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ORIGINAL PAPER

Landslide risk: some issues that determine societal acceptance

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Abstract This paper illustrates approaches to landslide risk acceptance in various parts of the world in the context of the willingness to accept that risk, the willingness to pay to reduce the risk, and the willingness to alter the environment in the process. These factors are interlinked using the ternary 'willingness diagram' which is also used to demonstrate how such willingness may change over time and to compare a range of generic approaches to landslide remediation as well as different conceptual approaches to landslide risk management. The willingness construct is intended to provide a readily understood framework for infrastructure owners and operators, amongst others, to understand how their approach to risk management compares with those in other regions, countries and contexts. Issues relevant to the response of society and groups of individuals to landslide risk, its acceptance and management include cultural factors, regulation and planning, budgetary constraints, vehicular vulnerability, and the often limited size of the event footprint compared to the vulnerability shadow that is cast are also discussed.

Keywords Landslides · Hazard · Risk · Budgets · Environment

1 Introduction

The risks associated with landslide hazards affect many parts of the world and many different cultures. The elements at risk may include infrastructure, public service buildings, commercial property and residential property as well as the occupants and users of such facilities. The type of element at risk and the vulnerability of those elements determine what might be described as a reasonable and proportionate response to a given risk profile. However, it can be difficult to compare such responses to risk in different parts of the world

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as the varied social (cultural) factors and economic circumstances can mean that the tolerance of risk is very different.

The common affirmation that we live in a 'risk-averse society' implies that the willingness to accept, or to tolerate, risk is low. In a broad context the willingness (and/or ability) of society, or other stakeholders, to pay for risk reduction measures or to alter the environment in order to accommodate them is determined by cultural, economic, political and other factors.

This is particularly so when the alleviation of risks due to landslides is considered, as risk reduction measures can be both costly and have a significant impact upon the environment. In parts of the world such as Hong Kong, landslide risks are a part of life, albeit not daily life, for the general population. However, in the majority of places such risks are both relatively low and manifest at relatively infrequent intervals.

In this paper a scheme is set out to describe the qualitative approach to landslide risk acceptance at a conceptual level. The term 'Willingness' is introduced as a *qualitative* measure of risk acceptance (or tolerance), the acceptance of costs associated with risk reduction and with environmental change associated with such measures.

The concept is illustrated by means of examples of different approaches to risk acceptance from the UK and beyond. The concept is also illustrated in terms of different generic approaches to landslide remediation and conceptual approaches to landslide remediation. Issues relevant to the response of society and groups of individuals to landslide risk, its acceptance and management are also discussed.

The scheme is constructed not as a replacement for, or a challenge to, the sociological literature and concepts (e.g. Wachinger and Renn 2010; Tapsell et al. 2010), which most certainly have their own place, but to provide a readily understood framework for infrastructure owners and operators, amongst others, to understand how their approach to risk management compares with those in other regions, countries and contexts.

2 Willingness: risk, cost and environment

Landslide hazards are commonplace and the associated risks affect many different cultures. The elements at risk may include infrastructure (e.g. roads, rail), public service buildings (e.g. hospitals, schools), commercial property (e.g. shops, factories, offices) and residential property (e.g. blocks of flats and houses). Clearly these elements at risk will also include, to a variable degree, the risk to life and limb of the users and occupants of such facilities. The type of element at risk and the vulnerability of those elements determines what might be described as a reasonable and proportionate response to a given risk profile. However, it can be difficult to compare such responses to different risk profiles in different parts of the world as the varied social (cultural) factors and economic circumstances can mean that the tolerance of the associated risk is very different indeed. It seems clear that such varied approaches to landslide risk are driven not only by the willingness to accept risk, but also by the willingness to pay to mitigate risk and the willingness to alter the environment in the process. These factors are interlinked using the ternary 'willingness diagram' (Fig. 1).

Provided that the willingness to accept risk, to pay and to alter the environment can be described at a conceptual level, the approaches in different parts of the world and in different situations may be simply, graphically and qualitatively compared to gain a deeper understanding of the drivers for the approach to risk mitigation. The willingness diagram inter-relates three parameters, thus constraining any one of the three in terms of the relative

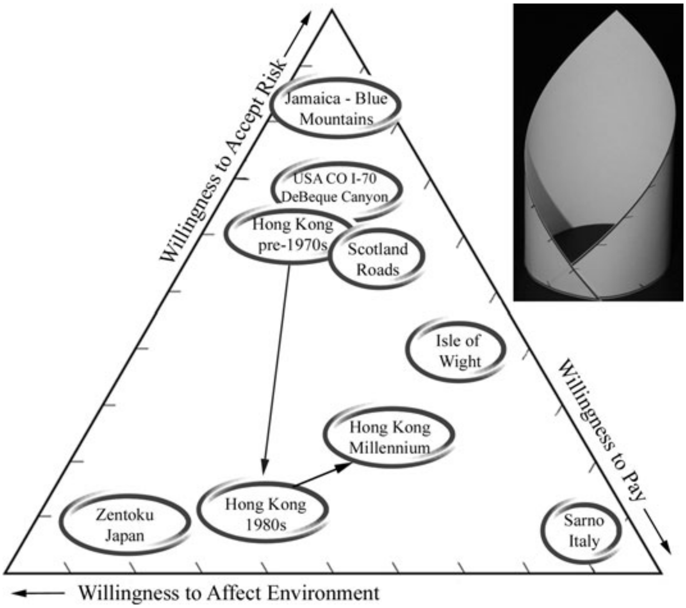

Fig. 1 The 'willingness diagram' showing the different approaches to landslide risk in the UK and other parts of the World. *Inset*: the extreme *bottom-left* and *bottom-right* corners of the ternary diagram tend to converge and the diagram might more strictly be rendered as if wrapped around a cylinder about a *vertical axis*

levels assigned to the other two. Thus, the assumption is implicit that there is a fixed amount of 'willingness' to share between the following parameters:

1. Willingness to accept (or tolerate) risk.
2. Willingness (and/or ability) to pay to reduce the risk.
3. Willingness to alter the environment in the pursuit of lower risk.

It is important to note that the diagram is not intended to highlight correct, let alone incorrect, approaches. It is intended to reflect *different* approaches which may be the result of a wide range of inputs to the decision-making process including engineering, geological, geomorphological, economic, data and information (in particular the availability of relevant data in a usable format, e.g. GIS), sociological, political, policy-led and cultural factors.

3 Approaches to risk acceptance in the UK

3.1 Isle of Wight

In the Isle of Wight (Fig. 2) the willingness to accept risk is relatively low and the willingness to pay relatively high, despite the fact that the risks are generally to property rather than to life and limb. At the same time the willingness to affect the environment is relatively low and these factors drive the use of the generally discrete and 'invisible' solutions that are implemented.

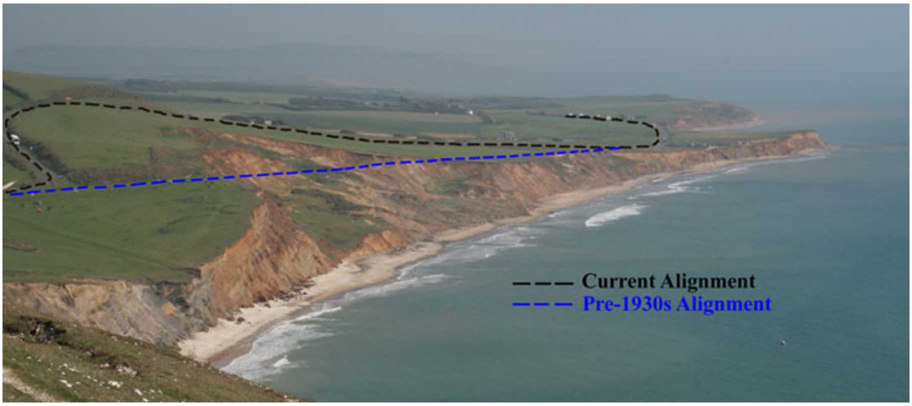

Fig. 2 Coastal landslides at Compton on the Isle of Wight in the south of the UK. The route of the old A3055 road is shown as is the alignment of the current road. The road was realigned in the 1930s to avoid the landslide features that intersected the alignment and can be seen in the central portion of the photograph. Further to the west the cliffs have been stabilised rather than the road being realigned

Since the year 1900 over 50 properties have been lost on the Isle of Wight, with damage to many others and to the local infrastructure, as a result of slow landslide ground movement. These and other impacts amount to an estimated annual cost to the economy of £3 million per annum. The impacts of uncertainty over ground conditions and the resulting knock-on effects on the availability of property insurance, and the local economy generally, were key drivers for research into the nature and scale of the ground movement problems. This coincided with the desire by the government to develop planning policy guidance for areas affected by instability (DOE 1990) and the commission of the 'Ventnor Study'. This initiative was then taken up by the Isle of Wight Council, which extended the study area and developed a 'Landslide Management Strategy' (McInnes 2000; McInnnes and Jakeways 2000; McInnes et al. 2006).

3.2 Scotland

In respect of Scotland's roads (Fig. 3) both the willingness to affect the environment and the willingness to pay are relatively low, and management solutions are thus favoured over intrusive engineering solutions. There is thus an acceptance of a certain level of risk although these risks are generally significantly less than those posed by road traffic accidents, for example (e.g. Finlay and Fell 1997).

Figure 3 illustrates standing traffic brought to a halt by two debris flows, including traffic between the two flows (top-right of Fig. 3). It seems self-evident that both the vehicles and the associated road users are exposed to an elevated level of risk from secondary events as the vehicles are both stationary and close together. Notwithstanding that, both the absolute and relative level of risk, compared to that to which moving vehicles are subject, will depend upon the time that the vehicles and road users remain stationary. While the evacuation of those outside the zone of the two initial events was relatively straightforward, the 57 occupants of the 20 vehicles caught between those events were airlifted to safety using Royal Air Force (RAF) and Royal Navy helicopters. Indeed, the secondary flow path overtopped a rock outcrop and swept a vehicle, belonging to the company responsible for the operation of the road, down the slope. The vehicle came to

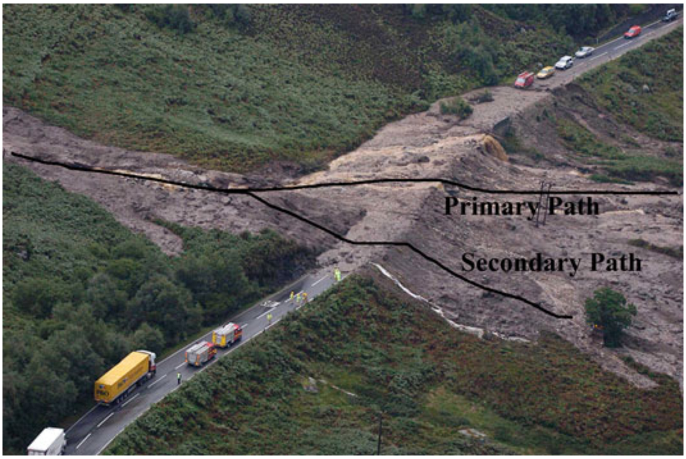

Fig. 3 Debris flow at Glen Ogle on the A85 road in Scotland, UK. This was one of two debris flows that blocked the road on 18 August 2004. Some 20 vehicles were trapped between the two flows, and the 57 occupants were airlifted to safety by helicopter and the road was closed for 4 days. The photograph shows the primary path of the debris as it passed first, and briefly, through a culvert and then overtopped the road and the secondary path as a rock outcrop was overtopped sweeping one vehicle away as illustrated in Fig. 4

rest at the base of a tree (Figs. 3, 4); fortunately the vehicle was unoccupied at the time and there were no casualties (Winter et al. 2006).

In Scotland social, economic and environmental factors are all key drivers for the willingness to accept risk. Roads in Scotland provide vital communication links to remote communities from both the social and economic viewpoint, and the severance of these communities from services and markets for goods is highly undesirable.

The landscape has both a social and an environmental value, but what is often forgotten is that its economic value to Scotland is substantial as it attracts significant economic activity in the form of tourism and is especially important to many of the remote communities potentially affected by landslides. The height of the tourist season coincides with the summer landslide season of July and August and thus, in parallel with the need to maintain access, detrimental effects on tourism from negative publicity are unwelcome to both politicians and the public. At the same time adverse visual impacts on the landscape by large defence/remediation structures (e.g. debris basins, overshoots, shelters) are seen as undesirable. Thus, the underlying philosophy of any remediation must be to preserve the natural landscape as much as is possible even if only to protect that which tourists come to visit (Winter et al. 2005, 2006, 2008).

The avoidance of adverse impacts on other valuable natural resources is also a key issue. Examples of such impacts might include the alteration of the hydrogeological regime of protected peat bogs and adding silt to protected/valuable salmon fishing/spawning rivers.

4 International approaches to risk acceptance

4.1 Jamaica

An example of the adverse impacts of severance on the socio-economic balance of communities may be drawn from Jamaica. A landslide on the B1 route in the Blue Mountains

Fig. 4 Debris flow at A83 Glen Ogle showing the vehicle belonging to the company responsible for the operation of the road after it was swept away by a secondary phase of a debris flow, coming to rest against the base of a tree

Fig. 5 Landslide on the B1 road at Section in Portland Parish, Jamaica. This event severed much of the local coffee production industry from the ports used to ship the product to market. (This picture is a photo-collage and some distortion is inevitable)

of Jamaica (Fig. 5) effectively severed the local coffee production industry from the most direct route to the international market for this high value product. A single landslide event placed severe constraints on the economy of the Blue Mountains. However, in this instance the key issue is the limited ability to pay for the substantial remediation measures required to restore the road to active use. This forces the willingness to accept risk to high levels while preventing any environmental change due to remedial works. The drivers are both the relatively weak national economy and also by the rather extreme landscape, which renders remediation measures costly.

This illustrates the tension between willingness and ability; these may in many respects be seen as opposite sides of the same coin. In this case the inability to pay determines the inability to affect the environment and forces the willingness to accept (or inability to mitigate) relatively high levels of risk. It should also be noted that economic factors also drive the unwillingness to affect the environment as the economy is heavily dependent upon coffee production.

Clearly, while the footprint of the actual event is relatively small, the vulnerability shadow is projected over a much greater area creating tangible economic losses, and less quantifiable social losses—from severance from markets; employment, health and education opportunities; and social activities. Such scenarios in respect of damage to linear infrastructure are by no means uncommon, let alone restricted to Jamaica. Indeed, similar arguments can be made in terms of the losses to the primary regional industries, particularly tourism, resulting from the Scottish debris flows described earlier.

4.2 Colorado, USA

The United States of America is often cited as a good, if not definitive, example of a risk averse society. However, the evidence does not always support this assertion. For example, the DeBeque Canyon landslide affects Interstate 70, the main national east–west route through Colorado (Fig. 6). During the last reactivation of the landslide in April 1998, the road heaved 4.3 m and shifted 3 m laterally towards the nearby river (White et al. 2007). The landslide continues to move, possibly forewarning of future rockslides from above and heaving rotation failures of the road. The Colorado Department of Transportation have undertaken a series of remediation measures as described by White et al. (2007) and commissioned a long-term monitoring system. However, the overall approach seems to be

Fig. 6 DeBeque Canyon landslide in Colorado, USA—the photograph is taken from the head of the landslide. Interstate 70 passes over the toe although the original toe extends to the other side of the Colorado River. The proximity of the river and railway are also evident, and a fissure is shown close to the head of the slide on top of which debris is clearly visible. (Image by kind permission of Jonathan L. White, Colorado Geological Survey)

that the movements described above are at an acceptable level and can be managed on an emergency works basis as and when they happen.

The example of DeBeque Canyon implies a high level of willingness to accept risk and an associated low level of willingness to pay, possibly driven by unwillingness to affect the environment and, potentially, by higher levels of risk elsewhere which may take priority.

4.3 Hong Kong SAR

Hong Kong provides an interesting counterpoint. Here, life has been valued at a high, but nonetheless realistic, level and the willingness to accept risk is relatively low. In the 1980s the willingness to affect the environment was at a relatively high level with hard engineering solutions often dominating the scene (e.g. Fig. 7); this most likely determined the costs and therefore the willingness to pay. However, in the latter part of the 1990s ('Millennium' in Fig. 1) and beyond there was a shift in the approach in Hong Kong and the willingness to affect the environment was much reduced, leading to softer solutions based upon the use of vegetation to reduce instability where appropriate. This may have been associated with an increase in the willingness to accept risk as some of the solutions used may be less robust. It may also have led to a potential increase in cost, and thus willingness to pay, if only in terms of an increase in the maintenance expenditure required for such solutions.

However, it is also possible to consider earlier periods of Hong Kong's history prior to the development of the current approach to slope safety (Anon. 2007) and to the earliest photographic records which date from 1889 (Anon. 2005). Prior to the 18 June 1972 and the Sau Mau Ping (Kowloon) and Kotewall Road (Mid-Levels) events that killed 71 and 67 people respectively, the willingness to approach landslides risk might well be described as being closer to that of present day Scotland with a rapid change to the '1980s' approach shown in Fig. 1 thereafter.

4.4 Japan

In Japan, the willingness to address risk is often viewed as being much higher than in other countries. Take, for example, the case of the Zentoku landslide on Shikoku Island, stabilised with a combination of 20 concrete piles, each 5.45 m in diameter, ranging in depth up to 44 m, 280 ground anchors and six drainage shafts with bored drainage arrays (Hong et al. 2005; Bromhead 1997); clearly cost was not the significant factor (Fig. 8). The combination of willingness to significantly modify the environment with intrusive engineering works and the unwillingness to accept even relatively low levels of risk combine to make the high costs involved almost a side issue. This points to the bottom-left and bottom-right corners of the ternary diagram tending to converge and the diagram might more correctly be rendered wrapped around a cylinder about a vertical axis (see inset to Fig. 1).

4.5 Italy

In May 1998 a total of 159 people were killed by a series of debris flows in the Italian town of Sarno (Campania). The response has been to construct a series of defence measures (Fig. 9) including barriers and debris basins up to around 200,000 m^3 capacity (Versace 2007). The remedial measures have been driven, amongst other things, by the desire of the local population to remain in the areas affected, albeit with a lack of willingness to accept

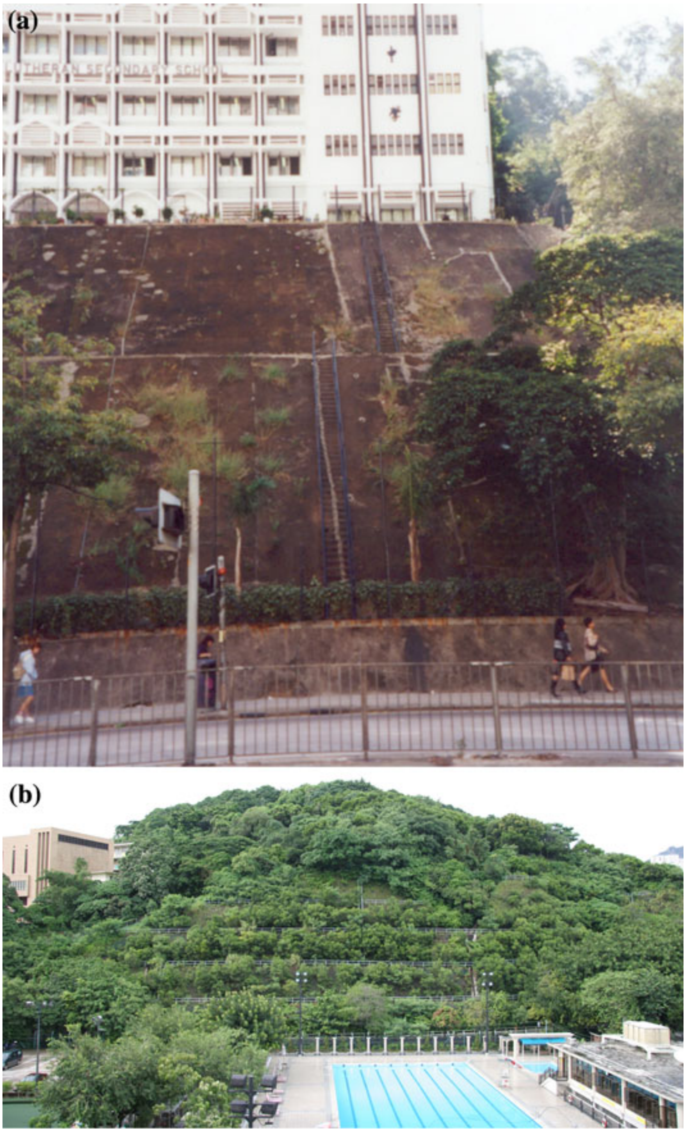

Fig. 7 Hong Kong SAR slopes: **a** a shotcrete (or chunam) stabilised slope in Kowloon. The photograph was taken in November 2000 and by this time it was no longer typical of the approach to slope stabilisation in Hong Kong; **b** a more typical contemporaneous approach shows a much 'greener' slope. Together these images help to illustrate how approaches to risk management may change over time. (Figure 7b is published by kind permission of the Head of the Geotechnical Engineering Office and the Director of the Civil Engineering and Development Department of the Hong Kong Special Administrative Region)

further risk. This has led to a willingness to expend resources and to pay for the risk mitigation measures. While the local environment has undoubtedly been changed this is almost incidental and the remedial measures incorporate sports facilities, such as the cycle track illustrated in Fig. 9 for use during periods of negligible/low risk, which it could be argued improve both the quality of life and environment for the local population.

Fig. 8 Stabilisation works at Zentoku landslide on Shikoku Island, Japan. The large concrete blocks are the head units for rock anchors. This type of stabilisation is not only costly, involving drilling and grouting of steel bars, but is also quite time-consuming especially where access is difficult

Fig. 9 Debris basin at Sarno in Italy. A cycle track has been incorporated into the perimeter of this feature as an amenity for the local population. (This picture is a photo-collage and some distortion is inevitable)

The examples from Japan and Italy demonstrate that where the willingness to accept risk is very low (affectively at a minimum), the issues of willingness to pay and to affect the environment effectively converge. As a result less restraint is placed upon these latter two factors than is otherwise the case, and it is appropriate to 'wrap' the diagram to illustrate this (see inset to Fig. 1).

5 Generic approaches to landslide remediation

There is a number of generic approaches to landslide remediation; these too can be represented on the willingness diagram (Fig. 10). Management clearly involves a relatively high willingness to accept risk, or a perception that the risk form landslides is relatively small compared to other existing risks, and has a relatively minimal impact on the environment while also being relatively low cost.

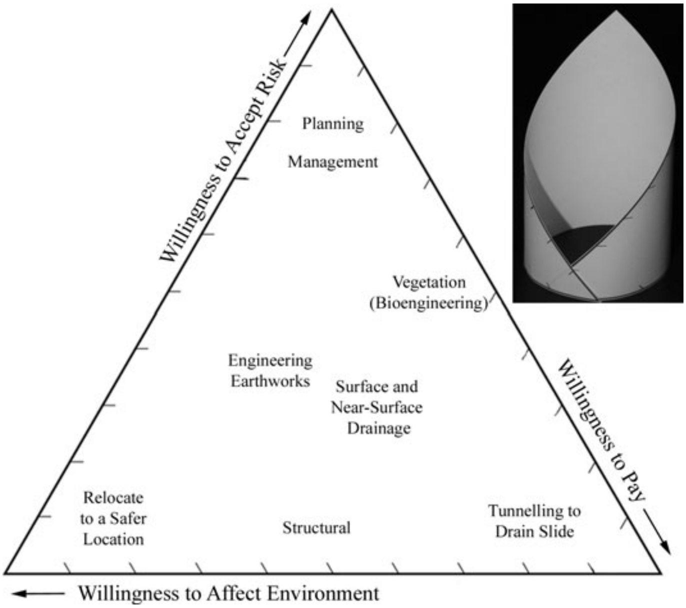

Fig. 10 The 'willingness diagram' comparing different generic forms of landslide remediation. *Inset*: the extreme *bottom-left* and *bottom-right* corners of the ternary diagram tend to converge and the diagram might more strictly be rendered as if wrapped around a cylinder about a *vertical axis*

Other, more intervention-led, mitigation strategies are rather more widely distributed on the willingness diagram. These include vegetation and bioengineering, engineered earthworks, surface and near-surface drainage solutions, structural solutions, and the construction of drainage tunnels.

Combinations of the above approaches might best be described by the lowest level of willingness to accept risk. However, it should also be noted that such combinations may reflect the technical demands of the solution and/or variations in other factors, such as vulnerability.

In general terms bioengineering is generally a least cost but possibly higher risk mitigation solution to many slope instability problems. Engineering earthworks may be relatively low cost but comprise a solution that can be rather intrusive, particularly in the short term as the vegetation cover develops, and often retains a measurable residual risk. Surface and near-surface drainage solutions usually tend to target the root cause of instability, namely water, and provided that such systems can be adequately maintained they usually have relatively low residual risk. In addition they tend to have only a limited effect upon the environment but the cost can be quite variable.

Structural solutions tend to be high cost, have a significant effect upon the environment and often reflect a lack of willingness to accept even small levels of risk. While such solutions can be appropriate the authors are also aware of instances in which they have been inappropriately applied, often by Civil or Structural Engineers failing to address the cause of the instability in the first place—typically water—and in some instances exacerbating the situation.

Tunnelling for drainage works is also a high cost solution but one which least affects the ground surface environment while reducing the risk associated with future ground movements. In some ways it may be seen as the ultimate structural solution, but one that addresses the critical issue of water causing instability.

6 Conceptual approaches to landslide risk management

The conventional approach to risk assessment may be described as the product of the probability of a given hazard event (H_P), the total value of the items threatened by the event (the elements at risk) (E) and the vulnerability (V) of those items to the event (the proportion of the elements at risk eliminated by the hazard event) (Lee and Jones 2004). Often the product of the elements at risk and the proportion that may be reduced by the event is described as exposure (Lee and Jones 2004).

This then allows the description of two distinct approaches to landslide risk reduction. Either the vulnerability of the elements at risk (exposure) may be reduced or the hazard itself may be reduced (Winter et al. 2005, 2008).

The reduction of the exposure of mobile elements at risk, such as vehicular or human traffic, will often take relatively straightforward forms. It may include the closure of roads and other routes and areas either in response to an initial event or temporarily at times when the likelihood of hazardous events occurring is higher. In some cases areas accessed by the public, such as the area in the vicinity of an unstable cliff face, may be closed for an indefinite period.

Engineering works to limit or remove a hazard may take many forms including drainage and/or reinforcing works to stabilise a landside. In the case of debris flow and rock fall then the works are more likely to include barriers of various types, catch pits, and undershoots and overshoots. However, the common denominator of most such works is their high cost and, most often, their disruption of the environment.

Perhaps the most extreme form of risk reduction is the reduction of the exposure of static elements at risk. This might include, for example, the removal of a population, the closure of public or commercial buildings, or the realignment of an infrastructure route such as a road. These three quite distinct approaches to landslide risk reduction are illustrated on the willingness diagram in Fig. 11.

Thus Fig. 11 focuses upon the reduction of landslide risk by means of reducing the exposure of mobile elements at risk, reducing hazards, and reducing the exposure of static elements at risk. These approaches are generally, and in sequence, increasingly more risk averse and costly responses which also have the potential to effect greater environmental change.

7 Discussion

7.1 The application of the willingness diagram

Clearly the level (or degree) of risk that exists at a given location and the willingness or ability to pay will, to a significant degree, affect the willingness to accept risk. However, the willingness to accept risk and the willingness or ability to pay are factors that may be viewed as forcing agents in the discussion that follows on the approach to risk in different areas of the world.

It might be possible to normalise willingness to pay with (say) gross domestic product (GDP), for example, and the willingness to accept risk with the overall level of that risk.

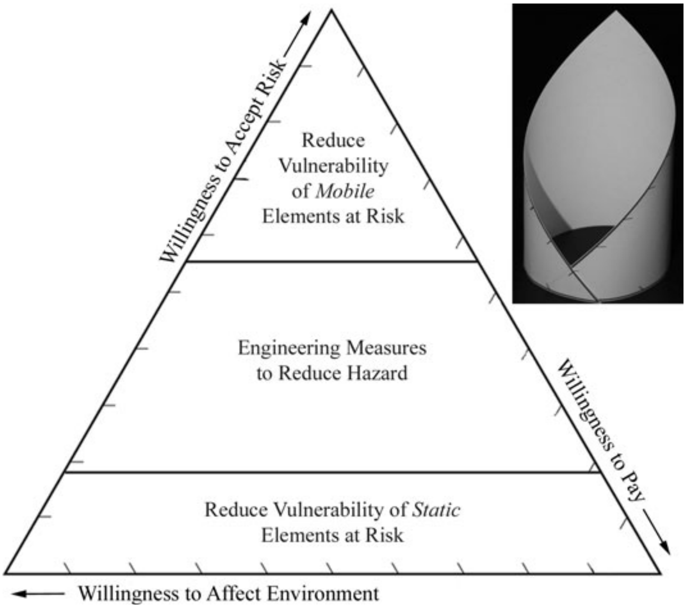

Fig. 11 The 'willingness diagram' showing conceptual approaches to landslide remediation. *Inset*: the extreme *bottom-left* and *bottom-right* corners of the ternary diagram tend to converge and the diagram might more strictly be rendered as if wrapped around a cylinder about a *vertical axis*

However, such increases would impose a significant and onerous data acquisition load on the use of the willingness diagram. It would also in the authors' view undermine the purpose of the work presented here. That purpose was to provide a simply constructed and, most importantly, quick and easily understood vehicle to present a given approach in the context of those from other areas of the world. One of the main requirements of the diagram was that it should be easily understood by non-landslide specialists including infrastructure owners/operators, politicians and the public.

As is suggested in the example from Hong Kong there is the potential to show the temporal changes in the willingness to accept risk, to pay for its reduction and to affect the environment in the process. Such changes may be event driven, but may also reflect the economic development of a society. Indeed, while it is fair to say that the events of 1972 and 1976 (Anon. 2005), in particular, were the immediate drivers for change in Hong Kong it is by no means clear that these changes would have happened, or been affordable, if it had not been for the substantial economic development experienced.

Other events may also influence such temporal changes in the approach to risk management. For example, in Scotland, where the first author lives and works, there has not as yet been a major fatality event associated with the type of debris flow event described earlier. While such an event is generally considered to have a relatively low probability of occurrence it might be anticipated that, if (or indeed when) it were to occur, it would lead to a significant shift in the willingness to accept risk, to pay for its reduction and, indeed, to modify the environment in the process.

That generic approaches to landslide remediation (Fig. 10) and conceptual approaches to landslide risk management can be plotted on the willingness diagram (Fig. 11) illustrates the broader potential of the approach described. Perhaps one of its most powerful uses is in describing the actions of landslides specialists to lay audiences that may be variously composed of infrastructure and building engineers, owners and operators, and politicians and the general public.

7.2 Regulation and planning

Clearly any approach to the willingness to accept risk, including at a personal, societal, political, cultural and regulatory level, is subject to the framework of Public Policy.

One other very important factor that will have a strong effect on the willingness of societies to tolerate risk is their ability to pay. In cases where relatively poor societies choose to do nothing it is relatively simple to attribute this inaction to the inability to pay. However, often relatively wealthy societies can afford to respond and while often taking an active approach to risk reduction there may be other instances where their approach is relatively inactive. This can be variously due to the influence of other risks, such as those related to road traffic accidents, which are either higher in reality and/or in perception but also due to the influence of regulation.

Regulations may be formed in response to concerns in respect of public safety and perhaps the best known instance is that of the rules laid down and systems operated by the GEO in Hong Kong. Another good example comes from the UK in the form of the Mines and Quarries Act of 1967, 1971 and subsequent regulations. These were implemented in the immediate aftermath on the Aberfan (South Wales) disaster of 1966 and effectively extended The Mines (Notification of Dangerous Occurrences) Order 1959 to include tip slides and other occurrences as reportable incidences. This event involved the collapse of a colliery spoil tip which subsequently engulfed a school with the loss of 144 lives, 116 of them children, on 21 October.

Planning policy guidance 14 (DOE 1990) also has had a strong influence upon new development on unstable ground in the UK and, in particular, sets out specific responsibilities, primarily upon the developer. Essentially the developer must determine by appropriate appraisal whether the development will be threatened by unstable slopes on or adjacent to the site or will initiate slope instability which may threaten its neighbours (there are other requirements in respect of other types of ground instability). If the findings are such that the ground is indicated to be unstable or may become unstable, then the developer must assess the suitability and sufficiency of the proposed precautions to overcome the actual or potential instability. The planning authority is specifically excluded from having a duty of care; it has no liability for subsequent loss with respect to individual landowners when granting applications for planning permission. It is, however, required to ensure that instability is taken into account as (only) one of the material considerations relevant to its determination. Schwab et al. (2005) give an excellent, US-based, overview of the influences that planning and planners can have in the response to landslide hazards and thus the risks that are generated by residential, industrial/commercial and infrastructure development.

The city of Laguna Niguel in California experienced a major landslide in March 1998 triggered by the El Nino storms of the winter of 1997–1998 affecting an existing hillside development (Niguel Heights built in 1986). The State regulations required site-specific slope investigations by qualified geologists or engineers for new developments are described by Scullin (1990) and Real (2005). The movement appears to have been within part of an existing landslide and at the site of the slide signs of distress had been reported during the preceding 3 years. Further landslide movements were experienced in October 2007, leading to the evacuation of homes.

Clearly a system of regulation and/or planning can exemplify a willingness on the part of society to pay to reduce risk, to restrict development where appropriate and to use the legal framework in order to achieve that end. However, there is clearly also a need for such systems to be enforced if they are to be meaningful.

Regulatory factors may also include those systems of control that are related to environmental factors including Areas of Outstanding Natural Beauty (AONBs), Sites of Special Scientific Interest (SSSIs) and European Designated Habitats (EDHs).

AONBs are UK Government-designated areas of countryside with significant landscape value in England, Wales or Northern Ireland (National Scenic Areas are designated in Scotland, although there are significant differences not least in terms of their legal status). The primary purpose of the AONB designation is to conserve and enhance the natural beauty of the landscape, with two secondary aims: meeting the need for quiet enjoyment of the countryside and having regard for the interests of those who live and work there. To achieve these aims, AONBs rely on planning controls and practical countryside management. As they have the same landscape quality, AONBs may be compared to the National Parks of England and Wales.

SSSIs are 'special' for their plants, animals or habitats, their rocks or landforms, or a combination of such natural features. Together they form a network of the best examples of natural features across Great Britain and support a wider network across the European Union collectively forming the best of Europe's natural heritage. Designation is intended to prevent, restrict and control those operations that are likely to damage the site's natural features. As their name implies these are usually quite discrete sites rather than the larger land areas covered by the AONBs and National Parks.

EDH sites are designated in compliance with the EC Habitats Directive and comprise Special Areas of Conservation, which are designated because they host important certain natural habitats or habitats of listed species. In the UK, European Sites are designated and conserved under UK legislation, which currently covers sites on land (including land covered by water), and territorial waters.

At a global level the system of World Heritage Sites, designated by the United Nations Educational, Scientific and Cultural Organisation (UNESCO), aims to identify and list sites of outstanding universal cultural and natural value that meet at least one out of ten selection criteria (Anon. 2008). While the direct funding available to preserve and maintain such sites may be relatively limited the indirect finding generated by publicity and associated additional tourism may well generate funds well in excess of those that might otherwise be available. In addition, in England, the Government has set in place policy guidelines (Anon. 2009) on the level of protection and management required for World Heritage Sites.

All of the aforementioned designations whether national, European or global will have an effect upon the willingness to expend financial resources and to alter the environment in the process of the remediation of landslide and other geohazards. While such a designation may be an inhibitor to action in terms of reducing the level of risk from hazards that may constitute, in whole or in part, the scientific merit of a given entity, once the risk reaches a level so as to threaten the existence or viability of the entity then action is likely to be driven by society (e.g. Margottini 2004).

7.3 Event footprint versus vulnerability shadow

Linear infrastructure such as services, communications and transport networks presents significant risk factors including the near-complete temporal occupation of the hazard zone, high vulnerability to damage, adverse orientation (as often the design demands limited gradients), and the construction of the infrastructure itself may increase landslide susceptibility (e.g. cuts, fills, interruption of groundwater flow, concentration of water). Indeed, as exemplified for the case of Jamaica, the vulnerability shadow for socio-economic factors may be projected over a far greater area than the specific event footprint. In many ways such linear infrastructure may be seen as something of a special case in terms of both the elements at risk and the associated diverse and extensive vulnerabilities.

Similarly the formation of landslide dams may also project a vulnerability shadow of much greater area than the event footprint. For example, in the Attabad on the Hunza River in Pakistan (Petley 2010), losses upstream relate to slow inundation and flooding while those downstream relate to the potential for the rapid release of the impounded floodwaters. The potential for the latter type of event may lead to socio-economic blight including adverse impacts on asset values, economic activity and quality of life. The impacts of fear and trepidation on quality of life and, potentially, human health, are less obvious and inevitably less well studied.

As an illustration, one can consider the economic impacts from a landslide event and its associated vulnerability shadow that closes a road, or other form of linear infrastructure, in three categories, as follows:

- Direct economic impacts.
- Direct consequential economic impacts.
- Indirect consequential economic impacts.

Direct economic impacts: The direct costs of clean-up and repair/replacement of lost/damaged infrastructure in the broadest sense and the costs of clean-up search and rescue. These are relatively easy to estimate for any given event.

Direct consequential economic impacts: These generally relate to 'disruption to infrastructure' and are really about loss of utility. For example, the costs of closing a road (or implementing single-lane working with traffic lights) for a given period with a given diversion, are relatively simple to estimate using well-established models. The costs of fatal/non-fatal injuries may also be included here and may be taken (on a societal basis) directly from published figures. While these are set out for the costs of road traffic accidents, or indeed rail accidents, there seems to be no particular reason why they should be radically different to those related to a landslide as both are likely to include the recovery of casualties from vehicles. Indeed, for events in which large numbers of casualties may be expected to occur data relating to railway accidents may be more appropriate.

Indirect consequential economic impacts: Often landslide events affect access to remote rural areas with economies that are based upon transport-dependent activities, and thus the vulnerability can be extensive and is determined by the transport network rather than the event itself. If a given route is closed for a long period then how does that affect confidence in, and the ongoing viability of, local business. Manufacturing and agriculture (e.g. forestry in western Scotland and coffee production in Jamaica) are a concern as access to markets is constrained, the costs of access are increased and business profits are affected and short-term to long-term viability may be adversely affected. Perhaps of even more concern are the impacts on tourist (and other service economy) businesses. It is important to understand how the reluctance of visitors to travel to and within 'landslide areas' is affected after an event that has received publicity and./or caused casualties and how a period of inaccessibility (reduced or complete) affects the short- and long-term travel patterns to an area for tourist services. Such costs form a fundamental element of the overall economic impact on society of such events. They are thus important to governments as they should affect the case for the assignation of budgets to landslide risk mitigation and remediation activities. However, these are also the most difficult costs to determine as they are generally widely dispersed both geographically and socially. Additionally, in an environment in which compensation might be anticipated, albeit often erroneously, those that have the best data, the businesses affected by such events, are also those that anticipate such compensatory events.

7.4 Vehicular vulnerability

The vehicles that occupy linear infrastructure also have a major impact on the elements at risk. Trains, for example, are usually relatively long, have extended stopping distances and are manoeuvrable only in the direction dictated by the alignment of the track. Road vehicles on the other hand are usually widely spaced, have shorter stopping distances and have a degree of manoeuvrability that, within the constraints of the road space, allows for hazard avoidance. The vulnerability of road vehicles is, of course, greatly increased when an obstruction, such as a landslide, causes the traffic to stop and the headway between vehicles decreases. The vulnerability to secondary events, such as those noted for Glen Ogle earlier in this paper, is then much greater and the importance of rapid and effective evacuation is highlighted.

It seems self-evident that stationery vehicles and the associated road users are exposed to an elevated level of risk from secondary events as they are both stationary and close together. Indeed, in discussing the risk to standing traffic from rock fall Fell and Hartford (1997) clearly indicate that the risk depends upon, amongst other factors, the length of time that the vehicles are stationary. This is well-illustrated by Bunce et al. (1997) who demonstrate that in the particular case that they present the risk to a moving vehicle from a falling rock is approximately one order of magnitude less than that to which a vehicle remaining stationary for 30 min at the same location is exposed.

7.5 Budgetary issues

Budgets for landslide risk mitigation will often be set in direct competition with those for the mitigation of other risks. Finlay and Fell (1997), for example, point out that the contemporaneous fatality rate in Australia, per million of the population, due to all landslides was around two orders of magnitude less than that for involvement in a road traffic accident while driving a car. Road administrations whose infrastructure is affected by landslides, for example, must balance the risks associated with both road traffic accidents and those from landslides and other hazards. It might be assumed that those risks associated with landslides might be deemed to be of relatively low importance. However, this does not take account of the fact that while the risk to life and limb from landslides may be, in relative terms, quite low, the risk to the operation of the network, and the associated socio-economic activities, from such events is of much greater magnitude.

In addition, it does seem that the risks associated with road traffic accidents are tacitly accepted. This may well be due to the fact that road traffic accidents are common and generally involve a relatively small number of casualties, compared to say an event such as a rail or air accident, even though the overall annual casualty rate is much higher. It seems unlikely, based upon the authors' experience that landslide risks are similarly accepted, either tacitly or otherwise; the relative infrequency of the events, compared to road traffic accidents, seems to be a likely contributor. In addition, in many parts of the world these infrequent events often involve higher numbers of fatalities (where fatalities occur). This in turn raises the profile of their coverage in the media and the amount of public and political interest generated to a much higher level, more akin to that of a rail or air accident.

8 Conclusions

In this paper it is demonstrated that the affirmation that we live in a 'risk-averse society' is not adequate to describe societies' responses to landslide risk. A broader context is required in order to understand such responses and this includes the willingness (and/or ability) of society to pay for risk reduction measures and the willingness to alter the environment in order to accommodate such measures, as well as the willingness to accept risk.

These factors accommodate the social and economic influences that have a major effect upon the willingness to accept risk and the spectrum of responses to landslide problems fit neatly into the ternary 'willingness diagram', illustrating in this triangular plane how different societies have different attitudes to risk acceptance, fiscal expenditure and the modification of the environment. Indeed, it is also demonstrated that the temporal shift in the attitude of a given society can be illustrated by using this tool. This tool does not in any way negate or compete with work undertaken in the social sciences on, for example, social vulnerability. It does provide a useful tool to allow infrastructure owners and operators to set their landslide risk reduction management activities in a broader context that embraces other regions, countries and cultural contexts.

It is also possible to illustrate both generic (engineering) responses to landslide remediation and different conceptual approaches to the reduction of landslide risk, focusing on the reduction of the exposure of mobile elements at risk, hazard reduction, and the reduction of the exposure of static elements at risk.

Issues relevant to the response of society and groups of individuals to landslide risk, its acceptance and management are also discussed. These include the effects of regulation and planning systems, the often limited size of the event footprint compared to the vulnerability shadow that is cast, vehicle vulnerability and budgetary issues.

References

Anon (2005) When hillsides collapse: a century of landslides in Hong Kong. Civil Engineering and Development Department, Hong Kong SAR (in English and Chinese)

Anon (2007) Thirty years of slope safety practice in Hong Kong. Civil Engineering and Development Department, Hong Kong SAR (in English and Cantonese)

Anon (2008) The operational guidelines for the implementation of the World Heritage Convention. UNESCO, Paris

Anon (2009) Circular on the protection of World Heritage Sites. Communities and Local Government Circular 07/2009. Department for Local Government and Communities, London

Bromhead EN (1997) The treatment of landslides. Proc Inst Civ Eng (Geotech Eng) 125(2):85–96

Bunce CM, Cruden DM, Morgenstern NR (1997) Assessment of the hazard from rock fall on a highway. Can Geotech J 34:344–356

Department of the Environment (DOE) (1990) Development on unstable land. Planning Policy Guidance, PPG14. HMSO, London (with annex 1, 1996 and annex 2, 2002)

Fell R, Hartford D (1997) Landslide risk management. In: Cruden D, Fell R (eds) Proceedings of the international workshop on landslide risk assessment, Honolulu, Hawaii. Balkema, Rotterdam

Finlay PJ, Fell R (1997) Landslides: risk perception and acceptance. Can Geotech J 34:169–188

Hong Y, Hiura H, Shino K, Sassa K, Fukuoka H (2005) Quantitative assessment on the influence of heavy rainfall on the crystalline schist landslide by monitoring system—case study on Zentoku landslide, Japan. Landslides 2(1):31–41

Lee EM, Jones DKC (2004) Landslide risk assessment. Thomas Telford, London

Margottini C (2004) Instability and geotechnical problems of the Buddha niches and surrounding cliff in Bamiyan Valley, Central Afghanistan. Landslides 1(1):41–51

McInnes RG (2000) Managing ground instability in urban areas—a guide to best practice. Centre for the Coastal Environment, Isle of Wight

McInnes RG, Jakeways J (2000) The development of guidance and best practice for urban instability management in coastal and mountainous areas of the European Union. In: Bromhead E, Dixon N, Ibsen M-L (eds) Landslides in research, theory and practice. Thomas Telford, London, pp 1047–1052

McInnes RG, Jakeways J, Fairbank H (2006) EU LIFE 'response' project. Final report for European Commission. Centre for the Coastal Environment, Isle of Wight

Petley D (2010) Dave's landslide blog. http://daveslandslideblog.blogspot.com. Accessed 12 Aug 2010

Real CR (2005) California's seismic mapping act: a statewide approach to landslide hazard mitigation. In: Schwab JC, Gori PL, Sanjay J (eds) Landslide hazard and planning. Planning advisory service report number 533/534. American Planning Association, Washington, DC, pp 143–153

Schwab JC, Gori PL, Sanjay J (eds) (2005) Landslide hazard and planning. Planning advisory service report number 533/534. American Planning Association, Washington, DC

Scullin CM (1990) Excavation and grading code administration, inspection and enforcement. Prentice-Hall, Englewood Cliff

Tapsell S, McCarthy S, Faulkner H, Alexander M (2010). Social vulnerability to natural hazards. CapHaz-Net: social capacity building for natural hazards—towards more resilient societies. Report number WP4. http://caphaz-net.org/outcomes-results. Accessed Feb 2011

Versace P (ed) (2007) La mitigazione del rischio da collate di fango: a Sarno e negli altri comuni colpiti dagle eventi del Maggio 1998. Commissariato do Governa per l'Emergenze Idrogeologica in Campania, Napoli (in Italian)

Wachinger G, Renn O (2010) Risk perception and natural hazards. CapHaz-Net: social capacity building for natural hazards—towards more resilient societies. Report number WP3. http://caphaz-net.org/outcomes-results. Accessed Feb 2011

White JL, Dessenberger NC, Ellis WL, Higgins J, Gaffney S (2007) The DeBeque Canyon landslide at Interstate 70, Mesa County, West Central Colorado. In: Proceedings, first North American landslides conference: field trips. AEG SP 22. OMNI Press, Wisconsin, USA, pp 104–122

Winter MG, Macgregor F, Shackman L (eds) (2005) Scottish road network landslides study. The Scottish Executive, Edinburgh

Winter MG, Heald A, Parsons J, Shackman L, Macgregor F (2006) Scottish debris flow events of August 2004. Q J Eng Geol Hydrogeol 39(1):73–78

Winter MG, Macgregor F, Shackman L (eds) (2008) Scottish road network landslides study: implementation. Transport Scotland, Edinburgh