The study took place at Fraser's Hill, in the state of Pahang, Malaysia. The area receives 20–410 millimetres of rainfall each month. The temperature is moderate, ranging from 18 to 22 °C annually, with high humidity, ranging from 85 to 95 per cent every month. The surrounding vegetation is lower montane forest.

Two study plots were chosen, and a control plot. Initial works involved soil nailing, using 300 live stakes of *angsana* tree branches and 200 cut stems of *ubi kayu*. Subsequently, major groundworks involved the installation of **geo-structures** (structures constructed from **geo-materials** such as bamboo and brush bundles, coir rolls and straw wattles). The volume of sediment trapped by the geo-structures was measured every two weeks, while plant species that were established on the retained sediments and on geo-materials were identified. The number of live stakes that produced shoots and roots was also recorded. Ten 1 metre-tall saplings of *Toona sinensis*, a fast-growing tree species, were planted at the toe of the slope for long-term stability.

The first slope failure was caused by seepage of drainage water into the cut slope of the access road. The total area affected by the landslide was about 0.25 hectare. Two large trees, 4–5 metres tall, were uprooted and ground vegetation and debris were washed downhill, preventing road access. The second and more extensive failure was located uphill and was a rotational failure. It covered an area of about 0.75 hectare. The landslide was probably triggered by seepage of water from a badly damaged toe drain beside the road.

Bio-engineering design: After six months

The bio-engineering designs involved the installation of 11 bamboo bundles ('faschines') and 16 brush bundles along rills and gullies. At suitable sites along contours, 10 coir rolls and 5 straw wattles were installed, using live stakes and steel wiring. Lighter geo-materials such as straw wattles and brush faschines were positioned on the upper slope face, while heavier geo-materials such as coir rolls were positioned lower down.

At the end of six months, the situation at each study site was assessed (Table 9.17).

Table 9.17 Selected geo-materials and total volume of sediment retained over six months at the two study sites

Geo-materials	Total sediment retained m^3	Total number of migrant species
Bamboo faschine	1.7	14
Brush faschine	1.0	17
Coir roll	2.2	20
Straw wattle	0.2	26
Total sediment retained by different geo-materials	**5.1**	–
Total number of migrant species	–	**77**

Live stakes and *Toona sinensis* saplings

At the end of six months, the live stakes had become living trees. A high percentage of *angsana* stakes (93 per cent) sprouted shoots and roots after a month, and 75 per cent of *ubi kayu* stems sprouted leaves within a week. Thus, live stakes were effective in stabilising unstable slopes.

Vegetation cover on slopes helped reduce soil erosion because shoots helped reduce the intensity of raindrops falling on the exposed soil. Furthermore, root-reinforced soils functioned like micro-soil nails to increase the shear strength of surface soils.

Slope stability

The indicator poles at both study sites moved less than 8°, unlike the indicator poles from the control plot, which moved about 20°. Without erosion-control measures, there was aggressive soil erosion during heavy downpours, which caused scouring of the steep slope below the tarred road and resulted in an overhang of the road shoulder.

Trapped sediments and vegetation establishment

A total of 57 geo-structures retained 5.1 m^3 of sediment after six months. The retained sediments and decomposing geo-materials also trapped moisture and provided ideal conditions for the germination of incoming seeds. After six months, it was found that 77 plant species were established.

After one year

A year after the study was first implemented, about 75 per cent of one study site was covered by vegetation, while 90 per cent of the second plot was re-vegetated. There was no more incidence of landslide at these two plots. However, at the control plot there was further soil erosion, which resulted in further undercutting of the slope face.

At the control plot, after one year, only seven plant species were present. These were weeds. The poor vegetation cover was probably due to unstable soil conditions caused by frequent soil erosion and minor landslides. It is believed that vegetation cover can provide a layer of roots beneath the soil layer and this contributes additional shear strength to the soil and slope stability.

The geo-structures were installed at a cost of about US$3078, which was cheaper than restoration works using conventional civil structures such as rock gabions, which cost about US$20 000. As the site is quite remote, higher transportation and labour costs would have contributed to the higher cost of constructing a rock gabion at this site. On the other hand, the geo-materials that are abundantly available locally are relatively cheap to make or purchase, and this contributed to the low project cost. The geo-structures were non-polluting, required minimal post-installation maintenance, were visually attractive and could support greater biodiversity within the restored habitats. The geo-materials used in this project, such as faschines, coir rolls and straw wattles, biodegrade after about a year and become organic fertilisers for the newly established vegetation.

After 18 months, the restored cut slopes were almost covered by vegetation, and there was no further incident of landslides. The geo-structures installed on site were cost-effective and visually attractive. The restored cut slopes were more stable and supported higher biological diversity.

Assessment of costs

The geo-structures cost approximately $3000 to install. In contrast, a rock gabion would have cost about $20 000 to install (as the area is remote, transport costs would increase, and there would be increased emissions of greenhouse gases). Moreover, the geo-structures were visually attractive, could support biodiversity, were locally available, and took just two weeks to install. In terms of a cost-benefit analysis, therefore, the geo-structure has a great deal to offer.

The sustainable livelihoods approach for volcano-related opportunities

In an article entitled 'Living with Volcanoes: The sustainable livelihoods approach for volcano-related opportunities', Ilan Kelman and Tamsin Mather outlined ways in which people could have a sustainable livelihood in volcanic areas.

The destructive forces of volcanoes are well known, for example Mt Pelée in Martinique killed approximately 30 000 people in St Pierre, while in 1985 lahars from Nevado del Ruiz, Colombia, killed approximately 25 000 people. National/regional impacts are represented by the 1783–84 eruptions of Laki on Iceland, which killed 24 per cent of Iceland's population and caused thousands of deaths elsewhere in Europe. Global volcano-related impacts have been noticeable through weather alteration, as was the case following the 1991 Mt Pinatubo eruption in the Philippines.

However, human fatalities linked to volcanoes have been relatively few. The death toll attributed to volcanoes since 1 CE is approximately 275 000. As with many disasters, volcano-related disasters also have psychological impacts.

Literature dealing with the volcanic risk perception tends to focus on threats and dangers from volcanoes, along with possible preparation measures, whereas information regarding perceptions of volcano-related benefits or opportunities are more limited.

The contributions of volcanoes to society are widespread. For example, the Mt Etna region represents just under 7 per cent of the land area of Sicily, yet is home to over 20 per cent of the population. Reasons for this intense human activity on the lower slopes of the volcano are not difficult to find, including fertile soils and a reliable freshwater supply. The Soufrière volcano on St Vincent brings agricultural, mining, quarrying and tourism benefits to St Vincent and the Grenadines. There are also geothermal resources, and the use of volcanic materials for making items such as basalt hammers and pumice, along with the archaeological and artistic gains from volcanism.

Dealing with environmental hazards

As exemplified by Mt Etna in Italy and Mt Mayon in the Philippines, people have good reasons for living near or on volcanoes, including good farmland and reliable water supplies. This sometimes yields dangers, despite the rewards. To balance the dangers or potential dangers with the gains or potential gains from environmental hazards, including volcanoes, a four-option framework has been developed (Table 9.18).

Table 9.18 Options and consequences for dealing with environmental hazards

Option for dealing with environmental hazards	Main implications
1 Do nothing	Disasters occur.
2 Protect society from hazards	Not always feasible and leads to risk transference, which augments vulnerability.
3 Avoid hazards	Not always feasible and can exacerbate other problems, augmenting vulnerability.
4 Live with the hazards and risks	Livelihoods are integrated with environmental threats and opportunities.

The first option is to do nothing, accepting that volcanic disasters will happen. Depending on the volcano, this option might be more viable or less viable. Mt Etna in Italy frequently erupts, so doing nothing could lead to a disaster, depending on the extent and characteristics of an eruption. In contrast, Mt Jefferson in the USA has not erupted in several centuries and doing nothing could be an option there.

The second option is to try to protect society from volcanic hazards, such as by strengthening roofs against tephra fall, building structural defences against lahars, pumping sea water onto lava (Heimaey, Iceland 1973), diverting lava (Mt Etna) or slowly degassing (Lake Nyos, Cameroon). However, this protection option is not always feasible. For example, not all gas releases could be averted through degassing. Large pyroclastic flows and lava flows are challenging to stop or even to redirect, although structures could be designed to afford some level of protection against these hazards. Moreover, reliance on protective measures could lead to a false sense of security, without tackling the root causes of vulnerability.

The third option is to avoid volcanic hazards, but that is not always feasible. Volcanic impacts are often not local and are sometimes even global, so all places on Earth have the potential for being severely affected by volcanic activity. Additionally, with global population increasing, constraints on land and resources frequently leave little option other than to inhabit areas that are potentially affected by volcanic hazards.

Moreover, avoiding volcanic hazards could cause further problems. Volcanic activity can yield advantages that might outweigh the problems. Moving away from volcanoes could yield other concerns, perhaps exposure to other environmental hazards or perhaps social challenges. After Montserrat's volcano started erupting in 1995, some families moved to England, only to be disappointed at the low standard of education in English schools. Many Montserratians were shocked, too, at the level of crime risk to which they were exposed on neighbouring Caribbean islands.

The fourth option – living with risk – means accepting that environmental hazards are a part of life and of a productive livelihood. A component of living with risk is localising disaster risk reduction. Disaster risk reduction, including pre-disaster activities such as preparedness and mitigation and post-disaster activities such as response and recovery, is best achieved at the local level with community involvement. The most successful outcomes are seen with broad support and action from local residents, rather than relying on external specialists or interventions. Although the long dormancy periods of volcanoes and significant uncertainties about eruptive pathways might make community interest in disaster risk reduction wane, few communities are vulnerable only to volcanic hazards.

The sustainable livelihoods approach

Sustainable livelihoods can be defined as creating and maintaining means of individual and community living that are flexible, safe and healthy from one generation to the next. The sustainable livelihoods approach is important in its application to volcanic scenarios in four ways:

1. Understanding, communicating and managing vulnerability and risk and local perceptions of vulnerability and risk beyond the immediate threats to life.
2. Maximising the benefits to communities of their volcanic environment, especially during quiescent periods, without increasing vulnerability.
3. Managing crises.
4. Managing reconstruction and resettlement after a crisis.

Applying the sustainable livelihoods approach

Managing vulnerability and risk

The first application of the sustainable livelihoods approach to volcanoes is understanding, communicating and managing vulnerability and risk along with local perceptions of vulnerability and risk beyond immediate threats to life.

Thinking ahead of the event ensures that:

- local livelihoods are preserved, meaning that the population has an easier post-disaster recovery except for cases of extreme destruction
- the affected population is confident that their livelihoods will remain, so they will be more willing to shelter and evacuate without putting their lives at risk for the sake of livelihoods.

Examples include attempts to prevent lava blocking Heimaey's harbour and balancing ski access to Ruapehu during active episodes, especially in light of the continuing lahar threat. In these instances, it was decided that saving only lives without considering livelihoods was unacceptable. Risk and vulnerability have been managed to achieve a balance between lives and livelihoods: living with volcanic risk.

Maximising community benefits sustainably

The second application is maximising the benefits to communities of their volcanic environment, especially during quiescent periods, while decreasing vulnerability. The livelihood benefits of volcanoes can be placed into three main categories: physical resources (for example, mining), energy resources (for example, heat) and social resources (for example, tourism).

Volcanoes play an important role in the formation of precious metal ores. However, if the volcano's activity increases, the mining resources, equipment and expected income could be jeopardised. The 2006 eruption of a 'mud volcano' in eastern Java, which was highly destructive to local livelihoods, resulted from borehole drilling.

Managing crises

The third application is managing crises. Emergency response and humanitarian relief are adopting the sustainable livelihoods approach, such as for the sectors of transitional settlement and shelter and food security.

Managing reconstruction and resettlement

The fourth application is managing reconstruction and/ or resettlement after a volcanic crisis. Montserrat provides a good example. Resettlement in the island's north, away from the most dangerous zones due to volcanic activity, included housing construction that was completed without sufficient attention to local culture, other hazards or livelihoods. The resettlement saved lives, but did not adopt a local approach to living with risk. Long-term problems emerged that the sustainable livelihoods approach might have prevented.

Disadvantages

Volcano-related evacuations have sometimes forced people to choose between staying in poorly managed shelters with no livelihood prospects and returning home to their livelihoods despite a high risk of injury or death from the volcano. This issue was witnessed in Montserrat, exacerbated by economic structures that encouraged farming in the exclusion zone (Figure 9.42).

Figure 9.42 Cattle in the exclusion zone, Montserrat

Figure 9.43 It is not always possible to see volcanic impacts as positive

Towards reducing volcanic impacts

Considering livelihoods is important in successful volcanic disaster risk reduction because they contribute to living with volcanic risk based on a localised approach. Living with volcanoes at the local level requires changes of perception and action, resulting in advantages for volcanic disaster risk reduction, although there can also be potential disadvantages (Figure 9.43). With the local population involved in monitoring, understanding, communicating, making decisions and taking responsibility for aspects of volcanic disaster risk reduction – with external guidance and assistance where requested – disadvantages can be minimised.

Three points emerge from applying the sustainable livelihoods approach to localised living with volcanic risk:

- First, not all livelihoods near volcanoes are volcano-related. Productive agriculture could be due to floodwaters rather than volcanic deposits.
- Second, not all volcanic activity necessarily yields livelihoods, or livelihoods that should be encouraged. Tourism and research activities in active craters (Figure 9.44), for example, tend to be discouraged in vulcanology. That level of risk-taking could also make the livelihood vulnerable. For example, if tourists were killed by a volcano, the area's tourism could suffer.
- Third, resource availability does not always imply resource use. Mining could be deemed too externally dependent or too environmentally and socially destructive to be worthwhile pursuing.

Volcanic risk perception and communication studies show that not everyone living by a volcano understands or accepts the actual or potential implications of the volcano. Risk and disasters emerge from volcanoes, but livelihood opportunities emerge from volcanoes too. Those opportunities form an integral part of volcanic disaster risk reduction.

Despite volcanic benefits, living with volcanic risk is not always feasible and volcanoes should not be relied on for livelihoods without careful consideration of potential drawbacks. Other approaches – do nothing, protect and avoid – should be considered, as well as appropriate combinations of the approaches for different combinations of volcanic risks, volcanic benefits and societal desires.

Figure 9.44 The world's only drive-in active volcanic crater, St Lucia

Case Study: Montserrat

The Soufrière volcano on Montserrat is a well-used example of the effects of a volcano in a LIC. It is over 15 years since the main eruption in 1997 in which 19 people died. The capital city, Plymouth, was abandoned, and became a modern-day Pompeii. Much of the southern third of the island became an exclusion zone (Figure 9.45). So how have things changed since 1997?

Figure 9.45 Plymouth and Soufrière, Montserrat

By 2002, Montserrat was experiencing something of a boom. The population, which had dropped in size from over 11 000 before the eruption to less than 4000 in 1999, had risen to over 8000. The reason was very clear. There were many jobs available on the island. There were many new buildings, including new government buildings, a renovated theatre, new primary schools and lots of new housing in the north of the island. There was even a new football pitch and stadium built at Blakes Estate (Figure 9.46). There were plans to build a new medical school and a school for hazard studies. To date, these have not been built.

Figure 9.46 Montserrat football pitch

However, by the summer of 2009 it was very clear that conditions on Montserrat had changed. The population had fallen to a little over 5200. There are two main reasons for this. The first is the relative lack of jobs. Although there was an economic boom in the early 2000s, once the new buildings were built many of the jobs disappeared. There are still plans to redevelop the island – a new urban centre and a new port are being built at Little Bay but they will not be complete until 2020. The museum has been built but not much else (Figure 9.47). Thus there are some jobs available but not so many as there were previously. Second, one of the new developments on Montserrat was a new airstrip. Once this was built, the UK and US governments stopped subsidising the ferry that operated between Antigua and Montserrat. This made it more difficult to get to Montserrat, both for visitors and for people importing basic goods. Thus the number of tourists to the island fell and the price of goods on the island rose. Many Montserratians were against the airstrip and campaigned unsuccessfully for the port to be kept open. It is possible to charter a boat and sail to Montserrat but it is far more expensive than taking a ferry.

Thus with fewer jobs in construction, a declining tourist sector and rising prices, many Montserratians left the island for a second time. Many went to Antigua and others went to locations such as Canada, the USA and the UK. Much of the aid that was given to Montserrat following the eruptions of 1997 has dried up. The UK provided over $120 million of aid but announced in 2002 that it was phasing out aid to the island. Nevertheless, in 2004 it announced a £40 million aid deal over three years.

Figure 9.47 Montserrat museum

The volcano has been relatively quiet for the last few years. However, there was an event in May 2006 that was relatively unreported. The Soufrière dome collapsed, causing a tsunami that affected some coastal areas of Guadeloupe, and English Harbour and Jolly Harbour in Antigua. The Guadeloupe tsunami was 1 metre high and the one in Antigua between 20 and 30 centimetres. No-one was injured in the tsunami but flights were cancelled between Venezuela and Miami, and to and from Aruba, due to the large amount of ash in the atmosphere.

So while volcanic activity in Montserrat is currently quiet, the volcano continues to have a major impact on all those who remain on the island. The economic outlook for the island does not look good – and that is largely related to the lack of aid, the difficulty and cost of reaching Montserrat and the small size of the island and its population.

Sustainable development and hurricanes

The achievement of equity, risk reduction and long-term development through local participation in recovery planning and institutional co-operation is the central issue in recovery and sustainable development.

The recovery phase is the least investigated and least understood of the four phases of a disaster (Figure 9.48) – pre-disaster mitigation, emergency preparedness, emergency response and recovery.

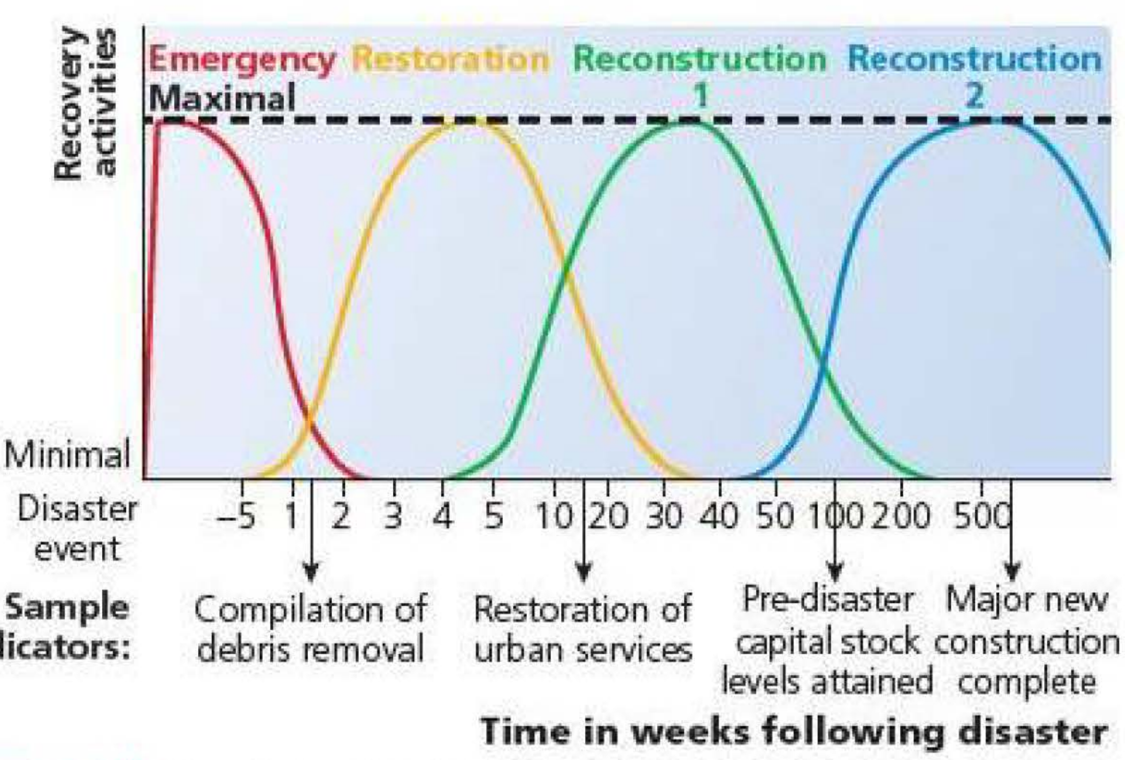

Figure 9.48 The four-stage model

Various LICs are trying to integrate recovery with sustainable development initiatives. Jamaica, for example, has shifted disaster recovery responsibilities from its national emergency management agencies to government agencies charged with environmental protection and long-term economic development and to community-based private voluntary organisations active in development initiatives such as housing, healthcare, watershed management and agriculture.

The four-stage model has four clear aspects:

1 Take emergency measures for removal of debris, provision of temporary housing and search and rescue.
2 Restore public services (electricity and water).
3 Replace or reconstruct capital stock to pre-disaster levels.
4 Initiate reconstruction that involves economic growth and development.

However, several studies suggest that the four stage model may be inaccurate. For example, stage 3 may occur in some areas while some areas are still in stage 1, and some groups may not have services restored as quickly, for example shanty-town residents, poor communities and immigrant groups. Many actual recoveries may not be so clear cut (Figure 9.49).

Successful recovery requires:

- integration of interested parties (government, non-governmental organisations, community groups)
- monitoring of programmes/enforcement of policies
- recognition of all people's rights (elderly, young, women, homeless, poor, migrants, refugees)
- leadership – ideally community-based (bottom-up) development
- resources.

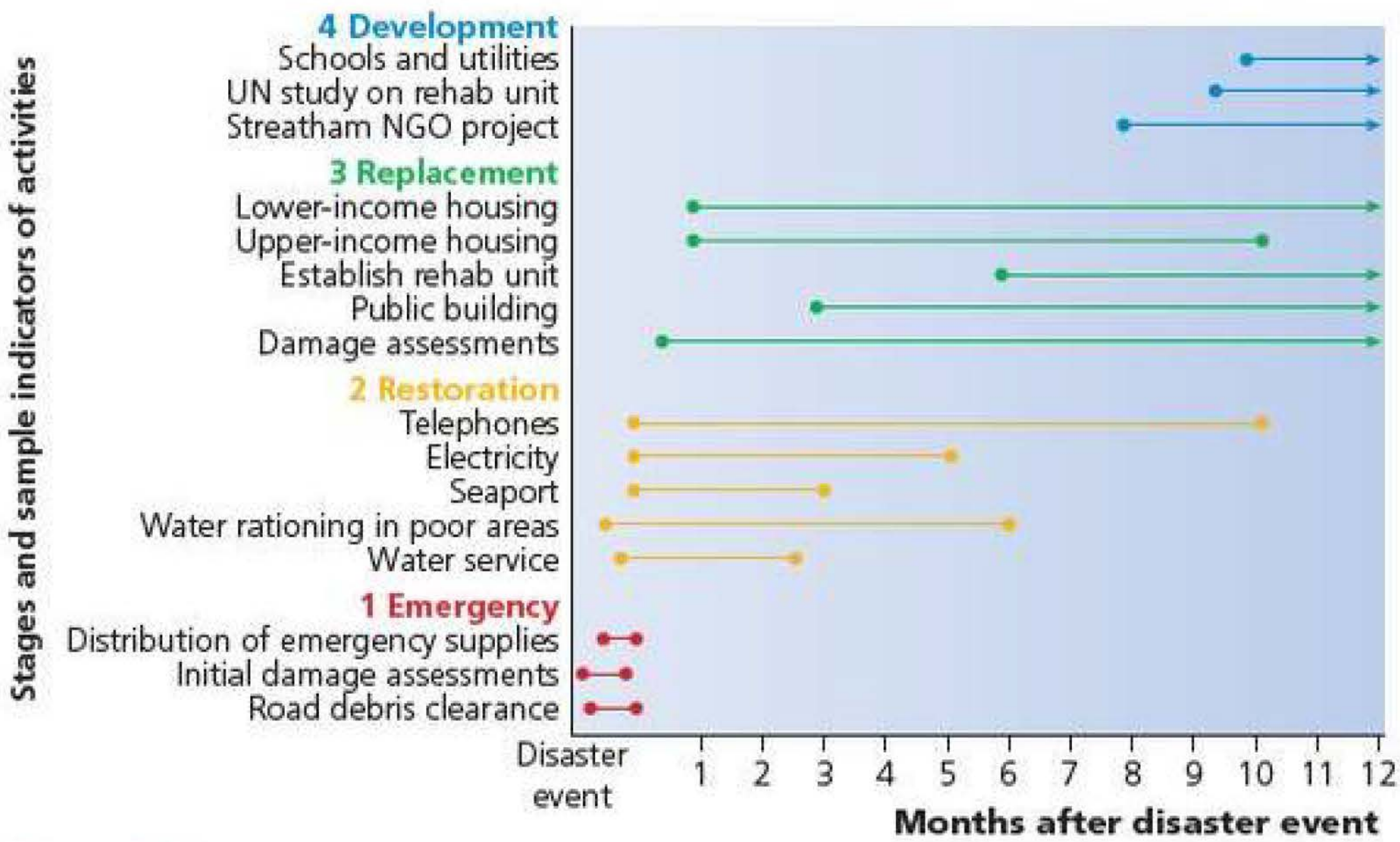

Figure 9.49 Recovery in Montserrat following Hurricane Hugo

Case study: Recovery after Hurricane Hugo

When Hurricane Hugo struck Montserrat on 17 September 1989, it was the first hurricane to hit the island in over 60 years. Eleven people were killed, 3000 people were made homeless and up to 98 per cent of buildings were damaged. All government buildings and schools were either partially or totally destroyed. Damage exceeded over US$360 million – devastating for the island.

Yet for some parts of Montserrat, the recovery was considered to be very successful. The village of Streatham near Plymouth was a small agricultural village of about 300 people. All the homes were damaged. The recovery was organised by local people – they rebuilt more than 20 homes and a new community centre, introduced new agricultural practices and improved the settlement's water supply.

Summary

Hurricanes in the Caribbean are serious. People and property are placed at risk, and government attempts to protect both are limited. Much of the construction in the Caribbean is informal, and lacks adequate building standards. Moreover, population growth suggests more people will be at risk in the future. In addition, global warming may potentially increase the frequency and magnitude of hurricanes due to increased atmospheric energy.

It might be more realistic to think of recovery as a process in which political, economic and demographic factors, as well as location, are important. Some groups are slower to recover than others. This raises questions about fairness and equity.

Top-down programmes managed by central government and international NGOs do not necessarily work well because they may be vulnerable to political manipulation.

Opportunities to relocate people and structures out of floodplains and other high-risk locations may be missed. Long-term sustainable development should include reduced environmental degradation – for example deforestation, soil erosion, habitat degradation – and improved housing and living conditions. One positive example of this was Streatham on Montserrat.

External donor organisations and charities must not just treat the symptoms of hurricanes – they must also address the causes of disasters alongside refocusing on long-term community development.

Promoting bottom-up recovery

A bottom-up community-based approach to recovery will be more effective than the traditional top-down approach, as it will respond to local people's needs and priorities. At Streatham, the disaster was used as a unique opportunity for change, and brought to the fore problems that are usually low in priority.

Strategies for long-term mitigation include:

- strengthening the housing stock
- improving land-use patterns
- environmental protection
- increased understanding of natural hazards.

Section 9.4 Activities

1 To what extent is the management of the Soufrière volcano on Montserrat an example of sustainable development? Give reasons for your answer.
2 Briefly explain the main methods of dealing with earthquakes.
3 In what ways is it possible to manage the risk of volcanoes?
4 Outline the advantages of geo-engineering over hard engineering structures for slope stabilisation.
5 Compare the main characteristics of the emergency phase following a natural disaster with that of the reconstruction/replacement phase.