REPORT OF FINDINGS ON THE PROPOSED IRALALARO HYDRO-ELECTRIC POWER SCHEME, TIMOR-LESTE

A report to the Haburas Foundation and the Australian Conservation Foundation

by

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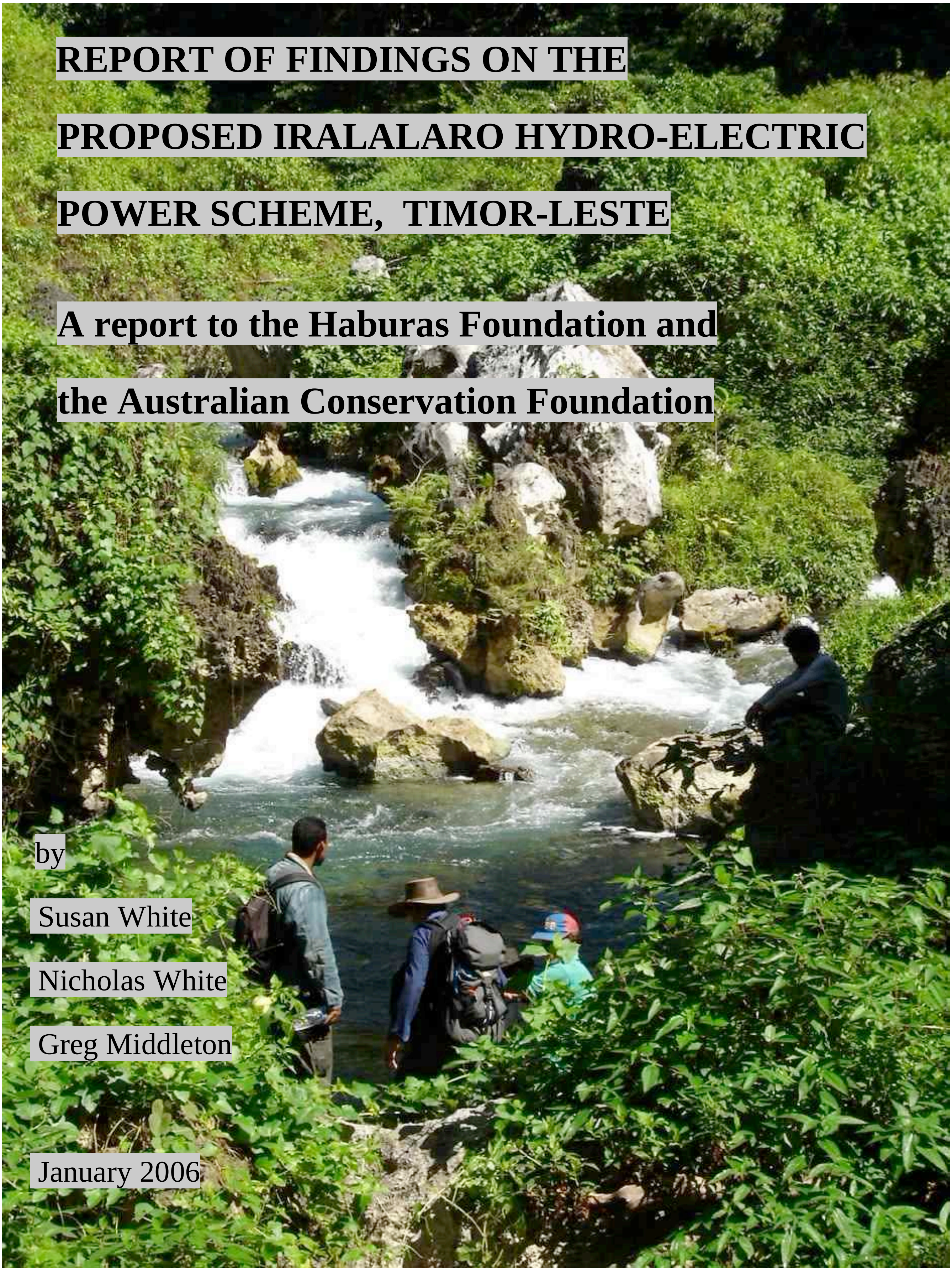

Mainina sinkhole, where the Irasiquero river disappears into the karst

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The authors acknowledge with thanks the assistance provided to them by the Australian Conservation Foundation and the Haburas Foundation in the preparation of this report.

We also thank the many people who provided information and assisted us during a visit to the Iralalaro area in 2005.

Senator Bob Brown first alerted us to the Iralalaro proposal and its potentially harmful environmental impacts.

CONTENTS

Executive Summary

This report is an appraisal of significant aspects of the proposed Iralalaro hydro-electric scheme. This scheme proposes to divert water from the Irasiquero River upstream of the Mainina sinkhole to a tunnel through the Paitchau Mountains leading to a power station on the coast. Studies of Timor-Leste's electricity generation and supply problems have identified hydro-electricity as a practical potential source and the Iralalaro scheme as the most economically desirable. Alternatives such as solar, wind and natural gas have received scant consideration.

The Iralalaro-Paitchau Mountains area is a karst region, containing a wide range of karst-related landforms and features. These include a large polje, collapse dolines, sinkholes, blind valleys, karren, caves and springs. A substantial component of the hydrology is underground and the area relies on underground water for almost all of its water supplies. The area has significant surface and underground geodiversity and biodiversity.

The proposal appears to have a number of significant limitations which, unless they are addressed, could seriously undermine the scheme's viability and/or cause significant cost overruns. Estimates of the construction costs appear to have underestimated the risks and costs of drilling, tunnelling and dewatering in karstic terrain, and as a result are inadequate. Understanding of the relationship between the lake and the watertable is inadequate, as are streamflow records, with consequent implications for sustainable power generation from the scheme.

The karst has not been subjected to a thorough and detailed study by experts in this specialised field, and the implications of the karstic nature of the terrain appear to have been poorly understood. A full investigation of the hydrology, caves and karst features of the region is essential and should be undertaken without delay.

The proposed hydro scheme is incompatible with the maintenance of many of the natural and cultural values which give the area its special significance and ecotourism potential. It jeopardises proposals to provide protection to the special environmental values of the area and could damage precisely the features most likely to attract adventure tourists, putting at risk the development of tourism in the region.

The people living closest to the proposed scheme appear ambivalent about the possible benefits. A lowered regional water table may affect the entire population and agricultural production east of Los Palos. The existing reports inadequately address the problems of the very limited infrastructure in the area and the issues of importing labour if appropriate labour cannot be recruited locally.

There are serious questions as to the ability of the proposed scheme to provide the claimed electricity output in perpetuity at the currently estimated costs and with the suggested low levels of environmental impact.

1. Background

The newly-independent nation of Timor-Leste suffers from a run-down and inadequate electricity generation and distribution system based on the use of expensive imported diesel fuel. Dili has diesel generated power available 24 hours per day but there are often outages. The current limited distribution system has serious problems and there is no countrywide distribution transmission system.

The island has no known coal or geothermal resources. There are currently no hydro, wind or tidal power-stations. Development of offshore, or possibly onshore, gas reserves is planned but is still some time away.

In studies conducted by Norwegians for the Government (Adeler et al. 2003), energy source options for the country as a whole were examined. Biomass was discounted, wind was accepted as promising, solar electric was discounted but hydroelectric schemes were examined in more detail.

Studies done over recent decades have indicated hydro-electric power is probably the most feasible indigenous energy source for short-term development and around 15 sites have been identified where water resources could be harnessed to provide electrical energy (ELC-Electroconsult et al. 1989, Asian Development Bank 2004). Of these, the Iralalaro project has been selected as the top priority, allegedly "because of its obvious capacity of generating electricity at low cost" (Adeler et al. 2003). As a result more studies have been done on this project than any other. Its location is shown in Figure 1.

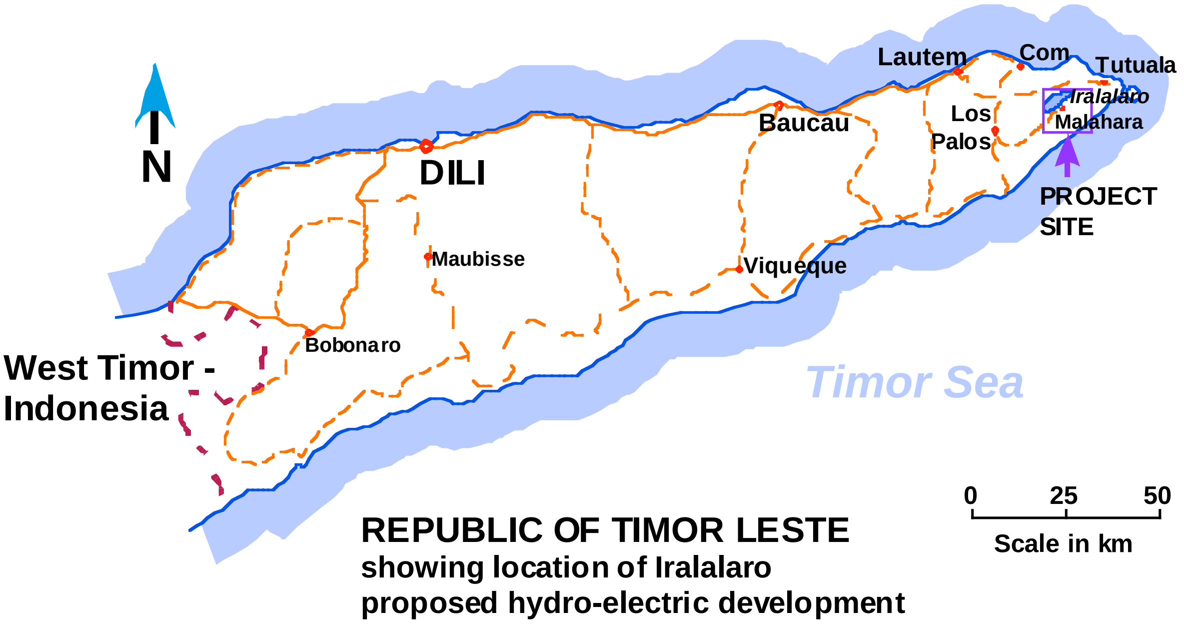

Figure 1. Location of Iralalaro proposal in the far-east of Timor-Leste.

It is not the purpose of this report to canvas a range of alternative energy sources or strategies for Timor-Leste and neither is it feasible for the authors to review all of the possible hydro-schemes which have been put forward. This report confines itself to a consideration of certain environmental, and particularly karst-related, aspects of the Iralalaro proposal and does not attempt to do more than raise a number of pertinent questions about aspects of the proposal which are within the expertise and fields of interest of the authors.

It is noted that the entire project would be located within an area of active karst.[1]

Some variation in spelling of local words and places occurs in this report due to such variation occurring in the literature, e.g. Ira Lalaro, Iralalaro.

1.1 Previous studies and development of the proposal

1. The original plan for a hydro-electric powerstation utilising the discharge from Iralalaro Lake was contained in "O Plano do Desenvolvimento de Timor" (Timor Development Masterplan) prepared in 1975 by Japanese Development Consultants, for the Timor-Japanese Association (cited by ELC-Electroconsult et al. 1989, p. 3-1). This plan envisaged the building of a dam on the Irasiquero River to raise the level of the river and Iralalaro Lake about 3.7 m. It was calculated that this project would have an installed capacity of 70 MW and be capable of generating 400 GWh annually. It was envisaged that water from the dam would flow through a short (600 m) power tunnel to a vertical penstock with a 325 m long shaft to an underground power-station (presumably deep under the Paitchau Range) with one large turbine and a 4,600 m tailrace tunnel discharging the water to the sea on the south coast. ELC-Electroconsult et al. (1989, p. 3-2) commented:

> *No site investigations, topographical, geological or hydrological, are mentioned in the report, to support the preliminary design developed; in particular, there is no mention about the karstic limestone formations in the area.*

The lack of field studies, and particularly the failure to appreciate the karst nature of the area, were obvious major shortcomings of this proposal.

2. The next development was "Laporan Survai Penjajagan Pembangkit Listrik Tenaga Air – Ira Lalaro – Timor Timur" prepared in 1985 by Perusahaan Umum Listrik Negara (PLN), Survey Division (cited by ELC-Electroconsult et al. 1989, p. 3-2). This proposed two options:

- A run-of-river type scheme – not involving any raising of the lake level; an installed capacity of 35 MW was estimated to be capable of generating up to 274 GWh/year; and
- A reservoir type scheme, raising the lake level to a maximum of 333 m a.s.l. (its natural level fluctuates between about 321 and 330 m a.s.l.); installed capacity of 42 MW was estimated to generate up to 320 GWh/year.

Details of the tunnels and powerstation appear similar to those proposed in 1975. According to ELC-Electroconsult et al. (1989, p. 3-3):

[1] For an explanation of the precise meaning of this and other technical terms, see Glossary.

Apart from the design of the project structures, the basic difference between PLN preliminary study [1985] and the previous report from Japan Development Consultants refers to the estimate of the available runoff.

3. A third iteration of the proposal was prepared in 1989 by a team of Italian, Swiss and Indonesian consultants: ELC-Electroconsult, Motor Columbus, P.T. Arkonin and P.T. Asianenco (ELC-Electroconsult et al. 1989). Parts only of vol. 1 ‘Main report’ and vol. 3 ‘Geology, hydrogeology and engineering geology’ have been available to the present authors. (Efforts to obtain the whole of vol. 3, reporting the main and, at least until very recently probably the only, geological investigations carried out on the site, from the current Norwegian consultants and the Timor-Leste Government have been unsuccessful.)

The 1989 proposal conceded, for the first time, that:

the high karstification of the Ira Lalaro depression and its surrounding limestones, practically impedes a water storage, and limits the civil design to a run of river scheme (ELC-Electroconsult et al. 1989, p. S-2).

This was a major concession, resulting from the realisation that because of the karstic nature of the area, it is likely that any dam built on the Irasiquero River or that attempted to raise the level of the Iralalaro Lake would result in the water flowing away through underground conduits. Such a dam would fail to impound water and the task of sealing all possible leakage points would be quite impractical – not to mention the costs involved.

The modified proposal included: a diversion cofferdam with crest at 323.5 m a.s.l., a diversion tunnel 2.3 x 2.7 m 145 m long and designed to take up to 30 cu.m/sec, a concrete gravity weir with crest at 320 m a.s.l. (rising about 6 m above the bed of the Irasiquero), a 3,150 m long concrete-lined power tunnel 2.2 m in diameter, a penstock tunnel 2.8 x 5.2 m, 160 m long, an outdoor powerstation and a 187 m tailrace. The powerstation would have an installed capacity of 27 MW and could produce up to 139 GWh per annum (‘firm’).

The report concluded:

The project, including about 190 km of transmission lines to Dili, is technically sound and economically feasible. It generates 191 GWh/yr of energy of which 73% is firm, a good result for a run of the river development; the installed capacity is 27 MW.

The project does not present specially complex technical problems. The civil construction can be carried out with conventional methods; it can be entrusted to Indonesian construction companies.

The economic and financial analyses show that the project meets the profitability criteria generally accepted by international agencies for the financing of developments of this type (ELC-Electroconsult et al. 1989, p. 2-1).

Despite these reassuring words, elsewhere the report admitted –

“… the scanty hydrologic data available for the studies represented a weak support for the feasibility of the Project [!] Furthermore, the phenomenon of the flooding of Lonina [the Mainina sinkhole (front cover)] needs to be known with more details” (p. 2-3);

and

> *"It is recommended to carry out a comprehensive geological study in order to clarify the stratigraphical sequence, with a special interest on the oldest formations of East Timor and also to define the tectonic[2] style of the whole area" (p. S-3).*

This paragraph's recommendations are discussed in detail in section 2.7.

4. The next point at which an insight is available into the development of the project is the 'Mission Report' prepared by a Norwegian team regarding cooperation between Timor Ministry of Transport, Communication and Public Works and the Norwegian Water Resources and Energy Directorate (NVE) in 2003 (Adeler et al. 2003). This report considers Timor-Leste's energy situation and alternative power sources before recommending:

> *… an updating of the 1989 feasibility study for Ira Lalaro hydropower scheme …* and *additional studies on geology and geo-hydrology [of the Iralalaro area] (also recommended by the consultant in the 1989 study), and has selected this project for priority because of its obvious capacity of generating electricity at low cost.*

An assessment by the Asian Development Bank in 2004 (ADB 2004) supported the assessment that the Iralalaro scheme was the most cost-effective of 8 schemes considered and, in relation to financial matters, stated:

> *The original estimate contained in the 1989 PLN study* [ELC-Electroconsult et al. 1989] *put the cost of the Ira Lalaro Project at $52.5 million. A Norwegian Water and Energy Directorate mission that visited Timor-Leste in late-2002* [Adeler 2003] *recommended the Ira Lalaro hydropower scheme as a priority project because of its obvious capacity to generate low cost electricity. The mission estimated the cost at about $160 million, including the transmission line, which represented approximately one third of the cost estimate. In this power sector master plan study the total project cost is estimated at about $60 million, of which $42 million would be for the hydropower plant and $18 million would be for the 190 km transmission line to connect the plant to the Dili system. This is considered a more realistic estimate, provided that procurement packaging is appropriate and international competitive bidding is employed.*

Notably, this report had no comment to make on environmental impact, except to observe that another feasibility report was underway. The issue of extra costs in relation to expensive construction and unforseen problems likely to arise in karst terrain was neither acknowledged nor addressed.

5. Evidently these recommendations were accepted because consultants for the same Norwegian agency (NVE) went on to prepare a 'Scoping Report' for an environmental assessment of the Iralalaro Hydropower Project (EPANZ Services 2004a). This report identified "major concerns within the project", being:

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[2] This is a veiled reference to the fact that the stability of the area in terms of earthquakes is uncertain. Earthquakes do occur regularly in this relatively unstable region. "Earthquake hazard assessment studies" were reportedly carried out (ELC-Electroconsult et al. 1989, p. 1-3), but the volume containing these has not been available to the present authors. However local people at Malahara village and Los Palos indicated that earthquakes have been rare in recent years.

- that the fate of the Irasiquero River, after it sinks at the Mainina sinkhole, has not been established. It was noted that:

  ELC-Electroconsult conducted tracer studies and picked up tracing material in the Tchino River, which would indicate a southwesterly trend for the groundwater. The aquatic study conducted by ERISS (EPANZ Services 2004b) from an analysis of the water quality results suggested that there was a poor match with the Tchino river water and that there were closer similarities to the Vero system. If this is correct this would indicate an almost direct route to the coast.

  (Figure 2. shows the location of the sinkhole and the two rivers mentioned.)

- that the project is located within one of the last, and probably the largest remaining, Tropical Dry forested area within Timor-Leste. The forest provides a range of habitats and maintains an extensive biodiversity base. Accordingly the area has a high conservation value and it is proposed as a protected area that may cover 620 km^2 (see Figure 2).

- that the tropical dry forest is home to several globally threatened birds including the critically endangered Yellow Crested Cockatoo.

- that 16 bat species are present, including two undescribed specimens that may be new records for Timor. 11 of the bat species are thought to be obligate cave roosters (EPANZ Services 2004c).

- that the waters of Lake Iralalaro and the Irasiquero River form a closed aquatic system with unique characteristics, including low species diversity. A new fish species *Craterocephalus* was discovered in the clear flowing waters of the middle section of the Irasiquero.

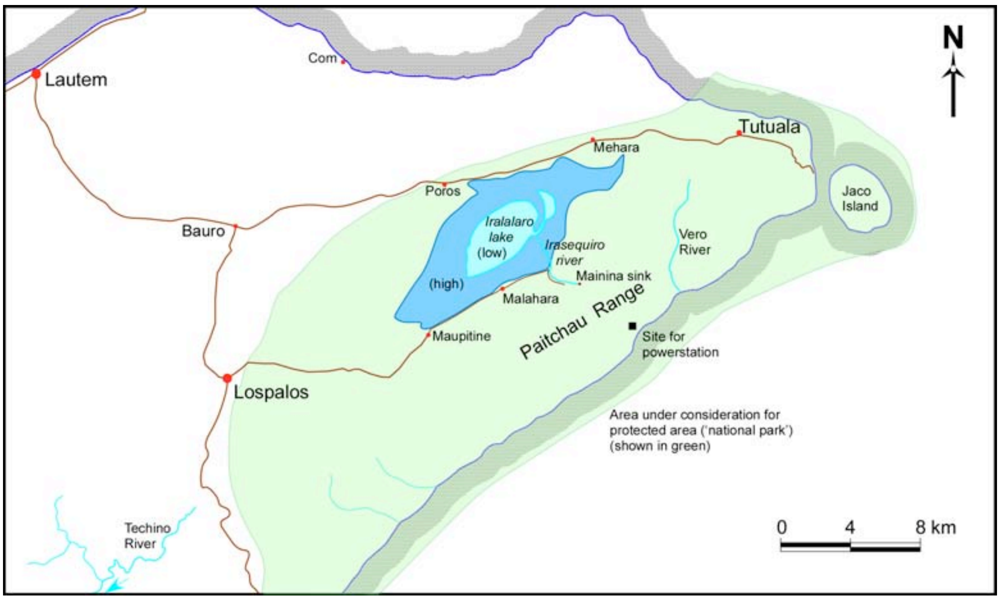

Figure 2. The major roads and the few rivers in the vicinity of Iralalaro, and the proposed protected area, eastern Timor-Leste (after Map 3, EPANZ Services 2004a)

6. Subsequent to the Scoping Report, and perhaps arising out of the concerns it expressed, particularly in relation to knowledge of geology, additional studies are reported to have been carried out (Demetrio de Carvalho pers. comm.)[3] In particular –

(a) a seismic study has been conducted across the Paitchau Range along the line of the proposed tunnel which may have been attempting to assess the suitability of the rock for tunnelling and

(b) dye tracing has been undertaken to try to determine the fate of the water sinking at Mainina. It is understood that dye was detected at three springs on the southern side of the Paitchau Range, as might be expected, and at four springs towards the north coast, in the vicinity of Com, which is quite unexpected and would appear to greatly increase the potential direct impacts of the proposed hydrological diversion.

However, despite the acknowledgement in the later reports, especially the Scoping Report, of the significance of the karst and the potential vulnerabilities associated with development on karst, no detailed study of the karst appears to have been undertaken by the proponents. This leaves considerable risks in both constructional and environmental areas. The issue of the costly and risky nature of construction in intensively karstified areas continues to be ignored.

1.2 The 2004 Proposal

As at the time of the Scoping Report (EPANZ Services 2004a), July 2004, the proposed project comprised:

- an intake dam upstream of the Mainina sinkhole, diverting the Irasiquero into
- a headrace tunnel carrying the flow under the Paitchau Range to
- a steel penstock (above or underground) leading to
- a powerhouse (above or underground), at sea level at Macca Beach with
- discharge to the sea.

The planned layout is shown in Figure 3.

Major ancillary activities would include the disposal of fill from the tunnels, and the power-station if it is built underground. A power transmission line would need to be built either (i) by the shortest route, across the Paitchau Range to near the intake and thence to Malahara and on to Dili, or (ii) by the longer but less difficult northern route, up the Vero River, to Tutuala and then to Dili via the north coast. The ‘substation’ shown near the intake on the plan on which Figure 3 is based would appear to presuppose adoption of the direct route.

[3] Requests to the proponents and the local Department of Environment for advice as to the findings of these studies have not been responded to.

A road would need to be constructed to the Mainina sinkhole site from Malahara, while access to the power-station site would either be by a new road constructed from Tutuala via the Vero valley, or by sea to a jetty at Maca Beach. While the 'Scoping Report' (EPANZ Services 2004a) states a preference for the jetty solution as it would remove the significant impacts of the road (and the impacts of its subsequent use) on the important remaining native forests of the area, it is noted that a map in a very recent Asian Development Bank report on roads (ADB 2005) shows proposals for new "district roads" leading from both the south and the north towards a currently non-existent location "Iralalaro" (which can only be interpreted as the site of the power-station) (see Figure 4).

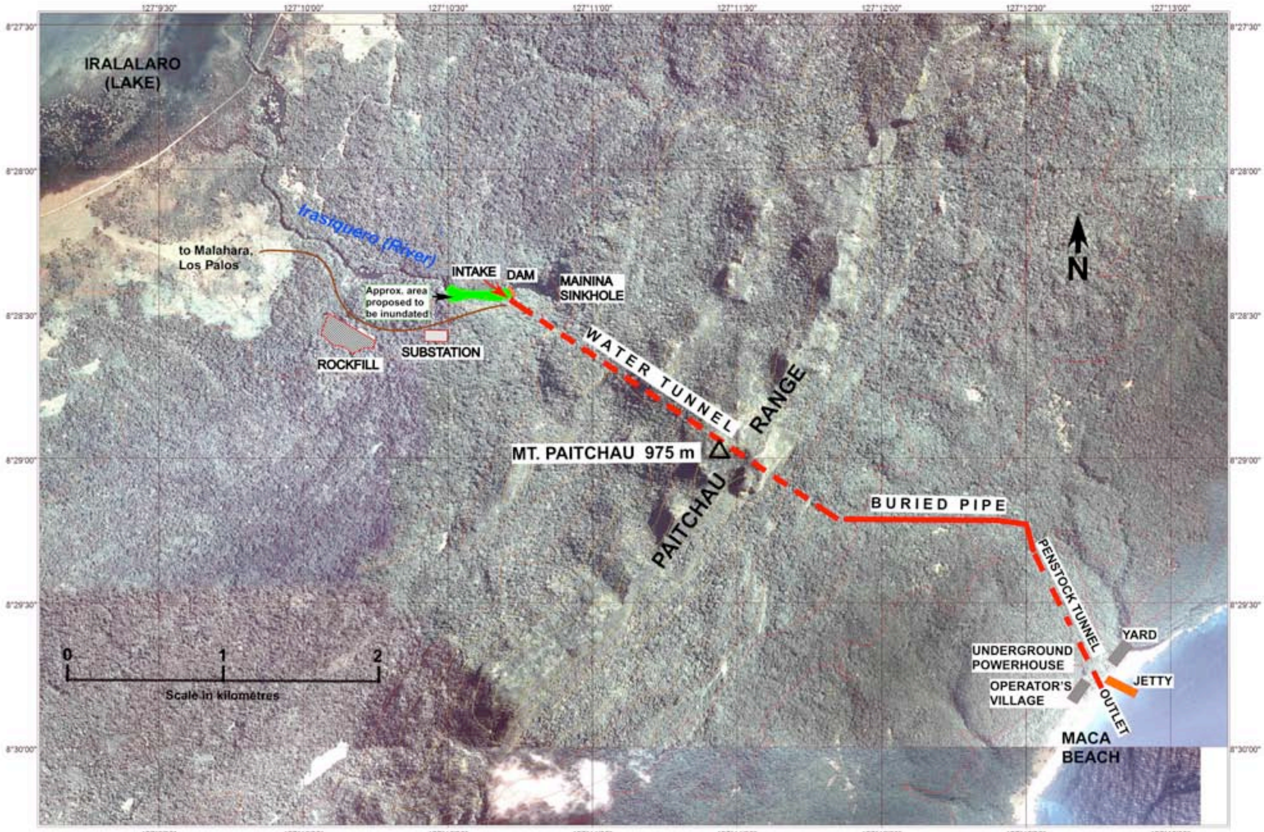

Figure 3. Major elements of the proposed Iralalaro Hydro-Electric Scheme, Timor-Leste.
[Derived from a plan prepared by Norconsult for Norwegian Water Resources and Energy Directorate #IR-001-C 5.1.2005 Based on 1:50,000 sheet 2507-61, FUILORO (1999) and superimposed on a rectified air photomap provided by the National Mapping Adviser, DNTP]

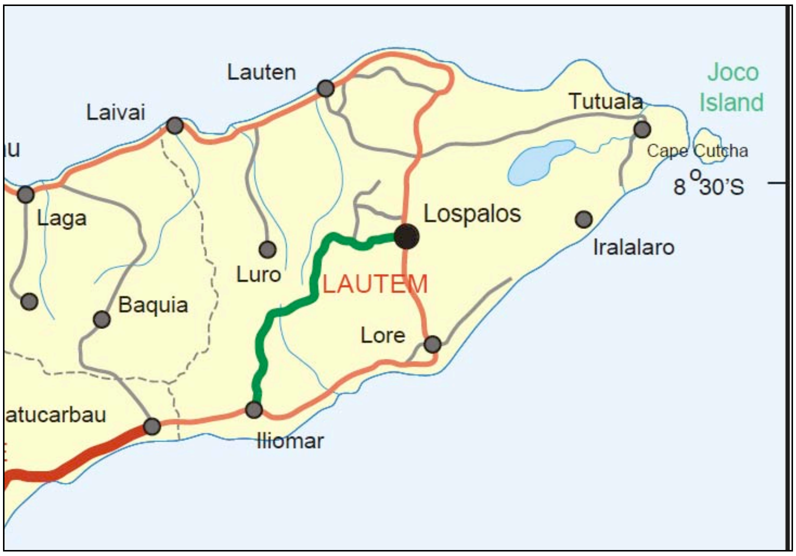

Figure 4. Map showing proposed new roads (grey lines) in the eastern part of Timor-Leste, including roads running towards the non-existent locality "Iralalaro". Continuation of either of these roads to the proposed power-station site would be comparatively simple and financially irresistible compared to the costs of constructing a major jetty and the relative inconvenience of continuing boat access to the power-station. [from ADB 2005]

2. Physical Environment

2.1 Regional context

The island of Timor is the largest of the Lesser Sunda Islands, which comprise the south-eastern part of the Indonesian Archipelago (Audley-Charles 1968). It lies south of the Equator between 8º 17' and 10º 22'S and 123º25' and 127º19'E. The island is about 365 km long and reaches about 100 km in width. Timor-Leste (East Timor), a former Portuguese colony, occupies the eastern half of the island and includes the enclave of Ocussi in the west, and the islands of Atauro and Jaco. Its area is about 14,875 square kilometres.

Timor is the largest island of the non-volcanic Outer Banda Arc, which is comprised of the islands of Buru, Ceram, Leti, Tanimbar, Kai, Timor and Roti (Figure 5), and is predominantly composed of calcareous sediments. Geologically it is part of the Australian Plate. The Banda Arcs lie between the Sahul shelf of Australia and the Sunda shelf of South-east Asia, a region characterised by crustal instability since the end of the Cretaceous (Audley-Charles 1968).

This report concentrates on the eastern-most end of the island, east of the town of Los Palos (Figure 1), in the district of Lautem.

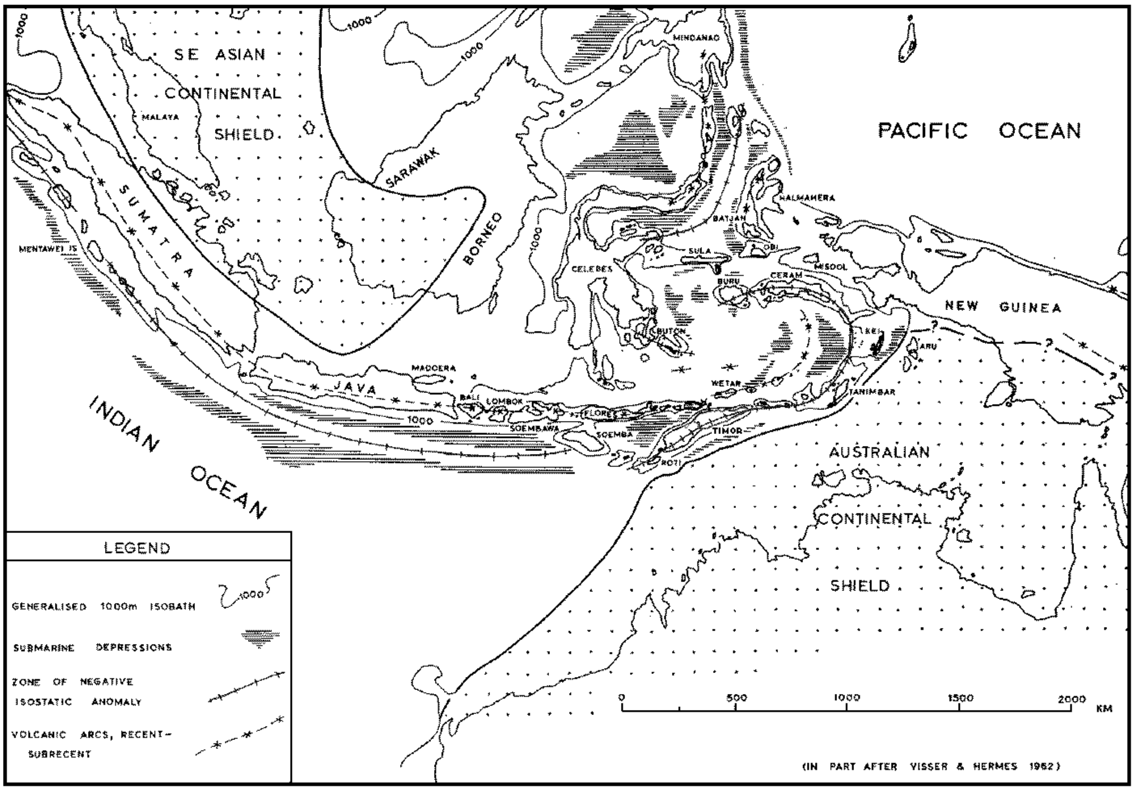

Figure 5. Timor in its regional structural context. It is one of a string of non-volcanic islands which form the Outer Banda Arc. [from Audley-Charles 1968]

2.2 Climate

The eastern end of East Timor has a wet tropical monsoonal climate characterised by a hot summer, distinct wet and dry seasons, pronounced monsoonal rainfall and relatively small temperature variation. The Lautem district is the wettest in East Timor.

The north coast of the district is relatively dry (500-1000mm rainfall p.a), with a distinct 8 month dry season, while the south and central areas are wetter and the dry season shorter (5-6 months). The only published rainfall data is from Los Palos where there is mean annual rainfall of 1,921mm. This is concentrated in the wet season from November/December to July. The dry season is very marked from August to October (EPANZ Services 2004a). Localised flooding occurs during the wet season.

Monthly average temperatures range from a maximum of 28.9ºC in November to a minimum of 18.8ºC in August. Humidity ranges from 82.2% (May) to 73.2% (October) (EPANZ Services 2004a).

Evaporation has been estimated at Los Palos as 1,033 mm p.a., which is less that the mean rainfall (1,921), but evaporation exceeds rainfall for 4 months (August - November). Also the rainfall record time is relatively short and even shorter term rainfall records from Malahara and Maupitine, east of Los Palos and to the south of the lake, record significantly lower rainfall than Los Palos (~37% less) and the evaporation would be similar (EPANZ Services 2004a).

Care must be taken when calculating rainfall recharge to the lake and underlying aquifer due to the limited time range of the rainfall data combined with the high evaporation deficit during the dry months and the trend of drier conditions on the southern side of the Iralalaro polje.

2.3 Geology

The geology of the area is shown in Figure 6. Most of the formations are limestones or contain limestones, except the oldest, the Permian 'Cribas Formation' and the recent 'Suai Formation'. There are several theories attempting to explain the tectonic and formational history of the island, e.g. Audley-Charles, 1968; Hamilton 1977; and Harris et al 2000, and this discussion on the geological history continues. However all theories agree that the island is composed of contributions from the Australian continental plate and the highly deformed rocks from the Banda Terrane. This suggests that Palaeozoic conditions similar to that shown in the Bonaparte Gulf Basin (Northern Australia) should be present but no evidence has as yet been published. Audley-Charles also observed:

> *Since the end of Permian times most of the sedimentary rocks formed on the site of Timor have been limestones, relatively little terrigenous material having been transported into the area. This suggests separation by wide seas from the continents of Asia and Australia since the end of Permian times; there is no pre-Permian record available* (Audley-Charles 1968, p. 1).

The oldest formation in the far east of the island is the Permian Cribas Formation, and is amongst the oldest rocks recorded from Timor-Leste. This formation comprises fossiliferous shallow water marine silty shale with calcareous and clay-ironstone nodules and flysch-like features and it is derived from elsewhere ('allochthonous'), probably from erosion of northern Australia (Audley-Charles, 1968, p. 59). Limestone occurs commonly at the top of the unit. Its contact with the overlying Triassic Aitutu Formation is not clear in this area and could be either tectonic or unconformable. The Cribas Formation is insoluble and is likely to form an aquiclude where it underlies limestones. The Cribas Formation is present as upthrust sections in the Paitchau Mountains south of the Iralalaro polje and along the north coast (Figure 6).

Overlying the Cribas Formation is the Triassic Aitutu Formation of up to 1000 m thickness which -

> *consists of about 80% calcilutites, 15% shales and calcareous shales, and about 5% calcarenites, lumachelles, quartz-arenites, radiolarites and highly bituminous rocks* (Audley-Charles 1968, p. 10).

The Aitutu Formation is a deepwater marine flysch with its major component (up to 800 m), calcilutites, being composed of fine calcite or aragonite mud. These must have been deposited, probably by precipitation from sea-water by the activity of plankton or bacteria, in a shallow marine environment under low-energy (calm) conditions. This is a highly soluble lithology; less than 5% of the material is insoluble. The Aitutu Formation is also present as uplifted sections in the Paitchau Mountains (Figure 6) (UNESCAP 2002).

The Aitutu Formation is followed by a very large time gap (over 200Ma) in the geological sequence in the far east of the island, from about 210 Ma (late Triassic) to about 1.6 Ma (beginning of the Pleistocene) when the Baucau and Poros Limestones began to form. Further west there are Jurassic, Upper Cretaceous and Palaeogene deposits but none are reported east of Los Palos. Lack of data seriously constrains the geological understanding of the eastern end of the island and the understanding of the lithologies and structures underlying the Iralalaro polje and is a serious problem for development in the area (UNESCAP 2002).

The area was subjected to tectonic activity including folding up until the Pliocene as the Pliocene Viqueque Formation, to the west of Los Palos, is folded. Except for the upthrust Permian and Triassic sediments of the Paitchau Mountains, the post-Pliocene sediments e.g. the Baucau Formation, blanket the eastern end of the island and are assumed to unconformably overly older folded and/or faulted sedimentary rocks (UNESCAP 2002).

The Baucau Formation is a "hard, vuggy, cavernous, massive, white coral-reef limestone which weathers to a pale grey" and is rich in fossils (Audley-Charles 1968, p. 37). It typically occurs as a series of terraces (representing raised beaches) and has a maximum thickness of ~100 m. The raised beaches indicate the continued uplift history of the area. It is widespread in the eastern part of the island and controls the topography of the Baucau and Lautem plateaus.

The Poros Formation occurs only east of Los Palos on the Lautem Plateau. It is

> *hard, thinly bedded limestone, and rich in gastropods and algae. It is pale-brown and cream colour when fresh; it weathers to a grey that renders it superficially similar to the Baucau Limestone. Locally it is vuggy because the gastropods tend to be more easily weathered and it is probably only about 20 m thick* (Audley-Charles 1968, p. 39).

The Poros Limestone is lacustrine and must have been deposited after the Baucau Limestone on which it rests had been elevated above sea-level. It is therefore not older than mid-Pleistocene and probably much younger (UNESCAP 2002).

The bed of the Iralalaro polje is in Quaternary alluvium, which here appears to be a heavy black clay. It may be the relative impermeability of this clay, which allows the lake to hold water. Virtually nothing is known about these deposits but researchers at the Australian National University plan to correct that deficiency through "a long term landscape history [study] of the proposed National Park, through palaeoecological research of the Iralalaro Lake

> *"… [which] potentially contains a long sediment record. Palynological and chronological research will contribute to our understanding of the influence of regional climate systems (monsoon) as well as people on the fragile environment." (Anon. 2005)*

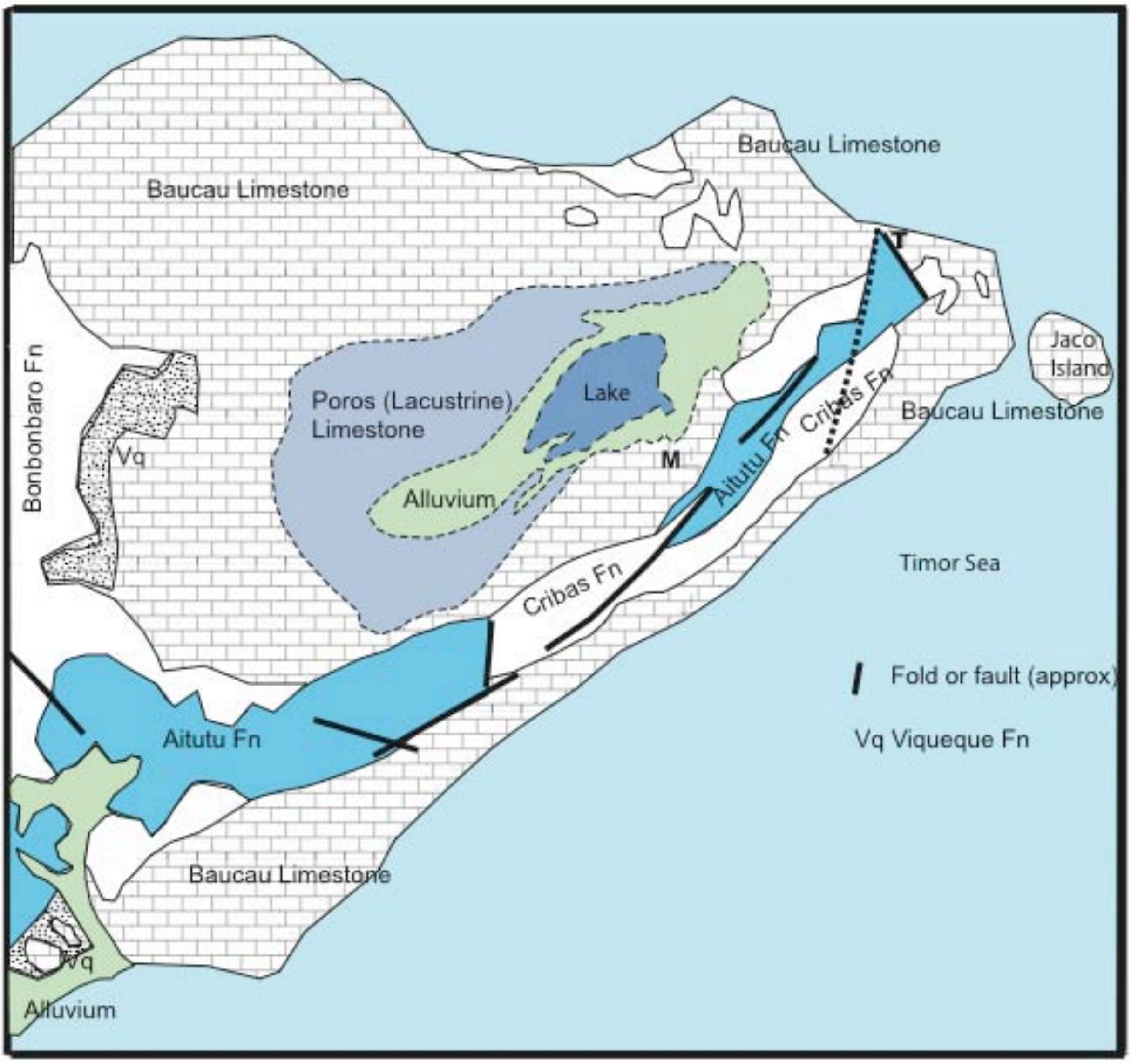

Figure 6. Geology of the extreme eastern portion of Timor-Leste [simplified from Audley-Charles 1968, and Partoyo et al 1978] NOTE: many of the lithological boundaries are inferred rather than from field mapping.

Audley-Charles was of the opinion that Timor, a mountainous island bordered by deep-sea troughs and with strong gravity anomalies, was likely to continue to suffer seismic instability. However, although the area between Los Palos and Malahara village has not experienced serious earthquakes in recent years, other areas of Timor-Leste, e.g. around Dili, have recently reported significant earthquakes.,.

2.4 Landform geodiversity and geomorphology

The study area within the Iralalaro-Paitchau Mountains area is a karst region, which contains a wide range of karst-related landforms and features. These include a large polje, collapse dolines, sinkholes, blind valleys, karren and caves.

2.4.1 Surficial karst landforms

The most outstanding single landform of the region is the huge *polje* in which the fluctuating Iralalaro Lake occurs. This feature is clearly seen in a digital terrain model of the region and related cross sections (Figure 7a, b) but is also clearly evident at ground level (Figure 8).

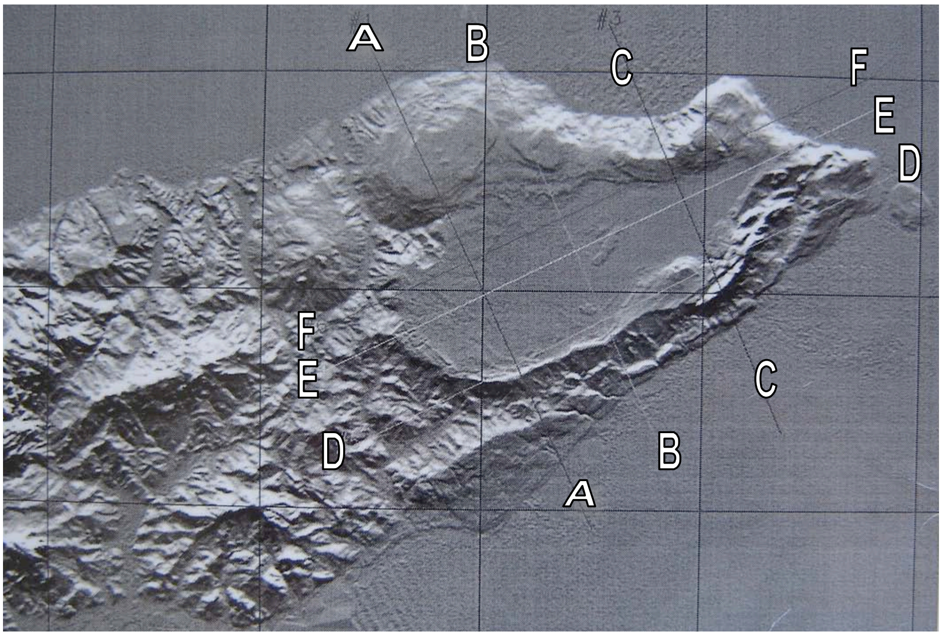

Figure 7a. Digital terrain model of eastern region of Timor-Leste, clearly showing the huge polje which contains the Iralalaro Lake. [*generated from SRTM 3-arc second data from USGS*] Cross sections A, B, C, D, E, F identified.

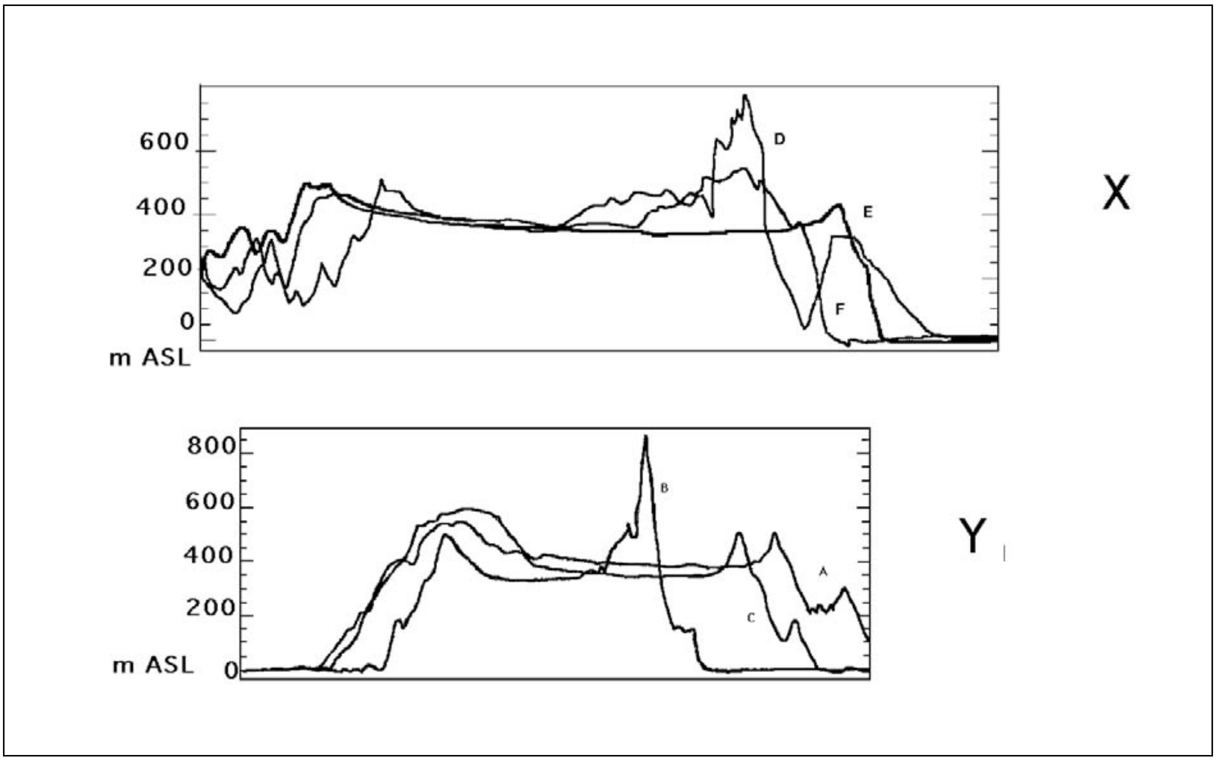

*Figure 7b. Cross sections across the digital terrain model Figure 7a; X are W-E sections and Y are N-S sections [*generated from *SRTM 3-arc second data from USGS].*

Figure 8. View north across the flat-floored Iralalaro polje from foothills of Paitchau Range.

Ford and Williams (1989) define poljes as

> *large, flat floored enclosed depressions in karst terrains … associated with the input or throughput of water.*

Their common hydrological factor is that as they developed close to the local water table; plains develop rather than deep valleys because "lateral fluvial planation (corrosion and corrasion) and deposition processes are more important than incision" (Ford and Williams 1989, p. 431). Gams (1973, 1978, cited by Ford and Williams 1989) recognised five types of polje, of which the Iralalaro example is a

> *Baselevel polje or 'polje in the piezometric level'. The polje floor is cut entirely across karst rock but is located in the epiphreatic zone and consequently is inundated at high stages of the water table.*

Ford and Williams (1989) describe baselevel poljes as "the purest kind of polje" as they do not depend on allogenic inputs or geological control. Poljes are typically associated with complex hydrogeological features such as exsurgences, swallets, estavelles, and lost rivers.

The estimated area of the Iralalaro polje is around 100 km^2. which makes it large by international standards; Gams (1978, cited by Ford and Williams 1989) lists 42 poljes in the Dinaric karst, of which only 6 are larger, and none are of the baselevel type. It is reported that the area of the Iralalaro surface water fluctuates from 10 to 55 km^2. Its catchment is 'authigenic', i.e. virtually entirely within the karst, and has an area of 406 km^2 (EPANZ Services 2004a, p. 8).

In other areas of the world, e.g. Slovenia, valleys around poljes are narrow and relatively short with steep sides. Many contain streams. This is similar to the valleys associated with the Iralalaro polje.

Associated with the polje are a number of small dolines, some of which had water at their lowest points at the time of inspection (August 2005) but most of which were dry. A small number had vertical sides and were filled with water to within a metre or so of the surface. While much smaller in scale, in form and appearance, they mimic the *cenotes* of the Yucatan Peninsula in Mexico, Florida U.S.A. and south-eastern South Australia (Figure 9). They provide an indication of the level of the watertable below the polje floor, especially during dry conditions.

The principal drainage from the polje is via the Irasiquero River which runs for about 3.5 km south to the Mainina *sinkhole* or *swallet*. The sink lies in a *blind valley* cut into the foothills of the Paitchau Range (Figure 10a, b).

Figure 9. Small water-filled doline of cenote form in the floor of the Iralalaro polje.

Figure 10. a. Approaching the blind valley of the Irasiquero River which ends at ... *b. the Mainina sinkhole*

The Mainina Sinkhole is a large and impressive feature at the blind end of a valley. The water sinks into a restricted swallet less than a metre in diameter in the river bed. Investigation of the swallet is difficult due to high velocities of flow, even in the dry season.

The Irasiquero River flows for 3.5 km though a *blind valley,* with a high head wall and a large boulder slide. The boulders are large (up to and over 5m diameter) and angular, indicating limited solutional modification. Small boulder caves are present in the boulder slide. It is unclear as to whether the collapse slide is due to the collapse of a previous swallet and cave or just undermining of the head wall. Further investigation of this feature could yield information on the strength and competence of the rock.

The valley periodically floods up to a level of ~20m above dry season river level, as indicated by the absence of forest below that level. The swallet is unable to easily drain the high discharge of the Irasiquero River during the wet season, and the water dams back.

The area on the south side of the polje has a disrupted drainage pattern as seen on satellite photos of the area. Superficial runoff in the wet season probably drains underground through a range of small sinks, which are obscured by the forest cover. Except for the Irasiquero River and the polje, there is very limited surface water in the dry season.

Apart from the Mainina sink it is postulated that there are other sinks around the rim of the polje:

> *There might occur also particular areas at the rim of the ground water reservoir [Iralalaro Lake] where some sort of "overspilling" (existence of Karstic siphons?) can take place after the lake water table has been raised by more than 2 m* (ELC-Electroconsult et al. 1989).

Such sinks might, in fact, be *estavelles,* which can act as springs or risings at drier periods when the lake level is low and water is contributed from the surrounding highlands.

The limestones of the area display a range of surface karst features, particularly karren (Figure 11 a, b, c). Areas of bare rock commonly show these features.

Figure 11a. Small solution pan – kamenitza – *on Baucau limestone near Mainina sinkhole.*

Figure 11b. Surface karren – solution-enlarged joints – on Aitutu limestone high in Paitchau Range

Figure 11c. Solution perforation in outcrop of Baucau limestone on floor of Iralalaro polje.

2.4.2 Subterranean Landforms, primarily caves

Very little documentation of caves has yet been carried out in the subject area, although caves are known in the Baucau area. Prior to 2005, the only known records were of archaeological sites in the extreme eastern portion of the area, between Tutuala and the coast, made by archaeologists. The only significant cave survey seems to have been one by O'Connor and Veth (2005) (Figure 12).

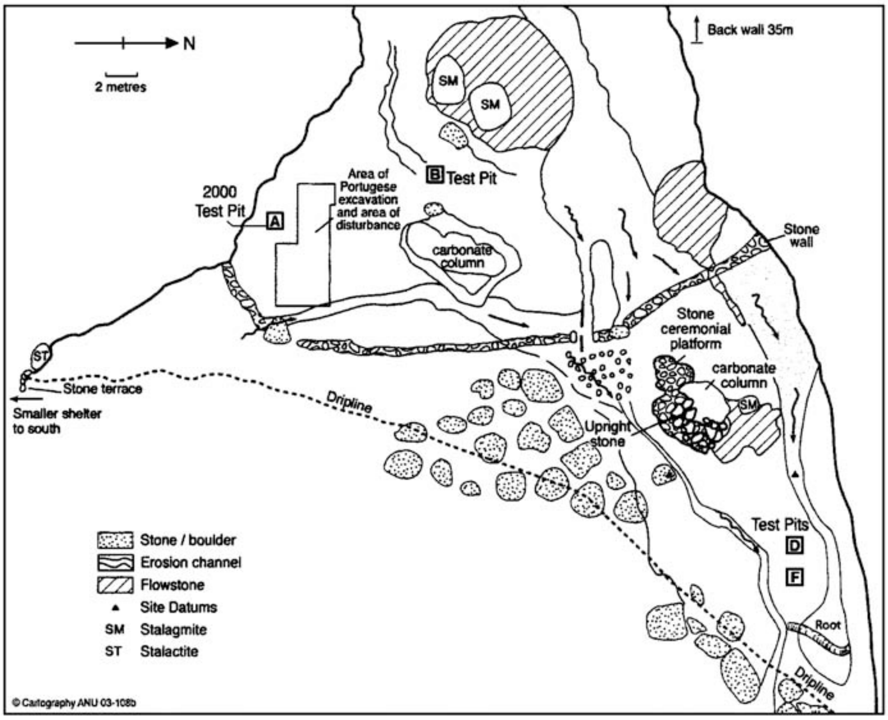

Figure 12. Plan of outer part of Lene Hara Cave, showing location of 2000 and 2002 test pits [after O'Connor and Veth 2005]

This cave has a very large entrance (Figure 13) and a number of large, dry speleothems (Figure 14). It barely possesses a dark zone, and shows no strong tendency to follow any particular orientation, so appears not to be joint-controlled. However, near horizontal bedding is strongly displayed in the northern wall of the main chamber (Figure 15). There is evidence of surface flow from the rear of the cave in the wet season but no well-developed streamway and no evident connection to a subterranean watercourse. The floor is generally rocky or dusty and has been heavily trafficked. The only area of flowstone in a near-natural state is adjacent to the southern wall towards the back of the chamber (Figure 16).

The cave has a number of panels of ancient art in the entrance and excavation has established occupation back as far as 35,000 BP (O'Connor, Spriggs and Veth 2002).

Figure 13. Looking out the large entrance to Lene Hara Cave; the line of stones is an artefact of occupation.

Figure 14. Most of the speleothems are large but dry and sunlight has encouraged the growth of moss and algae.

Figure 15. Pronounced near-horizontal bedding is in evidence in the northern wall of the outer chamber of Lene Hara Cave.

Figure 16. The only significant area of undamaged flowstone in the cave is adjacent to the southern wall towards the back of the chamber.

Other caves in the vicinity of Tutuala have also been the subject of archaeological study in recent years. Ile Kéré Kéré is a high but narrow overhang on the Tutuala Scarp, overlooking the sea (Figure 17a, b). It has large stalactites and flowstone deposits and wild bees build hives in its shelter; its art was recorded at least as early as 1967 (Almeida 1967, cited in O'Connor 2003). O'Connor (2003) lists nine 'new' rock-art sites in the eastern part of Timor-Leste, at least 6 of which (Lene Cécé, Lene Kici 1 – a 'tunnel cave' in a coral terrace which has been used as a refuge, Lene Kici 2 – another tunnel cave, Lene Kici 4 – a 7 m deep tunnel cave, Lene Kici 5 - 'a very large tunnel cave' ~30 m deep and Lene Kici 6 – a smaller tunnel cave) appear to be within the area under study. Their speleological significance cannot be assessed from the information available.

Figure 17a. Northern part of Ile Kéré Kéré rockshelter, inland from eastern tip of Timor-Leste.

Figure 17b. Part Ile Kéré Kéré rockshelter showing exposed stalactites and flowstone.

In August 2005, the authors were shown a cave in Baucau Limestone on a raised terrace near the village of Malahara. The Baucau Limestone here is a grey fossiliferous massive fine-grained calcarenite, very hard and competent despite its young age. Inspection revealed this to be a cave of significant extent and as it had not previously been documented, a survey was undertaken. The cave was found to be about 320 m in length, almost flat and with chambers generally over 4 m high (Figure 18).

The cave is remarkable for the strength of its passage orientation, NE-SW, clearly the result of very pronounced joint-control of solutional enlargement. There is abundant evidence in the cave, in the form of significant areas of roof spongework, of it having been primarily formed by phreatic waters. There is no evidence of vadose stream action.

The cave has abundant speleothems (Section 2.4.3), large chambers and, with its almost flat floor throughout, is easily traversed. It could be opened as an 'adventure' show cave with a minimum of effort and could make a significant contribution to local ecotourism.

The authors made a particular search for caves around the headwall at the Mainina sinkhole in the hope of finding higher level dry passages above the present, possibly water-filled conduits which carry the water away from the sink. While not successful, they did find a small cave, with abundant spongework, indicating solution under vadose conditions (Figure 19a, b). It indicated that the sink must have partly filled for extended periods in the past and may continue to do in wet years.

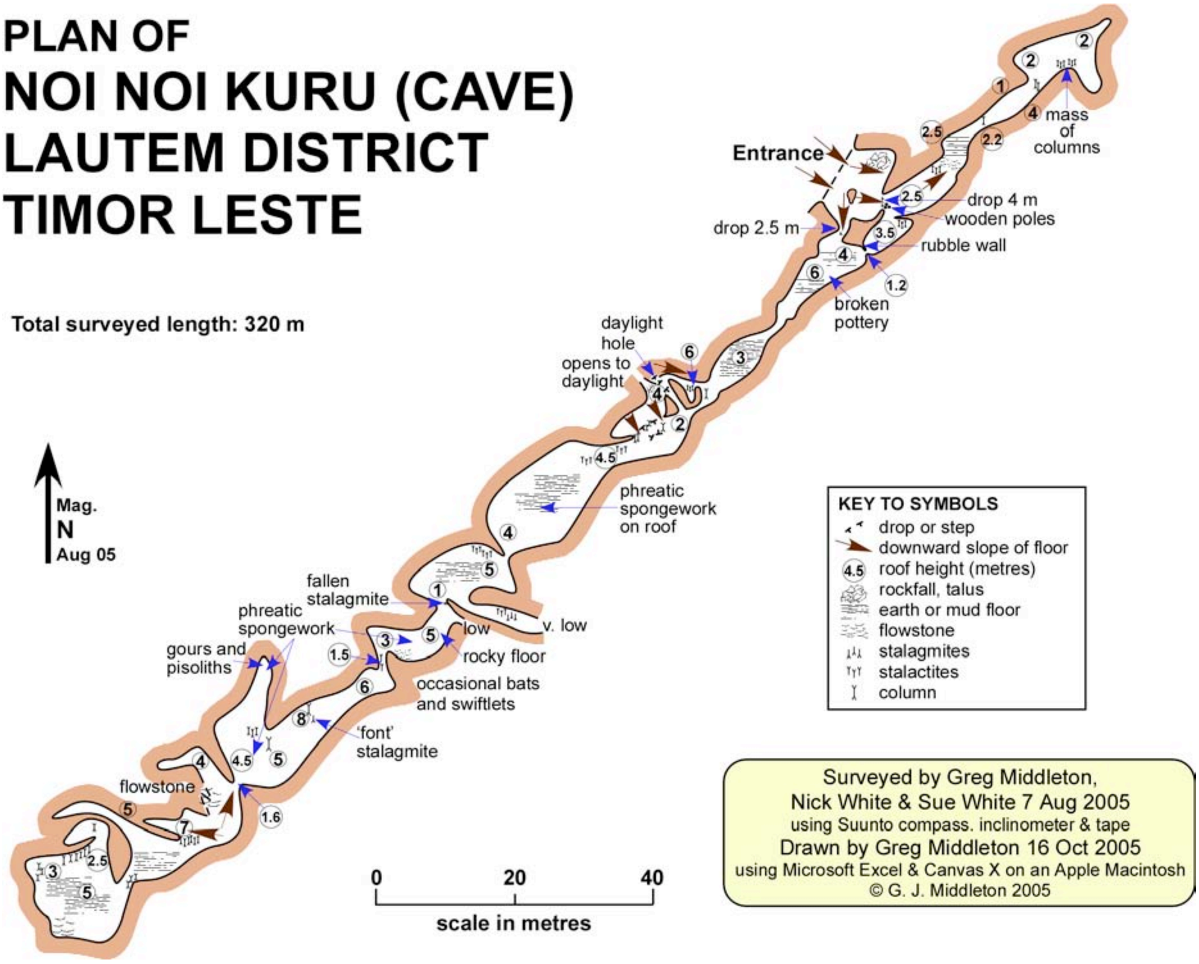

Figure 18. Survey plan of Noi Noi Kuru (= cave), located in Baucau Limestone, within forest, near the village of Malahara, Lautem District, Timor-Leste.

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Figure 19a, b. Small cave above Mainina sink with abundant spongework indicating phreatic solution.

There are reports of caves in the 1989 'Feasibility Report' for the proposed Iralalaro hydro-electric scheme (ELC-Electroconsult et al. 1989):

> *… dolines as well as large solution caves can also be found within the "Poros" and "Baucau" limestone areas. e.g. along the Ira Siquiro river, near the Malahara and Poros villages, etc* (p. S4).

> *… at the northern rim of the lake, river flow occurs mainly underground as it can be observed in caves within the karstified Poros and Baucau limestones. These caves are located still well above lake level (p. S6).*
>
> *… it seems that during the dry season there occurs a quite considerable reduction of the surface and "visible" (i.e. as observable in caves) subsurface recharge of the Ira Lalaro lake … (p. S6)*

Six caves were visited by the bat survey team in March 2004 (EPANZ Services 2004c, p. 5); unfortunately its report was not available to us at the time of our visit.

Lack of locational data prevented these caves being examined during the authors' site visit in August 2005 but it is clear that there is considerable karst, including cave, development of the Baucau Limestone. Although no large caves were observed in the limestones of the Aitutu Formation in the Paitchau Range, there were abundant surface karst features (Figure 11b) and one small cave was noted. Less than half a day was spent in this area and no deliberate search for caves was made, however potential exploration leads were noted. The lack of knowledge of caves in the Aitutu Formation is no indication as to the presence or absence of significant karst features, as no exploration has occurred. Other caves on the southern slopes of the Paitchau Mountains were reported to the authors by local people. The potential for significant karstification cannot therefore be ignored.

2.4.3 Cave contents

The observed caves contained a range of speleothems, Noi Noi Kuru being particularly well decorated with stalactites, columns and flowstone (Figures 20 and 21).

The floor of this cave consists of fine silt in many places, and it may contain pollen or other datable material. No doubt a minimum age for the cave could be determined by Uranium-Thorium or similar dating of a suitable speleothem, but as the Baucau Limestone is itself Quaternary, this cave can be no more than 1.5 Ma old.

The landowner who showed us Noi Noi Kuru told us that it has been used for refuge by the local people at times of civil strife. In 1975 it is said to have sheltered 60 families for two months. Broken pottery (Figure 22) indicated occupation but the cave did not appear to have suffered greatly from having had so many people staying in it. There was only one obvious modification: a rubble stone wall built most of the way across the passage below the entrance ('rubble wall' on Figure 18). It is notable that Lene Hara cave also exhibits a stone wall, in that case across its entrance/main chamber (see Figures 12 and 13)

Figure 20. Noi Noi Kuru is richly decorated with speleothems; roots also occasionally hang from the roof (the surface is heavily forested).

Figure 21. Impressive columns in lofty chambers are a feature of Noi Noi Kuru's decorations.

Figure 22. Broken earthen-ware pottery in Noi Noi Kuru indicates the cave has been occupied but there was no clear evidence of recent large scale occupation.

As noted above, Lene Hara Cave near Tutuala has been excavated and yielded evidence of occupation – in the form of pottery, stone artefacts, shell beads, marine shells and bone – dated, in the case of the shell material, at between 35k and 30k BP. Lene Hara, Ile Kéré Kéré and other caves/overhangs in the district contain a wealth of rock art (Figures 23, 24).

Figure 23. Geometric design and human figure art, Lene Hara Cave, near Tutuala.

Figure 24. Rock art, Ile Kéré Kéré limestone rockshelter, near Tutuala.

The rock art sites of the region have been documented by Glover (1986) and O'Connor (2003). Clearly, there is potential for the caves of this region to have high archaeological significance, especially as Timor is seen as a likely stepping-stone on the route taken by humans to Australia more than 55,000 years ago (Bednarik 2000). With the recent discovery of a new small-bodied human from cave deposits on the nearby island of Flores (Brown et al. 2004), interest in ancient cave occupation sites on Timor is likely to increase significantly.

The Baucau Limestone forms prominent clifflines and terraces; these are particularly evident south of Malahara village; indeed along the entire southern rim of the Iralalaro polje. Cliff-foot caves occur at the base of these cliffs and these are evidently used from time-to-time for shelter or storage.

2.5 Hydrogeology

No detailed information is available on the groundwater and hydrogeology of the area, although the surface hydrology has been described, based on limited data. This is a serious limitation of the Scoping Report (EPANZ Services 2004a) and other related documents. Substantial development is being planned in the absence of detailed hydrogeological data and the assumptions used to base the water volumes on are at best unproven. If incorrect they would have serious consequences for the viability of the planned hydroelectric scheme.

The following limitations seriously restrict the confidence that can be placed in the description of the hydrology in the Scoping Report:

- The lack of understanding of the nature of the Iralalaro depression as a polje and its close relationship with the groundwater aquifers and both local and regional hydrogeology.
- The absence of any quoted groundwater/hydrogeological data.
- The lack of any karst assessment beyond the basic acknowledgement that the area is karstic and has underground water flows.
- The lack of clarity as to the fate of water disappearing into the Mainina Sinkhole, both in geographical terms and as to quantities at different seasons, and the absence of an

understanding of the relationship between that water and the polje (particularly as there are local 'rumours' that the outflow water travels north, back under the polje!).

- The lack of any apparent attempt to draw up a water budget.

These problems are discussed in more detail in Section 2.7.

As Timor is an island, the hydrogeology of the eastern end of Timor-Leste is controlled by the relative position of sea level. The Island Karst Model (Mylroie and Carew 2000) (Figure 25), enables some understanding of the expected groundwater characteristics, although further detailed fieldwork is needed to understand the specific hydrogeology. Although Timor is a large island, it is not so large that the basic island karst/groundwater concepts would not apply. 'Carbonate-cover' islands such as Timor are directly influenced by the chemistry of marine and fresh water groundwaters and by sea-level changes. Islands are limited for recharge to the aquifers by their own areal extent, whereas on carbonate continental coasts the groundwater has access to significant recharge from non-carbonate areas. Carbonate islands have been categorised into 3 types as shown in Figure 25.

This model has been developed on a range of island situations, including oceanic islands with complex geology. Although Timor is not one of the islands from which the model's field data is sourced, sufficient similarities occur to suggest this model is useful until sufficient fieldwork can develop something more specific.

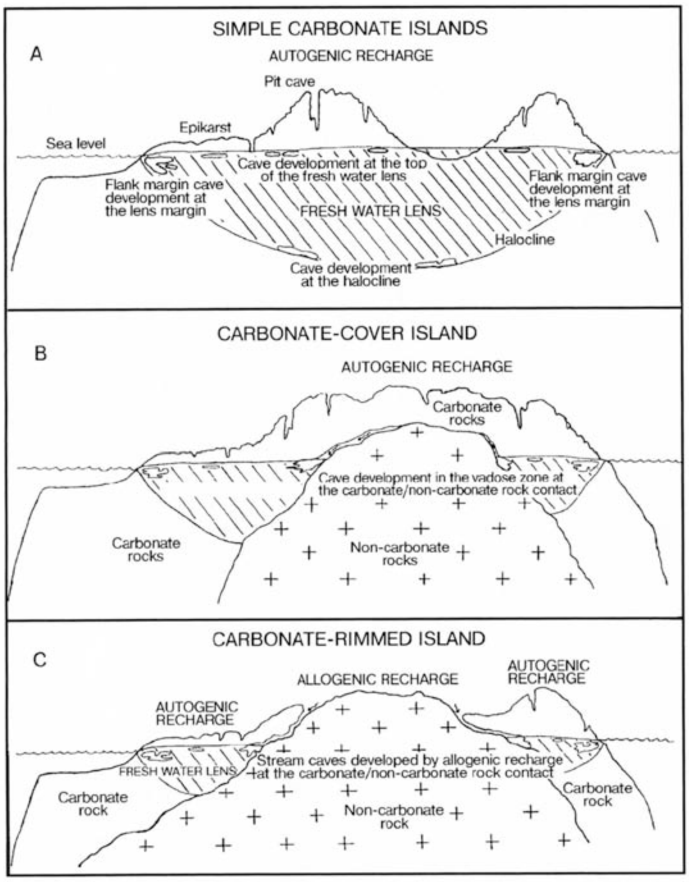

Figure 25. Island Karst Model. Features of three main types of carbonate islands. Section A is a simple carbonate Island. Section B is a carbonate-cover island. Section C is a carbonate-rimmed island. Timor is of Type B. [from Mylroie and Carew 2000 p 227].

A freshwater lens overlies the denser saline groundwater. The idealised lens shape (Figure 25) is modified/distorted by differences in rock lithology, porosity, permeability, transmissivity and water budget issues (Mylroie and Carew 2000). The freshwater lens in relatively young limestones such as the Baucau Limestone is more or less controlled by the sea level but modified in shape by any underlying non-carbonate rocks, such as the Cribas Formation. The top of the lens will grade to sea level as a regional watertable, and the lens is represented in the freshwater aquifers. This includes the aquifer underlying and interconnected with the polje. All recharge is from meteoric water (rainfall), but discharge is to the sea. Cave development occurs in 3 zones: the land surface with meteoric water, the top of the freshwater lens (water table) and the base of the freshwater lens (halocline). These last two situations occur where mixing corrasion occurs due to the mixing of waters with different levels of carbonate saturation (Mylroie and Carew 2000).

As a carbonate-cover island, Timor has some similarities with the simple carbonate island (type a), but the carbonate is a veneer over the non-carbonates and the carbonate/non-carbonate contact zone will have important hydrogeological implications especially with respect to cavernous development. Although the field studies used in the development of these models were on relatively tectonically stable islands, it is the relative position of sea level that is important for the position of the freshwater lens and water tables. The relative tectonic instability of Timor and its history of recent uplift have replaced the global Pleistocene sea-level fluctuations in controlling the position of the freshwater lens.

The hydrological studies that have been undertaken have seriously underestimated the complexity of karst in the area. The interaction of the polje and water table does not appear to be understood by those planning the engineering works. The total absence of a water budget is a serious deficiency.

2.6 Surface and underground biodiversity

Studies such as that carried out for UNDP in 2001 (Sandlund et al. 2001) drew attention to the great natural values of the Iralalaro-Paitchau area:

> *The lake Iralalaru in the eastern part of the country is relatively large and constitutes a very interesting wetlands ecosystem of which almost nothing is known in scientific terms … in the hills and mountains to the North, East and South of the lake, there are large areas of relatively undisturbed forest. We were told that the lake harbours crocodiles (probably* Crocodylus porosus, *saltwater crocodile … We could also observe a rich bird life. Otherwise, there are relatively few and small lakes in East Timor. …*
>
> *Iralalaru lake is surrounded by extensive and relatively well preserved forests. In particular, the mountainous areas between the lake and the sea to the South and East appear to be of good quality. Plans have been launched to develop this area into a Biosphere Reserve."* (Sandlund et al. 2001, p. 11)

The vegetation of the area is briefly described by EPANZ Services (2004a, p. 9):

> *The majority of the upland areas and the south coast are covered in forest, which includes areas of Tropical dry forest, Tropical semi-evergreen forest and Tropical*

> *evergreen forest. Elsewhere in those areas within the influence of fluctuating water levels areas of riparian vegetation and freshwater wetland have formed as around Lake Iralaloro and the Irasiquero River. A xeric area has formed on the coastal strip at Maca Beach on the south coast.*

This report, while proposing a hydro-electric development in the area, concedes

> *The Iralaloro/Paitchau area contains the single largest area of tropical forest remaining in Timor-Leste and is considered to contain the single best representation of natural dry tropical habitats for the islands of Timor, Wetar, Atauro, Roti and Semau. Lake Iralaloro has the largest and most biologically significant wetland area in Timor-Leste. While Tropical Dry forest and Tropical Semievergreen forest habitats occur elsewhere in Timor-Leste, the only occurrence of Tropical Evergreen forest is restricted to a small area above the Mainina [sink]hole on the north side of the Paitchau range, which makes this area of particular significance* (EPANZ Services 2004a, p. 18)

In relation to avifauna, a survey in 2003-04 by BirdLife International (Trainor 2004) found that ‘Paitchau-Iralalora’ and Jaco Island constitute two of nine ‘Important Bird Areas’ of Timor-Leste in that they possess “one or more species of global conservation concern, or one or more globally restricted-range bird species” and that Paitchau-Iralalaro had the highest number of ‘key’ bird species (16). There is no information or discussion on the importance of the polje to bird life.

Bats dominate the native terrestrial mammal fauna of Timor, comprising more than 90% of all species. A study of bats in the Iralalaro-Paitchau area by specialists from the Northern Territory Department of Infrastructure, Planning and Environment in 2004 (EPANZ Services 2004c) found 12 of the 24 species known from the Lesser Sunda islands (including Timor) to be present and added three or four new species. The most abundant bat was found to be the cave-roosting fruit bat *Rousettus amplexicaudatus* (Geoffroy's rousette), followed by *Rhinolophus canuti* (Canut's horseshoe bat) and two yet to be identified *Murina* species; *Hipposideros sumbae* (Sumba leaf-nosed bat) and *Rhinolophus celebensis* (Sulawesi horseshoe bat) also appear to be abundant in the area. The study found:

> *Eleven of the 16 species captured during the survey are likely to be obligate cave roosters. This list includes both mega and microbats. Diurnal roosts of only four of these species were located during the study:* Rousettus amplexicaudatus, Rhinolophus canuti, Hipposideros diadema *and* H. sumbae. *Other cave roosting species [identified] include* Eonycteris spelaea, Taphozous *sp.,* Rhinolophus celebensis, Hipposideros bicolor, *and all three* Miniopterus *species* (EPANZ Services 2004c, p. 19).

The only other native mammals recorded by the consultants are the Long-tailed Macaque, Common Spotted Cuscus *(Phalanger orientalis)* and deer *(Cervus timorensis)* – are all introduced to Timor. Glover (1986) adds the civet ‘cat’, *Paradoxurus hermaphroditus.*

The lake and Irasiquero River contain a population (estimated at 200-500) of the estuarine crocodile, *Crocodylus porosus.* The crocodile is revered as a totem animal by the local communities and is not hunted by them – however it has been hunted by others in the past (EPANZ Services 2004a). McCord's Long-necked Turtle *Chelodina mccordii* is found in the lake and river.

Formerly thought to be restricted and critically endangered, it now appears to be common in the area, up to 30/day being caught by the people of Malahara village alone (EPANZ Services 2004a).

A study of the aquatic ecology of the area by the Environmental Research Institute of the Supervising Scientist, Darwin (EPANZ Services 2004b) found:

- an unusually high diversity of aquatic plants in the Irasiquero river;
- a diverse macroinvertebrate fauna (57 families recorded) but no decapod crustaceans in the Iralalaro lake or Irasiquero river, presumably because they have no continuous surface water connection to the sea;
- "Spring sites on the Irasiquero contained commonly found amphipod and isopod crustaceans – groups typical of groundwater ecosystems. Thus groundwater below the Mainina sinkhole may harbour a specialist fauna - so-termed 'stygofauna'."
- 28 species of fish (of which 21 were in freshwater habitats and eight were in the Vero River estuary), most of which are widespread in the region, but two of which "are new to science and possibly endemic to Timor (*Craterocephalus* sp. nov. found in the Irasiquero River and *Lentipes* sp. nov. found in the Vero River)."

Very little is known of the subsurface fauna of the study area. The only study carried out to date to deliberately investigate part of this fauna is that on bats, mentioned above (EPANZ Services 2004c). This indicates that eleven of 16 bats identified from the area "are likely to be obligate cave roosters … : *Rousettus amplexicaudatus, Rhinolophus canuti, Hipposideros diadema, H. sumba, Eonycteris spelaea, Taphozous* sp., *Rhinolophus celebensis, Hipposideros bicolor,* and all three *Miniopterus* species. Bats were observed in Noi Noi Kuru during the survey but none were captured or identified. (This was one of the caves investigated by the bat survey team.)

During the authors' survey of Noi Noi Kuru, a number of invertebrates were observed, including spiders, cave crickets and a whip-scorpion or scorpion-spider (Figure 26).

Figure 26. A whip-scorpion or scorpion-spider in Noi Noi Kuru. This is an arachnid and member of the Order Amblypygi (or Phrynichida) – a common group in tropical caves. (Identification by Dr. Stefan Eberhard.)

The environmental consultants (EPANZ Services) to the Norwegian group promoting a hydro-electric development in the study area have drawn attention to the need, if the project proceeds to the environmental assessment stage, for "*Possible* assessment of stygofauna and flora within the karstic cave below the Mainina sink hole" and for further bat studies (EPANZ Services 2004a, p. 48). Elsewhere in their report the consultants concede (EPANZ Services 2004a, p. 35) that the dewatering of the karst below the Mainina sinkhole would have "an unknown effect on the so-called stygofauna, which is fauna, that is associated with underground karstic caverns. The extent and nature of such fauna has not been established." In considering possible mitigation measures, the consultants note:

> *It would appear that any assessment of stygofauna would be an extremely specialised task and this would be difficult and probably extremely hazardous if entry to the hole is required. It is possible that this may not be able to be realistically assessed.*

It does not seem to have occurred to the consultants that it may be possible to access the underground aquatic habitat through other, non-waterfilled entrances or to study the stygofauna where the karst drainage rises to the surface. They have not even suggested that any effort be made to locate such points.

2.7 Potential problems associated with the physical environment not addressed by the consultants

2.7.1 Potential problems for tunnelling in karst

The 1989 report barely mentions the possibility of problems for this major tunnelling project arising from the nature of the karstified rocks through which it must pass. In considering geology, ELC-Electroconsult et al. (1989) stated:

> *… the following geological features are of paramount importance for the project, namely:*
>
> - *As a negative effect, the high karstification of the Ira Lalaro depression and its surrounding limestones, which practically impedes a water storage, and limits the civil design to a run of river scheme;*
> - *As a positive effect, the presence of impervious shale which protects the mountain ranges from karstic groundwater intrusions and a competent crystalline limestone which if, as assumed, is not karstified, represents probably a good rock to cross with a power tunnel.*

There seem to be some rather large leaps of faith here, based on little evidence. There is a relatively impervious shale, the Cribas Formation (see Figures. 6 and 27) but there appears to be no reliable information as to its precise interface with the Aitutu Formation (which is largely carbonate rock) deep under the Paitchau Range. The 1:250,000 geological map of the area (Partoyo et al 1978) indicates significant faulting. The major tunnel would run from the sinkhole and pass under the range at a very low gradient. As Figure 27 shows, what it passes through depends on the position of the interface between the Cribas and Aitutu formations. As to whether the Aitutu Formation is karstified or not in this area remains to be discovered.

It is also clear that while the Cribas Formation appears to be impervious, water from the Mainina sinkhole *crosses* it to reach the south coast (as it outcrops on the south side of the range), as shown on Figure 27 and from the limited water tracing information. Either the Cribas Formation is not impervious or there are hydrological routes through it or around it.

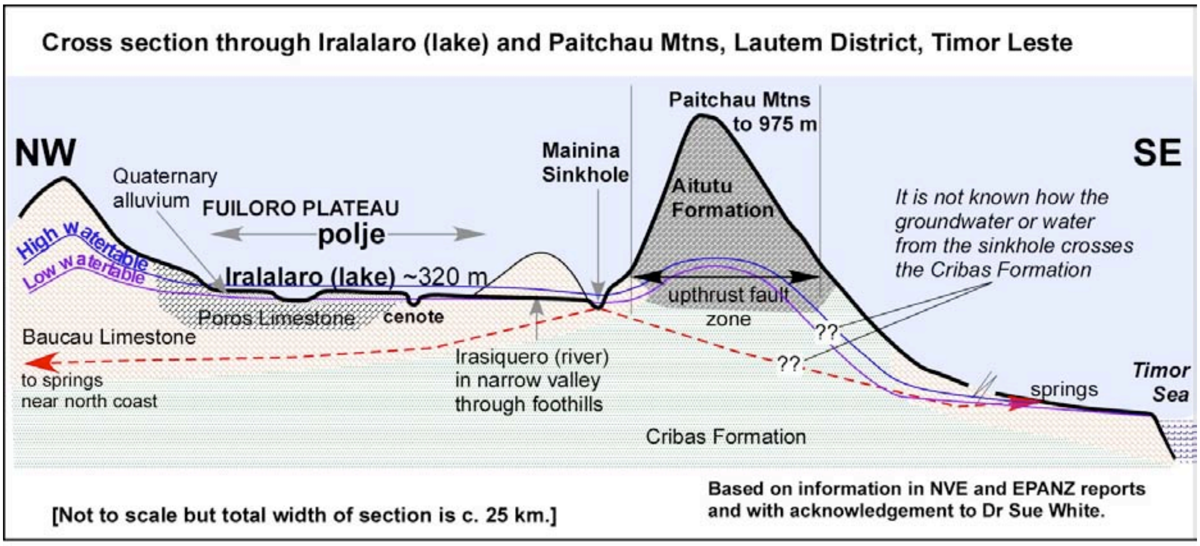

Figure 27. Schematic section through southern side of Timor-Leste in vicinity of Malahara village, showing the Iralalaro Lake and polje, the Paitchau Mountains, the inferred geology and presumed routes taken by underground water.

In recognition of the lack of detailed information, the 1989 report did go on to recommend the carrying out of

> *a comprehensive geological study in order to clarify the stratigraphical sequence, with special interest in the oldest formations … and also to define the tectonic style of the whole area … This study will be the base for new engineering geology investigations …*

To the best of the authors' knowledge such investigations have still not been carried out (though there have been verbal reports of some seismic investigations).

The 1989 study (ELC-Electroconsult et al. 1989) nevertheless concluded:

> *The project does not present specially complex technical problems. The civil construction can be carried out with conventional methods …*

This statement appears to totally dismiss the very real difficulties which tend to be the norm, rather than the exception, when undertaking engineering projects on, and especially under, karst terrain.

The 2004 report does not consider any possible problems relating to tunnelling or carrying out major excavations in karst. The only issue it addresses relating to tunnelling is the disposal of spoil, about which it states:

> *The amount of spoil that may be generated by the project construction and excavation activities may amount to 50,000 m^3. The major source of excavated*

> *material will be from the headrace tunnel, while other spoil will result from other underground facilities that may include an intake tunnel, penstock and powerhouse. …* (EPANZ Services 2004a, p. 41).

While spoil disposal problems are real enough, consideration needs to be given to problems that may arise in creating the spoil, i.e. during tunnelling and excavation.

The glib dismissal of any likely problems in the 1989 study and failure to address it in the 2004 report is in stark contrast to the attitudes of those with experience in karst engineering. Milanović (2000, p. 79) summarises the risks:

> *The nature of karst presents a great variety of risks associated with any kind of human activities. The risk component is unavoidable in spite of very serious and complex investigation programs, including all available investigation methods. Moreover, the risk can not be totally eliminated by increasing the investigative programs. Perhaps it can be minimized to an acceptable level, but never absolutely eliminated.*
>
> *Difficulties and failures in the development of karst terranes generally can be classified as technical and ecological. The technical difficulties and failures are connected with various man-made structures: dams, reservoirs, tunnels and intake structures. The ecological failures are a consequence of various human activities which deteriorate the environment and water quality, deplete water quantity and endanger underground fauna.*

Specifically, in relation to the boring of tunnels, Milanović (2000, p. 84) warns:

> *In underground structures such as tunnel excavation the risk aspect is emphasized, since the evaluation of engineering-geological characteristics of the media is based on expensive investigation works and difficult interpretation where reliability is hard to achieve. In the long and deep tunnels the risk is increased due to limited scope of "point" investigation works (boreholes), while conclusions are mostly based on surface investigations (geological mapping, geophysical works). The presence of large caverns at depths below 100 m is impossible to determine by existing methods from the surface. Moreover, it may present an important problem if tunnel boring machine (TBM) is to be used, particularly if the cavern is filled with clay.*

Excavating tunnels through karst rocks frequently poses problems because of –

(a) large voids in the rock which can make tunnelling difficult or impossible; in some cases delays and costs associated with overcoming such problems have been considerable – Marinos (2001) summarises the problems as:

- *bridging the void, if empty*
- *tunnelling through a geotechnically weak fill material*
- *confronting water inrush associated with mud flow if the void is water bearing and filled partially or totally with earth materials.*

(b) where faults or cavernous zones communicate between a tunnel and the surface, tunnelling can result in collapses into the tunnel and subsidence at the surface;

(c) leaks into the tunnels from karst aquifers – these not only pose a problem for tunnelers but may result in karst springs elsewhere in the system drying up or at least reducing their flow; again, rectification costs can be considerable;

(d) leaks from the tunnels where they are subsequently used to carry water – this can leak out through natural voids, requiring costly concrete linings to be installed.

Milanović (1997) describes the problems of tunnels encountering karst voids as:

- *free space (huge cavern) which should be overcome by filling, bridging or bypassing;*
- *cavity which is masked by cave deposits … It requires serious investigations and sometimes changing of excavation technology and complicated repair work is indispensable;*
- *source of groundwater into the tunnel with a capacity of hundreds, even thousands of litres per second;*
- *non-discovered caverns very close to the tunnel can provoke serious problems during the excavation and during the tunnel operation.*

In his view, the most vulnerable are tunnels for hydro-electric plants as the pressures involved are high.

According to Marinos (2001) –

> *The interaction of tunnelling and mining works with groundwater can be summarized as follows:*
>
> *During construction:*
>
> - *Inflows of water in the underground space, affecting normal construction procedures and possibly induce face and roof stability.*
> - *Sudden inflows associated with specific and localized geological features, e.g. faults, crushed zones, big karstic conduits etc.*
> - *Decline in yields of springs, decrease of groundwater discharge to wells.*
> - *Development of sinkholes in susceptible areas due to piping or internal erosion.*
> - *Unacceptable settlements, where compressible fine-grained soils or heavily fractured rock masses are present, due to the increase of effective stresses by lowering of the groundwater table.*
> - *Temporary contamination of groundwater occurring at lower elevations, by infiltration of polluting substances used for the construction.*
>
> *During operation*
>
> - *Infiltration of used chemically and organically contaminated waters from road or rail tunnels can affect the quality of the groundwater if the tunnels are crossing the non saturated zone.*
> - *Rise of piezometric levels by the obstruction of groundwater flow by lined tunnels; the rise is effective when the tunnel is located at a shallow depth under a shallow water table and can affect the built environment (foundation, basements) and/or mobilize contaminants in case of saturation.*
> - *Influence of the hydrostatic head on the lining of the tunnel.*
> - *Tunnel collapse by wide fluctuation in hydrostatic pressure associated with normal operation of hydraulic unlined tunnels.*

Marinos (2001) concludes:

> *Tunnelling and mining in karst require a thorough hydrogeological knowledge over a broader area. Lack of this knowledge may result in a design which will not be able to face problems or hazards that may occur during construction with probably dramatic consequences on the completion of the operation.*

In the case of the Paitchau Range, even though the underlying Cribas Formation is not significantly karstic, (which may therefore appear to improve the structural stability of the area), this may be of limited benefit. Impermeable beds on, in or under limestone, may actually increase collapse in bedrock voids due to focussing of water flow, which then increases void development (Mylroie 1987).

Marinos (2005) considers the potential problems in more detail.

Many cases of problems of all the above types are documented in the literature – some examples are summarised in Appendix 1.

Common investigations which should be undertaken to minimise potential problems with drilling in karst are outlined by Milanović (2004):

- *detailed geological mapping at the surface,*
- *drilling,*
- *water level monitoring,*
- *geophysical surveys (from the surface and from within the tunnel), and*
- *speleological exploration.*

In the present case none of these has been initiated (except for some sort of seismic survey along the pipe route) and no plan appears to have been drawn up although Adeler et al. (2003, p. 16) did recommend "additional studies on geology and geo-hydrology" – without spelling out what aspects these should concentrate on beyond referring back to similar recommendations in 'the 1989 study' (ELC-Electroconsult et al. 1989).

2.7.2 Karst drainage – the fate of the Mainina water

One of the first points conceded in the 2004 'Environmental Assessment' (EPANZ Services 2004a, p. 1) is that "The fate of this water [that entering the Mainina sinkhole] has not been established". It seems remarkable that any environmental assessment of this project did not rate the answering of this question as a top priority. The 2004 report admits that "much of the information in this [hydrology] section is derived from the ELC-Electroconsult report (1989)"[!] After citing the finding of the 1989 report that tracing had indicated a connection with the Tchino River (at least 25 km to the south-west – see Figure 2), the 2004 report states that its consultants found a better match of *water quality* [not even water chemistry] between the Mainina water and that in the Vero River (about 5 km to the east). These conflicting results are totally inconclusive and one could not even begin to assess the environmental impact of diverting this water if one did not know exactly where it went, conceivably to a number of discharge points, and equally conceivably to different places, or at least at different rates, at different stages of flow.

In a section dealing with "Screening of potential environmental impacts and mitigation measures", the 2004 report concedes that it cannot assess the impact of "dewatering of downstream areas" (EPANZ Services 2004a, p. 35). In relation to effects on possible downstream water supplies, the document states: "It is not known for sure where the flow from the Mainina hole emerges *if in fact it does"* (our emphasis). To suggest that the Mainina water might never resurface seems verging on the irresponsible; though the writer may have been thinking of a submarine rising, which is not impossible. It is admitted, however, that

> *The possible downstream effects include reduced flow to an emergent spring or a watercourse and depending on the location of the source this may have further downstream impacts on both the human and biological systems.*

The best the report can propose is:

> *Should the study proceed, further studies will need to be done to establish with more certainty the fate of the water that enters the Mainina hole.*

As mentioned above, it is locally reported that some dye tracing experiments have subsequently been carried out and that three risings towards the south coast have been identified, together with four towards the *north* coast. The southerly springs (which would have been expected) may cause the proponents little concern in the social context because this coastal area is almost unpopulated, however it is another matter to the north. Unfortunately, the consultants and the Government have so far failed to respond to requests for details of the dye tracing tests and it is not known if any flow times were determined or if there is any quantitative data on flows. Without such details and the construction of a fully documented water budget for the drainage basin (Figure 27 being a first draft) any decision to divert this water to another use would be irresponsible.

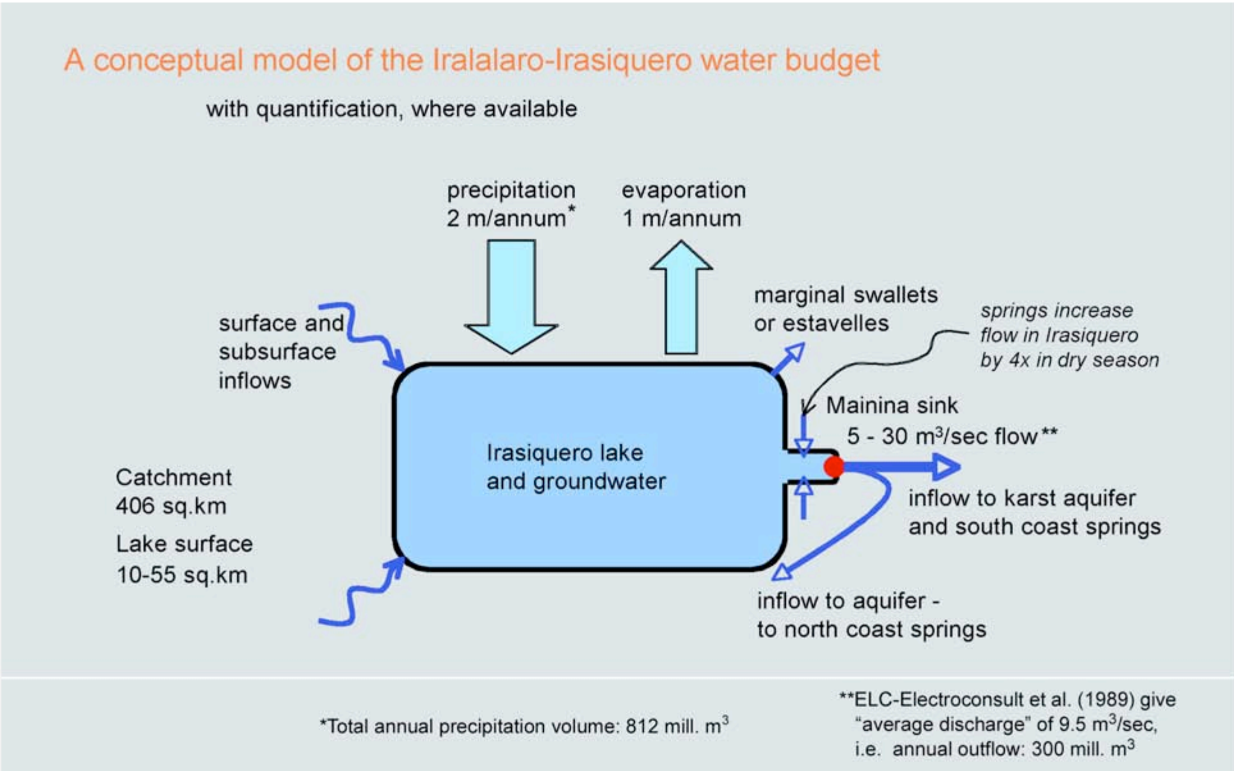

Figure 27. Towards a water budget for the Iralalaro Lake.
Losses to marginal swallets (ponors) are unknown, as are full details of flows into the Mainina sinkhole and the eventual fate of the water.

2.7.3 Potential problems resulting from dewatering karst

The 2004 report acknowledges that the project would have –

> *Possible effects on the structural stability of the karstic system should the flows diminish. Any subsequent collapses that may occur within the system could have other compounding effects with regard to the ability of floodwaters to be carried away via the Mainina karstic route.*

This concern is presumably founded on the problem of collapse induced by dewatering resulting in removal of buoyant support. Ford and Williams (1989, p. 409) observe:

> *In a fully saturated medium, the buoyant force of water is 1 t m^{-3} and if the water table is lowered 30 m, the increase in effective stress on the rocks is 30 t m^{-3}. If unconsolidated overlying materials are affected by such de-watering, compression occurs and the surface subsides.*

Vermeulen and Whitten (1999, p. 68) warn:

> *Excessive extraction of water may cause the drying up of aboveground and underground systems in limestone areas, leading to possible collapse as flooded cavities become filled with air. Small water bodies, which may be inhabited by small, site-endemic fish species and snails, will disappear, and with them the species. Alterations of flow patterns by the construction of dams, water extraction, and flood control in and around limestone areas will profoundly change the limestone environment and lead to the extinction of whole communities. The quantity of water and the availability of nutrients change, … aquatic habitats are destroyed, …*

There have been many well documented cases:

- In the most serious case of collapses caused by deliberate human dewatering of karst, over 25 years of pumping an area of dolomite and dolomitic limestone in South Africa has caused the loss of 38 lives in collapsing sinks and damage to structures amounts to tens of millions of rand (Brink 1984, cited in Ford and Williams 1989).
- White (1988) notes that "many of the sinkholes in Florida, a particularly sinkhole prone area, are a result of groundwater withdrawal and lowering of regional water tables".
- In central Italy in 1989 a sinkhole opened in the Pontina Plain which involved the collapse of 22,000 m^3 of material; its cause was attributed to prolonged overpumping of a karst aquifer; the trigger may have been a small earthquake in the vicinity (Bono 1999).
- Halliday (1998) documented the consequences of dewatering a small karst under part of Honolulu in 1934: new sinkholes developed, several houses 'lurched' and settled, sidewalks cracked and water and gas mains ruptured, 'huge caverns were exposed to view', sea water flowed in from the ocean polluting the groundwater; economic losses are believed to have been considerable.
- In South China, Xiang and Chen (1987) recorded 738 karst ground collapses, involving more than 30,000 pits or sinkholes, of which 66.4% were human-induced, mainly by pumping for water supply and draining mines. They emphasised the impact of sudden withdrawal of water and the relationship between the volume of water removed and the consequent collapse.

The wording of the 2004 report, quoted above, seems to indicate concern about collapse limited to the subsequent capacity of the karst aquifer/conduit system to carry away excess water in time of flood. This view totally ignores the damage to the karst system itself, the destructive consequences for the overlying land (be it gardens, villages or forest) and the further impacts on the groundwater system, including its fauna.

These examples demonstrate the reality of the problem. While the surface consequences of any collapse deep within the Paitchau Range seem unlikely to be significant, the nature of karst drainage is such that it should not be assumed that effects would only be felt along a straight line between the Mainina sinkhole and the springs towards the south coast. If the water also drains to the north, as suggested by the limited water tracing, the watertable underlying the whole region would potentially be affected.

On the other hand, it is documented that the existing flow into the Mainina sinkhole varies significantly throughout the year, from about 5 m^3/sec to 33 m^3/sec, and there is no evidence of this having led to collapse within the karst (although there has been no effort put into finding any). The possibility exists, however, that removing all, or most, of the last 5 m^3/sec and the permanent lowering of water levels could be the trigger, which destabilises the system.

2.7.4 Impact of dewatering on dependent fauna

While groundwater dependant fauna were not even hinted at in the 1989 study, they are at least mentioned in the 2004 one:

> *Spring sites on the Irasiquero contained commonly found amphipod and isopod crustaceans – groups typical of groundwater ecosystems. Thus groundwater below the Mainina sinkhole may harbour a specialist fauna - so-termed ‘stygofauna’* (EPANZ Services 2004a, p. 16).

In considering impacts and possible mitigation measures, the report notes that diversion of the Mainina water away from the karst may have impacts including:

> *An unknown effect on the so-called stygofauna, which is fauna, that is associated with underground karstic caverns. The extent and nature of such fauna has not been established.*

It then goes on to cast doubt on the feasibility of even investigating this fauna:

> *It would appear that any assessment of stygofauna would be an extremely specialised task and this would be difficult and probably extremely hazardous if entry to the hole is required. It is possible that this may not be able to be realistically assessed.* (EPANZ Services 2004a, p. 35)

As a means of mitigating the impacts of dewatering, the report suggests only “the provision of a downstream release that would be sufficient to maintain the health of the systems but at a lower level” without offering any suggestion as to how the ‘downstream release’ might be quantified or timed.

Any study purporting to responsibly consider the environmental impacts of the proposed scheme must properly investigate the stygofauna, assess its extent and significance and propose adequate measures to protect it, or at least propose measures to minimise adverse impacts on it.

3. Social and Political Environment

3.1 Background

Much of Timor-Leste's infrastructure was largely destroyed when the Indonesians were forced to leave in 1999. The electric power generation and distribution infrastructure, which was not destroyed, was dilapidated and suffered from lack of ongoing maintenance. Initial aid programs have repaired the existing generation plant in Dili but there is an obvious need to supplement this with new capacity and to distribute the power beyond Dili. This is what prompts the political response and the investigations of hydroelectric schemes and other possible energy sources to supply the growing economy.

In this section, we only try to address the social and political issues and constraints relevant to our evaluation of the Iralalaro hydro scheme and the more local social impacts in and around Malahara. It is important that development is appropriate.

3.2 History

People have been in Timor-Leste for thousands of years as archaeological studies show (see Section 2.4.2). They belong to a number of distinct ethnic groups and are of Malayo-Polynesian and Melanesian descent. The Portuguese arrived in the 16^{th} century and proceeded to use the island as a trading base and for sandalwood. They largely converted the people to Catholicism. It was not until a declaration of Independence in 1975 after a political revolution in Portugal, that Indonesia invaded and took over East Timor. The people of Timor-Leste did not succeed in gaining their independence until a UN-sponsored agreement in 1999. Most of the infrastructure damage occurred in the lead up to and during the liberation of Timor-Leste from Indonesian rule and the Indonesian supported militias. Free elections were held in 2002 after which the new government assumed responsibility from the United Nations Transitional Administration.

Portuguese and Tetum are the official languages. Indonesian and English are defined as working languages. Tetum is the major language spoken but in the eastern end of the island, Fataluku is the first language of the people.

The current population of Timor-Leste is given as 1,040,880 (July 2005) (2005 CIA World Factbook)..

3.3 Politics and Government

The Government was elected in 2002. There is an elected President and the Government is formed from the elected members of the single house of Parliament. The government has been moving cautiously with much of its decision-making and it is still in the process of building its administrative and governmental institutions. The country is divided into 13 administrative districts. The Iralalaro polje is in the Lautem district. At the village level, an elected headman governs each village. From what we observed these headmen exercise a lot of power and influence and are the mediators of change.

3.4 Economy

East Timor has been a very underdeveloped area for a long time. Indonesian troops and anti-independence militias caused significant damage to the productive economy and infrastructure in 1999. Coffee is the main export crop and there are only a few areas where rice is grown. There is little timber available for harvesting commercially and no economic mineral deposits have been discovered. Most of the rural population have family plots of land, which they use to produce food for themselves and the small amount of excess is traded or sold. Even this level of commerce is severely hampered by road and transport infrastructure. A country-wide electricity supply is needed for economic and social development. This could be either in the form of large schemes and an extensive distribution system or a number of smaller schemes.

There is limited and localised electricity generation and distribution and no interconnected transmission grid for the country. The Dili diesel generators have been repaired since 1999 but they have insufficient capacity and reliability. Other large towns have diesel generators of their own, but reliability remains a problem, e.g. Los Palos has power only available during the day. The cost of diesel for power generation is cited as one of the reasons to examine other options such as hydroelectricity. The diesel cost is about $US8 million annually; about the same as the coffee export income (Ministry of Transport, Communication and Public Works 2004).

Timor-Leste will derive significant royalties (billions of dollars) from off-shore oil and gas deposits. These deposits have been the subject of disagreement between Australia and Timor-Leste for some time, but is now reaching resolution. At the present time none of the development proposals involve processing or bringing oil or gas ashore in Timor-Leste, which the Government desires. Exploration for onshore oil and gas fields is underway, but even if commercial discoveries are made, the development time-frame for these would not solve the current electric generation capacity shortage.

3.5 Malahara and the Hydroelectric Proposal

Land and property ownership is still not resolved either in Dili or in rural areas. Around Malahara there is communal land across the bed of the polje (Iralalaro), which was grassland in August at the time of our visit and mostly used for grazing. Each family has a house and either direct traditional rights to a garden area or occupies a garden area by local agreement. These garden areas are above the high flood levels of Iralalaro and on the lower slopes of the Paitchau mountain range. They are semi-permanent and are not abandoned after a few years as the soil appears to be rich enough for ongoing continued cultivation. The village of Malahara gets its water from karst springs at the edge of the Paitchau Range, as do some of the garden areas. Although the rainfall is high (see Section 2.2), it is concentrated mainly in the December to March wet season, leaving a distinct dry season. Water storage over the dry season has not been a traditional practice.

There are longstanding traditional claims to land on the coast around the Vero River and where it is proposed to build the power station as well as in the vicinity of Mainina Sink (McWilliam 2003). These claims go back to Portuguese times when the Portuguese Colonial Government moved people into villages. Further consolidation occurred under the Indonesians after 1975 with a further forced move into larger villages. There is clear evidence of abandoned gardens from these previous times. The garden areas are marked by stone walls and the evidence of residual plantings such as palms and bananas. As well, there is traditional hunting in the Paitchau Mountains. These traditional land claims should be addressed and resolved before either the hydroelectric scheme or the “National Park” proposal (see Section 4.1) is acted upon.

The local economy in Malahara is based on semi-subsistence garden agriculture supplemented with grazing. There are cattle, buffalo, goats, horses, pigs and poultry. Gardens are planted with staples such as manioc, corn, plantain, banana, pumpkins and coconut plus a variety of other vegetables. Some excess production is for barter or sale. There is a little timber harvesting for local use. There are only a couple of locally owned trucks, a few motorcycles and not many bicycles. The road access from Los Palos is poor and obviously cut at times during the wet season (December-March).

Since Independence there has been a population “explosion” and in Malahara we were informed that there were about 29 family groups comprising a population of about 1,000. It was evident that about 40% of these were under 18 years old.

We refer above to the agrarian economy, which is dependent on the cycle of rise and fall of the lake level as the water in the Iralalaro polje responds to the seasons. The population in Malahara and the several villages on the north side of the lake are dependent on the lake and polje. However, the polje extends west to the vicinity of Los Palos and its much larger population. It is the total catchment of the polje and the people living within it, which may be affected if the hydro-electric scheme proceeds, and if over time the water table is significantly lowered.

The Malahara village has an excellent water supply currently piped to a tank from karst springs in the Baucau Limestone terrace behind the village. This situation may apply to other villages close to such springs. Lowering of the water table could seriously endanger that supply and in areas where the water table is low, e.g Tutuala village, water supplies are already difficult. This has serious implications for other economic development such as tourism.

At the present time there does not appear to be an excess of ”unemployed” labour in the Malahara village and surrounds. The community would obviously welcome a new source of employment and income into the area, but this might come at the expense of work in the gardens resulting in dependence on imported food. The existing infrastructure and supply lines do not currently support importation of more than rice and a few other staples at the present time and short term employment for some during the construction phase of a hydro-electric scheme could prove very disruptive to the community unless these issues are handled sensitively.

The local community appears divided about the hydro-electric scheme. Some perceive that the scheme will bring development and jobs whilst others perceive problems. The Malahara community certainly views tourism as contributing to its future. Several people were on scholarships learning languages and studying to take up roles in the tourist industry. Tutuala is already experiencing some nature-based tourism and has a certain amount of associated infrastructure such as accommodation, vehicles and access to the coast and Jaco Island for diving. In Malahara, there is very real opportunity to provide infrastructure for a sustainable nature-based tourism industry. Such nature-based tourism could include walking, horse riding, bird watching and adventure caving. The tourism sector is in very real need of coordination from Dili. There is a serious shortage of accommodation, transport and other related facilities.

4. Management of the Karst

4.1 Protected Area issues

Proposals to provide protection to the special environmental values of the Iralalaro-Paitchau area are long-standing. The situation is well summarised by McWilliam (2003):

> *The district of Lautem contains one of the finest contiguous blocks of dense lowland tropical and monsoon forest on the island of Timor. Covering an area of some 300 square kilometres and incorporating the heavily forested Paichao range of low mountains (to 925 m), this forest zone extends from the eastern extremity of East Timor (Jaco Island) in a narrow band (7-10 km) westwards following the unpopulated southern coastal hinterland. As a region with great ecological value and complex bio-diversity, the area has long been accorded special significance. During the period of Indonesian rule in East Timor (1975-1999), much of the forested zone was classified as a natural conservation reserve (*kawasan suaka alam*). This category of protection, on paper at least, prohibited logging and other forms of extractive activity within its boundaries. Subsequently, under the United Nations Transitional Administration in East Timor (UNTAET) from 1999, the area was re-classified and declared as one of 15 so-called, 'Protected Wild Areas' (UNTAET Regulation 19/2000). This sentiment and commitment to recognize and conserve the heritage and resources of the Tutuala-Paichao Reserve, has continued under the new government of an independent East Timor. In 2002, through its Directorate of Forestry, the government initiated a program to formally demarcate and legislate the area as the country's first 'National Park'.*

It appears that more recently, particularly in view of established rights within the area, the Government has sought to establish a mutually agreed framework for management with local communities bordering the forest area and is now considering a reserve category more in accord with IUCN's Category V (IUCN 1994) which would permit a range of traditional practices to continue (McWilliam 2003). The area believed to be under consideration for reservation is shaded green on Figure 2. Category V is unique among IUCN's protected area categories –

> *by making the core idea the maintenance of environmental and cultural values where there is a direct interaction between people and nature. The focus of management of Category V areas is not on nature conservation* per se, *but about guiding human processes so that the area and its resources are protected, managed and capable of evolving in a sustainable way - and natural and cultural values are thereby maintained and enhanced* (Phillips 2002).

This is not to say that the whole area should be actively managed to encourage or facilitate practices which would degrade natural qualities. Particularly fine examples of natural features within the Category V reserve could be declared as separate, more highly protected areas (eg Category 1a Strict Nature Reserve) or, more simply, some parts of the reserve could be zoned for a limited range of uses so as to favour nature conservation. This might particularly apply in the present case to the more rugged parts of the mountains or to parts of the south coast which have not been inhabited for many years. This is not to imply that development of the hydro-electric scheme elsewhere in the proposed reserve would be a compatible use. On the contrary, the proposed scheme is incompatible with the maintenance of many of the natural and cultural values which give the area its special significance.

In keeping with the intent of this type of protected area, management should be shared with the local community, not simply imposed by a central government agency. This is particularly so, given the history of this place and the experiences that its inhabitants have suffered at the hands of ‘government’. Nevertheless, a concerted program to inform the local community with regard to aspects of environmental management which may not be adequately addressed by traditional practices, (and karst will probably be one of these), will no doubt be necessary if the sustainable management of this outstanding area is to be assured.

4.2. Specific karst management issues

Caves and karst are significant and valued worldwide for many factors. The surface karst features are often striking because of the higher rock solubility in limestone and caves are a further development of this. Caves have values for their form, their beauty, their contents and the habitats they provide: sediments, bone deposits, archaeological material and biota such as specialized invertebrates and bats. Cave and karst areas are valuable for this geodiversity and biodiversity in their own right. They often play a role in local history and folklore.

Cave contents generally include soils or gravels and calcite deposits that can help elucidate past climatic conditions. Caves can also have animal bone deposits of importance, some of which are extinct species. In many instances caves have been or are used in for shelter, ceremony or artistic expression. Equally, many bat species have evolved to use the protected environment of caves for shelter. Further karst related research is necessary to understand the potential of the area.

Caves have always interested people. This is why humans have used them for various purposes such as shelter, food storage, burial sites, religious observance and these past uses leave behind a valuable archaeological record. Human occupation deposits or artworks in caves are often well preserved, allowing archaeologists to piece together past cultures. Cave invertebrates are often specialised and may include many species unique to a cave or cave area. This is because they have adapted and evolved as they became isolated from their counterparts above ground. These cave-adapted animals may include colourless or blind invertebrate species known as troglobites, as well as the much better known cave roosting bats. Many caves have a lot of beautiful decoration, termed ‘speleothems’. Such decoration is usually calcite and occurs as stalactites, stalagmites, shawls and flowstone, all of which may be fragile or subject to damage from muddy hands or boots. Before developing a cave for adventure tourism a careful assessment should be made of existing cave values and the contents, to ensure that these are respected and protected. Changes in use of caves and karst need to be done sensitively if the intrinsic values of the cave, its contents and biota are to be protected. In many cases, damage to a cave can be avoided or minimised by restricting access to a marked track.

A full inventory of the caves and other karst features of the region (especially pits, dolines, sinks, springs and dry stream courses) should be undertaken without delay as a first step in analysing the karst networks and connections – and their habitat, ecological, archaeological, palaeontological and other values. Such an inventory would serve as the basis on which plans could be developed for the proper management of these resources.

A key element in the responsible management of karst is the protection of the water sources and drainage networks which are fundamental to the formation, development and maintenance of the karst system and its associated fauna (and, to some extent, flora). This groundwater and its sources can be "out of sight and out of mind". The groundwater system in the Ira Lalaro polje has an associated stygofauna. This was only vaguely alluded to in the scoping studies (EPANZ Services 2004a). Studies of these creatures and their ecology need to cover all seasons through several years because the groundwater and lake levels will fluctuate between seasons and between years. Without further systematic studies of the fauna in the lake and the Irasiquero River and the associated groundwater stygofauna, it is not possible to assess how the stygofauna and associated ecosystems would respond. Certainly there could be effects on the top-level predators in the system: turtles, crocodiles and the undescribed fish species found in the initial evaluations. Such further studies are needed and are warranted as only the briefest of studies of the surface fauna have been conducted to date. At the very least expert consultants should be engaged immediately to investigate and evaluate the stygofauna and its ecosystem, to provide baseline data for later assessment.

There is a sizeable local human population, which derives its livelihood from agriculture in and around the lake. As discussed in Section 2, there is a serious concern that if the hydroelectric power scheme is built, then over time the groundwater level in the polje may be systematically and permanently lowered. If this were to occur then the livelihood of the Malahara community and other communities dependent on the lake, the groundwater as well as the associated ecosystem would be jeopardised. A groundwater system such as that which exists in this polje and the surrounding catchments, and downstream areas, can be subject to pollution problems that can affect beneficial uses of the groundwater. Faecal pollution at the present time is probably the main risk but indiscriminate use of agricultural chemicals or fertilisers could have detrimental effects also.

4.3 Ecotourism

The communities at the eastern end of Timor-Leste have only very recently begun to experience tourism-related visitor pressure. Tutuala now has some guesthouses and places where one can buy meals. Close to Tutuala is Valu Beach which provides access to Jaco Island. There is some capability to service recreational diving. Local guides will certainly take visitors to the caves Lene Hara Cave and Ile Kéré Kéré referred to in Section 2.4.2 and there are established walkways, from Indonesian times, to these sites.

The Malahara community currently has virtually no accommodation and eating premises and regardless of the hydroelectric scheme would be well advised to plan for a demand for such facilities. The natural attributes of Malahara lend themselves to nature-based tourism.

There are many possibilities for nature-based tourism such as birdwatching, walking, horseriding, adventure caving and more serious trekking objectives.

The cave we were shown, Noi Noi Kuru, would lend itself to adventure caving. No doubt there are others in the vicinity and we were told of other caves towards the coast. At least some of these have known associations with Fretilin activities as caves were used during the guerrilla campaign directed at the Indonesian occupiers. The Australian “Sparrow Force” activities in 1942 during the Second World War used a route from the coast over the Paitchau Mountain Range (www.geocities.com/dutcheastindies/east_timor.html). This history is known locally and needs further research. This is important because it is the sort of history which can greatly enrich tourist activities. For instance, Papua New Guinea receives many visitors to the Kokoda Trail along the route of one of the most important land battles between the Japanese and Australians during the Second World War. In Cuba there is a cave which formed the Western Army Headquarters from which Che Guevara controlled army activities when Cuba was under threat during the Bay of Pigs confrontation with the USA. The cave now forms a very successful part of the tourist itinerary for both Cubans and other visitors.

Protected area status of the polje and the forest and mountain area down to the coast would enhance the prospects for successful nature-based tourist operations. Planning for ecotourism needs to encompass the infrastructure facilities to support such tourism in and around Malahara and Tutuala. The caves used for adventure tourism deserve closer assessment than we were able to achieve during our visit. This should particularly assess occupation evidence, habitats of cave-dwelling bats, cave-dwelling biota and other sensitive areas e.g. sediments. Other aspects of adventure-cave tourist operations are to establish them with trained guides and have a “minimum impact objective”. Judicious track marking at an early stage can assure this.

We very firmly believe that ecotourism needs to be developed sensitively and local communities should be heavily involved in such activities. There are very good models we have seen in relatively remote areas, e.g. Brazil, where local control of activities ensures that money spent by tourists stays in the local economy supporting a sustainable basis on which the whole community benefits from the availability of jobs and money spent locally. Strategic planning needs to be undertaken if Malahara and other similar villages are to become ecotourist destinations. Recently villages close to the Kokoda Trail in PNG have needed assistance in such planning to manage the increase in numbers and issues such as accommodation development, littering, adequate payments for porters, issues about porter carrying weights and provisioning.

We are aware of reservations in the Malahara community about both the hydroelectric scheme proposal and equally about developments which tourism might bring. Only by community involvement in these developments will all parts of the community benefit. At the present time the Malahara community will struggle to sustain and benefit from a hydroelectric scheme development and is equally ill-prepared to provide for an ecotourism “boom”. The Malahara community was interested in the revenue and jobs but understandably seems very ambivalent about the intrusion that such development would bring.

4.4. Research

The Iralalaro area has excellent potential for interesting and significant research. The area has had little research except perhaps archaeological work and the biological surveys associated with the hydroelectric proposal.

There is potential for significant research in the earth science area such as karst and general geology. Research into the landscape evolution is being undertaken elsewhere in East Timor by geologists from the University of Melbourne under Professor M. Sandiford, but none is occurring this far east. This group has little interest or experience in karst geology but we see great opportunity for research into understanding karst in tropical areas of Australasia and the role karst has in landscape evolution in recently uplifted areas.

The understanding of karst and its relation to groundwater is fundamental to the future management and appropriate development of this part of Timor-Leste. A thorough understanding of the hydrological relationships of the system would assist in ensuring the sustainability of existing communities and in assessing the suitability of proposed developments.

5. Conclusions

The authors have some very grave concerns about the viability and the impacts of the proposed Iralalaro hydro-electric scheme. Based on the available reports, a brief site visit, their understanding of karst and research of the literature, it appears that there are serious gaps in the site studies and serious limitations on the understanding of the area by the consultants designing the scheme. The matters of concern have been addressed in the preceding report.

In conclusion, the scheme, in so far as the authors have been able to understand it, appears to have a number of serious limitations which, unless they are addressed, could seriously undermine the scheme's viability, or at least cause significant cost overruns.

1. The karst has not been subjected to a thorough and detailed study by experts in this specialised field and the implications of the karstic nature of the terrain appear not to have been adequately appreciated.

Despite several concerns being raised in the various feasibility studies in light of the karstic nature of the area, no study of the karst itself has been undertaken by karst specialists. As a result, ill-informed and possibly inaccurate statements about the karst have been put forward as authoritative (see Section 2.4). Symptomatic of this shortcoming is the fact that the lake on which the whole future of the scheme depends was not identified as being within a large and significant *polje*, the drainage issues associated with this have not been addressed and no attempt has been made to compile a quantified water budget for the whole system. Whilst important and interesting environmental studies on birds, bats and surface-water aquatic biota were undertaken, these are of less significance to the viability of the proposal as a hydroelectric scheme than the karst and the system's water budget. Furthermore, no attempt has been made to study the likely stygofauna which would be absolutely dependent upon the underground hydrological system proposed to be deprived of its primary inputs.

A related issue (see sections 2.3 and 2.4) is that the geology of this part of Timor-Leste is poorly understood and the geological maps are not of high accuracy. For example, the impervious shale is not mapped with any accuracy and the crystalline limestone is assumed to be non-karstic. Until detailed mapping is undertaken care needs to be taken in making engineering assumptions based on such limited geological knowledge.

A full inventory of the caves and other karst features of the region should be undertaken without delay as a first step in analysing the karst geology and hydrogeology (see sections 2.4, 4.2). The karst geological, ecological, archaeological, and palaeontological values can then be also assessed. Such an inventory would serve as the basis on which sustainable resource management can be based.

2. The cost of the scheme may have been seriously underestimated.

As a result of this limited attention to the karst, the cost of carrying out the proposed engineering works and of operating in karstic terrain has probably been seriously underestimated. Karst terrain is notoriously difficult to undertake engineering works in and there are many examples of such problems being underestimated in previous major projects.

It is not acceptable, were the project to proceed on current cost estimates and later be found to be far more expensive, for the consultants to claim that they could not have anticipated the extra costs. The high cost of construction in tropical karst terrain is well documented and justifies far more detailed site investigations than have been undertaken or appear to be contemplated in this case before cost estimates are finalised. It would be a serious issue if any case could be made to support any suggestion that potential problems had been avoided or ignored in order to minimize initial cost estimates.

3. Risks and costs of drilling and tunnelling in karstic terrain are probably underestimated and not given the detailed consideration they deserve.

As documented in Section 2.7.1 there is a serious lack of understanding of how difficult it is to anticipate the conditions for underground drilling in karstic terrain. The assumption that the limestones of the Paitchau Mountains are not very karstified is at best unproven. Very little investigation has been initiated (apparently there have been some seismic tests) and no detailed studies on geology and hydrogeology have been undertaken. It is essential for these studies to be undertaken before major design work is finalised. The common investigations undertaken to minimise potential problems when drilling in karstic terrain are detailed geological mapping at the surface, drilling, water level monitoring, geophysical surveys (from the surface and progressively from within the tunnel), and speleological exploration. Some of these should have been completed by this stage but as they have not they should be undertaken as soon as possible.

4. Risks and costs of dewatering the karst have neither been fully understood nor properly addressed.

As discussed in Sections 2.7.3 and 2.7.4, despite some minor comment in the Scoping Report (EPANZ 2004a) that the hydrogeology of the Mainina Sinkhole is not well understood and that the fate of the water has not been established, few if any further studies appear to have been initiated. To base a major hydroelectric scheme on so little data on an area whose problems of remoteness are compounded by the complexities of a karstic system could have serious consequences.

As the water entering the sinkhole flows from the polje lake it is augmented from the groundwater and is then returned to the groundwater. The short-term and incomplete hydrological data (particularly relating to the flow of the Irasiquero) appears an insufficient base on which to plan a major hydroelectric scheme.

If the regional groundwater aquifers were to be seriously depleted over the next few decades as a result of the scheme, long-term detrimental effects would likely be experienced in the whole area east of Los Palos

5. Water Budget issues.

No water budget has been calculated for the area (see Section 2.7.2). Although water budgets in karstic areas are difficult to calculate and may be of low accuracy, the fact that one has not even been attempted in this case is somewhat surprising. Coupled with the lack of understanding of the hydrogeology of the area, the lack of any form of water budget brings into question the basis for assuming the viability of the scheme over time.

6. Issues relating to ecotourism.

As outlined in Section 4.3, while ecotourism potential undoubtedly exists in the area, ecotourism is unlikely to benefit from the proposed hydro scheme, as suggested in the Scoping Report (APANZ, 2004a). Rather the potential relates to the mountains, forests, karst, caves, wildlife and the history/prehistory of the area. The hydro scheme could damage precisely those features most likely to attract adventure tourists, and so put at risk the development of tourism in the region.

7. Problems relating to protected area potential.

Proposals to provide protection to the special environmental values of the Iralalaro-Paitchau area are of long standing. The proposed hydro scheme is incompatible with the maintenance of many of the natural and cultural values, which give the area its special significance (See Section 4.1).

As well as assuring protected area status for the forest to coast area, there is a case for similar protection for the Iralalaro polje, the subterranean wetlands and their associated ecosystems. Further investigation is needed into the possibility of having the area protected under the Ramsar convention.

8. Lack of understanding of local infrastructure whilst selling the scheme as a potential employer.

The people living closest to the proposed scheme appear ambivalent about the proposed benefits (see Section 3.5). The assumption that the area would be able to provide sufficient labour is dubious. If sufficient labour (with the necessary skills) cannot be recruited locally, the issues of importing labour and providing them with housing, food and water have to be addressed. There is very limited infrastructure in the area and the existing reports do not appear to address such potential problems.

Overall, there appears to have been a serious tendency to ignore, or at least underestimate, potentially difficult problems in the documentation on the project to which the authors have been able to gain access. If major problems occur they will need to be addressed and they have the potential to significantly increase the cost of the scheme. Once Timor-Leste commits to the scheme it will not be able to withdraw if significant cost-overruns occur; it could find itself having to raise whatever additional costs arise.

The authors believe there are serious questions as to the ability of the proposed scheme to provide the claimed electricity output in perpetuity at the currently estimated costs and with the suggested low levels of environmental impact. The additional studies proposed would increase the reliability of information (especially in relation to karst geology and hydrology), and hence of cost estimates, and would vastly improve the ability of those interested to assess the true environmental impacts.

Glossary

a.s.l. Above sea level – the altitude of a point expressed as the vertical distance above mean sea level.

Allochthonous Said of material originating from a different locality than the one in which it has been deposited (www.spelogenesis.info/glossary).

Allogenic Formed or generated elsewhere, usually at a distant place (www.spelogenesis.info/glossary)

Alluvium A general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semi-sorted sediment in the bed of the stream or on its floodplain or delta or as a cone or fan at the base of a mountain slope (www.spelogenesis.info/glossary)

Aquaclude A formation, which, although porous and capable of storing water, does not transmit it at rates sufficient to furnish an appreciable supply for a well or spring. (www.spelogenesis.info/glossary).

Aquifer A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs; a ground-water reservoir; pervious rock that is completely saturated and will yield water to a well or spring (www.spelogenesis.info/glossary).

Aragonite A mineral composed of calcium carbonate, $CaCO_3$, like calcite but differing in crystal form; an unstable orthorhombic carbonate mineral (www.spelogenesis.info/glossary).

Authigenic Formed or generated in the same place as deposited (www.spelogenesis.info/glossary)

B.P. Literally means [years] "before present"; in fact, archaeologists have chosen "present" as 1950.

Blind Valley A valley, which ends at its lower point in a ridge or wall of limestone. It has (or had) either a perennial or intermittent stream flow that escapes underground at the lowest point (Jennings, 1985).

Calcarenite A carbonate rock/ limestone that consists predominantly (>50%) of sand sized calcite (or dolomite) particles. Many of the particles are the angular or degraded fragments of fossil shells (www.spelogenesis.info/glossary).

Calcilutite A limestone or dolomite made up of calcareous rock flour, the composition of which is typically nonsiliceous, though many calcilutites have an intermixture of clayey material – or – a calcium carbonate rock made up of grains or crystals with an average diameter less than 1/16 mm (American Geological Institute *Dictionary of Geological Terms*; Dolphin Books, NY 1962).

Calcite The commonest calcium carbonate ($CaCO_3$) mineral and the main constituent of limestone, with different crystal forms in the rhombohedral subsystem (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm)

Cenote Steep or vertical sided collapse doline floored by a lake whose surface is at the regional water table. The term originates from the many cenotes in the low karst plateau of Mexico's Yucatan, but has been applied to flooded dolines in Florida and elsewhere (www.spelogenesis.info/glossary).

Cliff-foot cave Cave developed at the base of a cliff, often related to higher water tables and or lakes.

Competent When referring to rock, strong and able to transmit compressive force further than a weak **incompetent** rock formation (Lapidus, D.F. *Collins Dictionary of Geology and Geophysics;* HarperCollins, Glasgow 1990).

Crustal instability Instability of the surface crust of the earth. Tectonic movement of the earth's crust will result in earthquakes being experienced in areas affected by crustal instability (Lapidus, D.F. *Collins Dictionary of Geology and Geophysics;* HarperCollins, Glasgow 1990).

Dewatering Process of removing water from rock or sediment.

Disrupted drainage Drainage pattern characterised by irregular stream courses due to underground capture of streams in karst areas. Other causes of disrupted drainage depend on the particular geology of an area e.g. volcanic flows also result in disrupted drainage

	(Lapidus, D.F. *Collins Dictionary of Geology and Geophysics;* HarperCollins, Glasgow 1990).
Doline	A closed depression draining underground in karst, of simple but variable form, e.g. cylindrical, conical, bowl- or dish-shaped. From a few to many hundreds of metres in dimensions (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm).
Epiphreatic	Referring to water moving with some speed in the top of the phreatic zone or in the zone liable to be temporarily in flood time part of the phreatic zone (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm).
Estavelle	An intermittent resurgence or exsurgence, active only in wet seasons. May act alternatively as a swallow hole and as a rising according to ground-water conditions (www.spelogenesis.info/glossary).
Exsurgence	A spring fed only by percolation water (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm).
Fault	A fracture separating two parts of a once continuous rock body with relative movement along the fault plane (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm).
Flowstone	Deposits of calcium carbonate, gypsum, and other mineral matter which have accumulated on the walls or floors of caves at places where water trickles or flows over the rock; layered deposits of calcium carbonate precipitated on rocks from water trickling over them (www.spelogenesis.info/glossary).
Flysch	A sedimentary deposit typically consisting of a thick sequence of interbedded marine sandstones, marls, shales and clay deposits deposited by turbidity currents similar to those of the European Alps (Lapidus, D.F. *Collins Dictionary of Geology and Geophysics;* HarperCollins, Glasgow 1990).
Fold	A bend in a geologic stratum (bed) with two flanks, often in anticlinal and synclinal sequence (www.spelogenesis.info/glossary).
Formation	The fundamental unit in rock-stratigraphic classification, consisting of a distinctive mappable body of rock (www.spelogenesis.info/glossary). This word is also used to refer collectively to stalactites, flowstone and other cave deposits but ‘speleothem’ or ‘decoration’ are preferred.
Groundwater	Phreatic water; water stored in aquifers.
GWh	Gigawatt-hour: a unit of energy, equivalent to 10^9 (one thousand million) watts of power expended for one hour.
Halocline	A locally steep salinity gradient along the interface between fresh groundwater and saline ground-water, such as is found at the base of the freshwater lens common beneath many limestone islands in the tropics. Water mixing and microbial activity are important influences on dissolution along the halocline, as shown for instance in blue holes (www.spelogenesis.info/glossary).
Joint	A planar or gently-curving crack separating two parts of once continuous rock without relative movement along its plane (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm).
Kamenitza	A small depression (up to a few meters in diameter and several centimetres deep) in a level calcareous surface, enlarged by the solution effect of water collecting between slight undulations. It is developed vertically at first by stagnant water; the steep sides thus evolved then induce the flow of water, which flutes the slope and so eventually widens the basin. Sediments and low orders of plant life frequently collect on the even floor, the latter aiding further solution by reactivating the pH of the water. (www.spelogenesis.info/glossary).
Karren	The minor forms of karst due to solution of rock on the surface or underground (Australian Speleological Fedn Inc: http://www.caves.org.au/i_terminology.htm).
Karst	Karst is terrain with distinctive hydrology and landforms arising from the combination of high rock solubility and well-developed solution channel (secondary) porosity underground (Ford, 2004).
Lacustrine	Deposited under freshwater lake conditions, pertaining to lake conditions.

Limestone A sedimentary rock consisting mainly of calcium carbonate, $CaC0_3$. The rock must contain at least 50% calcium carbonate to be termed limestone (Lapidus, D.F. *Collins Dictionary of Geology and Geophysics;* HarperCollins, Glasgow 1990).

Lithology The physical characteristic of a rock, including composition, grain size, texture, degree of cementation (or lithification) and structure, that determine the rock type; the physical properties and aspect of a rock (www.spelogenesis.info/glossary).

Ma Internationally accepted abbreviation for million years, commonly applied to measurements of geological time. This abbreviation is currently used in preference to My (www.spelogenesis.info/glossary).

Meteoric water Water recently involved in atmospheric circulation e.g. rainfall (www.spelogenesis.info/glossary).

Mixing corrasion (Mischungskorrosion) Dissolution of calcite (and hence of limestone) by ground water that is derived from the mixing of two different waters that were originally saturated with carbon dioxide but had reached saturation under differing carbon dioxide partial pressures. The resultant mixture is under saturated and capable of further calcite dissolution, because the relationship between calcite solubility and carbon dioxide partial pressure is non-linear (www.spelogenesis.info/glossary).

MW Megawatt – one million watts of power.

Palynology The study of pollen and spores, and their dissemination. Ancient pollens are useful in certain stratigraphic and palaeo-ecological studies (Lapidus, D .F. *Collins Dictionary of Geology and Geophysics;* HarperCollins, Glasgow 1990).

Permeability The property of rock or soil permitting water to pass through it. Primary permeability depends on interconnecting pores between the grains of the material. Secondary permeability depends on solutional widening of joints and bedding planes and on other solution cavities in the rock (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm).

Phreatic Zone Zone where voids in the rock are completely filled with water (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm).

Phreatic Pertaining to water in the zone of saturation, i.e. below the watertable. Water below the level at which all voids in the rock are completely filled with water (Australian Speleological Fed'n Inc: http://www.caves.org.au/i_terminology.htm).

Polje A large, flat floored enclosed depressions in karst terrain associated with the input or throughput of water. Hydrologically they develop close to the local water table; plains develop rather than deep valleys because lateral fluvial planation (corrosion and corrasion) and deposition processes are more important than incision (Ford and Williams 1989). Polje signifies the flat-bottomed lands of closed basins, which may extend over large areas, as much as 1,000 km^2.

Porosity The property of rock or soil of having small voids between the constituent particles. The voids may not interconnect (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm)

Seismic Pertaining to a naturally or artificially induced earthquake or earth vibration (Lapidus, D .F. *Collins Dictionary of Geology and Geophysics;* HarperCollins, Glasgow 1990).

Speleothem Any of a range of secondary mineral deposits formed in caves, most commonly composed of calcite (calcium carbonate); includes stalactite, straw (stalactite), stalagmite, column, helictite and flowstone (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm).

Spongework A complex of irregular, inter-connecting cavities intricately perforating the rock. The cavities may range from a few centimetres to more than a metre across (Australian Speleological Fed'n Inc: http://www.caves.org.au/i_terminology.htm).

Stalactite A speleothem hanging downwards from a roof or wall, of cylindrical or conical form, usually with a central hollow tube (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm).

Stygofauna Aquatic subterranean animals found in groundwater systems.

Swallet A place where water disappears underground in a limestone region. A swallow hole generally implies water loss in a closed depression or blind valley, whereas a swallet

	may refer to water loss into alluvium at a streambed, even though there is no depression (www.spelogenesis.info/glossary).
Tectonic	Pertaining to the structure of the earth's crust; particularly referring to the forces or conditions within the earth that cause movements of the crust such as earthquakes, folds and faults (Lapidus, D .F. *Collins Dictionary of Geology and Geophysics;* HarperCollins, Glasgow 1990).
Terrane	A rock or group of rocks together with the area of outcrop. (Lapidus, D .F. *Collins Dictionary of Geology and Geophysics;* HarperCollins, Glasgow 1990).
Transmissivity	The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Though spoken of as a property of the aquifer, it embodies the saturated thickness and the properties of the contained liquid as well. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths (www.spelogenesis.info/glossary).
Unconformity	A fossil land surface representing the absence of a sequence of sediments, unconformable adjective describing sediments deposited over an unconformity (www.spelogenesis.info/glossary).
Vadose	Pertaining to the aerated zone immediately above the watertable, percolation water (Aust. Speleol. Fed'n Inc: http://www.caves.org.au/i_terminology.htm).
Vadose Zone	The zone where voids in the rock are partly filled with air and through which water descends under gravity. When discussing a karst setting, it is preferable to use the term, vadose zone, so as to avoid confusion regarding chemical saturation. Synonym: unsaturated zone (www.spelogenesis.info/glossary).
Vug	A small cavity in rock usually lined with crystals. Adjective, vuggy (www.spelogenesis.info/glossary).
Water Budget	The quantitative accounting of water volumes involved in the hydrologic cycle (www.spelogenesis.info/glossary).
Water Table	The surface between phreatic water that completely fills voids in the rock, and ground air, which partially fills higher voids (Australian Speleological Federation Inc: http://www.caves.org.au/i_terminology.htm).

Geological Time Scale

ERAS	PERIODS	(and Epochs)	AGE (Beginning)
CAINOZOIC	QUATERNARY	Holocene (Recent)	10000 years
		Pleistocene	1.8 Ma
	TERTIARY	Pliocene	5 Ma
		Miocene	24 Ma
		Oligocene	34 Ma
		Eocene	55 Ma
		Palaeocene	65 Ma
MESOZOIC	CRETACEOUS		141 Ma
	JURASSIC		205 Ma
	TRIASSIC		215 Ma
PALAEOZOIC	PERMIAN		298 Ma
	CARBONIFEROUS		354 Ma
	DEVONIAN		410 Ma
	SILURIAN		434 Ma
	ORDOVICIAN		490 Ma
	CAMBRIAN		545 Ma
	EDICARIAN		620 Ma

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APPENDIX 1:

Some case histories of problems of tunnelling in karst

Ford and Williams (1989, p. 535) note that "Long tunnels in mountainous country may start in the vadose zone at each end but pass into a transient zone, or even a steady state phreatic zone, in their central parts". They state that "Modern practice is to drill a 360° array of grouting holes forward horizontally, then blast out and seal a section of tunnel inside this completed grout curtain. This largely deals with the hazard of catastrophic inrush i.e. a flooded cavity should be first encountered by a narrow bore drill hole that can be sealed off quickly". In the case of an 8 m diameter 600 m long tunnel through corallian limestone to provide cooling water for an atomic power station in Ontario, Canada, grouting forward was done in 20 m sections and the tunnel was cut in 8 m sections so that there was a 60% overlap of grout curtains. When a cavity was encountered that was too large to grout, it was sealed off and the tunnel was diverted around it – at substantial extra cost.

According to Marinos (2001), when tunnelling under large limestone massifs: "The potential of coming across large cavities at great depths (more than several hundreds of meters) seems to be limited. However, small active conduits have been reported in a case in France described by Petiteville and Toulemont (1974 cited in Calembert, 1975) where such conduits were found at a depth of about 1000 m."

Marinos (2001) describes the construction of the Giona tunnel for the Mornos-Athens water supply aqueduct. (This case is quoted at length as it appears to bear some similarities to the Iralalaro-Paitchau situation.) The tunnel traverses Giona Mountain for 14.6 km, parallel to the coast, at an altitude of 377 m, beneath a cover of 1700 m, and with the central section 14-20 km from the coast of the Corinthian Gulf, where the groundwaters of the mountain are discharged through coastal springs. The designers thought the tunnel would pass above the water table "due to the gentle hydraulic gradient expected for such a karstic environment" (Figure A-1(A)). Investigative drilling, however, appeared to show that the limestone was not karstified at depth, only finely fissured, so the water table could lie considerably above the tunnel (Figure A-1(B)) and low-level inflows might be expected.

The actual conditions were found to be more complex, with karstification only extending a few hundred metres from the surface, and roughly parallel to it (Figure A-2). Beneath the karstified zone the limestone is finely and tightly jointed, leading to low permeability. "The water table in the outer karstified parts of the mountain is below the position of the tunnel and rises above it in the non karstified central areas. In those areas, the limestone is of low to very low permeability and the flow can be thought of as that in a poor porous medium. Drainage in the tunnel is barely perceptible, mainly in the form of "transpiration", wet sidewalls or drip flows". However, two limited zones of high permeability did extend down to the tunnel, in the form of conduits, probably developed in fault zones (Figure A-3). These voids had to be bridged by fill and concrete slabs to allow the tunnel boring machine to proceed. Water was released under pressure from the first void; the second contained clay, sand and gravel, but had clear signs of carrying water at times. Following a storm, a flood reached the tunnel in 8 hours and it took a week for the water to drain away.

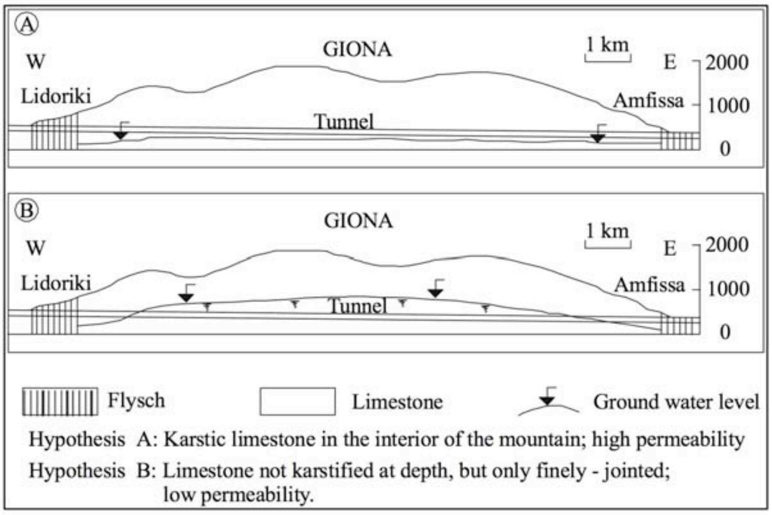

Figure A-1. Schematic sections of two hypotheses of groundwater development in Giona Mountain, Central Greece. (from Marinos 2001)

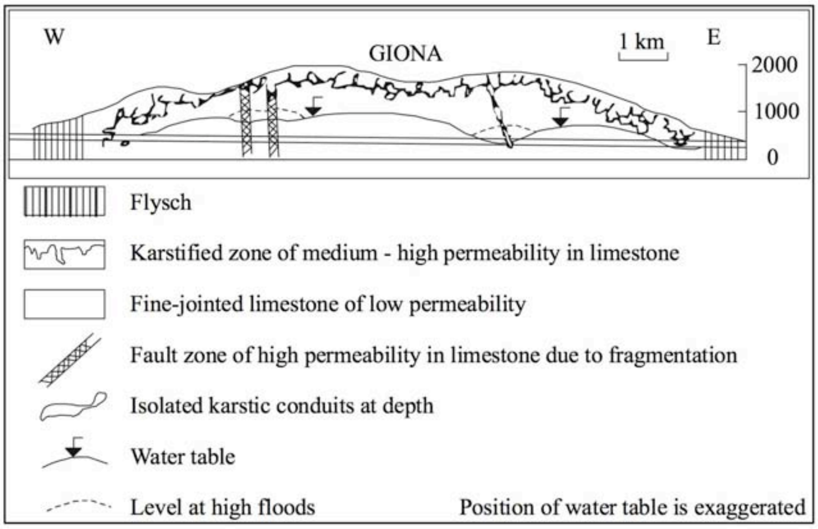

Figure A-2. Underground hydraulic regime of Giona Mountain, central Greece (Marinos 1992, cited in Marinos 2001)

"In total, more than 400 l/sec. of water entered the tunnel, 150 l/sec. of which were contributed by a single fault". The tunnel had to be grouted and lined, with a "tighter grouting program" at the ends where the more highly karstic zones were crossed and the water table was below the tunnel (Marinos 2001).

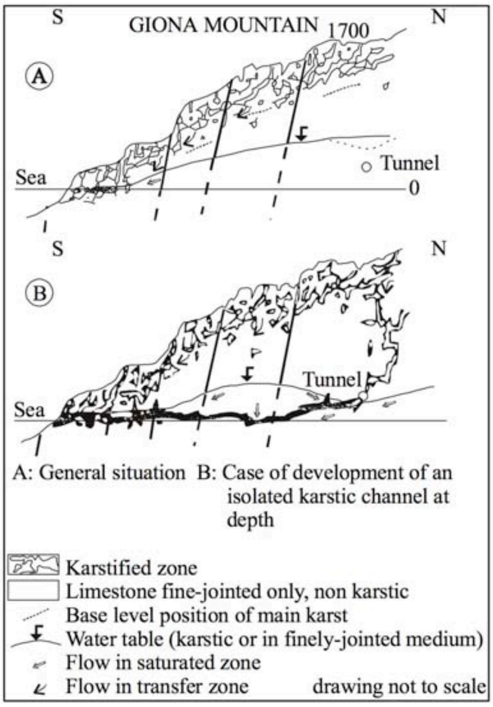

Figure A-3. Underground hydraulic regime of two cross sections of Giona Mountain (Marinos 1992, cited in Marinos 2001)

In Croatia, during the digging of the Učka tunnel, a large cavernous zone was encountered (Milanović 2000). The largest cave impacted was 175 m long and 70 m wide, while the tunnel passed close to a gallery 55 m high. It was impractical to fill the cave because it contained a permanent water flow; reinforced concrete arch structures were rejected as complicated and very expensive; to support the potentially unstable rock mass between the tunnel and the cave roof, a stabilised fill of limestone aggregate and cement was injected. The space between the strengthened aggregate and the cave roof was filled with concrete and 24 mm anchor bolts were installed.

Casagrande, Cucchi and Zini (2005) report the discovery, during excavation of an artificial gallery in the Trieste karst area, of a cavity of unusual and unexpected dimensions. The cavity was called 'Grotta Impossible' and consists of a passage network extending for over a kilometre with one chamber 130 m long, 80 m wide and extending up to 70 m high. The cavity had not been indicated by geological and physical surveys carried out in preparation for the drilling project.

Waltham et al. (2005) warn that –

> *Construction of tunnels in karst can encounter caves at any depth beneath the ground surface. Rock collapse may have already occurred or potential collapse may constitute a significant hazard, and remedial measures can match those of surface works that found on cavernous rockhead. Unstable sediment and debris is normal inside caverns, where it may require precautions and treatment comparable to surface sites that are prone to development of subsidence sinkholes.*

They note that

> *a large cavern in the path of a tunnel presents a difficult problem, and inevitably delays excavation. Where excavation is by a tunnel boring machine (TBM), the tunnel may have to be relocated or diverted around a large cavern, as it is technically impossible to head a TBM out of a rock wall into an open space.*

Chen (1994, cited by Waltham et al. 2005) reports that a number of railway tunnels in the well-developed karst of south-west China had to be re-routed around large caves, though smaller caves could be filled.

Milanović (2000, cited by Waltham et al. 2005) reported that –

> *A cave breached at mid-height by the TBM driving the Trebišnjica hydro-tunnel, in Bosnia Herzegovina, was filled with 386 m^3 of concrete to provide a solid floor over which the TBM could advance.*

Waltham et al. (2005) continue –

> *Concrete filling of caves may only be feasible where shuttering has been built to prevent potentially enormous concrete losses into extensive cave systems and also to prevent concrete blocking active conduits where free drainage must be maintained. Tunnels in both China and Germany have been built through open caves by retaining the tunnel lining as a protective roof, covered with a blanket of granular debris to reduce the impact of breakdown blocks falling from the unsupported cave roof.*

Milanović (2002, p. 178) cites a case where the excavation of a tunnel 140 m beneath the surface caused material to move down widened faults and cavernous zones, causing subsidence at the surface.

"Water leakage from a headrace tunnel tube eroded and washed away unconsolidated cave deposits in the section where a tunnel intersected a large filled cavern. Percolation through the tunnel lining caused intensive erosion and transport of great volumes of sandy-clay cave deposits toward deeper channel sections over time. This resulted in the development of an empty space around the tunnel tube, and formation of subsidence at the surface. Particularly dangerous was the washed-out part of the cavern situated below the lining, with a length of 16 m, a width of about 7 m and a depth of 8 to 15 m. The loss of support seriously endangered the stability of the tunnel tube" (Figure A-4) (Milanović 2002, p. 178).

In the case of the Dodoni tunnel in northern Greece, Marinos (2001) reported 'overbreaks' due to instability of the fill in karstic cavities:

> *Two major collapses occurred related to the presence of sinkholes at the surface with outcropping chimneys almost 100 m high. The voids were filled with clayey material and pieces of broken rock and were prominently wet. The main collapse had a diameter of 1.5 m in the tunnel and 3 m on the surface, leading to 1200 m^3 of material falling into the tunnel.*

A karstic palaeocanyon collapsed into the 2.2 km Montelungo tunnel on the Rome-Naples high-speed rail line in 1997 (Marinos 2005, p. 634). The palaeocanyon had been filled with limestone detritus in a saturated clayey mix and had not been recognised during the borehole and geophysical survey. About 50 m of the tunnel was completely filled with 2,000 m^3 of loose clay and saturated material, accompanied by a high water inflow for 48 hours. The palaeocanyon was successfully jet-grouted, creating a consolidated ring at least 6 m thick above the tunnel and penetrating the intact limestone, forming a beam.

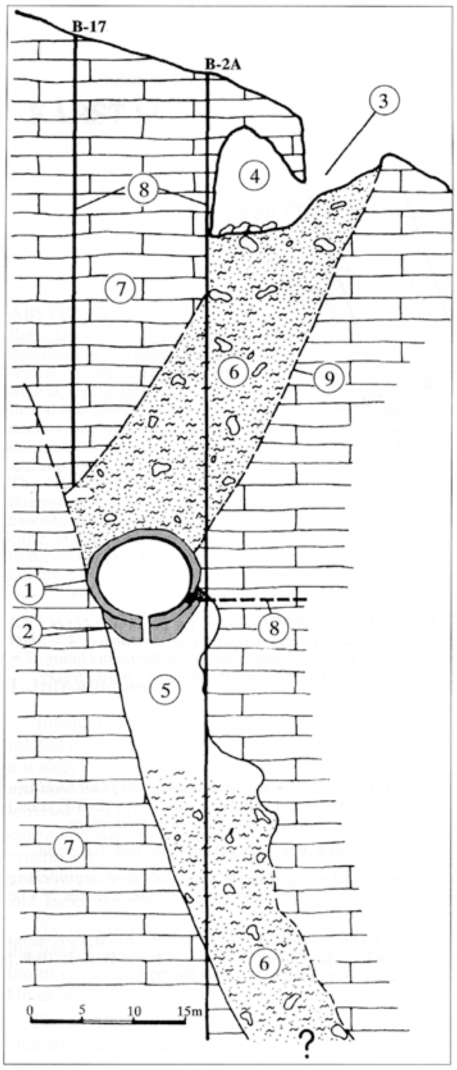

Fig. 12 - Headrace tunnel for HPP Capljina. Subsidence as a consequence of tunnelling operations: 1 = Tunnel lining; 2 = Part of lining additionally reinforced; 3 = Collapse; 4 = Cave origin as a consequence of collapse; 5 = Empty cavernous space below tunnel tube; 6 = Cave deposits (clay, sand, and limestone blocks); 7 = Limestone; 8 = Borehole; 9 = Fault.

Figure A-4. Subsidence caused by a tunnelling operation intercepting a sediment-filled cavity (from Milanović (2002), Figure 12)

Abundant karst cavities, often filled with red clay, adversely affected the tunnel-building-machines used to dig the Yellow River diversion tunnels in China in 2001 (Marinos 2005, p. 636). Groundwater inflows of about 50 l/sec were also recorded. The clay required time-consuming cleaning of the cutter head so foam was sprayed into the excavation front through the cutter head nozzles. “In one case of very disturbed ground a by-pass tunnel had to be dug by hand over the shield of the machine to reach the front of the cutter head where the zone was stabilised by means of resin grouting and self-drilling rock bolts”.

While excavating the 2.7 km long Zuckerberg sewer tunnel in Germany in 2003, unforeseen karstification features coupled with fault zones were encountered. These comprised limestone boulders mixed with loam or homogeneous loam and clay, totalling over 200 m (Marinos 2005, p. 637). In some cases forepolling was required to provide a stable passage. In places the loam-clay material was too soft to bear the weight of the tunnelling machine, in which cases the floor had to be strengthened with shotcrete and profiled manually. In places the entire tunnel cross section had to be supported with bolted liner plates. Probing ahead with 38 m long core drilling from the face and seismic monitoring were used to minimise the risk of encountering unpredicted conditions. Completion of the tunnel was delayed four months.

During tunnelling for the Simplon Tunnel between Switzerland and Italy in 1912 problems were experienced because of the intrusion of water; at the same time, springs 5 km away dried up. Karst conduits had to be sealed with concrete (Mudry and Chauve 1999).

In the excavation of the Mont D'Or railway tunnel between France and Switzerland, tunnelling had to be stopped from the French side when inflow reached 63 l/sec. On the Swiss side a fracture produced a flow of 1800 l/sec into the tunnel and this at times reached 5000 l/sec. Springs nearby dried up and others were affected. Concrete was used to seal the fracture but not before 17,000 m3 of rock and soil blocked the Swiss portal and two roads were destroyed. The total cost was about 100 million francs, whereas 17 million had been budgeted (Mudry and Chauve 1999).

Calembert reported problems with the building of the Gran Sasso road tunnels through Cretaceous limestones and Jurassic dolomite in Belgium. After karst conduits were intercepted water flowed in at a rate of 4,000 to 6,000 l/sec for 5 days, dumping more than 30,000 m3 of sand and rock in the tunnel. Rectification stopped work on the project for several months (Calembert 1974, cited in Calembert 1975, p. 122).

In Turkey, during digging of a 7,100 m tunnel in the north of the Tassus, "a karstic flow of 250 l/sec. invaded the tunnel, caused a prolonged stoppage of work and increased costs considerably" (Erguvanli 1974, cited in Calembert 1975, p. 122).

The Karawanken road tunnel was being pushed between Austria and Slovenia in 1989 when it breached a zone of crushed and sandy dolomite (Marinos 2005, p. 637). Large amounts of water and sand under high pressure were released from investigation borings. Despite the drilling of relief borings, an explosive collapse occurred and around 4,000 m3 of water came out under pressures up to 36 bars. To deal with the collapse a by-pass tunnel was constructed and a grouting shield had to be constructed ahead of the advancing face.

The Gotthard base tunnel runs for 57 km under the Swiss Alps. As prior experience with tunnels in the Piora Zone had shown extremely dangerous behaviour at depth (very high water loads) an exploration tunnel was bored 350 m above the base tunnel. Despite the use of blowout preventors, a blow out of sandy water occurred in one borehole with a peak of 600 l/sec. from the 96 cm borehole. Subsequently an 8 m thick concrete wall was constructed and intensive exploration campaign was initiated (Marinos 2005, pp. 641-642)

Three deep tunnels were bored between 1984 and 1993 as part of Milwaukee's water pollution abatement program (Day 2004). They were at depths of 80 to 100 m in Silurian dolostone. Lack of understanding of the karstic conditions and the hydrology led to the work being much more difficult, and expensive, than estimated; rock collapse, subsidence and groundwater intrusion necessitated remedial lining of 45% of the tunnels plus further grouting, costing $50 million above estimates, resulting in one death and delaying completion by 9 months. Operation of the system has been unsatisfactory because of groundwater inflows through leaks after heavy rain causing sewer overflows and polluted water leaking to groundwaters at other times.

Based on 25 years of experience with dams and pressure tunnels for hydroelectric projects located on soluble rock types, Merritt (1995) notes:

> *Water conveyance tunnels in hydroelectric projects may operate under high internal pressure depending on project design and site topography. Internal water pressures up to 20 bars are common. The pressure in vertical or inclined penstocks can be substantially greater.*
>
> *The watertightness of these tunnels depends on a number of factors: position of the groundwater table with respect to the hydraulic grade line (internal pressure line), rock permeability, rock modulus, and the solubility or erodibility of the surrounding material. Because these tunnels may be many kilometers long, are located under several hundred meters of cover, and often have no borings along the majority of their length, the contract documents have to provide for a number of lining types, the selection of which is made after excavation has revealed the rock conditions. Thus the post excavation selection process is an essential element in the design.*
>
> *Where the groundwater level is below the hydraulic grade line, leakage from a pressure tunnel is possible depending on the permeability of the rock. The definition of the water table is a critical element in the design process and must be defined either during the initial exploration program or during the excavation of the tunnel.*
>
> *Once the tunnel has been excavated, the selection of the appropriate lining is accomplished by making a detailed inspection of the rock conditions throughout. As may be expected, the presence of pervious solution features may be local or quite continuous. Caves can be found as somewhat isolated pockets or as part of a major system related to some persistent geologic structure. Where the caves or other solution features are local, the common practice is to remove any deformable material and backfill the openings with concrete prior to placement of the lining. Reinforcing bars are normally included in the concrete lining. A systematic consolidation grouting program is provided that includes a radial pattern of holes whose length is about 1.5 times the tunnel diameter. The grouting pressures required are equal to the eventual internal operating pressure. The drilling of grout holes also serves as further exploration regarding the location of caves close to the tunnel perimeter.*
>
> *Where the solution-related voids are substantial in size and believed to be continuous and where doubt exists about the ability of the rock to withstand the internal pressure of the operating tunnel, a steel liner or a heavily reinforced concrete lining, capable of spanning the known caves, should be selected. In such a case the lining is essentially impervious and considered to be free-standing in the tunnel. Grouting may or may not be necessary under these circumstances because the lining contains the water.*
>
> *Systematic geologic observations are required during the design and construction stage and must be integrated into the geotechnical basis for design. Caution must be exercised to avoid the common misconception that, after seeing the first solution feature during excavation, "it's only one small hole"! Experience indicates that where there is one there are many. When such circumstances occur, the more readily that the potential problem is recognized and thoroughly addressed, the less will be the adverse consequences.*