Section 4
Natural Hazards and Their Impacts on the Energy Sector

This section summarizes the natural hazards that confront Costa Rica and describes the analyses used to estimate their potential impacts on the national energy infrastructure.

The location of the areas that are susceptible to various forms of natural hazards in Costa Rica have been mapped in some detail and inserted into computerized geographical information system (GIS) maps. These maps were then overlaid with maps of the energy infrastructure. This perspective provided initial guidance as to the areas and types of hazards that were likely to interact with the energy infrastructure. Map 2 provides an example of such an overlay in which areas of landslide hazard were superimposed on the electric transmission network. The areas of overlap are shown in solid black.

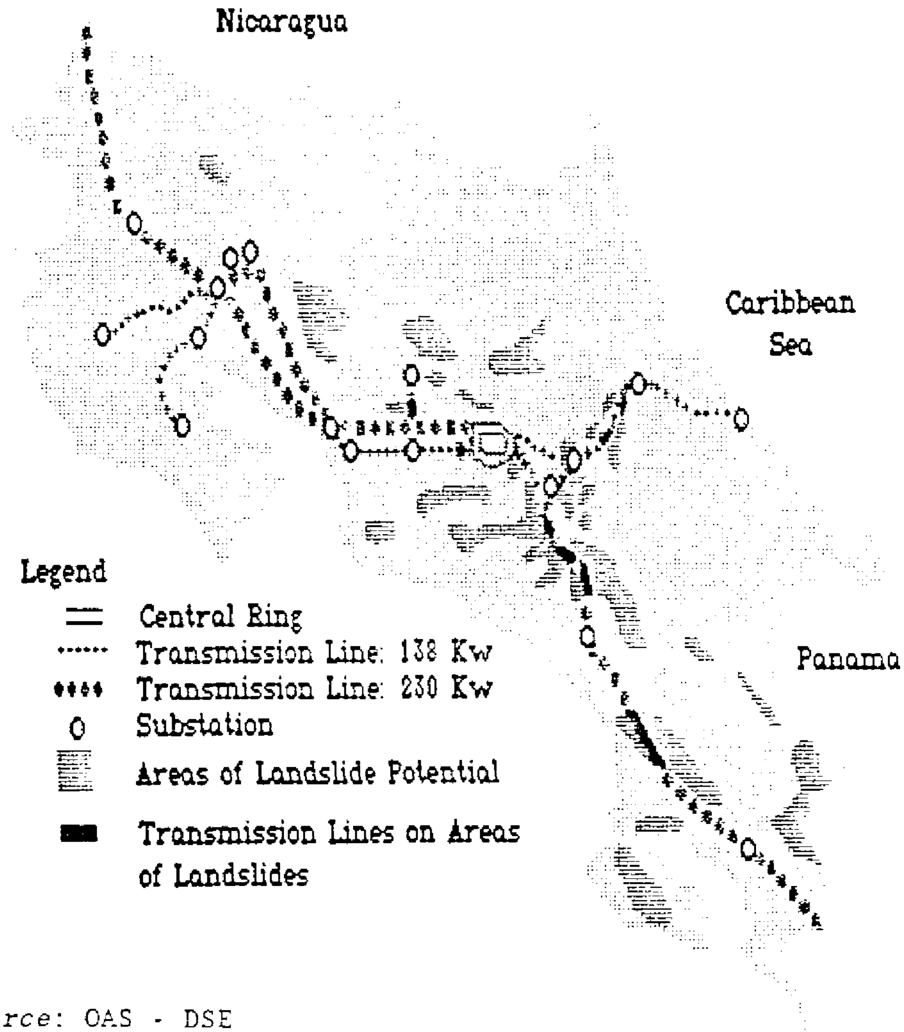
This initial identification was followed with a much more detailed approach with the generation of vulnerability matrices for each class of energy infrastructure described in the previous section. These matrices provided an evaluation of the relationship between components of the specific infrastructure against a list of hazards. The hazards in this comparison were the following:

- Earthquakes
    - Rupture
    - Landslide
- Floods
- Volcanic Eruptions
    - Solid, liquid or gaseous emissions
    - Tremors
- Droughts
- Independent Landslides
- Riverbed Scouring
- Hurricanes
    - Rain
        - Floods
        - Landslides
    - Wind
- Excessive Riverflows
- Erosion
- Deforestation

The repetition of hazards in this selection is intentional, permitting the evaluation of some hazards in their relationship to other events, ie, landslides associated with earthquakes, hurricanes or just landslides that occur without an identified dependence.[1]

[1] Because of the dependence, aggregations must be made before any numerical analysis can be applied across the columns of these matrices.

Map 2. Transmission lines in areas with landslide potential



Source: OAS - DSE

These matrices are presented in Tables 4, 5, 6 and 7. Consistent with the discussion of vulnerability in the introductory section of this paper, a somewhat arbitrary but, at the same time, useful categorization of vulnerability was used for individual entries in these matrices:

- 0: Vulnerability not applicable or very low susceptibility to this hazard.
- 1A: Potential vulnerability (identified but not confirmed) with major impact on the component.
- 1B: Potential vulnerability (identified but not confirmed) with minor impact on the component.
- 2A: Confirmed vulnerability with major impact on the component.
- 2B: Confirmed vulnerability with minor impact on the component.
- S: System-wide impact.

The last system-wide impact category was used to permit the effective inclusion of drought in the analysis. Drought in Costa Rica has a devastating impact on the energy system although virtually no impact on the infrastructure itself. The categories of potential vulnerability are used to describe those cases in which a vulnerability has been identified but there are no historical data to confirm the condition. Clearly, the words major and minor require subjective interpretations. For the purposes stated, a major impact means potential damage to the component requiring major costs and/or time to repair.[2]

Three approaches were used to formulate the vulnerability matrices. The first was direct field survey by the project team, the second, interpretation by natural hazards experts, and third, information gathered through structured interviews with the managers and technicians responsible for the operation and maintenance of these specific components. Many times these individuals had a wealth of experience concerning past natural events and their effects on these components. Precautions were taken to assure a balance between all three approaches as well as interview results to maintain a uniform vulnerability perspective in the generation of the matrices.

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[2] See Section 5 for further discussion of these issues

Table 4. Vulnerability matrix of the distribution system for gasoline, diesel, jet and kerosene

	COMPONENT	HAZARD: EARTHQUAKE		FLOODING	VOLCANIC ERUPTION		DROUGHT	INDEPENDENT	RIVERBED	HURRICANE			EXCESSIVE	EROSION	DEFORES-	COMBINED HAZARDS
									SCOURING	PRECIPITATION		WIND	RIVER		TATION	WITH SEVERE IMPACTS
		RUPTURE	LANDSLIDE		EMISSIONS	QUAKE		LANDSLIDES		FLOOD	LANDSL		FLOW			
1	PORT OF MOIN	0	0	0	0	0	0	0	0	0	0	2B	0	0	0	LANDSLIDES ARE THE
2	REFINERY	1B	0	0	0	0	0	0	0	0	0	2A	0	0	0	MORE SEVERE EVENTS;
3	PIPEL. LIMON-SIQUIRRES	0	0	2B	0	0	0	0	0	2B	0	0	0	0	0	THE COMBINATION OF
4	PIPEL. SIQUIRRES-TURRIALBA	0	0	2B	0	0	0	2A	2B	2B	2A	0	2B	0	0	INTENSIVE PRECIPITATION
5	TURRIALBA TERMINAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FOLLOWED BY A STRONG
6	PIPEL. TURRIALBA-EL ALTO	2B	2A	2B	2B	2B	0	2A	0	2B	2A	0	0	0	0	EARTHQUAKE CAUSING
7	EL ALTO TERMINAL	2B	0	0	2B	2B	0	0	0	0	0	0	0	0	0	SEVERAL LANDSLIDES
8	PIPEL. EL ALTO-AIRPORT	2B	0	0	0	0	0	0	0	0	0	0	0	0	0	WITH DAMAGE TO SOME
9	PIPEL. AIRPORT-LA GARITA	2B	2B	0	0	0	0	0	0	0	2B	0	0	0	0	SEGMENTS OF THE OIL
10	LA GARITA TERMINAL	2B	0	0	0	0	0	0	0	0	0	0	0	0	0	PIPELINES AND LIMITING
11	PIPEL. LA GARITA-BARRANCA	2B	2B	0	0	0	0	2B	0	0	2B	0	0	0	0	ROAD ACCESS WOULD HAVE
12	BARRANCA TERMINAL	2B	0	0	0	0	0	0	0	0	0	0	0	0	0	SEVERE IMPACT TO

Note:
0: Low susceptibility or not applicable
1A: Potential hazard (identified but not confirmed) - major impact to the component
1B: Potential hazard (identified but not confirmed) - minor impact to the component
2A: Confirmed hazard - major impact to the component
2B: Confirmed hazard - minor impact to the component
$: Impact to the system

Source: OAS/DRD/Energy Sector Case Study for Costa Rica with support of staff of DSE

Table 5 Vulnerability matrix of the railroad system

	COMPONENT	HAZARD														COMBINED HAZARDS
		EARTHQUAKE		FLOODING	VOLCANIC ERUPTION		DROUGHT	INDEPENDENT LANDSLIDES	RIVERBED SCOURING	HURRICANE			EXCESIVE RIVER FLOW	EROSION	DEFORES-TATION	WITH SEVERE IMPACTS
										PRECIPITATION		WIND				
		RUPTURE	LANDSLIDE		EMISSIONS	QUAKE				FLOOD	LANDSL					
1	LIMON-PANDORA (1)	0	0	2A	0	0	0	0	0	2A	0	2B	0	0	0	
2	LIMON-SIQUIRRES	0	0	2A	0	0	0	2B	2A	2A	2B	2A(6)	2A	0	0	
3	SIQUIRRES-TURRIALBA	0	0	2A	0	0	0	2A	2A	2A	2A	2B	2A	2A	0	
4	SIQUIRRES-GUACIMO (2)	0	0	2B	0	0	0	0	0	2B	0	2A(6)	0	0	0	
5	TURRIALBA-CARTAGO	0	1A	0	0	0	0	2A(4)	2A	0	2A(4)	0	2A(7)	2A	0	
6	CARTAGO SAN JOSE	2B	2B	0	0	0	0	2A(5)	0	0	2A(5)	0	0	0	0	
7	SAN JOSE-OROTINA	2B	2B	0	0	0	0	2B	0	0	2B	2A(6)	0	0	0	
8	OROTINA-PUNTARENAS	2B	0	2A(3)	0	0	0	0	0	2A(3)	0	2A(6)	0	0	0	
9	CORTES GOLFITO PORT															
	GONZALEZ SYSTEM (8)															

Note.
0: Low susceptibility or not applicable
1A: Potential hazard (identified but not confirmed) - major impact to the component
1B: Potential hazard (identified but not confirmed) - minor impact to the component
2A. Confirmed hazard - major impact to the component
2B Confirmed hazard - minor impact to the component
S Impact to the system

(1) Limited to banana industry use.
(2) Passengers and banana industry.
(3) Flooding associated with local rivers and tides in Puntarenas.
(4) Severe problem. Landslide occurring on slopes beneath the roadbed at site called Chiz. Slide activity that started November, 1988 it is now slow but continuous. Passengers traffic not permitted in this segment because of the dangerous situation.
(5) San Blas landslide located north of Cartago where the railroad crosses the Rio Reventado.
(6) Hazard associated with blow down electrical lines in this segment
(7) Bridge in danger in this segment because of movements in its foundations.
(8) INCOFER is presently decommissioning this line.

Source OAS/DRD/Energy Sector Case Study for Costa Rica with support of staff of DSE, RECOPE and INCOFER

Table 6. Vulnerability matrix of the highway system.

	Highway	Hazard: Earthquake – Rupture	Earthquake – Landslide	Flooding	Volcanic Eruptio – Emissions	Volcanic Eruptio – Quake	Drought	Independent Landslide	Riverbed Scouring	Hurricane – Precipitation Flood	Hurricane – Precipitation Landsl	Hurricane – Wind	Excesive River Flow	Erosion	Deforestation	Combined Hazards with Severe Impacts
1	PUERTO LIMON-SIQUIRRES	0	0	2B	0	0	0	0		2B	0	0				
2	SIQUIRRES-TURRIALBA	0	0	0	0	0	0	1A o 2A?		?	1A o 2A?	0				
3	TURRIALBA-CARTAGO	2A	2A	0	1A	1A	0	2A		0	2A	0				
4	CARTAGO-SAN ISIDRO	2A	2A	0	0	0	0	2A		0	2A	0				
5	SAN ISIDRO-PASO REAL															
6	SAN ISIDRO-PUERTO QUEPOS															
7	SIQUIRRES-GUAPILES	0	0	2B?	0	0	0	0		2B	0	0				
8	GUAPILES-VALLE CENTRAL (BY EL PARQUE)	2A	2A	2B?	0	1A	0	2A		0	2A	0				
9	GUAPILES-VALLE CENTRAL (BY PUERTO VIEJO)	0	0	2B	2A	2A	0	2A		2B	2A	0				
10	VALLE CENTRAL-LOS CHILES	1B	0	0	1B	1B	0	0		0	0	0				
11	VALLE CENTRAL-BARRANCA	0	0	0	0	0	0	0		0	0	0				
12	VALLE CENTRAL-PUERTO QUEPOS (COASTAL)	1A	1A	2B	0	0	0	2A		2B	2A	0				
13	BARRANCA-GUANACASTE-PENAS BLANCAS (INTERAMERICAN)	1B	0	1A	0	0	0	?		1A	?	0				
14	PASO REAL-CIUDAD NEILY (BY PALMAR NORTE)	1B	1B	2A?	0	0	0	?		1A	?	0				
15	PASO REAL-CIUDAD NEILY (BY SAN VITO)	1A?	1A?	0	0	0	0	2A		0	2A	0				
16	CIUDAD NEILY-PASO CANOAS	2A	0	?	0	0	0	0		?	0	0				

Note: 0: Low susceptibility or not applicable
1A: Potential hazard (identified but not confirmed) - major impact to the component
1B: Potential hazard (identified but not confirmed) - minor impact to the component
2A: Confirmed hazard - major impact to the component
2B: Confirmed hazard - minor impact to the component
S: Impact to the system

Source: OAS/DRD/Energy Sector Case Study for Costa Rica with support of staff of DSE and RECOPE

Table 7. Vulnerability matrix of the electrical system

	COMPONENT	HAZARD						
		EARTHQUAKE		FLOODING	VOLCANIC ERUPTION		DROUGHT	INDEPENDENT
		RUPTURE	LANDSLIDE		EMISSIONS	QUAKE		LANDSLIDES
	RIVERBASINS							
C1	ARENAL	0	2A	0	2A(17)	0	S	2A
C2	GARITA/VENTANAS-G	0	2B	0	0	0	S	2B
C3	RIO MACHO	0	2B	0	0	0	S	2B
C4	CACHI	0	2B	0	1B(18)	0	S	2B
	HYDROELECTRIC RESERVOIRS							
E1	ARENAL	2B	2B	0	1B(19)	0	S	2B(4)
E2	SANTA ROSA	2B	2B	0	0	0	0	2B
E3	SANDILLAL (EN CONSTR)							0
E4	GARITA	1B	0	0	0	0	0	2B
E5	RIO MACHO	0	0	0	0	0	0	2B
E6	CACHI	2B	2B	0	0	0	S	2A
	HYDROELECTRIC PLANTS							
P1	ARENAL	2B	1B	0	0	0	0	1B
P2	COROBICI	2B	1B	0	0	0	0	0
P3	CARITA-VENTANAS	2B	2B	0	0	0	0	2B
P4	RIO MACHO	2B	0	0	0	0	0	0
P5	CACHI	2B	1B	0	0	0	0	1B(3)
	THERMAL PLANTS							
P6	BARRANCA	2B	0	0	0	0	0	0
P7	SAN ANTONIO	1B	1B	0	0	0	0	1B
P8	COLIMA	1B	0	0	0	0	0	0
P9	MOIN	0	0	2A	0	0	0	0
	TRANSMISSION LINES							
	CENTRAL AREA RING	1B	0	0	2B(8)	0	0	0
T1	CACHI-RIO MACHO	1B	1B	0	0	0	0	1B
T2	RIO MACHO-ANILLO CENTRAL	1B	2A(7)	0	2B(8)	0	0	2A
T3	CACHI-ANILLO CENTRAL	1B	2A(7)	0	2B(8)	0	0	2A
T4	CACHI-SIQUIRRES	1B	1B	0	0	0	0	2A
T5	SIQUIRRES-MOIN	0	0	2A	0	0	0	0
T6	RIO MACHO-SAN ISIDRO	1B	2A	0	0	0	0	2A
T7	SAN ISIDRO-RIO CLARO	1B	2B	2A	0	0	0	2B
T8	RIO CLARO-PANAMA	1B	0	2A	0	0	0	0
T9	ANULO CENTRAL-GARITA	1B	1B	0	2B(8)	0	0	1B
T10	GARITA-JUANILAMA (13)	1B	1B	0	0	0	0	1B
T11	JUANILAMA-BARRANCA	1B	1B	0	0	0	0	1B
T12	GARITA-NARANJO	1B	0	0	2B(8)	0	0	0
T13	BARRANCA-ANULO CENTRAL	1B	2B	0	2B(8)	0	0	2B
T14	BARRANCA-ARENAL	1B	2A	0	2B(8,11)	0	0	2A
T15	BARRANCA-CANAS	1B	0	2B	2B(8,11)	0	0	0
T16	ARENAL-COROBICI	1B	0	0	2B(8,11)	0	0	0
T17	COROBICI-CANAS	1B	0	0	2B(8,11)	0	0	0
T18	CANAS-LIBERIA	1B	0	2B	2B(11)	0	0	0
T19	LIBERIA-NICARAGUA	1B	0	2B	2B(11)	0	0	0
T20	CANAS-GUAYABAL	1B	0	2A	2B(11)	0	0	0
T21	CANAS-COLORADO	1B	0	2B	2B(11)	0	0	0
T22	COLORADO-SANTA RITA	1B	0	0	0	0	0	0
	SUBSTATIONS							
S1	CENTRAL AREA SYSTEM	2A	0(16)	0	2B	0	0	0(16)
S2	RIO MACHO	2A	2A	1A	1B	0	0	1A
S3	CACHI	2A	2A	2A	1B	0	0	2A
S4	SIQUIRRES	1B	0	1A(14)	0	0	0	0
S5	MOIN	0	0	2A	0	0	0	0
S6	SAN ISIDRO	2A	0	0	0	0	0	0
S7	RIO CLARO	2A	0	1B	0	0	0	0
S8	GARITA	2A	0	0	1B	0	0	0
S9	JUANILAMA	2A	0	0	0	0	0	0
S10	BARRANCA	2A	0	1B	0	0	0	0
S11	NARANJO	1A	0	0	2B	0	0	0
S12	ARENAL	2A	2B	0	1B	0	0	1B
S13	COROBICI	2A	2A	0	1B	0	0	2A
S14	CANAS	2A	0	1B	1B	0	0	0
S15	LIBERIA	2A	0	2B	1B	0	0	0
S16	GUAYABAL	2A	0	0	0	0	0	0
S17	COLORADO	2A	0	0	0	0	0	0
S18	SANTA RITA	2A	0	2B	0	0	0	0

Table 7. (cont.)

HAZARD: RIVERBED SCOURING	HURRICANE PRECIPITATION: FLOOD	HURRICANE PRECIPITATION: LANDSL	WIND	EXCESIVE RIVER FLOW	EROSION	DEFORES-TATION	COMBINED HAZARDS WITH SEVERE IMPACTS		COMPONENT
									RIVERBASINS
0	0	2A	1B	0	2B	2A		C1	ARENAL
2B	0	2B	0	1A	2A	2A		C2	GARITA/VENTANAS-G
2B	0	2A	0	1A	0	0(1)		C3	RIO MACHO
2B	0	2A	0	0	2A	2A		C4	CACHI
									HYDROELECTRIC RESERVOIRS
0	0	2A	2B	0	2B	2A		E1	ARENAL
0	0	2B	0	0	0	0		E2	SANTA ROSA
0	0	2B	2B	0	2B	0		E3	SANDILLAL (EN CONSTR)
2B	0	2B	0	1B	0	0		E4	GARITA
2B	0	2B	0	1B	1B	0(1)		E5	RIO MACHO
2A	0	2A	0	0	2B	2A		E6	CACHI
									HYDROELECTRIC PLANTS
0	0	1B	0	0	0	0		P1	ARENAL
0	0	0	0	0	0	0		P2	COROBICI
2A	0(2)	2B(3)	0	2A	0	0		P3	GARITA-VENTANAS
0	0	0	0	0	0	0		P4	RIO MACHO
0	0(5)	1B(3)	0	0	0	0		P5	CACHI
									THERMAL PLANTS
0	0	0	0	0	0	0		P6	BARRANCA
0	0	1B	0	0	0	0		P7	SAN ANTONIO
0	0	0	0	0	0	0		P8	COLIMA
0	2A	0	2A	0	0	0		P9	MOIN
									TRANSMISSION LINES
0	0	0	0	0	0	0			ANILLO DEL AREA CENTRAL
0	0	1B	0	0	0	1B(6)		T1	CACHI-RIO MACHO
0	0	2A	0	0	0	0		T2	RIO MACHO-ANILLO CENTRAL
0	0	2A	0	0	0	0		T3	CACHI-ANILLO CENTRAL
0	0	2A	2A	0	0	2B(6)		T4	CACHI-SIQUIRRES
0	2A	0	2A	0	0	0		T5	SIQUIRRES-MOIN
0	0	2A	0	0	0	2A(6)		T6	RIO MACHO SAN ISIDRO
0	2A	2A	0	0	0	2A(6)		T7	SAN ISIDRO-RIO CLARO
0	2A	2B	0	0	0	0		T8	RIO CLARO PANAMA
0	0	1B	0	0	0	0		T9	ANILLO CENTRAL-GARITA
0	0	1B	0	0	0	0		T1	GARITA-JUANILAMA (13)
0	0	1B	0	0	0	0		T1	JUANILAMA BARRANCA
0	0	0	0	0	0	0		T1	GARITA-NARANJO
0	0	2B	2B(9)	0	0	1B		T1	BARRANCA-ANILLO CENTRAL
0	0	2A	2A(10)	0	0	0		T1	BARRANCA-ARENAL
0	2B	0	2B	0	0	0		T1	BARRANCA-CANAS
0	0	0	0	0	0	0		T1	ARENAL-COROBICI
0	0	0	0	0	0	0		T1	COROBICI-CANAS
0	2B	0	1B	0	0	0		T1	CANAS-LIBERIA
0	2B	0	1B	0	0	0		T1	LIBERIA-NICARAGUA
0	2A	0	0	0	0	0		T2	CANAS-GUAYABAL
0	2B	0	0	0	0	0		T2	CANAS-COLORADO
0	0	0	2A(12)	0	0	0		T2	COLORADO-SANTA RITA
									SUBSTATIONS
0	0	0(16)	2B(15)	0	0	0		S1	SISTEMAS DEL AREA CENTRAL
1A	1A	2A	0	0	0	0		S2	RIO MACHO
0	2A	2A	0	0	0	0		S3	CACHI
0	1A(14)	0	2A	0	0	0		S4	SIQUIRRES
0	2A	0	2A	0	0	0		S5	MOIN
0	0	0	0	0	0	0		S6	SAN ISIDRO
0	0	0	1B	0	0	0		S7	RIO CLARO
0	0	0	0	0	0	0		S8	GARITA
0	0	0	1B	0	0	0		S9	JUANILAMA
0	1B	0	1B	0	0	0		S1	BARRANCA
0	0	0	0	0	0	0		S1	NARANJO
0	0	2B	2B	0	0	0		S1	ARENAL
0	0	2A	0	0	0	0		S1	COROBICI
0	1B	0	1B	0	0	0		S1	CANAS
0	2A	0	1B	0	0	0		S1	LIBERIA
0	0	0	1B	0	0	0		S1	GUAYABAL
0	0	0	1B	0	0	0		S1	COLORADO
0	2A	0	1B	0	0	0		S1	SANTA RITA

Table 7. (cont.)

Note:

0: Low susceptibility or not applicable
1A: Potential hazard (identified but not confirmed) - major impact to the component
1B: Potential hazard (identified but not confirmed) - minor impact to the component
2A: Confirmed hazard - major impact to the component
2B: Confirmed hazard - minor impact to the component
S: Impact to the system

(1) Because of legal protection there is no significant deforestation. It is essential to maintain the forest to prevent future damage.
(2) Some flooding problems now mitigated with the construction of a wall.
(3) Known hazard of soil instability above the plant.
(4) Landslides associated with reservoir wave action
(5) Flooding of the plant in case of reservoir release in excess of 4000 m3/s.
(6) Associated with landslides in the area.
(7) Associated with Rio Reventado.
(8) Insulator breakdown because of the volcanic ash deposition.
(9) Problems associated with small tornadoes in this area.
(10) Operation and equipment failure.
(11) Problems with corrosion of lines, insulators and towers caused by acid gases of nearby volcanoes.
(12) Damage caused by the wind and the fact that the line crosses a long distance over the gulf.
(13) Regular failures of this line caused by lighting.
(14) Potential event but has not happened yet.
(15) Damage associated with tornadoes.
(16) The plant and substation in San Antonio are located near the Rio Varilla with a risk level of 1B.
(17) Killing of vegetation cover associated with volcanic gases.
(18) Associated with a laminar avalanche from Volcano Irazu in one of the reservoir tributaries.
(19) Avalanches are confirmed, there is doubt whether these avalanches would reach the reservoir.

Source: OEA/DDR/Energy Sector Case Study for Costa Rica
with support of staff of DSE and ICE

4.1 Natural Hazard Risks to the RECOPE Product Pipeline

Review of the vulnerability matrix in Table 4 for the RECOPE Pipeline shows relatively minor overall impact of natural hazards with most all hazards fairly well understood.

A hurricane crossing over Limón would likely cause serious damage to the refinery with less overall damage to the dock infrastructure. The terrain from Limón to Siquirres is flat and susceptible to flooding.

At Siquirres the pipeline begins the uphill climb to the pumping terminal at Turrialba and on to the terminal at El Alto. Throughout this area there are varying degrees of landslide hazards, the most serious occurring at the pipeline crossing of the Reventado River on the southern slopes of the IrazD volcano and just to the north of the city of Cartago. In 1957, the volcanic ash-laden soils gave away in a massive landslide (San Blas) in this riverbed causing numerous deaths and extensive damage downstream. This slide area is still very unstable with its continuing movement downstream causing continued scouring. There is evidence of erosion of the higher terrain on which the towers for the support of the pipeline bridge are located. The mixture of high rainfall, saturated soils and an earthquake could trigger another landslide taking out the pipeline and its towers as well as other energy infrastructure that crosses in this same general area.

From the highest point at the terminal at El Alto on to the west, landslides are not a major concern and are limited to areas of river crossing where the pipeline is exposed. It is through this area that there is some concern of earthquake damage although no pipeline damage has been experienced following the shocks that have occurred since these segments of the pipeline were installed. There is also some concern for the integrity of storage tanks at the various terminals from El Alto down to Barranca. Most tanks are of the floating type which should reduce their vulnerability to earthquakes.

4.2 Natural Hazard Risks to the National Railroad

As the railroad and the RECOPE pipeline from Limón to Siquirres and Turrialba follow similar alinement, the natural hazards are similar for both. However, as little maintenance and upgrading of the railroad have been executed, the railroad is at significantly higher risk. On the plains between Limón and Siquirres, the pipeline was moved and suspended from new road bridges; the railroad continues to suffer from flood related damage to its older bridges. Also because this segment of the railroad is electrified, hurricane wind damage to overhead wires would likely be extensive and expensive.

From Siquirres to the continental divide just east of San José, the railroad is vulnerable to damage from water runoff and landslides. Flooding can occur where the roadbed runs adjacent to steam beds. Bridges at river crossing are vulnerable to excessive water flows as well as the damage from rolling river-bottom boulders. The worst roadbed condition occurs at Chiz, located between Turrialba and Cartago where roadbed settling is continuous and requires regular repair simply to keep this rail segment in operation. Destruction of this segment by landslide could permanently close train operation between Limón and San José. Two alternatives have been identified if such an event happens: the construction of a tunnel or a very large bridge, both of which would require very large investments.

A major San Blas landslide would also likely destroy the railroad bridge across the Reventado River a few kilometers below the pipeline crossing.

The railroad lines to the west of San José are in good condition with generally minor repercussions expected from natural hazards. A major earthquake could cause breakages or bending of the rails; floods and high tides can inundate low lying areas next to the Pacific coast. As this rail segment is also electrified, there is also risk of wind damage to overhead wires. Although Atlantic hurricanes have almost never crossed the isthmus onto the Pacific coast, high local winds associated with storms do occur.

It is important to note that the country has more than adequate capacity of tank trucks for both heavy and light fuels to substitute for the transfer of fuels by both the pipeline and the railroad. More on this matter is discussed below in the specific event studies.

4.3 Natural Hazard Risks to the National Road System

There is only one major highway connecting Siquirres to Limón across the eastern plains; it is the only road access the country has to its eastern ports. However, this road is well constructed with high and long bridges over the rivers that carry the massive mountain water runoff surges that frequent this region.

At present there are three alternative roads for the mountain ascent between Siquirres and San José, providing reasonable security in case of road blockages caused by natural disasters. However, it should be noted that the newest of these three that passes through the Braulio Carrillo National Park to north of the Volcano IrazD experiences regular closures because of landslides. The older two roads also have problems with landslides but much less so than with the new one.

The other roads in the country with significant vulnerability to hazards include the mountain road between Cartago and San Isidro which is affected by landslides, and the southern coastal road between El Paso Real and Ciudad Neily which is occasionally flooded.

4.4 Natural Hazard Risks to the National Electrical System

As shown in the vulnerability matrix for the national electrical system (Table 7), the components of this system have been classified by river basins, reservoirs, hydroelectric plants, thermal plants, transmission lines, and substations. Some overall comments about the vulnerability to natural hazards for this system are made below.

Although the Arenal lake and river basin are affected by deforestation, erosion and landslides, the very large size of this reservoir compensates for the impacts of individual events. This watershed is in need of a river basin management program. If deforestation and mismanagement become larger in scale, impacts on the reservoir will become much more serious.

In general, there is a need for integrated management of all the Costa Rican hydroelectric river basins except for Río Macho which is reasonably well protected due to the national reserve in its upper watershed. Of all the hydroelectric systems, the most critical river basin management problem is associated with the

Cachí reservoir where sediments have become a serious problem due, in large part, to the Reventado (San Blas) landslide area

There is an important concern about the Arenal dam. Shortly after its construction was initiated, the long-inactive Arenal volcano located only 5 km to the south became active, spewing hot gases, rock and lava. It continues to do so today. If the Arenal volcano would have a major eruption, it is doubtful that the lava flow would reach the dam although this is not certain. This dam was very carefully designed to withstand a major seismic event and contains very extensive monitoring equipment to detect any stresses that might imply future damage.

All of the Costa Rican major hydroelectric plants have a vulnerability to earthquakes; this vulnerability is not considered major because of the design criteria used for these facilities, especially the newer ones. There have been landslide incursions in and around some of these plants; disturbed areas, however, have been carefully cemented. It is felt that further risk is minor. One concern that has been confirmed is the vulnerability to excessive water flow and rock damage at the river diversions and intakes of the Garita power plant.

There is little identified vulnerability to the small thermal power plants except that of potential flood and hurricane damage to the Limón plant.

The analysis of the transmission components in the electric system vulnerability matrix are based principally on the personal knowledge of these systems by ICE management and technicians. The major identified concerns include several elements.

The two transmission lines from Cachí and Río Macho to the Central Valley also pass directly over the San Blas landslide area Prior damage has occurred and towers have had to be relocated The other two lines with serious problems of landslides are those between Arenal and Barranca and between Río Macho and San Isidro.

The higher elevations in the norther region of the country are affected by strong winter winds. These winds are often the cause of transmission outages in the Arenal area during this season. Physical damage is virtually nil. Clearly, a hurricane passing through the northern part of the country could cause serious wind damage to transmission lines is this region. It is generally thought that transmission towers and lines are quite resistant to earthquake damage because of their inherent flexibility. An additional concern to transmission systems is the corrosion effect of volcanic gases. This question has not been analyzed adequately. Ash from volcanic eruptions is known to cause crossovers of insulators. Reports indicate that in such cases, the insulators and other equipment can be washed by water jets while the lines are in operation without hazard to personnel. This concern also needs to be analyzed in more detail.

A concern has been identified with respect to substation vulnerability to earthquakes, principally for major transformer damage. Although major concern has been assigned to this category, a much more detailed investigation needs to be made.

4.5 Summary of Natural Hazard Impacts on Energy Infrastructure in Costa Rica

Table 8 provides a summary of the results of the vulnerability matrices for the petroleum and electricity energy networks. The hazard categories have been combined to provide a reasonably independent set. The table provides the number of times an A or B vulnerability is assigned in those matrices, again avoiding double counting when categories have been combined. The number of different components in each category is identified next to the name of that category.

Some conclusions can be extracted from this summary matrix making reference to details from the individual matrices where necessary.

In the petroleum sector, type A (major impact) events include:

- Hurricane damage to the refinery - (note that hurricanes do occur in this region but are not common)
- Landslide damage to the product pipeline - (especially at San Blas - this event is not unlikely)

In the electricity sector, serious events include:

- River basin management concerns associated with erosion control, landslides and, in turn, problems of sedimentation in reservoirs - (existing problems are likely to continue)

- A water intake problem at one hydroelectric facility -(would be serious but the engineers think they have the risk under control)

- Landslide, flood, and wind vulnerabilities for various transmission segments - (San Blas landslide risk applies to two major transmission lines)

- Concern for the vulnerability of electric substations to earthquake damage; other concerns include landslide, flood, wind and excessive river flow damage.

Table 8. Vulnerability matrix summary for Costa Rica

		Earthquake Rupture	Landslide	Excessive Flood	River Flow	Volcanic Eruption	Wind
Ports (1)	A	-	-	-	-	-	-
	B	-	-	-	-	-	1
Refineries (1)	A	-	-	-	-	-	1
	B	1	-	-	-	-	-
Petroleum Terminals (5)	A	-	-	-	-	-	-
	B	3	-	-	-	1	-
Pipeline Segments (5)	A	-	2	-	-	-	-
	B	3	2	3	1	1	-
Hydroelectric River Basins (4)	A	-	3	-	2	1	-
	B	-	1	-	1	1	1
Hydroelectric Reservoirs (5)	A	-	2	-	1	-	-
	B	3	3	-	2	1	-
Hydroelectric Power Plants (5)	A	-	-	-	1	-	-
		B	5	4	-	-	-
Thermal Power Plants (4)	A	-	-	1	-	-	1
	B	3	1	-	-	-	-
Transmission Lines (23)	A	-	4	4	-	-	4
	B	22	5	-	-	14	4
Electric Substations (18)	A	15	3	6	1	-	2
	B	1	1	3	-	9	10

Note: - means not applicable
Source: OEA/DDR/Energy Sector Case Study for Costa Rica
with support of staff of DSE and ICE

Section 5
Event Studies

5.1 Event Study Selection

It is evident that the process of identification of the individual vulnerabilities of components of energy infrastructure as described in Section 4 is very intuitive and heuristic. This section serves to describe the process of setting priorities with the information that has been generated so as to select specific areas for more detailed analysis.

Figure 9 attempts to provide a more rigorous perspective of the intuitive processes used in the assignment of major and minor categories of impact (A and B respectively in the vulnerability matrices) for each component of infrastructure. The horizontal scale is a measure of the magnitude of an event which is inversely proportional to the probability of its occurrence. The vertical scale is a measure of the cost to put the component back in operation. The graph presented shows the shape of a typical curve growing from zero for low magnitude events to some limiting value which would represent the cost for complete replacement of the component. The vertical scale has been divided into the same two categories A and B used before.

The process of selecting either A or B for a given hazard and a given component is in reality a subjective judgment as to where on the graph, the selection of magnitudes (or probabilities) should be made. It is noteworthy to mention that the assignment of A, B and 0 was not difficult among the various technicians interviewed, with the only major difficulties occurring trying to decipher border line cases between A and B.

Besides the estimation of the impacts of natural hazards to individual components of the energy infrastructure, it is essential to consider the impacts of such damages to the national energy system. For the component that serves a critical role in the provision of energy to, for example, a large percentage of the country, the component damaged by a natural event is much more serious than similar damage to a component without a critical role. This criterion of energy system impact is the additional key element needed for the selection of specific event studies for further investigation.

The selection of event studies presented below were based on the following selection criteria

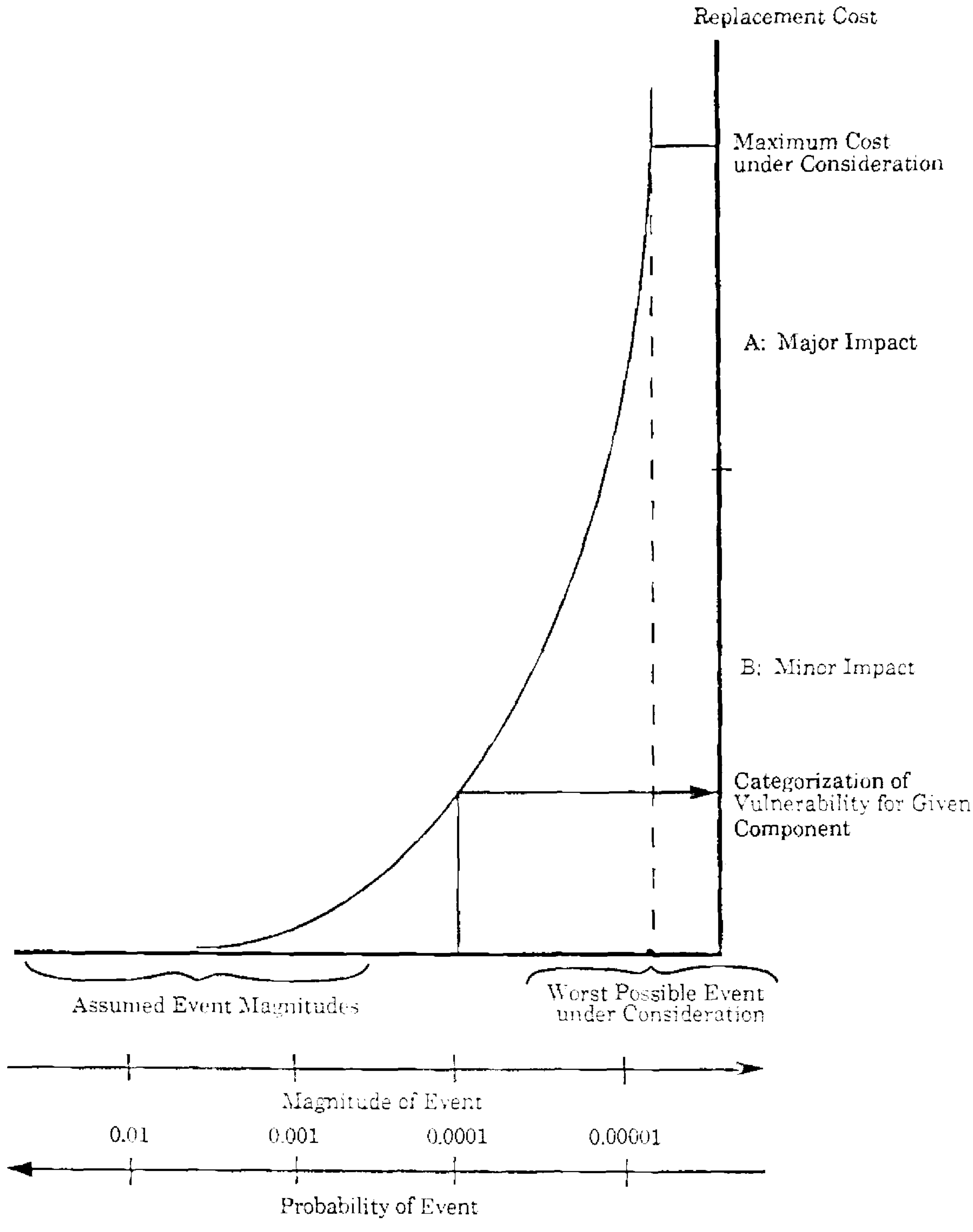
- Events that have major impacts on critical components.

- Events that have major impacts on two or more components of the energy infrastructure.

- Events that have major impacts on less critical components

Review of the events in which type A assignments were made are easy to analyze. For example, although it is accepted that the RECOPE refinery at Moín is susceptible to major hurricane wind damage, damage to the plant would not likely cause any serious interruptions to energy flow because all the products that the refinery produces could be easily imported directly. On the other hand, a landslide

Figure 9. Theoretical process of assignment of vulnerability categories



at San Blas could affect electrical transmission, the RECOPE pipeline, as well as the railroad at a critical point in the normal energy flow for the entire country. This latter event was selected for more detailed study (Event 2). After lengthy discussions with national engineers, it was decided to assign a value of B to the event of damage to the Arenal dam for all of the applicable hazards. Although the hazards conditions are clear, it was felt that damage to the dam based on its construction and monitoring was too unlikely to assign it a high vulnerability. The dam is one of the most critical electrical infrastructure components in the country providing assurance of water availability to almost fifty percent of the installed hydroelectric capacity in Costa Rica. It was decided therefore to include the loss of this structure as one of the event studies although it had a lower individual impact assignment (Event 1).

Finally, the concern for the vulnerability of electric substations to earthquake damage (an assignment of A), led to the selection of the most critical substation in the country, namely La Caja, located on the western end of the ring around San José. This substation is key for supplying power from three separate hydroelectric plants to the city (Event 3).

5.2 Event 1: Destruction of the Arenal Dam

5.2.1 Description of the Event

For the purposes of this analysis, the focus is on an earthquake of magnitude Richter 8 or greater and assumes that this event causes shifting of the materials of the dam which requires major reconstruction.

5.2.2 Description of Emergency Response

It is assumed that the type of impact on the dam would provide adequate time to permit a controlled drainage of the lake. The two hydroelectric power plants at Arenal and Corobicí would be forced to shut down when the water levels in the lake fell to a level that prohibited a continuous and adequate flow to these plants. Under these conditions, the remaining electric generation capacity of Costa Rica would be unable to meet its internal electricity demands.

To estimate the impacts of these shortfalls, the left-hand column of Table 9 presents a summary of the electricity provided in 1988 by the major power plants as well as imports from neighboring countries. Imports in that year consisted principally of electricity sales from the El Cajón project in Honduras.

The second column shows the likely national response to the event at the Arenal complex. As the operation of the major hydroelectric facilities was close to maximum in 1988, it is reasonable to assume similar outputs from the remaining plants: La Garita, Río Macho and Cachí. The thermal plants, one in Limón, one in Barranca, and two in the Central Valley have a design capacity of 141 MW. However, because of their age and state of maintenance, only 50 MW of firm continuous power can be expected, representing an overall capacity factor of about 35 percent. From Honduras, one could expect an equivalent of 300 thousand MWH per year. From Panamá, because the marginal power sources in that country are provided by gas turbines, one could expect, at best, a month of emergency electricity delivery equivalent to 30 MW of firm power. In the first month, the shortfall of energy sums to 25.2 thousand MWH.

After one month, without the imported energy from Panamá, the situation would worsen. The difference between the total available electricity and the demand represents a shortfall on an annual basis of 565 7 thousand MWH.

Table 9. Supply and cost of electricity in case of a loss of the Arenal dam

	Normal Annual Electric Generation 10^3 MWH	Emergency Annual Electric Generation 10^3 MWH	First Month of Emergency Electric Generation 10^3 MWH	Emergency Annual Costs of Electric Generation 10^3 US$	First Month of Emergency Costs of Electric Generation 10^3 US$
Arenal	468.5	0.0	0.0	--	–
Corobicí	550.6	0.0	0.0	--	–
La garita	627.9	627 9	52.3	--	–
Río Macho	571.1	571.1	47.6	–	--
Cachí	614.9	614 9	51.2	–	–
Imported	94.0	438.0	36.5	30100.0	2508.3
Thermal (Honduras)	190 6	300 0	25 0	4186 7	348.9
Imported (Panama)	–	0.0	21.9	0.0	2628.0
Emergency	–	565 7	25.2	84855 0	0 0
Total	3117 6	3117 6	259 8	119141.7	5485.2
Percentage of Lost Energy	–	18.14	9.71	–	–

Note: -- means "not applicable."
Source: OEA-DSE

It is assumed that because of the magnitude of the emergency, that ICE would contract foreign firms to provide mobile electric generation units located in appropriate sites near the electric grid and with reasonable access to their required fuel supplies. It may be possible to anchor generator barges or ships in Limón and Puntarenas with temporary transmission lines to the respective substations in Limón or Barranca. The capacity of the transmission lines from Limón to San José would limit the total capacity of emergency generators on the Atlantic side. It is also assumed for the impact analysis that these generators would be in place and begin generation three full months after the emergency begins.

In the best of conditions, it is assumed that it would take a year to rebuild the dam and another year to refill the Arenal reservoir

5.2.3 Summary of the Impacts

Table 10 provides a summary of the expected impacts over the 24 months of emergency conditions.

For the three months of electricity shortages in Costa Rica, it is assumed that the economic and labor losses would occur in proportion to the fraction of electricity shortfalls. Moreover, the losses are applied to only the activities of the cantons that are connected to the main electricity grid. As was discussed in the section on

Table 10. **Estimated impacts of the loss of Arenal dam**

	Costs Assigned To ICE 10^6 US$	Costs in Lost Production* 10^6 US$	Costs in Lost Foreign Exchange Assets* 10^6 US$	Lost Working Hours* 10^6 Hours
Repair Costs	74.1	0.0	0.0	0.0
Operational Costs in the First Month	6.9	19.7	8.9	1.8
Operational Costs in the Next Two Months	11.0	74.8	33.7	7.0
Operational Costs in the Next 21 Months	208.5	0.0	0.0	0.0
Totals	300 5	94.5	42.5	8.8

Note: * for agricultural and industrial sectors only
Source: OEA-DSE

methodology, the production loss estimates apply only to agriculture and industry. If the energy dependence relationships were similar for the rest of the economy, then the loss figures would be approximately two and a half times the levels presented under production.

For ICE, the costs of the event include the costs of reconstruction of the dam, the lost revenue from unsold electricity, the additional costs of thermal power generation and import purchases, as well the electricity purchased from the emergency generation units

5.2.4 Mitigation Alternatives

Given the low probability of major impact by an earthquake, it is doubtful that vulnerability reduction measures such as additional structural reinforcement or monitoring will be undertaken at the Arenal dam. Impact mitigation actions are advisable, however.

It is clear that the thermal plants used for peaking and backup operation need substantial renovation. Clearly, this action would improve but not solve a problem of the magnitude discussed here. The combination of the low probability of the event and the need for electric generation expansion in Costa Rica suggests a long term mitigation in guaranteeing that generation expansion take place away from the Arenal complex. Finally, it is important that ICE be prepared with all the information and contacts necessary should there be a future need to acquire emergency generation equipment from outside the country.

5.3 Event 2: Severe Landslide at San Blas

5.3.1 Description of the Event

The combined conditions that could exacerbate another and potentially more damaging landslide at San Blas would be a season of heavy rainfall resulting in deeply saturated soils, a very heavy recent rain causing high water runoff, and finally, a severe earthquake The earthquake could loosen the unstable material and begin movement of a very liquid material down stream. The event might activate other mass movements affecting much larger cross sections of the Río Reventado including the tops of the walls of the existing slide where all the energy infrastructure is supported. For this event, it is assumed that the landslide would take out the two electric transmission lines connecting Cachí and Río Macho to the central grid, the RECOPE pipeline, and among the various bridges downstream, the railroad crossing. It is clear that an event of this magnitude would include loss of life, especially in the more populated areas downstream.

It is also assumed that the width of damage caused by the slide would make it impossible to reconstruct the energy infrastructure in its original location, requiring the search for another crossing point or, at least, much longer crossing distances requiring much higher towers. The instability of the landslide area, would make it unwise to support any infrastructure setting directly on the slide material, or even worse, to attempt to construct a tower in this medium. For these reasons, it is assumed for the analysis that the damage caused by this event would not have even temporary repair for a full month after its occurrence.

5.3.2 Description of Emergency Response

Table 11 describes the sources and amounts of available electric energy to supply the cantons located to the northwest of the break in infrastructure. This region contains all of the Central Valley and the cantons that surround the grid following it to the border with Nicaragua. This region's annual electric generation needs for 1988 were 2791 8 thousand MWH. The plants that would partially cover these needs are Arenal, Corobicí, La Garita and three of the four thermal plants located in this area The balance of available supply would be imported from Honduras. The shortfall equivalent of 506.2 thousand MWH per year represents 18.13 percent of the area's electricity needs

The closing of the RECOPE pipeline as well as the interruption in operation of the railroad would shift all petroleum distribution to the only remaining supply source in Limón (the Turrialba facility along the pipeline is used only for pumping). All petroleum light products, diesel, gasoline, kerosene, and jet fuel as well as the heavies, principally fuel oil, would need to be moved by tank truck from Limón. The size of the tank truck fleet in Costa Rica is adequate to perform this job; these trucks are used regularly to distribute petroleum products from the existing terminals along the RECOPE pipeline to the points of demand. The question of road blockage is valid. With an earthquake of the magnitude to activate another San Blas landslide, it would seem evident that other landslides would be likely. There are three major road accesses to San José from Siquirres, the town where landslide concerns begin. It would seem unlikely that all three of these roads would be impassible for more than just a few days.

Table 11. Supply and cost of electricity in case of a severe landslide in San Blas

	1988 Normal Case 10^3 MWH	1988 San Blas Northern Area 10^3 MWH	1988 San Blas Costs 10^3 US$
Arenal	468.5	468.5	---
Corobicí	550.6	550.6	---
La Garita	627.9	627.9	---
Río Macho	571.1	0.0	---
Cachí	614.9	0.0	---
Thermal	94.0	338 6	21400.2
Imported	190.6	300.0	4186.7
Emergency	---	506.2	0.0
Total	3117.6	2791.8	25587.0
Percentage of Electricity Demand Not Covered	---	18.1326	---

Note: --- means "not applicable."
Source: OEA-DSE

The bottleneck appears at the transfer point in Limón. Evaluation of the maximum transfer capabilities at the Limón terminal showed a serious limitation for the transfer of diesel and a slight limitation for that of gasoline. Table 12 shows these results as applied to the 1988 figures for the transfer of light petroleum products by the RECOPE pipeline. The shortfall of 1 294 thousand barrels represents 28.64 percent of the total transfer. The transfer of fuel oil does not appear to be limited. Because of the importance of fuel oil to industrial production, this amount was included in the total transfer amount resulting in a reduction of the shortfall percentage to 24.73.

RECOPE maintains a reserve capacity of fuels in all of its terminals that would be used during the initial days of the emergency. At the end of the month when the infrastructure begins operation again, there will still be a period of shortfall until the system reaches a state of normalcy. (Note that the RECOPE pipeline is currently operating at near capacity.) For this reason, it was decided to maintain the petroleum shortfalls for the full period of one month.

5.3.3 Summary of the Impacts

The losses of 18.13 percent of electricity and 24.73 percent of petroleum products were applied to the cantons located within access to the electric grid to the northwest of the break in electric infrastructure at San Blas. For the rest of the cantons in the country, only the 24.73 percent petroleum loss was applied. Table 13 presents the overall results of this analysis.

Table 12. Impact of the transfer limits at Limón petroleum terminal

	Product Demand 1988 10^3 BBL	Annual Transfer Capacity Limon Terminal BBL/HR	Annual Maximum Transfer Limon Terminal 10^3 BBL	Shortfall in Transfers at Limon 10^3 BBL
DIESEL	2671	192.59	1518.4	1153
GASOLINE	1508	173.33	1366.5	141
JET FUEL	258	192.59	1518.4	0
KEROSENE	82	96 30	759.2	0
TOTAL	4519	---	---	1294
FUEL OIL	971	---	---	0
TOTAL	5490	---	---	1294

Short fall Fraction of Total Pipeline Transfers in 1988 .... 0 2864

Total Shortfall Fraction: Fuels used for Economic Production (Diesel, Gasoline, Kerosene and Fuel Oil) 0.2473

Note: --- means "not applicable."
Source: OEA-DSE

In the one month of emergency, ICE has a U.S.4 5 million dollar loss, principally in lost electricity sales, purchases of electricity from Honduras and in the high costs of the operation of the thermal plants. The repair cost to the towers and lines is not expected to be significant if it is just a question of two new towers and a longer stretch of cables.

The cost of repair for the pipeline could not be estimated in the time of this analysis, although, as with the case of ICE, the costs are not expected to be high. The amount of U.S.1.1 million dollars represents the additional costs that RECOPE would need to cover for the transportation of light and heavy petroleum products by truck from Limón to the petroleum terminals normally supplied by the pipeline.

The costs in lost agricultural and industrial production are significant, summing to U.S.68 1 million dollars. The losses in exports and labor are U.S.30.4 million dollars and 6 million hours, respectively.

Table 13. Estimated impacts of a severe landslide in San Blas

	Costs Assigned to ICE 10^6 US$	Costs Assigned to RECOPE 10^6 US$	Costs in Lost Production* 10^6 US$	Costs in Lost Foreign-Exchange Assets* 10^6 US$	Lost Working Hours* 10^6 Hours
Repair Costs	0.00	**	0.00	0.00	0.00
Operational Costs in the First Two Months	4.49	1.06	68 14	30.40	6.02
Totals	4.49	1.06	68.14	30.40	6.02

Note: * for agricultural and industrial sectors only
** means "not determined."
Source: OEA-DSE

5.3.4 Mitigation Alternatives

The seriousness of the San Blas landslide is a result of the concentration of energy infrastructure in one hazardous area. The characteristics of the potential event makes it unfeasible to attempt to structurally reinforce the energy infrastructure in the area as a vulnerability reduction strategy. The best approach to mitigation is to provide system redundancy so that alternative energy paths are available for immediate use in the case of a destructive San Blas landslide.

For electricity, the best alternative appears to be the construction of a new transmission line from Río Macho to the grid around San José, bypassing the San Blas area. This line should be designed for 230 KV to provide adequate capacity and also to serve to close the existing gap in the national 230 KV infrastructure.

For petroleum, the RECOPE pipeline reliability suffers from its lineal and one-directional flow. Whatever breakage in the line[2] implies a shutdown of petroleum transfer past that point. Any breakage between Limón and El Alto implies a complete shutdown of the line. The alternatives available are to construct a new line following a different route between say Siquirres and San José or to consider providing petroleum in a reverse direction from the Pacific in the case of a pipeline blockage in the eastern segment of the country. The proximity of the Barranca terminal to the Pacific coast strongly suggests the option of petroleum import from the west and conversion of the line to operate in reverse if that should be necessary.

[2] Breakage here means the rupture of the pipeline system which involves one or two pipelines depending on the location of the break.

RECOPE has studied one option for importing petroleum from a Pacific port.[3] That report recommends the use of the dock facilities at Punta Morales, 38 km to the north of Barranca as the best option versus providing a pipeline tie to the national port at Caldera located just a few km to the south of the terminal. The principal concerns at Caldera are the lack of dock space and insufficient depth. The docks at Punta Morales can accept up to 30 000 DWT capacity ships.

The RECOPE study proposes the installation of petroleum transfer infrastructure at Punta Morales and an eight inch pipeline to Barranca and the necessary additional tanks at this terminal. That study does not include analysis of the costs of pumps at Barranca nor the costs of installation of bypasses to the check valves which would permit use of the existing pipeline in reverse.

5.3.5 Description of the Selected Mitigation Projects

The projects selected for the mitigation of the Event 2 are slight modifications of those just described:

Project 1: New 230 KV Transmission Line between Río Macho and San Miguel

Project 2: Pacific Petroleum Import Infrastructure - Punta Morales

Project 1 appears on the ICE list of future electric infrastructure projects principally as an extension of the 230 KV transmission system. To date a specific routing has yet to be designed and costed. San Miguel is a proposed electric substation to be built on the northern side of San José (See Project 3). The extension of this line around the city provides a continuous 230 KV linkage with the lines from the northern part of the country. Using a cost of US$ 80 000/km for 230 KV line for the estimated 36 km total length and an addition US$ 700 000 for substation needs gives an initial estimate of U.S.3.6 million dollars as the project capital cost.

Project 2 requires more evaluation before a specific import site can be finally selected. For the purposes here, the project follows the recommendations of RECOPE in the study just cited and includes the petroleum product transfer facilities at Punta Morales, the pipeline to Barranca with the necessary additional infrastructure at that terminal. The total cost of this project was estimated by RECOPE at U.S.7.4 million dollars. It is recommended that in follow-up analyses that this project include the costs of additional pumps in Barranca and the required bypasses to permit the reversal of the pipeline to El Alto. The additional cost of these bypasses is not expected to be great

5.4 Event 3: Loss of the La Caja Substation

5.4.1 Description of the Event

A severe earthquake may cause destructive damage to the three 230-138 KV transformers in La Caja. These transformers provide the primary link between San José and the power delivered from the Arenal and Corobicí plants as well as the energy transferable from Honduras. The power from La Garita also passes

[3] RECOPE: Estudio de Prefactibilidad Multicriterio - Proyecto: Importación de Productos Terminados por el Litoral Pacífico, Mayo 1989

through this substation, however, without voltage change. Whatever damage that might occur in this latter linkage is expected to be easily repaired. Such is not the case with the transformers.

5.4.2 Description of Emergency Response

ICE does not maintain any spare 230-138 KV transformers. Besides the three at La Caja, there is one installed at Barranca and one at Río Macho. In the case of the loss of one of the former three transformers, ICE would disconnect the line from Río Macho to the south and transfer the Río Macho transformer by truck to replace the damaged unit.

The normal purchase of new transformers of this size is a lengthy process requiring a purchase announcement, submission of bids and when a contract is awarded, a period for assembly of the units, shipping and their installation. In an emergency situation, a government exception to this process may be obtained. As companies that produce large transformers rarely maintain an inventory of transformers with the specifications needed but make all transformers to order, emergency access for replacement transformers would most likely have to come from used equipment markets. If this acquisition could be arranged and the transfer to Costa Rica provided by air transport services, one could expect, at best, a one month loss in electric service because of the event.

The cut of 230 KV service at La Caja would affect all the cantons to the east and south of this point. In a similar format to that presented before, Table 14 provides a

Table 14. Supply and cost of electricity in case of a loss of La Caja substation

	1988 Normal Case 10^3 MWH	1988 La Caja South 10^3 MWH	1988 La Caja Costs 10^3 US$
Arenal	468.5	0.0	---
Corobicí	550 6	0.0	---
La Garita	627 9	627.9	---
Río Macho	571.1	571 1	---
Cachí	614.9	614.9	---
Thermal	94 0	308 4	18755.8
Imported	190.6	262 8	24241.7
Emergency	---	97.0	0.0
Total	3117.6	2482.1	42997.5
Percentage of Electricity Demand Not Covered	---	3 9099	---

Note: --- means "not applicable."
Source: CEA-DSE

summary of the electricity needed in the affected area in 1988. This zone would lose principal access to the electricity supplies from Arenal, Corobicí, Honduras, as well as the thermal plant in Barranca.[4]

As long as the Río Macho 230-138 KV transformer is not relocated, this area would receive energy from the plants at La Garita, Cachí, Río Macho as well as from Panamá and the thermal plants in the San José and Limón As is shown, on an annual basis, the shortfall in supply is only 97 103 MWH representing 3.91 percent of the total energy needed.

5.4.3 Summary of Impacts

Table 15 provides a summary of the estimated impacts of this event. Each new transformer is estimated to have an installed cost of US$500 thousand, implying a total replacement cost

Table 15. Estimated impacts of the loss of La Caja substation

	Costs Assigned to ICE 10^6 US$	Costs in Lost Production* 10^6 US$	Costs in Lost Foreign Exchange Assets* 10^6 US$	Lost Working Hours* 10^6 Hours
Repair Costs	1.5	0 0	0.0	0.0
Operational Costs in the First Month	4.0	6 9	1.9	0 6
Total	5.5	6.9	1.9	0.6

Note: For agricultural and industrial sectors only.
Source: OEA-DSE

of the three transformers of about U.S.1.5 million dollars. ICE costs include the costs of purchase of emergency power from Panama, the additional costs of thermal power generation and the costs of energy not sold. The economic and labor impacts are significantly less than in the other cases because of the small percentage loss in electricity availability.

5.4.4 Mitigation Alternatives

There are at least three mitigation approaches in this case. The most obvious is to provide an adequate inventory of transformers for replacement in case of such an emergency.

[4] A small amount of electricity could be passed from Barranca to La Caja through the La Garita circuit.

The second is to upgrade the standards for substation construction that guarantee protection against damage from major seismic events.

Another approach which would satisfy a broader range of objectives would be to provide route redundancy so that the La Caja could be bypassed in an emergency. Of the route options available, the most effective seems to be a new 230 KV line beginning at the Arenal power plant and ending at the central valley grid at a location other than La Caja and routed via the Atlantic side of the continental divide. This new line would provide a more assured supply of electricity to the communities in this area as well as the redundancy needed for the complete linkage between Arenal and San José on the Pacific slope. It can be seen in the vulnerability matrix for the electricity sector that this new line will mitigate not only the La Caja bottleneck but potential and existing natural hazard related problems along the entire existing route.

5.4.5 Description of the Selected Mitigation Project

Project 3 is a 140 km single circuit 230 KV transmission line between the Arenal substation and the Central Valley grid. The line will pass to the north of the Arenal reservoir so as to avoid the Arenal Volcano to the south. From the reservoir it will descend the Atlantic slopes of the mountains to a new substation which will serve the community of Ciudad Quesada. From there the line will continue to the central valley connecting initially at a new substation at San Miguel located on the northern side of the central grid. From here the 230 KV line will continue another 14 km to the La Caja Substation to complete the 230 KV circuit.

The total cost of this project is estimated to be US$23.6 million dollars.

5.5 Summary of the Results of this Study

Table 16 presents a summary of the estimated impacts of the three cases selected for evaluation in this study. In addition, the table shows the costs of the three mitigation projects. Map 3 gives an approximate location of each of three proposed projects.

It is important to note that these projects will have benefits in addition to just those of mitigation of the purported events. Project 3 will provide grid supplied electricity to another area of the country. Project 2 provides Costa Rica with access to Pacific markets for petroleum.

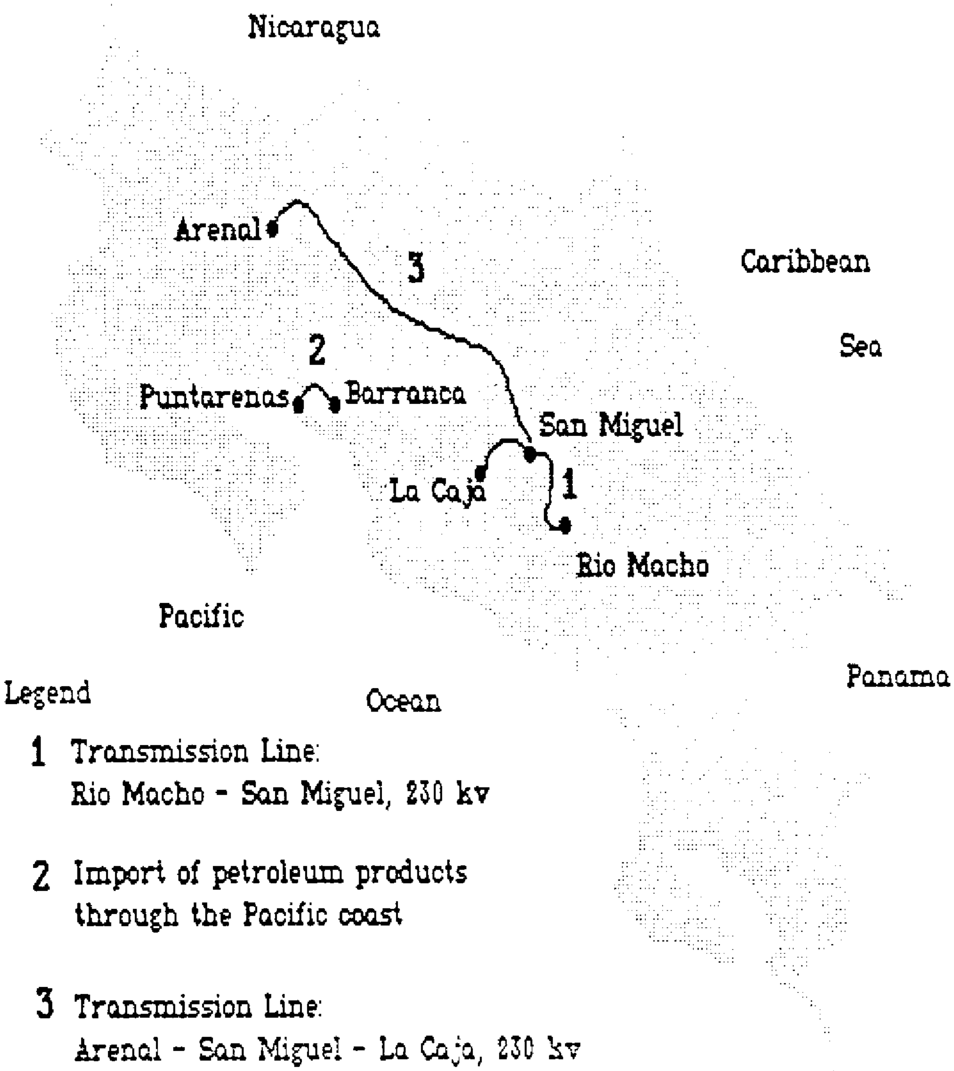
The presentation format provides a mechanism to give decision makers a tool for comparing natural hazard impacts with the costs of their mitigation. This approach could be used for the justification of a package of projects designed solely for mitigation, or more likely, because the individual projects are the responsibility of separate energy institutions, the process can be used as a part of the justification of these individual projects within their own expansion plans. This is expected to be the case in Costa Rica.

Table 16. Impacts of natural hazard events to the energy system of Costa Rica and costs of mitigation projects

	Event 1 Cost of Arenal Dam	Event 2 Destructive Landslide at San Blas at La Caja	Event 3 Earthquake with Destruction of Transformers
Cost to ICE (10^6 US$)	300.5	4.5	5.5
Cost to RECOPE (10^6 US$)	0.0	1.1**	0.0
Losses in Production* (10^6 US$)	94.5	68.1	6.9
Losses in Exports* (10^6 US$)	42.5	30.4	1.9
Losses in Employment* (10^6 Hours)	8.8	6.0	0.6
Cost of Inversion for <u>Mitigation Projects</u>:			
Transmission Line Río Macho/Anillo Central (10^6 US$)	---	3 6	---
RECOPE Pacific Project (10^6 US$)	---	7.4	---
Transmission Line Arenal/Central Ring (10^6 US$)	---	---	23.6

Note: * For agricultural and industrial sectors only.
** does not include costs of pipeline repair
--- means "not applicable."
Source: OEA-DSE

Map 3. Location of the proposed projects



Source: OAS - DSE