AUSCULTACIÓN EFICIENTE DE PRESAS:
LECCIONES APRENDIDAS Y NUEVAS TENDENCIAS

Risk Analysis, Monitoring and Surveillance: Basic tools in Dam Safety Management

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Chairman: ICOLD Technical Committee on Dam Surveillance

Propósito de la presentación

- Comparto mi experiencia en gestión de la seguridad de presas enfocando:
  - Análisis de riesgos
  - Vigilancia
    - Inspecciones
    - Auscultacion

So why risk analyses?

- Severe financial constraints
- Limited or no information
- Human capacity constraints especially from an operational point of view
- Difficulty with appropriate development solutions
- Consideration of failure mechanisms/ operational issues not normally considered with standards based approach

Why should there be such a discrepancy between our knowledge and our general practice? To some extent, I fear, because of too much specialization and too little appreciation of the interrelation of the various branches of civil engineering.

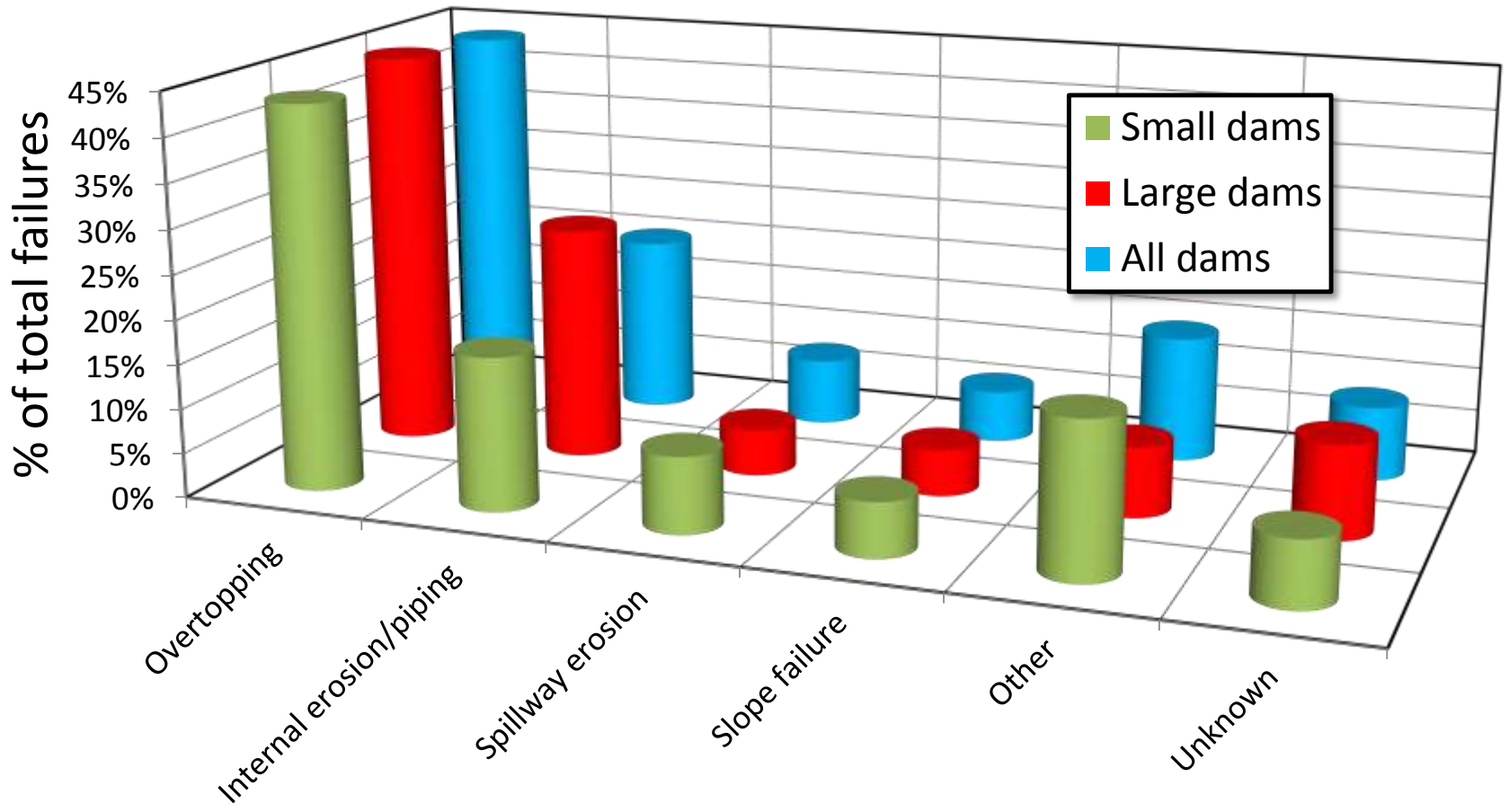
Ralph Peck

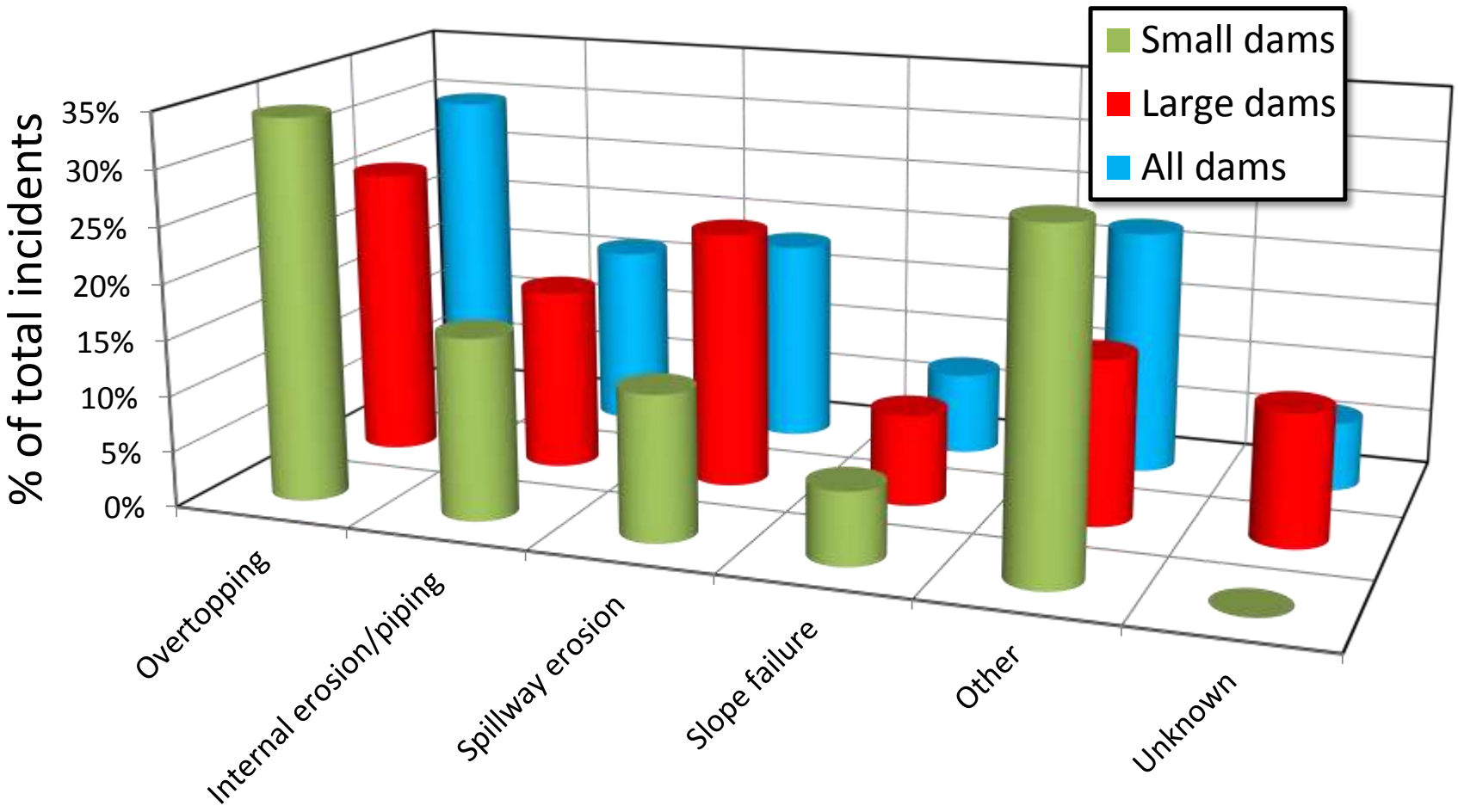
Approach

- Multi-level risk analysis (levels 0 to 2)
  - Level 0 – basic/qualititative
    - Simple probability calculations
    - Sound (experienced) engineering judgement
  - Level 2 – detail
- Most analyses only Level 0 due to financial & info constraints

Approach

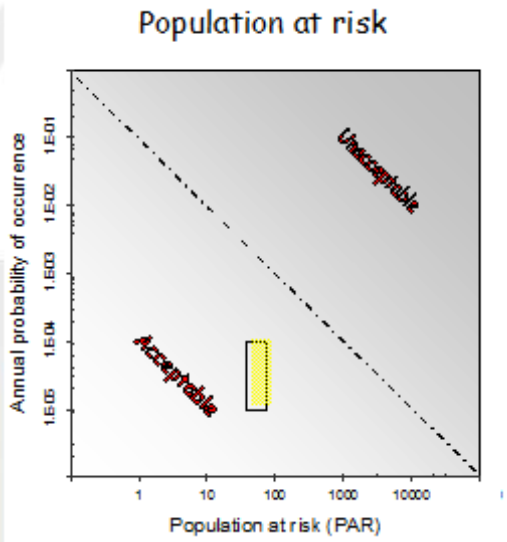
- STEP 1 - *Failure analysis*: Determine probability of dam failure by considering all possible failure mechanisms
- STEP 2 - *Consequence/hazard analysis*: Perform dam break analysis & assess potential losses in event of dam break
- STEP 3 - *Impact and risk assessment*: Evaluate acceptability of combination of impacts & risk
- STEP 4 - *Risk management*: Interpret, make decisions & act on findings of risk assessment

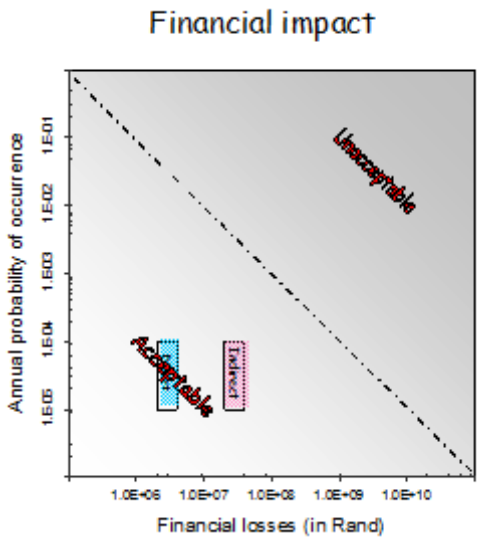

% of total failures
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Small dams
Large dams
All dams
Overtopping
Internal erosion/piping
Spillway erosion
Slope failure
Other
Unknown

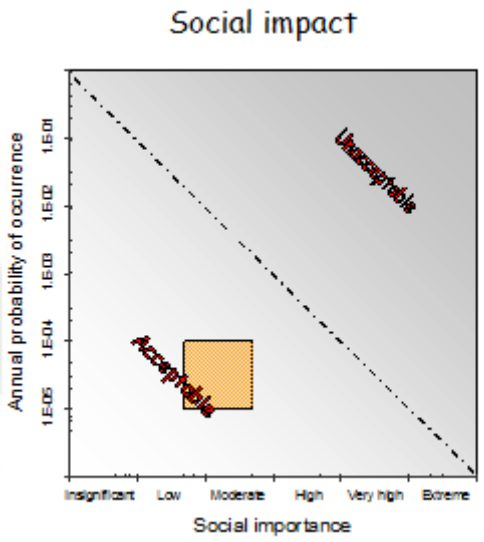

% of total incidents
35%
30%
25%
20%
15%
10%
5%
0%
Small dams
Large dams
All dams
Overtopping
Internal erosion/piping
Spillway erosion
Slope failure
Other
Unknown

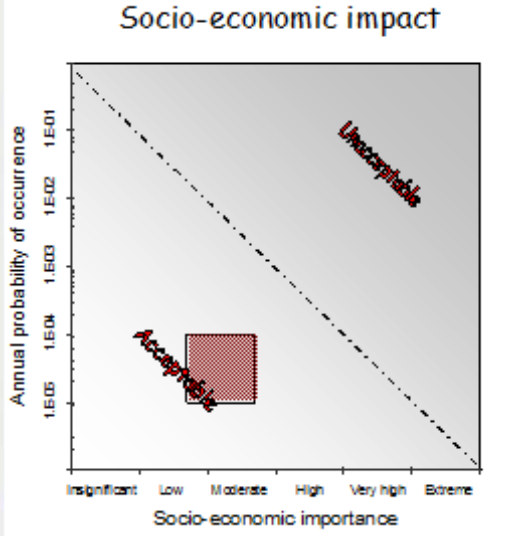
Approach

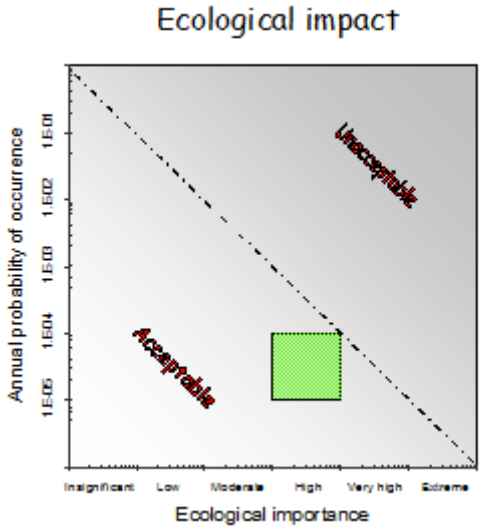
- Important failure analysis concepts for Level 0
  - *No detail fault & event trees*: Due to uncertainties in parameters -
    - Not warranted when applying confidence limits (68%) to data as uncertainties in the data dominate process & little or no significant advantage could be gained
  - Practical limit of calculated probabilities of failure is by default 10^{-6}
    - Failure probability of well-engineered dam with no known deficiencies = 10^{-5} to 10^{-6} by default
  - **Extend of failure probability at least 1 order of magnitude due to level of confidence – similar to USBR**


Population at risk
Annual probability of occurrence
1E-01
1E-02
1E-03
1E-04
1E-05
Unacceptable
Acceptable
1
10
100
1000
10000
Population at risk (PAR)

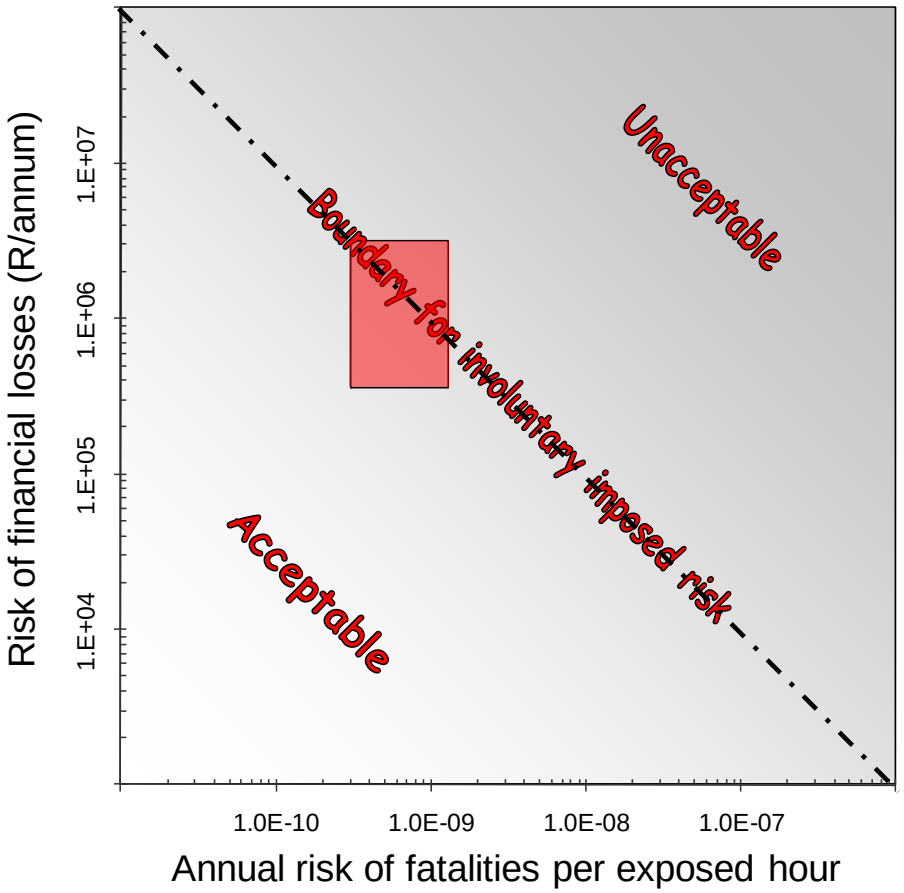

Financial impact
Annual probability of occurrence
1E-01
1E-02
1E-03
1E-04
1E-05
Unacceptable
Acceptable
Indirect
1.0E+06
1.0E+07
1.0E+08
1.0E+09
1.0E+10
Financial losses (in Rand)


Social impact
Annual probability of occurrence
1E-01
1E-02
1E-03
1E-04
1E-05
Unacceptable
Acceptable
Insignificant
Low
Moderate
High
Very high
Extreme
Social importance


Socio-economic impact
Annual probability of occurrence
1E-01
1E-02
1E-03
1E-04
1E-05
Unacceptable
Acceptable
Insignificant
Low
Moderate
High
Very high
Extreme
Socio-economic importance


Ecological impact
Annual probability of occurrence
1E-01
1E-02
1E-03
1E-04
1E-05
Unacceptable
Acceptable
Insignificant
Low
Moderate
High
Very high
Extreme
Ecological importance

Risk level


Risk of financial losses (R/annum)
1.E+07
1.E+06
1.E+05
1.E+04
Unacceptable
Boundary for involuntary imposed risk
Acceptable
1.0E-10
1.0E-09
1.0E-08
1.0E-07
Annual risk of fatalities per exposed hour

Range of purposes

- Started off as safety evaluations for use in portfolio management
- After more than 30 years of use:
  - *Planning*
    - Highlights for example risk of gated spillways not normally considered during planning – comparing apples with apples
  - *Design*
    - Importance of considering all failure mechanisms
    - Highlighting operational issues
  - *Dam safety evaluations*
  - *Rehabilitation options*
    - Including proper operation & maintenance
  - **DECISION-MAKING on especially O&M issues including proper surveillance**

Zoeknog Dam failure introduction

Background

Owner: Lebowa Homeland Government
Construction embankment: In-house Lebowa Homeland Government
Construction concrete Grinaker
Design and site supervision: Eksteen,van der Walt and Nissen

Basic Statistics

Height: 40 m
US slope: 2,5:1 upper part
4,0:1 lower down
DS slope: 2,0:1
Central clay core: 0,8:1
Chimney drain: Sand with Geo-textile upstream Blanket drain: Geotextile, sand, gravel and geotextile
Geology: Weathered granites

In hindsight

Dispersiveness tests only done prior to construction and not during construction
AASHTO specifications resulted in drier than optimum PROCTER moisture content
Homogeneous constructed
Blanket drain: 38mm aggregate sandwiched between geotextiles

Zoeknog Dam failure timeline

In hindsight (2)

Piezometers installed by Fil Filmalter (Kop-Kop) Latter discovered that blanket drain (left of outlet tunnel) not on founding level but 5m higher (indicated as founding level on drawings

Several warnings on OMC: Filmalter and DWA officials, (unofficially) pointed dubious OMC out

Piezometer warning:

Impoundment started towards end of 1992

Filmalter warned that one of the piezometers installed on the left-hand side of the outlet conduit is recording high pressures

Piezometer warning ignored 10 Jan 1993

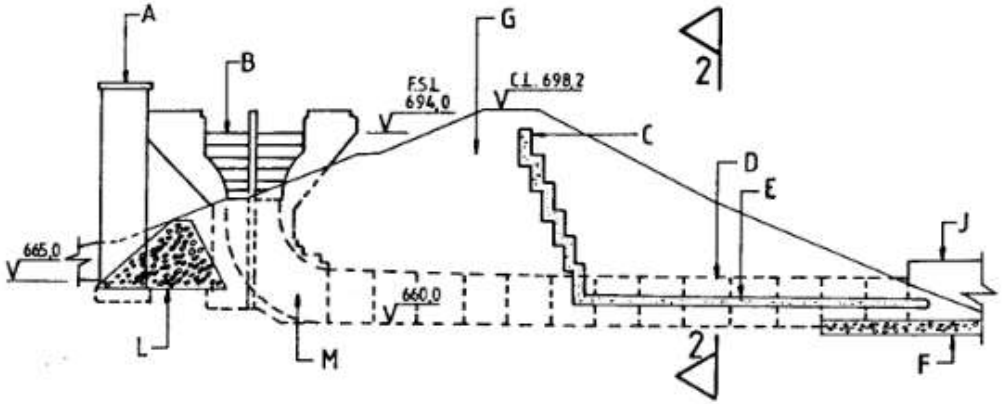


Fig. 1 (1-1)

Cross section of embankment adjacent to conduit

NOTATION

A- INTAKE TOWER
B- MORNING GLORY SPILLWAY
C- CHIMNEY DRAIN
D- CONDUIT
E- BLANKET DRAIN
F- STONE DRAIN
G- EMBANKMENT FILL
H- FOUNDATION LEVEL
I- TRENCH FILLING
J- TRAINING WALL
K- ROCK EXCAVATION FACE
L- ROCKFILL CONE
M- SPILLWAY SHAFT

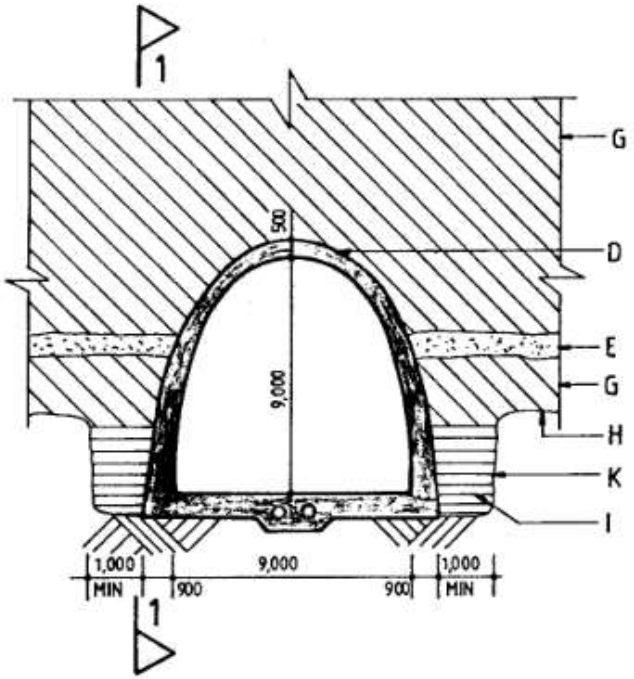


Fig. 2 (2-2)

Zoeknog Dam failure timeline

In hindsight (2)

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Zoeknog Dam failure timeline

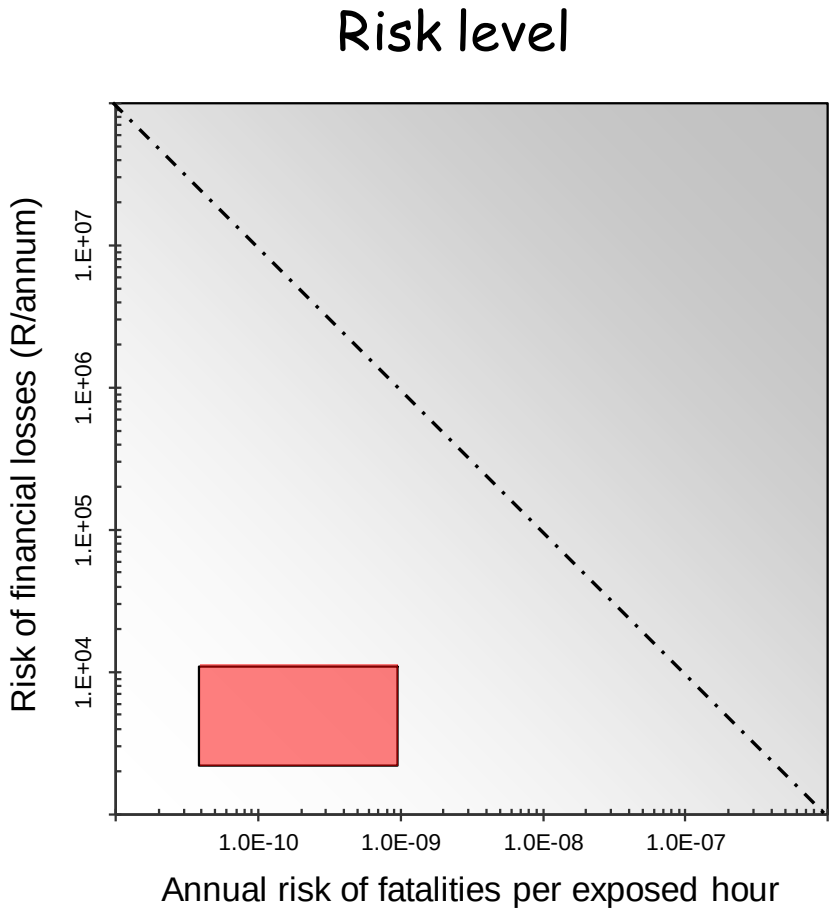
Jan 25 1993:
Dam failure early morning hours

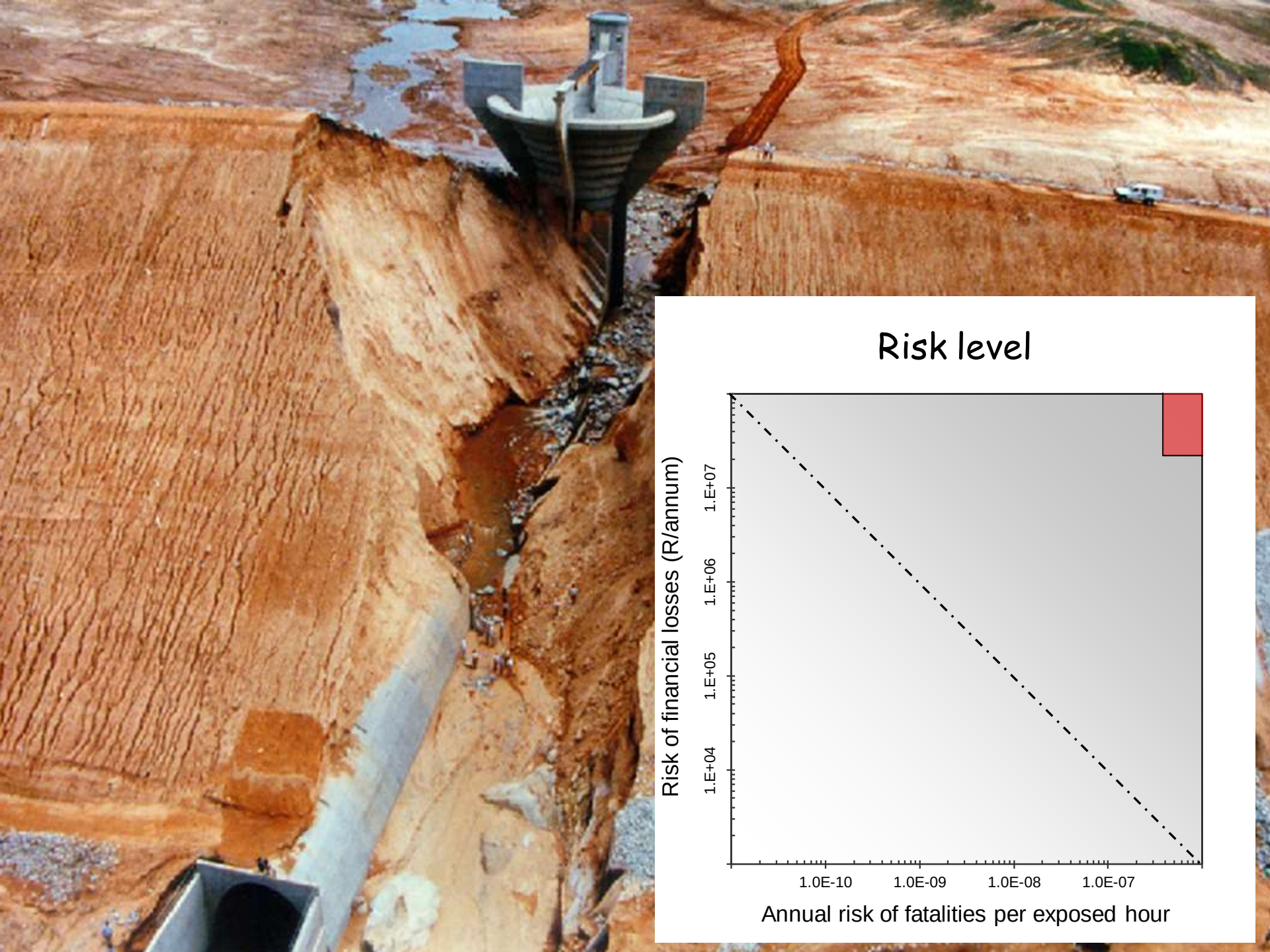
Soon after midnight guard heard water running …
Progressed from piping to dam empty in 6 hours.
No lives lost

Feb 2 & 4
Dam safety
First investigations:

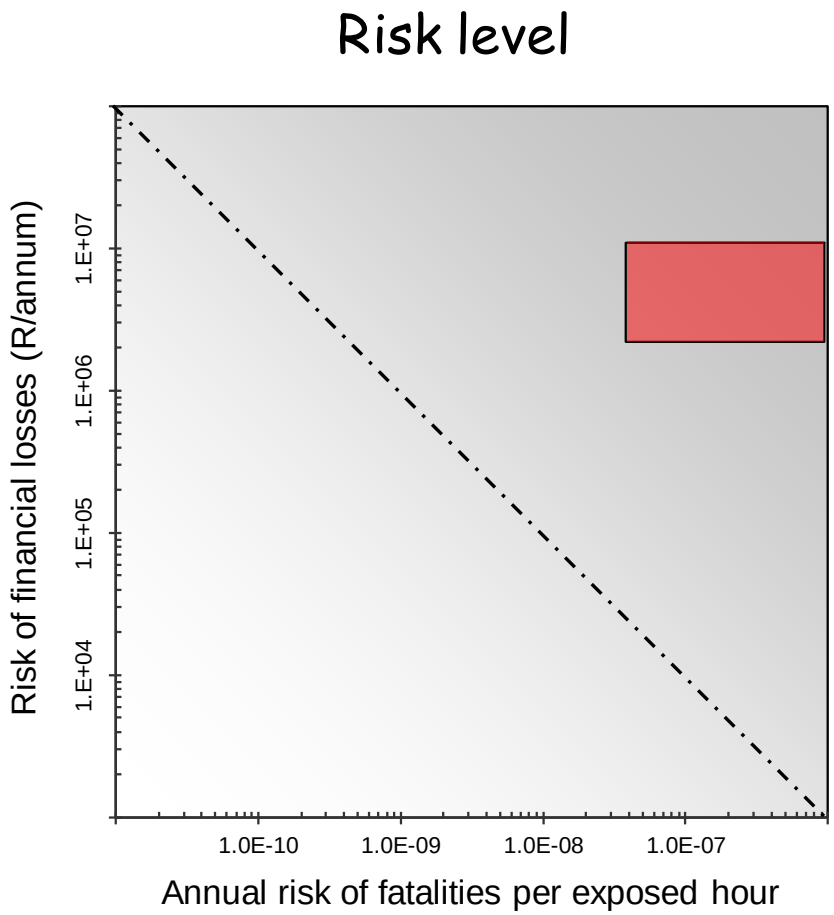
Feb 12
Another investigation

In a perfect world with a proper design, construction and operation

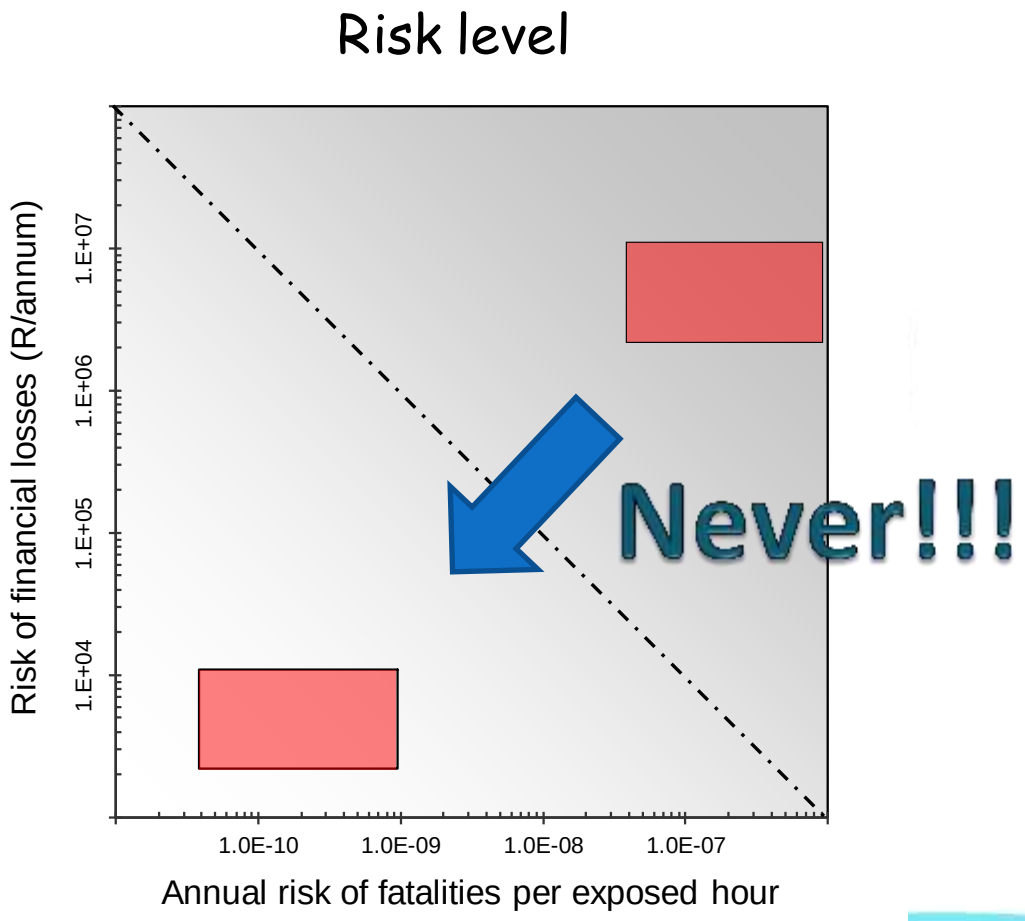



Risk level
Risk of financial losses (R/annum)
1.E+04
1.E+05
1.E+06
1.E+07
1.0E-10
1.0E-09
1.0E-08
1.0E-07
Annual risk of fatalities per exposed hour

React to piezometer warning during construction



The reality


Risk level
Risk of financial losses (R/annum)
1.E+07
1.E+06
1.E+05
1.E+04
1.0E-10
1.0E-09
1.0E-08
1.0E-07
Annual risk of fatalities per exposed hour
Never!!!

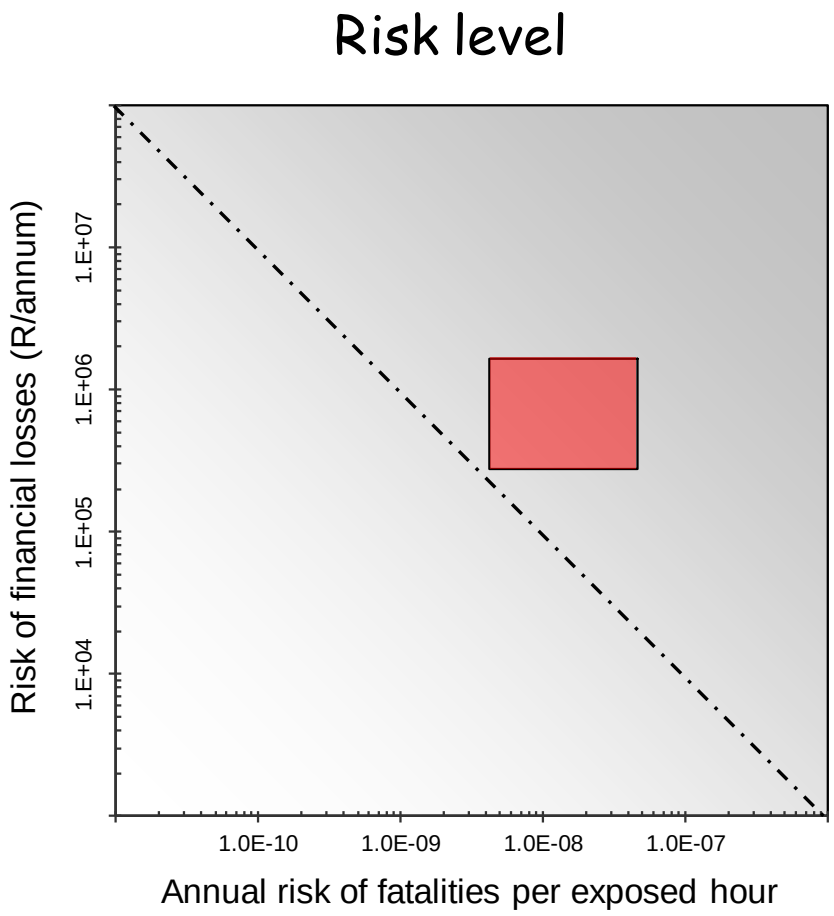
How important is visual inspections?

There is no substitute for systematic and intelligent surveillance……

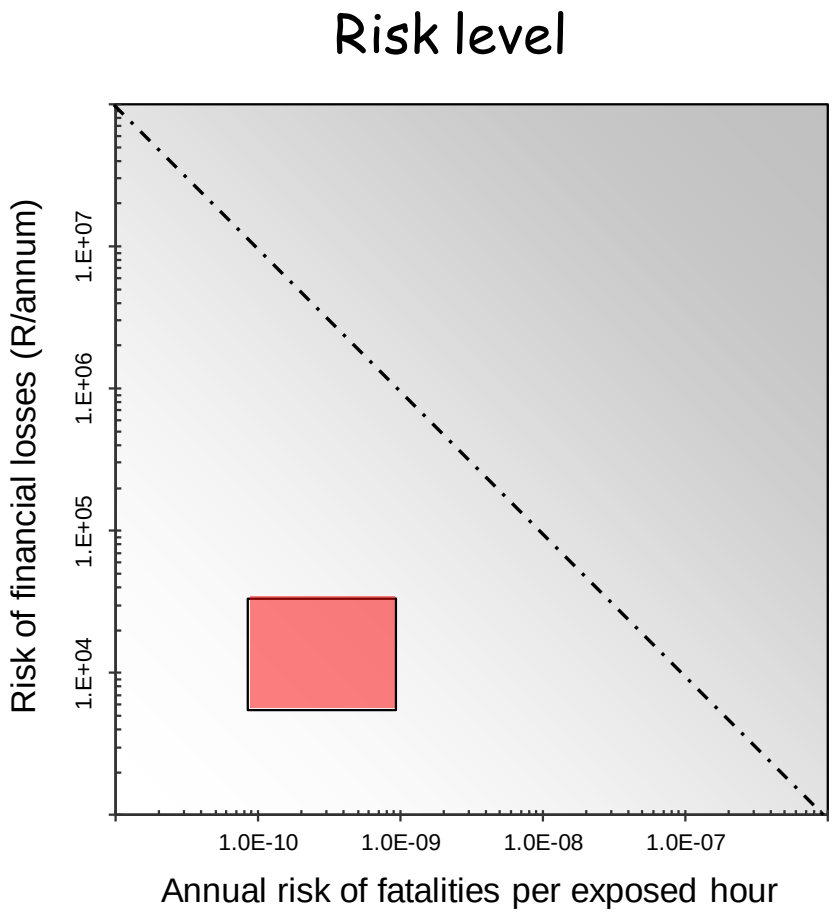
Ralph Peck


Sink hole

Current situation



Without the visual inspection results



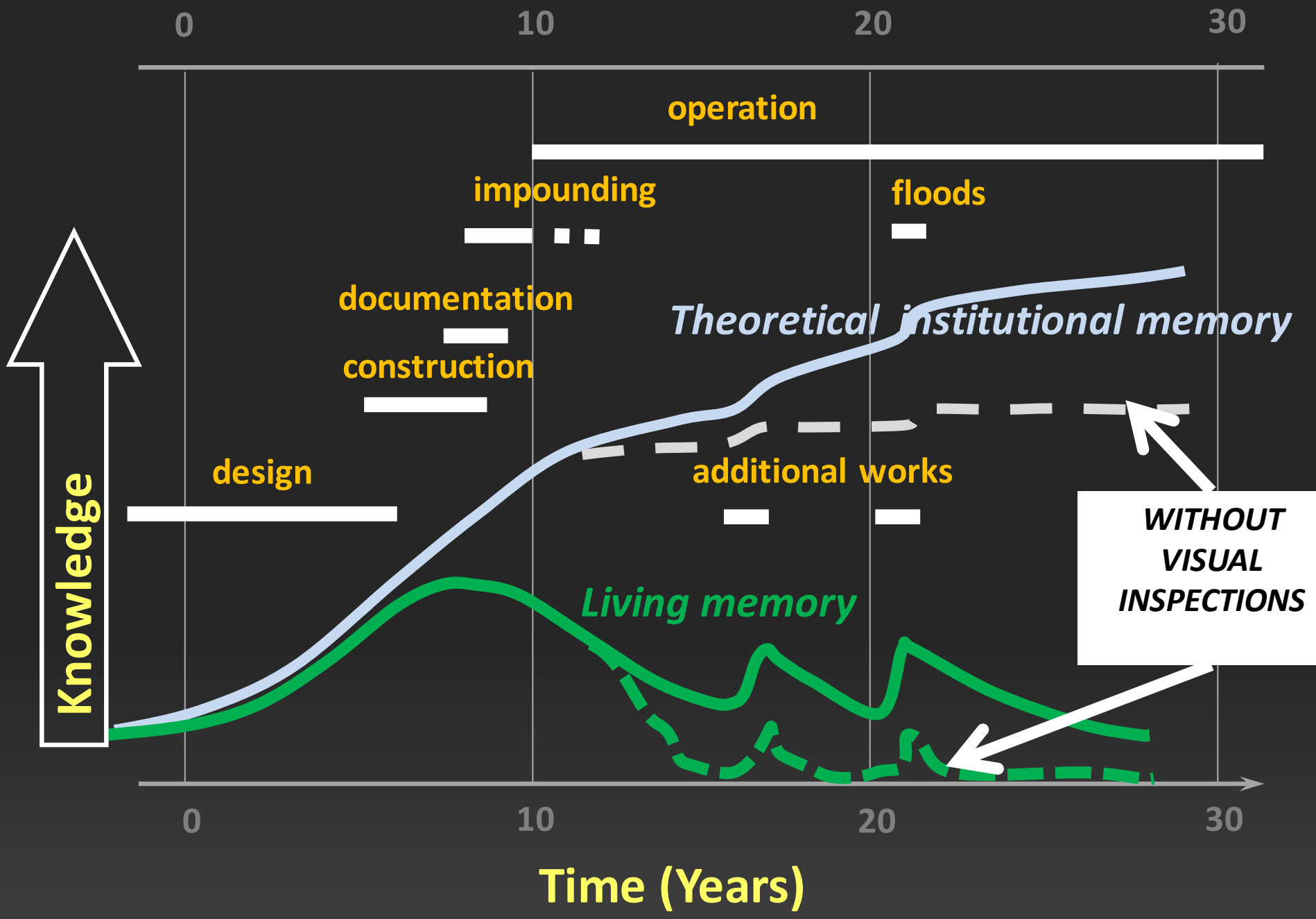
Intervention process

- Detail investigation to determine failure mechanism
  - How long have this sink hole been here?
  - Is there any other sinkholes?
  - What caused this sinkhole?
- Consider all possible interventions including costing
- Determine most appropriate by considering the unit risk reduction cost

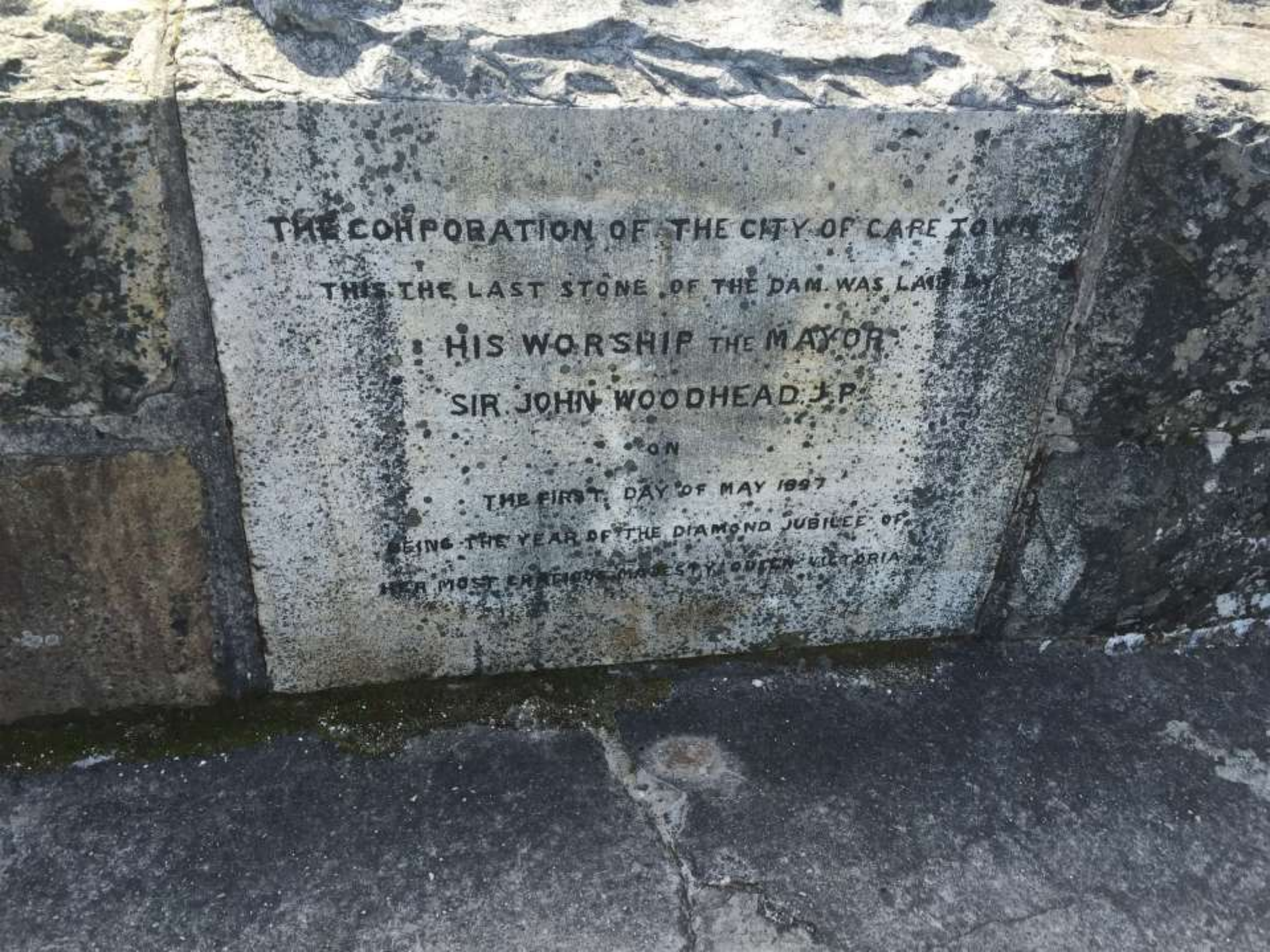
There is no substitute for systematic and intelligent surveillance……..

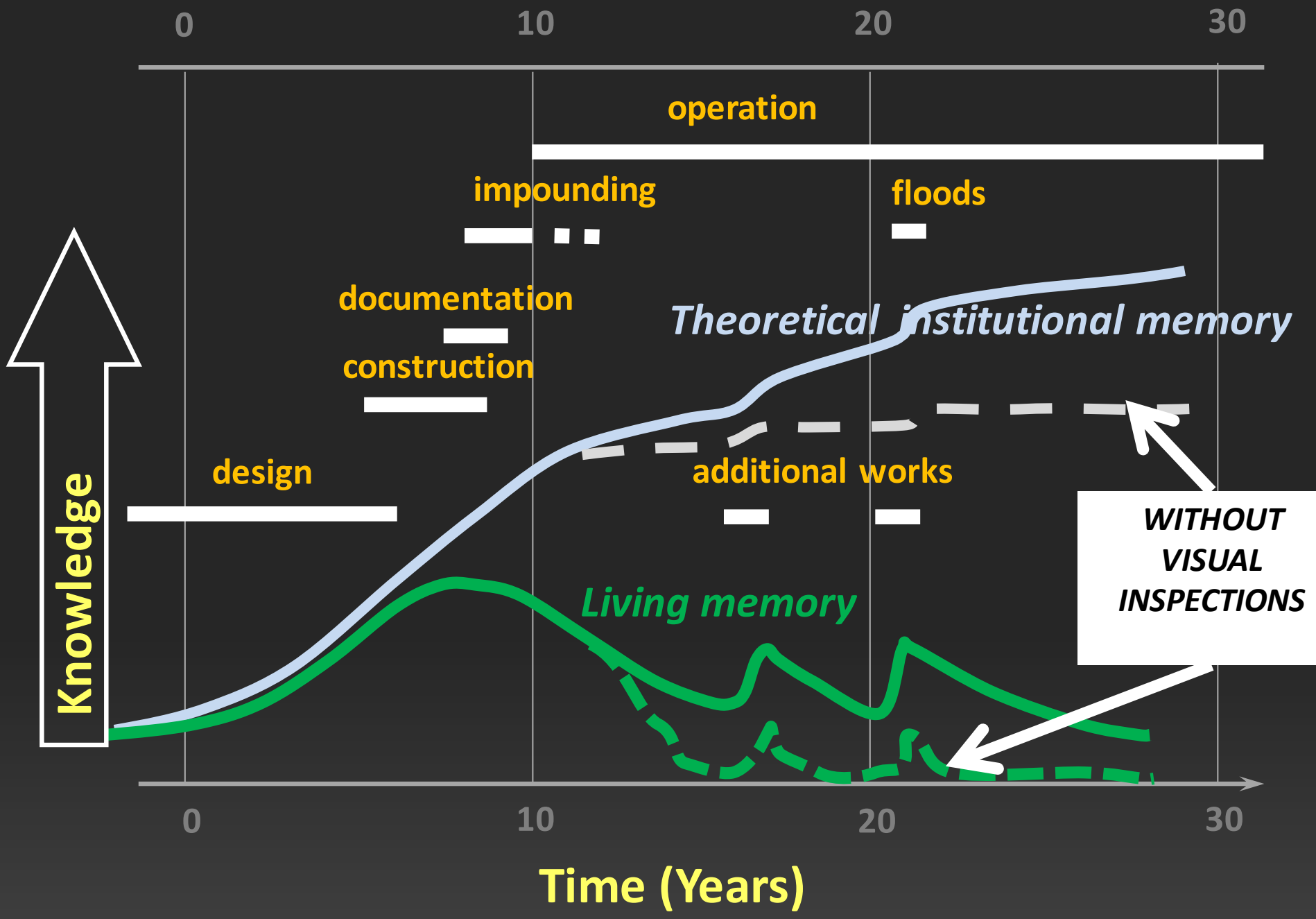
Ralph Peck

Value of visual inspections


0
10
20
30
operation
impounding
floods
documentation
construction
Theoretical institutional memory
design
additional works
WITHOUT VISUAL INSPECTIONS
Living memory
Knowledge
0
10
20
30
Time (Years)

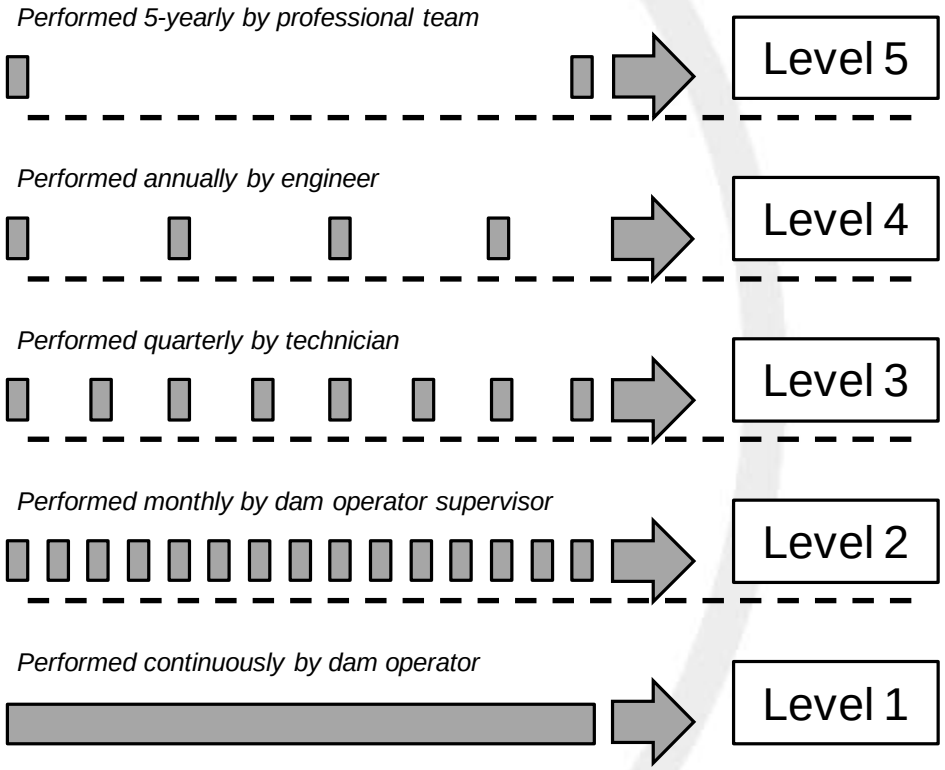
What is the lifespan of a dam?


THE CORPORATION OF THE CITY OF CAPE TOWN
THIS THE LAST STONE OF THE DAM WAS LAID BY
HIS WORSHIP THE MAYOR
SIR JOHN WOODHEAD J.P.
ON
THE FIRST DAY OF MAY 1897
BEING THE YEAR OF THE DIAMOND JUBILEE OF
HER MOST GRACIOUS MAJESTY QUEEN VICTORIA

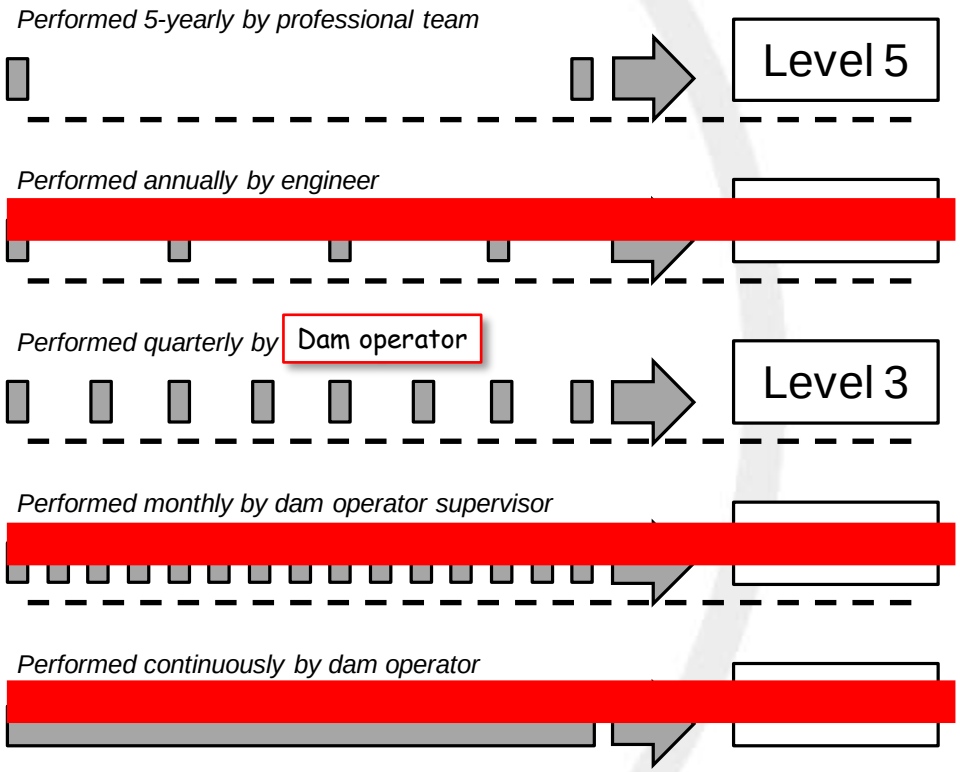

0
10
20
30
operation
impounding
floods
documentation
construction
Theoretical institutional memory
design
additional works
WITHOUT VISUAL INSPECTIONS
Living memory
Knowledge
0
10
20
30
Time (Years)

Visual inspection programs

Ultimate inspection program



Inspection program for smaller dams



Typical requirements

- Level 1 – Operator & Level 2 - Supervisors:
  - diligence
  - dam safety experience (especially of the particular dam)
  - a positive attitude
  - definitely not a high level of education
  - supervisors should ideally have progressed through ranks
- Level 3 & 4:
  - due diligence of utmost importance
  - relevant qualifications but diligent and intelligent individuals have progressed by means of appropriate experience & self-education

Failure factors

- Lack of will by decision-makers even though it is low cost
- Inappropriate levels of education and experience requirements & lack of refresher courses
  - Over-qualified/under experienced
  - Under qualified/under experienced
- Lack of recognition for value of routine visual inspections. Effectiveness of applying Hawthorne effect (a form of reactivity whereby subjects' show an increase in productivity due to the motivational effect of interest shown in them)

Concluding remarks

- Risk analyses
  - Over lifespan of dam
  - Quantify operational risks
  - Consider all potential failure mechanisms
  - Improve decision-making especially with Operation & Maintenance
  - Optimise technical decisions

Concluding remarks

- Visual inspections essential for development & accumulation institutional memory
- Plays important role in evaluation of dam behaviour
- Proper implementation of effective & successful visual inspection programme depends on:
  - properly designed formal process
  - appointment of appropriate personnel (diligent with the appropriate levels of experience & education for each of the levels of responsibility)
- Long-term success by applying the Hawthorne effect

Acknowledgements

- Dr Chris Oosthuizen

- All whom in some way or other contributed along the way

- Last but definitely not least – SPANCOLD invite


Thank you