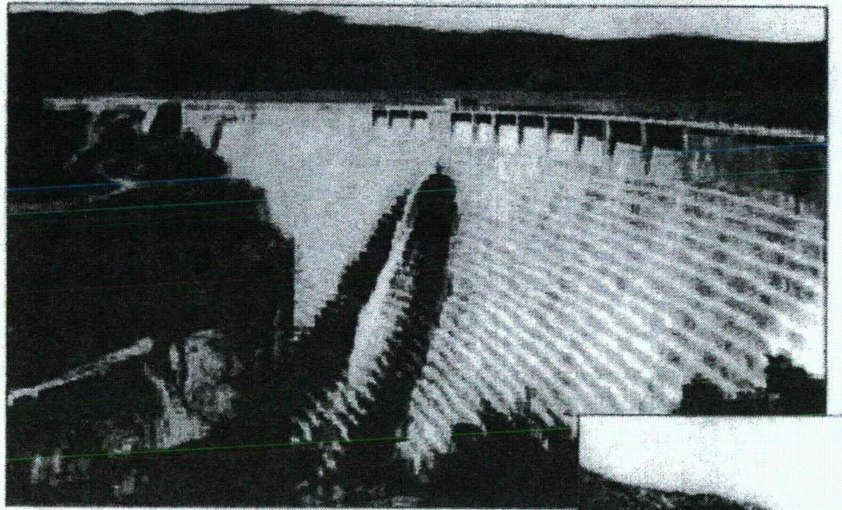
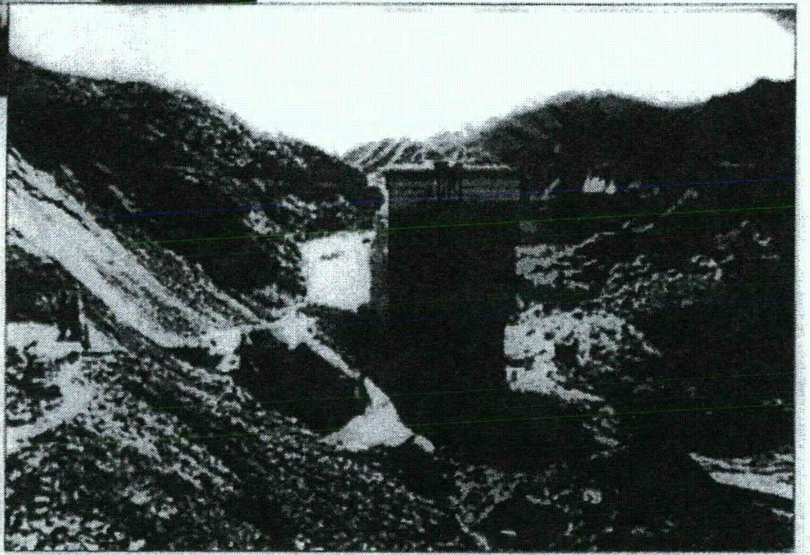
History of US dam failures

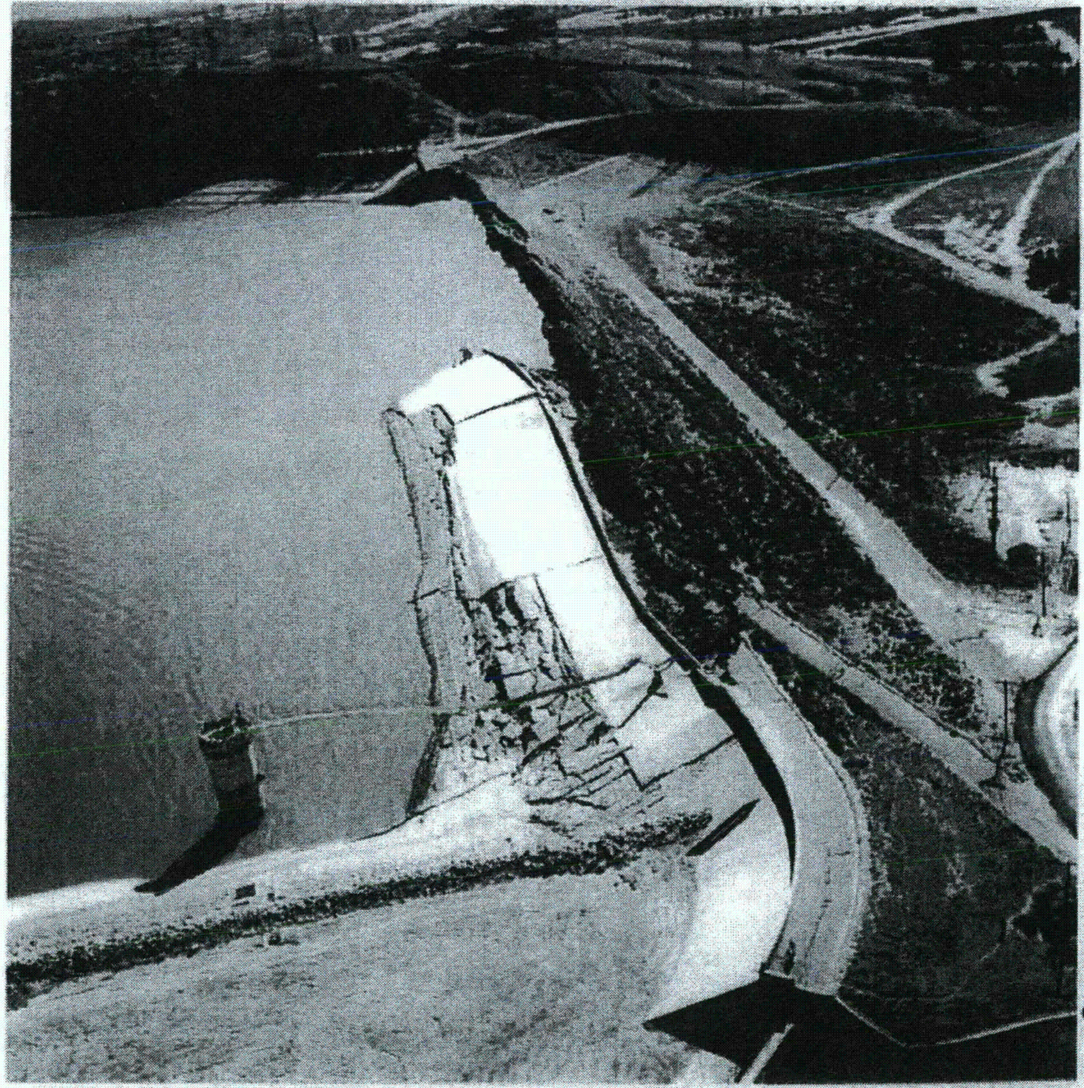


St Francis 1928



History of US dam failures

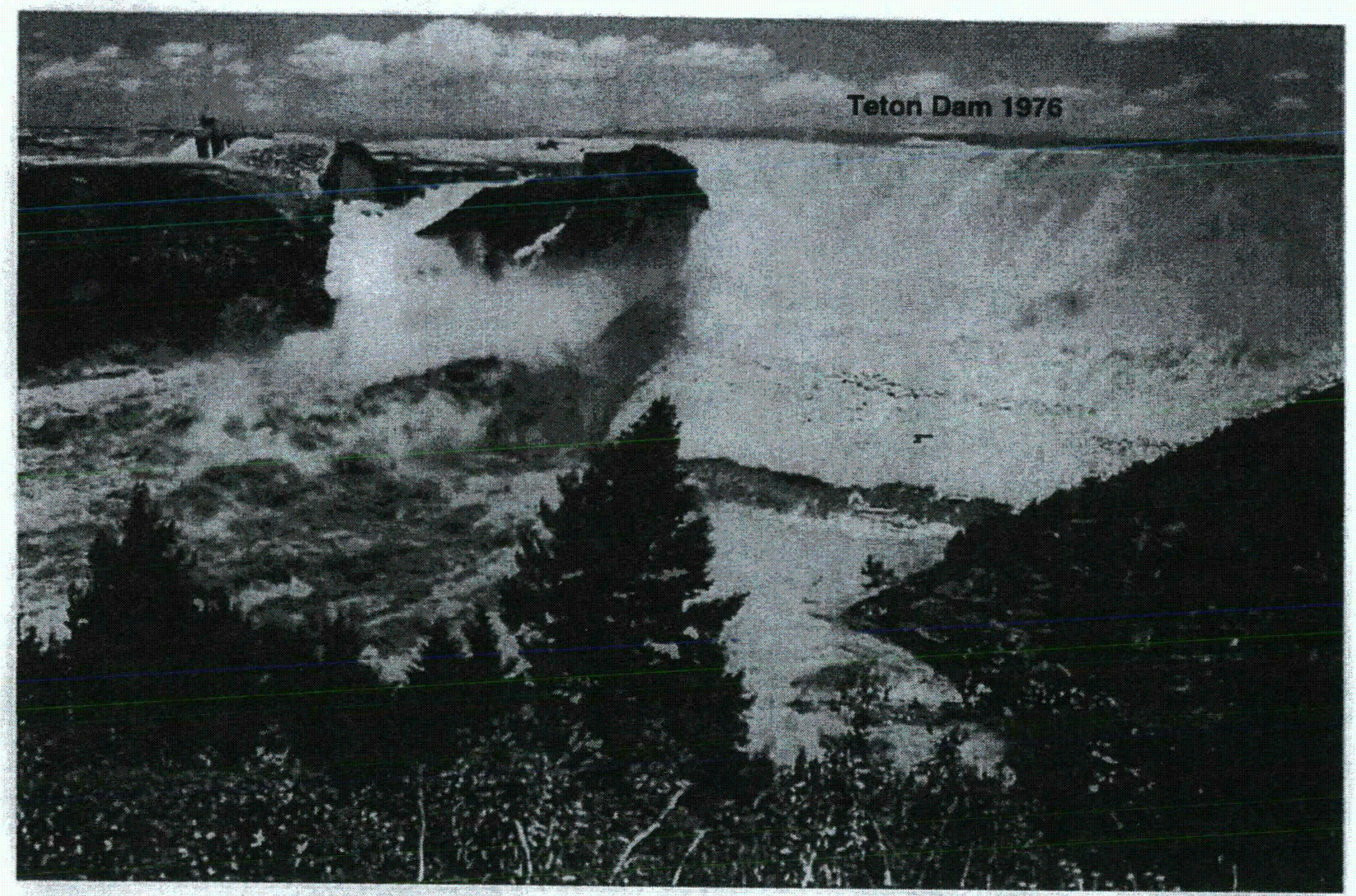
History of US dam failures



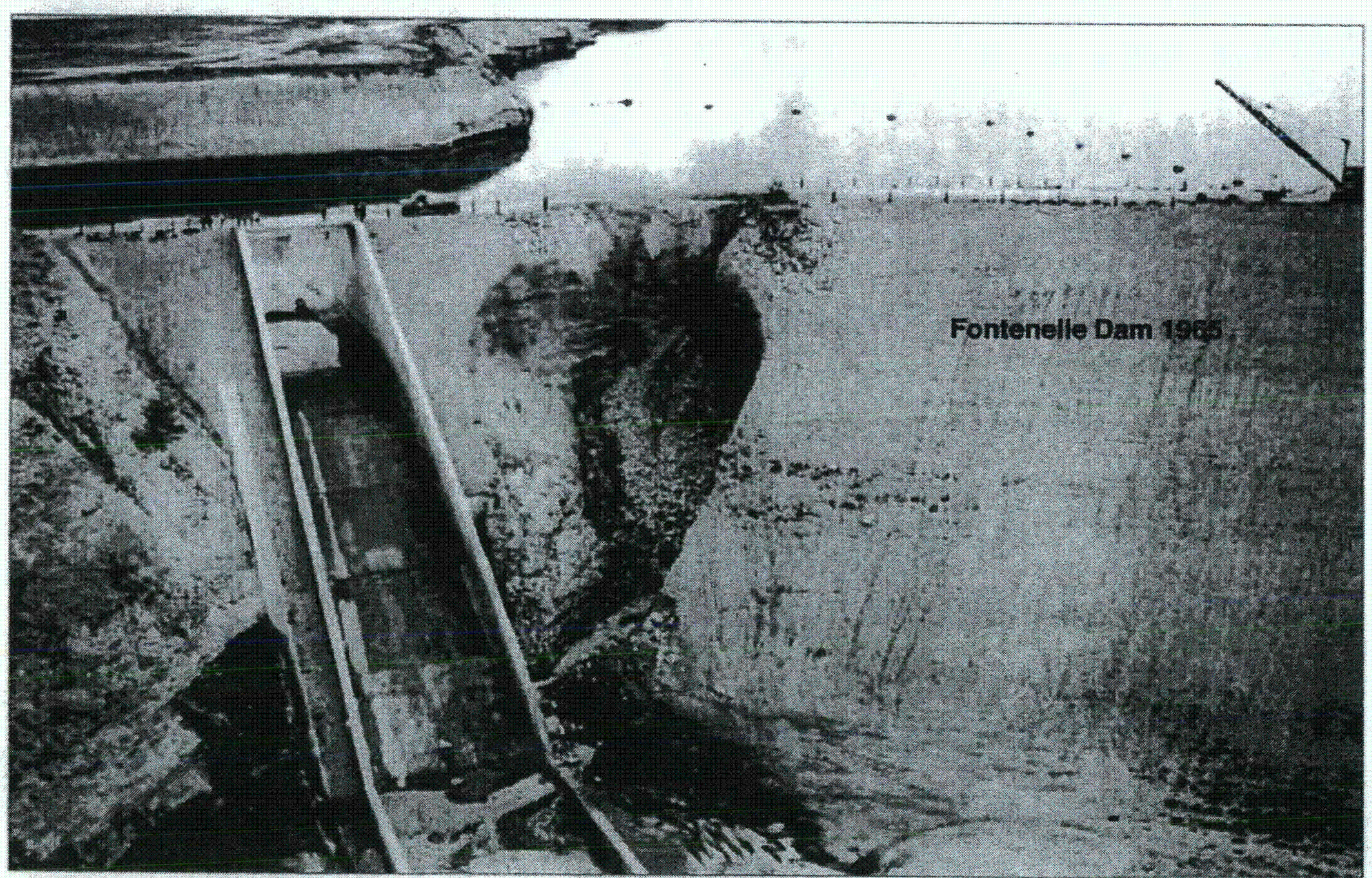
Lower Van Norman 1971

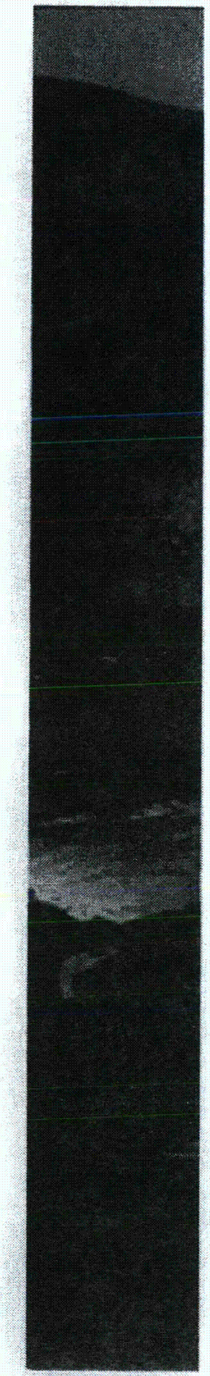
Collaborative at Maryland

History of US dam failures



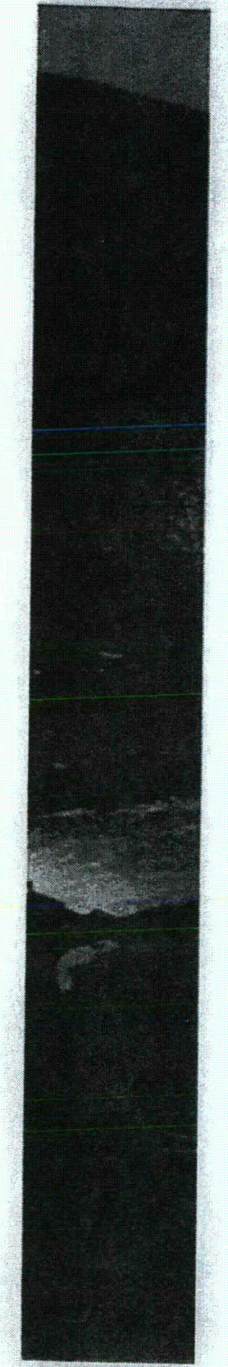
History of US dam failures



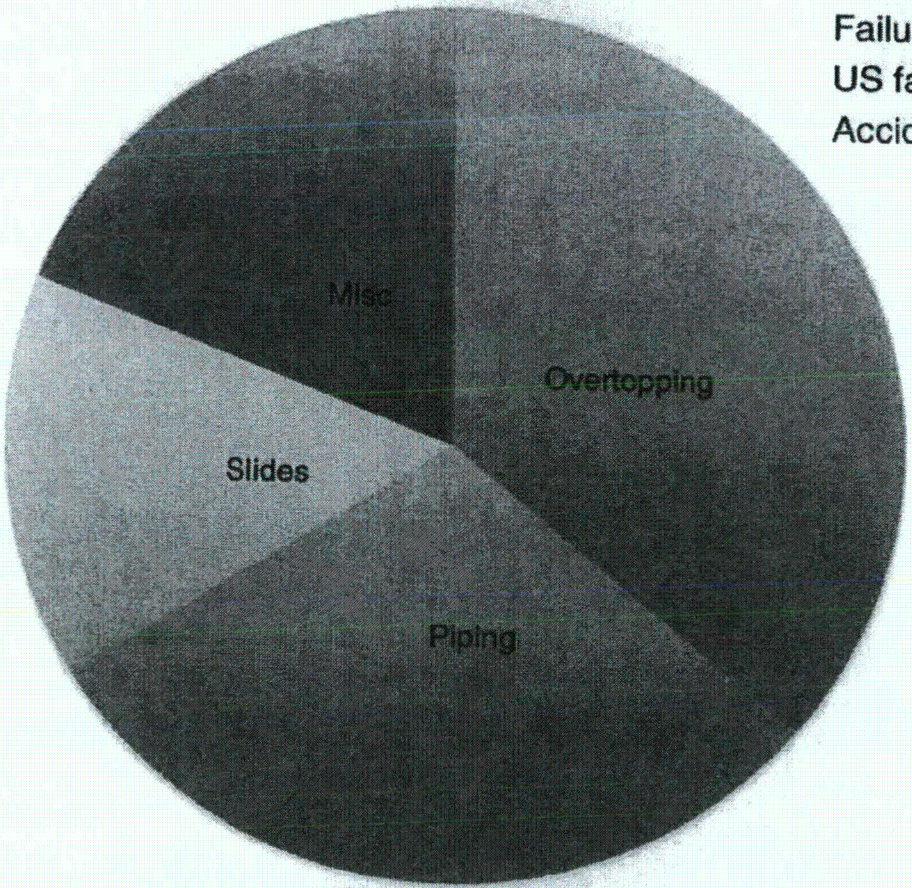


History of US dam failures

South Fork 1889	Overtopping
Walnut Grove 1890	Overtopping
St. Francis 1928	Geological defect
Mill River 1865	Overtopping (?)
Baldwin Hills 1963	Earthquake
Canyon Lake 1972	Overtopping
Buffalo Creek (tailings) 1972	Structural
Teton 1976	Piping
Kelly Barnes 1977	Structural
Laurel Run 1977	Overtopping
Lawn Lake 1982	Piping
Big Bay 2004	Piping
Taum Sauk 2008	Overtopping

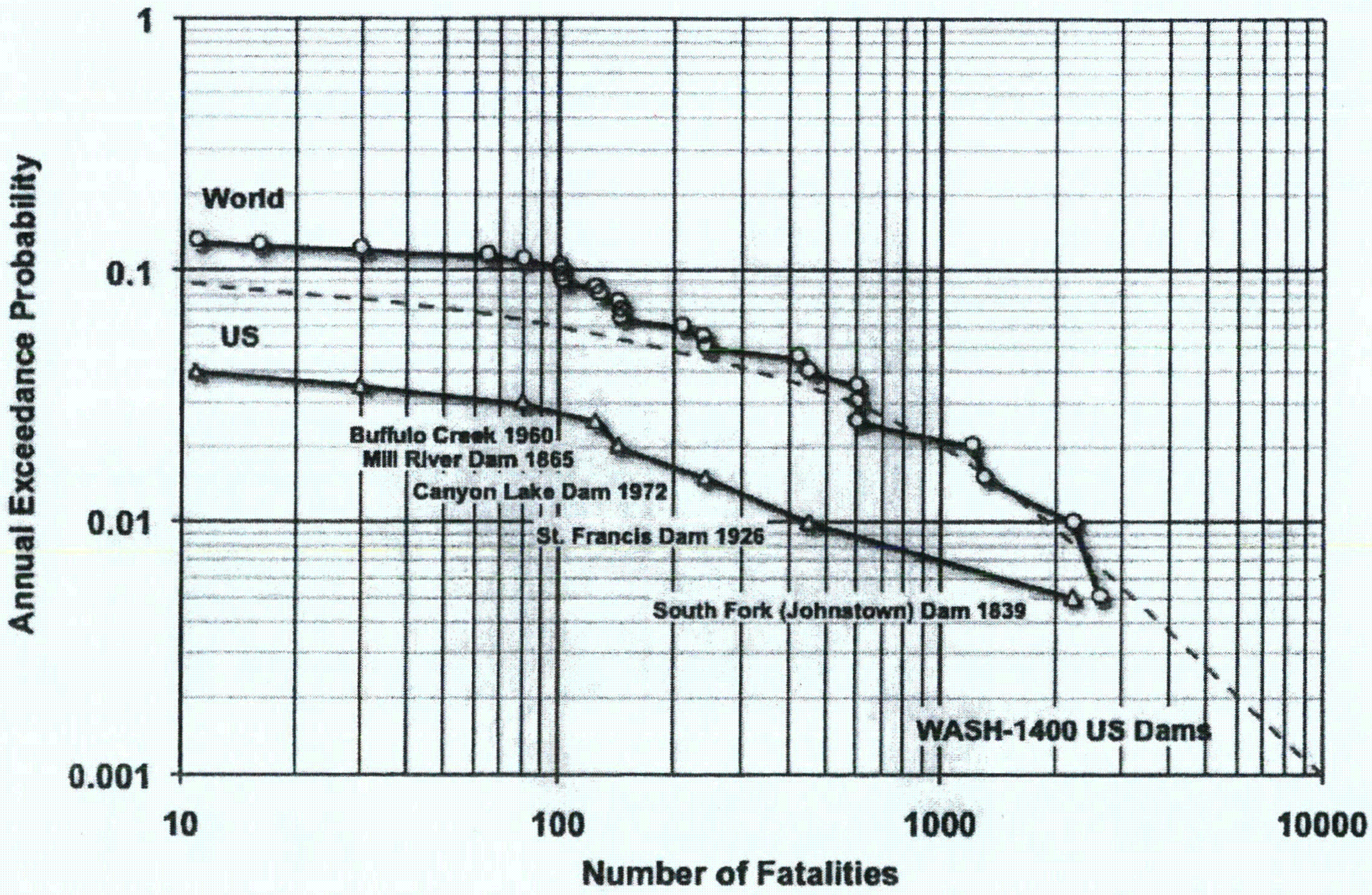


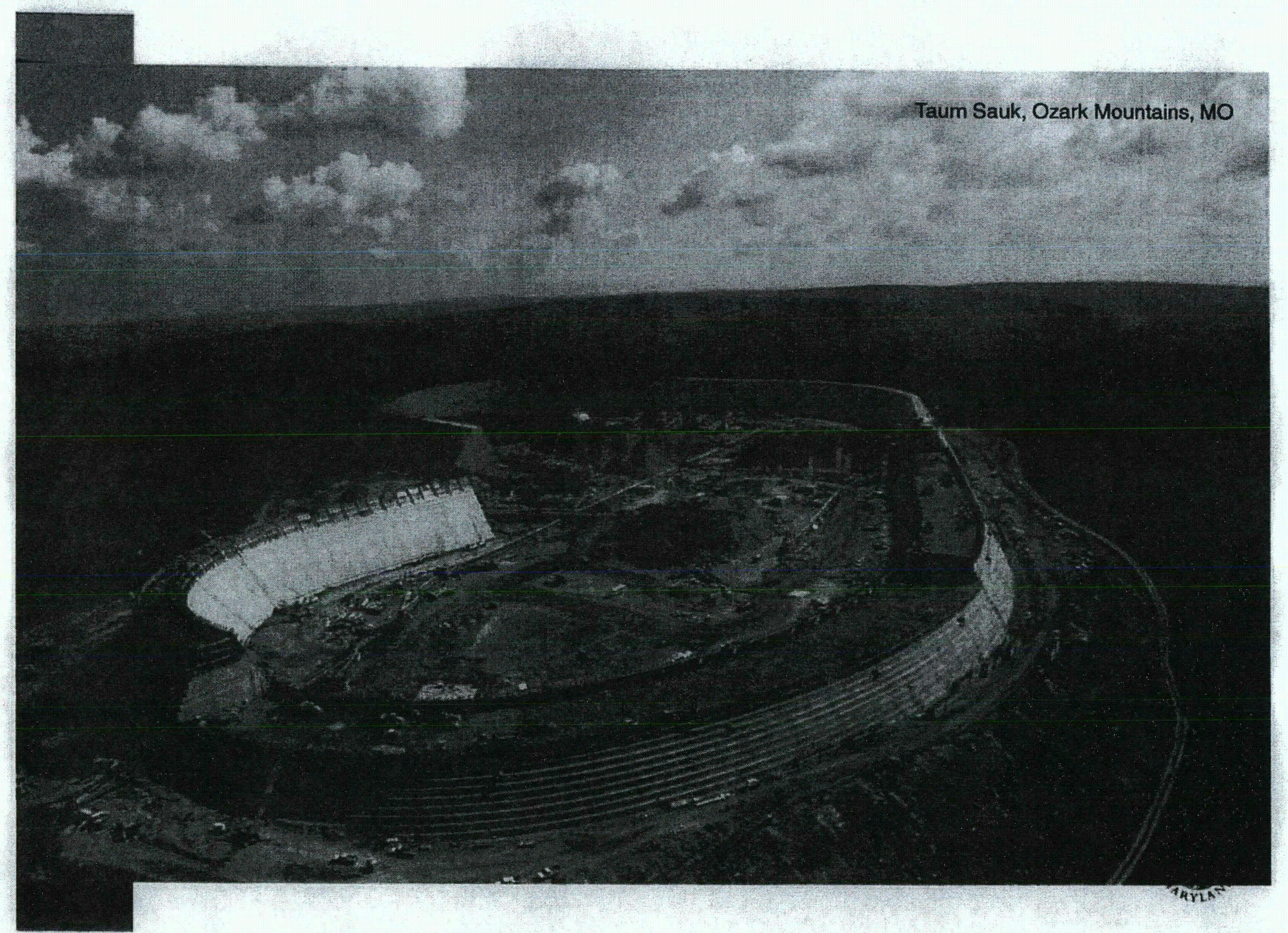
Frequency of dam failure

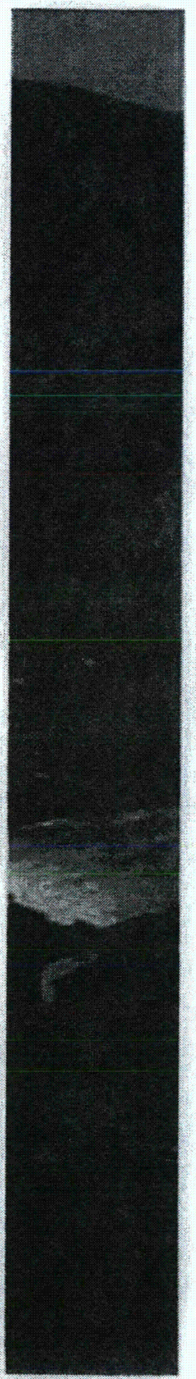


Failure rate ~ 1 / 10,000 dam-years
US failures ~ 5 – 10 failures per year
Accident rate ~ 2 x failure rate

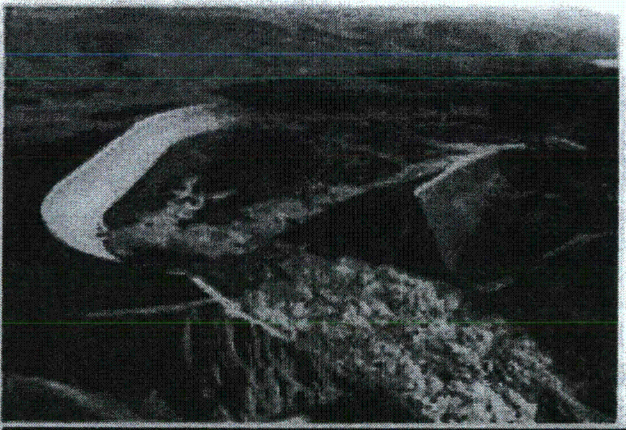
History of US dam failures

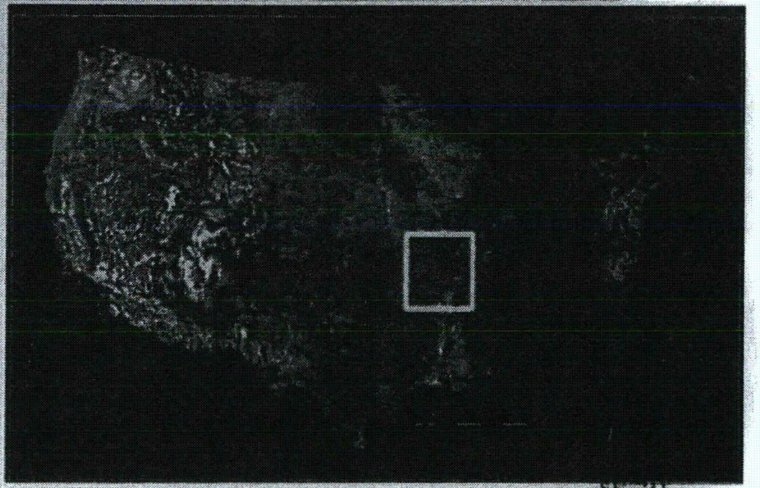



Taum Sauk, Ozark Mountains, MO



Taum Sauk pump-storage project





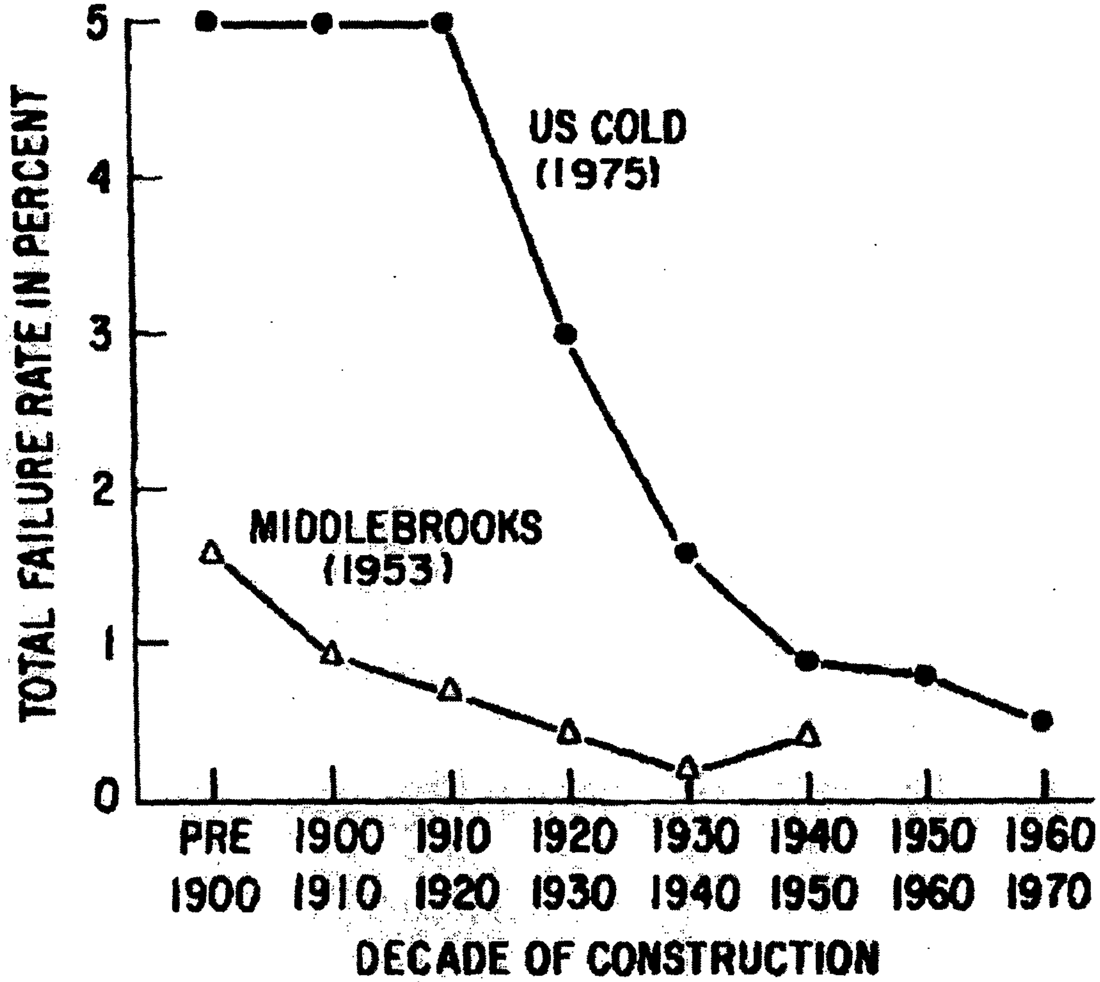
Frequencies of failure

TABLE 1. Failure Rates of Dams in the United States and Worldwide

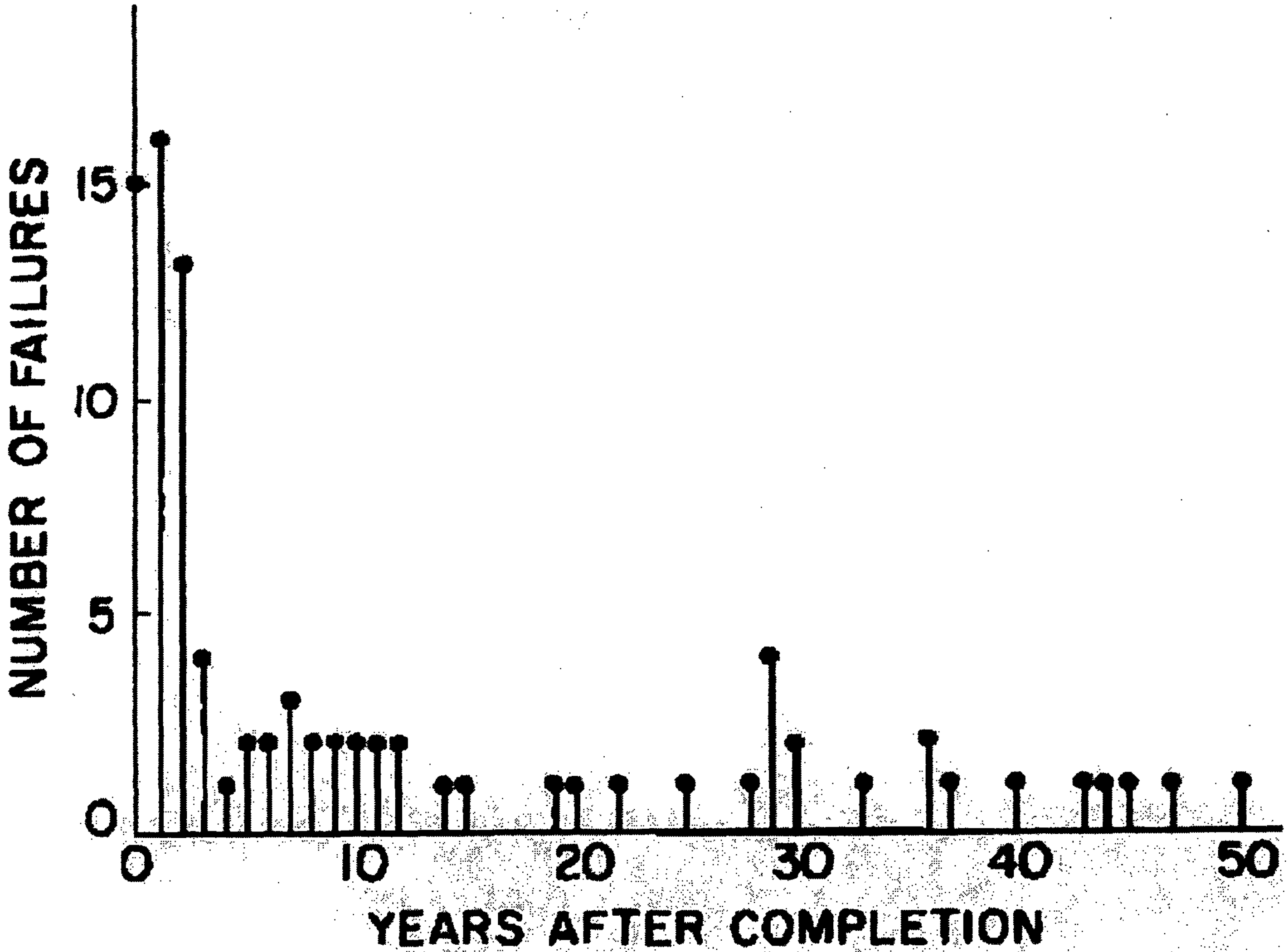
Area	Reference	Failures	Total Dams*	Period, years	Rate $(\text{dam year})^{-1}$
United States	*Gruner* [1963, 1967]	33	1764	40	5×10^{-4}
	Babb and Mermel [1968]				
	post-1940 dams	12	3100	14	3×10^{-4}
	USCOLD [1975]	74	4914	23	7×10^{-4}
	U.S. Bureau of Reclamation				
	[*Mark and Stuart-Alexander*,	1	4500†		2×10^{-4}
World	1977]	125	7500	40	4×10^{-4}
	Middlebrooks [1953]				
	[*Mark et al.*, 1977]	9	7833	6	2×10^{-4}
Japan	*Takase* [1967]	1046	2×10^{6}	15	4×10^{-5}
Spain	*Gruner* [1967]	150	1620	145	6×10^{-4}

*Approximate.
†Dam years.

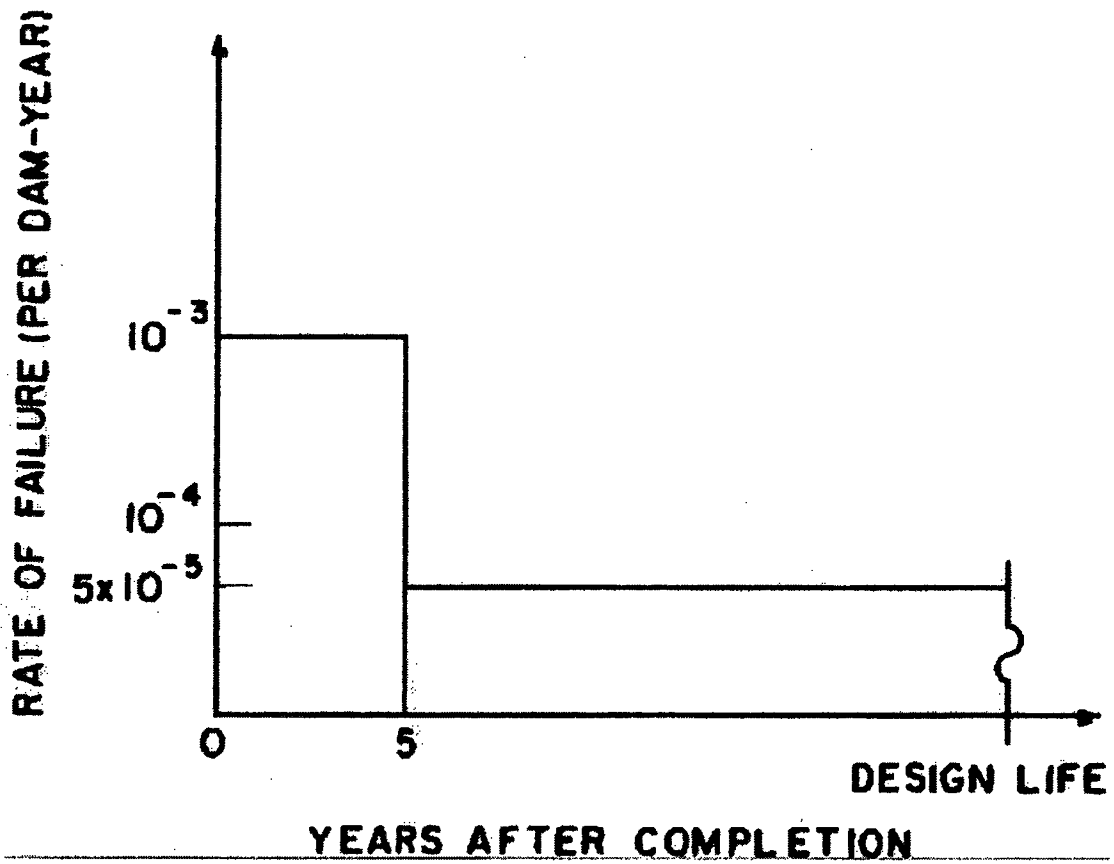
Frequencies of failure



Frequencies of failure



Frequencies of failure



PRA for dams

1. Dam inventory
2. Modes of failure
3. Actors, owners, & regulators
4. Risk and reliability analysis
5. Downstream consequences
6. Tolerable risk

Recent efforts related to PRA of dams

Risk studies and programs

- US Bureau or Reclamation risk cadre
- ANCOLD dam safety standard
- ICOLD dam safety risk guidance
- Dutch Delta Commission
- USACE dam and levee safety program

Systems risk analysis studies

- Interagency Performance Evaluation Taskforce (IPET)
- Delta Risk Management Study (DRMS)

Recent efforts related to PRA of dams

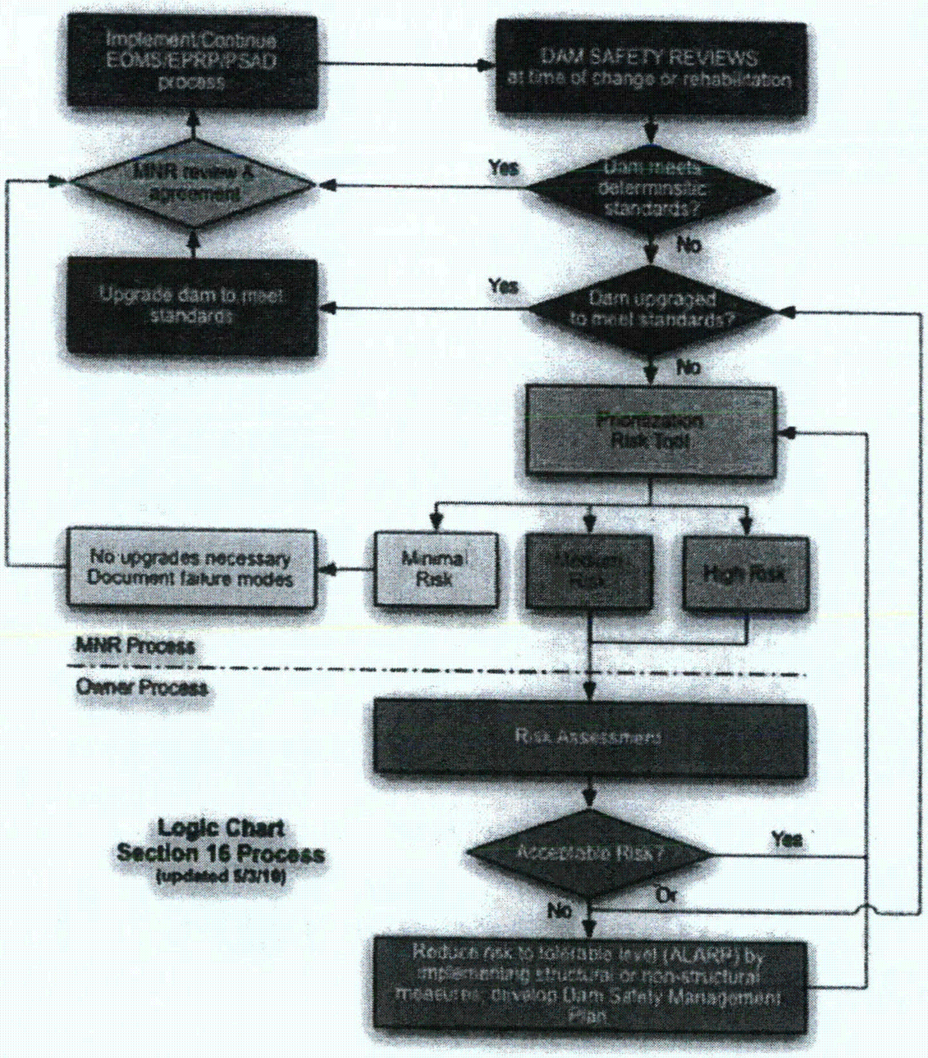
Risk screening efforts

- USACE Portfolio Risk Assessment
- FEMA Risk Prioritization Tool for Dams
- Ontario MNR Risk Screening Tool

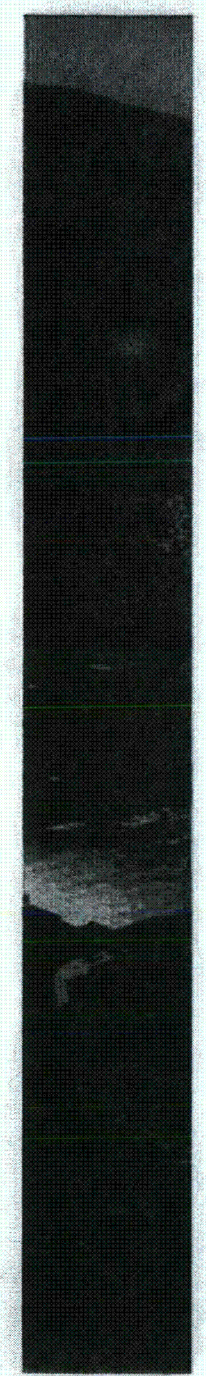
Agency interest

- USACE, USBR, FEMA, FERC, TVA, NRCS
- New *Principles & Standards* (CEQ)

Ontario Dam Safety Management Plan



The Water Collaborative at Maryland



PRA for dams

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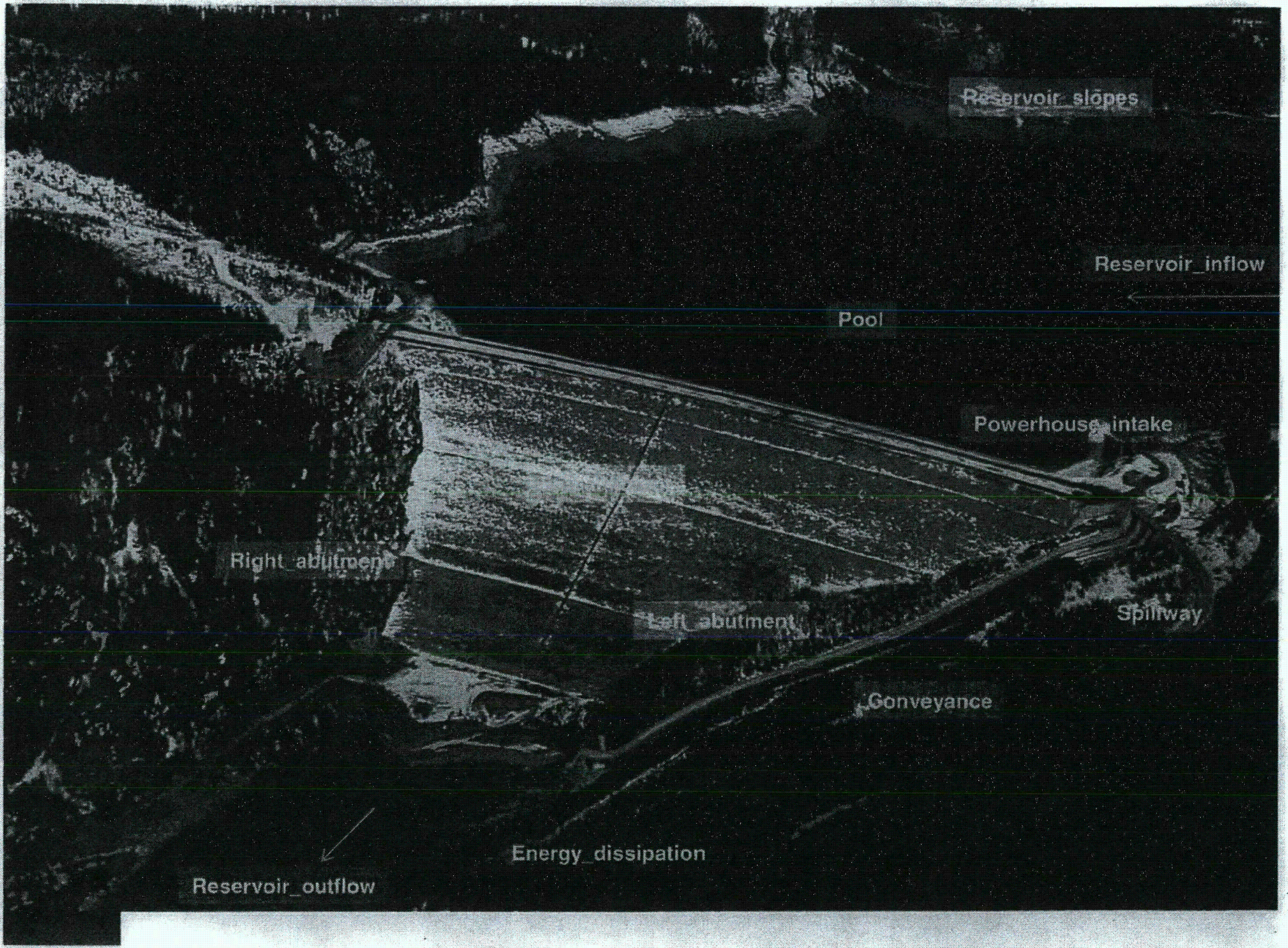


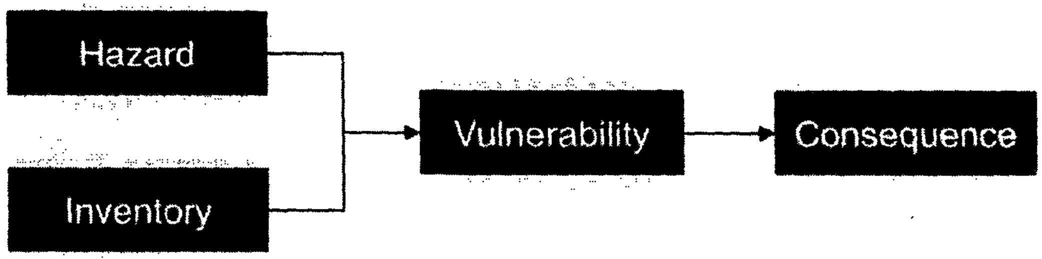
Reservoir_slopes
Reservoir_inflow
Pool
Powerhouse_intake
Right_abutment
Left_abutment
Spillway
Conveyance
Energy_dissipation
Reservoir_outflow

Risk methodology

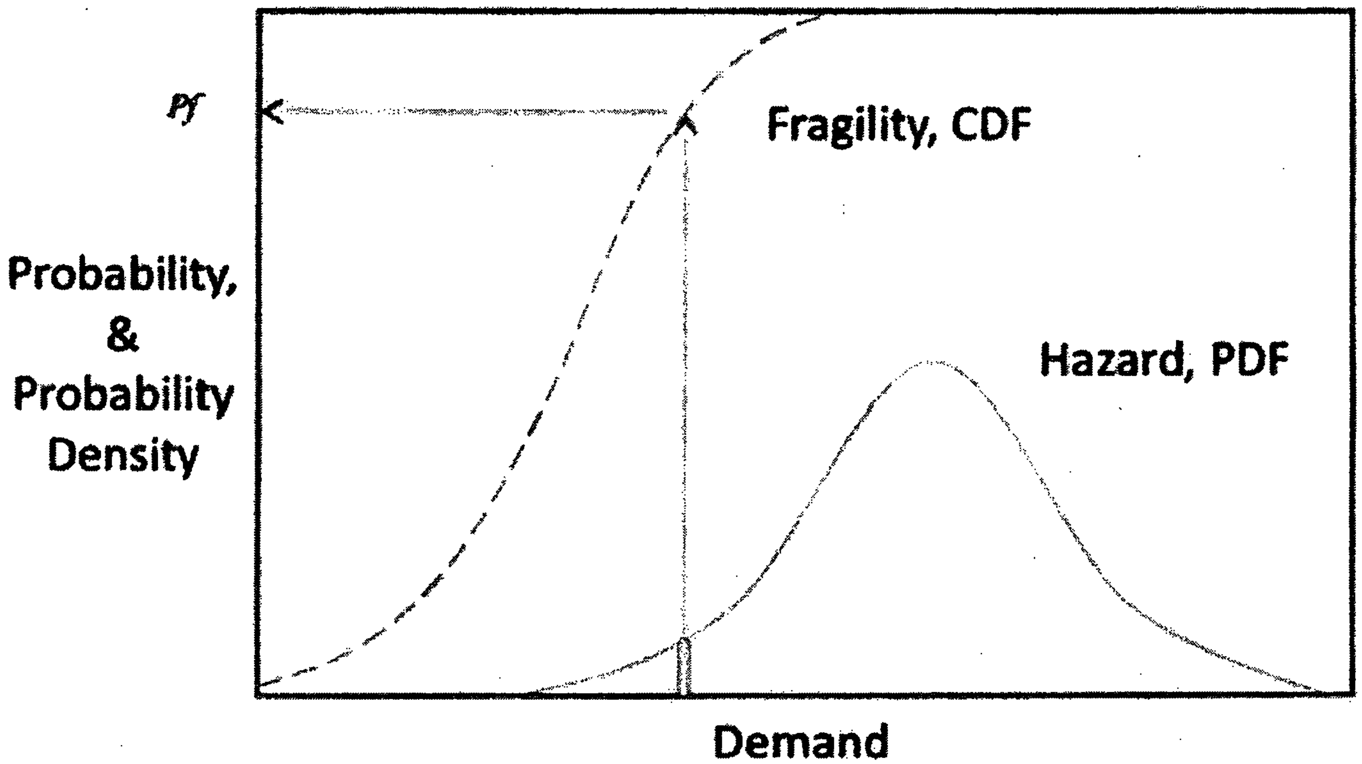
1. Risk register
2. Hazard evaluation
3. Vulnerability (FMEA, fragility curves)
4. Consequences (life, economics, environmental)

Risk methodology

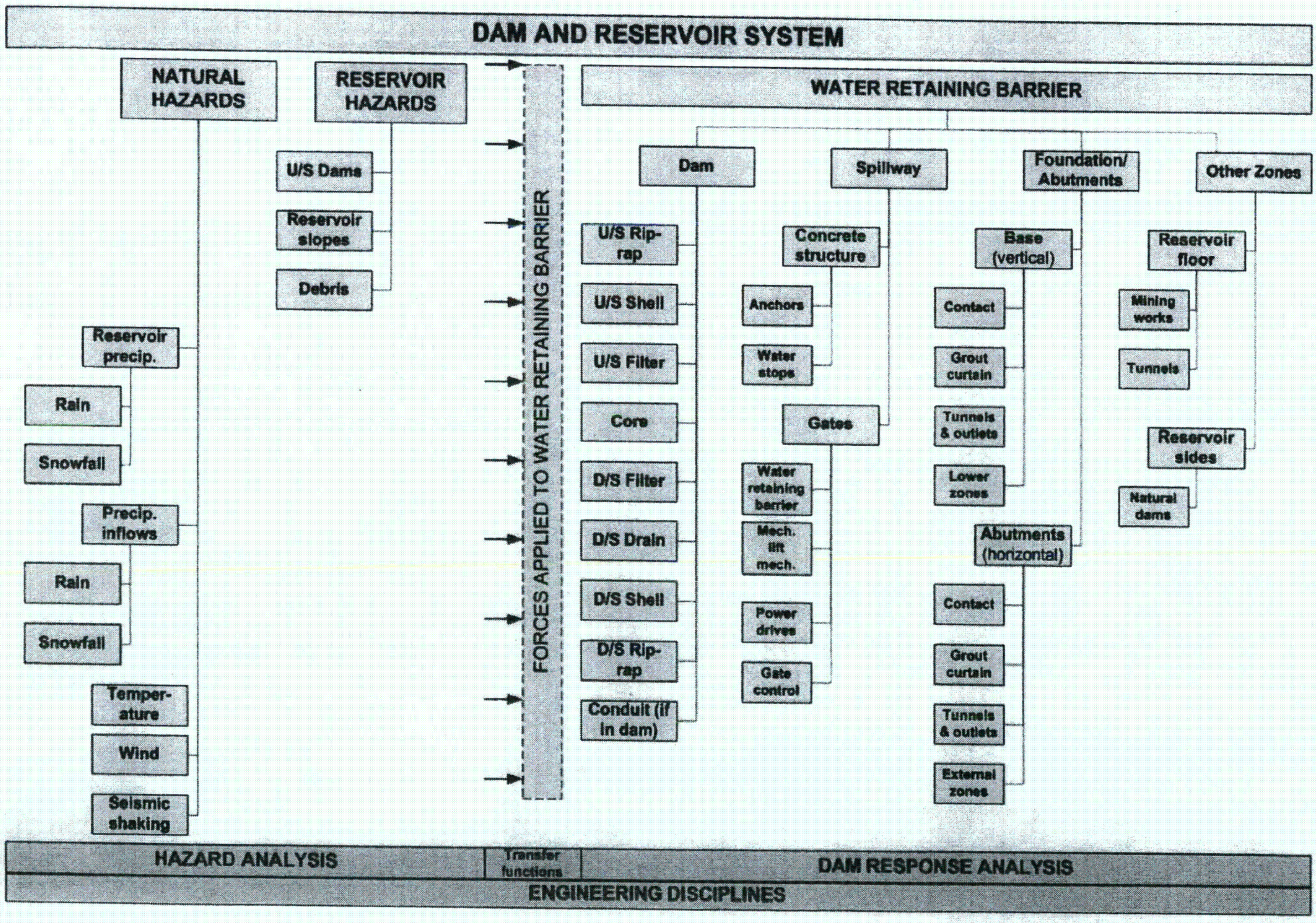
$$\text{Risk} = H \times V \times C$$

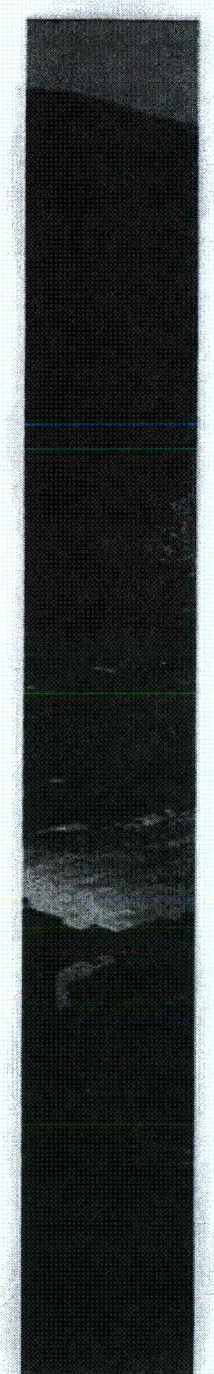


Capacity vs. demand



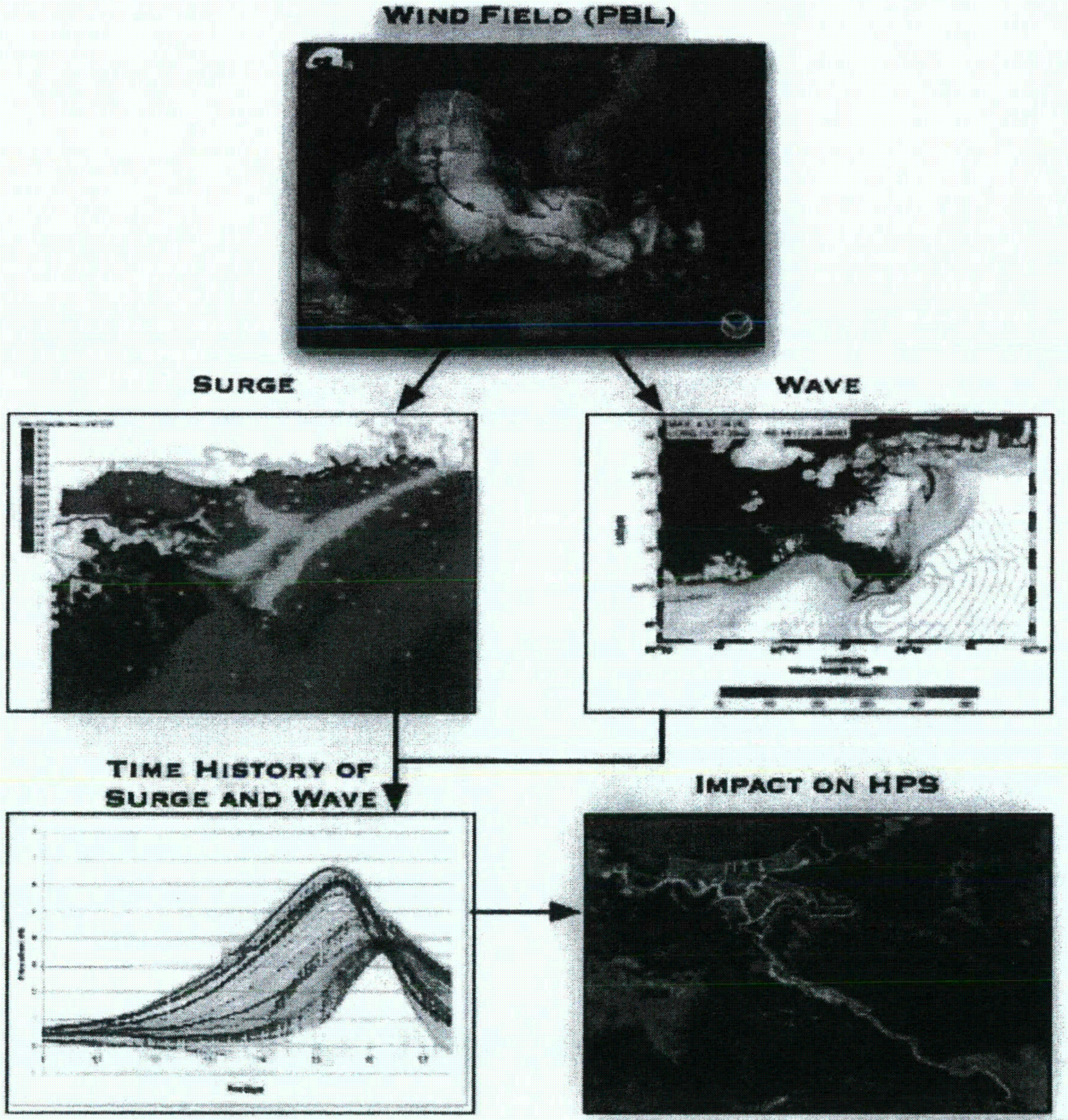
FRAMEWORK FOR DAM SAFETY ANALYSIS





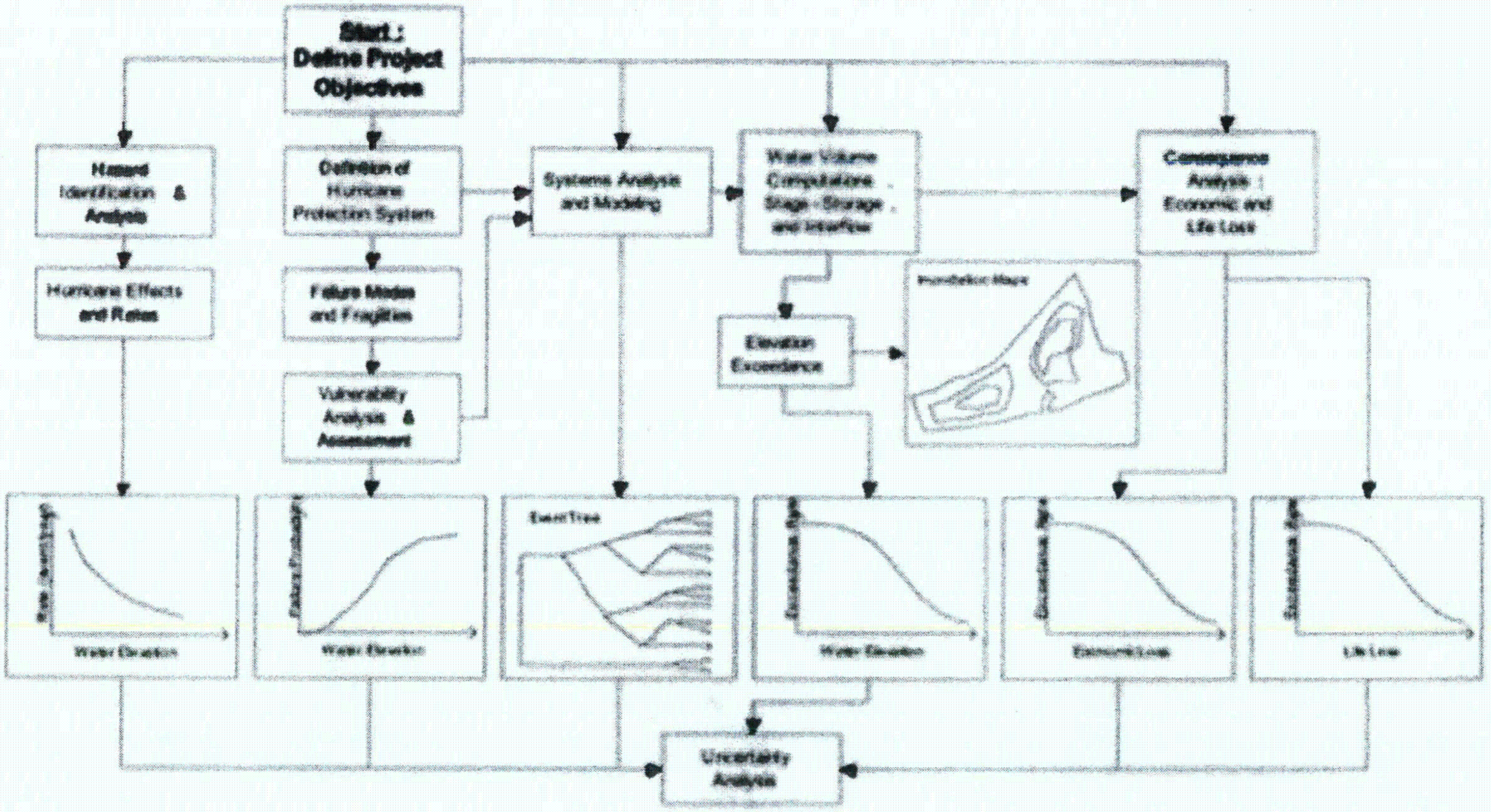
Interagency Performance Evaluation Taskforce

The Water Collaborative at Maryland



Wind Field (PBL)
Surge
Wave
Time History of Surge and Wave
Impact on HPS

Risk analysis methodology



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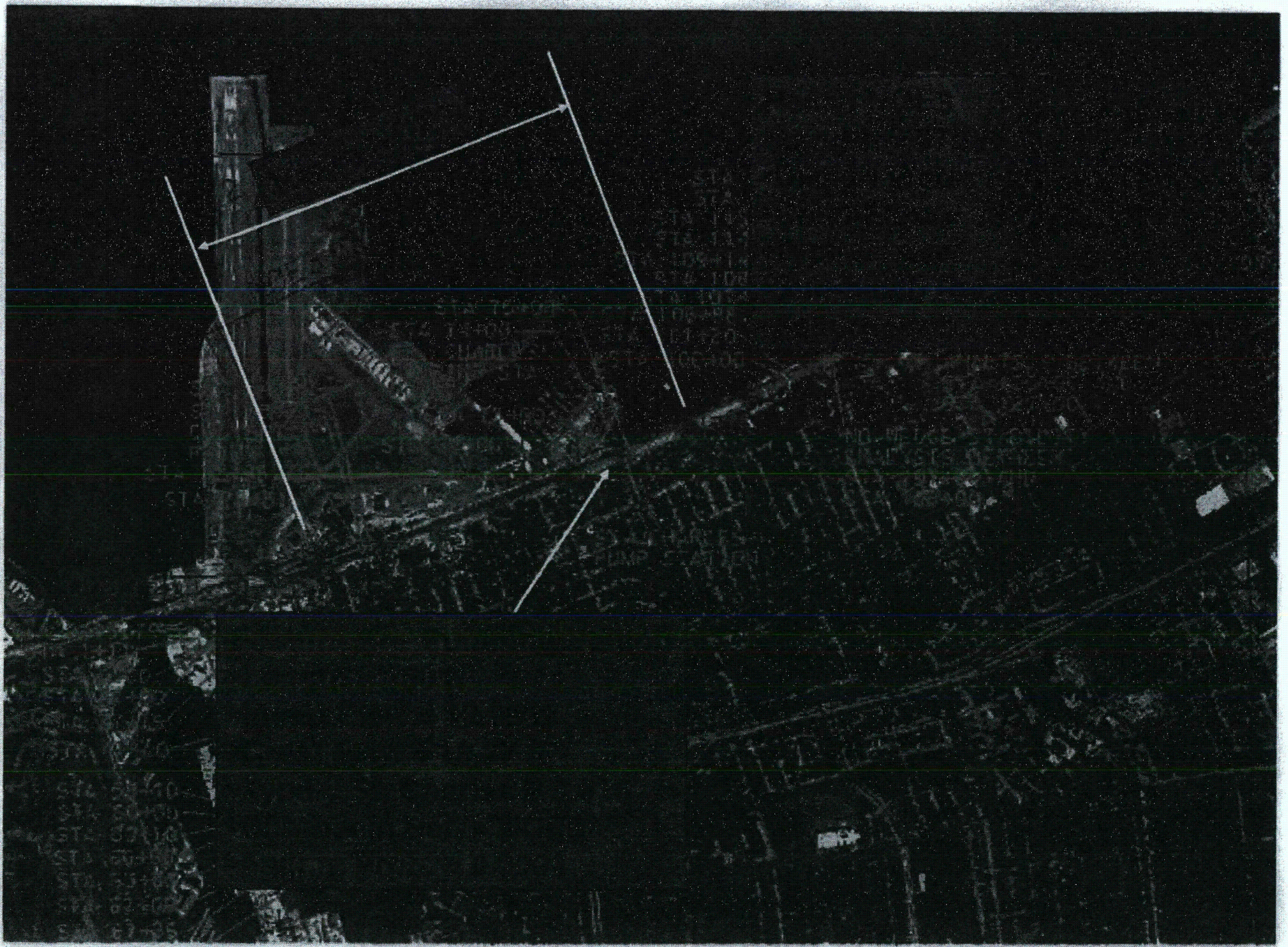
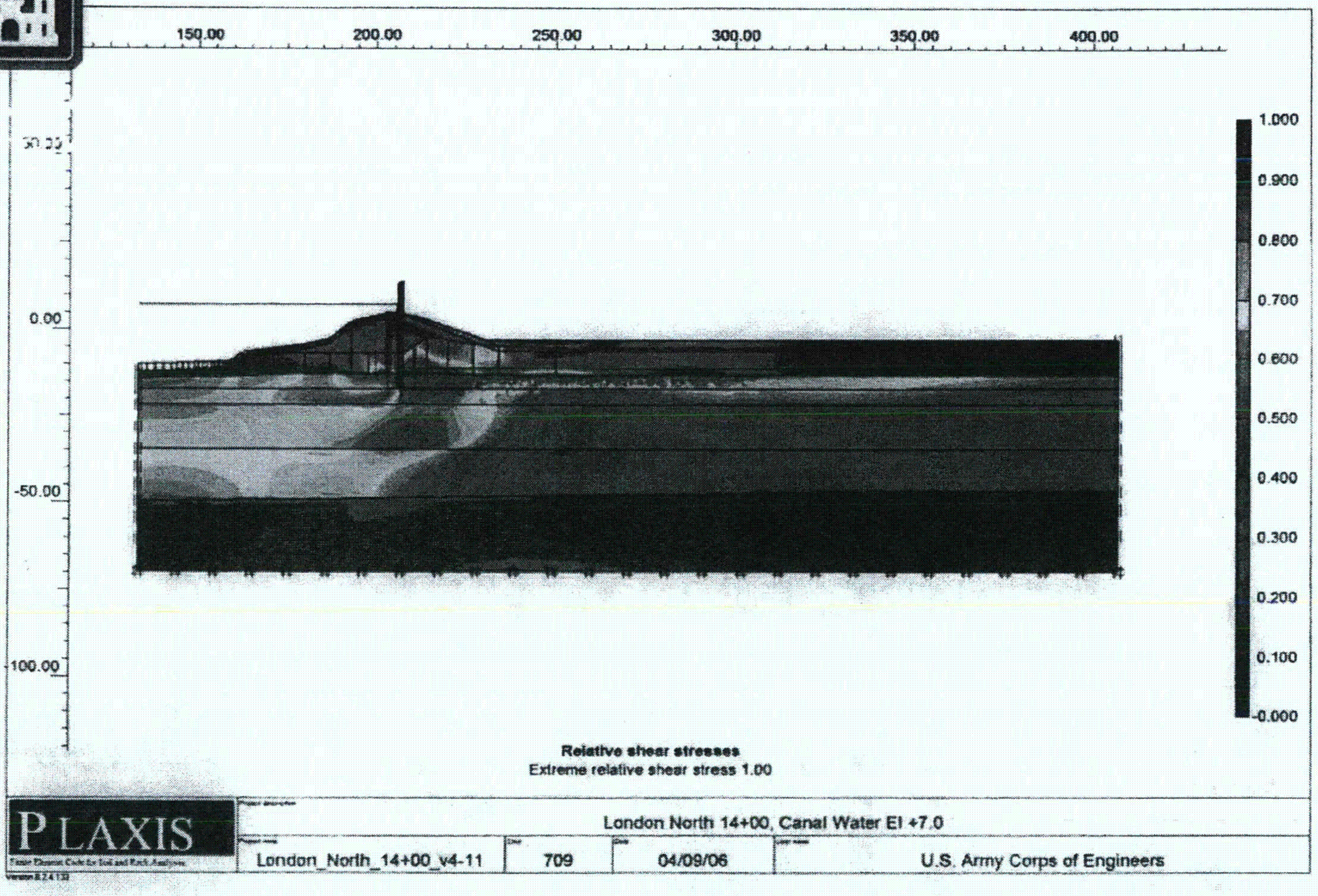
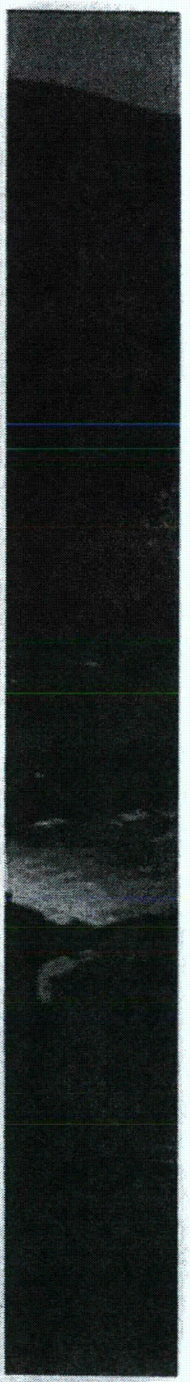
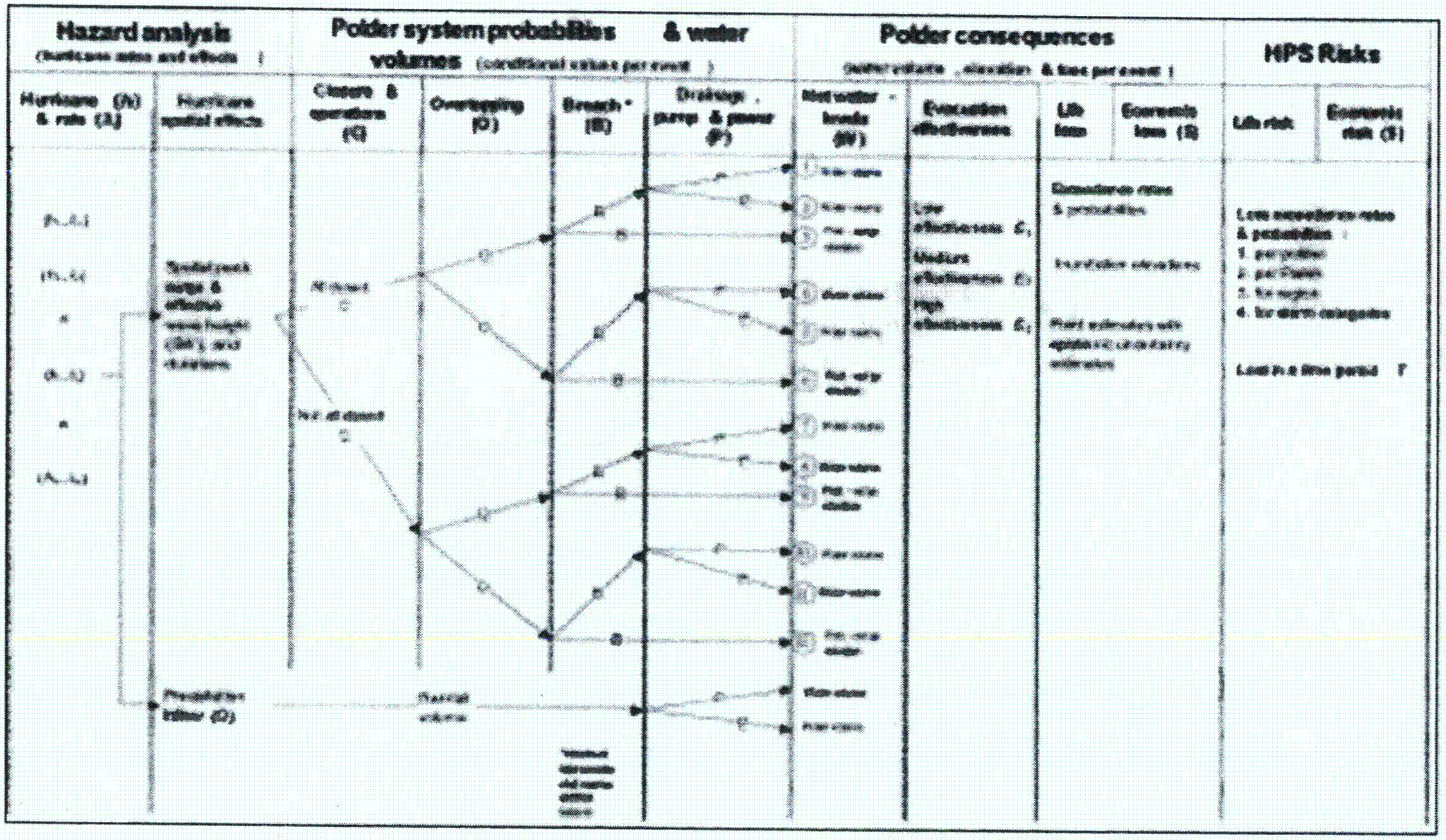


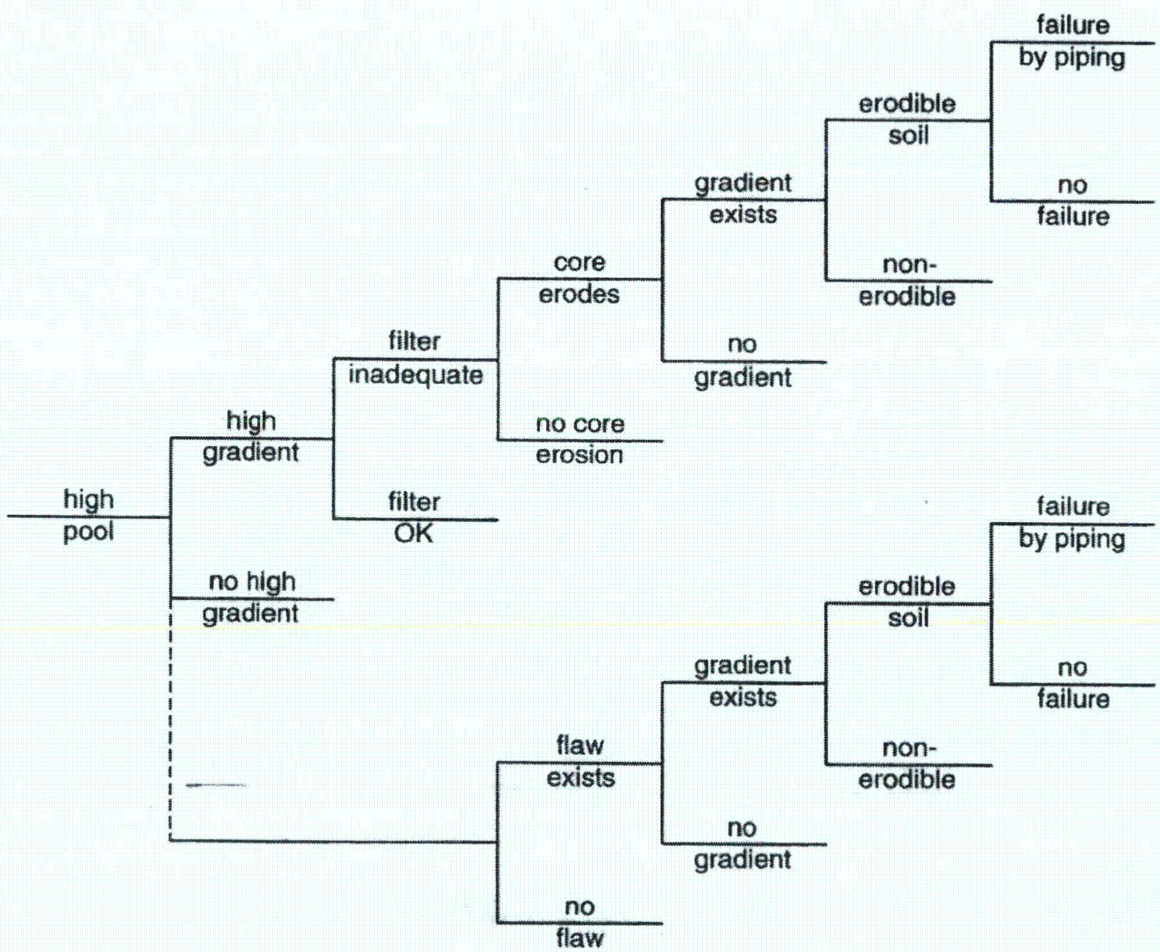


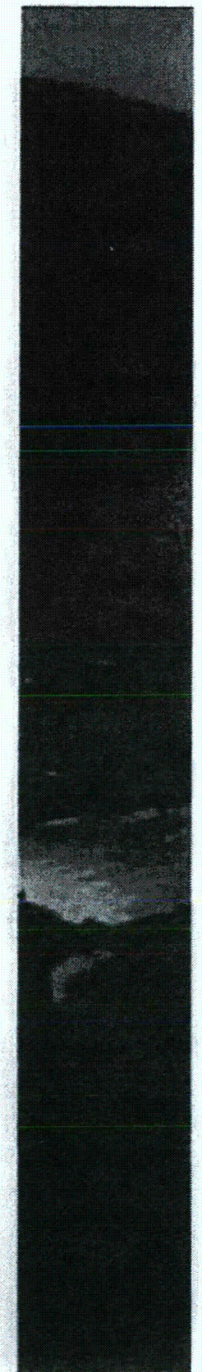
The Water Collaborative at Maryland



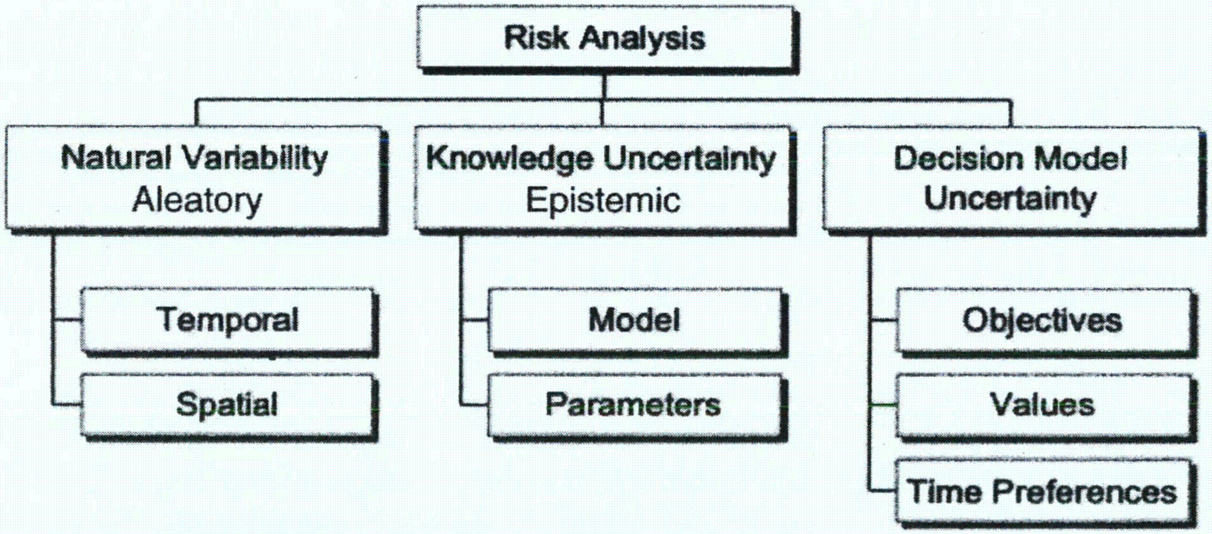

Hazard analysis
Polder system probabilities & water volumes
Polder consequences
HPS Risks

Event tree for piping



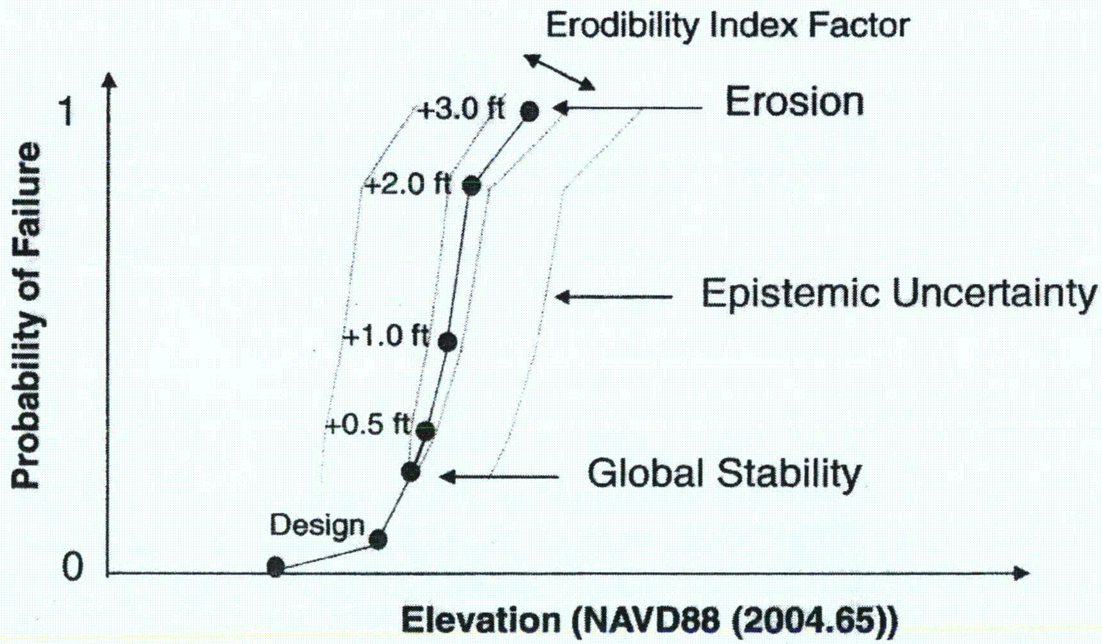


Nature of uncertainty

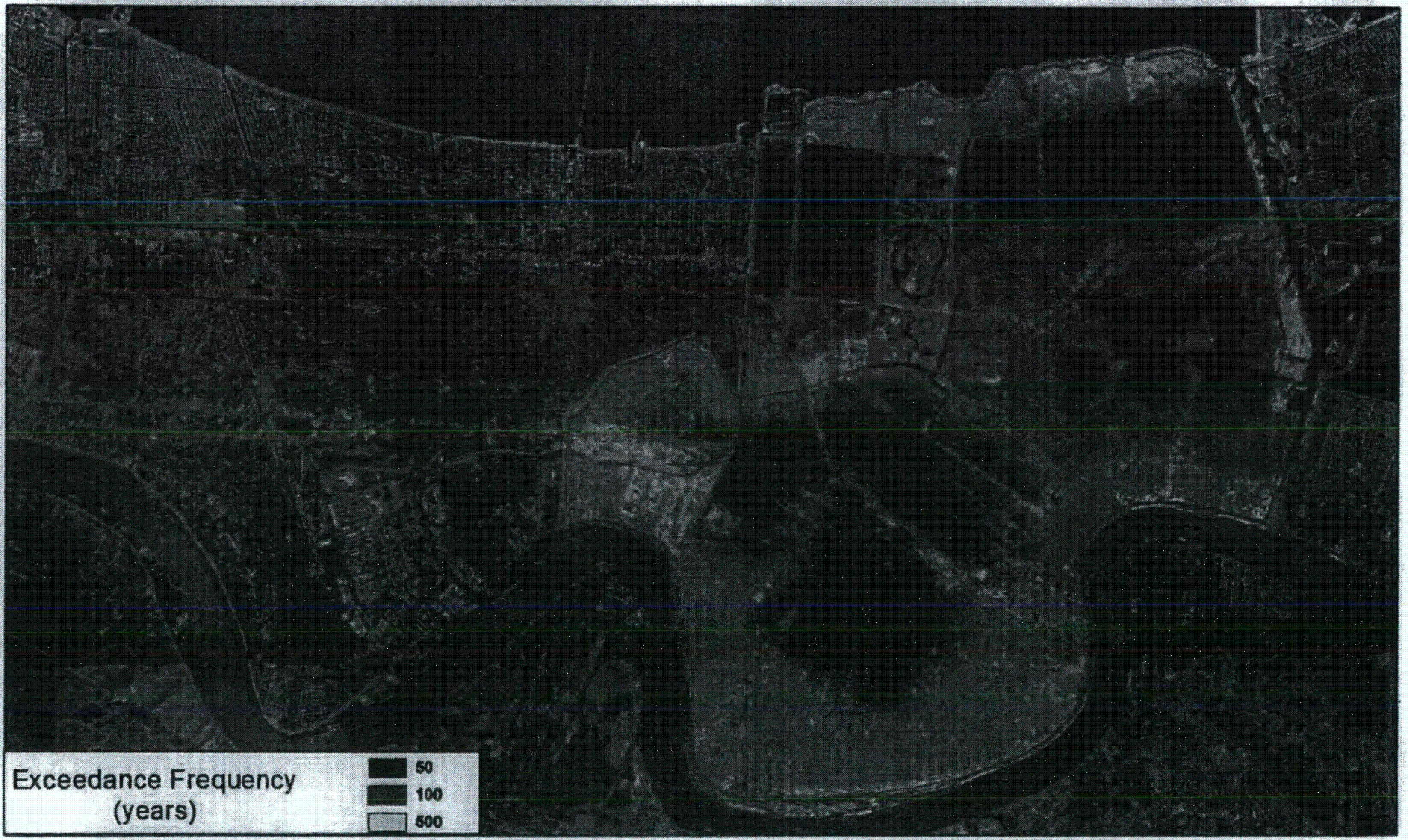


<u>Methods of assigning probabilities:</u>
Empirical (statistical)
Physics of failure models
Expert judgment

Reliability analysis

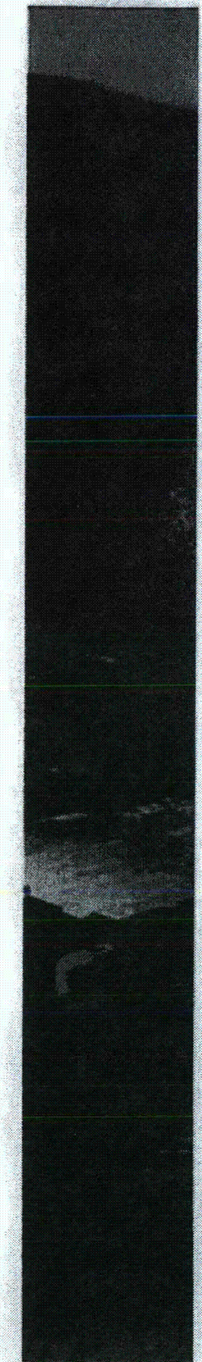


OM Current HPS Inundation



NOTES
- Evacuation has not been considered in the determination of fatalities.
- Elevation uncertainty values are for illustration only
- A return period of 1 in 50 years means there is a 2% chance every year of exceeding the plotted elevation, a 22% chance of exceeding the plotted elevation in 10 years and a 50% chance of exceeding the plotted elevation in 20 years.
- The performance of the pumping system has not been considered in the determination of the plotted elevations.

6/4/2007



PRA for dams

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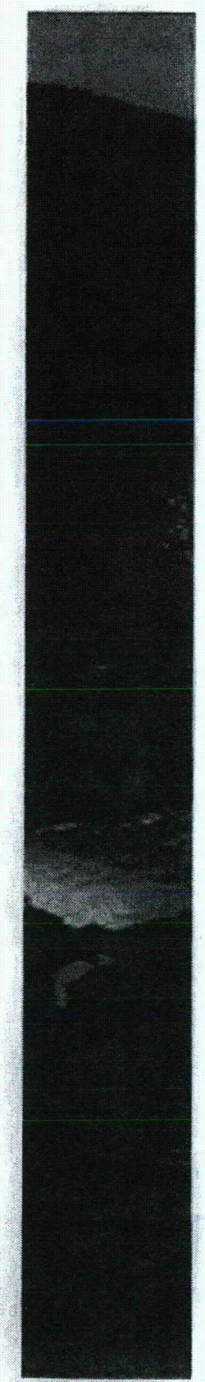

Estimating loss of life

Bureau of Reclamation approach

Dam Type	Cause of Failure	Special Considerations	Time of Failure	When Would Dam Failure Warning be Initiated?	
				Many Observers at Dam	No Observers at Dam
Earthfill	Overtopping	Drainage area at dam less than 100 mi^2 (260 km^2)	Day	0.25 hrs. before dam failure	0.25 hrs. after fw reaches populated area
		Drainage area at dam less than 100 mi^2 (260 km^2)	Night	0.25 hrs. after dam failure	1.0 hrs. after fw reaches populated area
		Drainage area at dam more than 100 mi^2 (260 km^2)	Day	2 hrs. before dam failure	1 hr. before dam failure
		Drainage area at dam more than 100 mi^2 (260 km^2)	Night	1 to 2 hr. before dam failure	0 to 1 hr. before dam failure
	Piping (full reservoir, normal weather)		Day	1 hr. before dam failure	0.25 hrs. after fw reaches populated area
			Night	0.5 hr. after dam failure	1.0 hr. after fw reaches populated area
	Seismic	Immediate Failure	Day	0.25 hr. after dam failure	0.25 hr. after fw reaches populated area
			Night	0.50 hr. after dam failure	1.0 hrs. after fw reaches populated area
		Delayed Failure	Day	2 hrs. before dam failure	0.5 hrs. before fw reaches populated area
			Night	2 hrs. before dam failure	0.5 hrs. before fw reaches populated area

Flood Inundation due to Malpasset Dam-Break Event

Simulated by NCCHE Flood Simulation System

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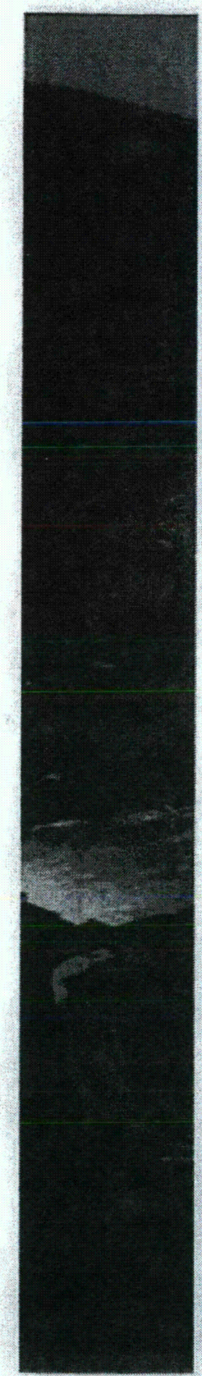

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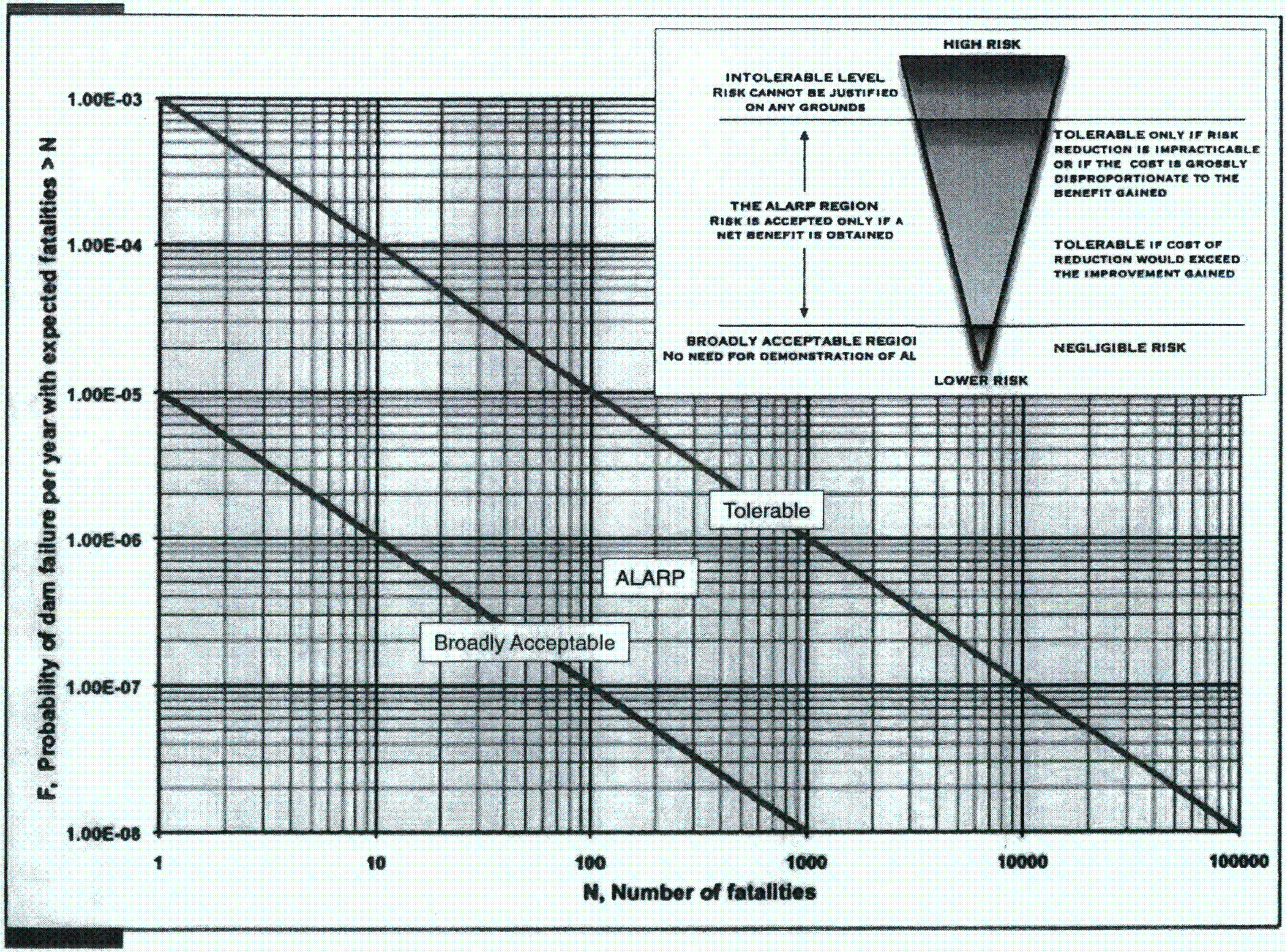
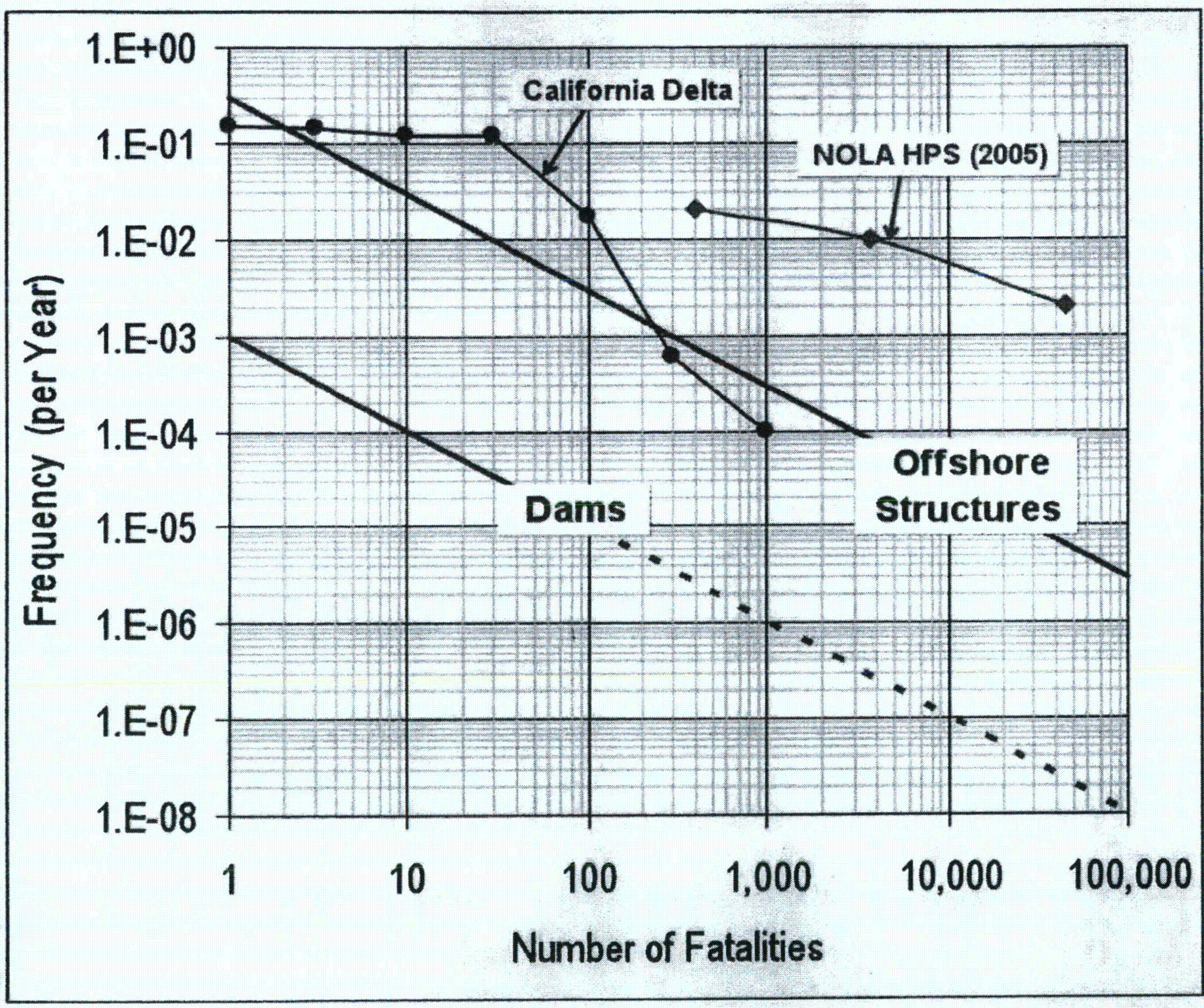
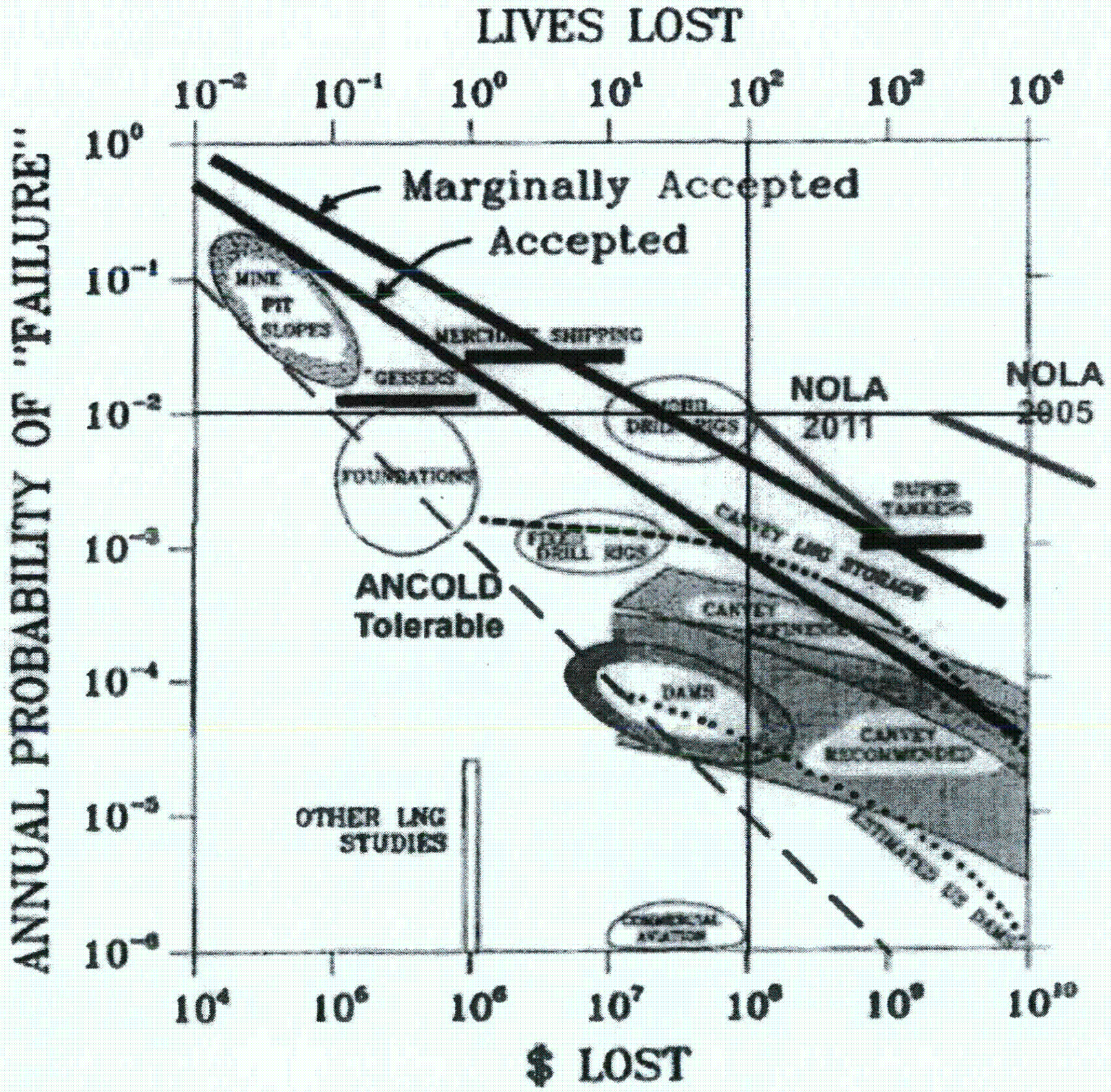


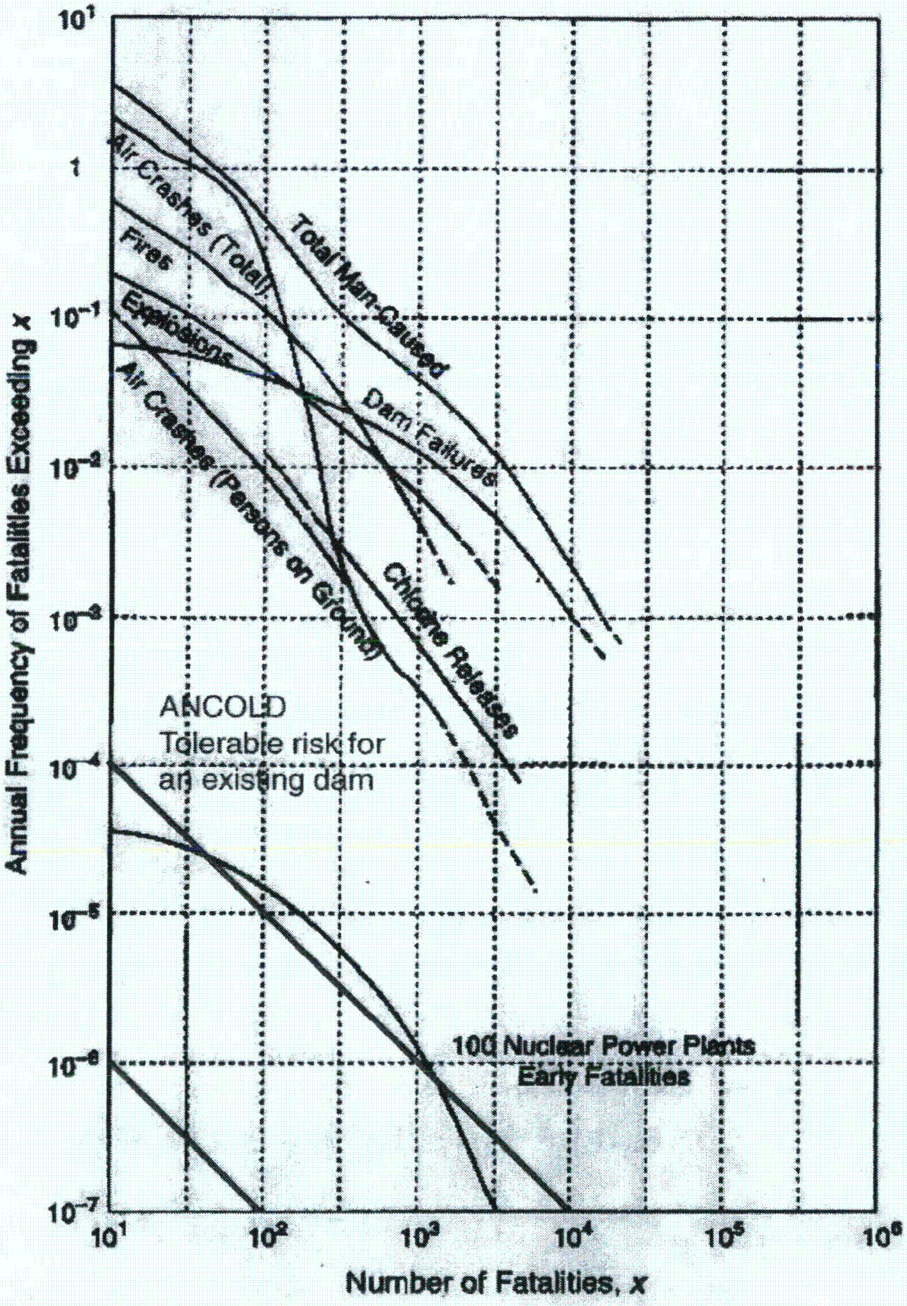
HIGH RISK
INTOLERABLE LEVEL
RISK CANNOT BE JUSTIFIED ON ANY GROUNDS
TOLERABLE ONLY IF RISK REDUCTION IS IMPRACTICABLE OR IF THE COST IS GROSSLY DISPROPORTIONATE TO THE BENEFIT GAINED
THE ALARP REGION
RISK IS ACCEPTED ONLY IF A NET BENEFIT IS OBTAINED
TOLERABLE IF COST OF REDUCTION WOULD EXCEED THE IMPROVEMENT GAINED
BROADLY ACCEPTABLE REGIOI
NO NEED FOR DEMONSTRATION OF AL
NEGLIGIBLE RISK
LOWER RISK
Tolerable
ALARP
Broadly Acceptable
F, Probability of dam failure per year with expected fatalities > N
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1
10
100
1000
10000
100000
N, Number of fatalities



1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
Frequency (per Year)
California Delta
NOLA HPS (2005)
Offshore Structures
Dams
1
10
100
1,000
10,000
100,000
Number of Fatalities

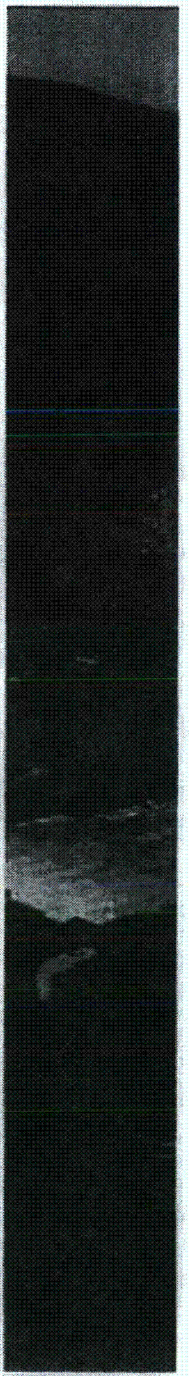


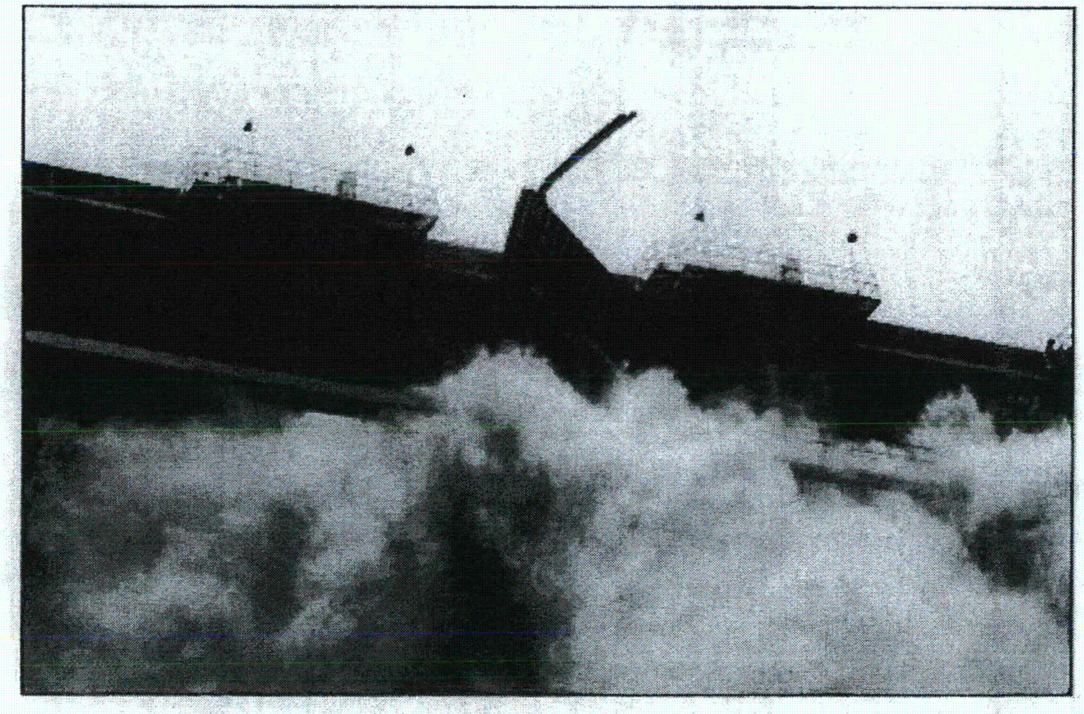
LIVES LOST
10⁻² 10⁻¹ 10⁰ 10¹ 10² 10³ 10⁴
ANNUAL PROBABILITY OF "FAILURE"
Marginally Accepted
Accepted
MINE PIT SLOPES
MERCHANT SHIPPING
"GEISERS"
MOBIL DRILL RIGS
NOLA 2011
NOLA 2005
FOUNDATIONS
SUPER TANKERS
FIXED DRILL RIGS
CANVEY LNG STORAGE
ANCOLD Tolerable
DAMS
CANVEY RECOMMENDED
OTHER LNG STUDIES
ESTIMATED US DAMS
COMMERCIAL AVIATION
$ LOST



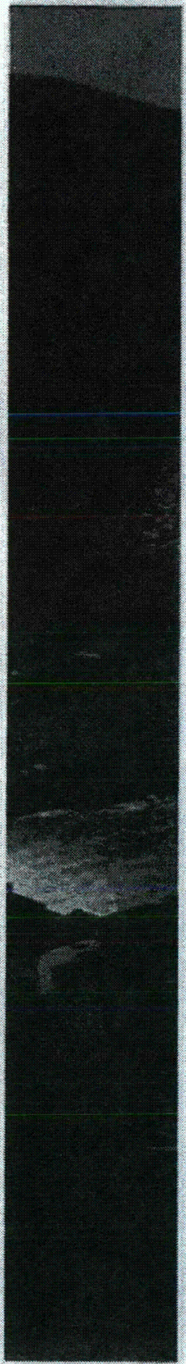
aborative at Maryland

Spillway Systems Reliability Project

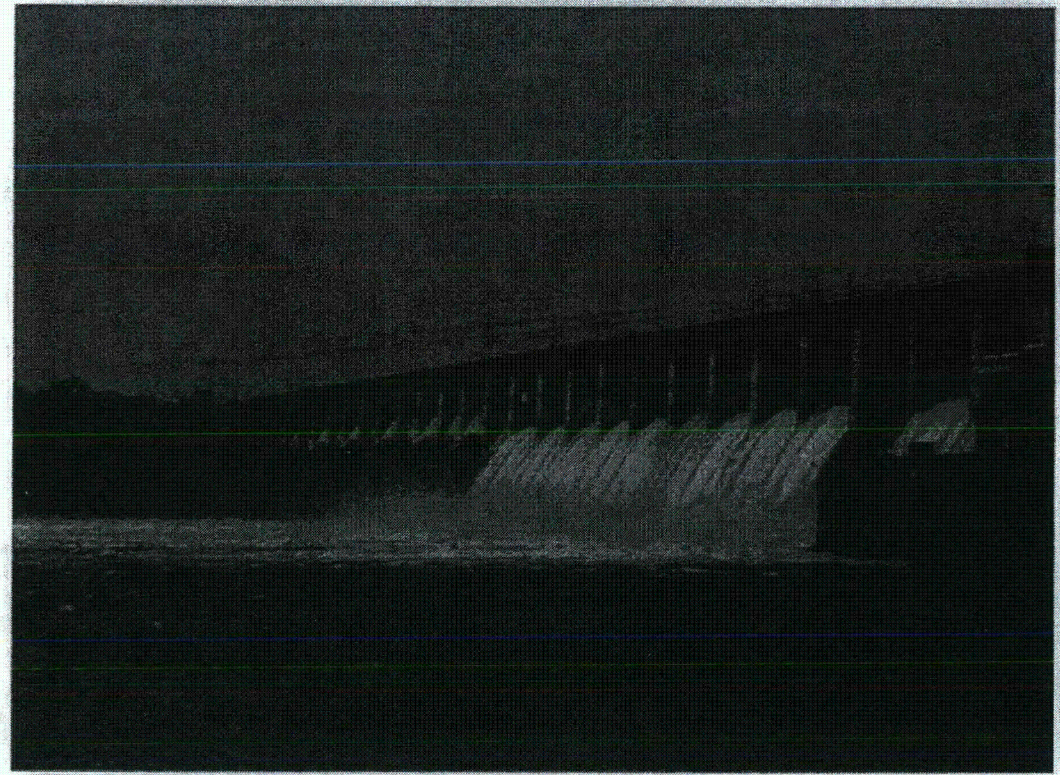




1995 Folsom gate failure (CA)



Spillway Systems Reliability Project



ELFORSK

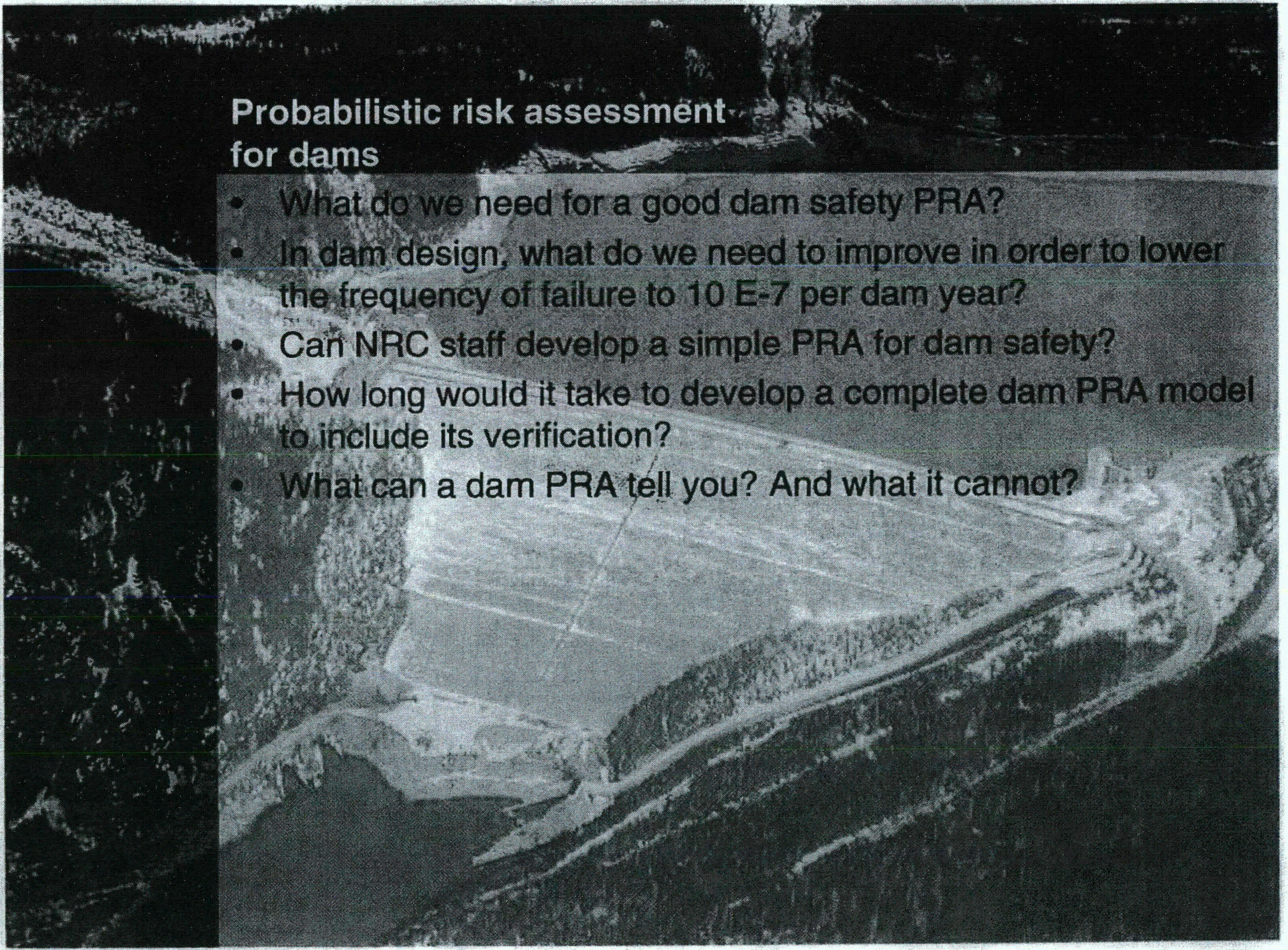
ONTARIOPOWER GENERATION

BC hydro

US Army Corps of Engineers

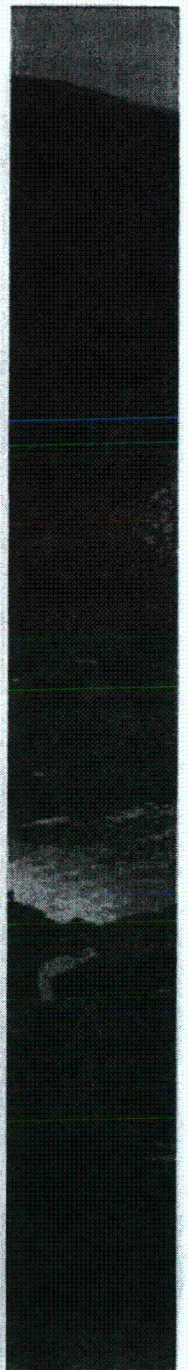
The Water Collaborative at Maryland

UNIVERSITY OF MARYLAND


Probabilistic risk assessment for dams
What do we need for a good dam safety PRA?
In dam design, what do we need to improve in order to lower the frequency of failure to 10 E-7 per dam year?
Can NRC staff develop a simple PRA for dam safety?
How long would it take to develop a complete dam PRA model to include its verification?
What can a dam PRA tell you? And what it cannot?

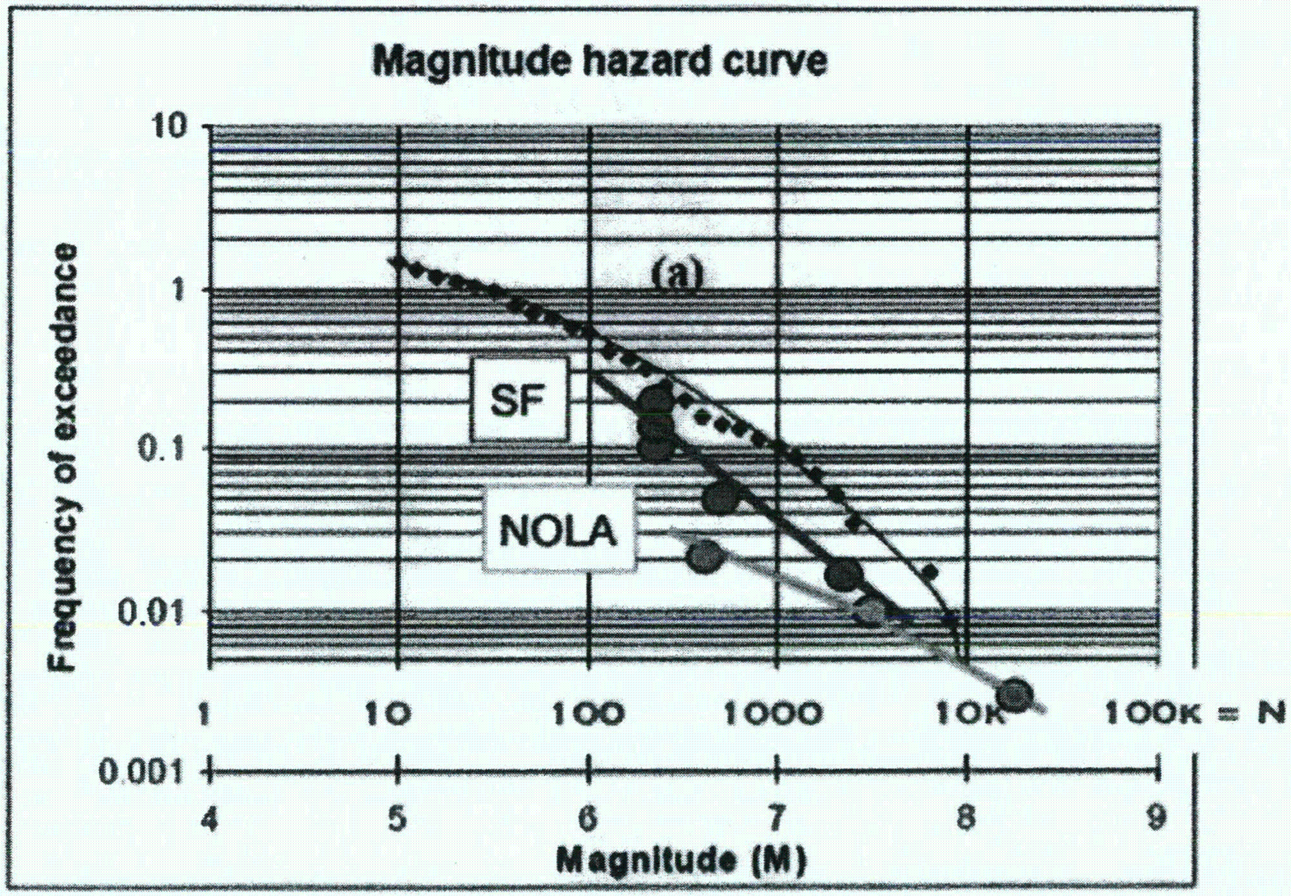
Thank you, and be careful

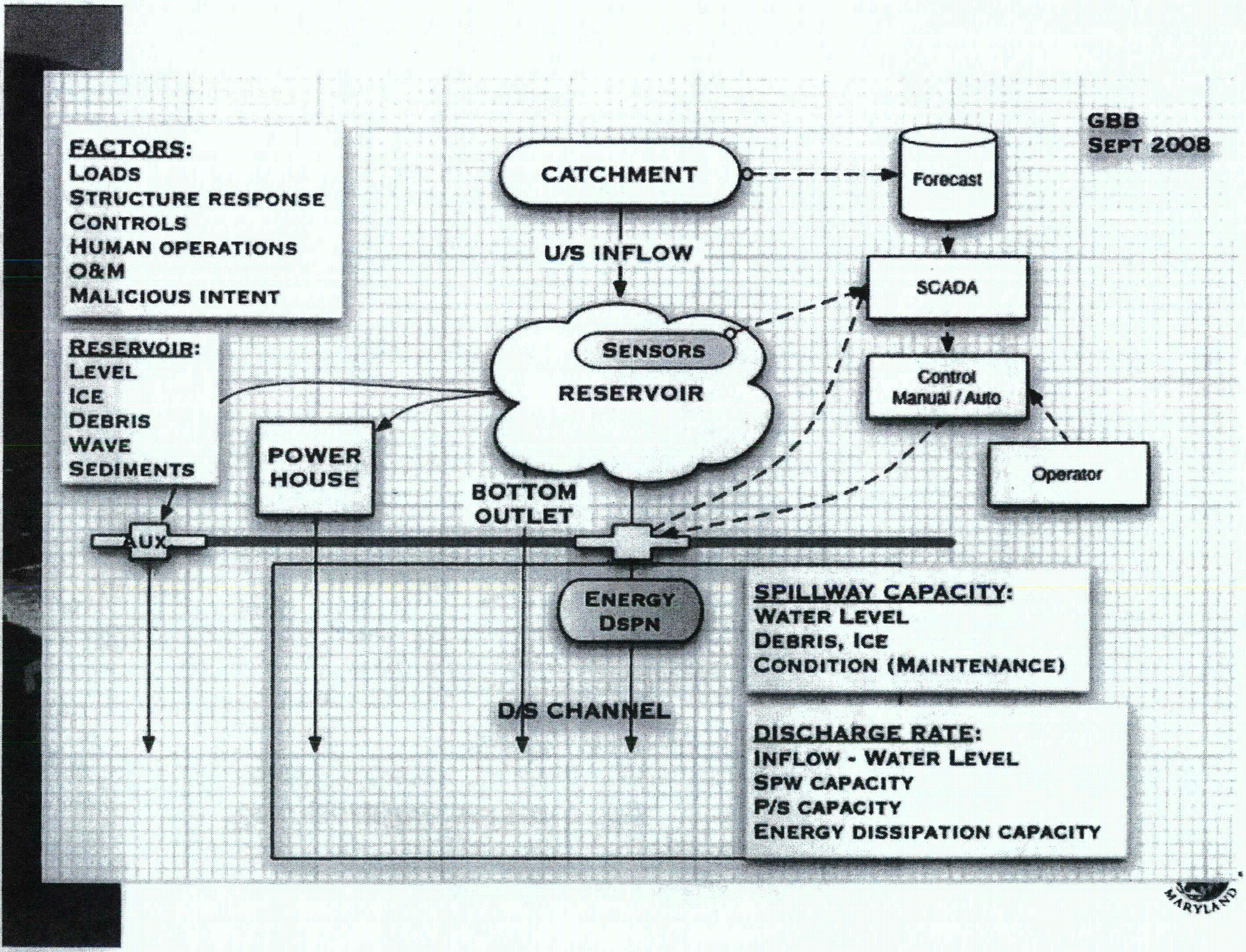
"'BE CAREFUL'! ALL YOU CAN TELL ME IS 'BE CAREFUL'?"



Extra slides

Comparative seismic risk




GBB
SEPT 2008
FACTORS:
LOADS
STRUCTURE RESPONSE
CONTROLS
HUMAN OPERATIONS
O&M
MALICIOUS INTENT
CATCHMENT
Forecast
U/S INFLOW
SCADA
SENSORS
RESERVOIR
Control
Manual / Auto
RESERVOIR:
LEVEL
ICE
DEBRIS
WAVE
SEDIMENTS
POWER
HOUSE
Operator
BOTTOM
OUTLET
AUX
ENERGY
DSPN
SPILLWAY CAPACITY:
WATER LEVEL
DEBRIS, ICE
CONDITION (MAINTENANCE)
D/S CHANNEL
DISCHARGE RATE:
INFLOW - WATER LEVEL
SPW CAPACITY
P/S CAPACITY
ENERGY DISSIPATION CAPACITY
MARYLAND

From: Perkins, Richard
Sent: Wednesday, October 17, 2012 12:54 PM
To: Criscione, Lawrence
Subject: FW: FYI

From: Perkins, Richard
Sent: Tuesday, October 16, 2012 4:05 PM
To: King, Mark
Subject: RE: FYI

Thanks Mark,

I did see it. I thought the article provided a stunning… and I'm not sure about what word to use next. Insight? Realization? Example? Admission? Truth? Wake-up-call? Example of human behavior? Study in psychology? Failure of a regulatory system? Failure of a company to come to grips with an issue? Example of total disregard for ethics and social responsibility? Example of how corporations behave absent an adequate regulatory environment.

Richard

From: King, Mark
Sent: Tuesday, October 16, 2012 3:05 PM
To: Perkins, Richard
Subject: FYI

Richard - thought you might find this article below interesting – it parallels your "**flooding**" concerns… and the potential NRC timeliness to addressing those concerns, going forward that the Japanese failed to heed for tsunami's / flooding.

Fukushima operator admits nuclear disaster avoidable

TOKYO | Fri Oct 12, 2012 11:09am EDT

Oct 12 (Reuters) - Tokyo Electric Power Co (Tepco), the operator of the wrecked Fukushima nuclear plant, said on Friday it could have dealt better with the plant's meltdowns if broad preparations were taken, reversing the previous management's view that the disaster was unavoidable due to an unexpected force of nature.

The comments were contained in a draft plan for the reform of nuclear power organisation a Tepco task force submitted to an independent advisory body, which held the first meeting on Friday, to improve safety and safety culture at Tepco.

The five-member advisory body to the board of directors, the Nuclear Reform Monitoring Committee, plans to hold a meeting once every two to three months to review the draft plan and make proposals, without a pre-fixed time to complete its mission

The Fukushima Daiichi plant, 240 km (150 miles) north of Tokyo, was hit on March 11 last year by a massive earthquake and tsunami that swamped its backup power and cooling systems, resulting in meltdowns of three of its six reactors

About 150,000 people were forced to flee as radioactive materials spewed, some never to return

Tepco, struggling under huge costs for compensation, cleanup and decommissioning, has since replaced top management with Chairman Kazuhiko Shimokobe, a lawyer who had crafted a compensation scheme for disaster victims, and President Naomi Hirose

"When looking back on the accident, the problem was that preparations were not made in advance, so we need a reform plan that will allow us to be sensitive in capturing opportunities for improvement and safety enhancement and lead to actual measures," the draft nuclear reform plan said.

It **was** possible to take action in regard of ~~tsunami~~ *[FLOODING]* defence based on the company's earlier tsunami *[FLOODING]* evaluations and it **was** also possible to diversify safety systems by referencing severe accident measures taken in other countries, the draft also said.

In a news conference attended by the committee members, Dale Klein, head of the committee and former chairman of U.S. Nuclear Regulatory Commission, said nuclear power can be safe in any country - even in quake-prone Japan - if done properly.

Tepco was nationalised earlier this year with a 1 trillion yen ($12.7 billion) injection of public funds in exchange for a turnaround plan, that includes restarting the Kashiwazaki-Kariwa nuclear plant, northwest of Tokyo, as early as in April 2013. ($1 = 78.5100 Japanese yen) (Reporting by Risa Maeda)

ARTICLE SOURCE: http://www.reuters.com/article/2012/10/12/japan-nuclear-idUSL3E8LC6W320121012

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From: Perkins, Richard
Sent: Wednesday, October 24, 2012 10:44 AM
To: Criscione, Lawrence
Subject: Some news from Japan on crop impacts

http://www.bloomberg.com/news/2012-10-24/japan-to-restrict-some-rice-shipments-in-fukushima-on-radiation.html

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Criscione, Lawrence

From: Perkins, Richard
Sent: Monday, December 03, 2012 3:44 PM
To: Criscione, Lawrence
Subject: Various presentations, e-mail 1 of 2
Attachments: Presentation_to_GIP_Panel_Briefing_2011_04_29.pptx

This attachment is publicly available as ML15111A052

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From: Perkins, Richard
Sent: Tuesday, January 15, 2013 11:49 AM
To: Criscione, Lawrence
Subject: Recent FOIA closures

http://pbadupws.nrc.gov/docs/ML1235/ML12352A276.html

http://pbadupws.nrc.gov/docs/ML1235/ML12352A273.html

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