Review of Zhang et al. "Hybrid Modeling on 3D hydraulic features of a step-pool unit."

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This paper presents results from a novel application of CFD modelling to a step-pool unit. This study is innovative and the results greatly enhance our understanding of the detailed 3D hydraulic characteristics of step-pools, which present a challenging environment for direct measurement. The results will also advance our understanding of the role of hydraulics in the formation and stability of step-pools and the effect of step-pools on flow resistance. The identification of two discrete hydraulic structures that function as energy dissipators in a step-pool unit, and the discussion of the energy dissipation of 2D compared with 3D hydraulic structures, are of particular interest. I would like to congratulate the authors on this study.

However, I have two main concerns about the way the results are explained, described and interpreted. On one level, these concerns are not particularly serious and can be relatively easily addressed in the paper to make it worthy of publication, but on a more fundamental level they show that there is some misunderstanding of the main underlying topics of the study.

Firstly, in the description of the results, there is misunderstanding of the coherent and persistent hydraulic structures in the step-pool, specifically in relation to the terms "wake", "hydraulic jump", "jet" and "regime". The authors in effect are using their own working versions of these terms. I shall discuss the use of each of these terms in turn.

The region at the toe of the step is referred to as a "wake" or "wake zone" (lines 258 and 261) and the flow recirculation cell at the toe of the step is referred to throughout the paper as a "wake vortex". The term "wake" usually refers to the region immediately downstream of an object or roughness element in flow whose dimensions are much larger than those of the object or roughness element. The term "wake" cannot be applied to flow immediately downstream of a channel feature whose dimensions are similar to those of the flow, and that acts as channel topography rather than roughness. The so-called "wake" is merely the region at the toe of the step and the "wake vortex" is a transverse flow recirculation cell attached to the toe of the step.

There is indeed a hydraulic jump in the pool, but the hydraulic jump (or more usually, "jump") is repeatedly referred to as a "surface jump" and described as existing only at the surface. A hydraulic jump is a feature that occupies the entire water column; the surface feature referred to by the authors of this paper as a "jump" is in fact the flow recirculation cell of the hydraulic jump, in which flow spills backwards down the adverse surface slope generated as flow decelerates to a subcritical condition from a supercritical one.

The authors refer to a "jet" or "jets" that exist(s) above the "wake vortex" and below the "jump" that is a feature separate to the "wake vortex" and "jump". For example, lines 435-436 talk about the "segmentation" of these features. However, the impinging jet of the step and its associated recirculation cell, and the flow within the hydraulic jump below the recirculation cell of the jump, are unified and single features rather than distinct and separate features. This is especially the case with the hydraulic jump, which as mentioned previously, extends through the entire water column; the so-called "jet" is merely the fastest downstream-directed flow within the hydraulic jump.

All three features described above ("wake"/"wake vortex", "jump" and "jet") are referred to as "regimes" by the authors, when "structures", "features" or "regions" would be more appropriate terms. A regime is a region of the flow that extends across the full width (or most of the width) and depth of the flow, and over a longitudinal distance usually several times the flow width. For

example, in terms of the Froude domain, the flow regime can be described as supercritical, subcritical, or transcritical. In this respect, the flow regime in the authors' experiment and simulation is transcritical, and this describes the flow over the step-pool unit, or a number of step-pool units.

In general, the identification and description of the hydraulic coherent structures need correcting and clarifying, including the locations of these features. There are further examples in the detailed comments below.

Secondly, the discussion of shear stress, dynamic pressure, form drag, skin friction, form and grain flow resistance and flow resistance partitioning at 514-523 is both confused and confusing, and illustrates an almost total lack of understanding of these subjects. I don't know where to begin suggesting editing this section, and I can only describe this section as nonsense. In any case, this section is oxymoronic. It partitions form and grain resistance before stating that attempting such partitioning is invalid. I suggest deleting it. It is possible that conclusions regarding the relative magnitude of grain resistance and form resistance at the reach or step-pool unit scale and regarding flow resistance partitioning could be drawn from the authors' results, but it would require significant analysis further to that presented in this paper. Specifically, it would require integrating the boundary shear stress over the step-pool unit and comparing it with the total shear stress due to the downstream component of the weight of water in the step-pool unit, and making any necessary adjustments for flow non-uniformity between the inlet and outlet sections.

Detailed comments are given below, with relevant line numbers.

Line 1 replace "on" with "of" in title.

Line 16 and throughout paper. Plural of vortex is vortices.

Lines 28-29 Abrahams et al. is not an appropriate reference here. Abrahams et al. is about the relationship between step-pool geometry and flow resistance. It does not directly address the effect of step-pools on channel stability.

Lines 32-33 insert "and" between "hydraulics" and "stability". Replace "these dimensions" with "them".

Line 42-45 replace "different from" with "unlike". Replace "which result in" with "resulting from". Replace "oscillation" with "alternation". Also relevant here is the fact that formative flows of step-pools are very high discharge, typically c. 50 yr return interval, making them impractical to measure. Delete "Salt or rhodamine dilution and".

Line 56 replace "at" with "to".

Lines 85-87 and 95-96 are repetitive of lines 77-80.

Section 2.1 There are missing experimental details. What were the stepstone dimensions, initial and final step height, and step spacing?

Lines 102-103 why was Froude scaling employed as opposed to some other form of scaling? Without giving justification, any scaling method used is arbitrary.

Lines 105-106 "We did not manually build any pool features…" What does this mean, and what was the initial constructed longitudinal profile?

Line 111 What are "T runs"? Delete "designed". Replace "step by step" with "stepwise".

Line 114 What does “discharge change interval” mean?

Line 123 Replace “step-pool-step” with “step-pool”.

Line 125 Replace “upstream area of” with “area upstream of”. Replace “step model” with “step-pool model”.

Line 127 The acronym “KS” has not been used before and needs to be explained.

Line 140 Replace “solution” with “software”. Full stop after “platform”. Start new sentence and replace “which” with “This software”.

Lines 152-156 What effect do these added topography components have on the reliability of the CFD results?

Line 191 This is a relatively low sampling period and frequency. How were the sampling period and frequency selected? High frequency turbulent fluctuations will be missed and will not contribute to shear stress, dynamic pressure or TKE. What effect will this have on the results?

Lines 200-201 Unit of measurement missing: 3 cm? How do these RMSE values compare to key length scales such as Step stone size, step height, step spacing etc.?

Lines 222-225 This is verbose, and the separation of total pressure into dynamic and hydrostatic components is trivial and it is not necessary to describe it.

2.4 Data Processing: there are missing calculations: how were bed shear stress and the forces acting on step stones calculated?

Line 255 delete “as the main flow”.

Line 258 replace “deviated” with “separated”. I suggest better and further explanation here. It is true that the jet at Y =-18 cm does not impinge on the bed but the jets at all three sections are separated from the bed by a vortex (flow recirculation cell); the jet at Y = -18 cm does not impinge on the bed because the vortex here extends further downstream than that at the other two sections and then merges with the jet.

Line 260 replace “feature” with “features”. Replace “limitation” with “reduction” or “contraction” or similar.

Line 269 and throughout paper. Replace “at the upstream area of” and “at the upstream of” with “upstream of”

Lines 271-272 “point of separation of the jet from the step face” would be better than “detaching point”. The point of separation of the jet and the contraction section need to be explained and described because it’s not clear where they are. “flow concentrates” is also confusing and inaccurate. I suggest using the phrase “high velocity regions”.

Lines 272, 274 and 276 “lower top elevations” and “higher top elevations” are confusing phrases. I suggest “low/high points within the step crest”.

Lines 273-275 “discrete vortexes near the bed surface” and “the gaps between the wake vortexes near the bed are filled with high speed flows”; “3D flow separation cells at the toe of the step with transverse axes separated in the transverse direction by regions of high speed flow” would be better. They expand in the longitudinal direction only with an increase in discharge. Also, the high

speed regions are centred on the contact points of the step stones and the flow separations cells are centred on the centres of the step stones, which is the reverse of your description.

Line 275 “contact points” would be better than “connecting points”.

Line 277-278 replace “pool bottom” with “base of the pool”. Replace “shrink” with “are less pronounced”. The jet is referred to here but was not mentioned in the description of the section at X0+15; mention in description of both sections to avoid confusion.

Line 278 As mentioned in the general comments above, the hydraulic jump is not a regime, it extends throughout the water column and it has flow velocities close to zero in its flow recirculation cell close to the surface.

Lines 281-282 There is no such thing as a surface jump.

Line 283 What does “the drop of flow velocity can be found in sections X0-6 and X0+2” mean?

Line 294 TKE is not turbulence intensity. The latter is dimensionless and is normally estimated as the RMS of turbulent velocity fluctuations normalised by the mean longitudinal velocity. Replace “overlaps” with “coincides”.

Lines 294-295 “high flow velocities in the upstream area of the step limits the development of turbulence”. This conclusion cannot be drawn because correlation does not indicate causation, but moreover, high mean flow velocity generally coincides with low TKE, and vice versa, because where TKE is high, it has been extracted from the energy of the main flow. The two flow properties are two sides of the same coin and it is incorrect to say one causes the other.

Lines 297 and 299, etc. as mentioned in the general comments, this region is not the wake of the step stones.

Lines 299-300 etc. as mentioned in the general comments, the jump is neither at the surface nor above the jet.

Line 302 Turbulent energy dissipation is not synonymous with TKE, so do not alternate between the two phrases. The highest TKE occurs near the interfaces with the jet because this is a region of high fluid shear.

Line 304 why is there a decrease in flow velocity with an increase in discharge? Replace “lead” with “leads” and “limitation” with “reduction”.

Line 311 delete “with a length of 50 cm”.

Line 314 replace “as the regime of jet” with “due to the presence of the jet”.

Line 316 replace “where the” with “of” and delete “shows up” and “to the”.

Line 319 Insert “pool” between “negative” and “slope”.

Line 332 replace “vortex” with “turbulent”.

Lines 335-336 the “vortex stretched across the entire channel width near the surface is the flow recirculation cell of the hydraulic jump, and the “discrete streamwise streaky vortexes close to the bed” are flow recirculation cells attached to the toe of the step formed by the separation of the jet from the step face.

Line 340 The thickness of the hydraulic jump is the flow depth.

Line 341 delete “in the pool”. The “jump regime” is the flow recirculation cell of the hydraulic jump. Replace “fades away” with “loses identity”.

Lines 343-345 I suggest for final sentence “On the negative slope, coherent structures mainly follow protruding grains (micro-scale bed structures but do not show streaky features as they do upstream of the step, even though the grain sizes are similar.”

Line 352 “point of flow separation of the jet from the step face” is better. However, the separation of the jet from the step face has not been properly described and needs a detailed description in section 3.1.1.

Lines 353 and 372 Replace “connection” with “contact”.

Line 355 Insert “of the jet” between “Impinging point” and “in the pool”.

Line 356 replace “at the locations more downstream” with “at locations further downstream”.

Lines 357-359 Explain

Line 370 replace “shear stress is further concentrated” with “The highest values of shear stress occur”.

Line 371 replace “top elevation” with “maximum height” and “influence” with “influences”.

Line 374 Replace “configuration” with “shape”.

Lines 376-377 insert “on” between “and” and “some”. Delete “comparing with surrounding grains”.

Line 384 replace “keeps increasing” with “increases”.

Line 385 replace “enhanced” with “increased”.

Line 388 replace “turns the” with “changes”. How can the lift force be downwards? This does not make sense.

Line 390 replace “turns” with “changes direction to”.

Line 391 insert “of magnitude” between “orders” and “smaller”.

Lines 391-395 Only lift and drag forces were mentioned in the methods and they were not given as x and z components. In other words, this x, y and z coordinate system for forces has not been mentioned before. The “bank stones” have also not been mentioned before. Insert “of any component” after “the y component of flow force has the largest magnitude”. Why is the transverse force component greater at the banks? Replace “enhanced” with “increased”. Replace “concentrates” with “is greatest”.

Line 401 How and why do C_D and C_L vary, and what does this mean?

Line 404 What does “keystone” mean here and why is stone 4 the keystone? Explain in methods.

Line 416 Replace “distinguished” with “the well developed”.

Line 419 replace “transverse inconsistencies of” with “a 3D”.

Line 421-423. This is incorrect. The vortexes (flow recirculation cells) at the step toe occur downstream of the centres of the step stone and the high speed regions between the vortices occur

downstream of the contacts between step stones. Also, whether the jet impinges on the bed or not is more related to momentum than kinetic energy.

Line 428 The jet that does not impinge on the bed at the base of the pool is not a surface jet. It still has a flow recirculation cell above it and is a classic jump. Surface jets are associated with oscillatory jumps (standing waves).

Lines 429-432 Delete.

Lines 435-438 This is incorrect. Delete up to and including “wakes vortex (Fig. 4)”.

Lines 438-439 “intense mid-profile fluid shearing within the hydraulic jump and between the flow recirculation cells at the step toe and the jet plunging over the step face generates high TKE” is better.

Lines 448-449 Why is this noteworthy?

Figure 13. The symbols are illegible.

Lines 463-465 This does not makes sense. Also, insert “at 49.9 l/s” between “examined” and “(Fig. 13)”.

Line 467 Insert “It is” before ”Worth noting”.

Line 474 insert “over a 2D step” between “vertical drop” and “with the”.

Line 486 Replace “turbulence with “TKE”. Replace “visualized” with “demonstrated”.

Line 487 Insert “up to a discharge of 43.6 l/s” after “flow increased”.

Line 488 The flow recirculation cell of the hydraulic jump expanded.

Line 492 Replace “variation patterns” with “response”.

Line 493 Replace “result” with “results”. The change in jet penetration angle was not mentioned in the results.

Line 494 replace “leaves” with “creates”.

Line 495 This contradicts lines 296-297 which state that the “wake” vortices have high TKE.

Line 499 More accurately, the jet angle and momentum influence both vortex dimensions and pool scour.

Line 500 replace “distributed” with “located”.

Line 503 replace “on the surrounding hydraulics in the pool” with “and pool hydraulics”.

Line 505 replace “get mixed” with “lose their identity”.

Line 508 Replace “on balance” with “in summary”.

Line 512 Replace “distribution” with “distributions”.

Lines 531 Delete “Considering that the gravity of the step stones does not change”.

Line 547 replace “tolerate” with “experience”. Is it static pressure? I would have thought dynamic water pressure would be transmitted through the pores to the bases of the stones.

Line 571 what does “in an integral form” mean?

Line 573 and onwards. Energy dissipation rate and TKE are not synonymous. I suggest sticking to TKE, which is precise because it’s what you have presented.

Line 576 replace “the expansion of” with “an increase in”.

Line 578 replace “restrained” with “small”. Replace “enhanced” with “greater”.

Lines 578-580 Dynamic pressure, shear stress and form drag: No, delete.

Lines 581-582 What are the implications of the variation in lift force? Replace “varying range” with “variation”.

Line 585 replace “to” with “of”.