STORMWATER 2010
National Conference of the Stormwater Industry Association
Conference Proceedings

APPROPRIATE CRITERIA FOR THE SAFETY AND STABILITY OF PEOPLE IN STORMWATER DESIGN

Author/s:
Dr Thomas D Shand, Project Engineer, Water Research Laboratory, University of NSW.
Assoc Prof Ronald J. Cox, Associate Professor, University of NSW.
Mr Grantley Smith, Senior Project Engineer, Water Research Laboratory, University of NSW.
Mr Mathew Blacka, Project Engineer, Water Research Laboratory, University of NSW.

Abstract

The safety of people in floodways or on flooded streets is of major concern in urban stormwater design and floodplain management. Human activity in floodways is inevitable with much development already in flood prone areas. The safety of people can be compromised when exposed to flows which exceed their ability to remain standing or traverse a waterway.

Over the last four decades, a number of numerical and laboratory-based experimental studies have been undertaken within Australia and internationally to define the limits of human stability within differing flow regimes. Human stability has been found to be influenced by numerous factors, however, the two most important parameters are flow depth and velocity, with depth dictating whether loss of stability is by sliding (friction) or tumbling (moment) failure.

This paper reviews early studies investigating this problem, collates and discusses subsequent experimental testing, empirical expressions and safety guidelines derived from these studies. The entire data-set of relevant experimental results is re-analysed and tolerable flow conditions related to human safety are presented.

1. Introduction

Current design guidelines for safety of people on floodways in Australia are simplistic, generally based on the product of flow depth (D) and velocity (V). The current Australian Rainfall and Runoff (ARR) guidelines (I.E.Aust, 1987) stipulate that *"to prevent pedestrians being swept along streets and other drainage paths during major storm events, the product of velocities and depths in streets and major flow paths generally should not exceed 0.4* m^2/s*"*. In contrast, the velocity-depth relationships that define unsafe wading and vehicle instability as presented within the 1986 NSW Floodplain Development Manual (DPW, 1986) and adopted within the 2005 Floodplain Development Manual (DIPNR, 2005) do not indicate constant D.V relationships (see Figure 1), but do place upper bounds on both depth (0.8 m) and velocity (2.0 ms^{-1}) for people to wade safely. Figure 1 highlights the discrepancy between the respective Australian Rainfall and Runoff and Floodplain Development Manual guidelines.

Besides the safety of the general community, safety on floodways is important to rescue workers who are frequently required to operate in hazardous conditions. Emergency Management Australia (EMA) is the national government agency responsible for managing disaster situations. EMA has published a series of manuals to assist other agencies and local governments in the planning for emergency situations including flooding. In regard to "Flood Hazard", EMA advice is that "wading by able-bodied adults becomes difficult and dangerous when the depth of still water exceeds 1.2 m or when the velocity of shallow water exceeds 0.8 ms^{-1} and for various combinations of depth and velocity between these limits" (EMA, 1999).

The two recognised hydrodynamic mechanisms by which stability is lost include *moment instability* and *friction instability* (refer Figure 2). A more comprehensive discussion is presented within Jonkman and Penning-Rowsell (2008) but, in brief, moment (toppling) instability occurs when a moment induced by the oncoming flow exceeds the resisting moment generated by the weight of the body (Abt *et al*., 1989). This stability parameter is sensitive to the buoyancy of a person within a flow and to body positioning and weight distribution. These factors are further discussed within the following analysis. Frictional (sliding) instability occurs when the drag force induced by the horizontal flow impacting on the legs and torso is larger than the frictional resistance between a persons feet and the ground surface. This stability parameter is sensitive to weight and buoyancy, clothing, footwear and ground conditions. A third cause of instability described within Jonkman and Penning-Rowsell (2008) is *floating,* which occurs when the water depth reaches a significant level and buoyancy forces lift the person from the ground regardless of velocity. Under floating conditions neither sliding or moment instability are applicable.

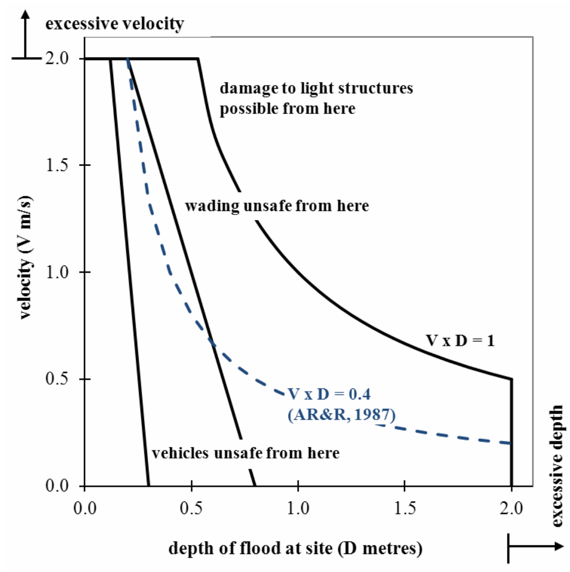

Figure 1 Depth-velocity relationships for floodway design (adapted from: Department Public Works, NSW, 1986) with the AR&R (1987) suggested D.V = 0.4 superimposed

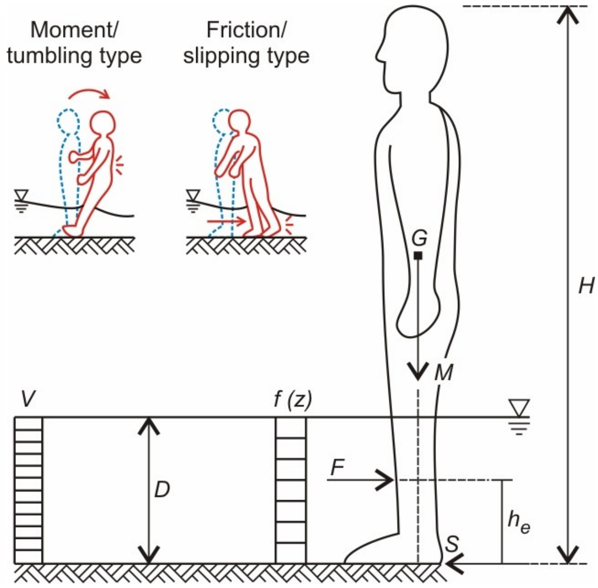

Figure 2 Models of moment and frictional instability (adapted from: Takahashi et *al*., 1992)

2. Review of Previous Investigations

2.1. Experimental Studies

Since the early human stability testing of children by Foster and Cox (1973), a number of laboratory and field-based studies have been undertaken both within Australia and internationally. Abt et al. (1989) undertook laboratory testing of 20 adults in flows up to 3 ms^{-1} and depths of up to 1.2 m. Takahashi et al. (1992), investigated the safety of dock workers during wave overtopping of harbour structures using a funneled basin. These latter tests included detailed measurements of force, friction and sliding which were used to compare with a computational model developed during the study. Karvonen et al. (2000) used a moving platform within a test basin to examine the stability of rescue workers in the RESCDAM project and Yee (2003) expanded the earlier work of Foster and Cox (1973) by testing the stability of four young children. Jonkman and Penning-Rowsell (2008) report on a study by the United Kingdom Flood Hazard Research Centre where a professional stuntman was subjected to varying flow depths and velocities within a quasi-natural waterway. A complete review of previous study test conditions and findings is presented in Cox et al. (2010) and summarised in Table 1.

While these studies have primarily focused on similar parameters including the height (H; m) and mass (M; kg) of subjects and the flow depth (D; m) and velocity (V; ms^{-1}), some variation in testing facilities and regimes exists across all the studies. A comparison of the observed limiting flow regimes (D.V) as function of subject Height*Mass (H.M) for all experiments is presented in Figure 3. The data shows significant scatter, although a general increase in tolerable flow with increased subject (H.M) is evident. The linear regression line is indicated for all data and for all data excluding that of Abt et al. (1989), with regression coefficients of $r^2 = 0.50$ and 0.80 respectively.

Table 1 Comparison of experimental test parameters.

	Foster and Cox	**Abt et al.**	**Takahashi et al.**	**Karvonen et al. (RESCDAM)**	**Yee**	**Jonkman (FHRC)**
Year	**1973**	**1989**	**1992**	**2001**	**2003**	**2008**
Setup	Flume	Flume	Funnelled basin	Moving platform through basin	Flume	Sluice-controlled flood relief channel
Surface	Painted timber	Concrete, turf, gravel and steel.	Metal load cell	Steel grating	Painted timber	Concrete
Slope	Horizontal	1(V):115(H) and 1(V):38(H)	Horizontal	Horizontal	Horizontal	1(V):100(H)
Subject Characteristics	Children (9 -13 yrs)	Civilian adults with safety equipment	Adults	Rescue workers with safety equipment	Children	Professional stuntman
Subject Action	Standing, walking, turning and sitting	Standing, turning and walking	Standing	Standing, turning and walking	Standing, walking	Standing, walking
Failure mechanism	Subject feels unsafe or loses footing	Subject looses footing	Subject looses footing	Subject looses footing	Subject feels unsafe or loses footing	Subject looses footing
Number of subjects	6	20	3	7	4	1
Range of D (m)	0.09 - 0.41	0.43 - 1.2	0.44 - 0.93	0.4 - 1.1	0.18 – 0.53	0.26 – 0.35
Range of V (ms^{-1})	0.76 - 3.12	0.82 - 3.05	0.58 - 2.0	0.6 - 2.6	0.89 – 2.12	2.4 – 3.1
Range of D.V (m^2s^{-1})	0.16 - 0.52	0.71 - 2.13	0.64 - 1.26	0.6 - 1.3	0.33 – 0.55	0.78 – 0.91
Range of H.M (mkg)	32 - 53.2	62.3 - 172.8	106.6 - 133.6	77 - 195	20.8 – 32.5	116

The Abt et al. (1989) data indicates substantially higher stability than all other data for adults (refer Figure 3). This cannot fully be explained. It is partially explained in that the purpose of the experiments was to determine the absolute limit of stability of the subjects to failure (personal communication with Abt, SR, 10 October 2003), that is the subjects were made to fail as opposed to determining if safety was compromised and the limits for a safe rescue action which was the objective of the Karvonen et al. (2000) study. Clothing had lower drag than that applicable to testing by Takahashi et al. (1992) and Karvonen et al. (2000) and subject performance was noted to improve with practice.

Ramsbottom et al. (2004) analysed both the Abt et al. (1989) and Karvonen et al. (2000) data and concluded that, based on a Student T test, the data sets were significantly different in statistical terms. The remainder of experimental data analysed during this study is more consistent with that of Karvonen et al. (2000); thus supporting the hypothesis that the Abt. et al. (1989) tests are from a different statistical population.

Of note are markedly differing tolerable D.V values for subjects of similar height and mass in the Abt et al. (1989), Takahashi et al. (1992) and Karvonen et al. (2000) tests. In the case of Takahashi et al., differing clothing, footwear and ground surfaces were tested which may partially explain the variation. However, there were lesser variables tested within the Abt et al. and Karvonen et al. tests. Variation in tolerable flow during these tests is attributed to "training" of the subject (Abt, pers. com, 2009); the subject learns how to position the body so to best resist the flow. The lowest stability values (D.V) for each subject was, in most cases, the first exposure test. These first exposure values of the Abt et al. (1989) data are more consistent with data from the other experimental sources.

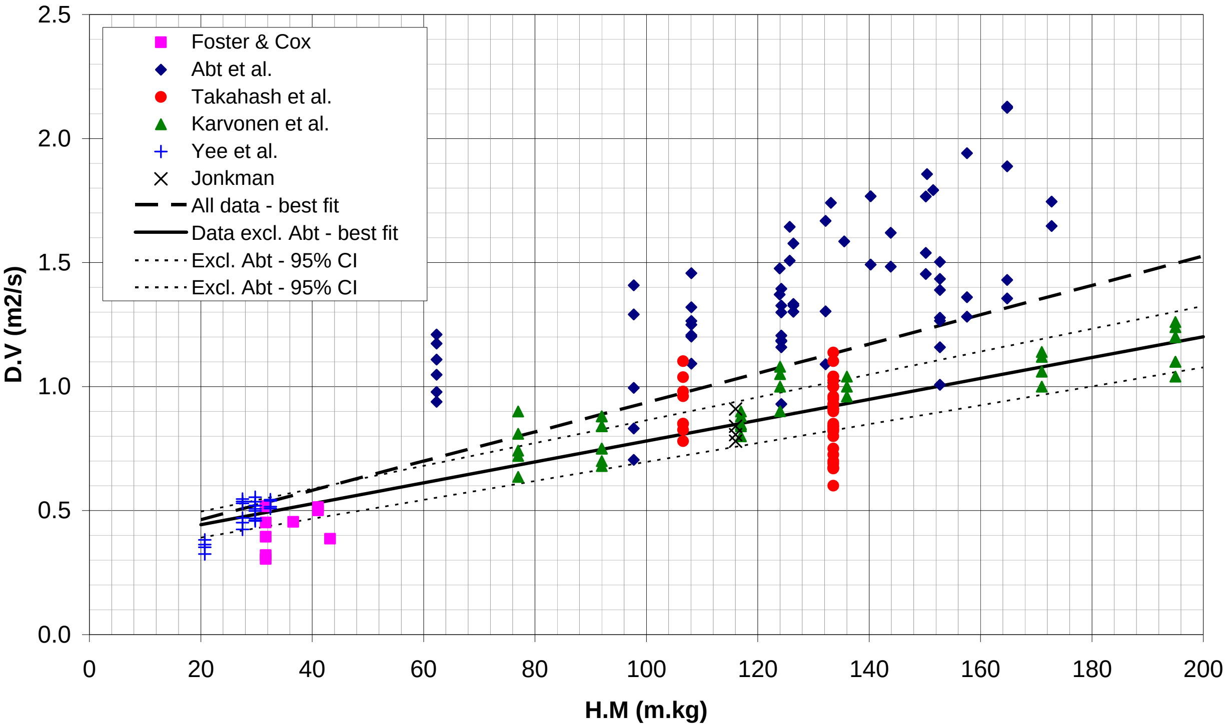

***Figure 3** Combined limiting flow rates (D.V) found as function of subject Height*Mass (H.M) including the linear regression line for all data (- - -), for all data excluding that of Abt et al. (1989) (—) and the 95% confidence intervals for all data excluding that of Abt et al. (····).*

Additionally, the specific differences in the terms of reference must be considered. Definition of the stability limit varied between studies. Such definitions included: when the subject felt unsafe and/or grasped the flume sides (i.e. Foster and Cox, 1973; Yee, 2003), when subjects either lost stability or manoeuvrability (i.e. Karvonen et al., 2000) or when subjects were washed off their feet (i.e. Abt et al., 1989). Additionally, subjects within the Takahashi et al. (1992) study were required only to stand, whereas some degree of activity including walking and turning were required in the other studies.

2.2. Empirical Expressions

Based on the result of experimental testing, a number of empirical expressions for human stability have been derived by both the original experimental investigators (i.e. Abt et al., 1989; Karvonen et al., 2000 and Ishigaki et al., 2005, 2008, 2009) and by third parties (i.e. Lind et al., 2004 and Ramsbottom et al., 2004, 2006). A full discussion of derived expressions is presented within Cox et al. (2010) with a summary presented in Table 2.

Table 2 Comparison of derived empirical expressions

Reference	Expression	Notes
Australian Rainfall and Runoff (I.E.Aust, 1987)	$D.V < 0.4$	-
Abt et al. (1989)	$D.V = 0.0929\left[e^{0.022(2.2M+H/25.4)+1.09}\right]^2$	-
Karvonen et al. (2000)	$D.V = 0.006H.M + 0.3$ $D.V = 0.004H.M + 0.2$ $D.V = 0.002H.M + 0.1$	Good Conditions Normal Conditions Poor Conditions
Lind et al. (2004)	$D.V_{cr} = K$	Coefficient, K, determined for specific data and varies for males and females and for differing clothing
DIPNR (2005)	$V = -3.3D + 2.7$	Limits: $V \leq 2.0\ ms^{-1}$; $D \leq 0.8$ m
Ramsbottom et al. (2006)	$FloodHazard = D(V + 0.5) + DF$ Where DF = Debris factor	Critical flood hazard: 0 Safe 0 – 0.75 Caution 0.75 – 1.5 Dangerous for some 1.5 – 2.5 Dangerous for most < 2.5: Dangerous for all
Ishigaki et al. (2005, 2008, 2009)	$M_0 = V^2 D/g + D^2/2$	Critical criterion for safe evacuation, M_0, ranges from 0.1 to 0.25 dependent on age and evacuation type

Lind et al. (2004) tested a variety of empirical expressions and ultimately found an expression dependent on a single calibrated coefficient to provide the best fit. However, this coefficient was dependent on whether the subject is male or female and the clothing type worn. This type of expression is not therefore particularly useful in defining safety criteria for a general population.

The flood hazard expression of Ramsbottom et al. (2006) was derived from both the Abt et al. (1989) and Karvonen et al. (2000) experimental data. The expression includes a constant of 0.5, intended to preserve some hazard in low velocity, high depth flows and a *debris factor* ranging between 0 and 1. The justification for either is, however, questionable with an expression excluding the 0.5 constant providing better statistical agreement with experimental data and, to the authors' knowledge, the effect of debris on stability remains so far untested. Additionally, there is no upper depth limit provided. Thus, large depths at low velocities are not necessarily classed as hazardous. This is impractical as once a subject becomes buoyant, they are inherently unstable and safety becomes dependent upon swimming ability.

The expression of Ramsbottom et al. (2006) is compared to all available experimental data within Figure 4 with an assumption of 0 debris factor. Results show that almost all children (Foster and Cox and Yee data) are unable to tolerate flows within the *low hazard zone* (Flood Hazard < 0.75). Almost all experimental data including the lower 'untrained' values of Abt et al. (1989) lie within the *dangerous for some*, or *moderate hazard* regime (0.75 to 1.5). Data within the *dangerous for most*, or *significant hazard* (1.5 to 2.5) is limited to the upper 'trained' values of Abt et al. and the larger Karvonen et al. test subject (H.M = 195).

In general, critical flows within the derived expressions are defined according to the product of flow depth and velocity. While some expressions use human characteristics of height and mass, such dependence makes the expression difficult to apply to a general population for planning or design purposes. Overall, while significant scatter exists in the experimental data, empirical guideline expressions presented within the NSW Floodplain Development Manual (1986, 2005) and Australian Rainfall and Runoff Guidelines (1987, 1998) tend to remain conservative for adult populations but not for children of low H.M. Additionally, except for the NSW Floodplain Development Manual (1986, 2005), the guidelines do not include upper thresholds of flow depth and velocity.

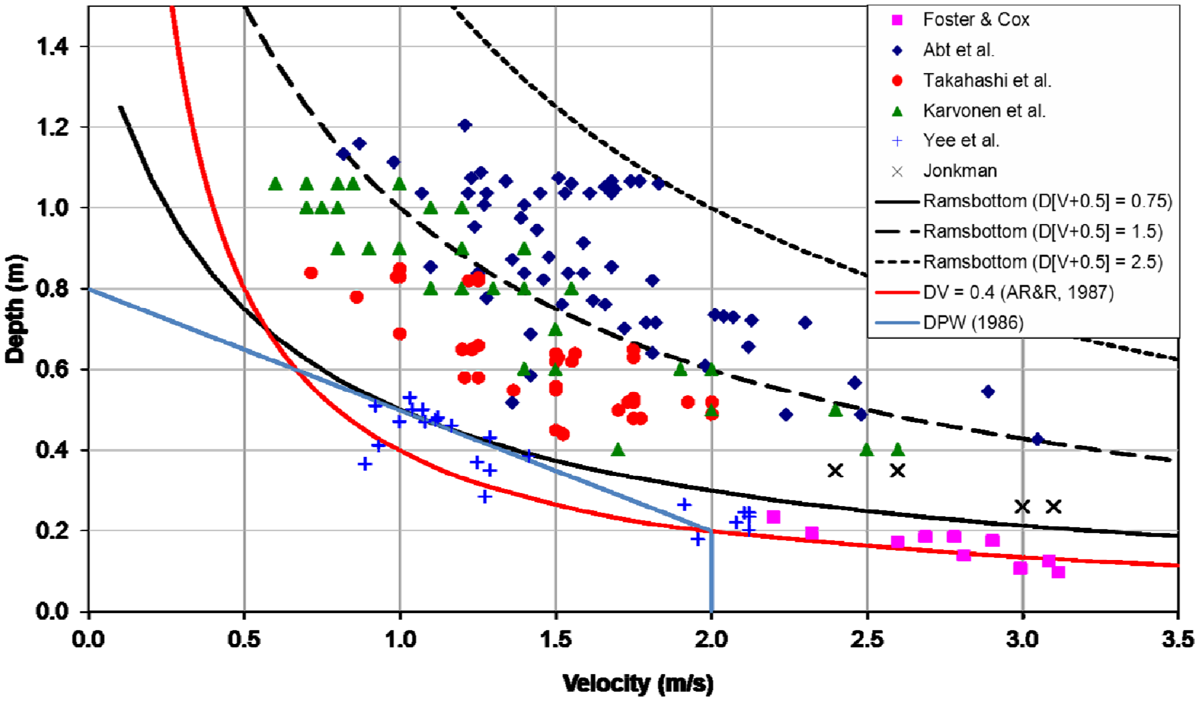

Figure 4 Comparison of Ramsbottom et al. (2006) stability thresholds (note: debris factor is assumed 0) with all available experimental data and the 1986 NSW Floodplain Development Manual Guidelines (DPW, 1986) and the current Australian Rainfall and Runoff Guidelines (I.E.Aust, 1987).

2.3. Computational studies

Analytical and computational studies have been undertaken by Takahashi et al. (1992), Keller and Mitsch (1993), Yee (2003) and Lind et al. (2004) to assess weight, drag and frictional forces as a function of flow depth and velocity and thus determine limits of stability. The human form is simulated by either simple shapes such as a cylinder (i.e. Keller and Mitsch, 1993) or parallelepiped (i.e. Lind et al., 2004) or by more complex forms including legs and a body (i.e. Takahashi et al., 1992) and in some cases a moment stability mass lever arm which approximates the distance from the heel to center of gravity. Such a lever arm provides a mechanism to simulate the increased stability achieved by 'leaning' into a flow.

While computational methods are able to test a wide variety of human and flow characteristics, results are highly dependent on the assumed coefficients of friction and drag. A friction coefficient of 0.3 and drag coefficient of 1.2 was adopted within the Keller and Mitsch (1993) study. However, no sensitivity assessment was evident and Takahashi et al. (1992) measured friction coefficient values between 0.6 and 1.0 with a lowest value of 0.4 for concrete covered with relatively slippery seaweed. Similarly, Takahashi et al. (1992) found coefficient of drag values to range between 0.6 and 1.1 depending on the subject and clothing worn. Yee (2003) adjusted the friction and drag coefficients and length of the lever arm to better fit experimental data, however, accurate definition of these terms remains problematic in computational studies. It is noteworthy that within the Yee (2003) study, the lever arm length for the Abt et al. data had to be increased as the "trained" subjects used muscle/body balance to better resist the flow - effectively increasing the moment stability mass lever arm.

3. Reanalysis of experimental data

A plot of the relationship between human factors (H.M; mkg) and flow regime (D.V; m^2s^{-1}) utilizing all available experimental data for persons standing or walking in flows is presented within Figure 5. Significant scatter is observed within the data. This scatter may be attributed, in part at least, to a number of external parameters including: test surface material; subject actions (standing or moving), experience and training, clothing and footwear and physical attributes additional to height and mass including muscular development and/or other disability; the definition of stability limit (i.e. feeling unsafe or complete loss of footing).

The use of human size characteristics (H.M) as an independent variable in defining general flood flow safety guidelines is not considered practical given the wide range in such characteristics within the population. In order to define safety limits which are applicable for all persons, hazard regimes are defined for adults (H.M > 50 mkg) and children (H.M = 25 to 50 mkg). Infants and very young children (H.M < 25 mkg) are considered unsafe in any flow without adult support. These hazard regimes are plotted together with available experimental data as a function of flow depth and velocity in Figure 6.

Low hazard regimes are indicated where D.V < 0.4 m^2s^{-1} for children (H.M = 25 to 50 mkg) and D.V < 0.6 m^2s^{-1} for adults (H.M > 50 mkg). These regimes encapsulate all data points except for very small children (H.M < 25 mkg) suggesting that, excluding adverse environmental parameters, all persons (other than very small children and frail older persons) should be able to navigate waterways regardless of experience in the low hazard regime. A moderate hazard zone which is dangerous for some adults and all children is defined between D.V = 0.6 to 0.8 m^2s^{-1}. The flow value of D.V = 0.8 m^2s^{-1} defines the limit at which a professional stuntman began to lose footing within the Jonkman and Penning-Rowsell (2008) experiments and thus may be inferred to define the limiting working flow for experienced personnel such as trained rescue workers. Between flow values of D.V = 0.8 to 1.2 m^2s^{-1} is a zone of significant risk (dangerous to most), with a flow value of 1.2 appearing to provide an upper limit on tolerable flow for all experiments and across all human size characteristics except for the upper 'trained' Abt et al. (1989) data.

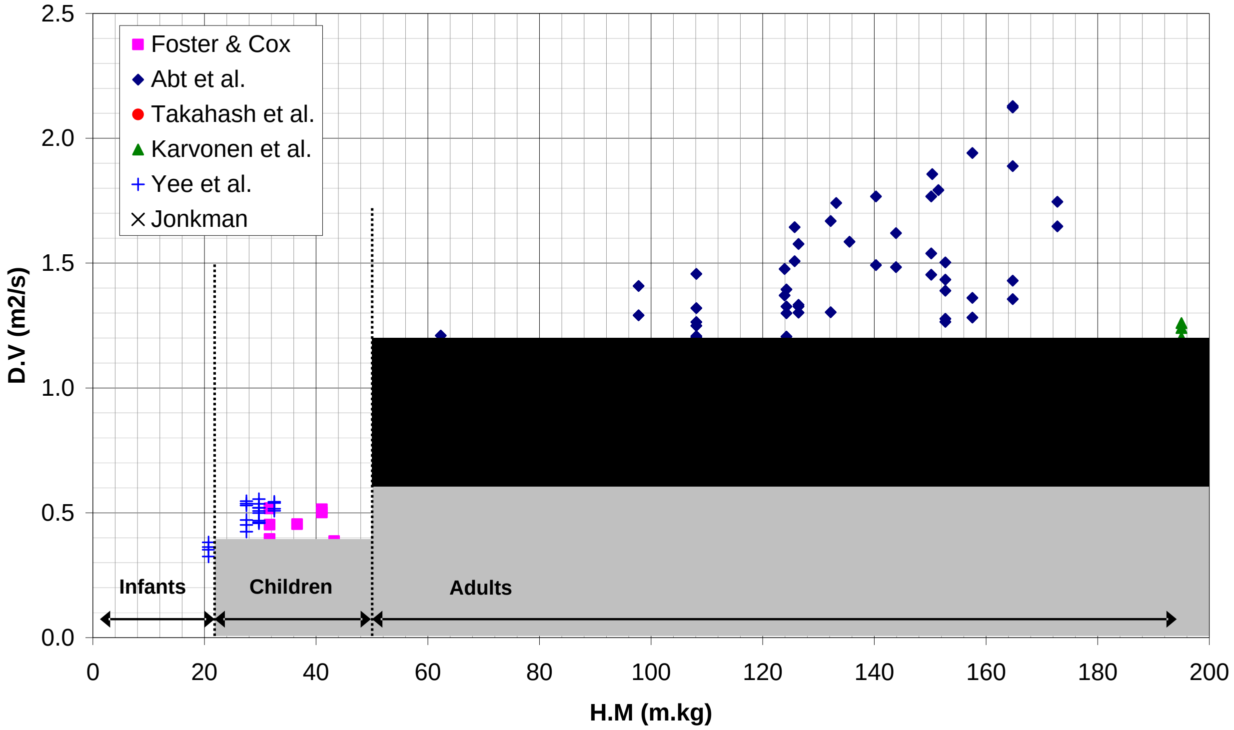

Figure 5 Flow values (D.V) indicating hazard regime as a function of subject height (H) and mass (M) for all experimental data sources. A low hazard zone (🟩) is indicated for children (H.M = 25 to 50 mkg) and adults (H.M > 50 mkg). A moderate hazard zone (🟧) which is dangerous for some adults is indicated, with D.V = 0.8 defining an upper working limit for trained adults. A significant hazard zone (🟥) which is dangerous for most adults is indicated, with higher D.V values (D.V > $1.2m^2s^{-1}$) constituting extreme hazard, dangerous for all adults.

Due to limitations of experimental data at depths greater than 1.2 m for adults and 0.5 m for children and at velocities greater than 3.2 ms^{-1}, these are suggested as upper bounds on the applicability of safety values. This upper depth limit of 1.2 m for adults is in agreement with that suggested by Emergency Management Australia advice (Cox et al., 2004) and is theoretically justified as subject buoyancy will rapidly decrease stability at greater depth, with safety then becoming dependent on swimming ability. This is an assumption which cannot be made for the population as a whole, especially children where an upper depth limit of 0.5 m is suggested. Similarly, a number of the subjects within experimental tests commented that maintaining footing was difficult in very rapid flows regardless of depth (Jonkman and Penning-Rowsell, 2008). Based on these comments and the lack of data at velocities greater than 3.2 ms^{-1}, specifying an upper bound of 3ms^{-1} on the applicability of safety values is prudent.

While tests of stability when sitting have been excluded from analysis within Figures 5 and 6, studies have shown that once footing is lost stability is further reduced due to the greater surface area presented to the flow and that footing is unlikely to be regained unless a reduction in flow conditions occurs (Cox et al., 2004).

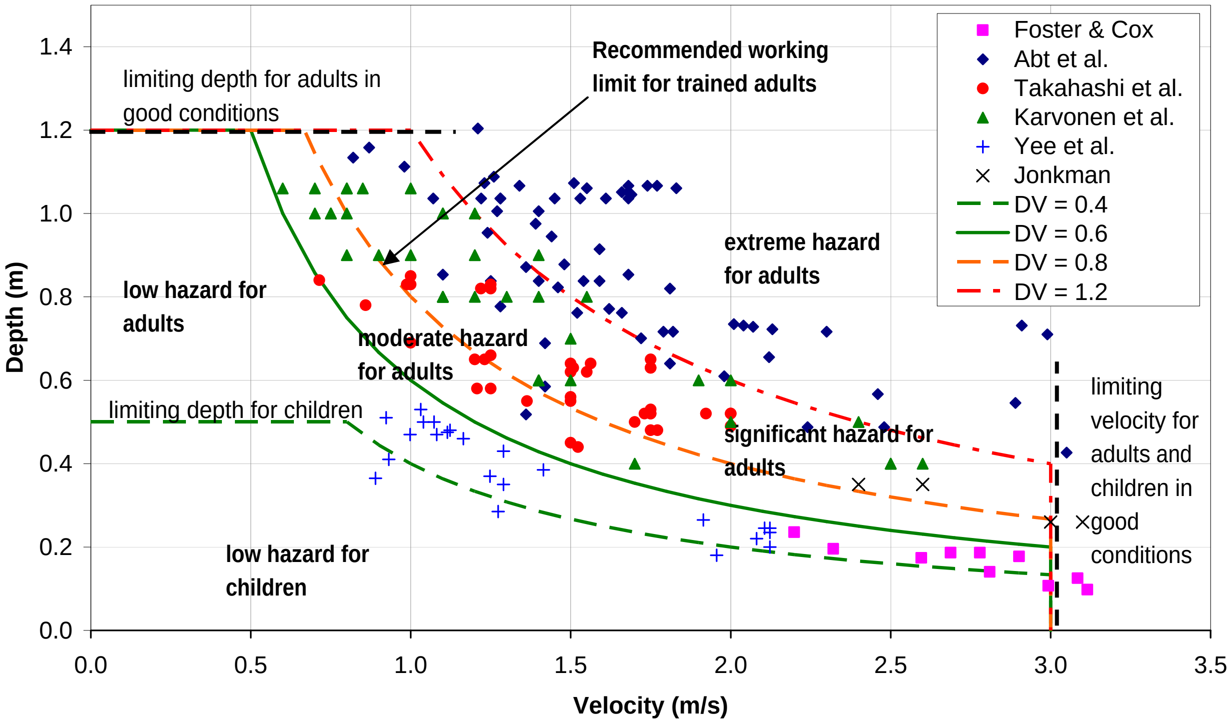

Figure 6 Proposed hazard regimes as a function of depth and velocity and compared to available experimental data.

4. Conclusions

Human stability within floodways has been found to be dependent on many factors. The two most important factors are flow depth and velocity, with depth found to dictate whether loss of stability is by sliding (friction) or tumbling (moment) failure. High depths increase buoyancy and reduce friction underfoot typically resulting in tumbling failure while low depth-high velocity flows may cause sliding instability. Cox et al. (2004) suggest that high depth, low velocity flows are more dangerous as, once footing is lost, a person is more likely to be swept away and drowned.

Over the last four decades, a number of laboratory-based experimental studies have been undertaken within Australia and internationally to define the limits of stability within differing flow regimes. Significant scatter is observed within the individual data sets and, to a more significant degree, when all data sets are combined. This scatter may be attributed to a number of external parameters including the test surface material, required subject actions, subject experience, clothing and footwear and the definition of stability limit.

Based on the results of these studies, a number of empirical and computational models have been derived to predict safe flow thresholds. However, due to the typical exclusion of the above variables, model agreement with experimental data has often been poor. The current Australian Rainfall and Runoff (ARR) guidelines (I.E.Aust, 1987) stipulate that *"to prevent pedestrians being swept along streets and other drainage paths during major storm events, the product of velocities and depths in streets and major flow paths generally should not exceed 0.4* m^2/s*"*. It is concluded that this guidance is conservative for adults and equates to a low hazard for most children.

Two sets of safety criteria have been developed based on re-analysis of data collected during previous laboratory and field investigations. For children with a height and mass product (H.M) of between 25 and 50, low hazard exists for flow values of $D.V < 0.4\ m^2s^{-1}$, with a maximum flow depth of 0.5 m regardless of velocity and a maximum velocity of $3.0\ ms^{-1}$ at shallow depths ($D < 0.2$ m). Under these flow regimes, the children tested retained their footing and felt *"safe"* in the flow. For adults ($H.M > 50$), low hazard exists for flow values of $D.V < 0.6\ m^2s^{-1}$ with a maximum depth limit of 1.2 m and a maximum velocity of $3.0\ ms^{-1}$ at shallow depth ($D < 0.3$ m). Moderate hazard exists between $D.V = 0.6$ and $0.8\ m^2s^{-1}$, with a tolerable working flow regime of $D.V < 0.8\ m^2s^{-1}$ recommended for trained safety workers or experienced and well equipped persons. Significant hazard exists between $D.V = 0.8$ to $1.2\ m^2s^{-1}$, with the upper limit of stability observed during the majority of investigations of $D.V = 1.2\ m^2s^{-1}$. Above this flow rate hazard is extreme and should not be considered safe for standing or traversing.

Hazard regimes as a function of limiting flow values for infants, children and adults are presented within Table 3.

Table 3 Flow hazard regimes for infants, children and adults

DV (m^2s^{-1})	**Infants, small children (H.M ≤ 25) and frail/older persons**	**Children (H.M = 25 to 50)**	**Adults (H.M > 50)**
0 – 0.4	**Extreme Hazard; Dangerous to all**	**Low Hazard[1]**	**Low Hazard[1]**
0.4 – 0.6		**Significant Hazard; Dangerous to most**	
0.6 – 0.8		**Extreme Hazard; Dangerous to all**	**Moderate Hazard; Dangerous to some[2]**
0.8 – 1.2			**Significant Hazard; Dangerous to most[3]**
> 1.2			**Extreme Hazard; Dangerous to all**

[1] Stability uncompromised for persons within laboratory testing program at these flows (to maximum flow depth of 0.5 m for children and 1.2 m for adults and a maximum velocity of $3.0\ ms^{-1}$ at shallow depths).
[2] Working limit for trained safety workers or experienced and well equipped persons ($D.V < 0.8\ m^2s^{-1}$)
[3] Upper limit of stability observed during most investigations ($D.V > 1.2\ m^2s^{-1}$)

It should however be noted that loss of stability could occur in lower flows when adverse conditions are encountered including:

- **Bottom conditions**: uneven, slippery, obstacles;
- **Flow conditions**: floating debris, low temperature, poor visibility, unsteady flow and flow aeration;
- **Human subject**: standing or moving, experience and training, clothing and footwear, physical attributes additional to height and mass including muscular development and/or other disability, psychological factors;
- **Others**: strong wind, poor lighting, definition of stability limit (i.e. feeling unsafe or complete loss of footing).

As described within Cox et al. (2003), there is a lack of test data for very young children and frail/older persons. These populations are unlikely to be safe in any flow regime and, as such, care is required in locating aged care and retirement villages as well as childcare centres and kindergartens.

ACKNOWLEDGEMENTS

This project was made possible by funding from the Federal Government through the Department of Climate Change and Energy Efficiency. This report and the associated project have been undertaken as part of the update of the Australian Rainfall and Runoff Guidelines by Engineers Australia.

REFERENCES

Abt, S.R, Wittler, R.J, Taylor, A and Love, D.J. (1989). Human Stability in a High Flood Hazard Zone, *Water Resources Bulletin*, American Water Resources Association, 25 (4), pp 881-890.

Cox, R.J. & Ball, J.E. (2001). Stability and Safety in Flooded Streets, *Conference on Hydraulics in Civil Engineering*, Hobart, The Institution of Engineers, Australia.

Cox, R.J., Yee, M. and Ball, J.E. (2004). Safety of People in Flooded Streets and Floodways. *8th National Conference on Hydraulics in Water Engineering*, *Gold Coast*. The Institution of Engineers, Australia.

Cox, R.J., Shand, T.D. and Blacka, M.J. (2010). Appropriate Safety Criteria for People in Floods. *WRL Research Report 240.* ARR Project No. 10, prepared for Institution of Engineers Australia. 22p.

Department of Public Works, (1986), *Floodplain Development Manual,* New South Wales Government, Sydney, Australia.

Department of Infrastructure, Planning and Natural Resources, (2005) *NSW Floodplain Development Manual,* New South Wales Government, Sydney, Australia.

EMA (1999) *Managing the Floodplain*. Australian Emergency Management Series, Part 3, Volume 3, Guide 3, Emergency Management Australia, Canberra.

Foster, D.N. and Cox, R.J. (1973). Stability of Children on Roads Used as Floodways, *Technical Report No. 73/13,* Water Research Laboratory, The University of New South Wales, Manly Vale, NSW, Australia.

Institution of Engineers, Australia (1987) *Australian Rainfall and Runoff*, Vol. 1&2. (Ed: Pilgrim, D.H.) Institution of Engineers, Australia.

Ishigaki, T., Baba, Y., Toda, K. and Inoue, K. (2005): Experimental study on evacuation from underground space in urban flood, *Proc. of 31st IAHR Congress* on CD-ROM, Seoul.

Ishigaki T., Onishi Y., Asai Y., Toda K. and Shimada H. (2008a). Evacuation criteria during urban flooding in underground space, *Proc. of 11th ICUD*, Scotland, UK. (on CD-ROM).

Ishigaki T., Kawanaka R., Onishi Y., Shimada H., Toda K. and Baba Y. (2008b). Assessment of safety on evacuation route during underground flooding, *Proc. of 16th APD-IAHR*, Nanjing, China,141-146.

Ishigaki, T., Asai, Y., Nakahata, Y., Shimada, H., Baba, Y. and Toda, K. (2009) Evacuation of aged persons from inundated underground space, in *Proceedings of the 8th International Conference on Urban Drainage Modelling*, Tokyo, 2009.

Jonkman, S.N. and Penning-Rowsell, E. (2008). Human Instability in Flood Flows. Journal of the American Water Resources Association, Vol. 44, No. 4, pp 1 – 11.

Karvonen, R.A., Hepojoki, H.K., Huhta, H.K. and Louhio, A. (2000). The Use Of Physical Models In Dam-Break Flood Analysis, Development of Rescue Actions Based on Dam-Break Flood Analysis (RESCDAM). *Final report of Helsinki University of Technology*, Finnish Environment Institute.

Keller, R.J and Mitsch, B. (1993). Safety Aspects of the Design of Roadways as Floodways, *Research Report No. 69,* Urban Water Research Association of Australia.

Lind, N., Hartford, D. and Assaf, H. (2004). Hydrodynamic models of human stability in a flood. Journal of the American Water Resources Association. February 2004.

New South Wales State Flood Plan*, (2001). Sub-Plan of the New South Wales State Disaster Plan (DISPLAN),* State Emergency Management Committee, Sydney.

O'Loughlin, G.G. and Robinson, D.K. (1998). *Urban Stormwater Management - Book 8, Australian Rainfall and Runoff - A guide to Flood Estimation,* Edited by DH Pilgrim, The Institution of Engineers, Australia.

Ramsbottom, D. Floyd, P. and Penning-Towsell, E. (2004). Flood Risks to People, Phase 2: Draft Inception Report.

Ramsbottom, D. Floyd, P. and Penning-Towsell, E. (2006). Flood Risks to People; Phase 2: Project Record. FD 2321/PR. Department for Environment Food and Rural Affairs, United Kingdom. 166p.

Takahashi, S., Endoh, K. and Muro, Z-I, (1992). Experimental Study on People's Safety against Overtopping Waves on Breakwaters, *Report on the Port and Harbour Institute,* 34 (4), pp 4-31 (in Japanese).

Yee, M. (2003). Human Stability in Floodways, *Undergraduate Honours Thesis,* School of Civil and Environmental Engineering , University of New South Wales, Sydney, Australia.