

Reclamation Workshop to Review Current Operations Practices
Focus on Communicating Risk, Uncertainty and
Incorporating Climate Information

June 17, 2009

Risk, Uncertainty and Decision Concepts for Water Resources Systems Operations

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RAC

Engineers & Economists

Utah State
UNIVERSITY

IDSRM

Outline

- 1) Some Definitions
- 2) Comparing uncertainty analysis results with deterministic (best estimate) analysis results (Dam failure life-loss estimation)
- 3) An uncertainty analysis in which natural variability and knowledge uncertainty are distinguished (Dam failure risk assessment)
- 4) Six levels of complexity in the treatment of uncertainty in risk analysis
- 5) Organizing the Risk and Uncertainty Analysis and Selecting Decision Criteria
- 6) Using Ensemble Inflow Forecasts For Improved Reservoir Operation and Emergency Management (Folsom Reservoir)
- 7) Uncertainty Analysis: 24-month Study Mid-Term River Operations Model for the Lower Colorado River
- 8) An Example of Real-time Updating of Forecasts Using Uncertainty Estimates

1) Some Definitions



Risk

(Risk Analysis and Uncertainty in Flood Damage Reduction Studies (NAP 2000))

- ... the probability that some undesirable event occurs
- ... sometimes used to describe the combination of that probability and the corresponding consequence of the event (*e.g. risk cost or annualized life loss*).
- The Corps measures risk by the **probability that system operation is undesirable** (e.g., the probability that a levee fails or that an ecosystem restoration project fails to meet a standard).
- **The complement of risk is reliability, the probability that a system operates without failing.**

Uncertainty

(Risk Analysis and Uncertainty in Flood Damage Reduction Studies (NAP 2000))

- ... a lack of sureness about something or someone, ranging from just short of complete sureness to an almost complete lack of conviction about an outcome.
- Doubt, dubiety, skepticism, suspicion, and mistrust are common synonyms. Each synonym expresses an aspect of uncertainty that comes to play in risk analysis.
 - Uncertainty with respect to natural phenomena (*natural variability*) means that an outcome is unknown or not established and is therefore in question.
 - Uncertainty with respect to a belief (*knowledge uncertainty*) means that a conclusion is not proven or is supported by questionable information.
 - Uncertainty with respect to a course of action (*policy uncertainty*) means that a plan is not determined or is undecided.
- In many, but not all, situations a lack of sureness can be described by probability distributions. The term uncertainty should be used to describe situations without sureness, whether or not described by a probability distribution.

Sources of uncertainties

Aleatory Uncertainty

Epistemic Uncertainty

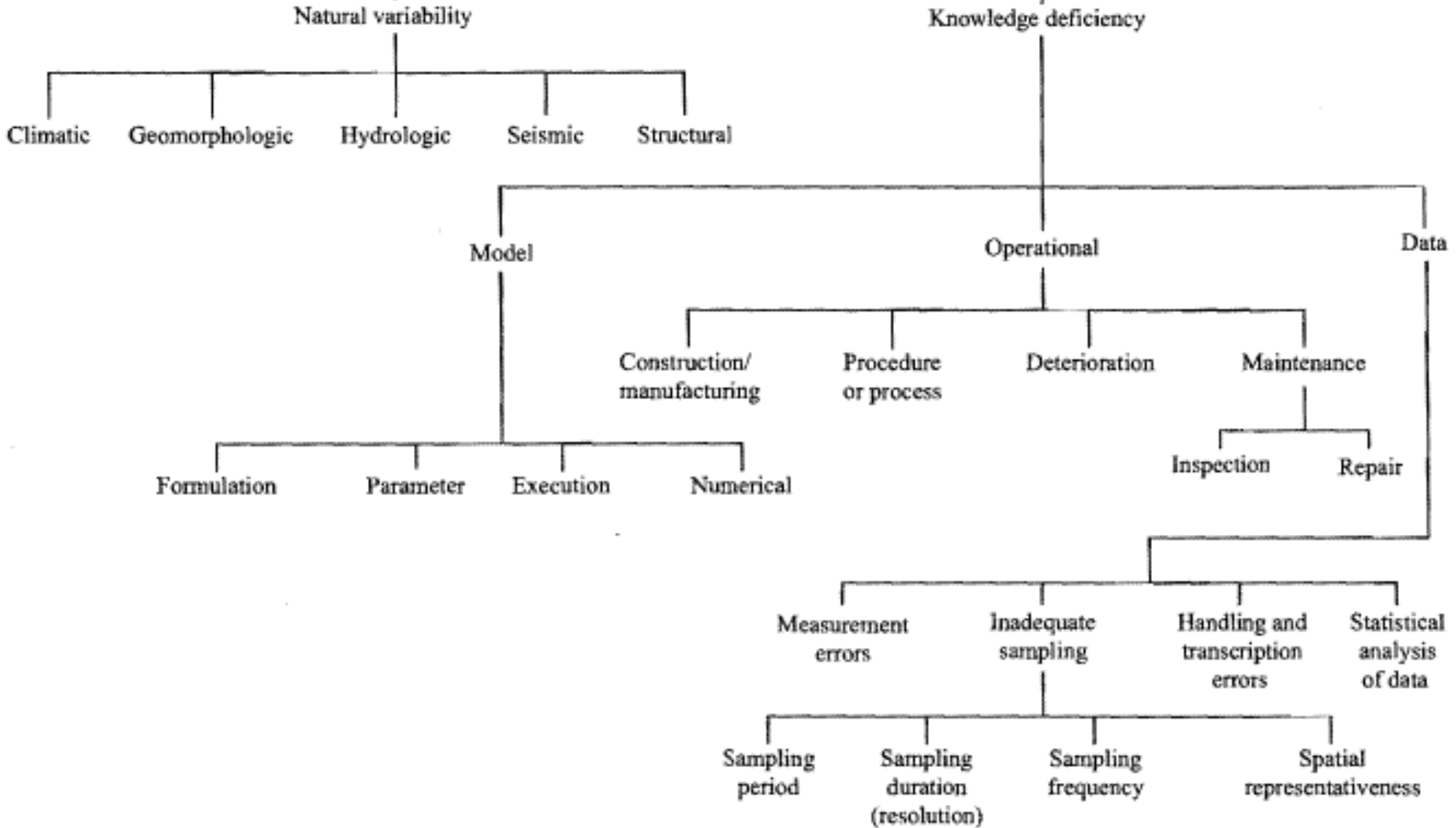
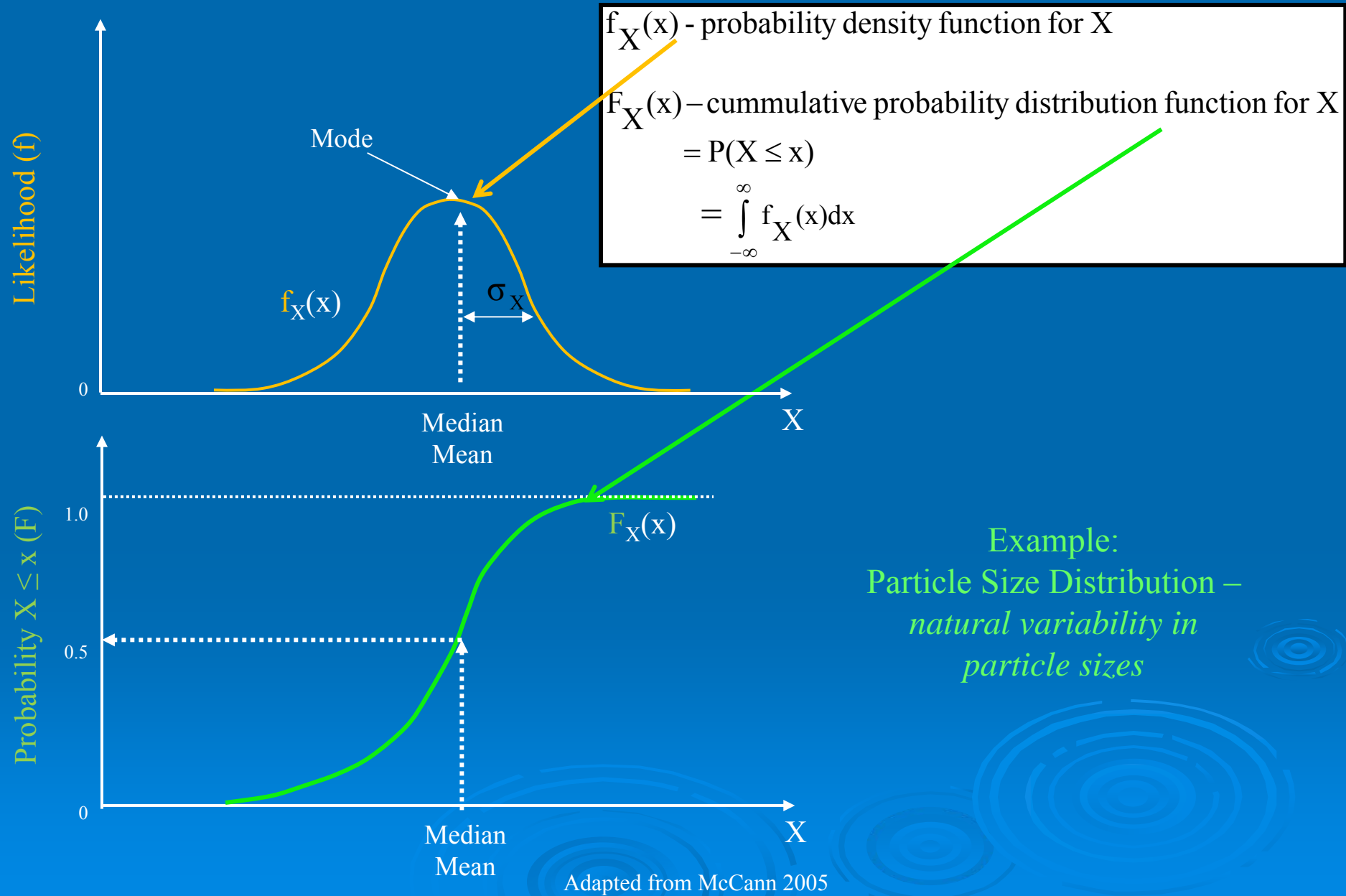
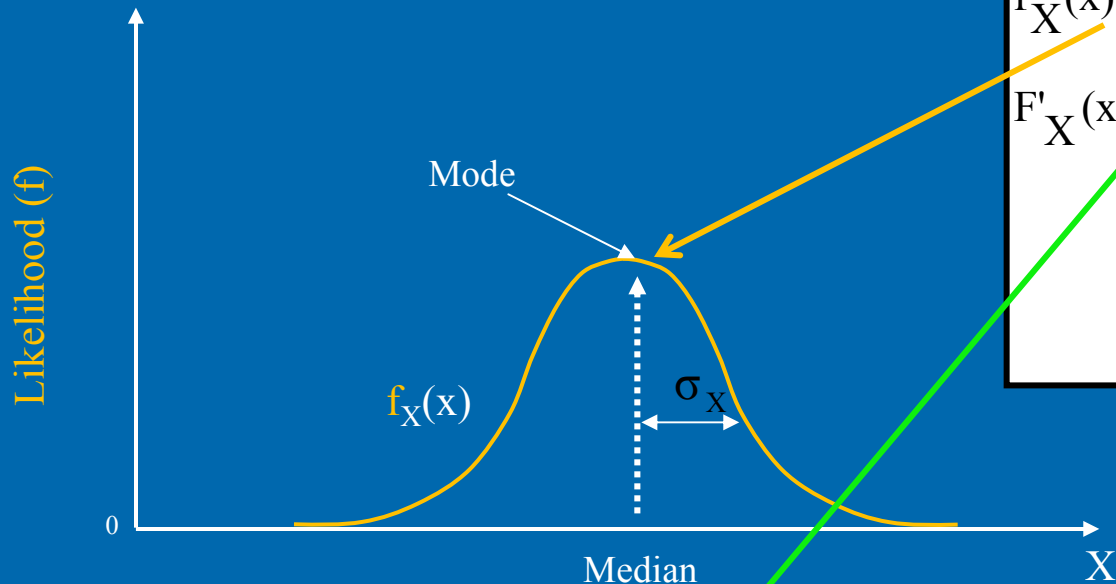


Figure 1.1 Sources of uncertainty.

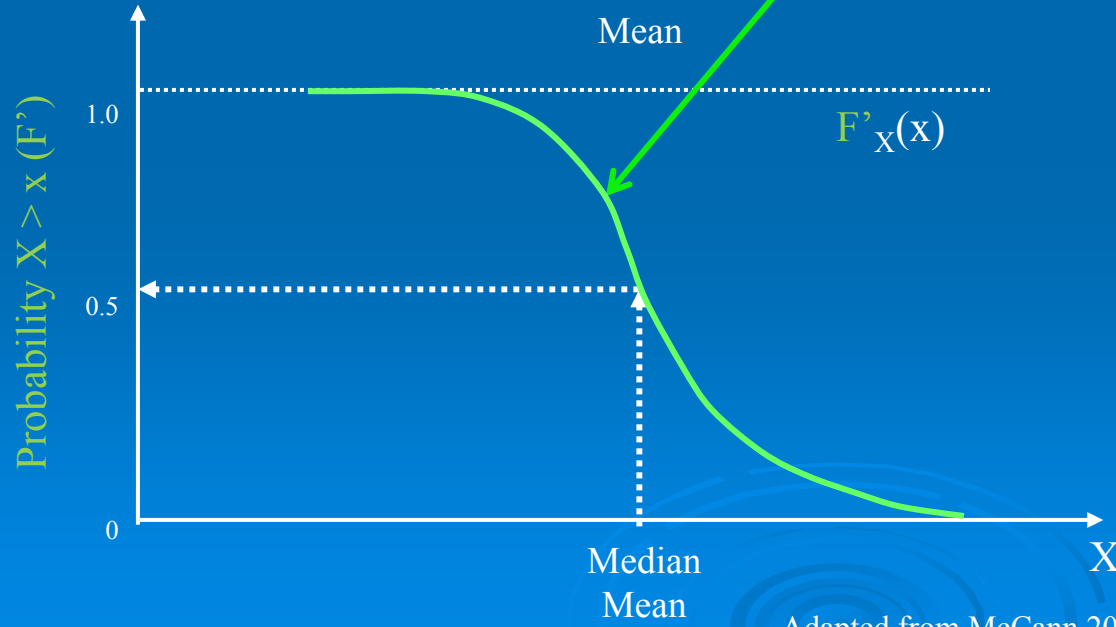
Non-exceedance Distribution (CDF)



Exceedance Distribution (CCDF)

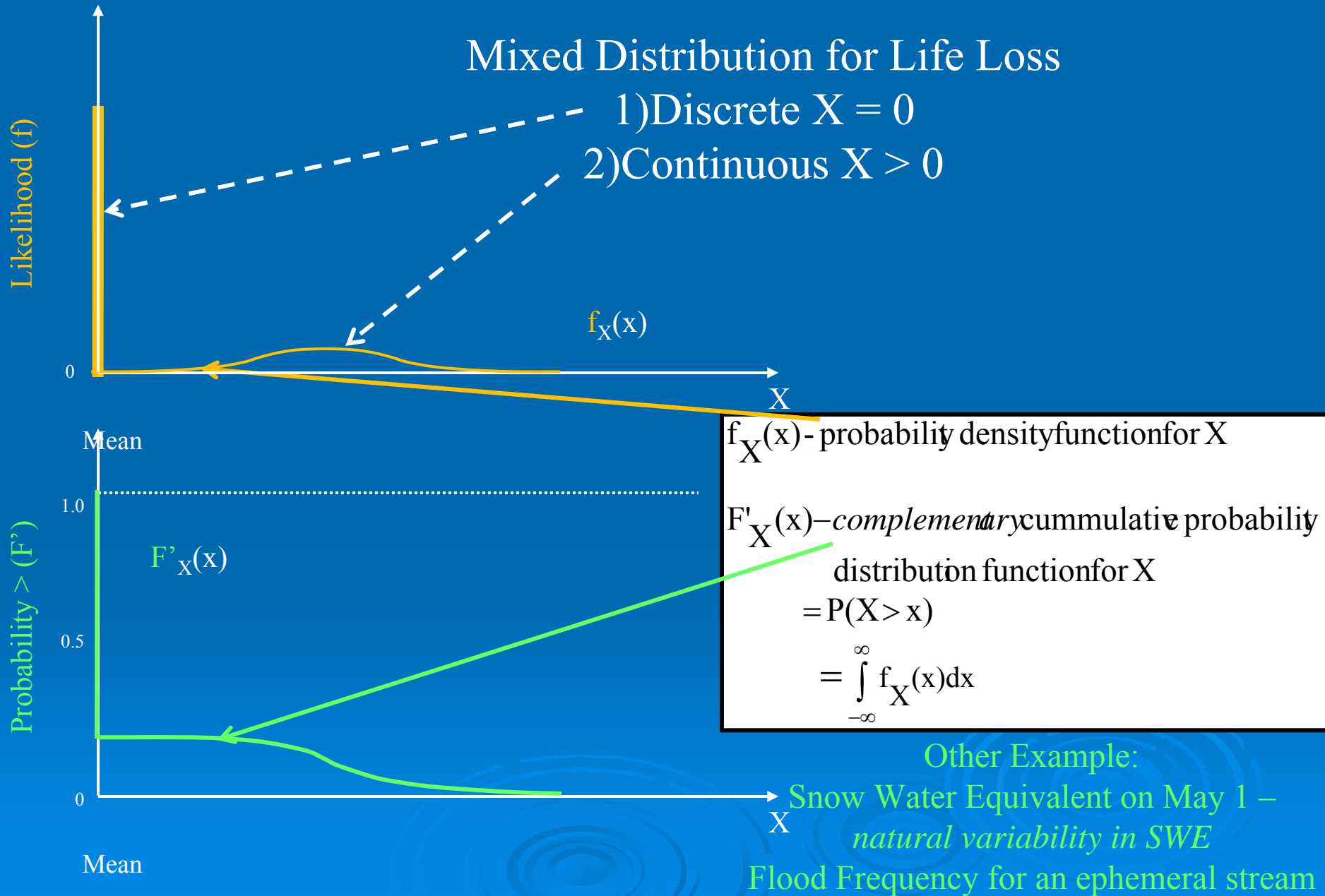


$f_X(x)$ - probability density function for X
 $F'_X(x)$ - complementary cumulative probability distribution function for X
 $= P(X > x)$
 $= \int_{-\infty}^{\infty} f_X(x) dx$

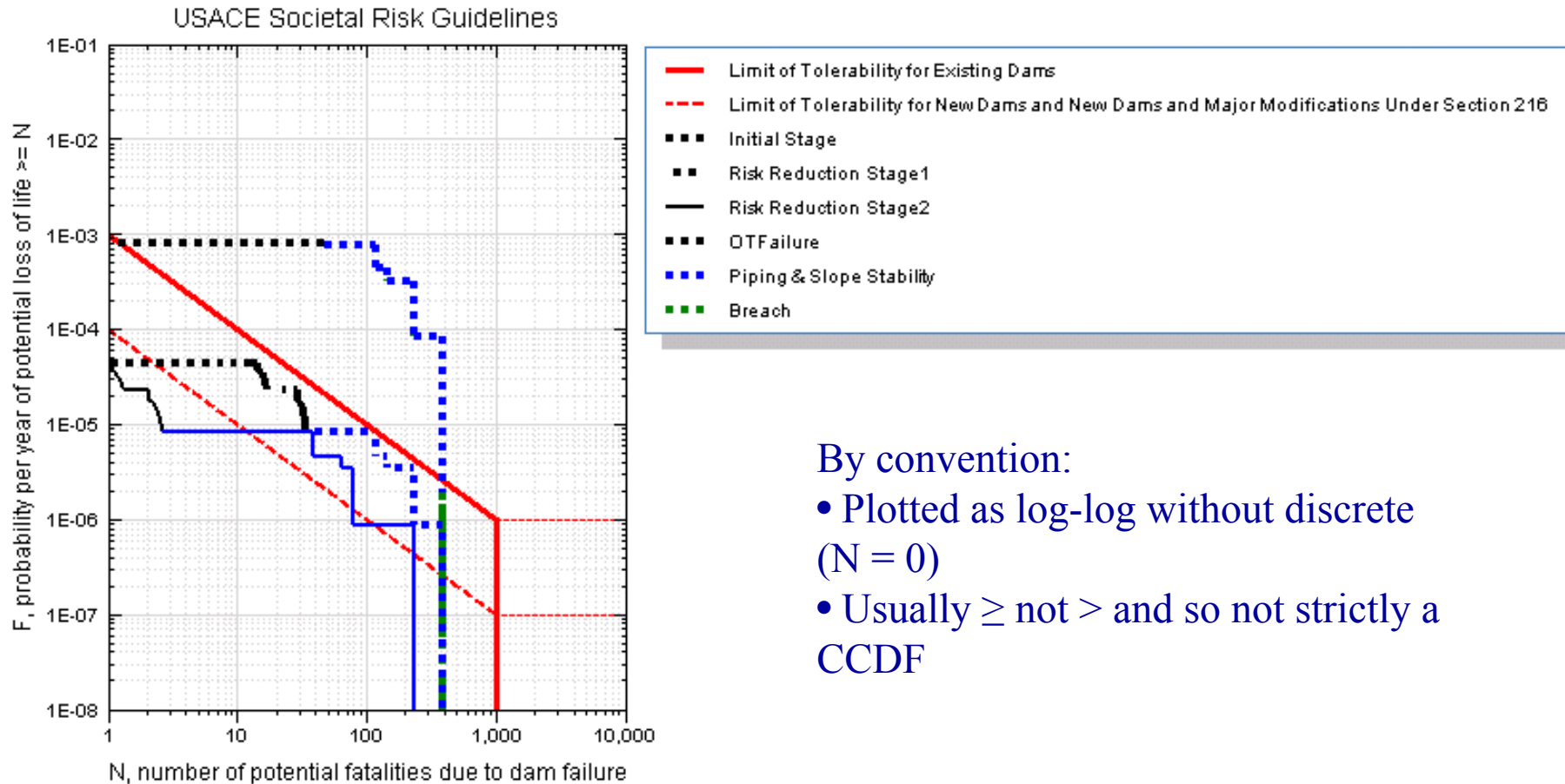


Examples:
Flood Frequency and Seismic Hazard Relationships – natural variability in annual peak flow rates or annual peak ground acceleration

Mixed Exceedance Distribution



Example of USACE societal tolerable risk guidelines and F-N plot



2) Comparing uncertainty analysis results with results from deterministic (best estimate) analysis

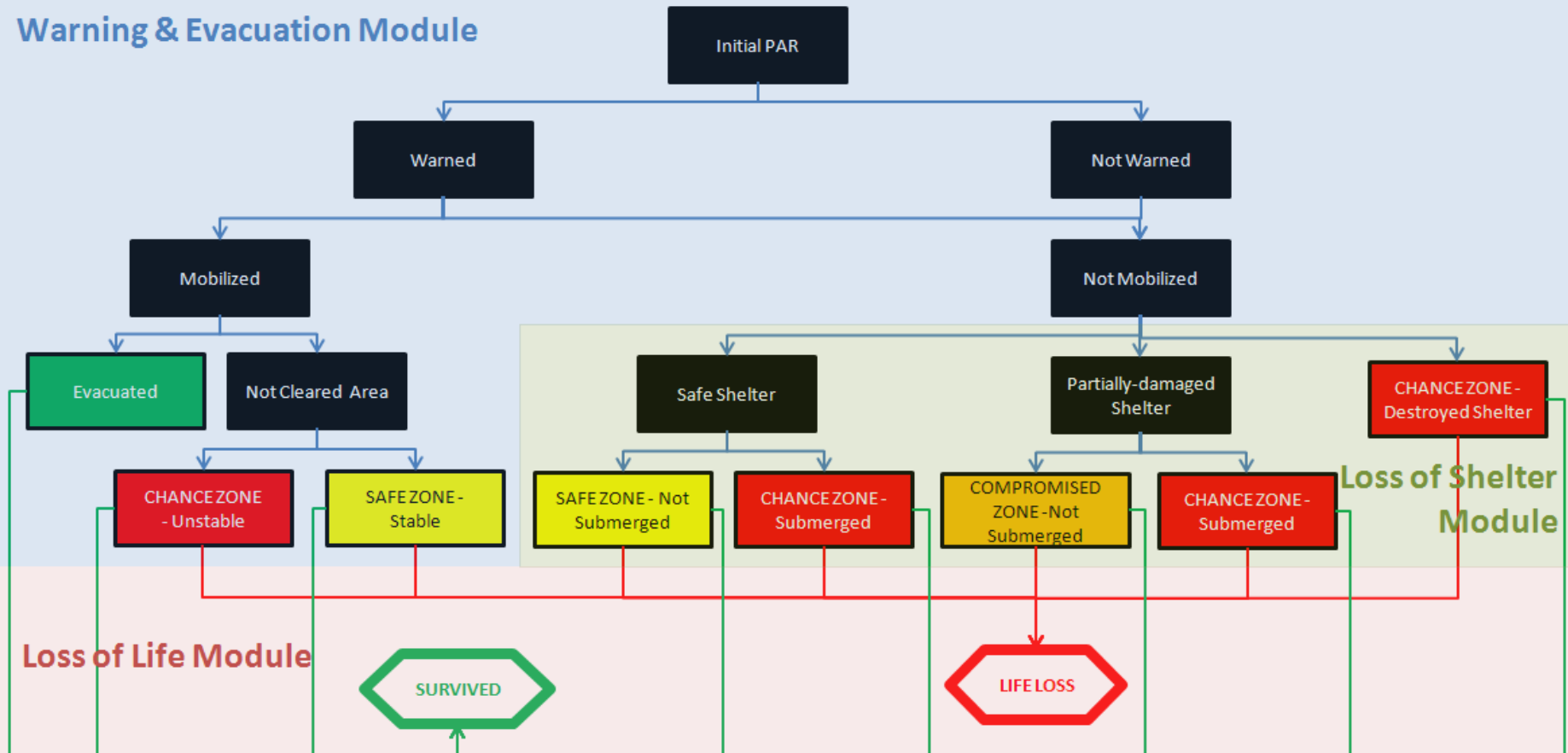
Life-loss estimation for dam safety risk assessment
(Aboelata and Bowles 2005)

<http://uwrl.usu.edu/people/faculty/DSB/lifesim.pdf>

Simplified LIFESim - USACE

(Aboelata and Bowles 2005)

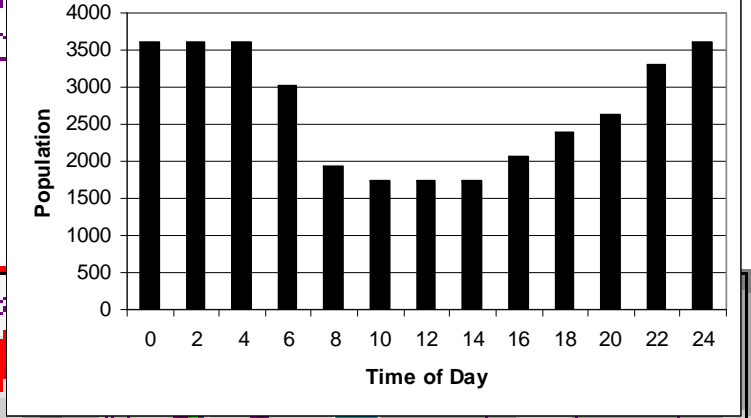
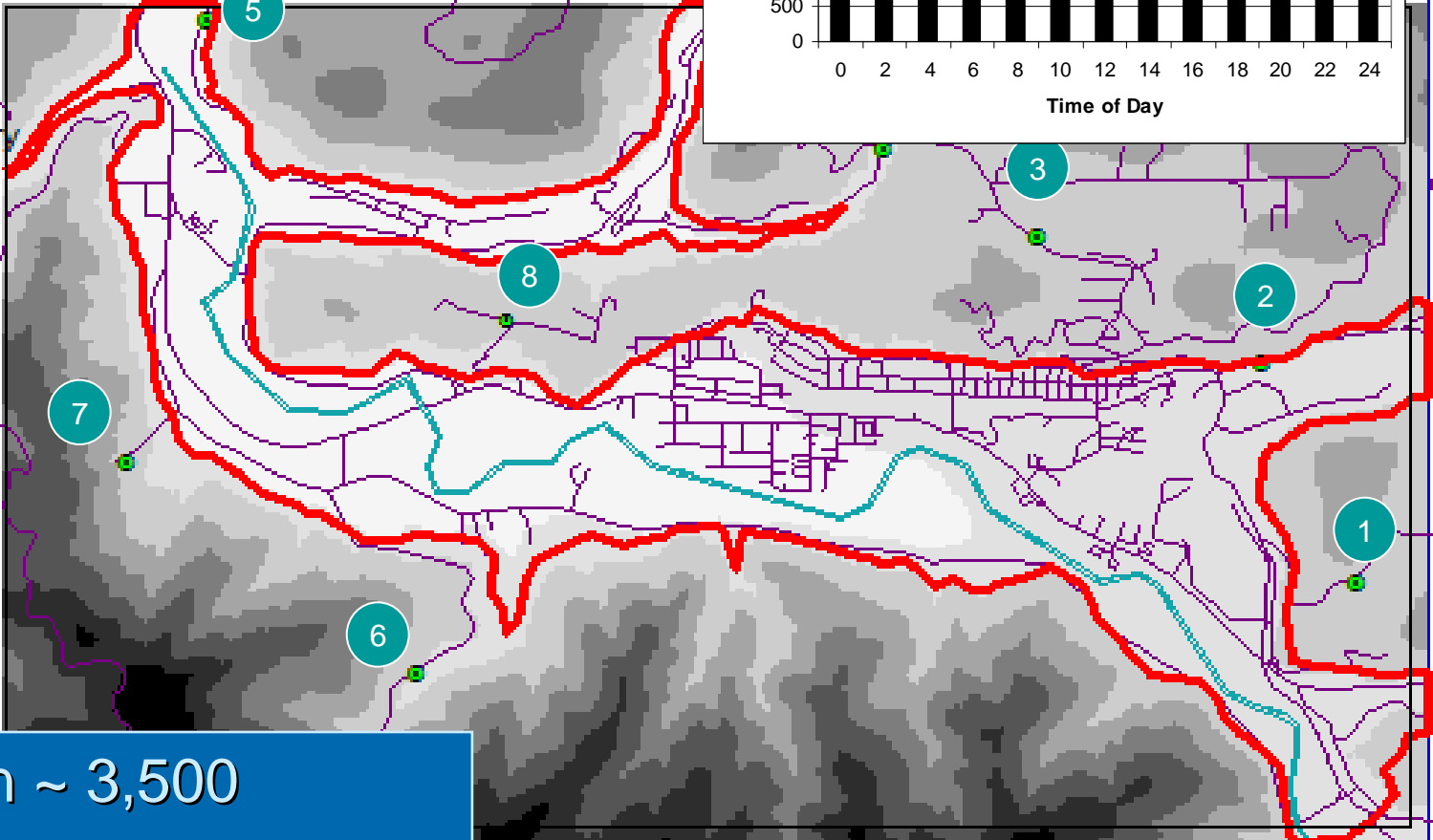
Warning & Evacuation Module



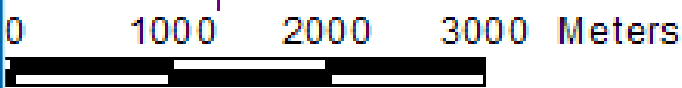
Community (A)



- Flooding Boundary
- Shelter-ds2.shp
- River.shp
- shelters
- Roads
- DEM
 - 300 - 350
 - 350 - 400
 - 400 - 500
 - 500 - 600
 - 600 - 700
 - 700 - 800
 - 800 - 900
 - 900 - 1200

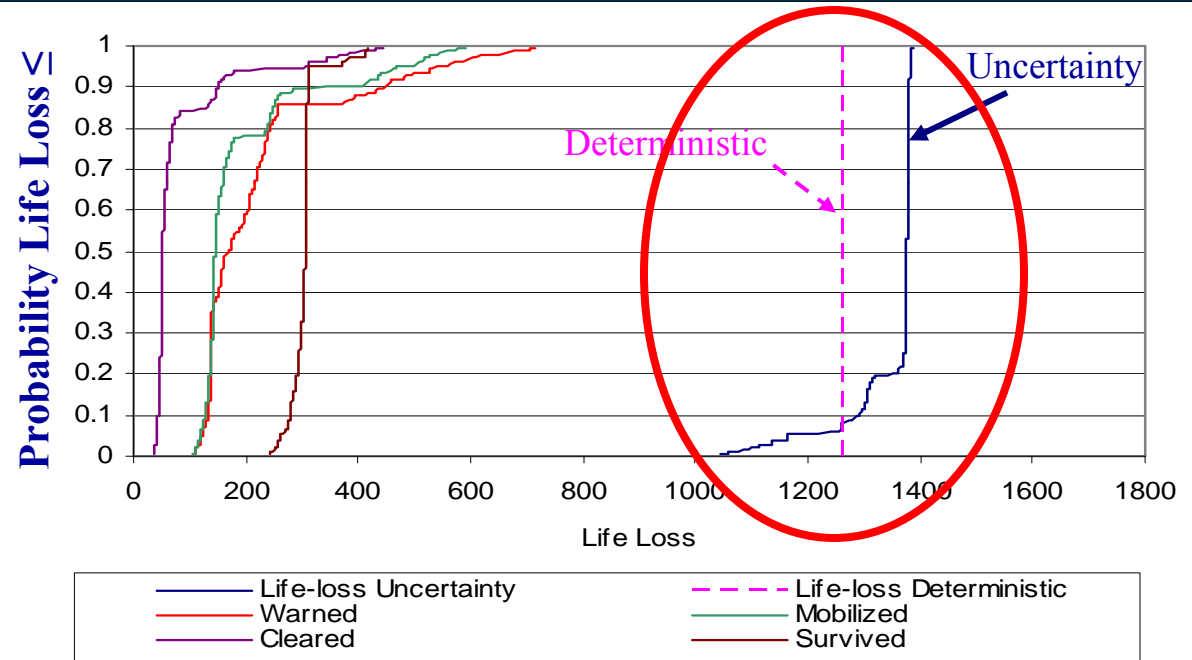


- Population ~ 3,500
- 8 – 13 km downstream
- ~100 m embankment dam
- Sunny-day dam failure

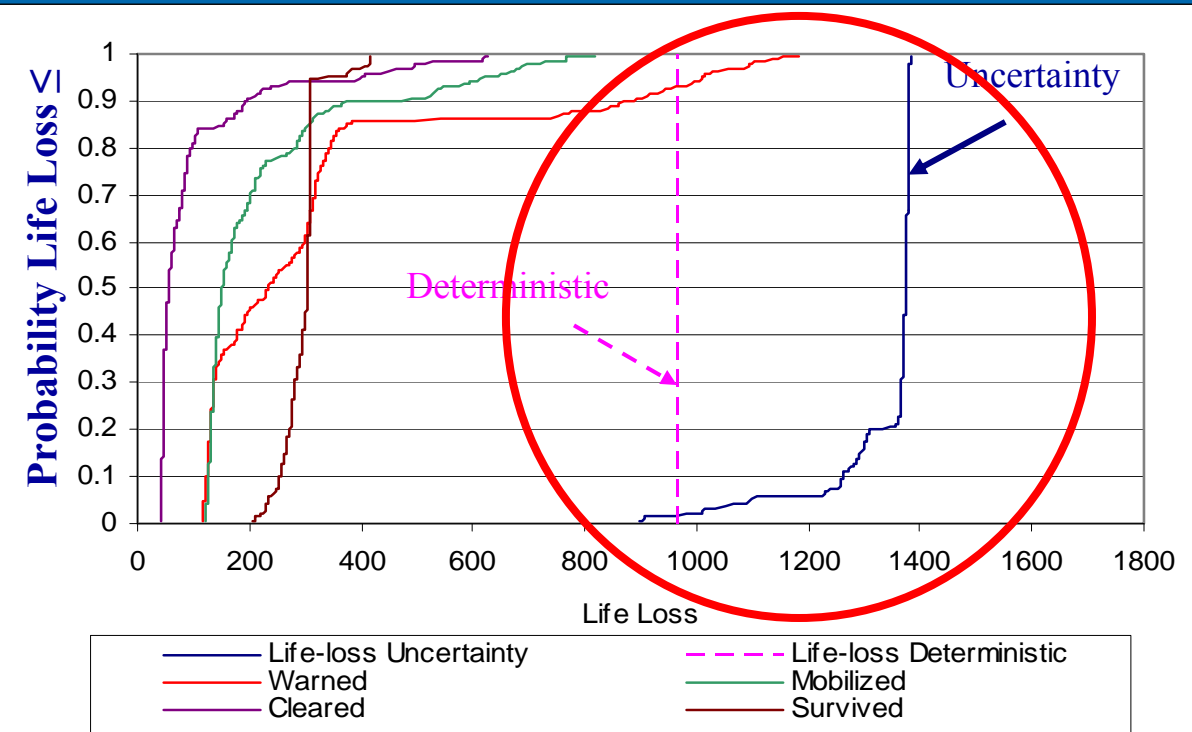


Uncertainty Mode – Sudden Failure During Day

Inefficient warning
(Sirens)

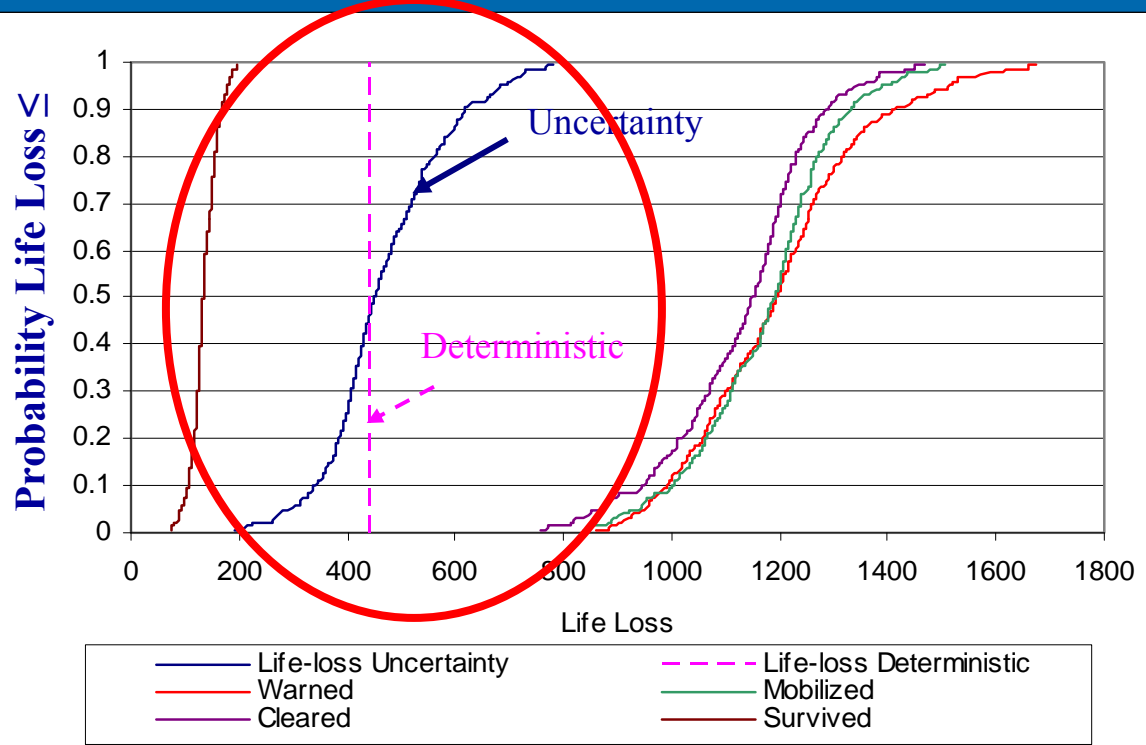


Efficient warning
(Sirens and Tone-alert
radios)

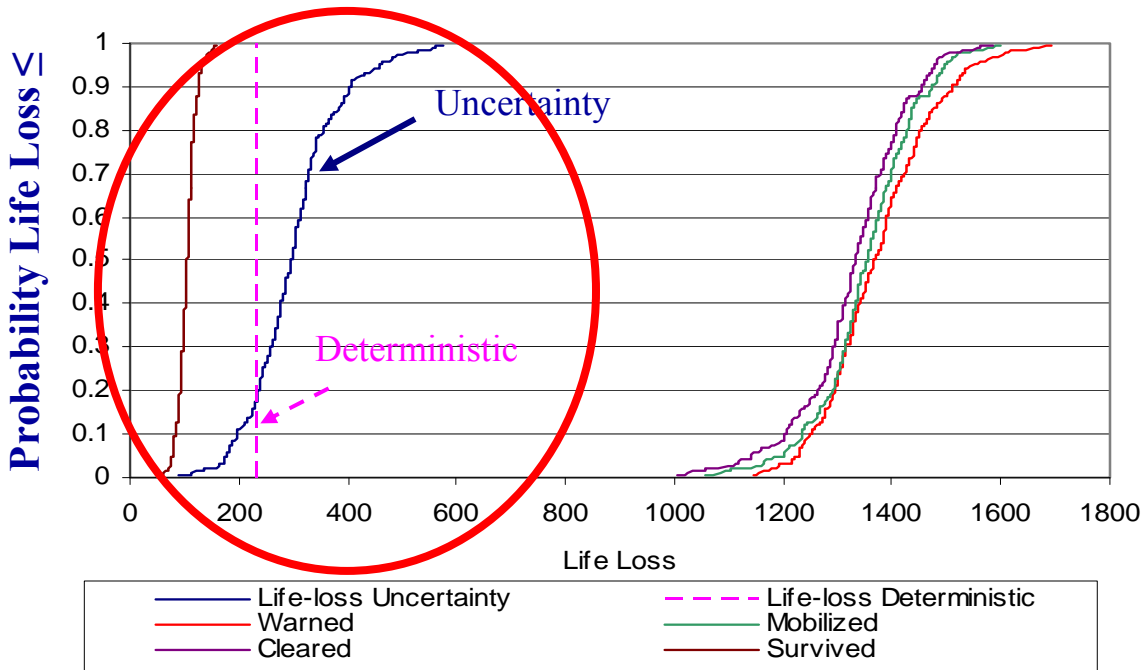


Uncertainty Mode – Delayed Failure During Day

Inefficient warning
(Sirens)



Efficient warning
(Sirens and Tone-alert
radios)



Best Estimate Inputs do not necessarily lead to Best Estimate Outputs

So it is unrealistic to think of
incorporating uncertainty as
simply adding confidence limits to
a deterministic model output

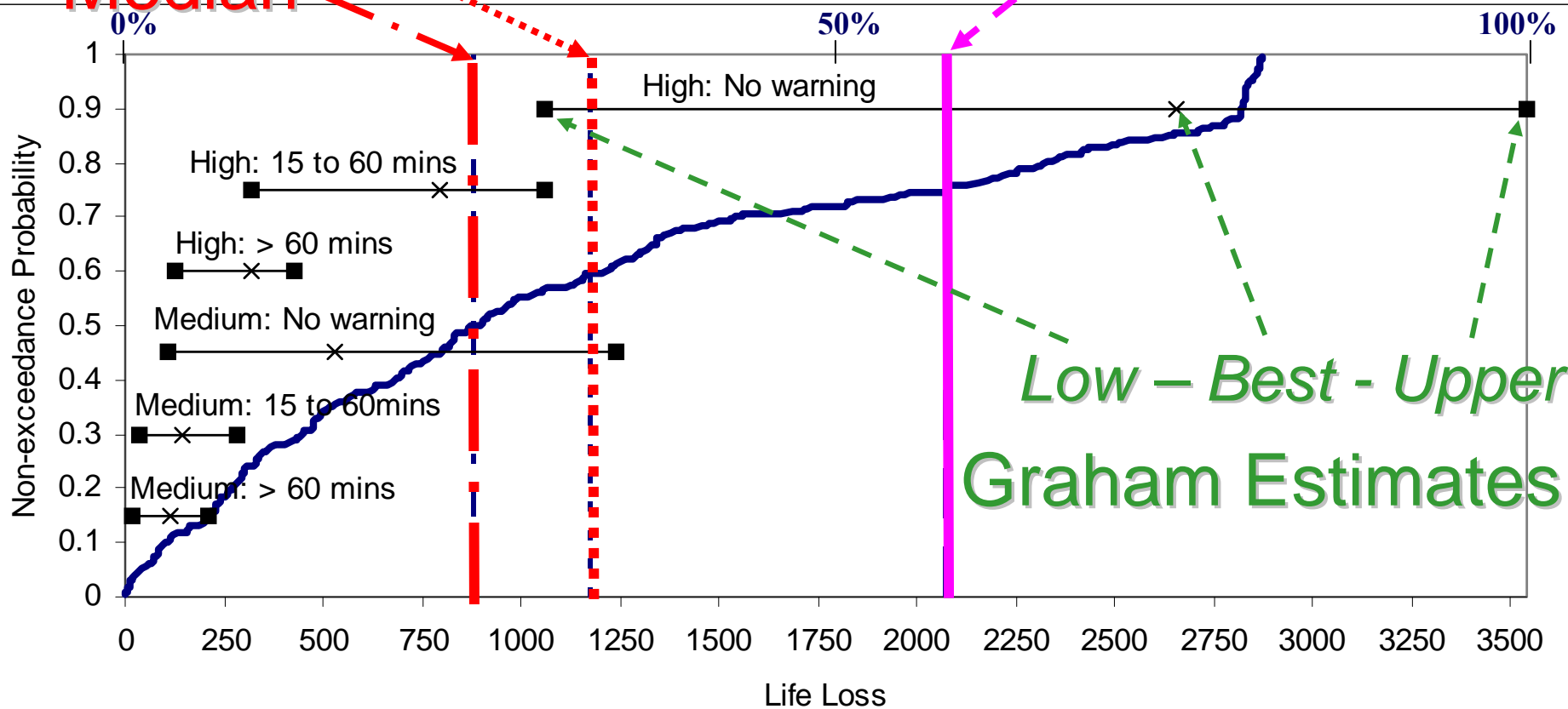
LIFE-LOSS INCLUDING UNCERTAINTY ON TIME OF ISSUANCE OF WARNING AT NIGHT

Uncertainty Estimates

Deterministic

Mean Median

Estimate



— Uncertainty
 — Deterministic
 - - - Mean
 - - - Median
 —■— Graham (1999) Estimates

The more significant sources of uncertainty that are included the wider the range of the resulting uncertainty distribution

Limiting the number of significant sources of uncertainty that are considered leads to “conditional” estimates of uncertainty

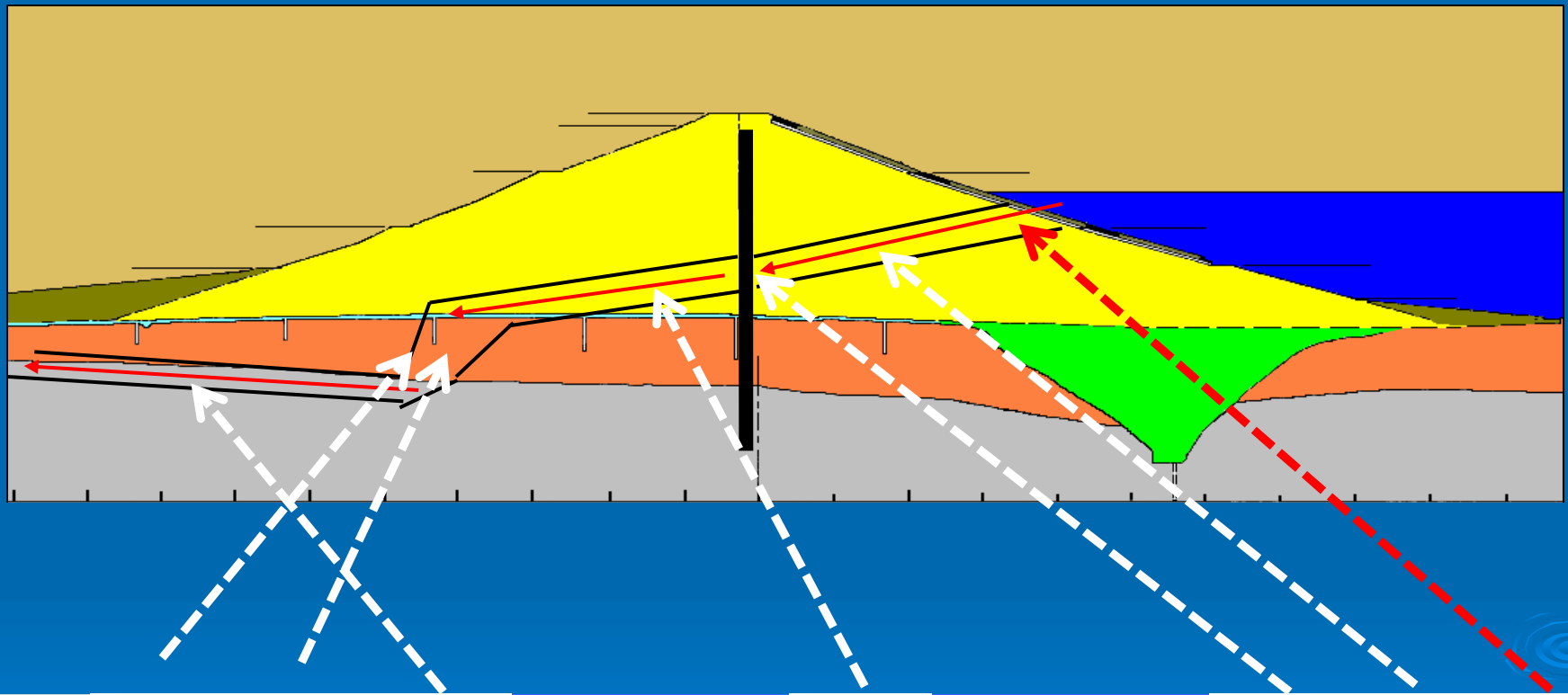
3) An example of an uncertainty analysis in which natural variability and knowledge uncertainty are distinguished

An evaluation of operating restrictions as an interim risk reduction measure for a piping-seepage dam failure mode (Bowles et al 2009

<http://uwrl.usu.edu/people/faculty/DSB/USSD%202009%20Bowles%20Nashville.pdf>

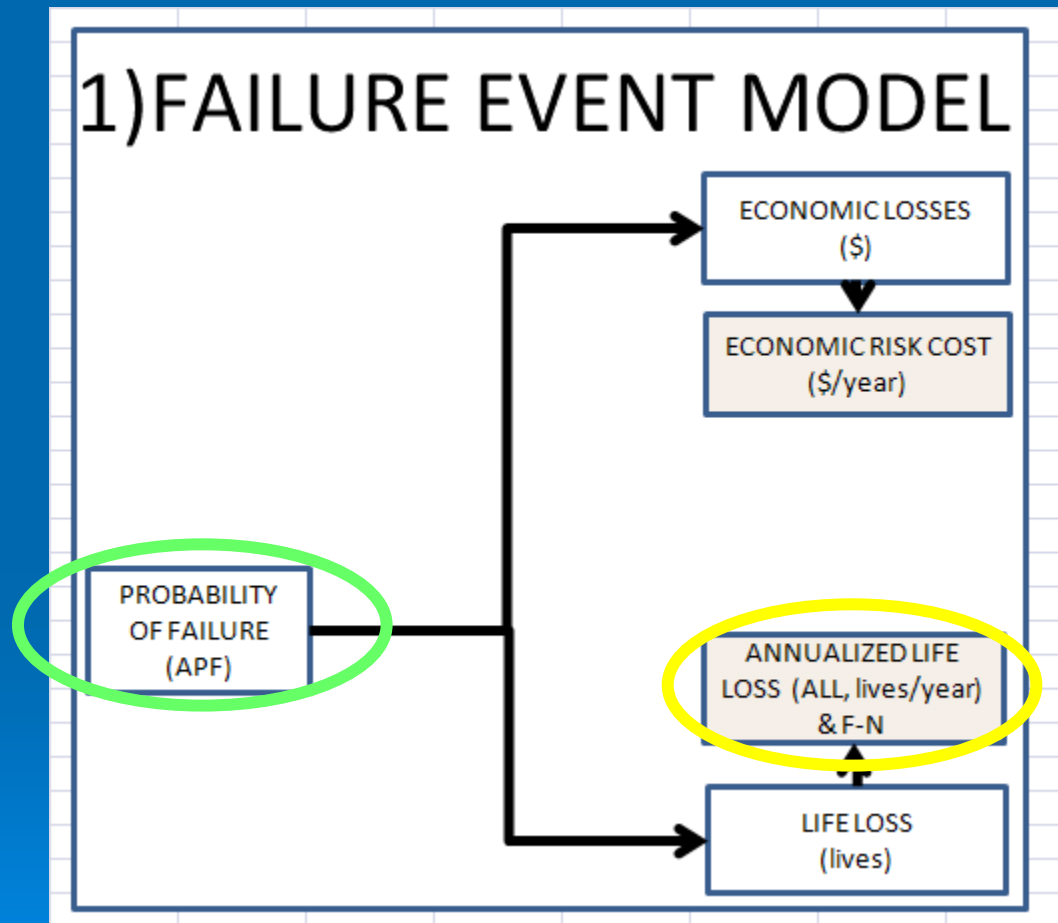
Failure Modes

Piping of the alluvial foundation and embankment material into the bedrock foundation in areas with and without an existing core wall.



| | | | | | | | | | | | |
|-----------------------|-----------------------------|------------------------------|--------------------------------------|----------------|---|--|----------------|------|--------------------------------|-----------------------------|---------------------------|
| Development Level No. | 1 | 2 | 3 | Intervention 1 | | 4 | Intervention 2 | | 5 | 6 | 7 |
| Branch No. | i | ii | iii | iv | v | vi | vii | viii | ix | x | xi |
| | Cavity connected to an exit | Loss of material into cavity | Material moves through Karst to exit | | | Pipe forms, stays open with backward erosion | | | Pipe passes through/under wall | Pipe forms upstream of wall | Gross enlargement of pipe |

1) A nested approach to modelling natural variability and knowledge uncertainty



**Tolerable Risk
Limit Guideline
Evaluation
- Reclamation**

1) APF

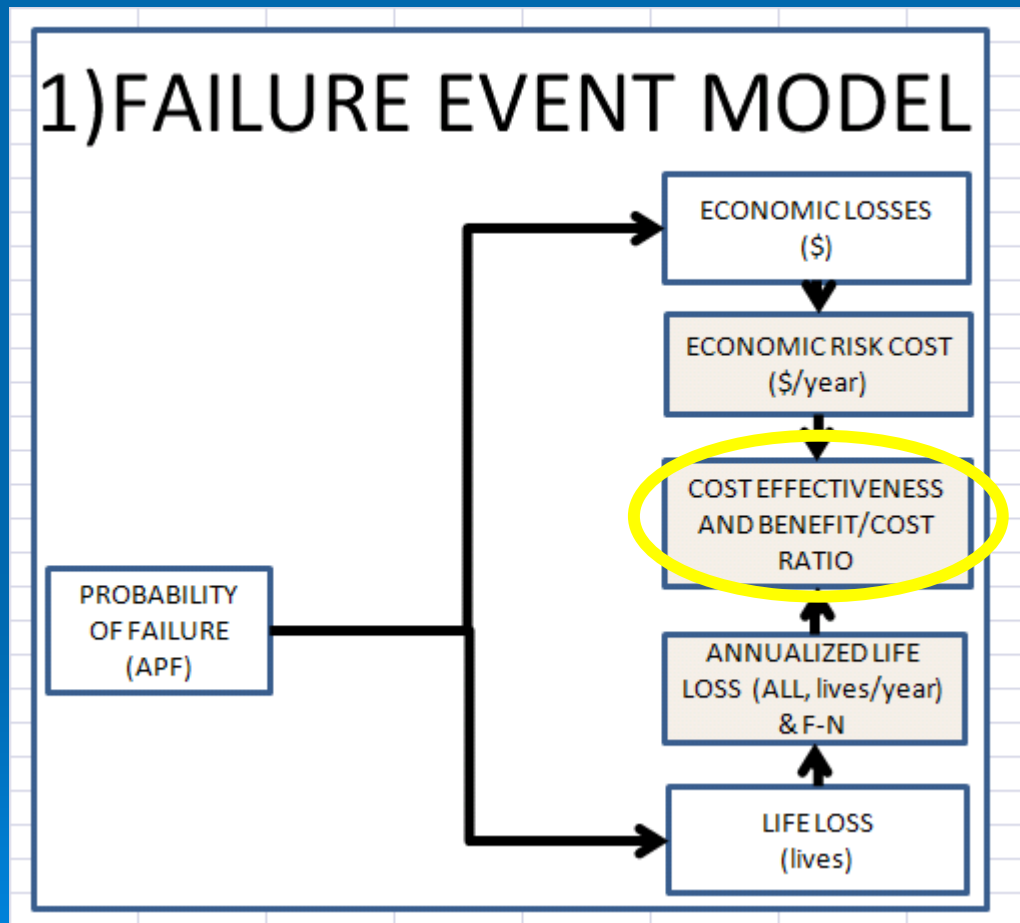
2) ALL

- ANCOLD

3) IR

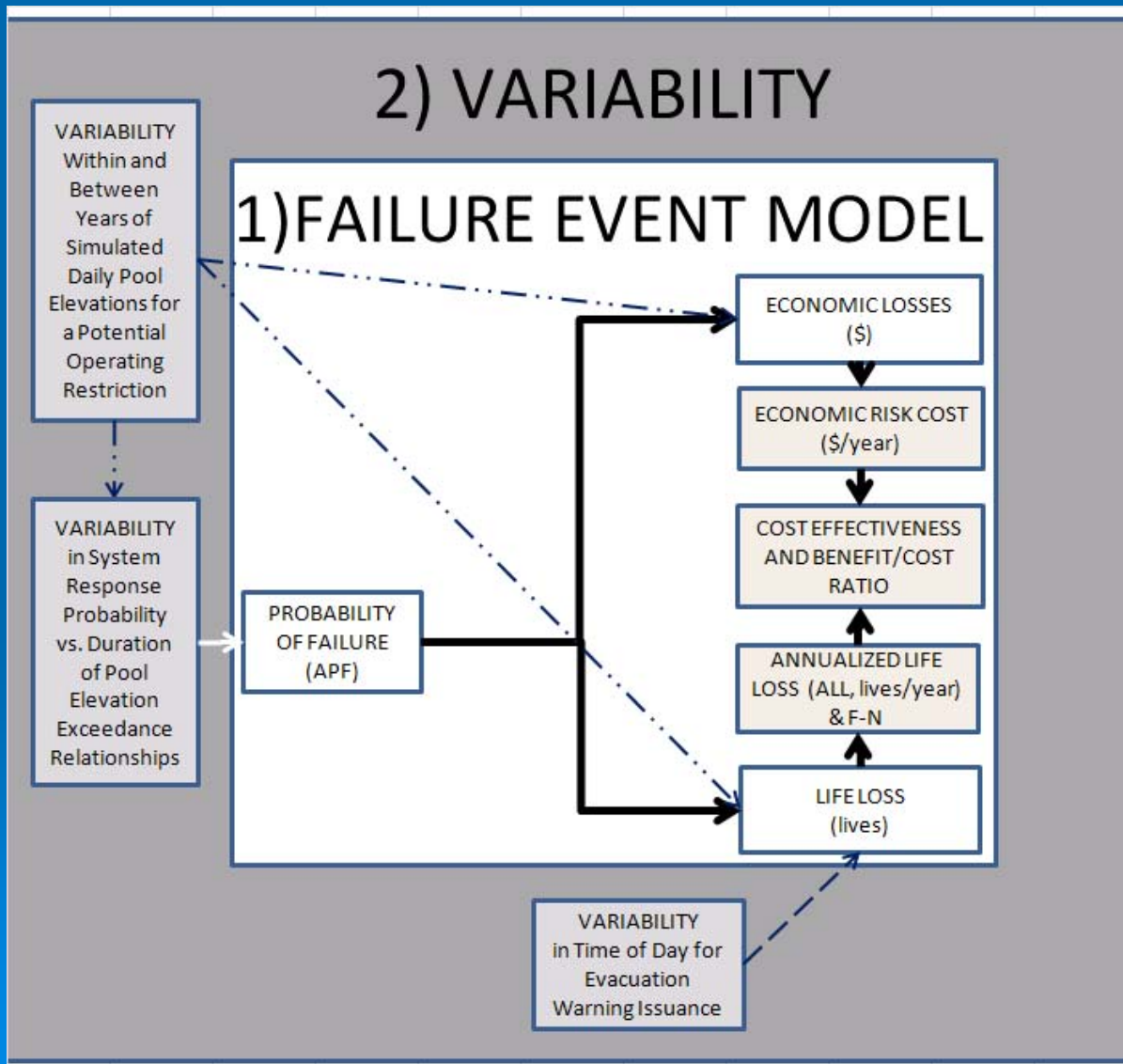
4) SR

1) A nested approach to modelling natural variability and knowledge uncertainty

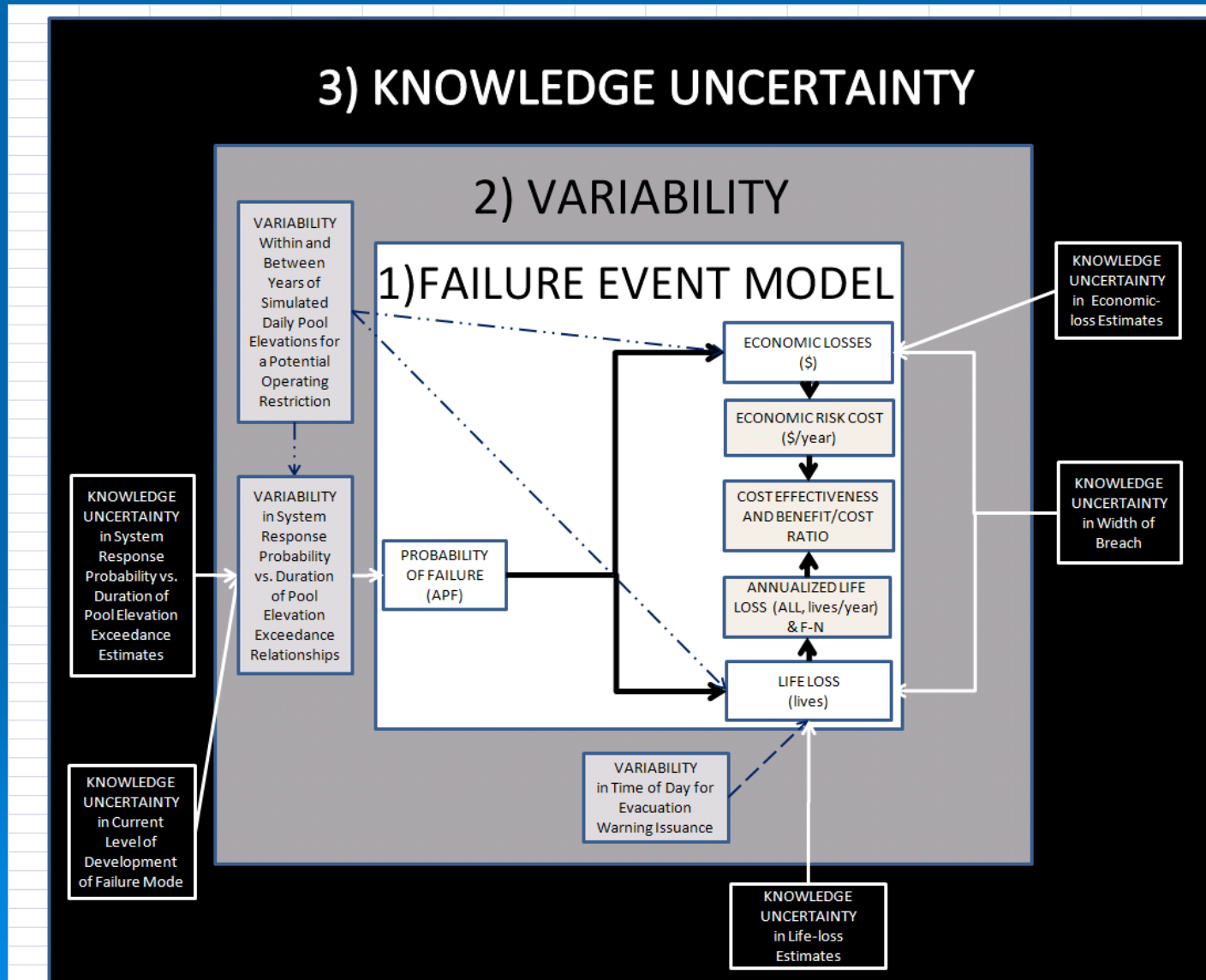


**ALARP/
Disproportionality
Evaluation**

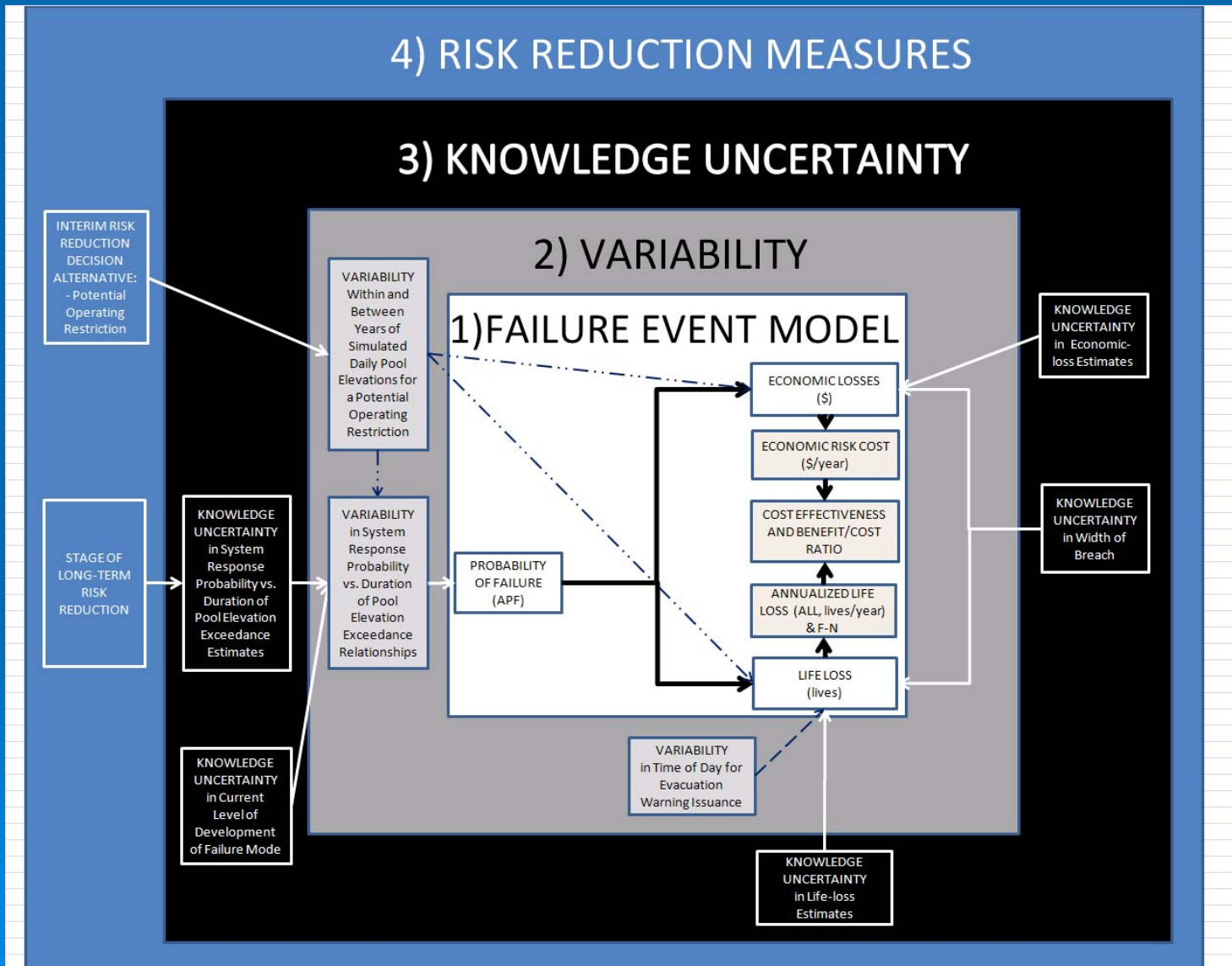
1) A nested approach to modelling natural variability and knowledge uncertainty



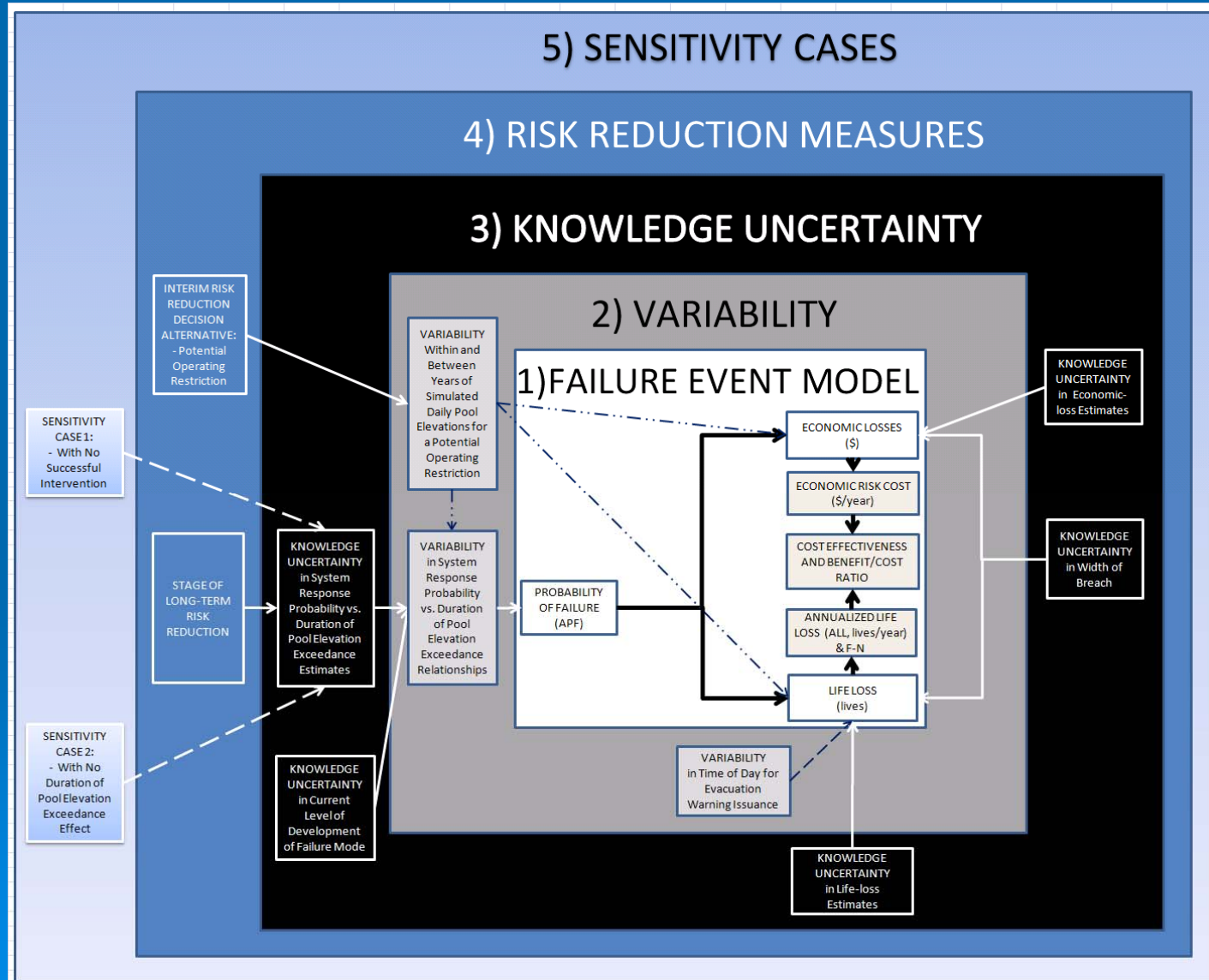
1) A nested approach to modelling natural variability and knowledge uncertainty



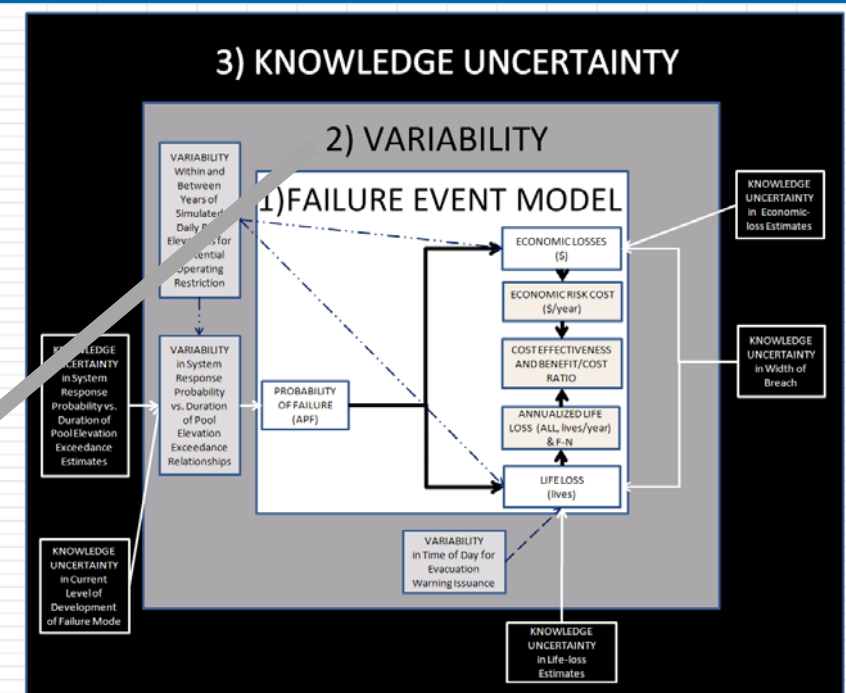
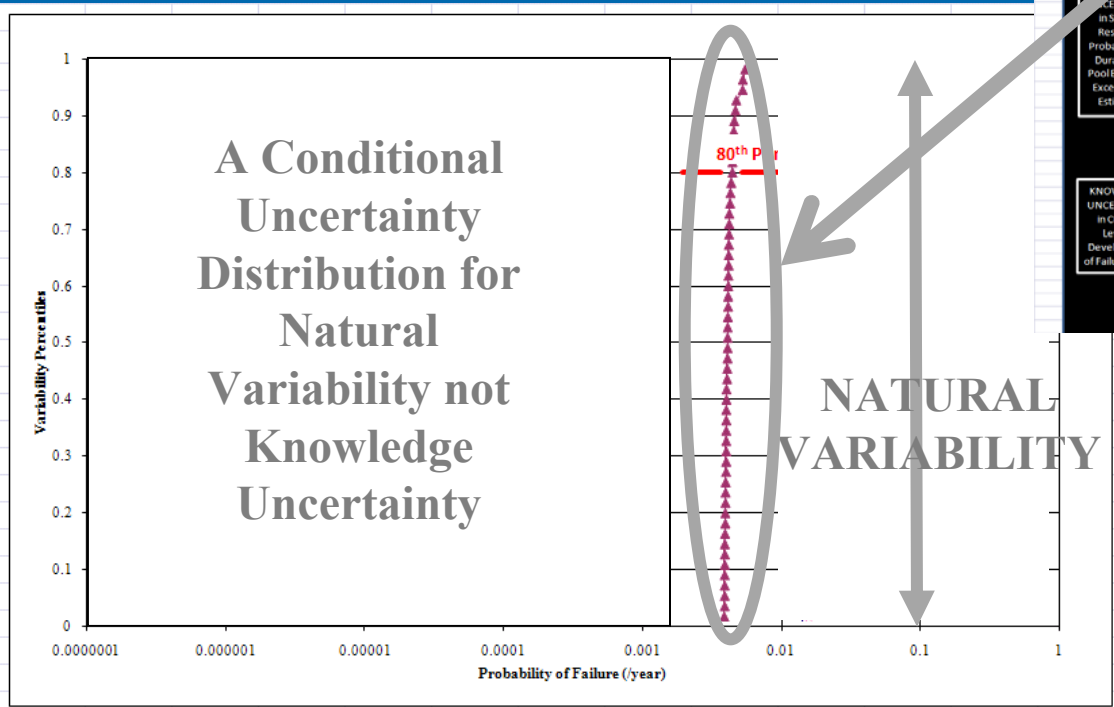
1) A nested approach to modelling natural variability and knowledge uncertainty



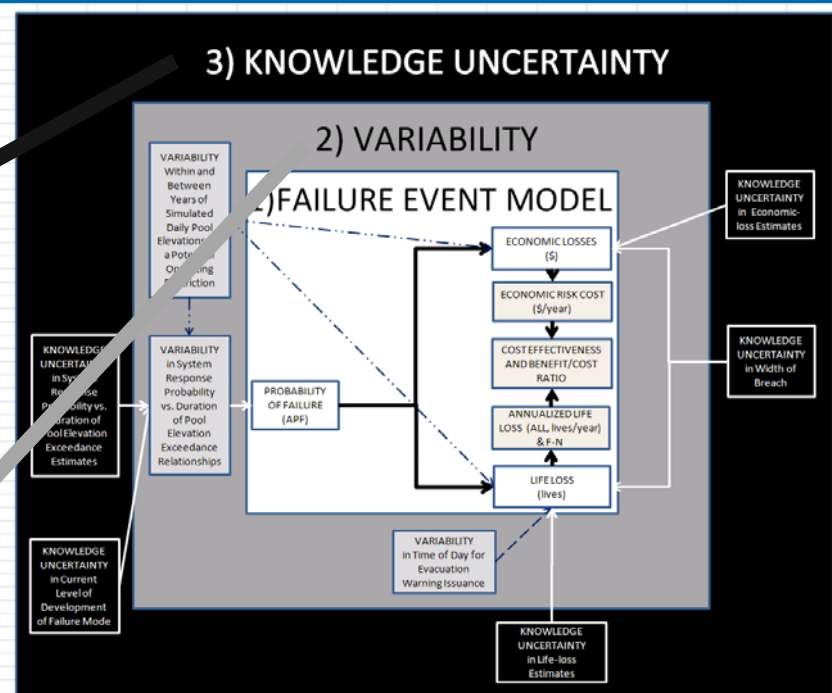
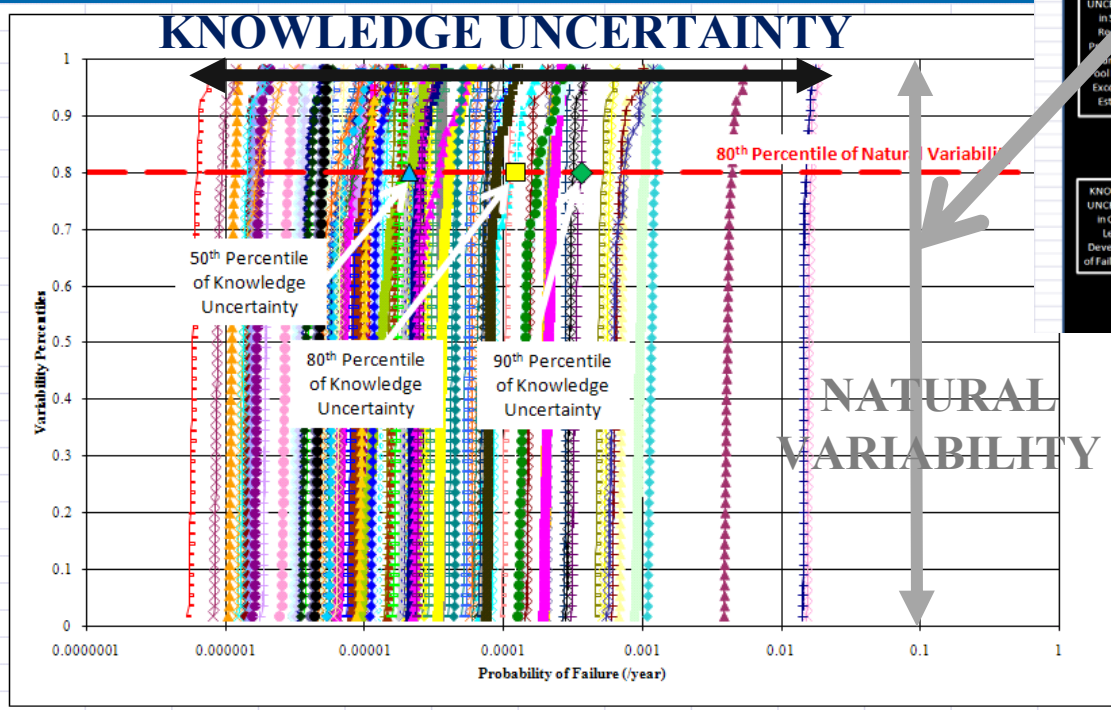
1) A nested approach to modelling natural variability and knowledge uncertainty



4) Accounting for natural variability and knowledge uncertainty in tolerable risk evaluation and risk-reduction decisions



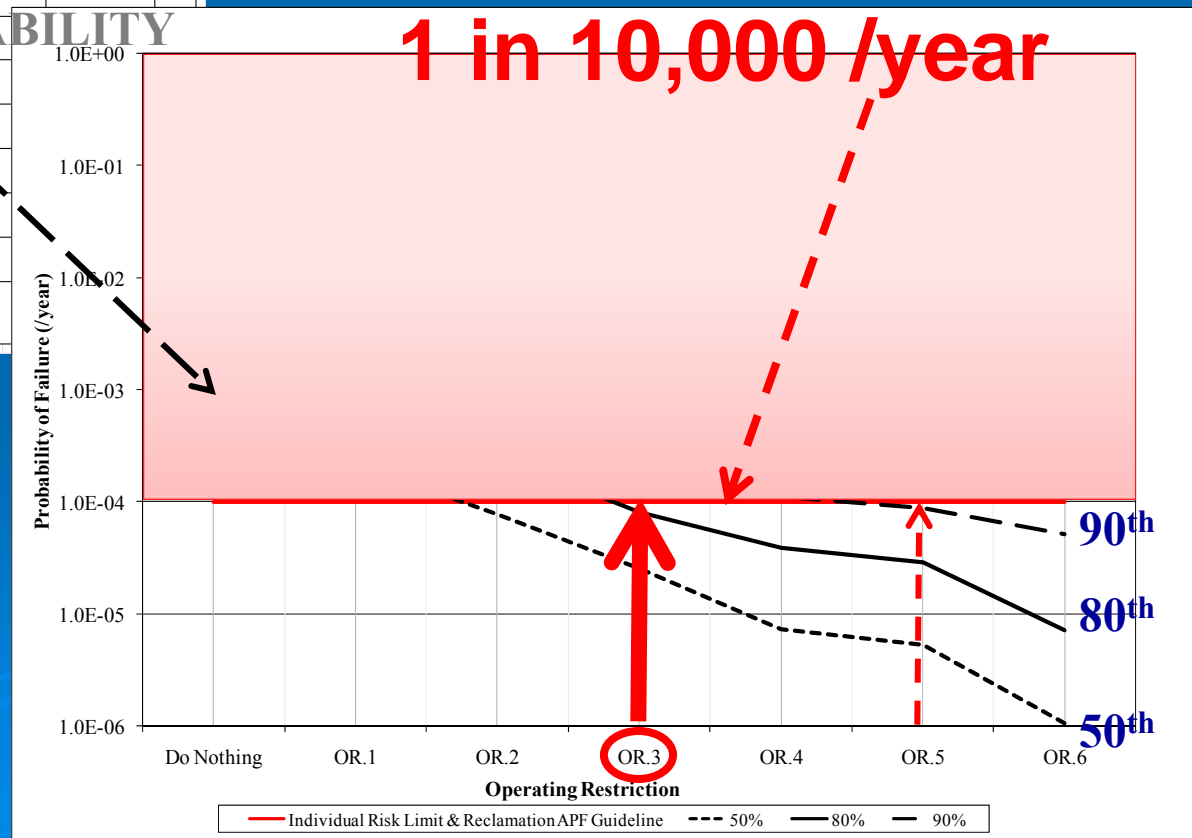
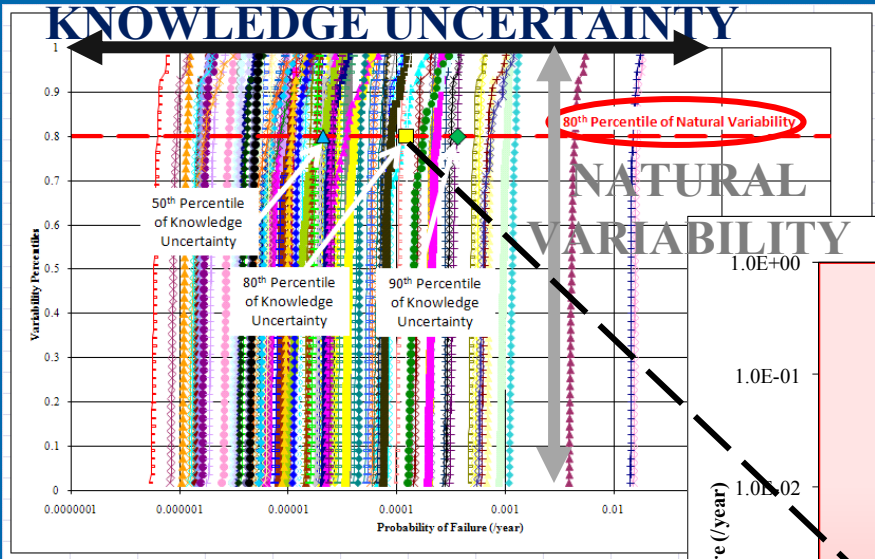
4) Accounting for natural variability and knowledge uncertainty in tolerable risk evaluation and risk-reduction decisions



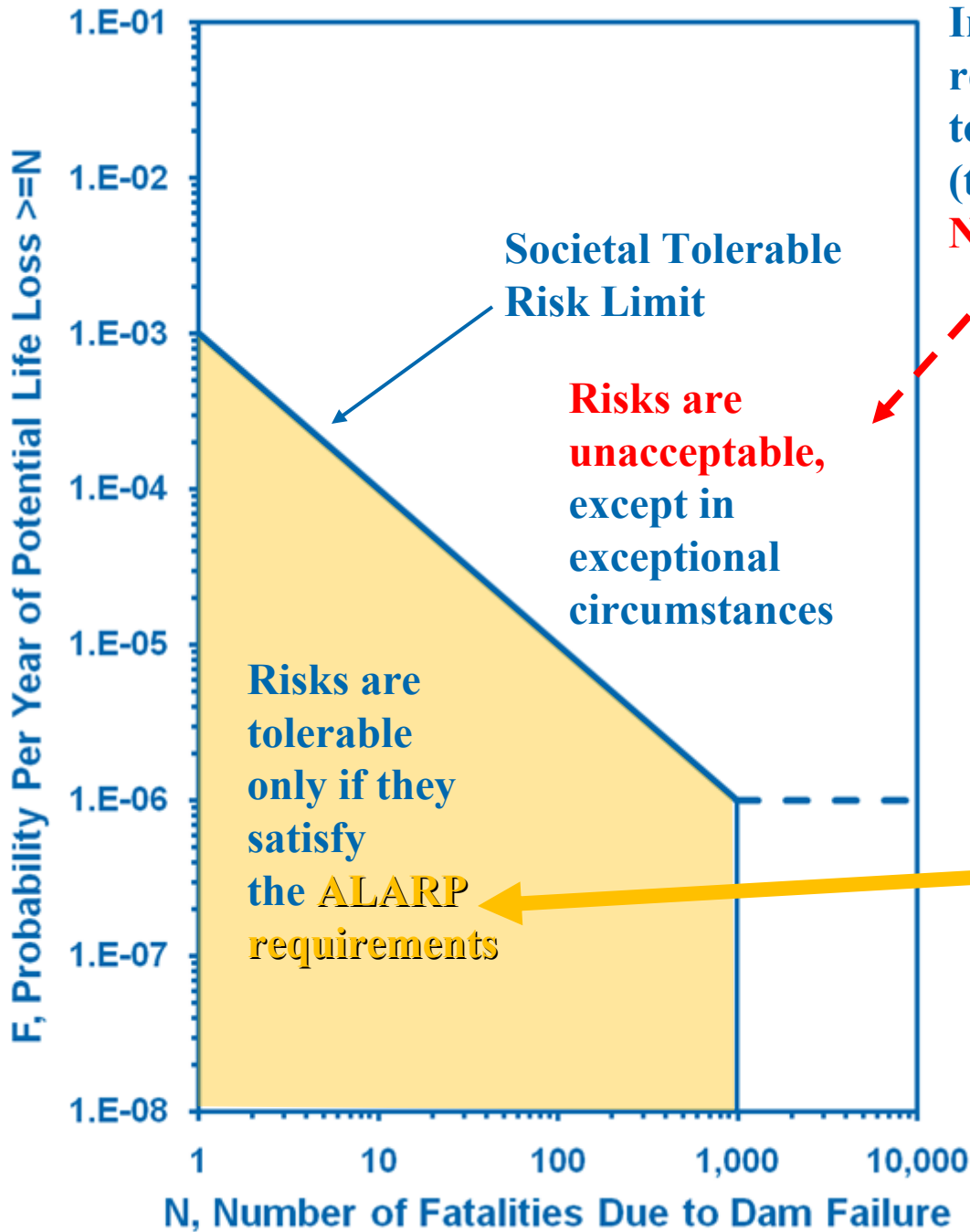
4) Accounting for natural variability and knowledge uncertainty in tolerable risk evaluation and risk-reduction decisions

Probability of failure (APF) & Individual Risk Limits

1 in 10,000 /year



(80th Natural Variability)



In the Unacceptable Region risks are reduced **without consideration to cost** to achieve minimum safety levels (tolerable risk limits).

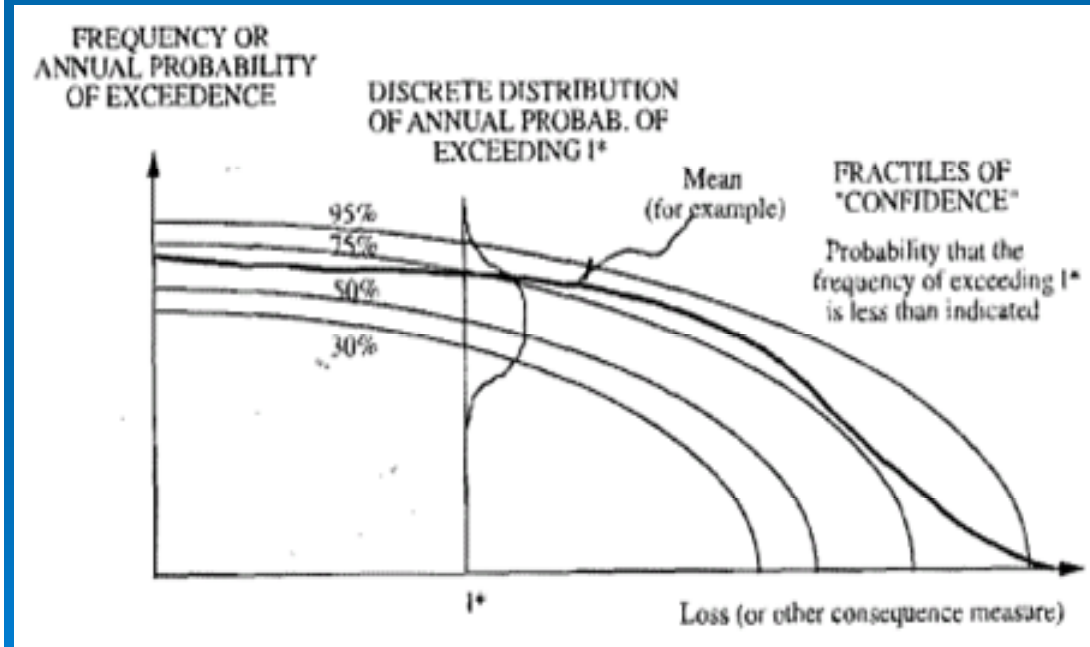
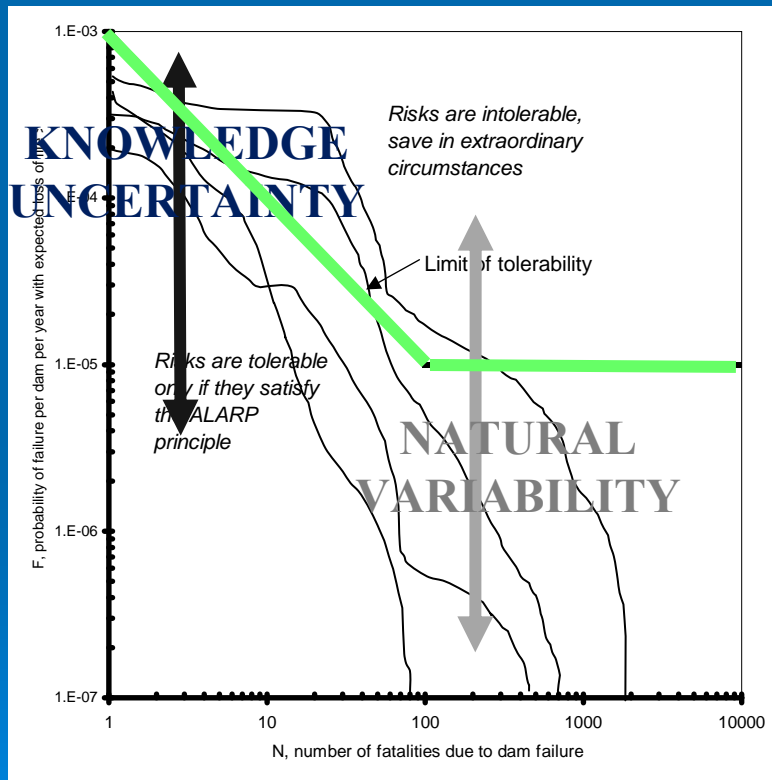
No balancing of cost and benefit.

ALARP Region
in Proposed
USACE
Societal Risk F-
N Chart

ALARP Region
Disproportionality of costs and
benefits is considered below
tolerable risk limits

4) Accounting for natural variability and knowledge uncertainty in tolerable risk evaluation and risk-reduction decisions

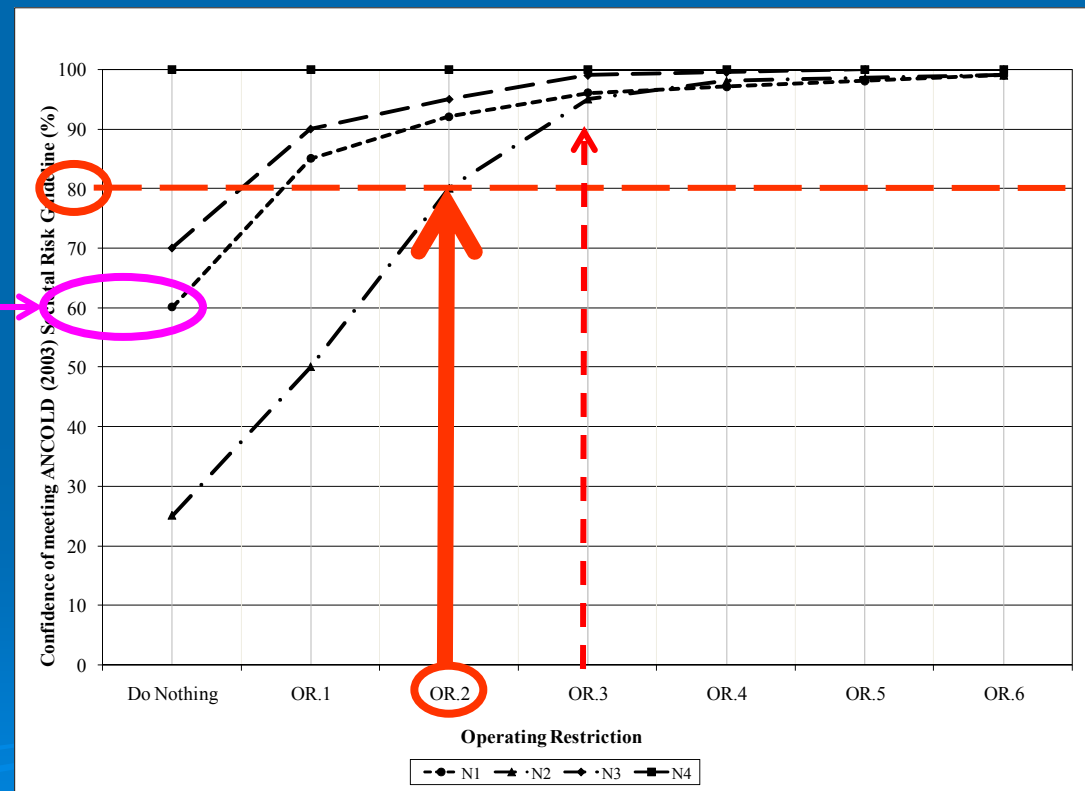
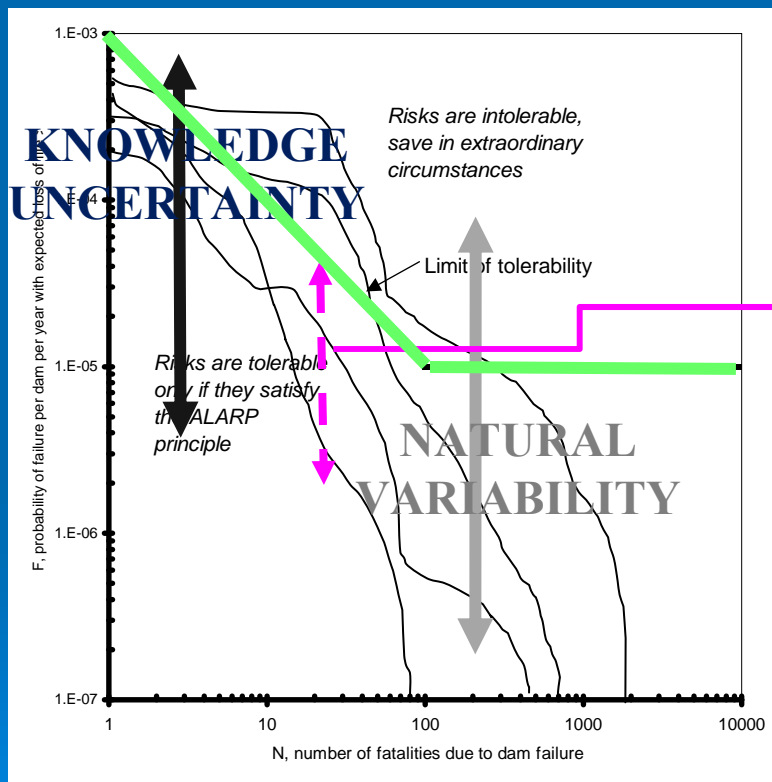
Societal Risk Limit



(80th Natural Variability, 80th Knowledge Uncertainty)

4) Accounting for natural variability and knowledge uncertainty in tolerable risk evaluation and risk-reduction decisions

Societal Risk Limit



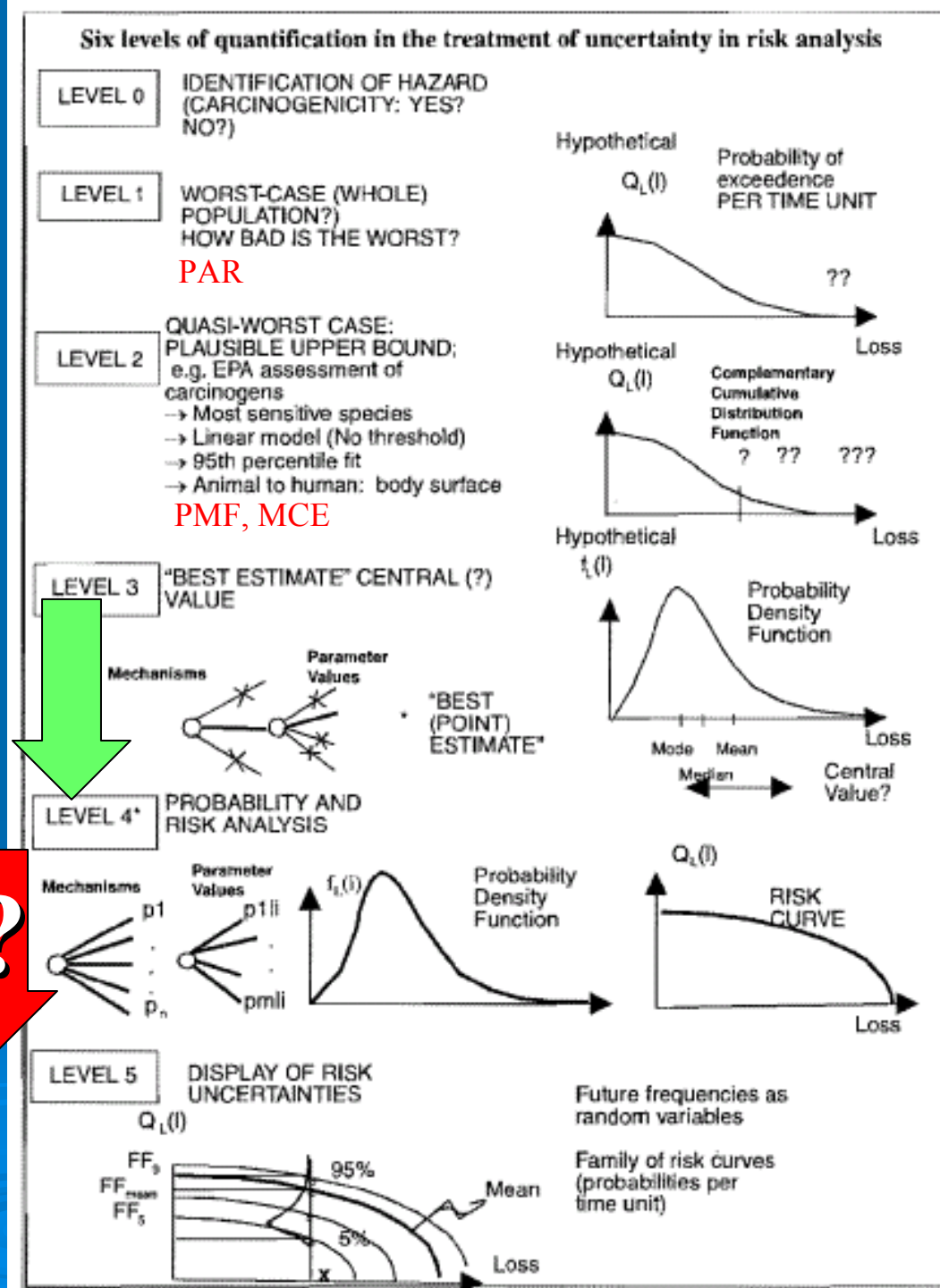
(80th Natural Variability, 80th Knowledge Uncertainty)

4) Six levels of complexity in the treatment of uncertainty in risk analysis



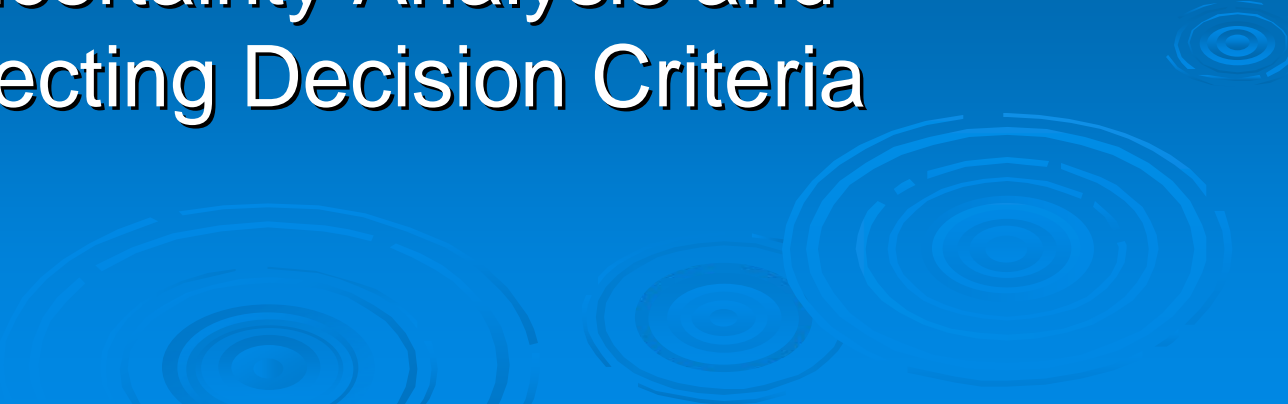
Six levels of complexity in the treatment of uncertainty in risk analysis

(Pate-Cornell 1996)

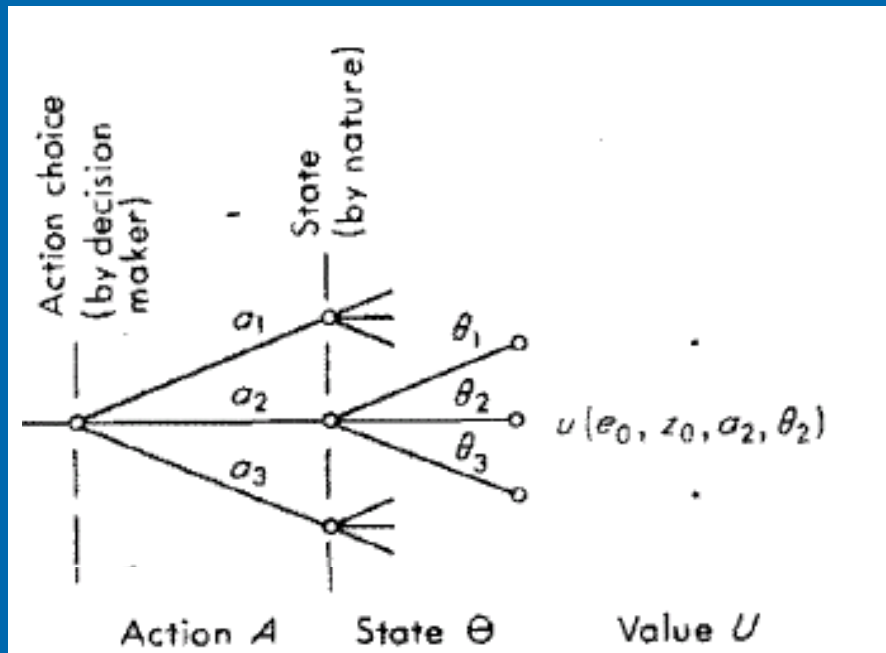


5) Decision Analysis

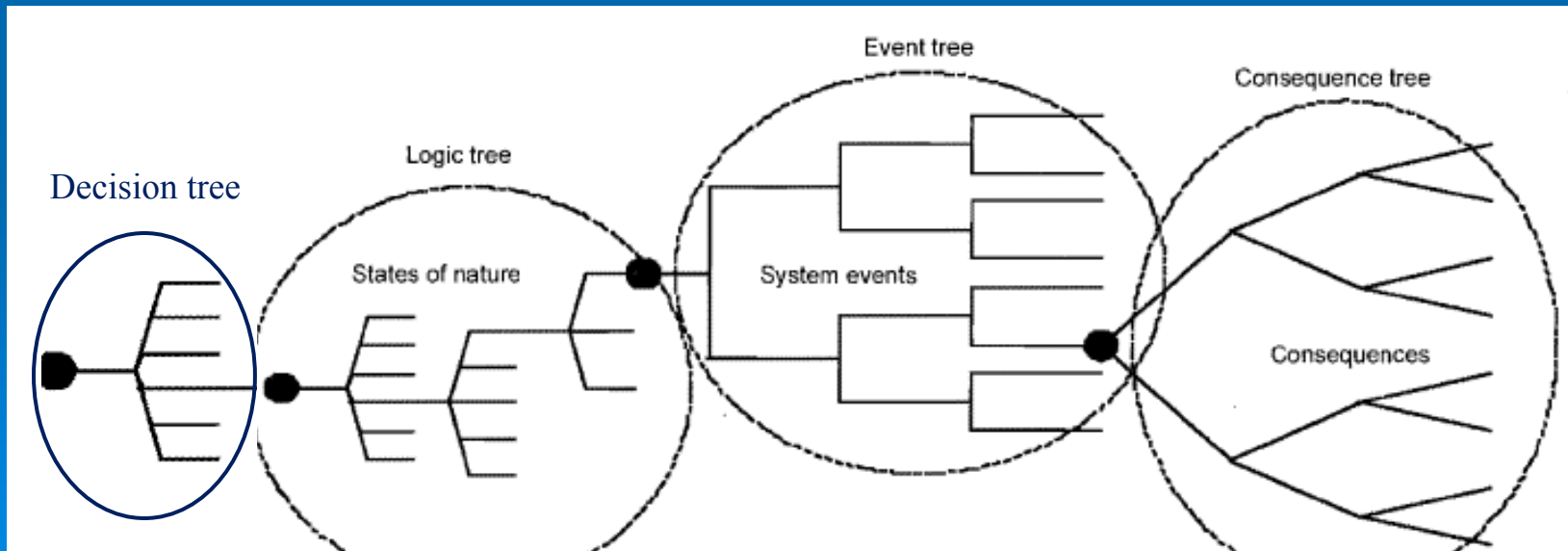
Organizing the Risk and
Uncertainty Analysis and
Selecting Decision Criteria

The background features several sets of concentric circles in a lighter shade of blue, resembling ripples in water, positioned in the lower right and bottom center areas of the slide.

Decision Analysis



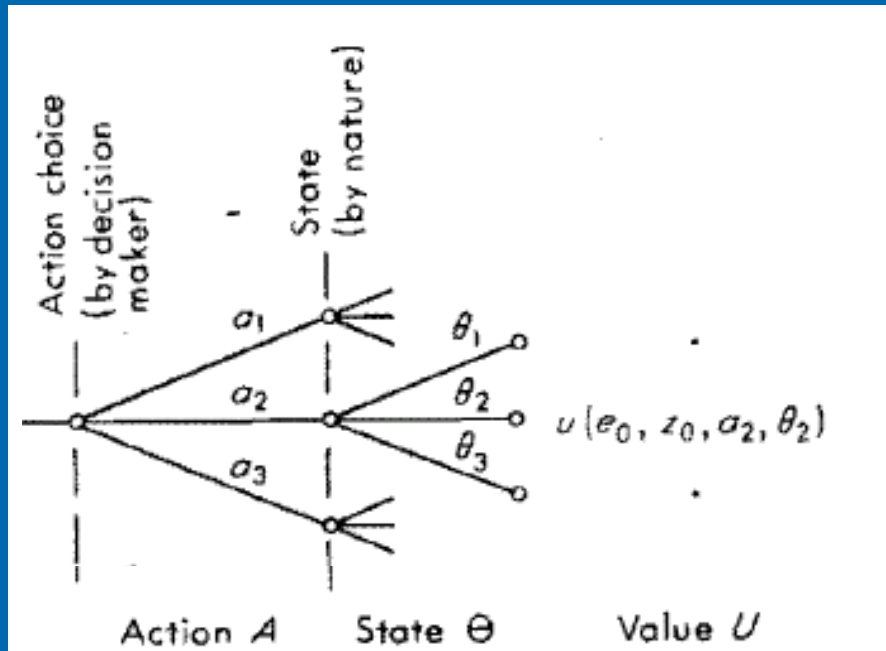
Decision Alternatives – State of Nature - Consequences



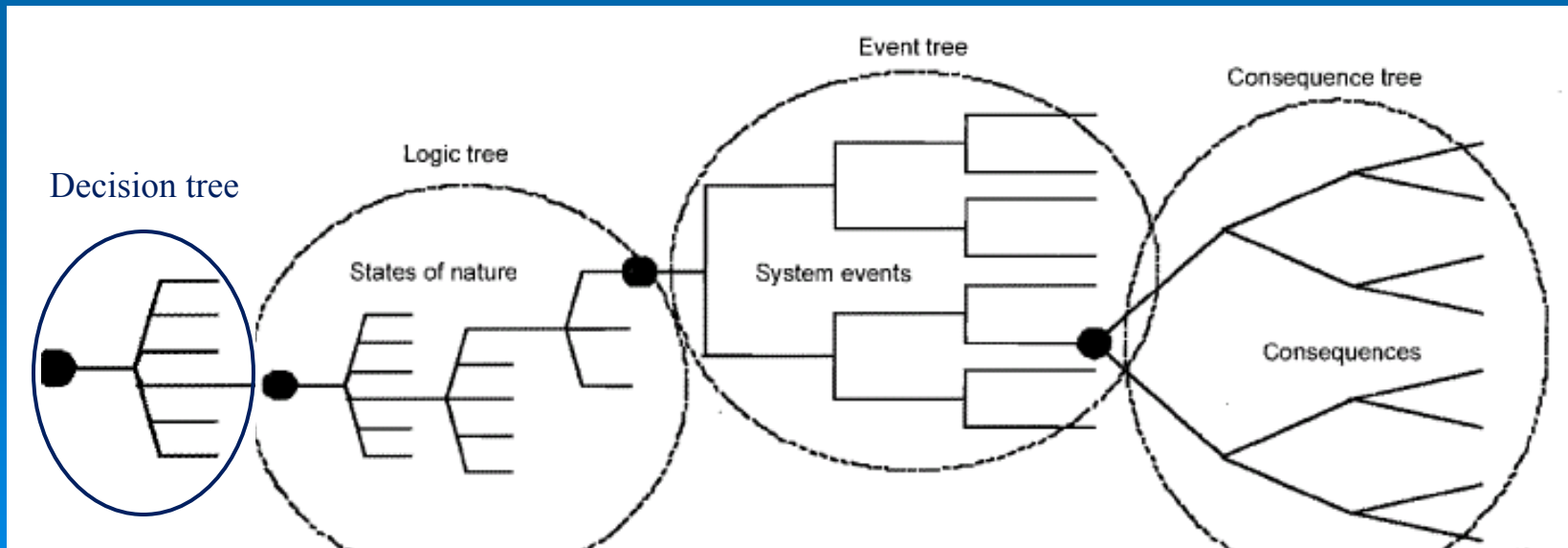
Decision Alternatives – State of Nature – System Performance - Consequences

Decision Analysis

- Typically focuses on Expected Values, e.g. \$/year
- May not be appropriate decision basis

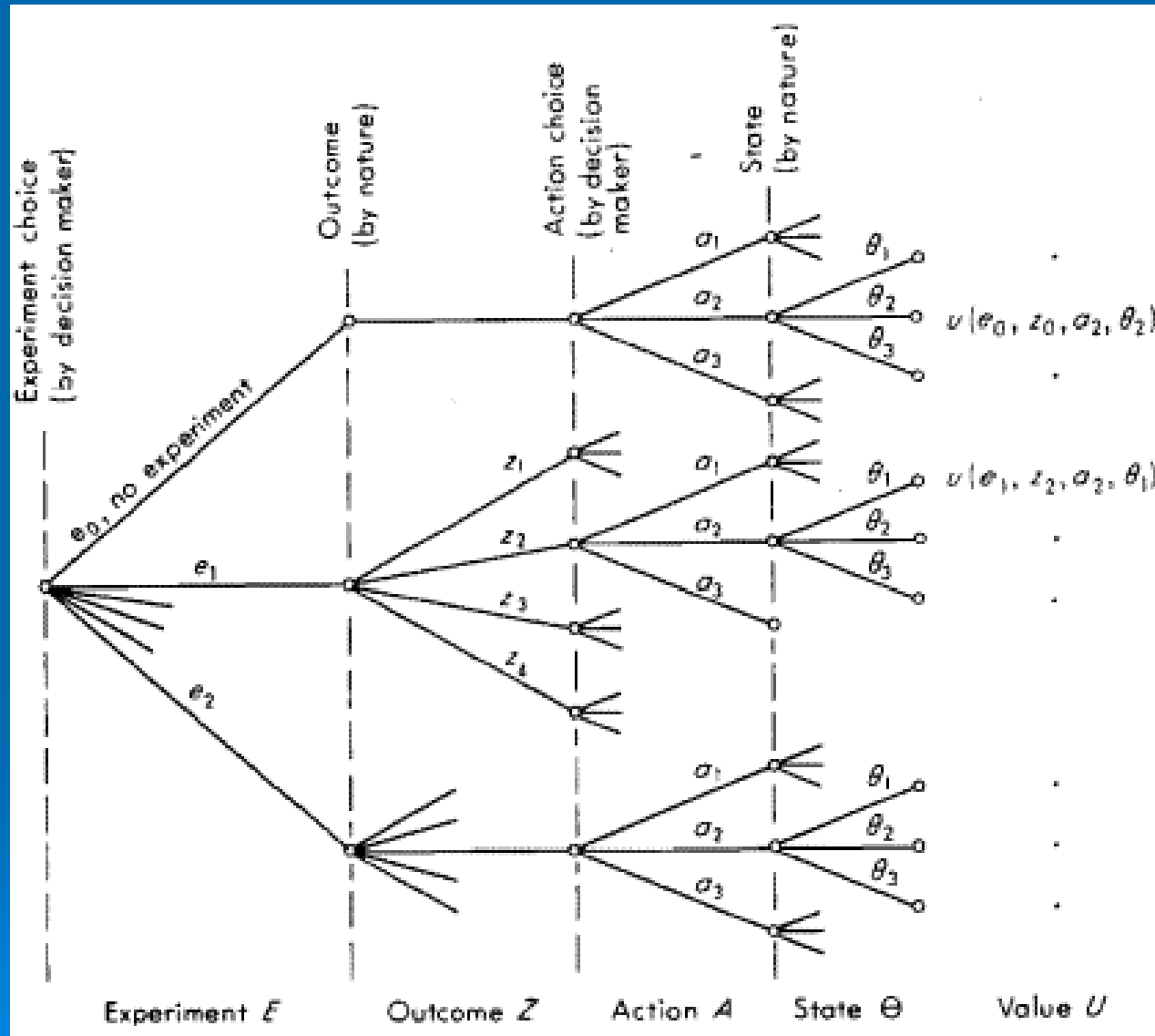


Decision Alternatives – State of Nature - Consequences



Decision Alternatives – State of Nature – System Performance - Consequences

Assessing the Value of New Information



Alternatives for New Information – New Information Outcome - Decision Alternatives – State of Nature – Consequences
(System Performance Not Shown)

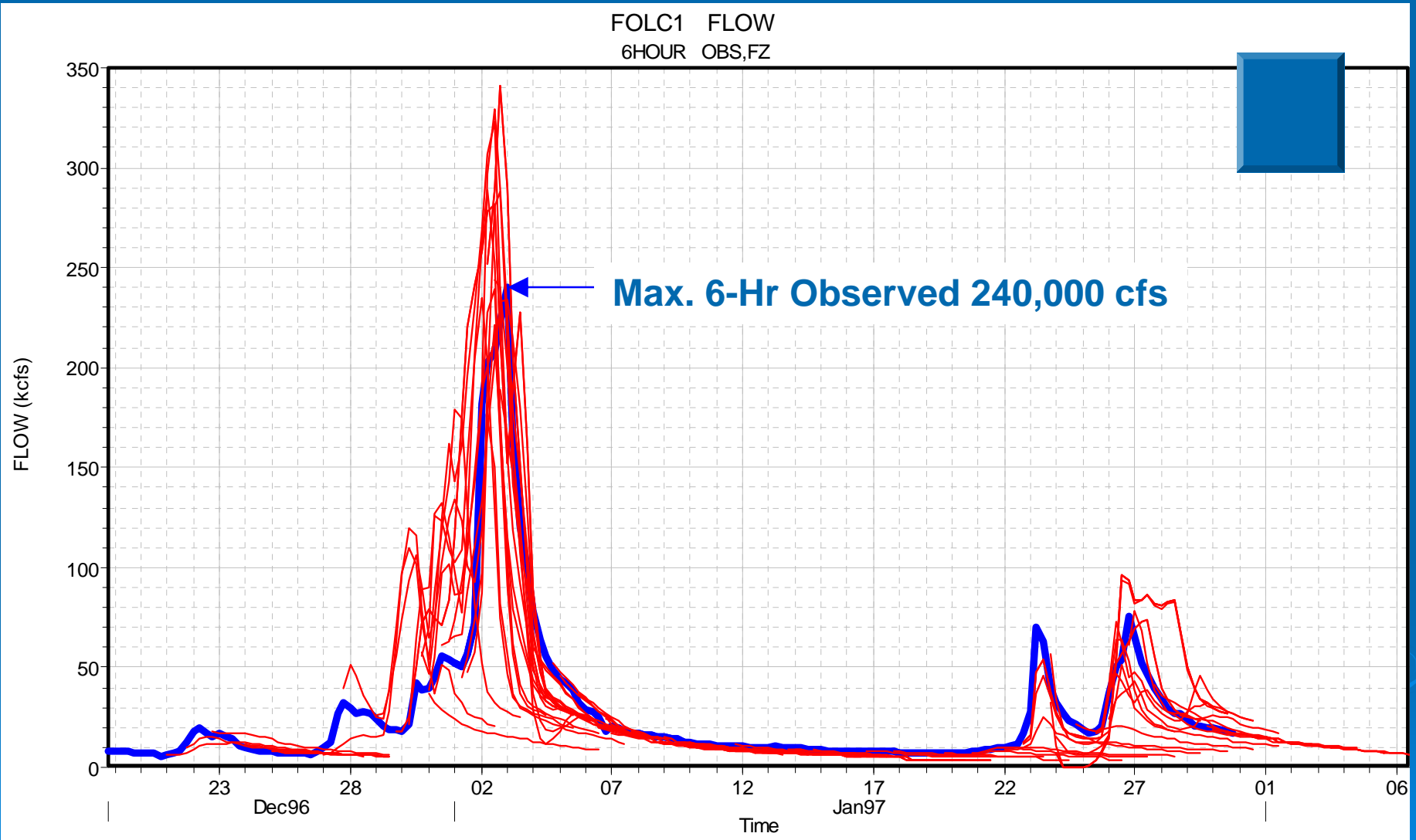
6) Using Ensemble Inflow Forecasts For Improved Reservoir Operation and Emergency Management

Folsom Project, Sacramento, California

(Bowles et al 2004

<http://uwrl.usu.edu/people/faculty/DSB/USSD2004.pdf>)

Folsom 1997 New Year Flood - Observed & All Forecast Flows



REAL-TIME Simulation Forecasting System Components

Real-time Inflow Forecast Error Simulator

NWS RFC

Rec CVO

Precip
F/C

SS-SAC

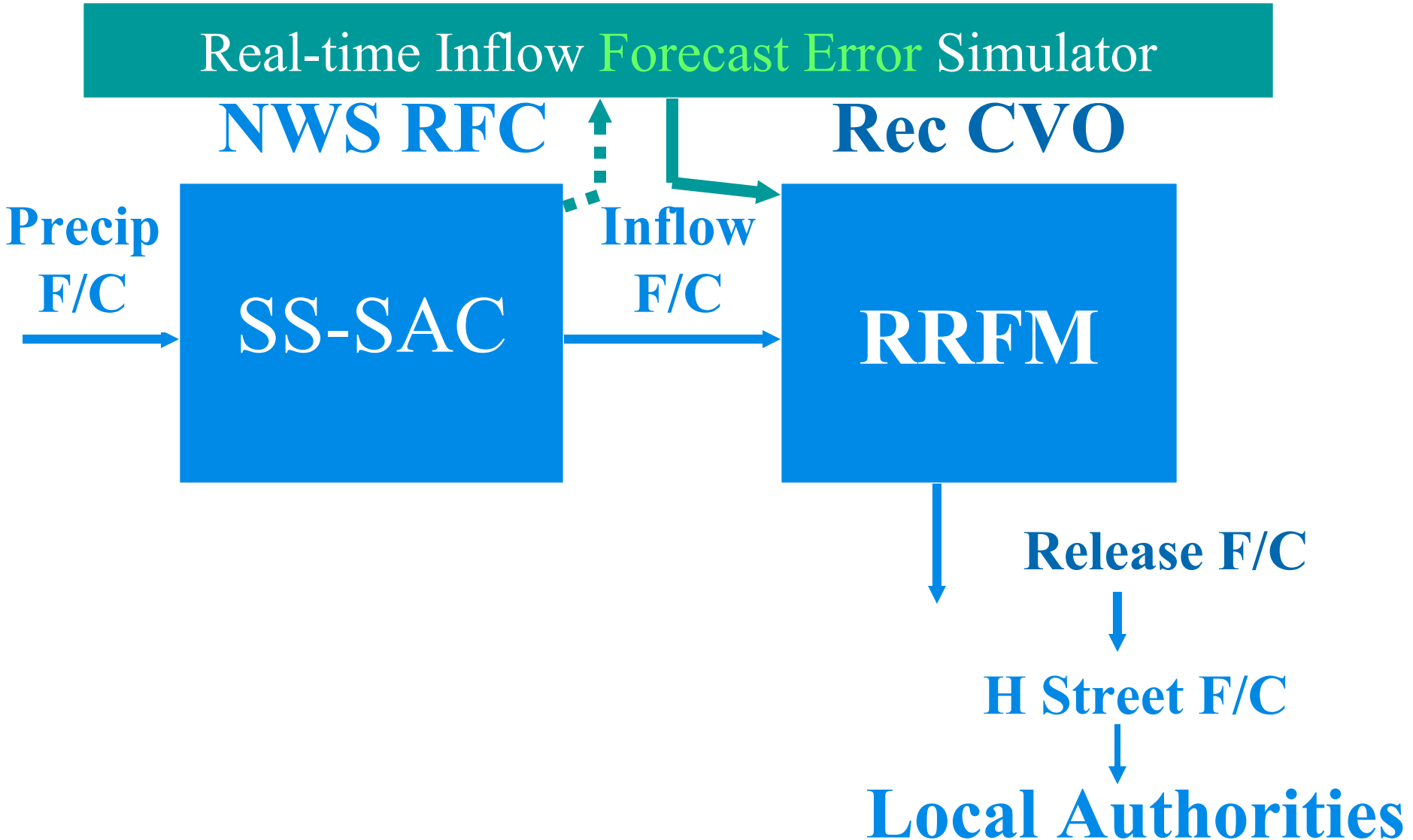
Inflow
F/C

RRFM

Release F/C

H Street F/C

Local Authorities



Simulated Instantaneous Forecast Releases X cfs

Uncertainty Results - Simulation Releases

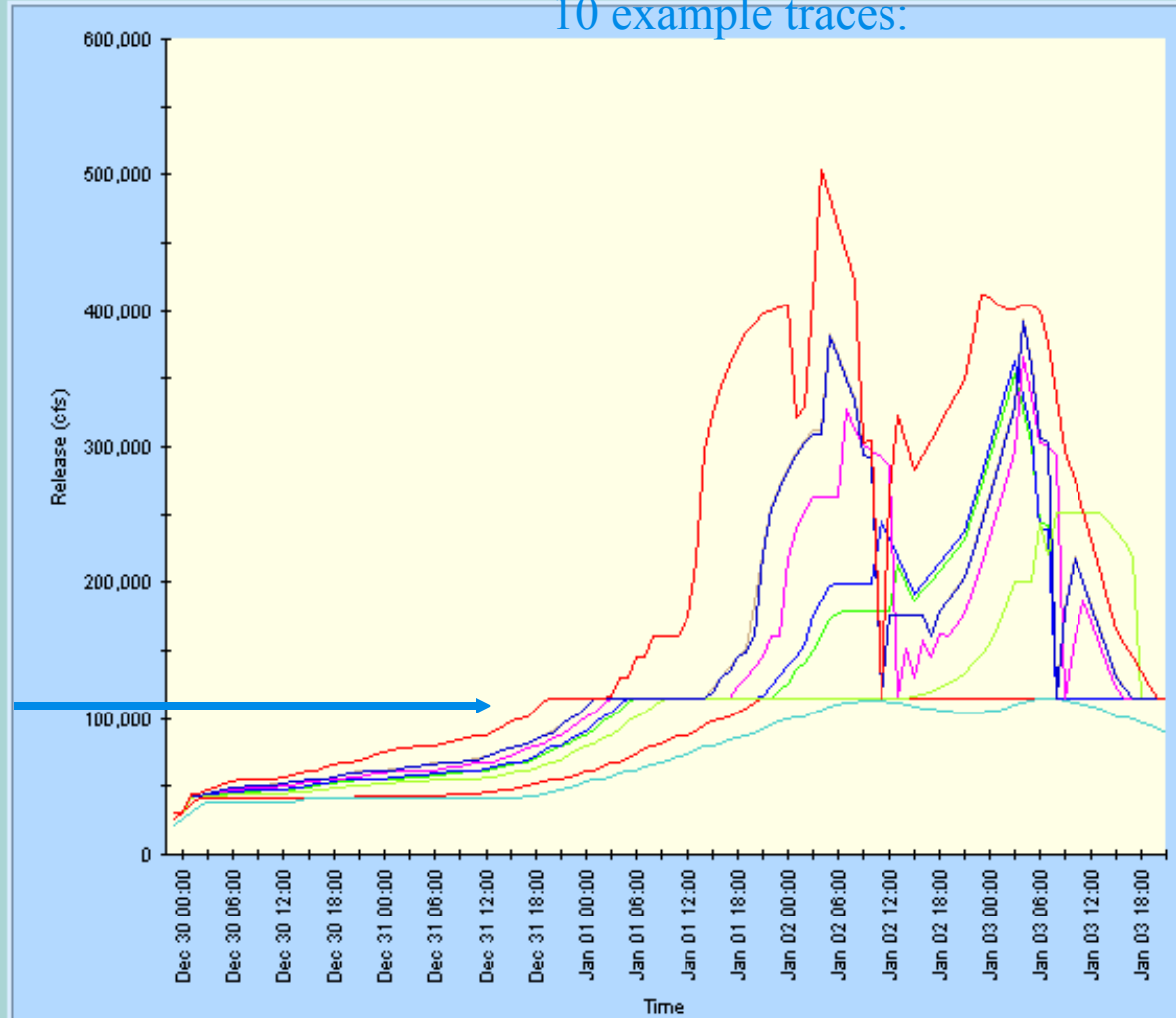
Print Copy Preferences Archive

| Forecast | # Runs |
|------------------|--------|
| 12/29/1996 10:00 | 51 |
| 12/29/1996 22:00 | 1500 |
| 12/31/1996 22:00 | 1500 |

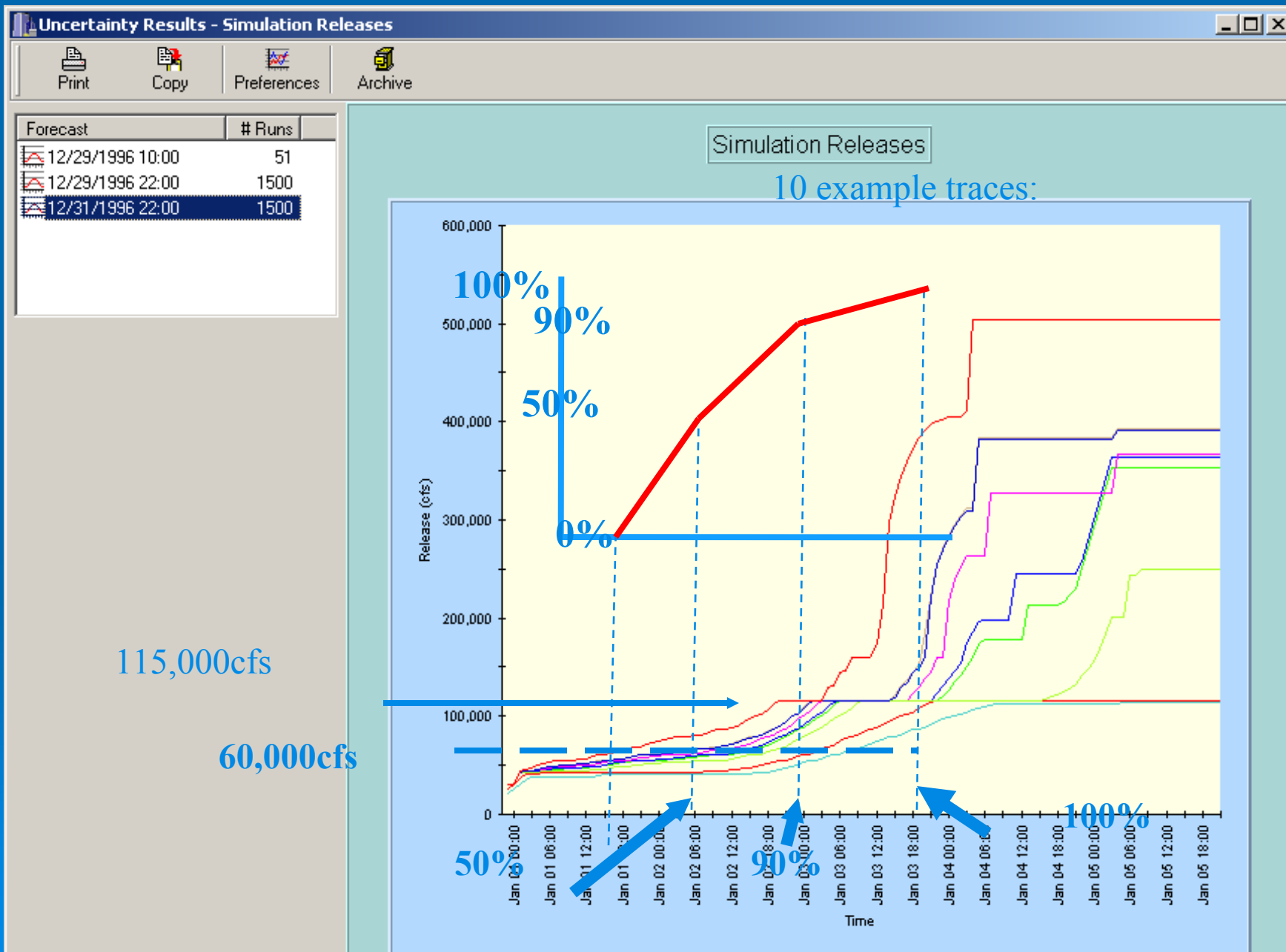
115,000cfs

Simulation Releases

10 example traces:



Simulated Maximum Forecast Releases X cfs



Prob. P of Max. Rel. exceeding X cfs by Time T

Uncertainty Results - Lead Time vs Probability



Print



Copy

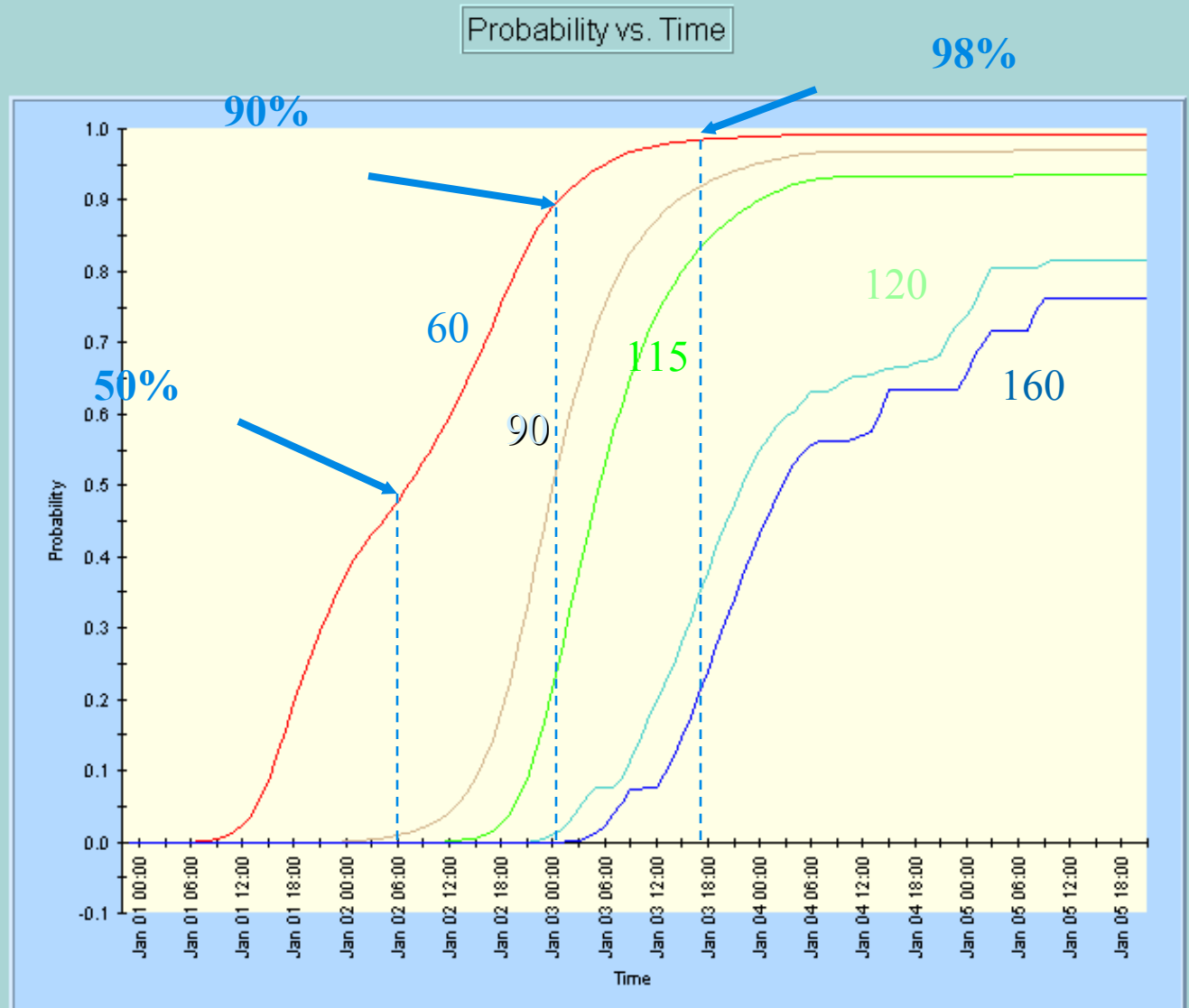


Preferences



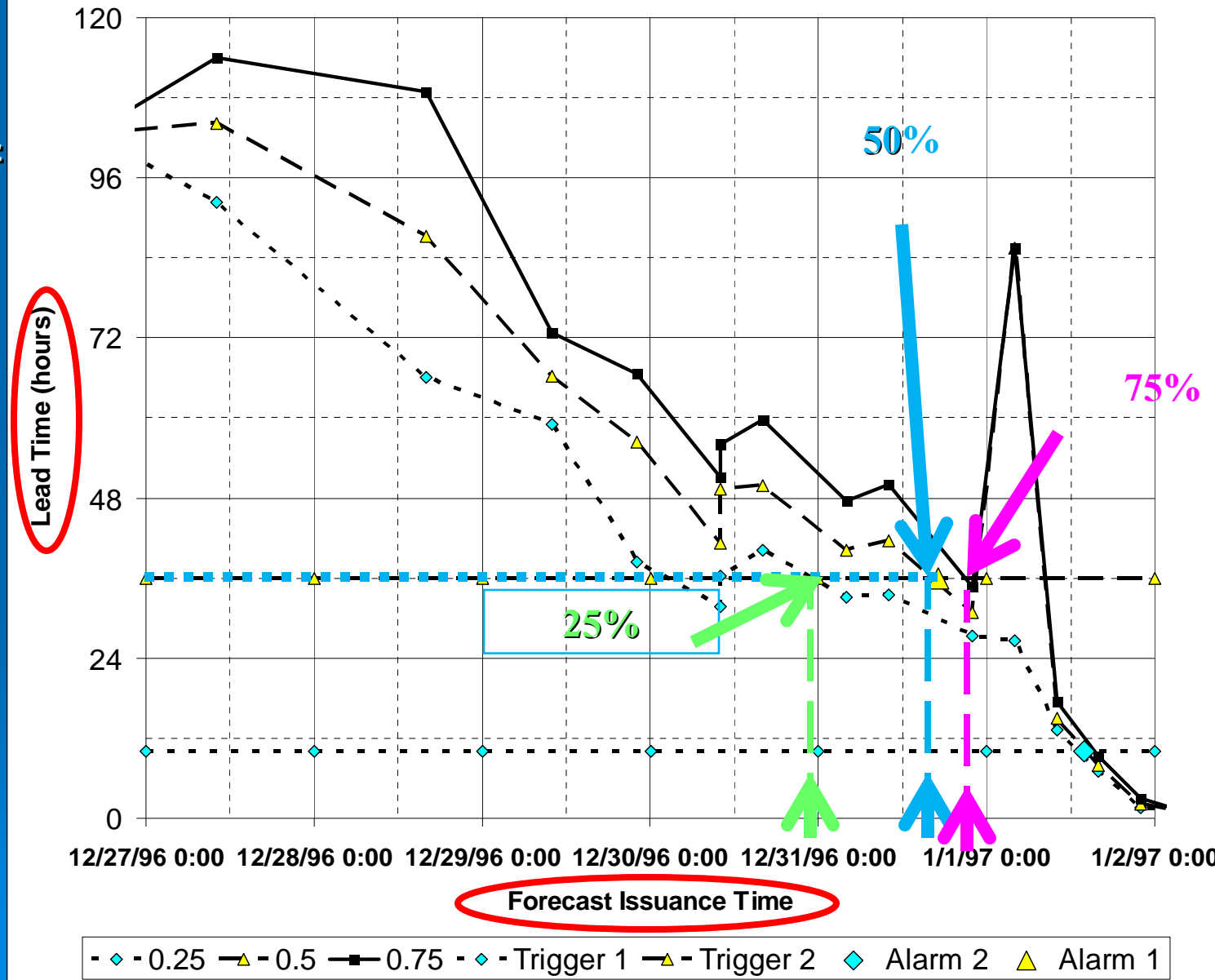
Archive

| Forecast | # Runs |
|------------------|--------|
| 12/29/1996 10:00 | 51 |
| 12/29/1996 22:00 | 1500 |
| 12/31/1996 22:00 | 1500 |



Example of Probabilistic Triggering of Evacuation Alarms

Lead Time vs Forecast Issuance Time for X cfs Release



7) Uncertainty Analysis: 24-month Study Mid-Term River Operations Model for the Lower Colorado River

Shana Tighi (LC Region) and David Bowles

Risk & Uncertainty Task Force Workshop, July 11-12, 2006

and

Uncertainty Analysis: Mid-Term River Operations Model for the Lower Colorado River. Poster presentation at the River Systems Management Workshop, Las Vegas, Nevada. November 2005. (S. Goffman Tighi and D.S. Bowles)

<http://uwrl.usu.edu/people/faculty/bowles.html>

Input Forecast Uncertainty Model

- Non-Flood Control, Non-equalization Conditions
- 23 Input variables
 - Consumptive use of major water users (15)
 - Tributary inflow (4)
 - Side inflow (gain/loss) along river reach (3)
 - Glen Canyon Dam outflow (1)
- Serial correlation and cross correlation
- Data from January 1992 to December 2005
- Data must be representative and statistically homogeneous (*detrend and transform*)
 - Atypically high flows in the Gila and Bill Williams Rivers during 1993 and late 2004-early 2005.


Potential Demand Forecast Biases

- Since implementation of the Inadvertent Overrun Policy (IOP), users may intentionally overestimate annual water use to provide a cushion against needing to seek additional water approvals towards the end of the year.
- Since implementation of the Quantitative Settlement Agreement (QSA), agricultural users may intentionally overestimate annual water use to protect their senior rights and provide a cushion against unexpected need prior to releasing water to lower priority municipal users.

Demand Trends

- Trends associated with lower water use by California agricultural users as required per the QSA.
- Trends associated with shifts from agricultural use to urban water use.

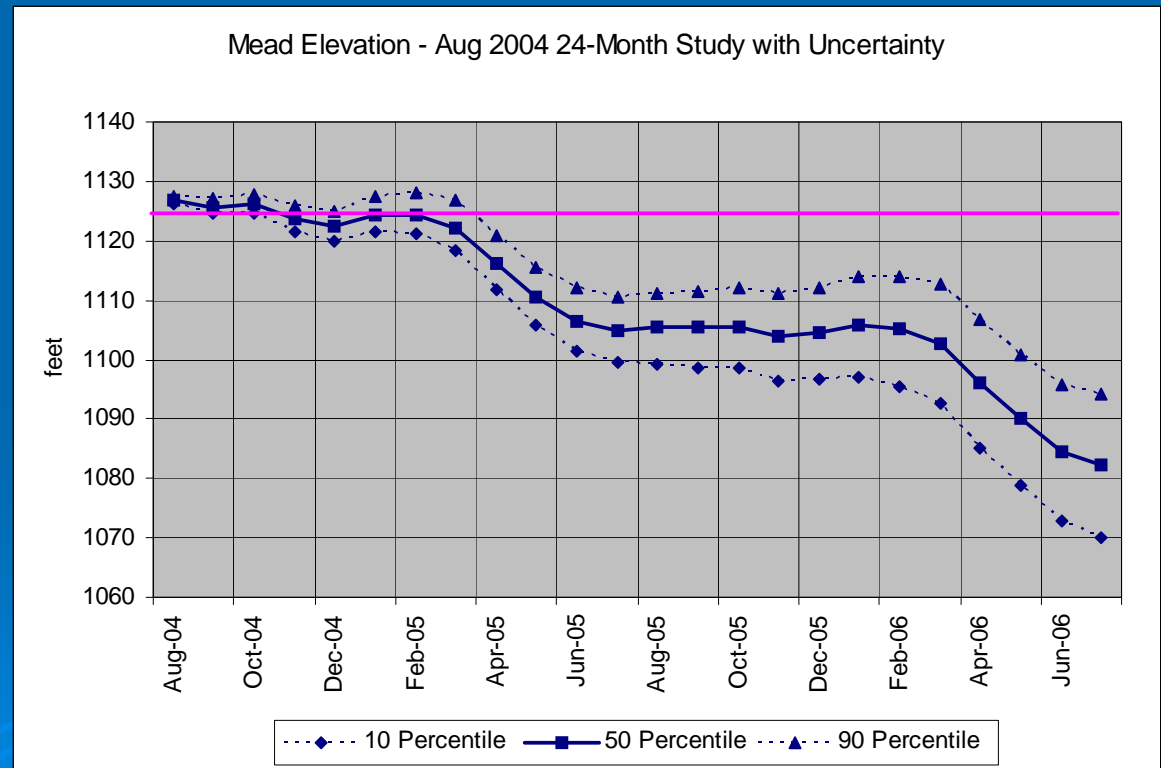
Using Information about Uncertainty to Answer Management Questions

- Point-in-time Questions
 - What will Lake Mead elevation be on Dec 31, 2004?
 - Multiple Time Period / Cumulative Amount Questions
 - How much energy will Hoover generate over the 2005 Water Year?
 - Will Lake Mead elevation be at least 1125 feet during June, July, and Aug?
- 

Point-in-time Questions

Calculating statistics over each time step works for point-in-time questions because no serial correlation is necessary

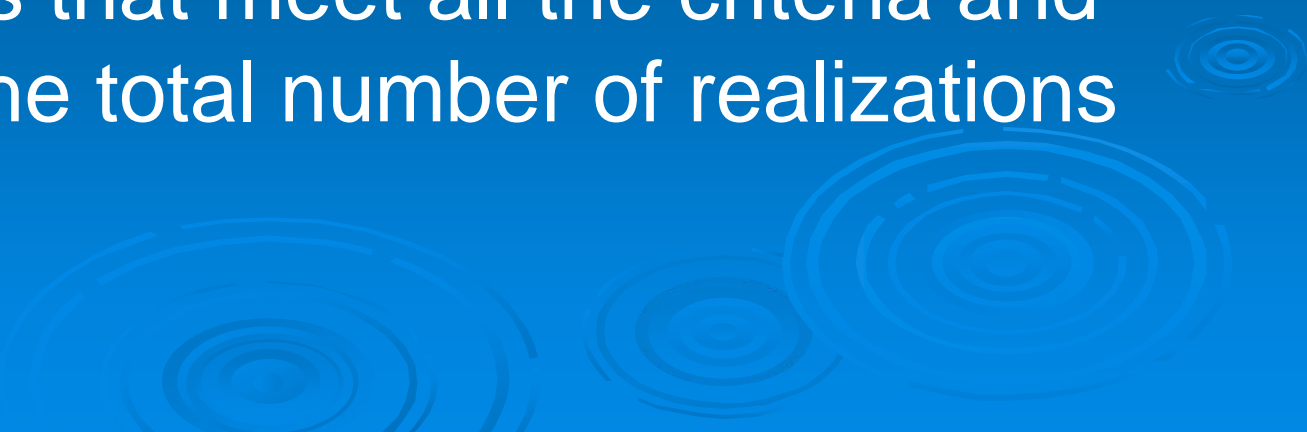
| | Mead Elevation | | |
|--------|----------------|---------------|---------------|
| | 10 Percentile | 50 Percentile | 90 Percentile |
| Aug-04 | 1126.33 | 1126.93 | 1127.57 |
| Sep-04 | 1124.49 | 1125.54 | 1127.17 |
| Oct-04 | 1124.47 | 1126.05 | 1127.78 |
| Nov-04 | 1121.45 | 1123.66 | 1125.77 |
| Dec-04 | 1120.00 | 1122.41 | 1124.87 |
| Jan-05 | 1121.48 | 1124.25 | 1127.33 |
| Feb-05 | 1121.07 | 1124.31 | 1127.96 |
| Mar-05 | 1118.32 | 1122.21 | 1126.76 |
| Apr-05 | 1111.70 | 1116.06 | 1120.95 |
| May-05 | 1105.78 | 1110.63 | 1115.56 |
| Jun-05 | 1101.29 | 1106.58 | 1112.10 |
| Jul-05 | 1099.45 | 1104.96 | 1110.51 |
| Aug-05 | 1099.36 | 1105.39 | 1111.08 |
| Sep-05 | 1098.60 | 1105.44 | 1111.35 |
| Oct-05 | 1098.54 | 1105.61 | 1112.22 |
| Nov-05 | 1096.32 | 1103.77 | 1111.23 |
| Dec-05 | 1096.64 | 1104.46 | 1111.94 |
| Jan-06 | 1097.00 | 1105.67 | 1113.97 |
| Feb-06 | 1095.57 | 1105.02 | 1114.05 |
| Mar-06 | 1092.64 | 1102.80 | 1112.76 |
| Apr-06 | 1085.11 | 1096.16 | 1106.67 |
| May-06 | 1078.73 | 1090.21 | 1100.93 |
| Jun-06 | 1072.71 | 1084.44 | 1095.84 |
| Jul-06 | 1070.11 | 1082.28 | 1094.16 |



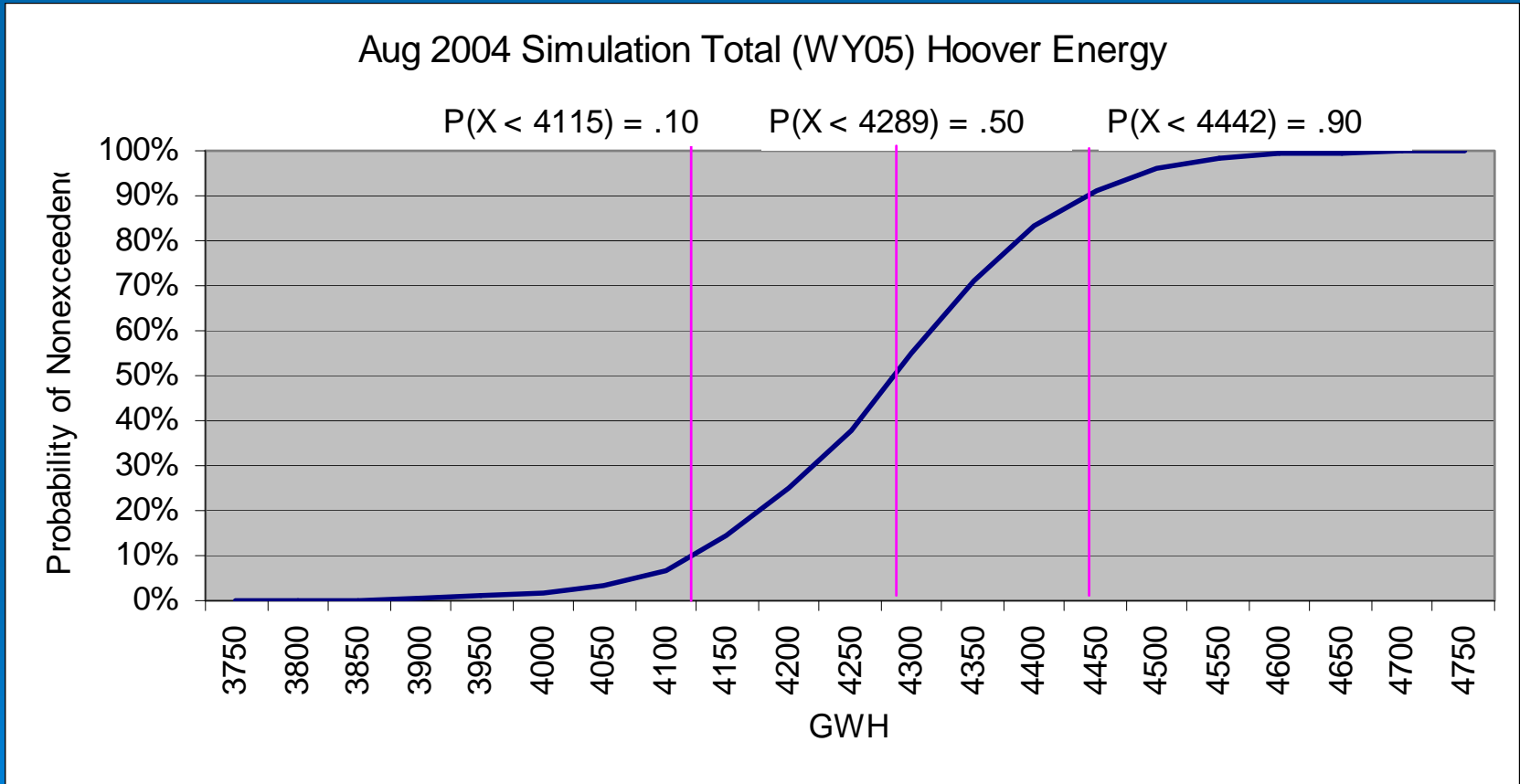
Multiple Time Period Questions

- Calculating statistics over each time step will not work because we are interested in cumulative values over time
- Selecting a single “input trace” for each percentile will not work because each realization is equally likely (i.e., there is no most likely realization)

Multiple Time Period Questions

- Cumulative Amounts - Sum the values over the time period in question, for each realization, and present the results as box plots, histograms, or CDFs.
 - Frequency Analysis - Count the number of realizations that meet all the criteria and divide by the total number of realizations
- 

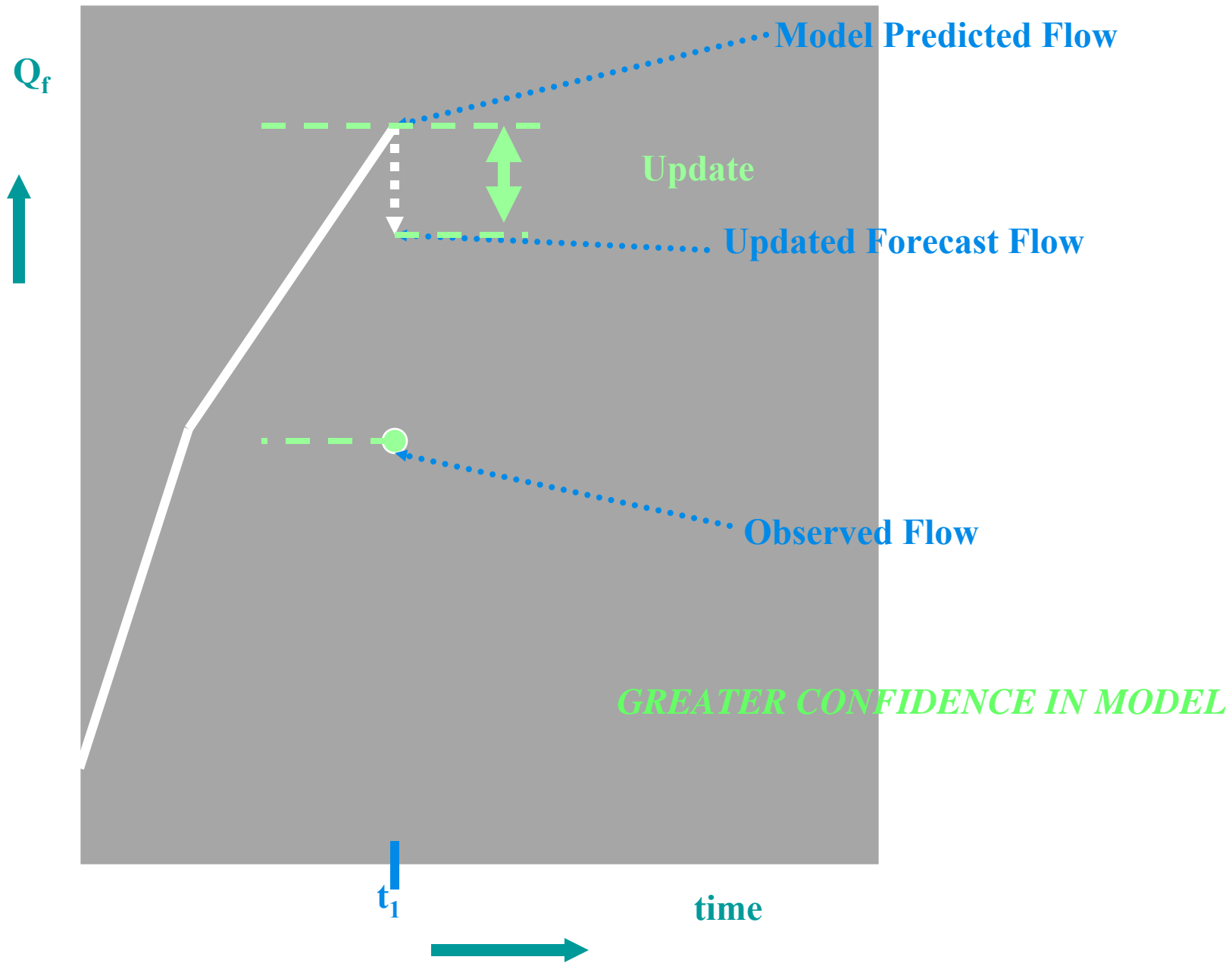
Cumulative Amount – How much energy will be generated at Hoover over WY2005?

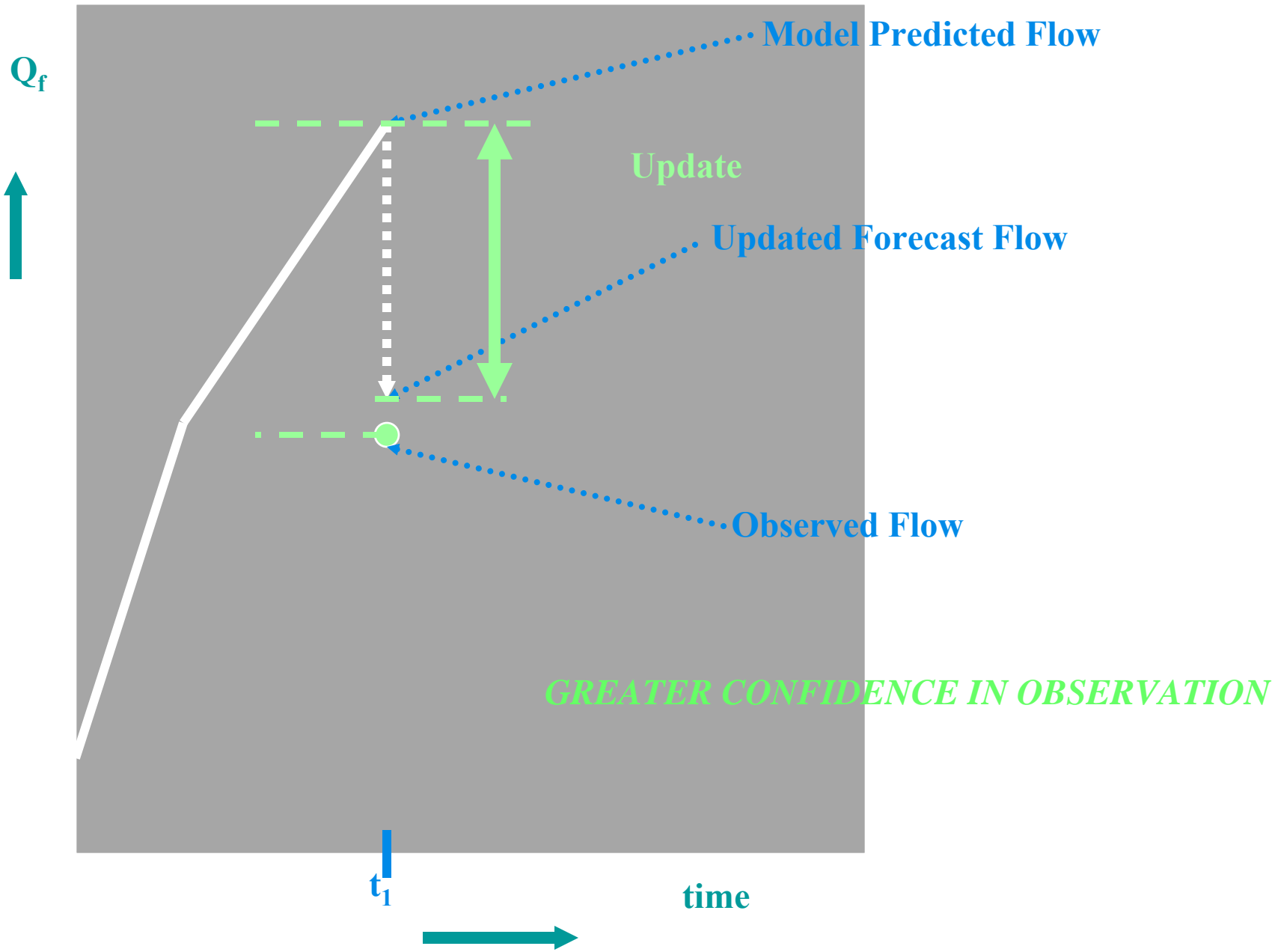


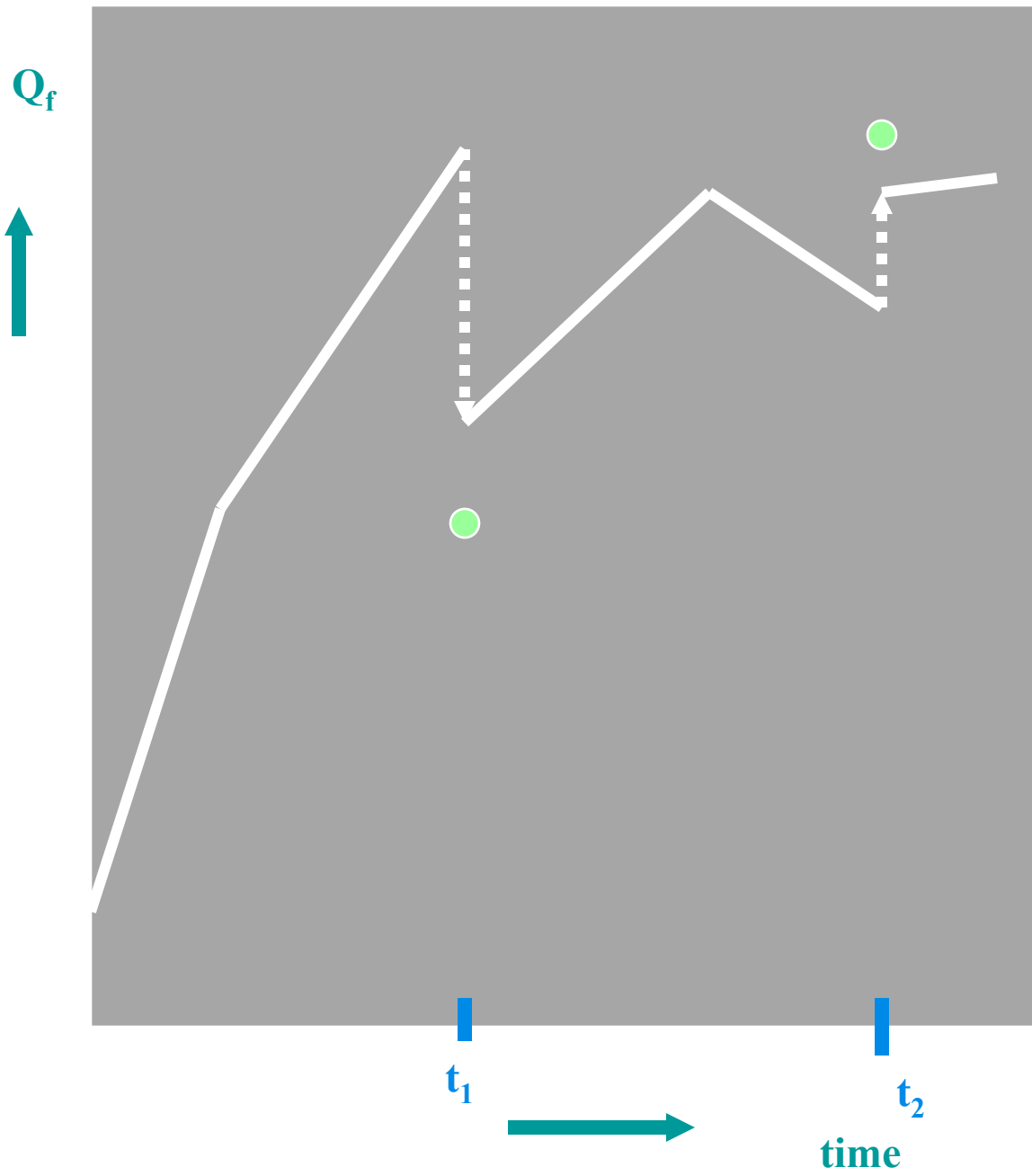
8) An Example of Real-time Updating of Forecasts Using Uncertainty Estimates

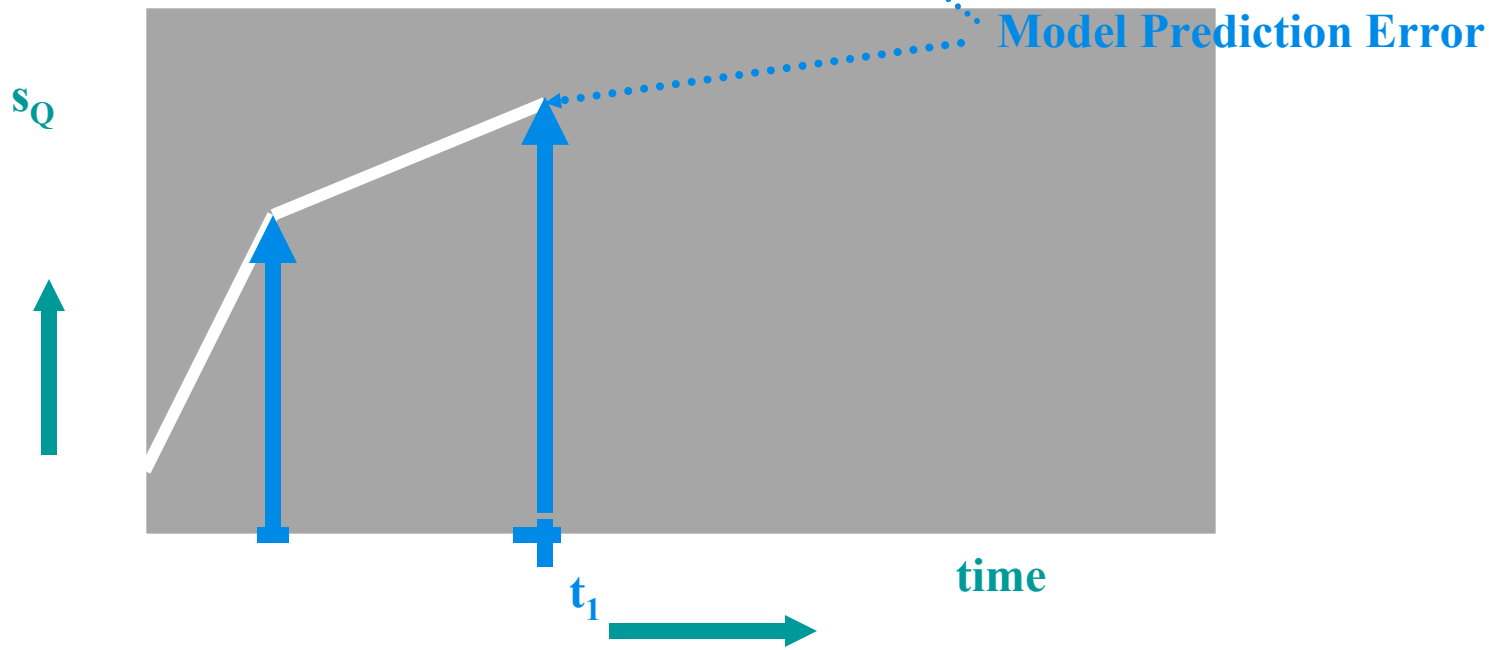
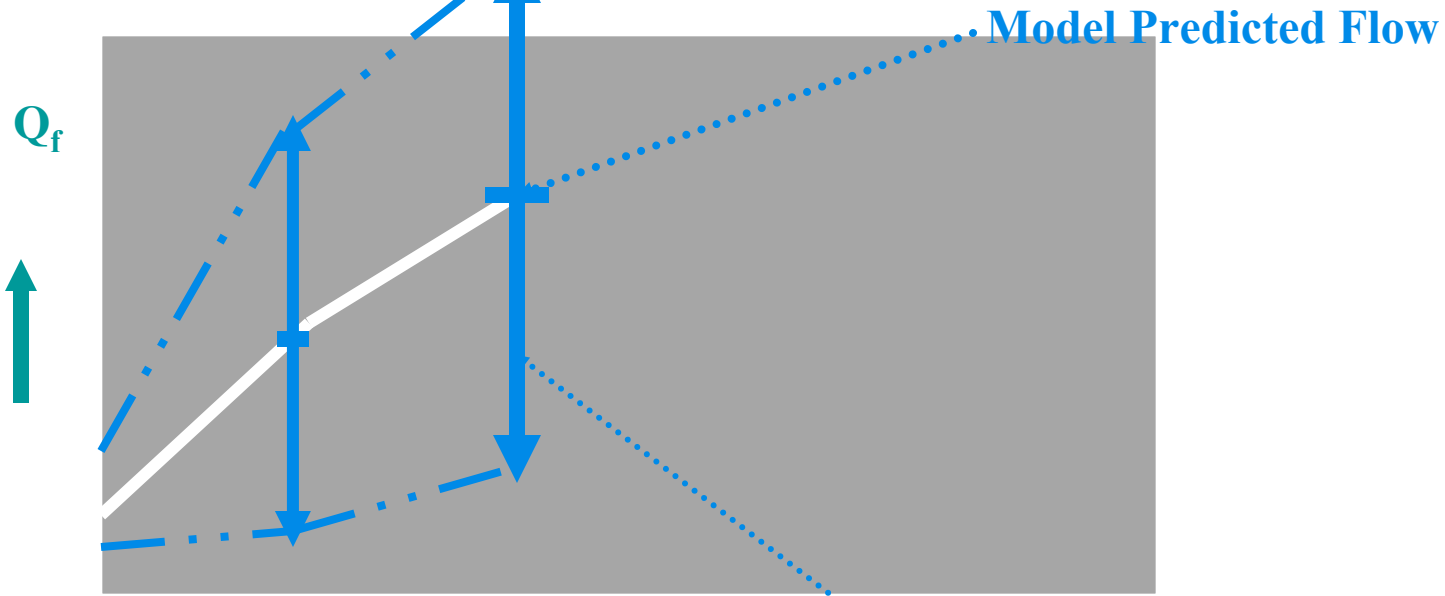
Using “Extended Kalman Filter”
State Space Model

The background of the slide is a solid blue color. In the lower right quadrant, there are several decorative elements consisting of concentric circles, resembling ripples in water. These circles are light blue and vary in size and opacity, creating a subtle pattern.



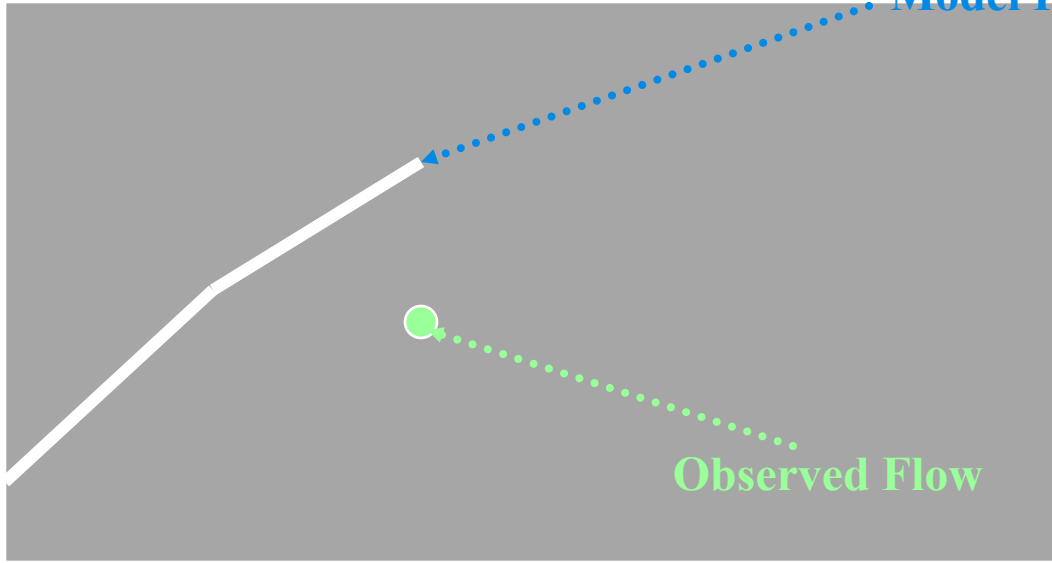






Model Predicted Flow

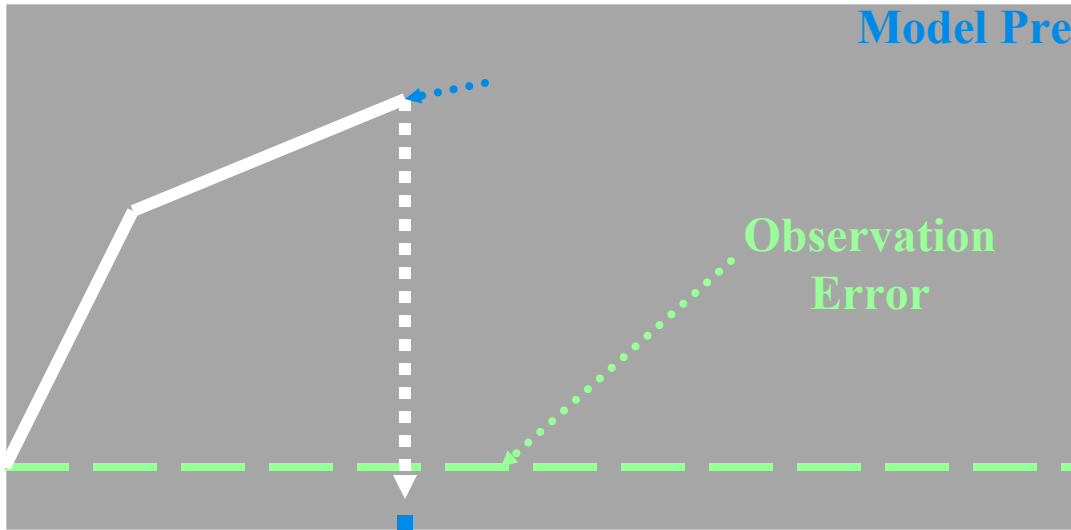
Q_f



Observed Flow

Model Prediction Error

s_Q

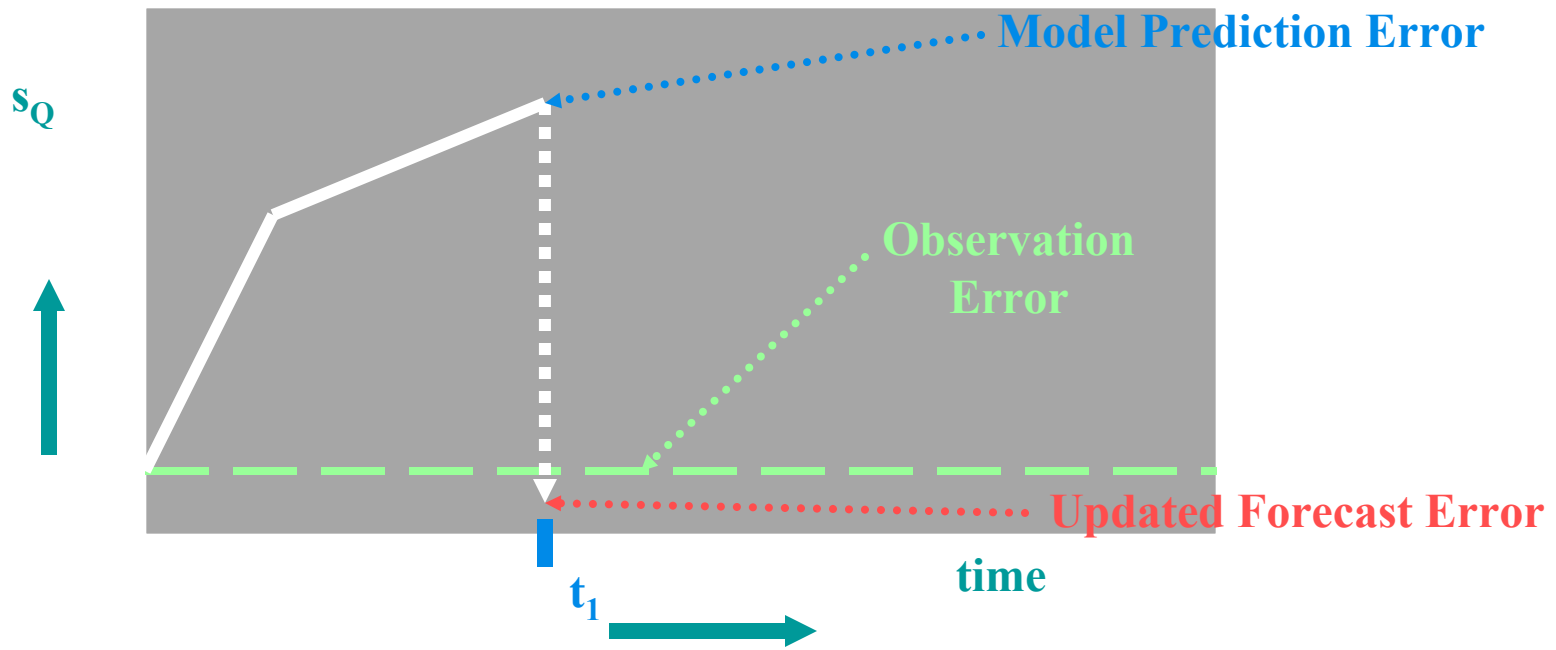
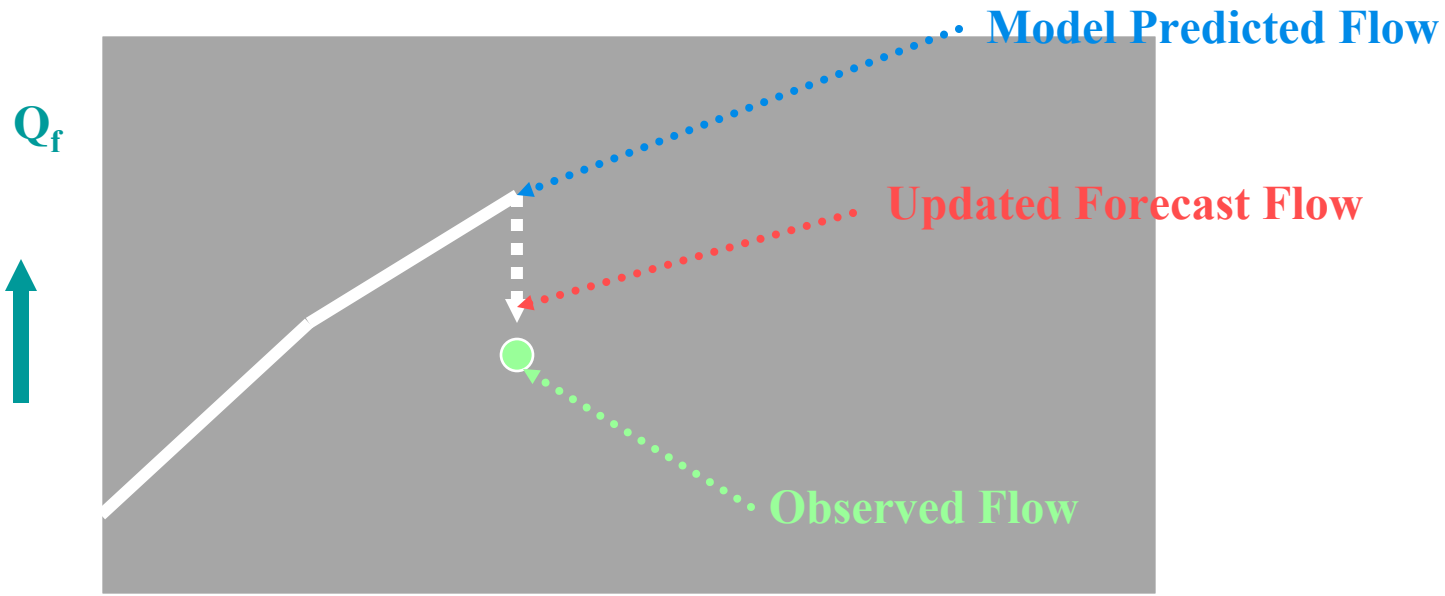


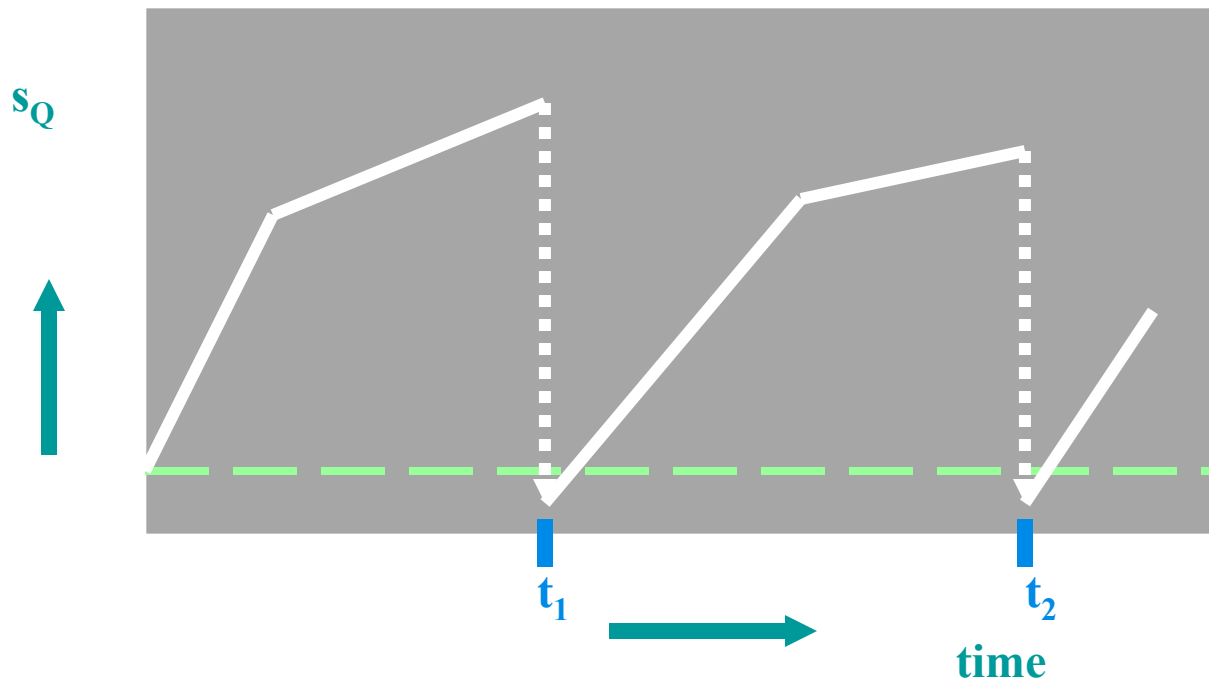
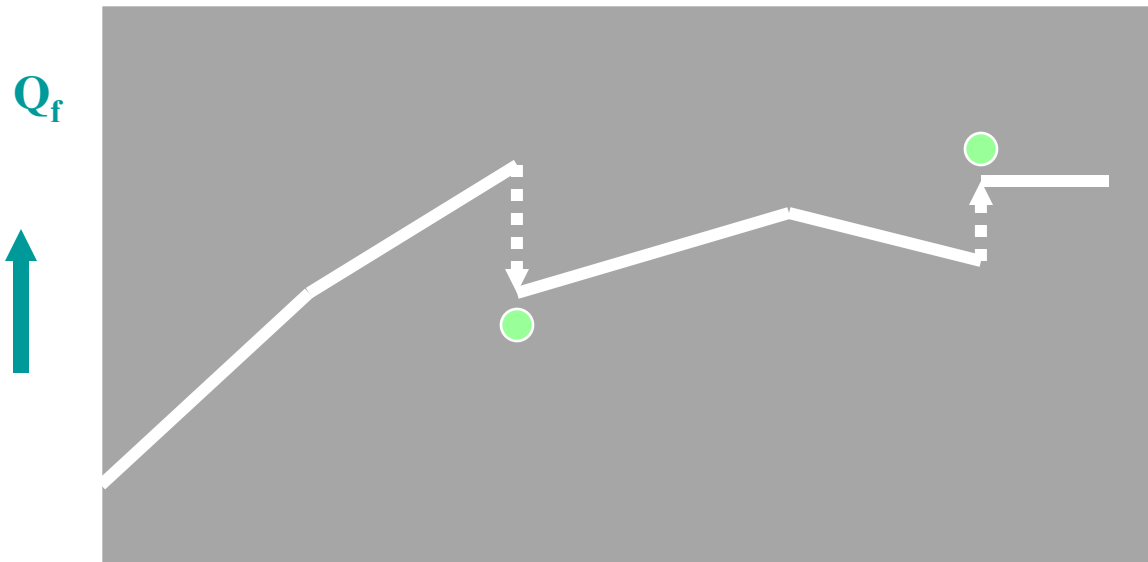
Observation Error

t_1

time







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