Comparative analysis of hydraulic modelling tools for rock chute design in waterway management

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Key points

- Rock chutes are one of the most commonly used bed grade control structures across Australia in urban and regional waterways.
- The CHUTE program included in the eWater Toolkit is commonly used software to design rock chutes.
- The results of hydraulic parameters using CHUTE were compared with other hydraulic modelling packages.
- The results of CHUTE were compared with hydraulic models to assess the limitations of the CHUTE program in the estimation of hydraulic parameters and the design of rock chutes.

Abstract

Rock chutes are commonly used in waterways as a bed grade control structure to safely reduce channel slopes and control erosion. They play an important role in stabilising waterways and protecting surrounding infrastructure. In practice, however, designing rock chutes is not always straightforward. While the e-Water Chute program is recommended in multiple guidelines, its results do not always align with outputs from other hydraulic models.

One of the key differences relates to the predicted location of the hydraulic jump along the chute. This is a critical design parameter, as it directly influences the minimum required chute geometry and overall stability. In addition, e-Water Chute has shown a high sensitivity to downstream boundary conditions. However, the assumptions utilised in the program are not always correct, which can lead to the overestimation or underestimation of the rock chute geometric elements.

To better understand these differences, this study compares simulations from e-Water Chute, HEC-RAS 1D, HEC-RAS 2D with shallow water equation, and TUFLOW across a range of hydraulic scenarios. The confirmation of results across both TUFLOW and HEC-RAS 2D using the shallow Water equation was used as a reference benchmark to evaluate the accuracy and reliability of each approach. By systematically assessing model performance under varying conditions, the study aims to clarify where discrepancies arise and their significance.

The outcomes of this research will help practitioners better understand the strengths and limitations of e-Water CHUTE relative to other modelling tools. Ultimately, the goal is to support more robust rock chute designs and enable more confident, evidence-based decision-making in urban and rural waterway management.

Keywords

Rock Chute, e-water CHUTE, waterways, bed control structure, urban waterways

Introduction

The longitudinal slope of a waterway is one of the most important geomorphological controls on channel behaviour and is closely linked to erosion and sediment transport processes. Steeper channel slopes are typically associated with increased stream power, shear stress, and flow velocity, which in turn elevate the risk of bed incision and bank erosion. Geomorphological assessments that identify an elevated erosion risk may recommend a range of management responses, including modifying the longitudinal profile using bed-grade-control structures.

Rock chutes are one of the commonly used bed-grade control structures in waterway management. Rock chutes may be defined as relatively short, steep grade-control structures that provide a stable transition from one bed gradient to a lower bed gradient through rock armouring (DSE, 2007).

Rock chutes dissipate energy by forcing the flow to transition from supercritical to subcritical conditions, where the hydraulic jump occurs. In other words, we force the hydraulic jump, which is a highly turbulent and destructive hydraulic phenomenon, to happen on the chute where the risk of scouring is low due to the rock protection. Therefore, the formation of a hydraulic jump on rock chutes is critical to ensure that energy dissipation occurs where the channel is protected by rocks.

The CHUTE program, developed by the CRC for Catchment Hydrology and distributed through the eWater Toolkit, is a simplified hydraulic design tool for rock chutes used in waterway management. The program assists in estimating the location of the hydraulic jump on rock chutes under a range of design discharges and basic hydraulic parameters such as flow velocity, water depth, Froude number, and Total Energy Loss (TEL). The program is referenced and applied within several Australian waterway design guidelines, including Melbourne Water Constructed Waterway guidelines and Technical Guidelines for Waterway Management. As such, understanding the capabilities and limitations of the CHUTE program is essential to ensure its appropriate application in the design of bed-grade control structures. Figure 1 illustrates a typical chute diagram with a graphical explanation of chute elements.

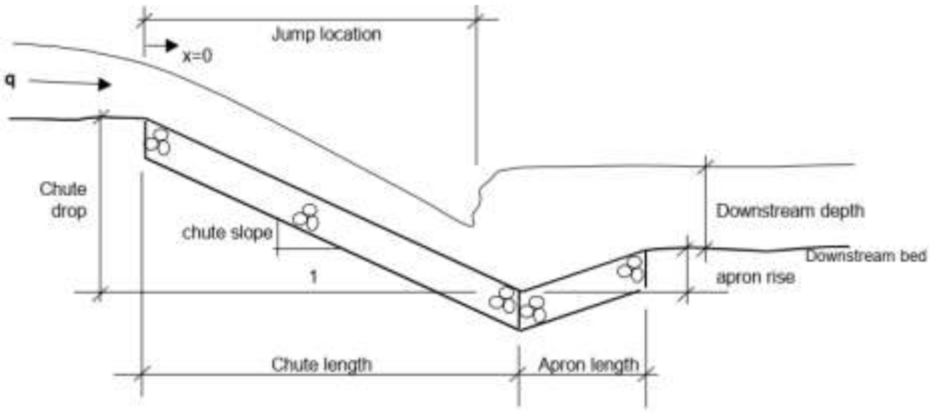

Figure 1 Schematic rock chute (Source: CHUTE design manual guidelines)

Methodology

In the design of a rock chute, it is critical that flow transitions from supercritical to subcritical conditions on the chute structure before the apron. If a hydraulic jump does not occur on the chute, there is an increased risk of scour formation downstream. This can result in erosion due to increased flow velocity, shear stress, and turbulence over steep sections of the channel.

During the chute design process, key parameters such as chute drop, width, and length are adjusted to promote the formation of a hydraulic jump within the chute. As a result, the ability of hydraulic models to accurately estimate the location of the hydraulic jump is critical to the safe and reliable design of rock chute structures. A second important consideration in chute design is the accurate estimation of hydraulic parameters, such as velocity, shear stress, and Froude number, to support a cost-effective design while maintaining structural stability and erosion resistance.

Rock chutes are typically designed under two main scenarios: (1) stabilising river reaches experiencing severe scour to arrest upstream migration of a channel headcut, and (2) locally reducing channel bed gradients between control points where the channel is unarmed by introducing one or more chutes to break the longitudinal slope of the river. A case study representing the second scenario was selected to assess the eWater CHUTE model's performance under relevant hydraulic conditions. The outputs from eWater CHUTE were compared with results from HEC-RAS 1D, HEC-RAS 2D, and TUFLOW models to evaluate the consistency of hydraulic predictions across different modelling platforms.

Case study – Warrenheip Creek, Ballarat, Victoria

Warrenheip Creek is a small, confined waterway on the outskirts of Ballarat, Victoria. The creek is characterised by a deep, narrow channel, with steep banks approximately 4–5 m high and a typical channel-bed width of 3–4 m. Ongoing channel incision occurs along sections of the creek, contributing to increased instability of the channel. Two rock chute structures with trapezoidal cross-sections were designed for this study reach. The chutes are connected by an intermediate compound channel with a relatively gentle bed slope of 0.015 m/m. This Creek is an urban waterway, so, in accordance with urban waterway design guidelines, a design flow of 1% AEP was selected for the rock chutes, equivalent to 12 m3/s. The flow rates were calculated using RORB model.

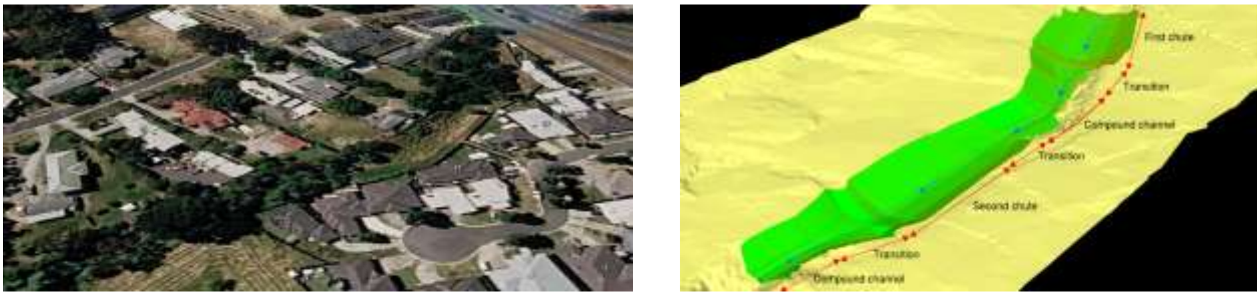

Figure 2 Warrenheip Creek (left), simulated compound channel and rock chutes (right)

Comparison of CHUTE results with different boundary conditions

A comparison of CHUTE results was undertaken with different boundary conditions. According to the CHUTE design manual, four options are available as the downstream boundary condition of the rock chute. These options are Rating Table, Normal depth, Y critical+10% and Average Y critical and normal depth, with the first three options being more common. The user manual for CHUTE recommends using the rating table over the other options, with the critical depth option introduced as the most conservative. According to the package user manual, the rating table should be extracted from a hydraulic model such as HEC-RAS.

Figure 3 illustrates the CHUTE input parameters as well as the extracted rating table from TUFLOW modelling downstream of rock chutes for Warrenheip Creek, respectively. The hydraulic condition is assessed by CHUTE as supercritical downstream of the structure, which contradicts the results of TUFLOW modelling, where the flow is subcritical. This is because CHUTE uses the chute width to convert the flow rate (Q) to flow per meter (q) downstream of the structure. However, this assumption is not always valid due to potential differences between the base of the chute structure and the downstream channel's base width.

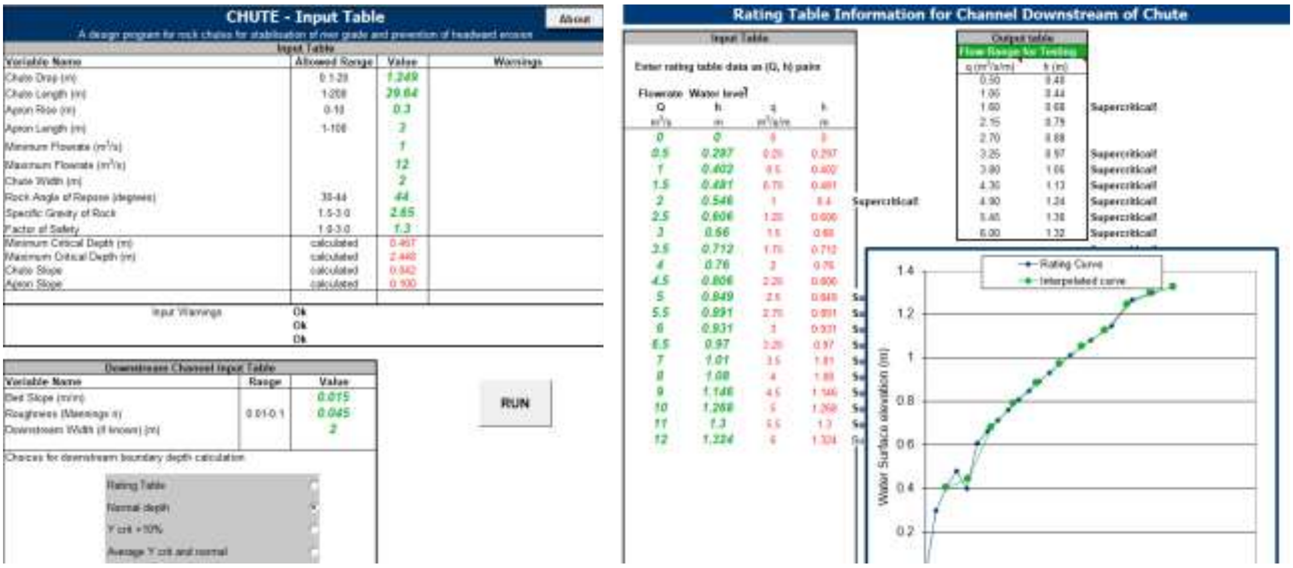

Figure 3 CHUTE input parameters (left), the rating table downstream of the chute from TUFLOW

Due to the program limitation in full assessment of the hydraulic condition downstream of the structure, CHUTE concludes that the hydraulic jump passes from the rock chute which is contrary to the results of CHUTE analysis with other boundary conditions. Figure 4 illustrates the results of the program analysis under three boundary conditions.

Results																
Calculations for range of flows				d/s boundary depths (m)			Specific Energy			Jump Conditions						
Q (m^3/s)	d50 Normal (mm)	d50 Calculated (mm)	Bank Angle (degrees)	Used	Rating table	Critical	u/s	d/s	Extra	Scenario	Description	Location (m)	Depth (m)	Y conj.	Loss	Friction loss
1.00	139	139	22	0.402	0.402	0.2943	0.441	0.481	0	2	jump in chute; OK	22.278	0.203	0.410	0.027	0.883
2.10	228	228	22	0.441	0.4412	0.4826	0.724	0.73	0	2	jump in chute; OK	23.820	0.333	0.671	0.043	0.900
3.20	302	302	22	0.681	0.6808	0.6390	0.959	0.962	0	2	jump in chute; OK	24.084	0.443	0.887	0.056	0.889
4.30	368	361	22	0.788	0.7876	0.7782	1.167	1.167	0	2	jump in chute; OK	24.494	0.540	1.078	0.067	0.882
5.40	428	417	22	0.883	0.8826	0.9058	1.359	1.36	0	2	jump in chute; OK	25.108	0.630	1.253	0.077	0.871
6.50	485	473	22	0.970	0.97	1.0249	1.537	2.361	0.819	3	er! Jump past end of	32.640	0.000	0.000	0.000	0.126
7.60	536	521	22	1.052	1.052	1.1375	1.706	2.329	0.612	3	er! Jump past end of	32.640	0.000	0.000	0.000	0.326
8.70	588	565	22	1.126	1.1262	1.2448	1.867	2.33	0.444	3	er! Jump past end of	32.640	0.000	0.000	0.000	0.486
9.80	637	607	22	1.244	1.2436	1.3476	2.021	2.377	0.342	3	er! Jump past end of	32.640	0.000	0.000	0.000	0.593
10.90	684	646	22	1.297	1.2968	1.4467	2.17	2.381	0.184	3	er! Jump past end of	32.640	0.000	0.000	0.000	0.738
12.00	729	684	22	1.324	1.324	1.5425	2.314	2.428	0.057	3	er! Jump past end of	32.640	0.000	0.000	0.000	0.835

Results																
Calculations for range of flows				d/s boundary depths (m)			Specific Energy			Jump Conditions						
Q (m^3/s)	d50 Normal (mm)	d50 Calculated (mm)	Bank Angle (degrees)	Used	Rating table	Critical	u/s	d/s	Extra	Scenario	Description	Location (m)	Depth (m)	Y conj.	Loss	Friction loss
1.00	139	139	22	0.416	0.402	0.2943	0.441	0.49	0	2	jump in chute; OK	22.059	0.203	0.410	0.027	0.874
2.10	228	228	22	0.698	0.4412	0.4826	0.724	0.813	0	2	jump in chute; OK	21.621	0.334	0.671	0.043	0.816
3.20	302	297	22	0.950	0.5808	0.6390	0.959	1.094	0	2	jump in chute; OK	20.961	0.443	0.886	0.056	0.758
4.30	368	356	22	1.187	0.7876	0.7782	1.167	1.354	0	2	jump in chute; OK	20.092	0.542	1.075	0.065	0.697
5.40	428	406	22	1.416	0.8826	0.9058	1.359	1.602	0	2	jump in chute; OK	19.037	0.635	1.244	0.071	0.635
6.50	485	447	22	1.640	0.97	1.0249	1.537	1.84	0	2	jump in chute; OK	17.803	0.725	1.399	0.076	0.571
7.60	536	482	22	1.860	1.052	1.1375	1.706	2.073	0	2	jump in chute; OK	16.395	0.813	1.540	0.077	0.505
8.70	588	502	22	2.077	1.1262	1.2448	1.867	2.301	0	2	jump in chute; OK	14.837	0.899	1.670	0.077	0.439
9.80	637	518	22	2.292	1.2436	1.3476	2.021	2.525	0	2	jump in chute; OK	13.101	0.987	1.787	0.073	0.373
10.90	684	523	22	2.505	1.2968	1.4467	2.17	2.748	0	2	jump in chute; OK	11.160	1.079	1.890	0.066	0.307
12.00	729	516	22	2.717	1.324	1.5425	2.314	2.965	0	2	jump in chute; OK	9.011	1.177	1.977	0.055	0.242

Results																
Calculations for range of flows				d/s boundary depths (m)			Specific Energy			Jump Conditions						
Q (m^3/s)	d50 Normal (mm)	d50 Calculated (mm)	Bank Angle (degrees)	Used	Rating table	Critical	u/s	d/s	Extra	Scenario	Description	Location (m)	Depth (m)	Y conj.	Loss	Friction loss
1.00	139	139	22	0.324	0.402	0.2943	0.441	0.445	0	2	jump in chute; OK	23.083	0.203	0.410	0.027	0.919
2.10	228	228	22	0.531	0.4412	0.4826	0.724	0.73	0	2	jump in chute; OK	23.563	0.333	0.671	0.043	0.899
3.20	302	302	22	0.703	0.6808	0.6390	0.959	0.967	0	2	jump in chute; OK	23.976	0.443	0.887	0.056	0.885
4.30	368	361	22	0.856	0.7876	0.7782	1.167	1.178	0	2	jump in chute; OK	24.363	0.540	1.078	0.067	0.871
5.40	428	416	22	0.996	0.8826	0.9058	1.359	1.371	0	2	jump in chute; OK	24.705	0.630	1.252	0.076	0.861
6.50	485	466	22	1.127	0.97	1.0249	1.537	1.551	0	2	jump in chute; OK	25.014	0.715	1.414	0.084	0.851
7.60	536	513	22	1.251	1.052	1.1375	1.706	1.721	0	2	jump in chute; OK	25.300	0.796	1.565	0.091	0.843
8.70	588	556	22	1.369	1.1262	1.2448	1.867	1.884	0	2	jump in chute; OK	25.562	0.874	1.709	0.097	0.835
9.80	637	596	22	1.482	1.2436	1.3476	2.021	2.039	0	2	jump in chute; OK	25.806	0.949	1.846	0.103	0.828
10.90	684	635	22	1.591	1.2968	1.4467	2.17	2.189	0	2	jump in chute; OK	26.030	1.021	1.977	0.108	0.822
12.00	729	671	22	1.697	1.324	1.5425	2.314	2.334	0	2	jump in chute; OK	26.242	1.092	2.103	0.113	0.816

Figure 4 CHUTE results for Warrenheip Creek with boundary conditions of rating table (top), normal depth (middle) and critical depth (bottom)

The program conclusion in the scenario where the program uses the rating table encourages designers to make the rock chute wider or longer to force the hydraulic jump to occur within the structure. Whereas the results of the model analysis under normal or critical depth scenarios reassure designers regarding the location of the jump. These results suggest limitations in the model's ability to reliably perform hydraulic analysis when the rating-table option is applied and challenge the prevailing perception that the critical-depth assumption represents the most conservative design scenario.

Location of the hydraulic jump

The location of the hydraulic jump was assessed by comparing the water-level profiles and Froude numbers predicted by the hydraulic models and eWater CHUTE along the proposed chute. The hydraulic models show good agreement in the predicted water profile along the channel. eWater CHUTE is the only program that does not follow the same pattern, with the steep water profile extending along the full length of the rock chute, including the chute apron.

The assessment of Froude number results from TUFLOW, HEC-RAS 1D, and HEC-RAS 2D shows general agreement between these hydraulic models. The flow is supercritical over the upper half of the chute before transitioning to subcritical conditions over the lower half. eWater CHUTE is the only program that produces a different outcome, indicating that the hydraulic jump passes through the chute. This discrepancy appears to be related to the way eWater CHUTE uses the chute base width to assess the downstream hydraulic condition as either subcritical or supercritical.

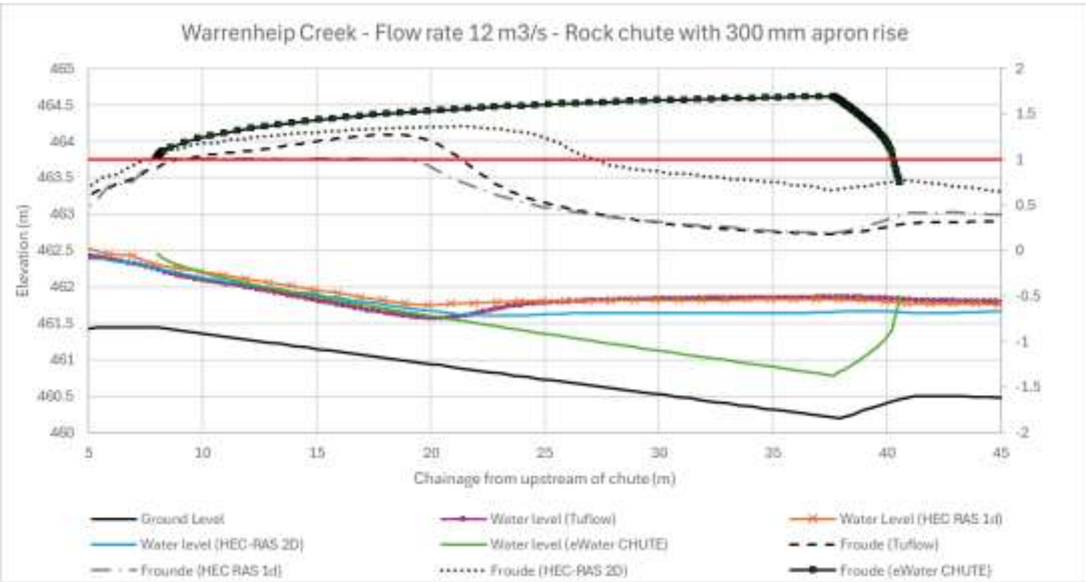

Figure 5 Comparison of water profile and Froude number for a flow rate of 12 m^3/s

To compare the model results under a consistent condition in which all models predict a hydraulic jump on the structure, the chute base width was increased from 2 m to 3 m. The hydraulic modelling was then updated using the revised geometry across all modelling programs. Figure 6 presents the results of this test.

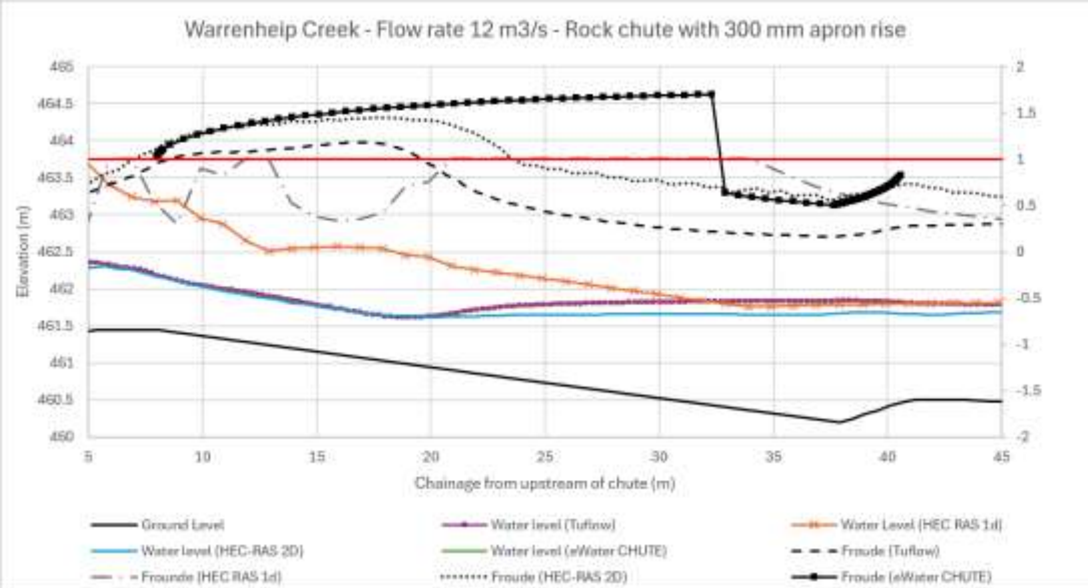

Figure 6 Water profile and Froude number for a rock chute with a widened base width of 3 m and a flow rate of 12 m^3/s

The comparison of hydraulic parameters for the widened chute shows that, although eWater CHUTE predicts a hydraulic jump on the chute structure, there remains a difference between the predicted hydraulic jump location from eWater CHUTE and the two-dimensional hydraulic models. Under this scenario, the results from eWater CHUTE and HEC-RAS 1D are relatively similar. However, given the greater capability of two-dimensional hydraulic models to represent hydraulic conditions, and the close agreement between HEC-RAS 2D and TUFLOW, the results suggest that both eWater CHUTE and HEC-RAS 1D diverge from the best estimate of the hydraulic jump location in this case.

Flow velocity

Using the revised geometry described above where the chute structure is widened, flow velocity results were compared across CHUTE and the other hydraulic modelling programs. At a flow rate of 12 m3/s, the 1D and 2D hydraulic models show good agreement, particularly TUFLOW and HEC-RAS 2D. In contrast, CHUTE predicts flow velocities approximately 1.5 times higher than the average velocities estimated by TUFLOW and HEC-RAS 2D.

The comparison for the lower flow rate of 4 m^3/s indicates a wider range of estimated velocities across the modelling programs. However, the velocities estimated by eWater CHUTE remain the highest and appear to be overestimated. The sudden drop in flow velocity predicted by CHUTE is not observed in the profiles generated by the other modelling programs.

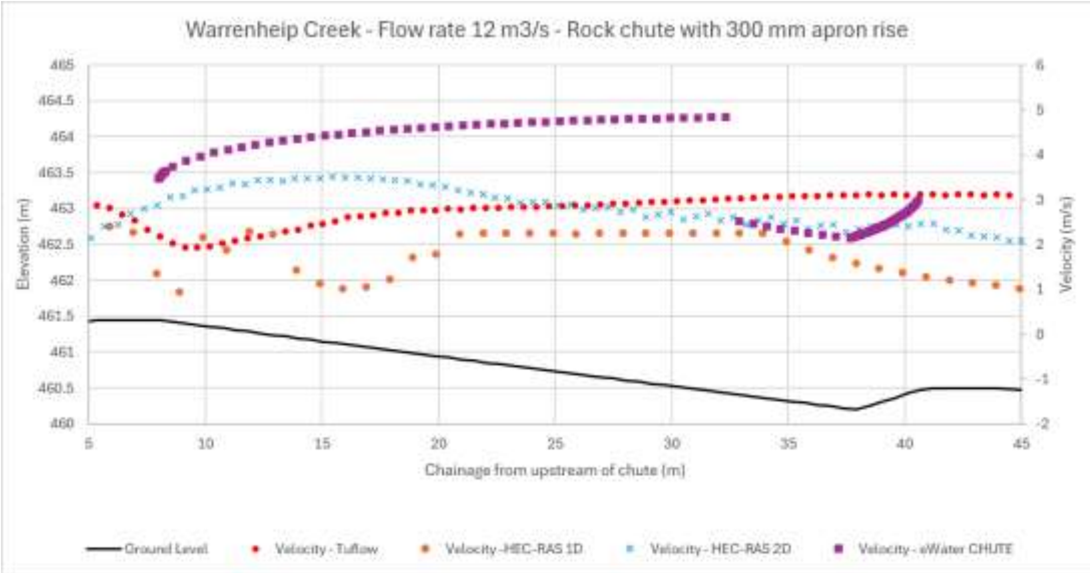

Figure 7 Distribution of flow velocity for the flow rate of 12m^3/s

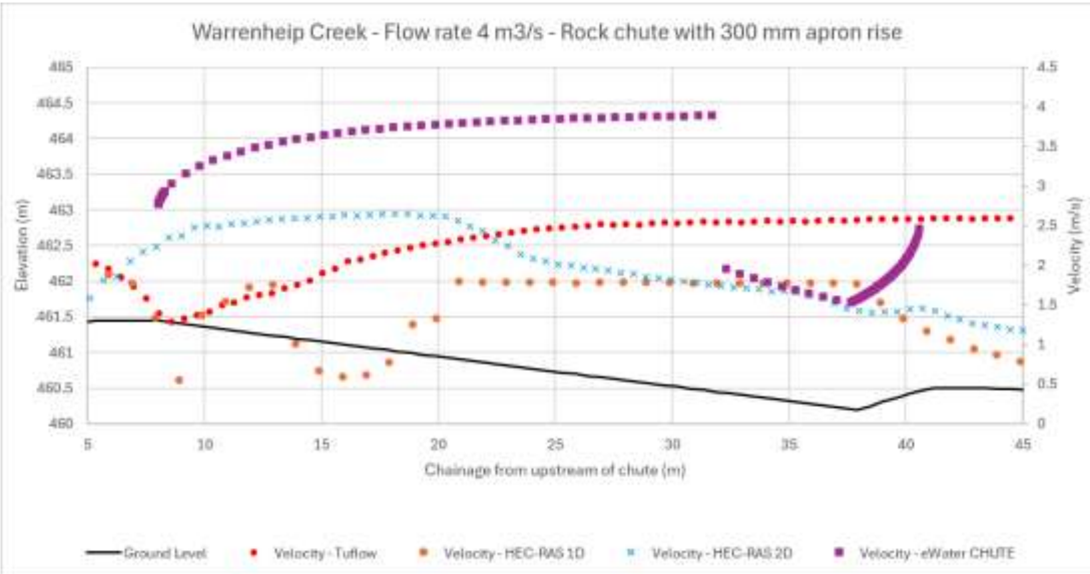

Figure 8 Distribution of flow velocity for the flow rate of 4m^3/s

Rock sizing

To verify the rock size calculated using the e Water CHUTE model, rock sizes were estimated using several well-known equations. The results were then compared with those from e Water CHUTE. The empirical equations were applied using hydraulic outputs from both the HEC-RAS 2D and TUFLOW models. The following methods were included in the assessment.

- HEC-11 is an American Federal Highway Administration (FHWA) guideline for the design of riprap revetments used for channel bank stabilisation and erosion control in streams and rivers. The manual provides empirical procedures for determining rock sizing and revetment configuration based primarily on flow velocity, channel geometry, and hydraulic stability considerations.
- The shear-based riprap sizing approach presented by Price (2021) was also assessed. The method relates the median rock size (D50) to the applied boundary shear stress using a safety factor to account for hydraulic stability and uncertainty. This approach was recommended as a

supplementary Australian riprap sizing method suitable for application with modern 2D hydraulic modelling outputs. The adopted equation is: D50 = $S_f \times \tau$.

The calculated D_{50}, based on a flow rate of 12 m3/s, are presented in Table 2 and Figure 9.

Table 2 Calculated Riprap Sizes from Different Empirical Methods – 12 m³/s

Method	D_{50} (mm) – HEC RAS 2D	D_{50} (mm) – TUFLOW
HEC 11	230	380
Shear-Based Riprap Method	300	350
Shields	480	450
e-Water CHUTE (rating table)	528	
e-Water CHUTE (critical depth)	529	
e-Water CHUTE (normal depth)	493	

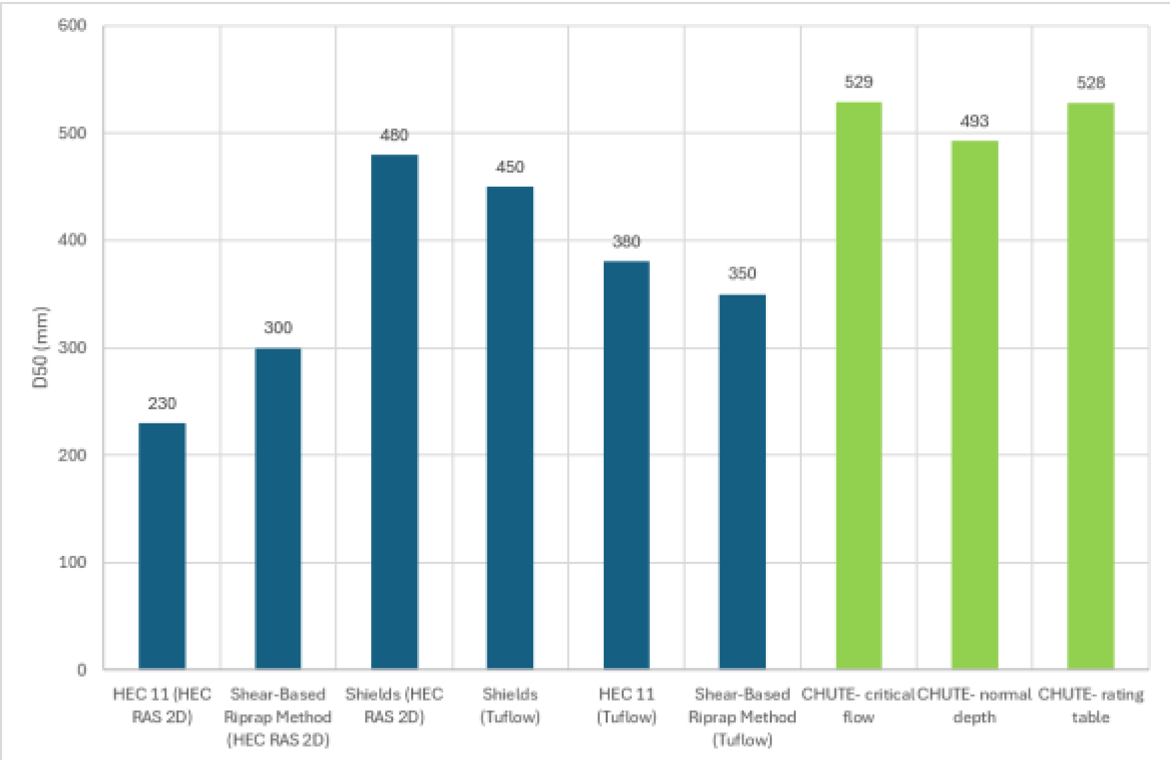

Figure 9 Comparison of estimated rock size using different equations

The estimated rock size ranges from 230 mm to 529 mm. These lower values do not appear reasonable for a rock chute where a highly turbulent hydraulic jump is expected. This is probably because the method presented by HEC 11 is to estimate the size of rocks for rock beaching where flows are less turbulent than a hydraulic jump.

Although there is not a big difference between the estimated rock size by eWater CHUTE and the calculated size of rocks using other equations, the size of rocks using eWater CHUTE is approximately 100 mm larger than most methods.

Conclusions

This study compared the performance of commonly used hydraulic modelling tools for the design of rock chutes, with a particular focus on the eWater CHUTE program's ability to predict the location of the hydraulic jump and key hydraulic parameters. The results demonstrate that, although eWater CHUTE program is a widely adopted design tool in Australia, particularly in Victoria, its performance can diverge significantly from more sophisticated hydraulic models under certain hydraulic conditions.

The comparison undertaken for the Warrenheip Creek case study shows strong agreement between TUFLOW and HEC-RAS 2D (shallow water equations) in predicting water levels, Froude number distribution, and the location of the hydraulic jump along the chute. In contrast, eWater CHUTE produced different outcomes for some scenarios, particularly when the downstream boundary condition was defined using a rating table. Under these conditions, the model frequently predicted that the hydraulic jump would pass through or beyond the chute, contrary to the results of the 1D and 2D hydraulic models.

Comparison of flow velocity predictions further reinforces these conclusions. The estimated rock size across different approaches ranges from 230 to 529. In practice, these values will be rounded up to the next whole number, such as 250 mm and 550 mm. The values calculated by eWater CHUTE are higher than the values estimated by the results of modelling from other programs. It is concluded that the higher values estimated by eWater CHUTE are because of overestimating flow velocity along the chute structure.

Overall, this study demonstrates that eWater CHUTE has limitations in predicting hydraulic parameters critical to rock chute design. While a hydraulic model is required to generate a rating table for eWater CHUTE, transferring the design process back to CHUTE after developing a hydraulic model appears unnecessary. Based on the findings of this study, 1D hydraulic models, and more importantly 2D hydraulic models, provide a more robust framework for estimating chute geometry. Rock sizing can then be undertaken using hydraulic outputs from these models and equations suitable for chute conditions, where hydraulic jumps are expected to occur.

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