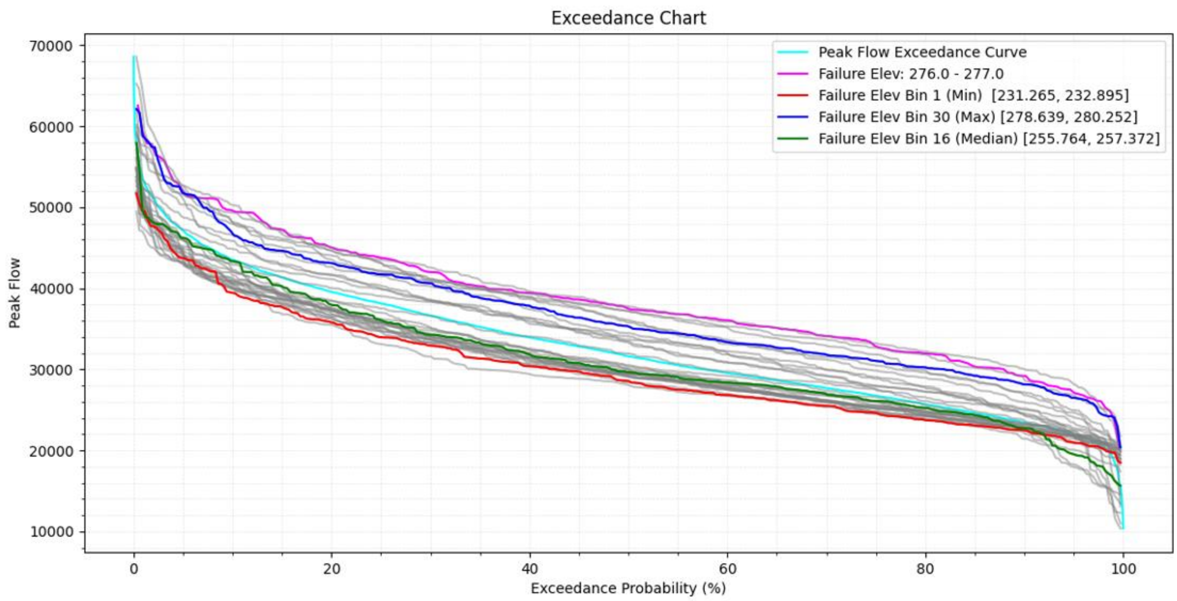


Figure 15 Breacher-Post – Exceedance Charts

4.5 Binned Data

Similarly to exceedance plots, binning data is a useful tool for estimating critical parameters where relationships to peak flow aren't directly correlated. Shown in Figure 16, binning failure elevation also suggests a critical failure elevation between RL 276 to 277. Binning can also be applied to coefficients to check their relationship to peak flow, shown in Figure 17 orifice coefficient of discharge seems to have negligible impact on peak flow.

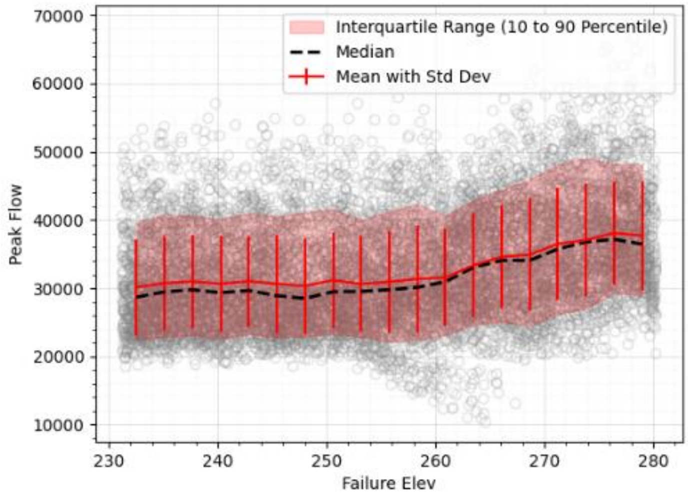


Figure 16 Breacher-Post – Binned Data Charts (1 of 2)

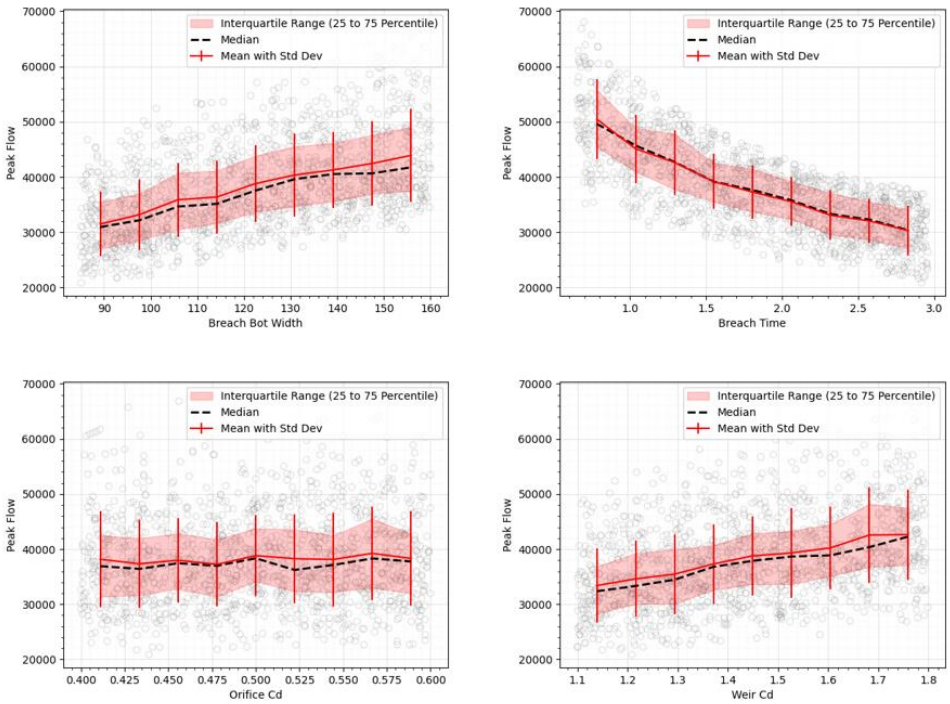


Figure 17 Breacher-Post – Binned Data Charts (2 of 2)

4.6 Scatter Plot

Colour coded (by peak flow) scatter plot has been included as an optional chart in Breacher-Post. It's use hasn't been explored in detail yet but there's potential use for visualising relationships, identifying clusters and enhancing the modellers interpretability of results

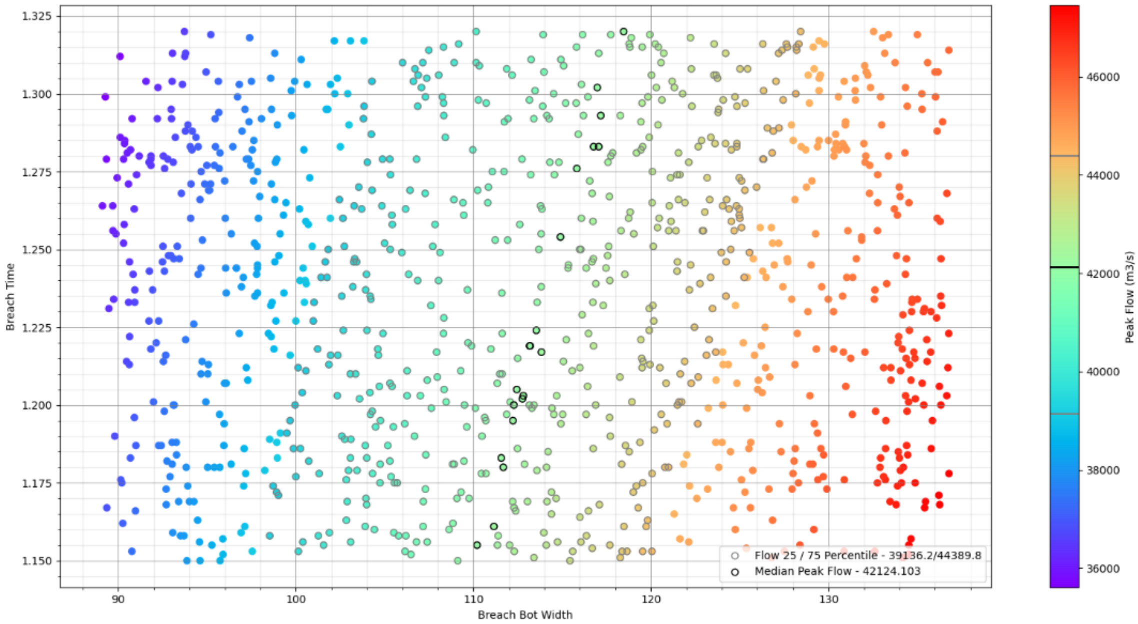


Figure 18 Breacher-Post – Scatter Plot of Breach Time, Bottom Width and Peak Flow

5 Validation

Four (4) dams of real world sites, with varying storage, embankment heights and embankment types (i.e. earthen or rockfill) were selected. For each of these dams, six (6) scenarios were developed with varying failure types, conditions, and breach parameters. This is documented in Table 2.

Breacher and HEC-RAS models were developed for each of these scenarios, with breach hydrographs and changes to dam storage levels compared to confirm Breacher replicates the breach process of HEC-RAS. The results from this are shown in Figure 20, Figure 21, Figure 22 and Figure 23.

Some interesting observations were found by the Forward Hydro team during the validation process:

- Outflow velocity during piping in HEC-RAS seemed to have an upper limit. During testing this was around 11 m/s for several of the scenarios. This capped velocity may be due to one of the following:
    - In HEC-RAS, like other hydrodynamic solvers, velocity and timestep impact stability (relating to Courant number). An upper limit to velocity would reduce the frequency of hydrodynamic models going unstable, and ~ 11 m/s might be reasonable given HEC-RAS' minimum timestep (0.1 seconds).
    - An established relationship in the solver between piping erosion and velocity that hasn't been documented.
    - Influence of "lateral structure flow stability factor" in smoothing (or dampening) estimated computed flows
- Breach progression in HEC-RAS, especially for a piping failure, was very difficult to replicate in Breacher and required substantial testing and verification, an example from this is shown in Figure 19. Once the team could replicate the breach progression, and on review of publications (relating to the HEC-RAS breach progress and general literature on dam breach progression), it was understood why this approach was adopted in HEC-RAS. ***Our take away from this exercise was breach progression and the influence it has on breach width, elevation, hydrograph shape and peak flow is highly influenced by assumptions made by the programmer of the software tool chosen by the user. We strongly recommend other software developers of similar dam breach tools provide similar validations to provide confidence in programmed assumptions.***
- Instabilities during a HEC-RAS model run can compound causing substantial changes to hydrograph shape and peak flow, Site 3 in this validation had minor instabilities that while time consuming to resolve, were left in the model result to showcase this effect. See Figure 22.

- In hydrodynamic modelling, adaptive timestep influenced hydrograph shape and peak flow, largely due to small mass balance errors for larger timesteps compounding prior to breach peak flow. These mass balance errors influenced volume within the dam as it approached peak flow, thus influencing peak flow. When using adaptive timestep with hydrodynamic models, it's strongly recommended to sensitivity test the lowest allowable timestep. Similarly with Breacher, it's highly recommended to sensitivity test timestep, which can rapidly be done by randomising the command input.

Results overall demonstrate, for the scenarios tested, Breacher was able to replicate HEC-RAS.

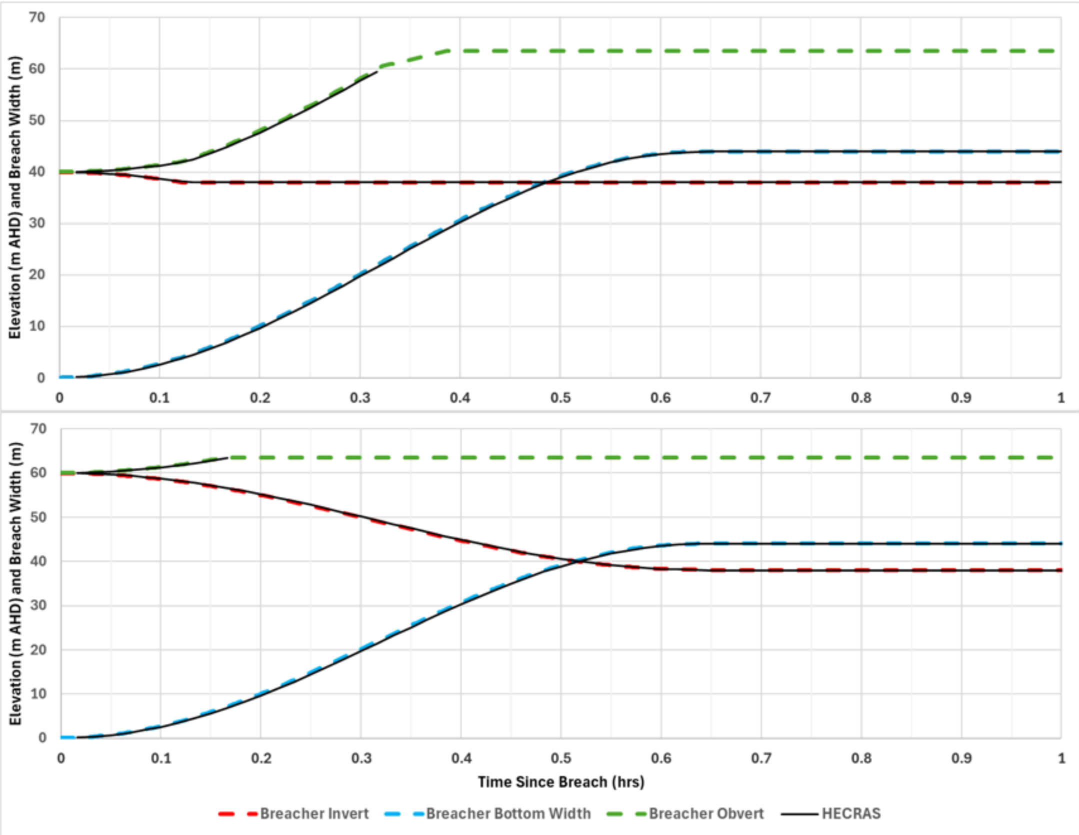


Figure 19 Breach Progression Validation – Breacher vs HEC-RAS

Table 2 List of Validation Runs

Run #	Site #	Failure Type	Tailwater	Inflow	Failure Mode	Breach Time	Initial Storage	Failure WSL	Failure Elev	Side Slope
1-1	1	SDF	Yes	No	Piping	0.64	63.5	63.5	40	0.5
1-2	1	SDF	Yes	No	Piping	0.64	63.5	63.5	50	0.5
1-3	1	SDF	Yes	No	Piping	0.64	63.5	63.5	60	0.5
1-4	1	FFS	Yes	Yes	Overtopping	0.64	63.5	63.5	63.5	0.5
1-5	1	FFS	Yes	Yes	Overtopping	0.64	63.5	63.7	63.5	0.5
1-6	1	FFS	Yes	Yes	Overtopping	0.64	63.5	63.9	63.5	0.5
2-1	2	SDF	Yes	No	Piping	0.65	61	61	40	0.5
2-2	2	SDF	Yes	No	Piping	0.65	61	61	50	0.5
2-3	2	SDF	Yes	No	Piping	0.65	61	61	55	0.5
2-4	2	FFS	Yes	Yes	Overtopping	0.65	61	61	61	0.5
2-5	2	FFS	Yes	Yes	Overtopping	0.65	61	61.2	61	0.5
2-6	2	FFS	Yes	Yes	Overtopping	0.65	61	61.4	61	0.5
3-1	3	SDF	Yes	No	Piping	0.66	160	160	157	0.5
3-2	3	SDF	Yes	No	Piping	0.66	160	160	158	0.5
3-3	3	SDF	Yes	No	Piping	0.66	160	160	159	0.5
3-4	3	SDF	Yes	No	Piping	0.66	162	162	159	0.5
3-5	3	SDF	Yes	No	Piping	0.66	162	162	160	0.5
3-6	3	SDF	Yes	No	Piping	0.66	162	162	161	0.5
4-1	4	SDF	Yes	No	Piping	0.57	66	66	60	0.5
4-2	4	SDF	Yes	No	Piping	0.57	66	66	60	0.5
4-3	4	SDF	Yes	No	Piping	0.57	66	66	60	0.5
4-4	4	SDF	Yes	No	Piping	0.57	66	66	60	0.5
4-5	4	SDF	Yes	No	Piping	0.57	66	66	60	0.5
4-6	4	SDF	Yes	No	Piping	0.57	66	66	60	0.5

Run #	Site #	Failure Type	Tailwater	Inflow	Failure Mode	Bottom width	Bottom elevation	Weir Coefficient	Orifice coefficient	Top of Dam
1-1	1	SDF	Yes	No	Piping	44	38	1.3	0.5	63.5
1-2	1	SDF	Yes	No	Piping	44	38	1.3	0.5	63.5
1-3	1	SDF	Yes	No	Piping	44	38	1.3	0.5	63.5
1-4	1	FFS	Yes	Yes	Overtopping	44	38	1.3	0.5	63.5
1-5	1	FFS	Yes	Yes	Overtopping	44	38	1.3	0.5	63.7
1-6	1	FFS	Yes	Yes	Overtopping	44	38	1.3	0.5	63.9
2-1	2	SDF	Yes	No	Piping	65	36	1.44	0.55	61
2-2	2	SDF	Yes	No	Piping	65	36	1.44	0.55	61
2-3	2	SDF	Yes	No	Piping	65	36	1.44	0.55	61
2-4	2	FFS	Yes	Yes	Overtopping	65	36	1.44	0.55	61
2-5	2	FFS	Yes	Yes	Overtopping	65	36	1.44	0.55	61.2
2-6	2	FFS	Yes	Yes	Overtopping	65	36	1.44	0.55	61.4
3-1	3	SDF	Yes	No	Piping	23	156.65	1.44	0.55	160
3-2	3	SDF	Yes	No	Piping	23	156.65	1.44	0.55	160
3-3	3	SDF	Yes	No	Piping	23	156.65	1.44	0.55	160
3-4	3	SDF	Yes	No	Piping	23	156.65	1.44	0.55	162
3-5	3	SDF	Yes	No	Piping	23	156.65	1.44	0.55	162
3-6	3	SDF	Yes	No	Piping	23	156.65	1.44	0.55	162
4-1	4	SDF	Yes	No	Piping	43	53.95	1.1	0.5	67.09
4-2	4	SDF	Yes	No	Piping	43	53.95	1.5	0.5	67.09
4-3	4	SDF	Yes	No	Piping	43	53.95	1.8	0.5	67.09
4-4	4	SDF	Yes	No	Piping	43	53.95	1.45	0.4	67.09
4-5	4	SDF	Yes	No	Piping	43	53.95	1.45	0.55	67.09
4-6	4	SDF	Yes	No	Piping	43	53.95	1.45	0.6	67.09

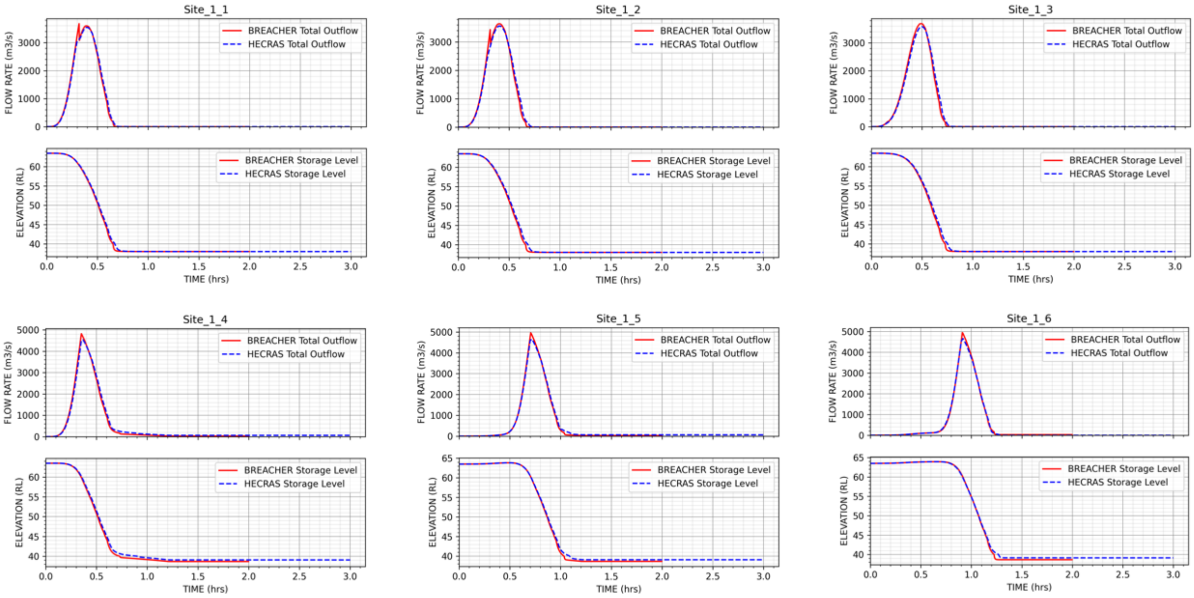


Figure 20 Site 1 Validation – Breacher vs HEC-RAS

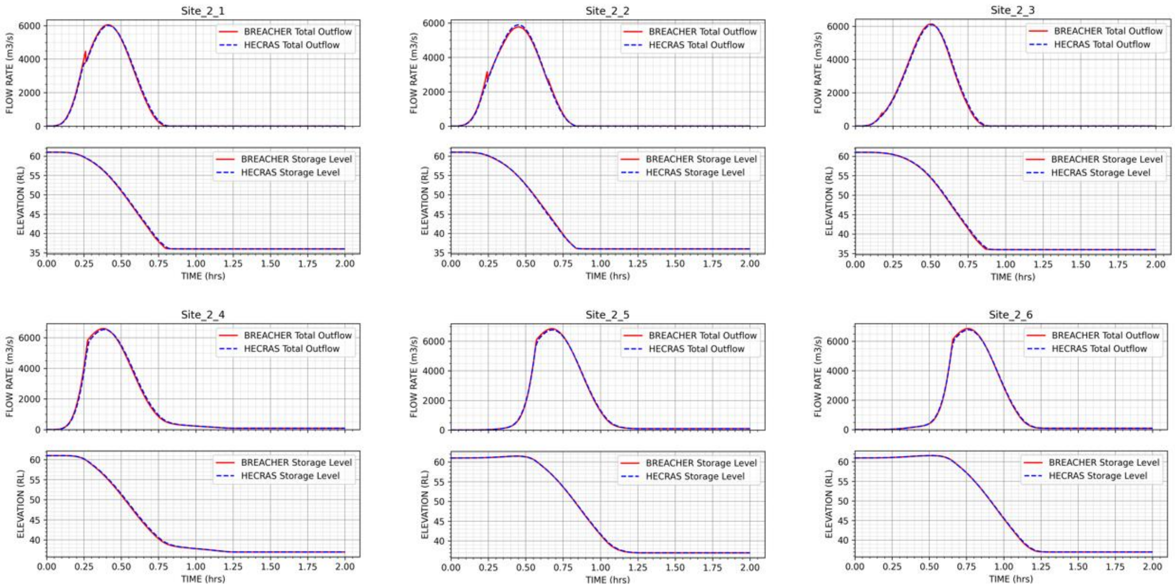


Figure 21 Site 2 Validation – Breacher vs HEC-RAS

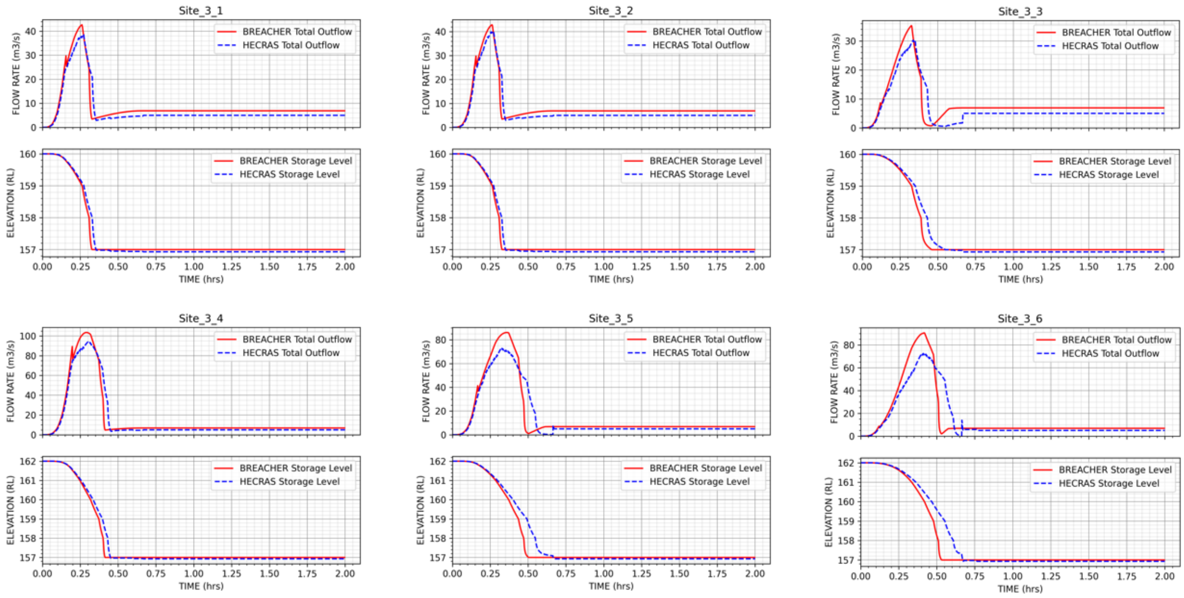


Figure 22 Site 3 Validation – Breacher vs HEC-RAS

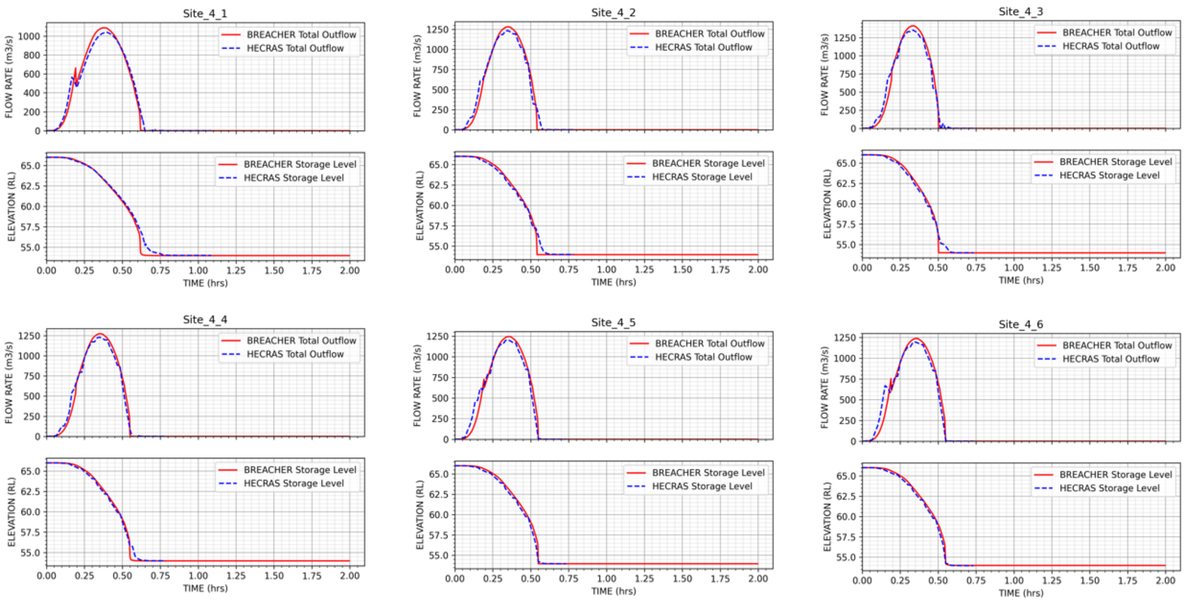


Figure 23 Site 4 Validation – Breacher vs HEC-RAS

6 Case Studies

6.1 Validation Site 1 – Sunny Day Failure

Site 1, an approximately 3,000 ML dam was selected for a detailed validation study.

Comprehensive mode was initially run with Breacher to check for a similar dam with a historical failure, Bradfield (Figure 24) was identified.

Comprehensive mode also provided feasible breach ranges (peak flow, width and time) according with the preprogrammed literature (Figure 25). From this, a breach bottom width of 30 to 55m and time of 0.4 to 0.8 hrs was selected.

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!! CHECKING HISTORICAL DAM FAILURES !!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

BEST MATCHED DAM FROM AZMI THOMSON 2024, FILTERING BY FAILURE MODE AND DAM TYPE:
 Dam_Name Failure_Mode Dam_type hd(m) hw(m) hb(m) S(106m3) Vw(106m3) Wave(m) Dam_Erodibility Bave(m) Tf(h) Qp(m3/s)
Bradfield            P       HD 28.96    24 28.96      3.2      2.96      76              ME       -   0.5     2370
```

Figure 24 Site 1 Case Study – Breacher Historical Event Match

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! BREACHER COMPARISON TO PUBLICATIONS !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

PEAK FLOW FUNCTIONS (m3/s)
-> Breacher Peak Flow:    [redacted]
-> Froehlich 2016:        2200.54667
-> Froehlich 1995:        2973.68292
-> Hooshyaripor 2014:     1358.77292
-> Xu Zhang 2009:         2381.24479
-> Zhong 2020:            2020.11235
-> Azmi Thomson 2024:     2734.76941

BREACH WIDTH FUNCTIONS (m): AVERAGE WIDTH, BOTTOM WIDTH
-> Breacher breach width:    [redacted]
-> Froehlich 2016:           42.65889, 29.90889
-> Froehlich 1995:           43.06748, 30.31748
-> Xu Zhang 2009:            33.14629, 20.39629
-> Zhong 2020:               58.04622, 45.29622
-> Azmi Thomson 2024:        69.59555, 56.84555

BREACH TIME FUNCTIONS (hrs)
-> Breacher breach time:    [redacted]
-> Froehlich 2016:          0.43686
-> Froehlich 1995:          0.43166
-> Xu Zhang 2009:           1.05608
-> Zhong 2020:              0.80449
-> Azmi Thomson 2024:       0.4764
```

Figure 25 Site 1 Case Study – Breacher Literature Comparison

1,000 simulations were then run with the following randomised parameter ranges:

- Breach_Time = [0.4, 0.8]
- Failure_Elev = [38, 63.5]
- Breach_Bot_Width = [30, 55]
- Weir_Cd = [1.2, 1.6]
- Orifice_Cd = [0.2, 0.5]

Resulting hydrographs from the 1,000 runs were extracted in Breacher-Post (Figure 26). The Breacher-Post, Binned Data tool was used to the critical failure elevation (elevation producing on average, or median, the highest peak flow). It was found for this dam and the SDF, R.L. 49 m produced the highest peak flow (Figure 27).

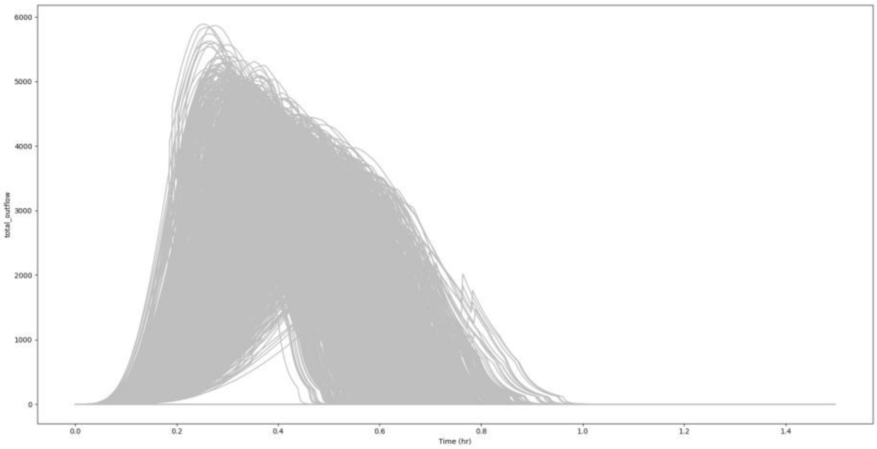


Figure 26 Site 1 Case Study – Change to Breach Hydrograph with Randomised Parameters

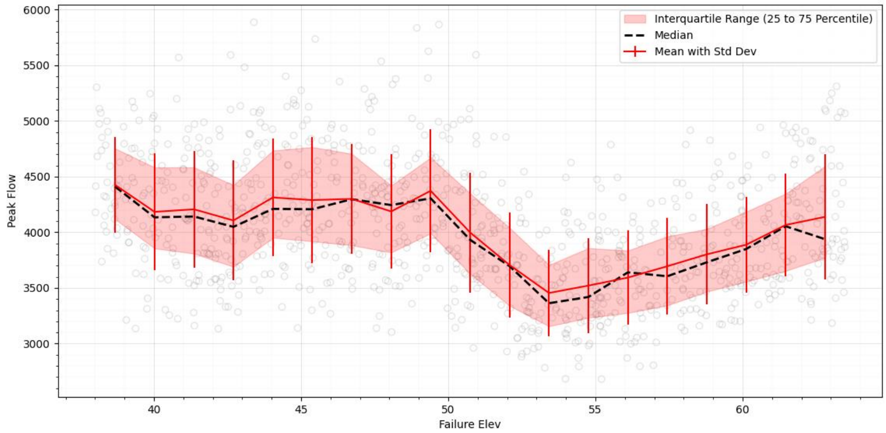


Figure 27 Site 1 Case Study – Critical Failure Elevation

Breach failure elevation was fixed to R.L. 49 m (Failure_Elev = 49), previous runs and the summary file were cleared, and 100 new simulations ran.

Binning orifice coefficient of discharge (Orifice Cd) found no obvious correlation between selected Orifice Cd and peak flow (Figure 28). As such a value of 0.3 was adopted.

A similar approach was adopted for weir coefficient of discharge, which aided in identifying a Weir Cd of 1.4. With only 2 randomised parameters remaining, Breach Time and Breach Bottom Width, results were once again cleared and a final 1,000 simulations ran.

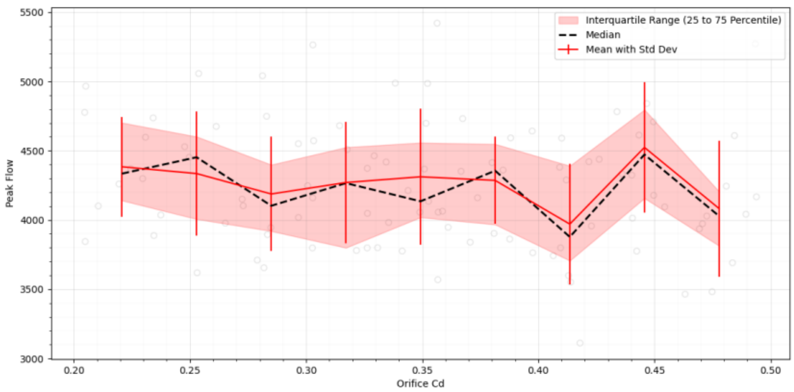


Figure 28 Site 1 Case Study – Orifice Cd

Peak flow distribution for the 1,000 runs is provided in Figure 29 and peak flow distribution relative to breach time and bottom width is provided in Figure 30.

Interestingly, the median peak flow (4,355 m^3/s) is higher than that predicted in the comprehensive literature assessment (between ~ 2,000 to 3,000 m^3/s). This isn't unexpected, as historical larger dam failures carry substantial uncertainties regarding the estimate of breach time and peak flow, this was well documented in (Azmi and Thomson, 2024).

The above being said, the median peak flow is less than 50% above the upper range estimated in the literature assessment and 80% above the matched historical dam (Bradfield).

While some can consider this a reasonable validation of the median peak flow, ultimately the judgement of the modeller is required at this point to select the most appropriate peak flow, corresponding parameters and be satisfied of it's suitability for use.

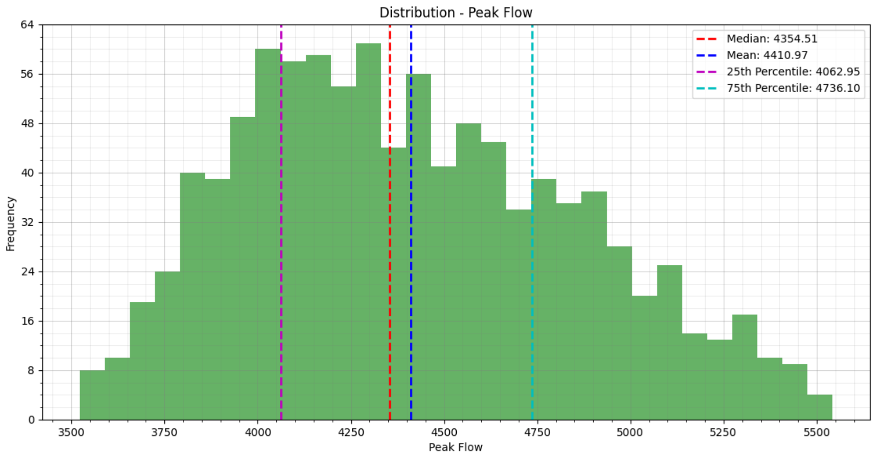


Figure 29 Site 1 Case Study – Final Peak Flow Distributions

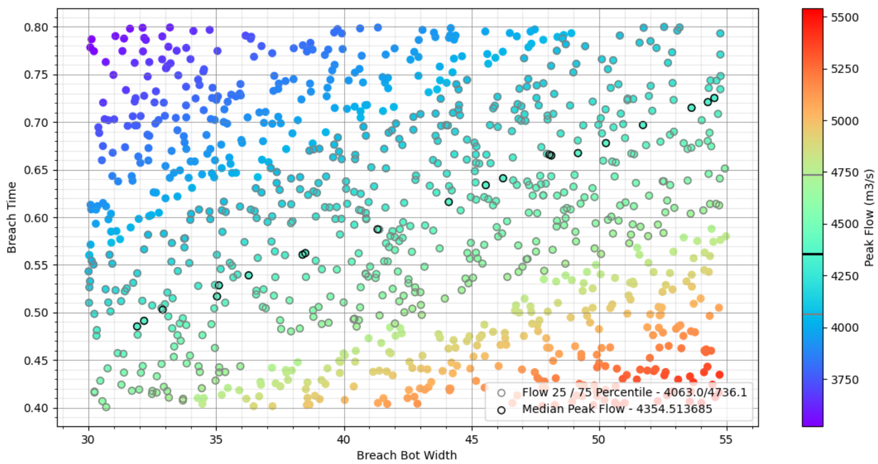


Figure 30 Site 1 Case Study – Breach Time and Bottom Width Relative to Peak Flow

6.2 Estate Basin – Sunny Day and Multiple Flood Failure Assessments

As part of an estate development project, an above ground basin was proposed to mitigate increases in runoff. While a relatively minor storage (~ 5 ML to the spillway), proximity to a road and private properties posed potential failure risks. The following events were assessed as part of this assessment to quantify these risks:

- Sunny Day Failure (SDF)
- 1 in 5 year (20% AEP) flood failure (FFS)
- 1 in 20 year (5% AEP) FFS
- 1 in 100 year (1% AEP) FFS
- Probably maximum flood (PMF) FFS

Due to complexities of the hydrodynamic model provided (rain on grid plus various fixed inflow locations) and the basin having a large surface area relative to storage volume, an alternative approach to modelling the basin in Breacher with inflows was required. Basin outflow hydrographs and peak elevations were extracted from the hydrodynamic model for each of the events described above.

The basin was then simulated in Breacher as an SDF failure model for all events (even the FFS events) with fixed water levels matching the peak elevations extracted from the hydrodynamic model. If the outflow hydrographs were included in Breacher as inflows, this would cause a "double counting" of basin attenuation effects.

A comprehensive simulation was ran for all events in Breacher to estimate initial parameter ranges (example for SDF shown in Figure 31), the parameter ranges identified in the comprehensive simulation are summarised in Table 3. Decision making was made around failure mode, with overtopping of the spillway found to be critical for most of the events, and piping of the embankment found to be critical for the PMF.

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!! CHECKING HISTORICAL DAM FAILURES !!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

BEST MATCHED DAM FROM AZMI THOMSON 2024, FILTERING BY FAILURE MODE AND DAM TYPE:
 Dam_Name Failure_Mode Dam_type hd(m) hw(m) hb(m) S(106m3) Vw(106m3) Wave(m) Dam_Erodibility Bave(m) Tf(h) Qp(m3/s)
Haas Pond            O       HD     4  2.99  3.96        -    0.0234       -               ME    10.7     -        -
```

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! BREACHER COMPARISON TO PUBLICATIONS !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

PEAK FLOW FUNCTIONS (m3/s)
-> Breacher Peak Flow:  7.52122
-> Froehlich 2016:      11.66766
-> Froehlich 1995:      19.2747
-> Hooshyaripor 2014:   4.32109
-> Xu Zhang 2009:       5.69741
-> Zhong 2020:          4.68337
-> Azmi Thomson 2024:   17.10322

BREACH WIDTH FUNCTIONS (m): AVERAGE WIDTH, BOTTOM WIDTH
-> Breacher breach width:  5.3, 4.25
-> Froehlich 2016:         6.17532, 5.12532
-> Froehlich 1995:         4.5604, 3.5104
-> Xu Zhang 2009:          4.08827, 3.03827
-> Zhong 2020:             5.31102, 4.26102
-> Azmi Thomson 2024:      4.31288, 3.26288

BREACH TIME FUNCTIONS (hrs)
-> Breacher breach time:  0.2
-> Froehlich 2016:        0.19705
-> Froehlich 1995:        0.12449
-> Xu Zhang 2009:         0.27098
-> Zhong 2020:            2.12011
-> Azmi Thomson 2024:     0.84611
```

Figure 31 Estate Basin Case Study – SDF Breacher Comprehensive Assessment

Table 3 Estate Basin Case Study – Summary of Comprehensive Mode Identified Parameters

Scenario	Parameter	Parameter Range	Failure Mode
SDF	Bottom Width	3 - 5	Overtopping
	Breach Time	0.1 - 0.3	
	Failure Elevation	18.6	
20% AEP	Bottom Width	3.5 - 8	Overtopping
	Breach Time	0.1 - 0.3	
	Failure Elevation	18.6	
5% AEP	Bottom Width	3.5 - 9	Overtopping
	Breach Time	0.1 - 0.3	
	Failure Elevation	18.6	
1% AEP	Bottom Width	3.5 - 10	Overtopping
	Breach Time	0.1 - 0.3	
	Failure Elevation	18.6	
PMF	Bottom Width	5 - 9	Piping
	Breach Time	0.1 - 0.35	
	Failure Elevation	16.5 - 21	

The simulated PMF runs were imported into Breacher-Post to identify the critical piping elevation, the resulting plot is shown in Figure 32 and binned elevation plot from Breacher-Post in Figure 33. The breach time and bottom width relative to peak flow is shown in Figure 34.

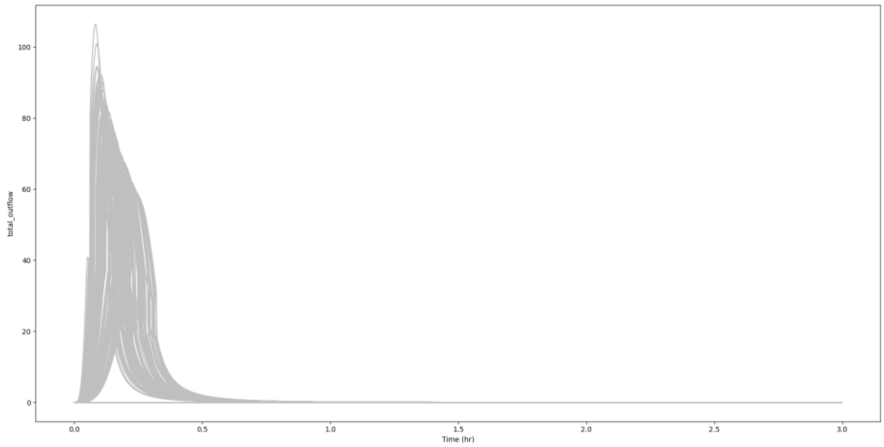


Figure 32 Estate Basin Case Study – PMF Simulated Runs

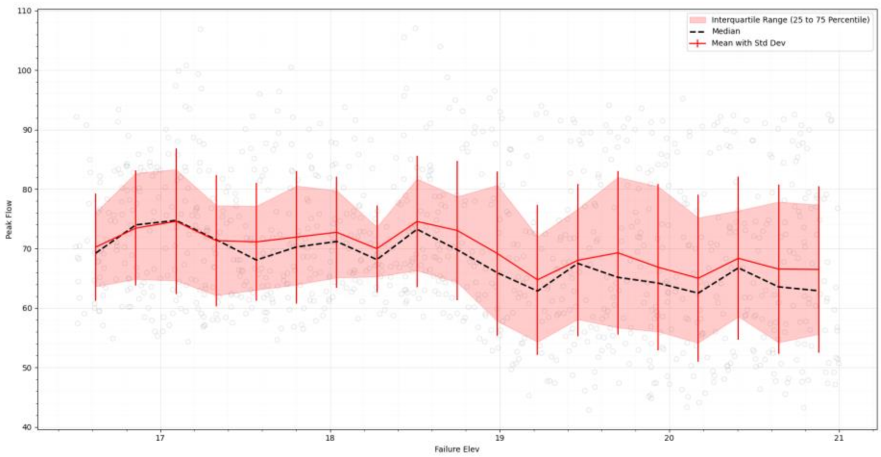


Figure 33 Estate Basin Case Study – PMF Binned Failure Elevations

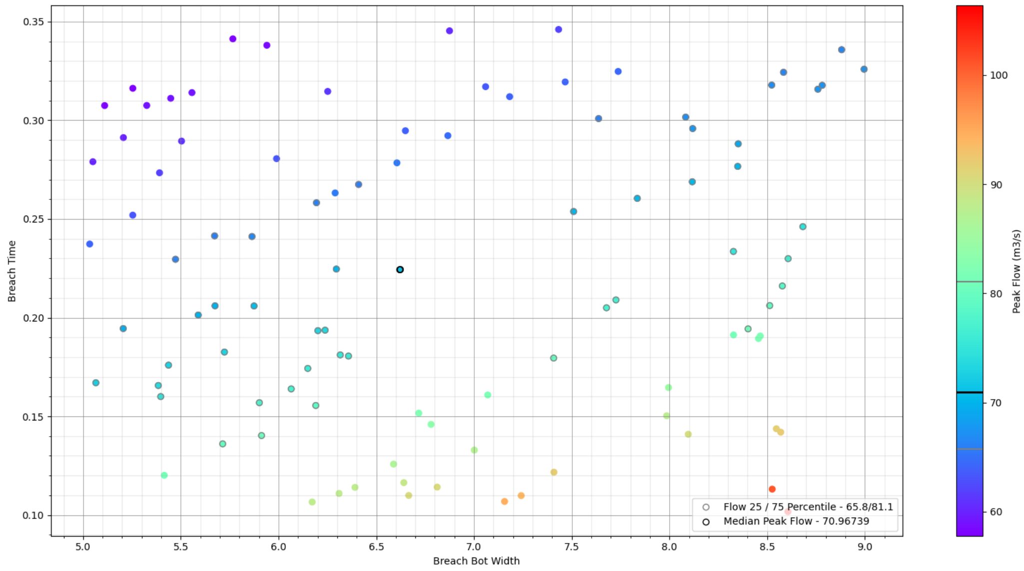


Figure 34 Estate Basin Case Study – PMF Breach Time and Bottom Width Relative to Peak Flow

A weir and orifice coefficient of discharge of 1.45 and 0.3 was identified as suitable for all simulated events, this was following additional simulations and analysis.

Results from all the breach scenarios are summarised below, with the updated peak flows (once reinforced with the original outflow hydrographs) included.

- Sunny Day Failure (SDF):
    - Breach time: 0.2 hrs
    - Breach width: 4.25 m
    - Breach peak flow: 7.5 m^3/s
    - Literature peak flow range: 4.6 – 12 m^3/s
- 1 in 5 year (20% AEP) flood failure (FFS):
    - Breach time: 0.22 hrs
    - Breach width: 6.2 m
    - Breach peak flow: 24.62 m^3/s
    - Literature peak flow range: 13 – 30 m^3/s
    - Combined (breach + release) peak flow: 46.6 m^3/s
- 1 in 20 year (5% AEP) FFS
    - Breach time: 0.25 hrs
    - Breach width: 7 m
    - Breach peak flow: 28.55 m^3/s
    - Literature peak flow range: 14 – 33 m^3/s
    - Combined (breach + release) peak flow: 46.6 m^3/s
- 1 in 100 year (1% AEP) FFS
    - Breach time: 0.275 hrs
    - Breach width: 7.6 m
    - Breach peak flow: 32.16 m^3/s
    - Literature peak flow range: m^3/s
    - Combined (breach + release) peak flow: 72.4 m^3/s
- Probably maximum flood (PMF) FFS
    - Breach time: 0.22 hrs
    - Breach width: 6.7 m
    - Breach peak flow: 71.68 m^3/s
    - Literature peak flow range: 35 – 96 m^3/s
    - Combined (breach + release) peak flow: 204.1 m^3/s

An example of the combined (breach + release) flow hydrograph, for the PMF, is shown in Figure 35.

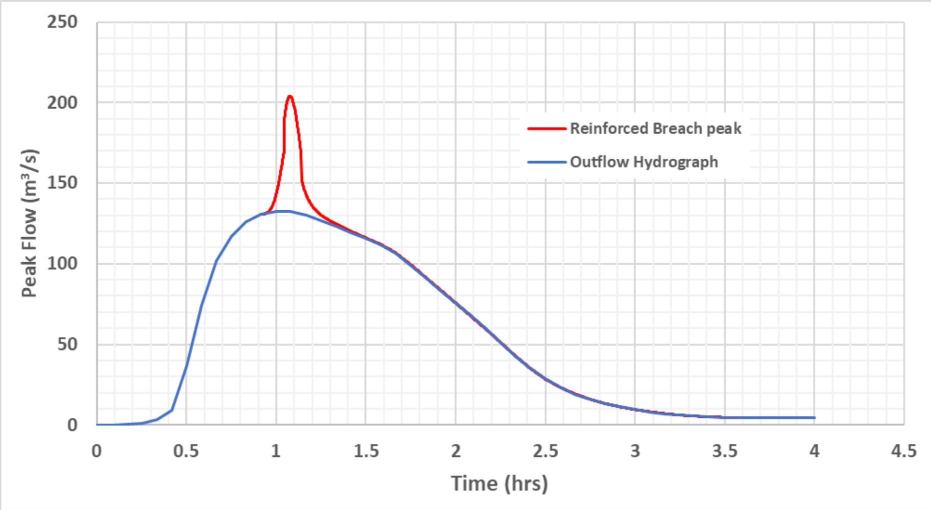


Figure 35 Estate Basin Case Study – Outflow and Breach Reinforced Hydrograph

As the Breacher peak flow for each event correlated with peak flows from the literature for all events when utilising parameters (breach bottom width and breach time), it became evident that the results are both reasonable and feasible.

This correlation demonstrates that, by accurately modeling these parameters, one can achieve realistic predictions of dam break scenarios.

7 References

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Xu Y, Zhang LM (2009) Breaching parameters for earth and rockfill dams. J Geotech Geoenviron Eng 135(12):1957–1970. https://doi.org/10.1061/(asce)gt.1943-5606.0000162