HOW DOES CLIMATE CHANGE AFFECT THE ASSESSMENT OF LANDSLIDE RISK?

• It won't change the assessment process, but might make estimation of landslide probability harder.
• Uncertainty will increase – but there are usually other significant sources of uncertainty (e.g. consequences, asset failure criteria, vulnerability, exposure).
• Decisions must be made, despite uncertainty
INTRODUCTION: HAZARDS AND RISK

- **Risk** is the potential for adverse consequences, loss, harm or detriment.

- **Risk = Prob. (Geohazard event) x Adverse Consequences**

- **Geohazards** are geological materials, features or processes that in particular circumstances could lead to loss.

- **Adverse consequences** might include accidents, loss of life, damage to assets and facilities, environmental impacts and associated financial losses.
RISK ASSESSMENT

what can happen? i.e. hazard assessment;

how likely is it? i.e. estimating the probability of the hazards;

what will be the losses and damages? i.e. consequence assessment

does it matter? i.e. risk evaluation;

what should be done about the risks? i.e. risk management

MARK LEE JULY 2006
RISK VALUES

• Reducing risk to a *mathematical value* – allows comparison of landslide “risk” with other risks – *third party damage, explosion* or *fire* - in order to determine their relative significance.

• Same values of “risk” can be the product of different combinations of *probability* and *consequence*:

  • a 1 in 2 chance (Prob. = 0.5) of landslide movement causing $1M worth of damage
  • a 1 in 200 chance (Prob. = 0.005) debris flow causing $100M of damage;
  • a 1 in 4,000 chance (Prob. = 0.00025) catastrophic flood with losses of $2B.
  • All have *mathematical expectation values* of $0.5M.
  • Risk values may be the same although the “perceived threats” may be different.
WHAT DO RISK VALUES MEAN?

Risk is ever present. Risk can be increased, decreased, transferred but rarely eradicated.

RISK MANAGEMENT: KEY PRINCIPLES

- There is a level of risk that is *unacceptable*;
- Below this threshold risks may be *tolerated* not accepted;
- If the risk is *unacceptable* it must be avoided or reduced, irrespective of the benefits;
- If the risk falls within the *ALARP* region then cost may be taken into account. Beyond a certain point investment in risk reduction may be an inefficient use of resources.
RISK TOLERABILITY CRITERIA: F-N CURVES

These are *explicit* statements of risk tolerability. In most cases the limits of tolerability are *not defined* – they will reflect the perceived severity of risk and the resources/responsibility to act.
DEVELOPING F-N CURVES

Risk values can be presented in the form of F-N curves. These are plots of the cumulative frequencies of events (F) causing N or more losses (N can be a specified level of financial loss or a number of fatalities etc.).

To generate an F-N curve, the geohazard events (scenarios) are sorted from the lowest to the highest consequence.

Individual points on the curve represent combinations of consequence and cumulative frequency/probability.
USE OF F-N CURVES

PLOT THE F-N CURVE RELATIVE TO RISK ACCEPTABILITY CRITERIA
GEOHAZARD RISK MODEL

F

GEOHAZARD EVENT

"HITS" DEVELOPMENT

HIGH INTENSITY EVENT: DAMAGE

LEVEL OF DAMAGE

FINANCIAL LOSS

N

SMALL RAPID LANDSLIDE

HITS PIPELINE

DAMAGES PIPELINE

FULL-BORE RUPTURE

$22.5M LOSSES

GEOHAZARD SCENARIO

DAMAGE EVENT

OUTCOME SCENARIO

CONSEQUENCE

QUESTION 1. WHAT COULD HAPPEN?
QUESTION 2. HOW COULD IT HAPPEN?
QUESTION 3. WHERE COULD IT HAPPEN?
QUESTION 4. WHAT IS THE CHANCE OF IT HAPPENING?
LANDSLIDE RISK, CASPIAN PIPELINES

GEOMORPHOLOGICAL MAP (EXTRACT)

PIPELINE ROUTE

REAR SCARP
OLD ROCKFALL AVALANCHE
DGVIRI RIVER CHANNEL
MUDSLIDE HEAD
MUDSLIDE TRACK
MUDSLIDE DEBRIS APRON
TADRISI DEBRIS FAN

SCHEMATIC SUMMARY MODEL

400m

1800m
CASPIAN MUDSLIDE: RISK ASSESSMENT (F VALUES)

1. Identify and characterise potential hazards to the pipeline (*hazard assessment*);
2. Define failure modes and critical impact thresholds (*damage potential*);
3. Assess pipeline vulnerability to landslide hazards (*vulnerability assessment*);
4. Development of a probability model and estimation of probabilities (*probability assessment*);
5.Revision of the probability model to take account of *geotechnical stability improvements* and define the residual risk.
**STEP 1: LANDSLIDE HAZARD**

*Landslide scenarios* are credible sequences of events that could result in landslide movement.

For the Caspian mudslide, credible scenarios for landslide events affecting the **mudslide track** are:

**Scenario 1**: Loading of the mudslide track, leading to landslide reactivation;

**Scenario 2**: Unloading of the mudslide track, leading to landslide reactivation.
STEP 1: LANDSLIDE HAZARD

SCENARIO 1: LOADING OF TRACK

1.1 Rockfall avalanche from the mountain slopes to the south;
1.2 Extreme groundwater conditions in mudslide head (close to ground surface);
1.3 Earthquake (seismic acceleration).

MUDSLIDE RESPONSE

• Downslope advance of mudslide head units into track area

SCENARIO 1; LOADING

POTENTIAL TRIGGERS:
• 1.1 Rockfall avalanche from the mountain slopes to the south;
• 1.2 Extreme groundwater conditions in mudslide head (close to ground surface);
• 1.3 Earthquake (seismic acceleration).
OUTCOMES:
- Secondary mudslide developed within main mudslide track;
- Reactivated movement of the main mudslide

POSSIBLE LANDSLIDE CHARACTERISTICS:

<table>
<thead>
<tr>
<th>EVENT</th>
<th>VELOCITY</th>
<th>CUMULATIVE DISPLACEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CREEP</td>
<td>&lt;0.01m/year</td>
<td>&lt;0.01m</td>
</tr>
<tr>
<td>MINOR</td>
<td>&lt;1m/year</td>
<td>&lt;1m</td>
</tr>
<tr>
<td>MAJOR</td>
<td>1m/month</td>
<td>&gt;1m</td>
</tr>
</tbody>
</table>
STEP 2: DAMAGE POTENTIAL

Not all landslide events will cause damage to the pipeline. The potential for damage is controlled by the magnitude of the *lateral loadings* and *unloading* imposed by the event. This is a function of the intensity (e.g. mass and velocity) and duration of the event.

- **Lateral loading**: pipe rupturing as a result of differential horizontal and/or vertical movement of the landslide mass.
- **Unloading**: pipe failure as a result of removal of support along a significant length following landslide movement.
STEP 2: DAMAGE POTENTIAL

- A simple model of the critical loadings was developed, focusing on the scale of ground disruption (e.g. velocity and cumulative displacement) and impact stress that could be expected to cause failure (i.e. rupture, bending).
- Specific thresholds have been identified:
  - *Lateral loading*: >1m displacement over a 25-30m length;

<table>
<thead>
<tr>
<th>EVENT</th>
<th>VELOCITY</th>
<th>CUMULATIVE DISPLACEMENT</th>
<th>DAMAGE POTENTIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>CREEP</td>
<td>&lt;0.01m/year</td>
<td>&lt;0.01m</td>
<td>NO</td>
</tr>
<tr>
<td>MINOR</td>
<td>&lt;1m/year</td>
<td>&lt;1m</td>
<td>NO</td>
</tr>
<tr>
<td>MAJOR</td>
<td>1m/month</td>
<td>&gt;1m</td>
<td>YES</td>
</tr>
</tbody>
</table>
STEP 3: VULNERABILITY

• **Vulnerability** is a measure of the chance (0 to 1) that the pipeline would fail if it were impacted by a landslide of a particular size/intensity.

• At present, little is known about component vulnerability to landslide movement. BP Colombian experience was used as a guide.

Size and direction of the slide are **KEY factors**. The greatest spills and down time occurs when the slide movement is parallel to the pipeline alignment (TYPE B).
STEP 4: PROBABILITY MODEL

• What is the chance of a landslide causing pipeline rupture in a particular time period (year)?

Prob.(Rupture) = Prob. (Landslide) x Prob. (Impact|Landslide) x Prob.(Rupture|Impact)

• The symbol “|” denotes “given”, as in given that the previous event has occurred.
• Prob. (Landslide) is a measure of the expected likelihood of a particular landslide event (e.g. reactivation).
• Prob. (Impact|Landslide) is a measure of whether the ground displacement was of sufficient intensity to damage (impact) the pipeline.
• Prob. (Rupture|Impact) is a measure of the chance (0 to 1) that the pipeline would be ruptured if it were impacted by a landslide of a particular size/intensity (i.e. vulnerability).
STEP 4: PROBABILITY MODEL

An indication of the expected *likelihood of each landslide scenario occurring* was made on the basis of the field observations, together with experience of landslide activity in this area and worldwide.

The likelihood classes used in this assessment are:

<table>
<thead>
<tr>
<th>Likelihood Class</th>
<th>Descriptor</th>
<th>Description</th>
<th>Estimated Annual Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ALMOST CERTAIN</td>
<td>The event is expected to occur</td>
<td>&gt;0.1</td>
</tr>
<tr>
<td>2</td>
<td>LIKELY</td>
<td>The event will probably occur under adverse conditions</td>
<td>&gt;0.01</td>
</tr>
<tr>
<td>3</td>
<td>POSSIBLE</td>
<td>The event could occur under adverse conditions</td>
<td>&gt;0.001</td>
</tr>
<tr>
<td>4</td>
<td>UNLIKELY</td>
<td>The event might occur under very adverse circumstances</td>
<td>&gt;0.0001</td>
</tr>
<tr>
<td>5</td>
<td>RARE</td>
<td>The event is conceivable but only under exceptional circumstances</td>
<td>&gt;0.00001</td>
</tr>
<tr>
<td>6</td>
<td>NOT CREDIBLE</td>
<td>The event is inconceivable or fanciful</td>
<td>&gt;0.000001</td>
</tr>
</tbody>
</table>
STEP 4: PROBABILITY MODEL

Probability estimates for the mudslide track scenarios are:

<table>
<thead>
<tr>
<th>LANDSLIDE SCENARIO</th>
<th>TRIGGERS</th>
<th>OPEN FORUM LIKELIHOOD</th>
<th>ESTIMATED PROBABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. LOADING</td>
<td>1.1 ROCKFALL AVALANCHE</td>
<td>RARE</td>
<td>0.00075 (c. 1 in 1300)</td>
</tr>
<tr>
<td></td>
<td>1.2 EARTHQUAKE</td>
<td>UNLIKELY-POSSIBLE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.3 HIGH GROUNDWATER</td>
<td>UNLIKELY-POSSIBLE</td>
<td></td>
</tr>
<tr>
<td>2. UNLOADING</td>
<td>2.1 EARTHQUAKE</td>
<td>UNLIKELY</td>
<td>0.00025 (1 in 4000)</td>
</tr>
<tr>
<td></td>
<td>2.2 HIGH GROUNDWATER</td>
<td>UNLIKELY</td>
<td></td>
</tr>
</tbody>
</table>

The combined probability of a landslide event within the mudslide track is **0.001** (0.00075 + 0.00025; 1 in 1000).

Prob. (Landslide) = 0.001
STEP 4: PROBABILITY MODEL

- Only major events involving >1m displacement over a 25m length are considered to have the potential to damage the pipeline (i.e. *major events*).

- The relative likelihood of a major event, compared with creep or minor events (<1m displacement) is judged to be:

<table>
<thead>
<tr>
<th>EVENT</th>
<th>VELOCITY</th>
<th>CUMULATIVE DISPLACEMENT</th>
<th>DAMAGE POTENTIAL</th>
<th>RELATIVE LIKELIHOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CREEP</td>
<td>&lt;0.01m/year</td>
<td>&lt;0.01m</td>
<td>NO</td>
<td>0.25</td>
</tr>
<tr>
<td>MINOR</td>
<td>&lt;1m/year</td>
<td>&lt;1m</td>
<td>NO</td>
<td>0.25</td>
</tr>
<tr>
<td>MAJOR</td>
<td>1m/month</td>
<td>&gt;1m</td>
<td>YES</td>
<td>0.5</td>
</tr>
</tbody>
</table>

\[
\text{Prob. (Impact|Landslide)} = 0.5
\]
STEP 4: PRE SLOPE IMPROVEMENT RISK

- The vulnerability factor represents the uncertainty as to whether a landslide event of a particular intensity will actually cause pipe rupture.

- It has been assumed that only two-thirds of major landslides (i.e. >1m displacement) would actually lead to pipe rupture (i.e. 66%).

\[ \text{Prob. (Rupture|Impact)} = 0.66 \]

What is the annual probability of a landslide causing pipeline rupture in the mudslide crossing?

\[ \text{Prob.}(\text{Rupture}) = \text{Prob. (Landslide)} \times \text{Prob. Impact|Landslide)} \times \text{Prob. (Rupture|Impact)} \]
\[ = 0.001 \times 0.5 \times 0.66 \]
\[ = 0.00033 \text{ (1 in 3030)} \]
STEP 5: RESIDUAL RISK (POST IMPROVEMENTS)

Drainage and slope improvement works in the mudslide area will reduce the probability of pipeline rupture due to landslide movement. It has been assumed that the stability improvement measures will reduce the risk by a factor of 10 (i.e. x 0.1).

It is expected that this underestimates the benefits of stability improvement and, hence, gives an upper estimate for the residual risk:

\[
\text{Residual Risk} = \text{Prob. (Rupture)} \times \text{Stability Improvement Factor} \\
= 0.00033 \times 0.1 \\
= 0.000033 \text{ (c.1 in 30,000)}
\]
Recent climatic modelling by IPCC suggests that in the Caspian Region, over the next 100 years there could be an increase in winter precipitation by between 5-20% and an increase in winter temperatures, i.e. there may be a tendency for the winter precipitation to fall as rain rather than snow.

These predicted changes in climate will probably lead to an increase in the probability of landslide activity in the region, given the sensitivity of the landslides to high groundwater levels.

CLIMATE CHANGE AND RISK: UNCERTAINTY

- “As we know there are *known knowns*. There are things we know we know. We also know there are *known unknowns*. That is to say we know there are some things we do not know. But there are also *unknown unknowns*, the ones we don’t know we don’t know"

Epistemic (model) uncertainties arise from lack of knowledge about the behaviour of a phenomenon. *Lack of knowledge uncertainty*.

Aleatory (random) uncertainties arise from possible variation and stochastic errors in the values of the parameters and their estimates.

**Parameter uncertainty** may often be assessed by use of "objective" statistics to give probability distributions

**System uncertainty** cannot normally be assessed by "objective" statistics and must be assessed "subjectively"

**Uncertainty** is a combination of parameter and system uncertainty
THE RISK ASSESSMENT PROCESS

<table>
<thead>
<tr>
<th>Knowledge of Consequence</th>
<th>Knowledge of Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>

- Ambiguity about the Risk
  - uncertain or unknown impacts;
  - uncertain how to value consequences

- Ignorance about the Risk
  - changing climate;
  - new/unknown processes;
  - insufficient data

- Good Knowledge of the Risk
  - unchanging environment;
  - good historical data;
  - good consequence models

- Uncertain probability
  - poor historical record;
  - limited evidence of frequency of extreme events

Risk is sensitive to the availability of knowledge of geohazards and consequences;

As our knowledge increases the confidence in the risk assessment will increase;

Additional knowledge will reduce uncertainty (e.g. with *known unknowns*) and minimise the potential for unforeseen conditions (e.g. the *unknown unknowns*).
CLIMATE CHANGE AND RISK ASSESSMENT: SO WHAT?

• Risk assessment is a tool for considering management options, rather than supporting engineering design (pragmatism not precision);
• The focus should be on defining:
  – are the risks intolerable?
  – are risk reduction measures worthwhile i.e. do the benefits exceed the costs?
• Risk assessment involves a range of model components:
  – Hazard models;
  – Hazard probability models;
  – Asset failure models;
  – Vulnerability models;
  – Consequence models.
• Climate change increases uncertainty in hazard probability models.
• Decisions must be made, despite uncertainty.