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AVERTING PREDICTED LANDSLIDE CATASTROPHES: WHAT CAN BE DONE?

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ABSTRACT

Today landslide science is more complete than at the time of the Vajont catastrophe, although some way from being perfect. However, a factor is still present that allowed the Vajont disaster, and a number of other catastrophes since, to occur - organisational and governmental reluctance to acknowledge the unacceptably high probability of a specific disaster and take actions to avert it. At three tourism centres in New Zealand there is substantive evidence that a large landslide can be triggered by an earthquake; and that each event can cause hundreds of millions of dollars of damage and up to several hundred deaths (depending on the timing of the event). There can be no useful warning of any of these events. Risk analyses suggest that the risks are in all cases some orders of magnitude greater than acceptable societal levels. Further investigation could clarify all these risks, but local and national authorities are reluctant to pursue this. The uptake of science by decision - and policy-makers is constrained by short-term economic and political considerations. The relevant science needs to published and publicised in such a way that it can neither be misunderstood nor ignored.

INTRODUCTION

Recent history contains many examples of natural disasters that were foreseen and even predicted, and subsequently occurred, with catastrophic consequences. The question arises, why was nothing done to warn those at risk? Examples include the Indian Ocean tsunami of 2004 (Bilek *et alii*, 2007), the lahar that devastated Armero in 1987 (Voight, 1990) and the Huascaran disaster of 1970 (Evans *et alii*, 2009); and of course the Vajont disaster of 1963 (e.g. Semenza & Ghirotti, 2000). In each case, there was credible scientific evidence that the catastrophe would occur, and this evidence was provided to the civil authorities responsible for public safety; in each case no action was taken prior to the occurrence of the predicted event, with the result that thousands of people died. Herein we attempt to answer the questions:

1. Would better science have been more credible to the authorities and allowed them to take preventive action (evacuation)?
2. Would better communication of science have prevented the disaster? If so, how can science communication be improved?
3. If the answers to these questions are negative, what is the fundamental stumbling-block that prevents science being effective in disaster management? How can it be overcome?

We apply these questions to three current situations in New Zealand where science suggests that coseismic landslides threaten the lives of hundreds or thousands of people, yet there is little or no public or governmental appetite for further investigation to clarify the risks. In two cases mitigation by relocation is the only option, and evidently implies significant costs, but could be affordably carried out over

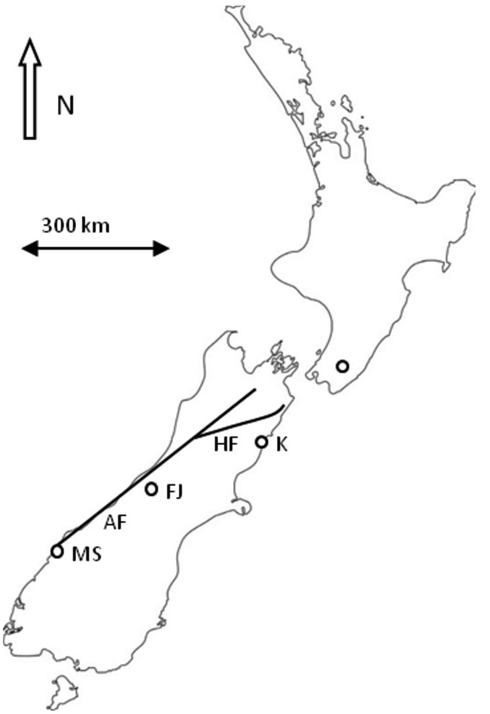

Fig. 1 - Outline map of New Zealand indicating potential South Island landslide locations (K = Kaikoura; FJ = Franz Josef; M = Milford Sound) and major faults (AF = Alpine fault; HF = Hope fault)

an extended time period; in the third, modification of the natural situation appears feasible, at a cost that is an order of magnitude smaller than by estimated damage and loss of life.

CLEAR AND PRESENT DANGERS

FRANZ JOSEF GLACIER

The tourist township of Franz Josef Glacier lies beneath the western range-front of the Southern Alps in New Zealand's South Island (Fig. 1). It is developing rapidly to support the growing tourism trade, and during spring, summer and autumn may host 1-2 thousand tourists as well as several hundred permanent residents. It lies on the Alpine fault, the active boundary between the Australasian and Pacific tectonic plates; this fault generates M~8 earthquakes every 2-300 years, the last of which was in 1717. The annual probability of such an earthquake is ~1-2%. Immediately behind and overlooking the township is a hillslope with a distinctly stepped upper profile (Fig. 2; Barth, 2013), similar to those at two known large prehistoric rock avalanches adjacent to the same fault

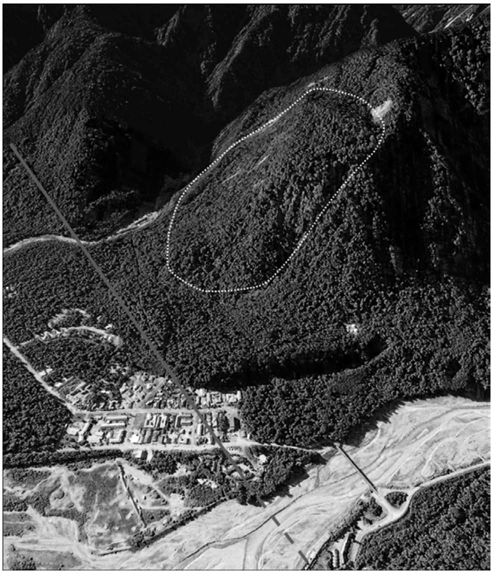

Fig. 2 - Potential 10^7 m^3 rock avalanche (white dotted line) above Franz Josef Glacier township. Grey line = Alpine fault. Road bridge at lower right is about 140 m long

Fig. 3 - The 0.6 km^3 coseismic Cascade rock avalanche, South Westland (Barth, 2013). Dashed white line is Alpine fault; dotted line outlines the 1 km wide headscarp. Note stepped slope profile at far side of headscarp, indicating partially-failed rock mass. The 10 km^2 deposit is the hummocky area at lower centre and right

(one shown in Fig. 3). The hypothesis that postglacial earthquake shaking has initiated a failure surface in the upper part of the schist slope, which extends deeper at every earthquake and is accompanied by settling of the upper slope, can be neither proved nor refuted prima facie, and neither can the corollary that during a future earthquake a large rock avalanche will occur from this slope. Evidently both hypothesis and

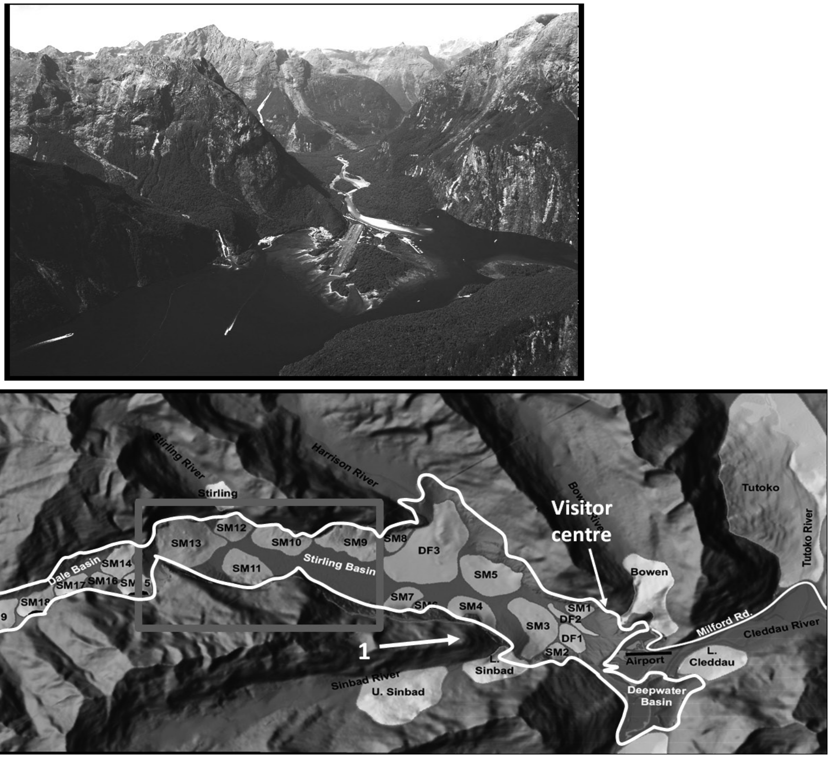

Fig. 4 - (Upper) *View of Milford Sound* - (Lower) *Postglacial landslides on the bed of Milford Sound (*Dykstra*, 2013). Arrow 1 indicates line of sight of upper view. SM = landslide deposit; DF = density flow; L = lake. Shoreline in white*

corollary are of crucial significance to the future of the town, and a detailed risk assessment needs to be carried out, but no action has so far been taken by local or national authorities. If the probability of the rock avalanche occurring in the next earthquake is say 1% (there have been about 60 earthquakes since deglaciation at 15 ka), then the annual probability of the event is about 1 in 10^{-4}; if 100 people die then the annual death risk is about 10^{-2}, a very conservative estimate and yet some orders of magnitude greater than the acceptable societal risk for such an event. The landslide probability is, of course, additional to the much greater earthquake probability. There will be no effective warning of the landslide, and no way of preventing it.

MILFORD SOUND

The fiord-head of Milford Sound (Fig. 1) is visited by thousands of people each day except in winter when the access road is closed due to avalanche danger. All visitors remain at sea-level for their whole visit unless they take a scenic flight. Milford Sound is a typical fiord with 1000-m high very steep rock walls. On its bed are the deposits of at about 20 rock avalanches with minimum volumes ~10^6-10^7 m^3 (Fig. 4; Dykstra, 2013), all of which have fallen since the Fiord deglaciated about 15000 years ago. The rock avalanches are probably coseismic, as the Alpine fault runs just offshore about 16 km from the head of the fiord, and there will be no warning of a rock avalanche. Thus about once every thousand years a rock avalanche generates a tsunami with an amplitude of at least 4 m and a runup of ~17 m. It is estimated that long-term this will give rise to about 0.5 deaths per year at the present visitor rate (Dykstra, 2013), again some orders of magnitude greater than societally acceptable; no mitigation is possible.

KAIKOURA

Some kilometres south of Kaikoura on the east coast of the South Island (Fig. 1), a large sediment deposit is accumulating in the head of the Hikurangi Canyon due to northward drift of coastal sediments (Fig. 5). There is evidence that about every 200 years this deposit (presently ~ 0.25 km^3 in volume) fails coseismically

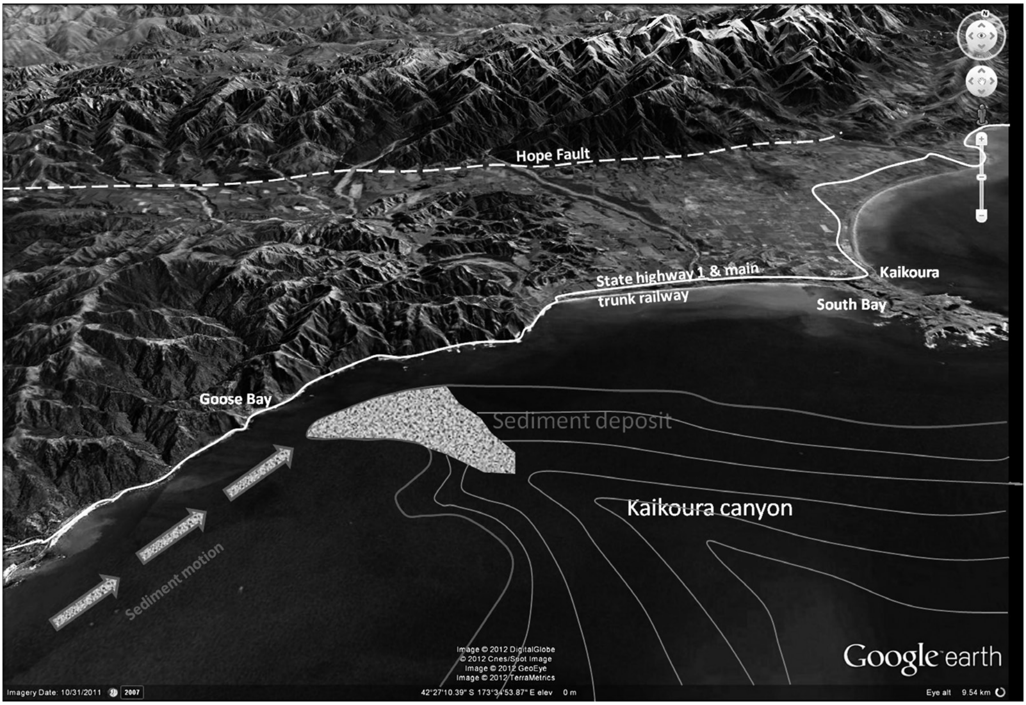

Fig. 5 - Potential tsunamigenic submarine landslide south of Kaikoura

(Lewis & Barnes, 1999) and generates a local tsunami with amplitude up to 10 m and runup of ~20 m (Walters *et alii*, 2007). Tsunami deposits have recently been identified ~15 m above sea-level close to the head of the canyon. It has been estimated that this event can cause up to 200 deaths and $200M of other costs; no effective warning is possible due to the near-field nature of the event. In this case, however, large-scale suction dredging of the head of the deposit could in principle increase the stability of the deposit against coseismic failure, at a cost of about $10M; this would subsequently need to repeated at intervals of several decades. Considerable analysis of the deposit stability would be required to design the mitigation dredging procedure and frequency, and is certainly feasible. This hazard was first identified in 1999, but apart from raising the awareness of the local community little has been done.

None of these situations is in any way unusual or extreme in geomorphological terms; the processes involved are reasonably well-studied and well-understood, and similar events have been recorded elsewhere (e.g. recent coseismic rock avalanches in Alaska, Taiwan, Pakistan & China; catastrophic fiord tsunami at Lituya Bay, Alaska, in 1958; submarine-landslide tsunami in Lake Geneva, 563 A.D.; Kremer *et alii*, 2012). There is very little room for doubt that the events outlined above are able to occur, and the estimated probabilities lead to societal risks that are orders of magnitude greater than acceptable. The consequences in each case are potentially catastrophic in both human and economic terms, and would undoubtedly be severe in political terms if the relevant authorities had been informed of the situation. In the Franz Josef case, however, there remains some uncertainty about whether the slope identified will ever collapse, and to resolve this requires numerical dynamic stability analysis of the slope - not a completely straightforward task due to its difficult access, rainforest cover and location in a national park, but certainly feasible. Given the gross imbalance between uncertainties and potential consequences, however, it is hard to believe that nothing has been done to clarify or manage these situations.

MORE & BETTER SCIENCE?

To what extent is the unwillingness of authorities to act on scientific information indicating likely future catastrophes the result of shortcomings in the quality and quantity of the science? If this is indeed a factor, then we should expect the situation to improve over time as science grows in both quantity and sophistication. The fact that foreseeable landslide catastrophes are still not taken seriously 50 years after Vajont perhaps indicates that the available scientific information is not a key issue - today we know much more about large landslides and their causes and triggers than we did in 1962, and we have orders of magnitude more empirical data on landslides that have been studied. Further, we are much more capable of modelling the future behaviour of large slope failures on the basis of theory, and can thus make quantitative predictions of failure much more readily than was possible 50 years ago.

However, this improvement in current capability does not mean the scientific investigation of a potential catastrophe will be necessarily carried out to this capability, because high-quality investigation and modelling requires significant funding from the relevant authority - which will not be forthcoming if the authority is not seriously concerned. There is thus a Catch-22; until the responsible authority is seriously concerned by convincing information, convincing information cannot be provided.

This signals an interesting behavioural anomaly; science continues to advance and improve the quantity and quality of knowledge that can be provided about a specific situation, and such improvements are substantially funded by Governments (usually via Universities or Research Institutes) on the basis that *the resulting improvements in disaster prevention will justify the cost of the research*, but other government organisations will not fund their utilisation in a specific case. There is evidently a substantial contradiction here.

I therefore conclude that the availability of scientific information is not a significant factor in the reluctance of authorities to take action in respect of potential catastrophes.

BETTER SCIENCE COMMUNICATION?

Another possible explanation for the lack of enthusiasm on the part of authorities to fund scientific studies of potential catastrophes is that they don't understand the situation; in other words, they are not receiving information from scientists in a manner or form that convinces them of the need to act. Government officials are very busy people, under a wide range of pressures (economic, political and cultural) from both above and below; in addition, they are rarely familiar with the processes and language of science, nor with the personalities of scientists. Scientists are also under ever-increasing pressures to justify their existence by winning research grants and publishing more papers than the next guy; and scientists are generally not well-acquainted with local or national government personnel or operations. Scientists see politicians at all levels making decisions that in many cases seem to go against scientific rationale, without understanding that the soft factors in decision-making can outweigh science, and they interpret this as lack of rationality - to a scientist, the crowning sin. Politicians see scientists coming at them with bewildering demands for funding that they do not understand, and that, if granted, may result in unwelcome information becoming public; and with uninformed criticism of institutional decision-making that is far from endearing. There is a lack of common ground and understanding between scientists and government officials that, bluntly, limits the trust each group has in the other. This suggests that improving the communication of science is a more complex task than at first appears.

The first requirement of improving science communication is to improve scientists' understanding of the political process. This doesn't mean that scientists have to like or approve of the process; it is the system we have and we can't easily change it, so it must simply be accepted as a necessary and unalterable fact of life - like gravity, it's a hindrance some times. (Incidentally, I suspect many politicians have parallel reservations about the system in which they operate.) Communication of difficult information between two people is only possible if they trust each other - only then will they be prepared to put in the hard work needed to couch their own information in carefully-designed terms, and to translate the other's information so that it becomes acceptable into one's own world-view. Likewise, politicians need to grasp the world in which scientists work, in order to appreciate that science is (in principle) different to policy or dogma - it should act as a real-world constraint on policy and dogma, so that these do not conflict with the behaviour of nature.

This is evidently not going to be a rapid or straightforward process. It is to some extent recognised by the occasional (and perhaps token) appointment of science advisors to high-level politicians, and the presence of scientists in local government organisations - but the latter is increasingly rare as organisational science is out-sourced. The fact is, trust cannot be out-sourced: the personal acquaintance between scientists and politicians (not to mention planners and engineers) that used to occur in local government offices is increasingly rare.

For these and several other reasons, better communication of science to decision-makers lies way beyond simply rephrasing descriptions of what is in the minds of scientists, so that decision-makers will comprehend it. There are factors in comprehension that go far beyond agreement on the meanings of individual words and phrases, and are not easily achievable. While scientists generally do not communicate well, even within the confines of their disciplines, the gains to be made by teaching them to use simpler words are probably not significant. Politicians are in general better at communicating with the public at large - their future, after all, depends on persuading people to vote for them - but *their willingness and ability to get to the heart of science and be moved to act by it is constrained by a host of political, logistical, cultural and personal factors*. And in this, I believe, we get close to the kernel of the problem. Communication is indeed the underlying issue, but we need to dig deeper to understand the impediments to communication, before suggesting how it can be improved.

TIME-SCALES

Geologists think in geological time-scales, of up to millions or billions of years. Earth scientists generally have shorter time-frames, but when thinking about the intervals between large landslides the appropriate time-unit is the century or millennium. By contrast, society in general is accustomed to think in human time-scales, which span generations (small numbers of decades) at most. Societal decision-making, however, is commonly carried out by elected bodies whose duration is even shorter - seldom longer than a small number of years; this time-frame is imposed by the need to stand for re-election at the end of the period. Re-election requires societal popularity, which is likely to be dependent of the attitude of the populace to the current issues. In this context, re-election is unlikely for someone standing for a policy of restricting land-use because of a landslide that might not happen for thousands of years. This is particularly the case when local economic issues dominate the political landscape, and when immediate fiscal pressures can evidently be relieved by increased development of sites vulnerable to rare but catastrophic events.

Here we clearly have a difficult problem; how to balance short-term 'needs' (in fact these are desires, because what is at stake is a particular and relatively high standard of living) against the genuine need of long-term security against loss of life. Ironically, in many such cases long-term cost-benefit analyses show clear long-term net economic benefit in avoiding the vulnerable areas, because the costs are so high when the disaster occurs; but this has little impact when the short-term economics are so much better *assuming the event does not happen in the short term*. Statistically, of course, the disaster is much more likely to occur over the long term. Nevertheless, the event will certainly happen one day (we don't know when). In due course the event will happen in the short-term - and due course might be now.

This I believe is a fundamental reason that hazards science finds little fertile soil in the minds of decision-makers. A further reason lies in the mind-set of our leaders. These are likely to be people of forceful mentality, who are not risk-averse, so they are in fact willing - perhaps more willing than most of their electorates - to take short-term risks for long-term gain. Those who are fortunate enough to be successful naturally ascend to positions of power where, it can be argued, they are more in control of their circumstances and less likely to be unlucky. Empirically many of them are wealthy, again indicating greater-than-average ability to judge short-term risks well. It is unlikely that such people will take so seriously the threat of a future catastrophic event that they will forego short-term profit. Finally, most of the populace and its leaders have no experience of the types of event the scientists are talking about, so simply cannot be deeply affected by the prospect of their occurrence.

Thus I posit an intrinsic tendency, built into the structure of democratic society, to underemphasise science related to infrequent but catastrophic disasters of any kind, including large landslides. Recognition is the first step towards remediation; but is there in fact any way to alter this situation?

A SOLUTION: ACCOUNTABILITY?

The Achilles Heel of societal decision-makers is that they are held accountable by society, via their legal responsibilities, when disasters occur due to demonstrable and wilful lack of care on their part. Referring to my personal experience: DAVIES (2002) published a peer-reviewed paper in the Journal of Hydrology (New Zealand), demonstrating that the risk of loss of life in a holiday park from landslide-dambreak flooding was (a) some orders of magnitude greater than societally acceptable and (b) manageable only by relocation of the park. This public domain paper came to the attention of the Government at both local and national levels and, aided by an unusually risk-averse Chief Executive in a key Ministry, the Minister appreciated that if the disaster occurred, the Minister would be responsible if nothing were done because the public-domain information had been ignored. The park was eventually relocated.

This may be applicable more generally. If there is *peer-reviewed and published science that directly and unequivocally* demonstrates a *clearly unacceptable* risk to the public from a *demonstrably possible* disaster (i.e. of a type and scale that has occurred in a comparable situation elsewhere in recorded history), then any Government that neglects to take action is, by omission, directly responsible for the consequences. The words in italics are key; there must be no room for doubt, no wriggle-space for a smooth-talking Minister. In the case of Vajont, this was perhaps not the case; the scientifically-foreseen collapse of Mt Toc could not be communicated by reference to any other such event in recorded history, thus leaving room for the science to be dismissed as scare-mongering, because the public and government had no pictures in their minds of such an event. The same applies to the Mt St Helens disaster in 1980; there was no historic description of an event of this nature and scale to which public and politicians could relate.

THE WAY FORWARD

On this basis, the way forward for the three New Zealand cases outlined above becomes clearer. There must be peer-reviewed science published, and publicised, specifically related to these cases that leaves no doubt that the events can (and in fact will) occur; that the consequential risks are unacceptable by a large margin; and that either no mitigation is possible, or mitigation can and must be undertaken. In two cases further work is needed:

FRANZ JOSEF - A 3D dynamic stability analysis of the rock slope is needed to ascertain the degree of shaking required to cause it to collapse. This requires a detailed investigation of the rock mass characteristics of the hillslope, which is logistically challenging but certainly technically feasible.

KAIKOURA - Further work is needed to better characterise the tsunami deposits at Goose Bay and elsewhere; and, again, a 3D dynamic stability analysis of the sediment accumulation against seismic shaking.

MILFORD SOUND - Here, all that is needed is that the paper be written.

Publication of such papers may seem a daunting task for an individual scientist, especially a young one with much to lose by antagonising funding agencies and governments. It may result in some resistance from the decision-makers, and perhaps from the public. There may also be hostility from within the conservative science community, for “giving science a bad name” by “scaremongering”; one hopes, however, that there would also be support from other parts of the science community.

The papers must be able to be understood by lay people, because the electorate alone has the power to persuade governments to change policy or behaviour. Then, in the case that the decision-makers decide to do nothing, and the public disagrees with them, the decision-makers can be replaced at the next election. If the public agrees with them, and agrees to take responsibility for the risks it knows that it runs, that is perfectly acceptable.

The earth scientist’s responsibility to society in such cases is to use all possible methods to put the relevant scientific information in front of the public and the decision-makers in such a way that it can neither be misunderstood nor ignored.

SUMMARY

The risks to society posed by future coseismic landslides in New Zealand are societally unacceptable and in most cases manageable only by relocation of assets; this management strategy is supported by long-term cost-benefit analyses. However, governments are intrinsically loath to take seriously the risks posed by infrequent but catastrophic geological events, because their priorities are short-term and would be constrained by consideration of long-term risks. This conflict can perhaps best be resolved by public awareness of and access to scientific information describing the situation, in the context of the government’s duty of care to its citizens.

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