The Evolution of a Risk-Zoning System for Landslide Areas in Tasmania, Australia

P. C. STEVENSON
Engineering Geology Section; Geological Survey of Tasmania
D. J. SLOANE
Engineering Geologist; Geological Survey of Tasmania

SUMMARY A man's house is his greatest material possession and to lose it is a personal disaster. The publication of reliable information of the expected risk from landslide damage can sometimes prevent this loss, and should be the task of geologists in the service of governments.

Estimates of risk, made by a process such as that to be described, should be published so that land use can be designed to avoid or minimise the landslide hazard. This hazard is comparable in personal impact to that due to flood, forest fire, earthquake, or cyclone. Estimates of risk can best be presented as zones on a topographic map.

The initial input to the risk zoning system is the topographic map which is divided into slope angle classes. The geological map can be interpreted to show the susceptibility to weathering, the formation of slip-prone talus, and the groundwater hydrology of various rock types. The combination of geology and slope classes can then be used to broadly indicate areas of possible instability.

The second stage is the direct approach where geological conditions are confirmed by field study and may be re-mapped at a suitable scale for the particular investigation. The morphology of the area is studied and mapped together with any features indicative of mass movement. Anomalous slope complexity is considered to be a major indicator of an unstable pre-history.

Detailed studies are made of selected critically unstable and stable areas using a similar methodology to the above with additional stratigraphical, geomechanical and hydrological information obtained from drilling. Stability analyses are calculated using the above information. This combined with all other information indicates the threshold slope angle for each rock type.

The result is a two tier zoning scheme of which one is descriptive and one proscriptive. The original descriptive system is of five classes of increasing landslip risk. This will shortly be altered to a simpler three class system. The proscriptive system is based on legislation and prohibits building or allows it to occur under a specific section of Building Regulations.

Some comments are made on the problems of administration.

1 INPUTS TO THE ZONING PROCESS

1.1 Topography

The topographic map is the first input to the zoning process. An examination of even 1:100 000 maps, contoured as ours are at 20 m intervals, can enable steeper areas to be recognised and marked for closer examination. Our current Tamar Valley Landslip Zone Maps are at a scale of 1:15 840 (Figure 1) and while extremely useful, inadequacies have become apparent as individual house lots are difficult to distinguish at this scale. Certain areas have been mapped at 1:2 500, an ideal scale for mapping small townships. The availability of suitable topographic maps is often the deciding factor and our existing maps are to be now remapped at a scale of 1:10 000 where the average city house lot will appear as 1.8 mm by 3.6 mm. In the absence of suitable topographic maps we have used aerial photographs enlarged to 1:5 000 and even produced our own oblique aerial photographs enlarged to a similar scale. The latter have proved very useful when mapping small landslip areas less than 3 km in extent.

Whatever suitable maps are chosen, slope angle classes are drawn on them. The choice of classes depends on the prevailing topography and geology and the scale and contour interval of the topographic map. Several methods have been used including paper templates and circular perspex templates extending over five contour intervals with each designed to represent the various slopes selected as the upper and lower bounds of each slope class. For aerial photographs slope angles are measured in the field by clinometer and the same slopes are used as standards for comparison on stereo-images. Another approach is to construct, using the methods of Miller (1961), square based pyramids having apparent sideslopes of predetermined angles. These are plotted on transparent film and viewed as a stereopair so as to form a model in space. This is laid over the photopair and direct comparisons made with unknown slopes. Where suitable computer facilities are available slope classes can be produced directly on the topographic map. This method is to be used in our next zoning investigation.

The initial result is therefore a series of slope angle classes drawn on a suitable base map. The ultimate and essential source of information is the landscape itself.

1.2 Geology

The second input to the zoning process is the geological map. We are fortunate in that good

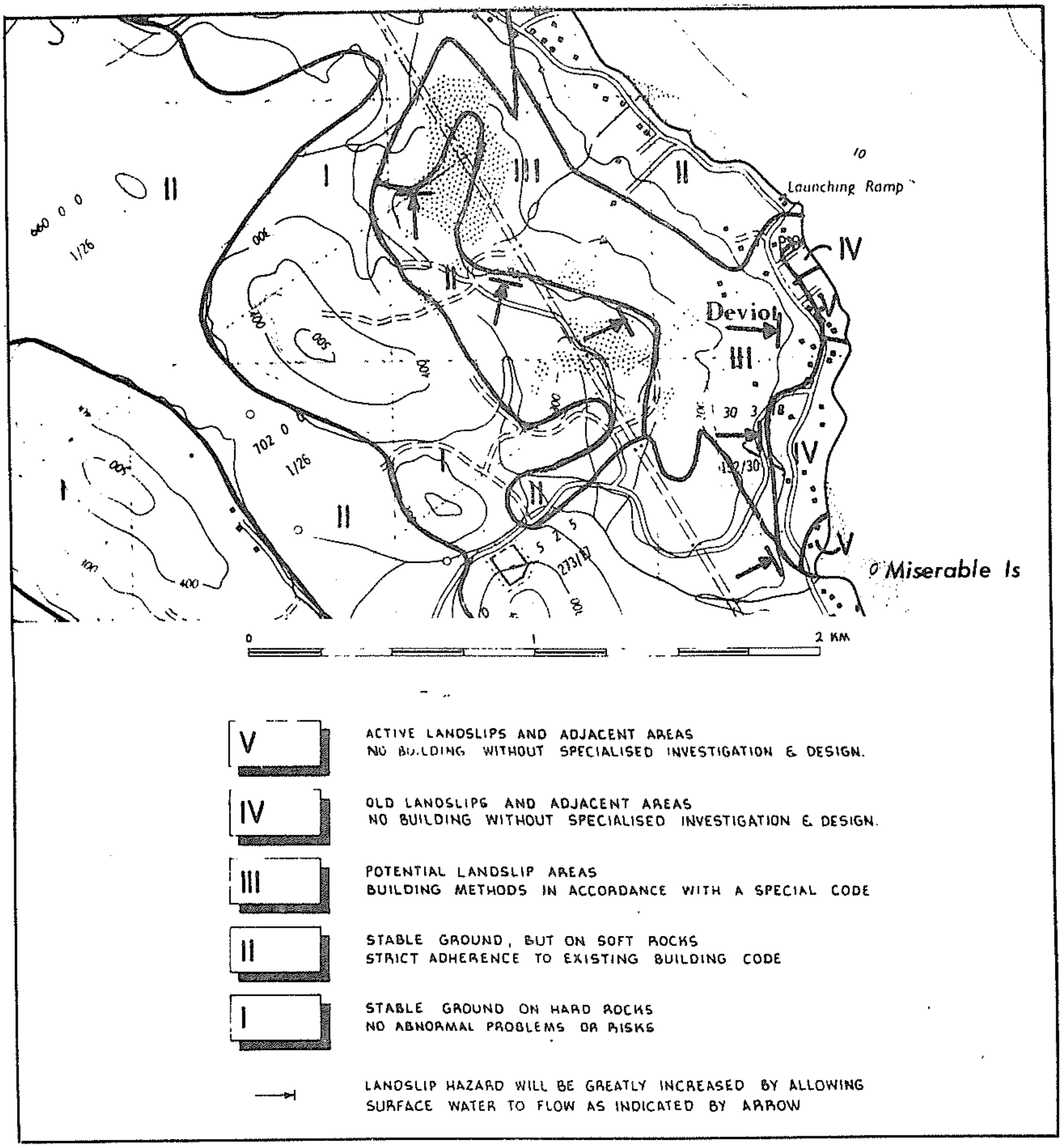

Figure 1 A section of the Batman Bridge sheet of the Tamar Valley landslip zone maps

1:50 000 geological maps exist of most of the areas we are required to investigate. However when zone mapping is conducted on a 1:10 000 scale or less then adjustments and additions are often required to be made to the geological base map. Where geological maps do not exist then this mapping is required as part of the geomorphological appreciation to be discussed later.

The geological map, if it does not already do so, must be interpreted in terms of rock types. Clays and weak shales will primarily suggest themselves as slip-prone materials but only field examination will determine this.

The harder rocks must also be considered as they may often function as loads at critical places on clay slopes, and more importantly as aquifers. The recognition of the influence of surface aquifers in producing instability in adjacent soft rocks was recognised by Denness (1972) as the reservoir principle and we have found this principle to be of the utmost importance where, as in our area, fresh fractured basalt overlies soft lacustrine sediments on steep slopes. The relationship between aquifers and their resulting springs, and the movement of colluvium in hillcreep must also be appreciated as occlusion of springs by mass movement may be a very potent agent of instability. The solid geology as indicated in most geological maps is therefore to be inspected for the presence of soft or softenable rocks and for aquifers capable of producing spring lines on or above steep slopes in these materials.

There is however, a considerable limitation to this simple approach. The colluvial materials on the slopes are probably critical in determining slope stability and are not usually represented on a geological map. Here a direct method has to be used, that of inspecting the slopes on each rock type in the field and determining the colluvium thickness, expected variation, and general nature. This process can be treated qualitatively at this stage but will need to be pursued in detail when the morphology is dealt with. Recent geological mapping has changed in that surficial deposits are now often differentiated, consequently improving their usefulness.

The geological map does not recognise the state of weathering of the rocks. This factor may drastically alter the whole nature of the rock and consequently affect its stability potential.

At this point the information obtained from the topographic map with slope classes and the geological map can be combined. This will indicate areas that may be unstable or potentially unstable. These areas will require more detailed inspection at the next stage in the zoning process which involves direct field observation.

1.3 Morphology

The geomorphic mapping process relies on field observation and the recognition of slope features associated with mass movement.

Some consideration of slope classes has already been made. The angles which are used as the class limits are chosen after an examination of active failures. An inspection of several recent failures in what appears to be the same geology will generally indicate a lower limiting angle. With so many factors influencing the stability of slopes, it might be thought that the slope angle is too simple a criterion to use, but an extended area of similar materials, where several failures can be compared has, in our experience, generally indicated a lower bound to the failing slope angle. This we have called the critical angle or threshold slope angle for the prevailing geology.

Where the geology changes, the critical angle will change also. Our areas show a variety of critical angles, for example in Tertiary lake sediments 7° is taken, while on weathered basalt soils 14° is used. It would be illusory to depend too much on these exact angles but the whole process of zoning is an approach to an ideal and the establishment of critical angles is a step on the way.

Slope segments are mapped in the field by outlining breaks of slope and slope angle measurements are taken by inclinometer. Comparisons may then be made between observed slope angles and the threshold slope angle. Slope mapping forms the basis of the geomorphic map. Features from the slope map which may indicate active or previous mass movement include arcuate scarps which may have become vegetated or subdued by erosion, benching of slope profiles often with backsloping areas, and unusual convexities or concavities of slope regions. Slope complexity has been used by us as indicative of the mass movement history of a slope region when compared with much simpler slopes profiles in adjacent areas on the same hillslopes.

The next stage of our geomorphic appreciation is directed to the surface drainage features. The textbook examples of drainage patterns are not uncommonly seen to be represented in the field, but in mass movement areas disruption of drainage is a marked characteristic. The scale on which this occurs is often not large enough to appear significant on a 1:100 000 topographic map, but on photos or in the field it is usually obvious. Simple stream flow patterns diverted by debris tongues, ponds behind rotated blocks, and the subsequent drainage along rather than across the contours of the original slope, seepages, hillside swamps with no outlet, small valleys containing paired streams, and many other anomalies in the surface hydrology can point to movement. Other features to be mapped include anomalous leaning or kinked trees and the universally present but ill-defined 'hummocky ground'.

All these features have been exhaustively described by others and Pulinowa et.al.(1977) have produced an atlas of symbols to represent the whole of the morphology. To these natural features may be added the stretching of fences, cracks in roads, walls, and pipes, the tilting, distortion and final destruction of buildings. All must be recorded on the geomorphic map.

At this stage the three major inputs will contribute to a map which will indicate active and inactive areas of mass movement. Features associated with such phenomena will be apparent and areas similar in slope, geology etc. can be outlined as regions of potential instability where caution may be required when landuse decisions are to be made.

1.4 The Age Problem

The problem of dating a particular landslip feature is perhaps the most difficult part of the zoning process. Underestimation of the age of a disrupted slope may lead us into conservatism so that even Pleistocene slope failures which may be perfectly stable under present conditions are considered unstable. The question that arises is what is the age of the disturbance? It is a question of real significance because any zoning scheme must be based on the realisation that it operates in a time scale short by geological standards, but long in comparison to the occupancy of a house. A period of fifty years is a convenient yardstick, almost a lifetime, long for a house of light modern construction, long enough to see several generations of active engineering geologists and to see dramatic changes in investigation technique. It is all the more reason for zoning to be placed on a practicable and defensible methodology for it is going to influence urban land use beyond the foreseeable future.

Dating old mass movements is difficult but where possible we can attempt to predict how soon the mass movement cycle will be repeated. The work of Hutchinson (in Skempton and Hutchinson, 1976) shows that in well placed cases dates can be found for old movements, but in Australia with less than two hundred years of recorded history the problem is doubly difficult. Currently active movements can be readily observed and the value of photographs, measurements and descriptions is important as features rapidly become indistinct either by natural erosion or deliberate concealment.

Mass movement is also part of the response of geology to climate so that climatic variation studies both in the long and in the short term are of some use. Rainfall variations are influential in controlling pore pressures in fissured clays and the monitoring of piezometers through several years has revealed some unexpected and significant behaviour in relation to landslide movements (Knights and Matthews, 1976). Rainfall records can usefully be reviewed against historical accounts, although correlations based on newspaper articles have not been very successful. Beyond rainfall records, recent advances in Holocene climatology may enable the truly fossil movements of the end of the last glacial stages and beyond to be separated out. In our case the sheer size of what we believe to have been Pleistocene failures compared with modern failures, together with the anomalous relation to what are now permeable sediments, enable us to distinguish them with some confidence.

The problem of the role of vegetation in controlling stability is still with us. It cannot really be regarded as established that vegetation invariably increases stability. It depends too much on what vegetation, what climate, and what kind of slopes are involved.

A consideration of the age of a landslip movement is therefore important in our decision making process when trying to ascertain if these areas are currently stable and are likely to remain stable within the life of the landslip zoning system.

1.5 Detailed Studies

We must now turn to the crux of the zoning problem where we see landslides in action. Working in this field where potential failures or long term stability are everyday concepts, the sight of a slope actually undergoing failure is a sobering experience. When the slope is actually failing, it is possible to say that the factor of safety is less than unity, that the many conditions for failure are satisfied, that doubts are removed and, however the process works, it is doing so here and now. A failure provides an example of the process that is of great value for it is then possible to investigate a real example, not a scenario or a potential situation.

The methodology is the same as in a regional analysis. The topography of the slide and its immediate surroundings, and the geological setting must be discovered. The materials present must be examined and sampled by drilling, and the soil parameters and water conditions determined. The changes in time in water conditions, particularly of pore pressures must be recorded. The variability of these is of particular importance in analysis.

With this sum of information we must proceed to set up an analysis of the failure so that the limits of the input parameters may be found and to check for realism. Classical analysis after Bishops simplified method, or for shallow slab failure, after Skempton and De Lory is known to be incapable of coping with the real world facts of progressive failure or long term stability. Many other formulations are current but none show any advantages in the real world, and stability analysis must be recognised for what it is, a simplified mathematical model of the failure process to be considered as another tool useful in the assessment of stability but no more credible for its numerical appearance.

Stable areas where no sign of past movements can be distinguished and dormant areas where past movement is known or suspected must also be subjected to analysis. The determination by back analysis of acceptable values of input parameters must be made as a parallel to the work in active areas. The stability of the stable areas as well as the failure of the active areas must be confirmed by analysis.

The empirical methods outlined by Stevenson (1977) have some relevance here for they enable the relative stability of an area to be estimated in relation to the analysed areas. Analysis cannot be used in a great number of locations for reasons of cost and effort, but if it can be used in the more critical places, then other similar locations can be estimated with perhaps only a minimum of groundwater information.

2. THE ZONING SCHEME

We have now accumulated a great deal of information on the area to be zoned, and we must now turn to the task of synthesis. The zoning scheme can be considered as land use planning with respect to a geological hazard that is the risk of landslip movement.

Zoning has always been conceived in our minds as a control on the development of dwelling houses. Any larger structures are not generally built or owned by individuals on their own financial resources, and the impact of damage is borne corporately. In most countries landslides are not an insurable risk and every possible precaution must be taken to avoid damage as the cost falls heavily on individual owners. In those countries where some corporate risk is borne, this does not relieve the cost but only spreads the impact.

Larger structures, public buildings, installations, road and rail routes all carry with them the assumption that adequate investigation has been made in the course of which the landslide risk has been recognised and minimised either by design or relocation. If the assumption is invalid then damage may result, but it will be borne by the community at large and not by an individual.

2.1 Descriptive Zones

In this State a two-tier zoning scheme has evolved. The lower tier is descriptive, and until recently consisted of the following classes:

- I Stable ground on hard rocks.
- II Stable ground on soft rocks.
- III Potential landslip areas.
- IV Old landslips and adjacent areas.
- V Active landslips and adjacent areas.

This system attempts to represent the geological truth as far as this can be known, in terms that any reasonable person can understand. The zones are advisory, are published in easily obtainable, cheap maps and are circulated to local councils and other interested government departments.

Zone I is, in our areas, normally on dolerite, basalt or sandstone, weathering is no more than moderate, and the soil cover is not normally greater than 1.5 m. It is essentially a zone where clay failures cannot exist and slope failures of other kinds are vanishingly small under the impact of urban housing. One cannot rule out the exceptional occurrence which may be brought about by a previously unknown phenomenon or incompetent building methods.

Zone II is those areas where clay and deep soil capable of slope failure exist, but slope angles are less than the minimum observed failure slope. These areas are often subject to a swelling soil problem, but this is not directly relevant.

Zone III is those areas where both sufficient slope and failure-prone materials are present, but where no failures are known to have taken place. Presumably the groundwater conditions are not such as to bring about failure, but the possibility exists that a change in conditions caused by development could precipitate instability.

Zone IV is those areas where sufficient evidence exists of past instability to warrant an assumption of reactivition, and those areas adjacent which such reactivition could endanger.

Zone V is those areas where measureable movement is taking place and those areas which could be endangered.

In the light of the analysis that has been described boundaries must be drawn on the zone map, on the strength of the topographic, geologic, and morphologic findings and with the assistance of the stability analyses, but without reference to existing man-made structures.

The Tamar Valley Region of northern Tasmania has been mapped as a series of 1:15 840 maps using the above five descriptive zones. This system is now to be simplified to a three zone system designed for ease of use by the public, local authorities and government institutions. The new three zone system is more proscriptive in nature and the zone definitions are broadly based on whether development may proceed without restrictions, may proceed with some restrictions or may not proceed at all. The three zones will be:-

1 Green Zone. Areas where no undue risk is recognised and building and development may take place under the normal control of councils under the Building Regulations.

2 Yellow Zone. Areas where doubts exist as to the stability of the area and a more or less detailed investigation is required before building can take place. Some or all of the terms of the special regulations for landslide areas (Building Regulations Part IV, Division 5, 1978) would apply, the impact of these depending on the results of the investigation.

3 Red Zone. Areas where active movement is occurring and building is prohibited.

In this three zone system the Green Zone would closely correspond to Zone I and II of the original system, the Yellow Zone would closely correspond to Zone III and some of Zone IV and the Red Zone would be similar to part of Zone III and Zone IV and all of Zone V. These zones can be defined descriptively for the benefit of interested authorities and persons.

In summary the lower tier, descriptive zone system is used to persuade the public, local councils and government authorities of the danger and risk of the landslide hazard.

2.2 Proscriptive Zones

The second tier of zones is brought into use when advice is no longer enough and compulsion becomes necessary. The zones are proscriptive, and are proclaimed under the State's Local Government Act (1974).

Legal sanctions sometimes become necessary when settlements have existed before the recognition of the extent and seriousness of the landslide risk. In this case, the risk must be made plain to the owners of houses in the area so that they may be able to take prudent precautions such as the maintenance of drainage or the avoidance of deep earthworks on steep slopes, and as a warning to intending purchasers.

It may also happen that entrepreneurs have committed themselves to the construction of housing before the recognition of the risk. They will of course wish to lose as little of their investment as possible, and the zones inform them of the constraints on building.

The proscriptive zones are known as A and B landslip zones under the Act. In an 'A' zone all building is prohibited with some minor exceptions. In a 'B' zone, buildings are controlled in respect of size, siting, drainage, earthworks and the removal of trees. Restrictions are included as Part IV, Division 5 of the Tasmanian Building Regulations (1978).

The problems that arise when landslip risks are first recognised are unavoidable. We have previously generally been consulted after the problem has occurred rather than during the initial development of potentially unstable areas. Local councils and Government authorities have now become more aware of the problem and little development of potentially unstable areas can now occur without inspection by the Tasmanian Department of Mines.

The relationship between the zones of the I-V scale of descriptive zones and the A and B proscriptive zones has evolved through usage, and introduces a useful degree of flexibility into the system. Originally, B, the zone where limited building could take place, was taken as equivalent to III and A as equivalent to IV and V. As the whole problem has been investigated and our confidence has increased, a partial relaxation has been made in zone IV. The term 'old landslips' has always included structures of a range of ages. The oldest of these, probably originated under different climatic conditions and are now quite stable, and so can be released for controlled building. Different parts of old structures also vary in their potential for failure. The heel area is often quite stable, while the oversteepened toe zone may still show parasitic modern failures.

Another advantage of the two-tier system of zoning is that amendments to the descriptive zones are easily introduced as they arise from detailed investigations, while proscriptive zones require a statutory process. In practice, even the first kind of amendment has not been very common, and the original descriptive zones have proved to be a good general guide.

Any recommendation for the proclamation of Landslip Areas under Section 431A of the Local Government Act No. 2, 1973 would necessitate a transformation of the Green-Yellow-Red zones into 'A' and 'B' areas in the same way as has occurred previously with the five zone system. Broadly Yellow areas would become 'B' landslip areas and Red areas would become 'A' landslip areas, not automatically but after specific investigation and recommendation by the Tasmanian Department of Mines.

2.3 Problems of Administration

The administrative procedures have not functioned well. Little guidance can be offered in this respect as the political climate and that of public opinion, and indeed the whole physical circumstances surrounding the social impact of the landslide process are likely to be quite different in another society.

Briefly, the proclamation process is initiated by the geologists working on the landslide survey. They become aware of damage or the risk of damage and of the possibility of social loss. The geological and morphological circumstances are closely examined, and if time permits, some subsurface work is done, mainly to establish material properties and water conditions. A recommendation is then made by the departmental director, and is passed to the local authority (council) of the area concerned, which has the responsibility of informing all landowners that zoning has been recommended, and calling for objections.

The whole confrontation has culminated in the past in an Objectors Meeting, where objectors are able to meet the geologists. These meetings, surprisingly, are often able to calm the worst fears of some objectors, and to explain the logic of the recommendation to those affected. While not a pleasant experience for the geologists, it is an interesting and useful one, both in appreciating the effect of the investigation and in conveying difficult scientific and technical concepts to an interested and unsympathetic section of the public.

The inability of the council to identify and inform every involved landowner has proved to be the greatest stumbling block, especially when proclamations have to be made in already built-up areas. This process has tkane more than two years, and in one case has had to be abandoned. A simpler and perhaps less scrupulous process may have to be adopted.

The impact of a proclamation depends on the state of development. Where little or no work has been done on the ground by the developers, and the land is still rural, the effect is simply to prevent or restrict building. In 'B' areas, where restrictions apply, some discussion takes place on the exact details of what may be built where, and how adequate stability may be achieved. These discussions are a fertile source of ideas for construction methods, and some progress has been made in using 'B' areas wisely and well.

Where a developed township is proclaimed, the main effect is on new building, which is either prohibited, resulting in open spaces being left or is again restricted. Proclaimed areas in towns are usually those where some destruction of houses has taken place and the open spaces are readily accepted, and become parks or lesser amenity areas. Proclamation in areas of damage is easily achieved as little persuasion of its necessity is required. In areas of potential instability, the whole process of conviction must be worked through and is only ever partially successful.

The loss of land value is probably the greatest complaint aimed at the zoner. His reply generally takes the form that he is merely restoring to the land the correct value that was previously overestimated in error. To the charge of arrogance in presuming to do so, he can only reply that the care he has taken is demonstrably greater than that used in the first place when 'market forces' operated. We are not aware of any systematic studies that have been made of changes of value in the market as a result of landslide zoning, although valuations for taxation purposes have been altered on an 'ad hoc' basis.

Generally the descriptive five zone maps have proved useful in the majority of areas where little or no development has occurred. The local councils and government authorities may use these to control the development of these areas by acting on the advice of the Tasmanian Department of Mines without the need for proscriptive zone proclamation. The proposed new three zone proscriptive maps will work in the same way as the previous system but will be easier for the public, local councils and government authorities to interpret.

3 CONCLUSIONS

This paper has outlined the methodology behind the development of a descriptive and proscriptive landslip zoning system currently in use in the State of Tasmania, Australia. A new three zone descriptive system that has evolved from experience with the previous system and which is to be used in the future, has also been discussed.

The implementation of the zoning process is to constitute a warning to those who seek to use the land that instability is, or may be, present. If it is, let them beware. If it may be, then the use and value of the land may be protected by prudent precautions. Forewarned is forearmed.

If warnings fail, are inaccurate, or come too late, loss can result, and can be protracted and devastating both materially and spiritually for the individuals and families affected. Only those who have suffered such a disaster can appreciate the effect of it.

Landslides are unique among natural disasters in that they are uninsurable. Why this should be so may be related to their comparative rarity, their usually small area of impact, and their often slow and unspectacular behaviour. Floods, fires, earthquakes, cyclones and tsunamis, none fulfil these three conditions, and so have attracted public attention and consequent sympathy for their victims.

Landslides have been regarded as 'acts of God', a lawyers term implying a blind unpredictability. This paper attempts to show how a system has been evolved to establish landslide zones, and so predict as far as is presently possible the risks of this disaster. The establishment of insurance should now be possible.

4 ACKNOWLEDGEMENTS

We wish to acknowledge the work of our colleagues of the Tasmanian Geological Survey and the benefit of discussions with them, from which this system of zoning has evolved during the last ten years.

This paper is published with the permission of the Director of Mines, Tasmania.

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