Rebuilding Rabaul

SUMMARY

On 19th September 1994, Rabaul in the East New Britain Province of Papua New Guinea was a modern town of 17,000 people. At 6.00am on that morning, it was essentially destroyed by the effects of a twin volcanic eruption triggering earthquakes, ashfalls, pyroclastic flow, mudflows, flash floods and tsunamis.

SMEC International was commissioned by the Gazelle Restoration Authority to undertake the risk assessment, technical feasibility, planning and subsequent design and documentation for the reoccupation and restoration of Rabaul Town.

The challenge was to plan and design infrastructure that will be less susceptible to the effects of another eruption of similar size and nature to the 1994 eruption. This task required a delicate appreciation process addressing the genuine needs and aspirations of the community balanced against:

- *real and apparent hazards and their associated risks,*
- *restoration costs, and*
- *opportunity to use existing and recoverable infrastructure.*

This was achieved by the foresight and professionalism of a team lead by SMEC International with the close cooperation, review and approval of the client, community and relevant authorities.

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FEATURES OF EXCELLENCE

Prior to the 1994 eruption, Rabaul had the most extensive infrastructure compared to any other town in Papua New Guinea. Combined with its natural beauty and warm, friendly people, Rabaul was an ideal place to live, work and visit. The eruption of September 1994 and the ensuing aftermath damaged or destroyed most of the town. A similar eruption in 1937 also damaged a large section of the town, therefore the effects of an eruption are clear but the means of dealing with these massive forces of nature are not so obvious.

SMEC International as prime consultant working in association with Beca Gure (PNG) Pty Ltd, Asia Pacific Surveys Pty Ltd and M+E Partnership was commissioned to assess the damage to the infrastructure, identify hazards and risks, assist in re-planning the town and ascertain the best means of restoration. This was achieved during a fourteen-month project with a multi-disciplined team of foreign and local experts involving engineering feasibility, physical planning, and detailed engineering design and documentation.

The aim of this submission is to portray the engineering excellence involved and the appreciation applied to the restoration of a town extensively damaged twice by volcanic eruptions within 55 years. All evidence predicts there will be another eruption of equal magnitude within 40 years. The plan prepared and now implemented takes this fact into account and aims to mitigate the loss of life and infrastructure should such an event occur.

The members of the team found themselves grappling with concepts of '*risk*', '*compromise*', and '*mitigation*'. The goal was to plan and design a town to meet the needs and aspirations of the community and government, but also ensure life and property is less susceptible to the various current and future hazards. SMEC and its associates were able to achieve this goal and in the process demonstrate the definable features of engineering excellence required to fulfill the real demands of such a challenging project.

Features of excellence can be summarized as:

> ***Assessment of Hazards and Risks***. The impending hazards confronting Rabaul are very real: volcanoes, tsunamis and earthquakes. The Team was able to determine the complex nature of these hazards and ascertain the associated risks. This has not been done before and cast into perspective the *'risk'* component of the analysis.
>
> ***Classification of Volcanic Effects***. Rabaul is nestled in a huge volcanic caldera and there will be another eruption. Therefore, it was essential to understand the effects of the last eruption such that the new infrastructure could be re-planned and re-designed to minimize the effects of a new eruption. The Team assessed the damage to the entire town and classified the volcanic effects.
>
> ***Formulation of the Town Plan***. SMEC convinced the client to re-plan the town taking into account the risk of allowing population to reach it's pre-eruption level, the new anticipated functions of the town, broad-based economics, and the extent of damage in some areas. SMEC was the facilitator for this plan and brought together diverging views of the government and community to agree on a **'compromise'**. This was an intense and extremely difficult process, as it would ultimately require the resumption of land from some 9,000 people.

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Development of the Engineering Plan. Designing a town that has been extensively damaged by two volcanic eruptions within 55 years is unique and demanding. SMEC challenged conventional wisdom and developed a restoration plan for all infrastructure that would *'mitigate'* the effects of another eruption

SMEC International achieved these features of excellence was duly recognized by the client as described in a letter (Annex 1) from the Project Manager of the Gazelle Restoration Authority.

'SMEC International carried out the work with admirable degree of thoroughness, understanding the complexity of the situation in Rabaul, and facilitating the production of a post eruption zoning plan for the town to guide the future restoration and development of the town.'

Photo 1 Rabaul Town - early 1980's

Photo 2 Rabaul Town - post eruption 1995

'Tuvurvur' Volcano is at the top of the photo and is still erupting to the present day.
Other dormant volcanoes are evident within the caldera that encompasses the town and harbour.
Ash up to 3m deep covers most of the town.

Photo 3 View of 'Vulcan' Volcano looking north towards Rabaul Town

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ASSESSMENT OF HAZARDS AND RISKS

Prior to the eruption Rabaul town had an excellent port, a developed industrial and commercial sector, comprehensive infrastructure, offices of National and Provincial Departments, and community facilities such as a public library, swimming pool and orchid gardens. In general, this was a modern town that was able to provide all of the services expected of a larger city.

The eruption of 1994 demonstrated in catastrophic terms the physical damage and destruction of public and private property. The volcanic hazards, identified in the course of the project that produced most of the damage in Rabaul during and after the eruption were:

- ashfalls
- mudflows and flash floods
- mudfills
- earthquakes
- tsunamis
- corrosion.

Figure 1 Hazards Map

Illustrates existing and future hazards

Ashfalls. Ash up to 3 metres deep was deposited over the entire town imposing severe live loads to structures, smothering roads and services, and blocking stormwater drainage. The ash was able adhere to steep surfaces greater than 45 degrees as the initial ashfalls were wet. Subsequent layers bonded to this initial layer and also became saturated due to incessant rain. Some roof structures were exposed to ash loads of up to 5.4 kN/sq.m. Consequently, the immense ashfall loads caused most of the initial wide spread damage.

Mudflows and Flash Floods. The volcanic eruption generated its own micro-climate as a result of the thick ash plumes reaching a height of 5km. This caused constant torrential rain for weeks after the initial eruption. The steep slopes of the caldera wall and the high intensity rainfall resulted in mudflows and flash flooding throughout most of the town. The drainage system had already been inundated with ash and debris, therefore the mudflows and flash floods travelled in an indiscriminate manner and caused significant damage to infrastructure and property.

Mudfills. Initial ashfalls were saturated, fine-grained material. Under the weight of subsequent layers of ash, this initial layer flowed into confined spaces such as locked rooms, stormwater pipes and telecommunication junction pits. Depths up to 300mm were reported and, once the mudfills dried and hardened, proved extremely difficult to excavate.

Earthquakes. The seismic activity that triggered and accompanied the volcanic eruption was of intensities up to 7 or 8 on the Modified Mercalli (MM) scale. Whilst little damage was caused by the initial earthquakes, it will be shown later that, subsequent seismic events contributed to wide spread damage.

Tsunamis. The eruption and pyroclastic flow from Vulcan generated a 2-3m tsunami and which reached up to 200m inland. Compared to other events, little damage was caused by this.

Corrosion. Volcanic ash contains compounds including sulphur and chlorides that can be highly corrosive. Corrosion of all types of metals, including aluminium alloys and zinc, started immediately and accelerated rates of corrosion continue today.

Pyroclastic Flow. A pyroclastic flow was generated by the sudden, massive eruption of Vulcan. Such a flow is produced by super-heated ash and gas falling down the tall volcanic column and rushing along at ground level at hundreds of kilometers per hour. Pyroclastic flow is considered the most dangerous volcanic hazard to life and property. Fortunately the pyroclastic flow produced by Vulcan was of low intensity and Rabaul Town was not seriously affected. However, the pyroclastic flow destroyed some buildings around Vulcan and a tsunami was also produced.

Future Hazards. The Rabaul Volcanological Observatory has predicted that there will be another eruption. The magnitude, the source(s) of the eruption, and when it will occur are essentially unknown. In a combined approach with the Observatory, Professor Russell Blong (Risk Advisor) was able to establish that based upon a limited documented history, it is expected that there will be another eruption within 40 years of the 1994 eruption and its magnitude will be less than or similar in size.

Apart from volcanic eruptions, planning the restoration of Rabaul had to take into account all present and future hazards. Rabaul has also been exposed to earthquakes, tsunamis and landslides that may not be directly connected to a volcanic eruption.

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During the last eighty years there have been 12 seismic events of intensity 7 to 8 on the Modified Mercalli scale. Earthquakes of this magnitude have generally produced only minor structural damage.

Seven tsunamis have occurred in Rabaul over the last 110 years; two caused by volcanic eruptions in 1937 and 1994, four caused by tectonic earthquakes and one caused by a large avalanche from Ritter Volcano in West New Britain. All of these tsunamis ranged between 2-3m high within Simpson Harbour. These tsunamis have caused only minor damage but the recent disaster in Sandaun Province is a stark reminder of the danger of these natural events.

CLASSIFICATION OF VOLCANIC EFFECTS

All infrastructure within Rabaul was affected by one or more volcanic hazards resulting from the eruption. It was important to understand these hazards, as it would set the parameters for mitigating their effects in the Engineering Plan. A summary of the findings is detailed below:

Building Damage. Most of the initial structural damage was caused by ashfall. It had been found that most buildings collapsed under 300mm of ash corresponding to an approximate live load of $5.4kN/m^2$. Over two thirds of the town was exposed to ash depths greater than 300mm.

Mudflows and flashfloods quickly destroyed buildings within the flow paths. The momentum and destructive power of the ash-laden water was intensive even at shallow depths of less than 0.5m. In February 1994, during a 70mm rainfall, standing waves up to 1m high were recorded indicating velocities of several metres per second.

Some 24 hours after the initial eruption a sequence of small, localized earthquakes were experienced in Rabaul. At this time a significant amount of the ashfall had already been deposited across the town. Therefore, the combination of the ash loadings and horizontal seismic loadings, even though of small magnitude, accelerated the rate of structural failures within Rabaul.

The tsunami caused only minor damage in Rabaul, however 30 houses at Matupit Island were destroyed and timber wharves in the port area were damaged.

Road and Stormwater Drainage Networks. The eruption quickly inundated stormwater drains with volcanic debris. A combination of ash fall and subsequent mudflows swamped roads up to 2m deep. Today, more than 65 percent of the original road and drainage networks remain covered with volcanic debris. Whilst the covered roads and drains are not functional they remain relatively protected from erosion and the effects of lack of maintenance.

Water Supply System. The water supply transmission and distribution lines remained intact. This was rather surprising considering the intense earthquake activity prior to and during the eruption. Historically, the Waterboard has found that the network has survived earthquakes possibly due to the construction or nature of the soils. Similarly to previous seismic events, the performance of the bores and aquifers would have been affected. However, the main impact was the destruction of most reservoirs and three pump stations.

Wastewater System. The wastewater system was small and serviced less than one quarter of the town. The system survived relatively intact. There was some ingress of ash into the lines and the two pump stations and the sewerage treatment plant (Imhoff Tank) were damaged and decommissioned.

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Photo 4 Town Centre - pre-eruption

Photo 5 Town Centre - post eruption

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Telecommunications. The roof of the telephone exchange collapsed and the equipment was completely destroyed. The underground cabling network appeared to survive relatively intact although most cross-connection units were damaged or destroyed. The underground cables were installed in conduits and the cable joints are sealed with a waterproof heat shrink sleeve. It was determined that the majority of cables could be reused even in the most damaged areas of the Town.

Power Supply and Reticulation. The Rabaul Power Station suffered little damage from the eruption, however the station was decommissioned and the diesel generators removed. Falling trees and buildings damaged large sections of the reticulation system. Some transformers were damaged by the effects of the eruption. Currently about 40% of the original 47 transformers are in operation. Although most of the poles in Rabaul are steel, and exposed to corrosion, most have remained intact and could be reused.

Corrosion. Corrosion is an ubiquitous problem and continues to be the ongoing volcanic hazard affecting all infrastructure. Sulphates and chlorides in the ash were found to be particularly destructive, even on metals not normally susceptible to a high rate of corrosion such as zinc and anodised aluminium.

FORMULATION OF THE TOWN PLAN

Once the condition of the town was established and the hazards and risks realised, the development of a clear picture for the future town was the next step in Rabaul's restoration. SMEC played a pivotal, independent role in the Town Plan development. SMEC was able to act as facilitator in the process of developing a plan, evaluating dissenting opinions and reconciling solutions. The Town Plan was therefore a compromise. Rather than having negative connotations, it expressed a positive meaning towards establishing an intermediate position between conflicting opinions and issues reached by mutual concession. The Town Plan was to become the key instrument for the use of government, the community at large, and the funding agencies.

Starting Point. Initially SMEC aimed to achieve a balanced, accountable framework for development. The process had to begin from an unbiased position, and proceed in an objective way. Much sentiment had been bred over a period of three years during which nothing had happened. Opinions surfaced in various quarters, and demands or expectations were high. At the outset the issue of risk had to be addressed head-on. It could not afford to allow an issue to remain unresolved, capable of rearing its head at any point during the process in a destructive way.

Risk. SMEC found the concepts that were embraced by the community included the following:

- The idea of a risk-free living environment was unrealistic, and personal perception of risk varied widely. The importance of any risk to the Rabaul community cannot be scientifically evaluated,
- Rabaul Town is not the sole product of a stable physical environment, but rather social and economic factors are more important,
- Risk is a comparative concept. People made judgments by making comparisons elsewhere. Members of the community compared some major cities in the world (and the western world at that) located in areas of high risk, and
- The biggest risks on earth statistically are hunger and war, both of which are absent in Rabaul. Community conception of well being focused more importantly on social and economic factors, rather than whether or not there may be another eruption in 30 or 40 years.

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While the above were powerful arguments, this holistic view crystallised a common understanding that the real-world issue was really the financial risk of investing in renewed infrastructure.

The Cost/Risk Factor. This became a public responsibility issue, and encouraged a consensus that the new town should be constrained in size. There was clear logic to exclude the southern extremity of town which is closest to the most active volcanoes, most ash cover (therefore cost to rehabilitate), and also the most likely to suffer a future similar fate.

The Government Position. Policy framework reflecting the official position, from National down to Provincial and Local Government level had been well thought through and was clear.

The Provincial Capital functions had been relocated to Kokopo as part of an associated thrust to develop economically in other urban areas of the province outside Rabaul. The importance of Rabaul to the provincial economy as port was reinforced due to its magnificent natural harbour. Other acknowledged roles for Rabaul were as a commercial centre and tourist destination.

SMEC provided the impetus through the services of Ms Sandra Finster (Urban Planner) for the government and community to realize a common goal. Having officially accepted a future role for the town, and with it a community willing to return, government of every level had to be prepared to drop the barrier of 'volcanic risk' issue and deal with planning issues in a positive way. While any form of hazard cannot be prevented, the focus of government control was shifted to minimizing its effects.

The Driving Forces. The pent-up impatience to re-build was evident in various sectors of the community, the most vocal being port-related industry, land owners, and users of community facilities.

It was apparent that if the new Town Plan was to be sensitive to need, and considered successful in its implementation, the planning process had to focus on the positive attributes and strengths driving the desire to re-build. It was clear to identify that Rabaul had unique qualities to do with its setting and historical past. The legacy of an enviable economic structure and social harmony have been difficult for other towns to emulate.

Obstacles. A big difficulty to any development in Rabaul was recognised at the outset. It was to do with property insurance. The insurance industry had ceased to underwrite property within the area of influence of Rabaul's volcanoes, including the whole town. Resolving this problem was identified as vital to the success of any plan, and an initiative was taken to open up discussion direct with the insurance industry.

The Planning Process. With some big issues out of the way, and a relatively neutral canvas, the routine part of the exercise was much like any other including the collection and analysis of information, evaluation of this data, and design.

The complexity and detail lifted this study out of the ordinary. The difficult part of the process was the dilemma in evaluating the criteria, weighting them, and applying value judgements. This was under intense scrutiny, and must be answerable to any of the numerous stakeholders. SMEC understood there was no perfect answer. The aim was to maximise benefits across the board and the challenge was to unite the interests in the concept of a community-owned town image that everyone related to.

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A Steering Committee was established to oversee the planning process, and must take credit for the success attributed to the final Town Plan. The committee performed numerous functions providing guidance, organising access to information and people, participating in assigning values, and decision-making in general. Its highest role was in acknowledging ownership of the outcome on behalf of government and the community. The committee had a broad representation, was knowledgeable, reliable, and above all committed. It had power and clout. Such a structure forming the backbone of the planning process was an ideal model for any study to follow.

A conscious effort was made by SMEC to keep design issues in the plan simple, flexible, and easily understood. In particular the oft-made mistake of introducing design prescriptions was avoided, but rather an encouragement was given to the implementation agencies to focus on town "character" and locally relevant impacts.

DEVELOPMENT OF THE ENGINEERING PLAN

Subsequent to the Town Plan, an Engineering Plan was formulated. In general, the Town Plan focused and prioritised the restoration needs of the civil infrastructure. This set the framework for the roads and drainage restoration and other works such as stabilization of the vast ash beds and siltation control. SMEC also coordinated a plan for the reconnection of utilities through the service departments such as Elcom, Telikom and the Waterford. The service departments were genuinely interested in restoring utilities to clients but would only reconnect services in the damaged and unoccupied areas when there was some government-endorsed reconstruction plan.

The Engineering Plan was then determined through a conventional design process from conceptual design to preliminary design through to final engineering design and documentation. The whole design process was monitored by the same committee that supervised the production of the Town Plan to ensure consistency with their restoration approach, and in particular, the staging of works.

The Restoration Approach. The Town Plan divided the restoration of Rabaul into three stages with stage one to be implemented immediately and the subsequent stages implemented when further development was warranted. SMEC ensured a controlled and coordinated program (Figure 2) enabling infrastructure to be restored to meet demand. In a generalised form, the works were required to be undertaken in the following order:

- erosion control,
- restoration of roads and stormwater drains,
- reoccupation of individual stages, and
- reconnection of services.

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Figure 2 Stages of Restoration

Note that the southern extremity of the town including the airport is to be abandoned.

Erosion Control. The stabilisation of ash beds on the caldera wall and the coastal plain was deemed to be the first and most important step in the restoration of Rabaul (Figure 3). Ash will readily choke drains, inundate cleared roads, and frustrate attempts to reconnect utilities. Stabilization was proposed through the revegetation of these areas however ash is essentially sterile as it does not contain nitrogen or phosphorus. To achieve this aim SMEC instigated independent research to be undertaken by the Lowlands Agricultural Experimentation Station (LAES) in East New Britain to identify species and varieties of plants that would grow in this environment.

The caldera wall and coastal plain were considered separately, the former would be aerially seeded using a crop duster or helicopter, the latter by hand using community groups. Involvement of community groups in a large-scale revegetation project was seen as an important and positive means of including the general community to assist in the restoration of the town.

Revegetation of the entire caldera wall and coastal plain was considered, irrespective of the relevant planned stages, as it was a strategic measure to stabilise these areas for future development and reduce the airborne dust problem.

Siltation Control. Erosion of the ash beds will continue no matter how effective the erosion control or revegetation program. Control of the deposition of material was considered using a restored or upgraded drainage system combined with strategically placed gully check dams, bamboo planting, silt traps and groynes.

Protection of the vital port facilities was deemed to be highest priority. Figures 4 and 5 show the measures established to protect the port from siltation using gully check dams and bamboo stands at the base of the caldera wall, and large silt traps adjacent to the wharves. Littoral drift of ash along the coastline was addressed as a separate threat, which will be alleviated by the construction of a groyne.

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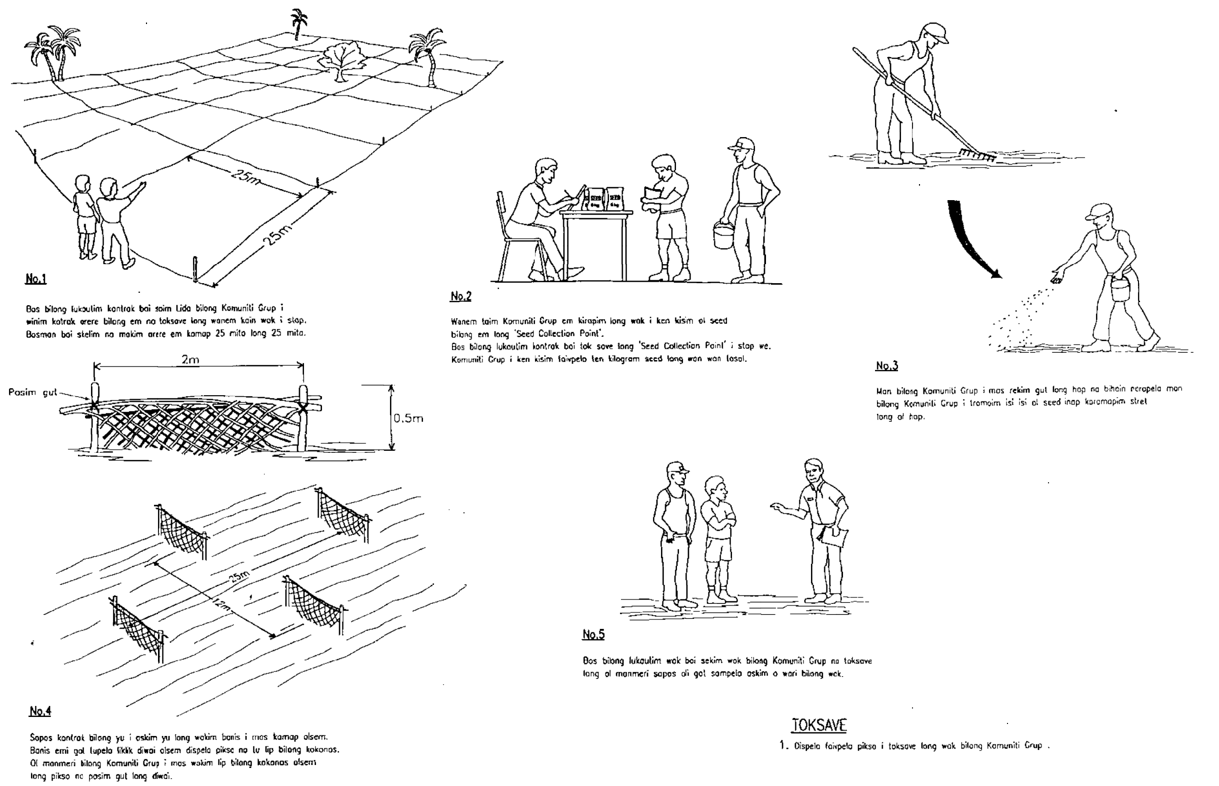

Figure 3 Broadacre Grassing

Community Group involvement was considered an important part in the restoration program. Design of the stabilisation of the ashbeds on the coastal plain and on the steep caldera wall proved to be the most challenging design component. Contracts were written in Melanesian Pidgin and drawings produced in cartoon form for easy understanding.

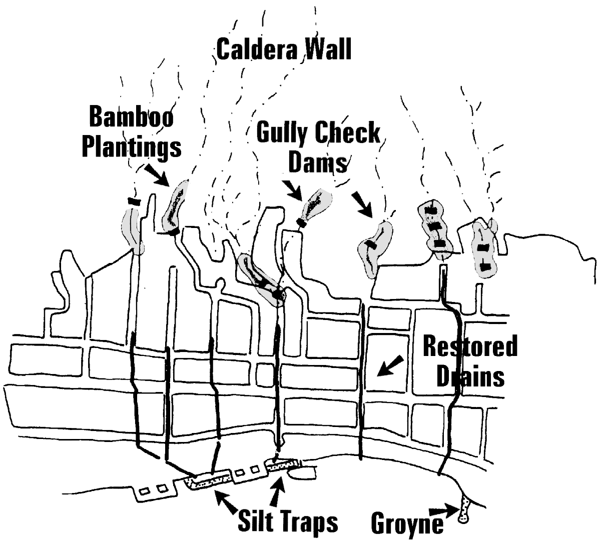

Figure 4 Portion of the Drainage Design

Drainage, erosion and siltation controls were identified as critical aspects for restoration.

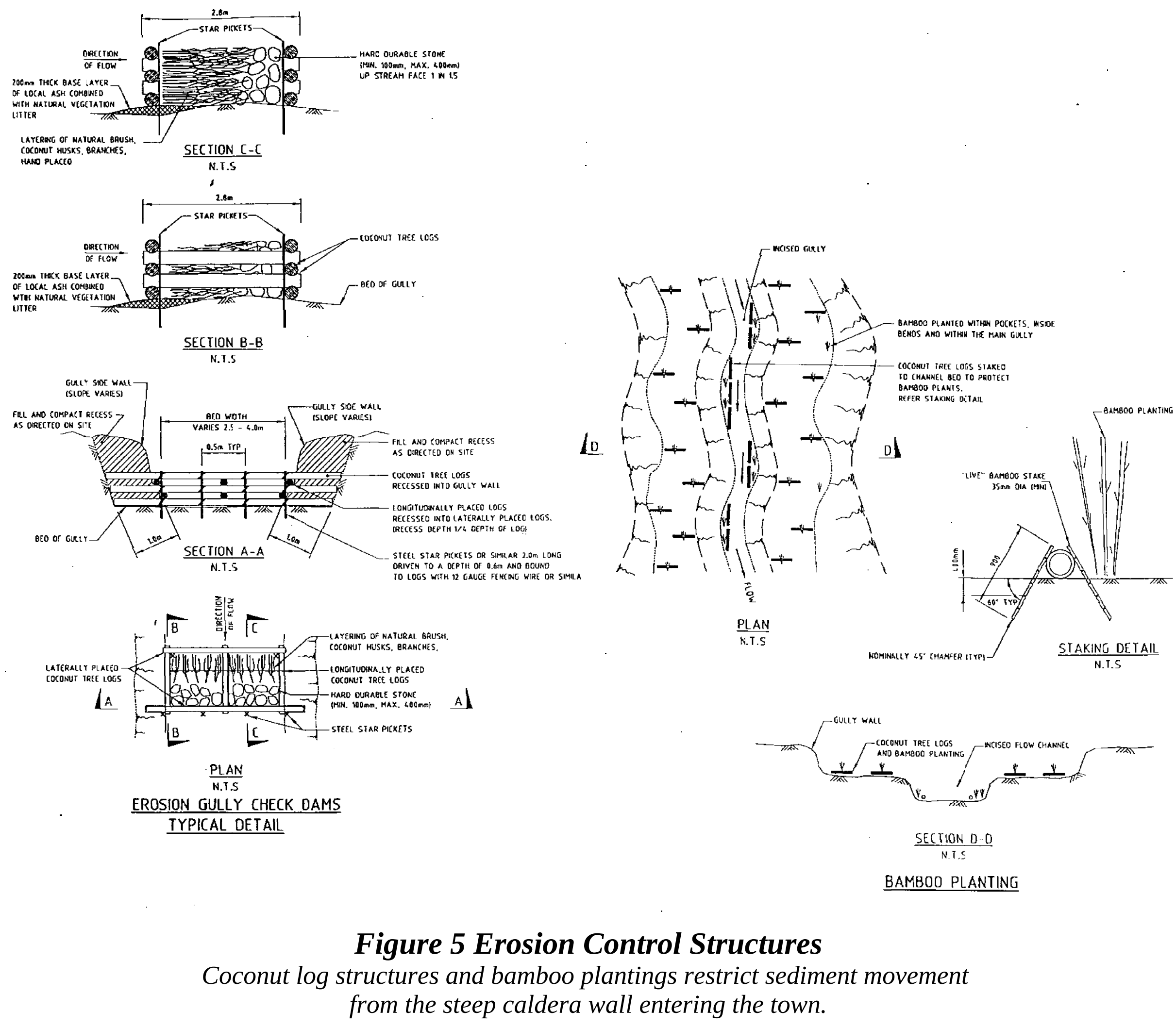

Figure 5 Erosion Control Structures

Coconut log structures and bamboo plantings restrict sediment movement from the steep caldera wall entering the town.

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***Restoring Roads and Stormwater Drains**.* Once large areas of the caldera wall and coastal plain have been revegetated and stabilised, roads and drains in ash-covered areas could then be restored. The Engineering Plan stipulated that unused road and drainage networks in the unoccupied regions of the town should remain covered in ash until there is a genuine need for their use. This was considered important for a number of reasons:

- Sufficient time is required for the stabilisation or revegetation of the ash beds. The premature clearance of the roads and drains in the ash-covered areas will prevent these networks becoming an unnecessary maintenance burden to continually clear the ash.
- Ash-covered roads are in a sense preserved. It had been determined through Mobil Australia that the constituents of the ash and its leachate, in particular sulphuric acid, would have little or no effect upon the bitumen binder. Provided the bitumen seal remains covered it will stay protected from erosion and ultraviolet light deterioration. Therefore, covered sealed roads can be expected to have a markedly reduced rate of deterioration.
- Covered drains will not be exposed to the severe erosion problems and would not require ongoing maintenance.

***Reoccupation of Stages**.* The restoration of the ash-covered roads and stormwater drains would facilitate the reoccupation of these areas. This would be a progressive or 'staged' development that would follow a coordinated and controlled program cognisant of the Town Plan.

***Reconnection of Services**.* The clearance of successive roads and drains and the reoccupation of these areas would allow the service departments to provide electricity, telecommunications, and water and wastewater services. The service departments indicated that they would respond to future demand but did not intend to undertake detailed future planning until the demand is realised.

Mitigation Measures. The Engineering Plan had to embrace mitigation measures to deal with the effects of natural hazards. SMEC established a number of measures to reduce the impacts of all hazards including the obvious effects from another eruption. This task was not easy, as huge forces of nature are involved such as volcanic eruptions, tsunamis and earthquakes. Some of the measures identified by the Team are discussed below:

Drainage. The eruption of 1994 demonstrated the need for proper stormwater drainage. Flash floods and mudflows caused significant damage because of the indiscriminate direction of the flow paths. It was determined that the road system in Rabaul would function as ideal secondary drains provided that the flows could be contained within the road reserves. Most of the roads running north-south and east-west have a constant grade between 2-5% from the caldera wall to the harbour. To contain the flows within road reserves it was recommended that ash on adjacent allotment should be left in situ, therefore providing a clearly delineated flow path. In this way the risk of building damage from mudflow and flash floods is diminished.

Building Regulations and Standards. Special consideration was required for building regulations to protect property and provide safety to the general community. Regulations recommended complimented existing Standards, or in their absence, provided short-term guidance. It was determined that regulations or indeed Standards cannot provide design recipes which remove the designer's flexibility to achieve their desired solution, but instead must provide adequate design information and parameters. A balance will have to be achieved incorporating anticipated construction costs, risk of natural hazards, and the risk to life.

For example, during the last eruption parts of the town received 3m of ash. If these loadings are considered indicative over a 50-year life span, then newly designed buildings would possibly be unaffordable concrete boxes. After careful consideration of a number of factors it was determined that a design ash load of 300mm was the best compromise and would be adopted as an interim building regulation until a formalized Standard was produced.

Other building restrictions raised during the feasibility, town planning and design phases included:

- To provide protection from mudflows, flash floods and landslides, buildings should not be reconstructed on the slopes of the caldera wall or within major flow paths close to the caldera wall.
- Effects of tsunamis should be considered for buildings close to the shoreline.
- Allotments should be raised to assist in channelling mudflows and flash floods along the road reserves.
- Steep pitched roofs are recommended as they provide a naturally stronger roof construction and some ash shedding capabilities.
- A combination of ash and seismic loads should be considered a possible worst case scenario during structural design.

Utilities. SMEC recommended numerous measures to reduce the impacts of another eruption to the utilities, such as:

- Underground power distribution despite the cost being twice the cost of. an aerial network. Aerial Bundled Conduits (ABC) were recommended as the preferred cable for aerial distribution. These cables are covered in a sheath of plastic and therefore less susceptible to corrosion and a simple pole without cross members is required which is easier to repair.
- Special water reservoirs were recommended constructed to be earthquake and ash load resistant.
- The water distribution system should be redesigned to incorporate redundancy, such as loop mains, strategically placed reservoirs, and re-establishing more than one bore.

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PROJECT DATA

Client	
Gazelle Restoration Authority **Contact Details**	Sir Henry ToRobert, KBE Chairman Gazelle Restoration Authority P.O. Box 1175 Port Moresby Phone (675) 3211888 Fax: (675) 3211986 OR Mr John Painap OBE Project Manager Gazelle Restoration Authority KOKOPO East New Britain Papua New Guinea Phone: (675) 982 8768 Fax: (675) 982 8767
Consultancy Services	
SMEC International in association with: Beca Gure (PNG) Pty Ltd, Asia Pacific Surveys Pty Ltd and M+E Partnership Pty Ltd	
Period of Consultancy	January 1997 – May 1998
Person Months	28 International 30 Local
Project Data	
Pre-eruption Population Current Population Planned Population	17,000 3,000 8,000
Direct Costs of Damage to Rabaul Town	Infrastructure ~$100 million Insured Losses ~$60 million Uninsured Losses ~$120 million *Total ~$280 million*
Restoration Costs for Infrastructure (less buildings)	Stage 1 ~$17 million Stage 2 ~$5 million Stage 3 ~$18 million
Value of Designed Works	~$15 million

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ORGANISATION AND STAFFING

Photo 6 The Project Team

L to R: Robert Goldsmith (Geotechnical Engineer) Professor Russell Blong (Risk Advisor), Tony Lucy (Project Director), Geoffrey Flynn (Structural Engineer) Elsa Carlson (Office Manager), Lawrie Carlson (Project Manager) John Ecroyd (Water/Wastewater Engineer) Lot Zauya (Road Engineer)
Missing: Sandra Finster (Urban Planner) Neil Whiting (Power and Telecommunications Specialist) Graham Levy (Drainage Engineer) Andrew Wassen (Surveyor) Paul Wells Green (Ports and Harbours Specialist) Kevin Fehon (Traffic Specialist)

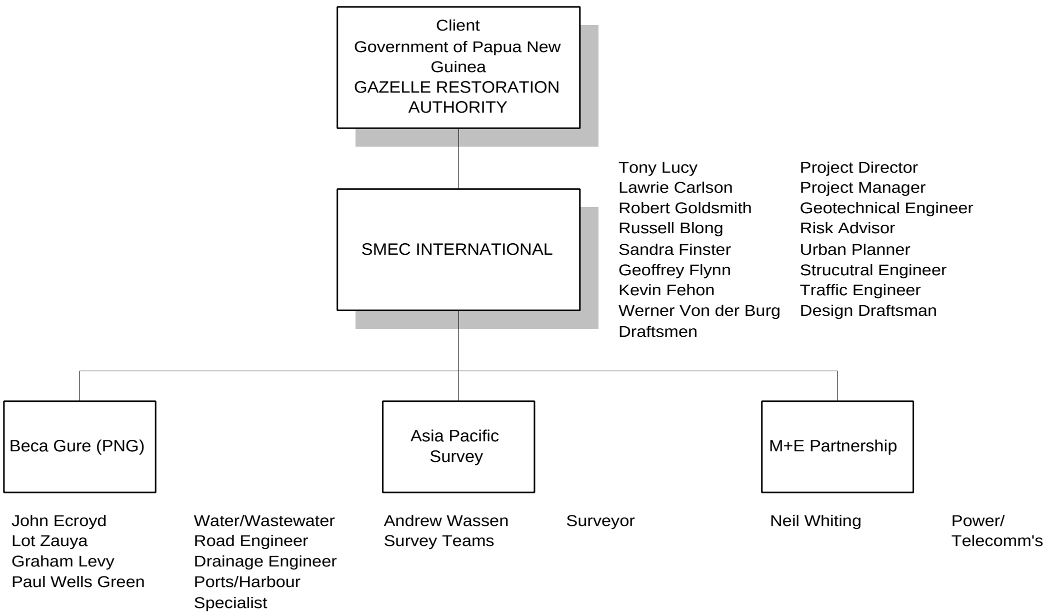

Figure 6 Consultant's Organization Chart

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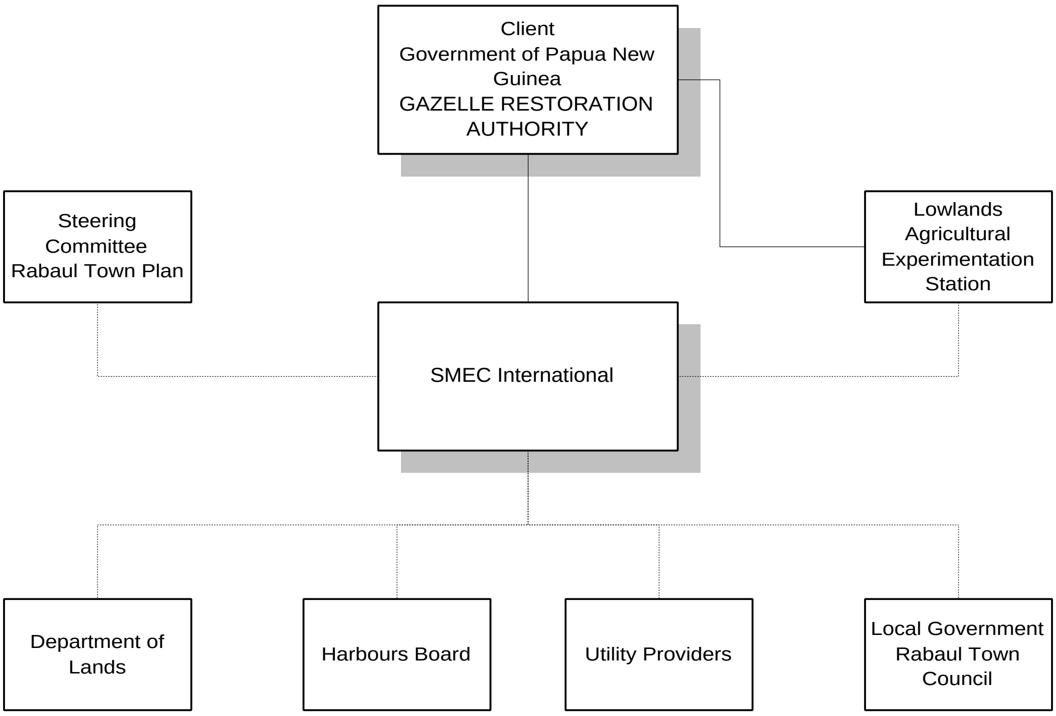

Figure 7 Project Organisation Chart

CONCLUSION

The results of the 1994 eruption in Rabaul were catastrophic yet the response by SMEC and its associates, in co-operation with the clients, government departments, and community resulted in a number of plans showing initiative and engineering excellence.

SMEC and its associates grasped the complex issues involved in this project, such as the concepts of *risk, compromise* and *mitigation*. The features of excellence that SMEC's team displayed were:

Assessment of Hazards and Risks. SMEC determined the complex nature of these hazards and associated risks. Additionally, they cast into perspective the *'risk'* concept, that would influence the overall project.

Classification of Volcanic Effects. SMEC assessed the damage to the entire town and classified the volcanic effects.

Formulation of the Town Plan. SMEC was the facilitator for the plan and brought together diverging views of the government and community to agree on a workable *'compromise'*.

Development of the Engineering Plan. SMEC challenged conventional wisdom and developed a restoration plan for all infrastructure that would *'mitigate'* the effects of another eruption

To the credit of the community and the government who are prepared to support it, Rabaul will continue to live.

In years to come, when the events of September 1994 are fading in people's minds, it is hoped that Rabaul will again enjoy the status as the pre-eminent town in Papua New Guinea in which to live, work and visit. However, it is important to remember that there will be another eruption and opportunity now exists to rebuild a town that will be less susceptible to these forces of nature.

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