ARR Essentials

Mark Babister, Monique Retallick

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Acknowledgements

- Bill Weeks
- Rory Nathan
- Peter Coombes
- Steve Rosso

Outline

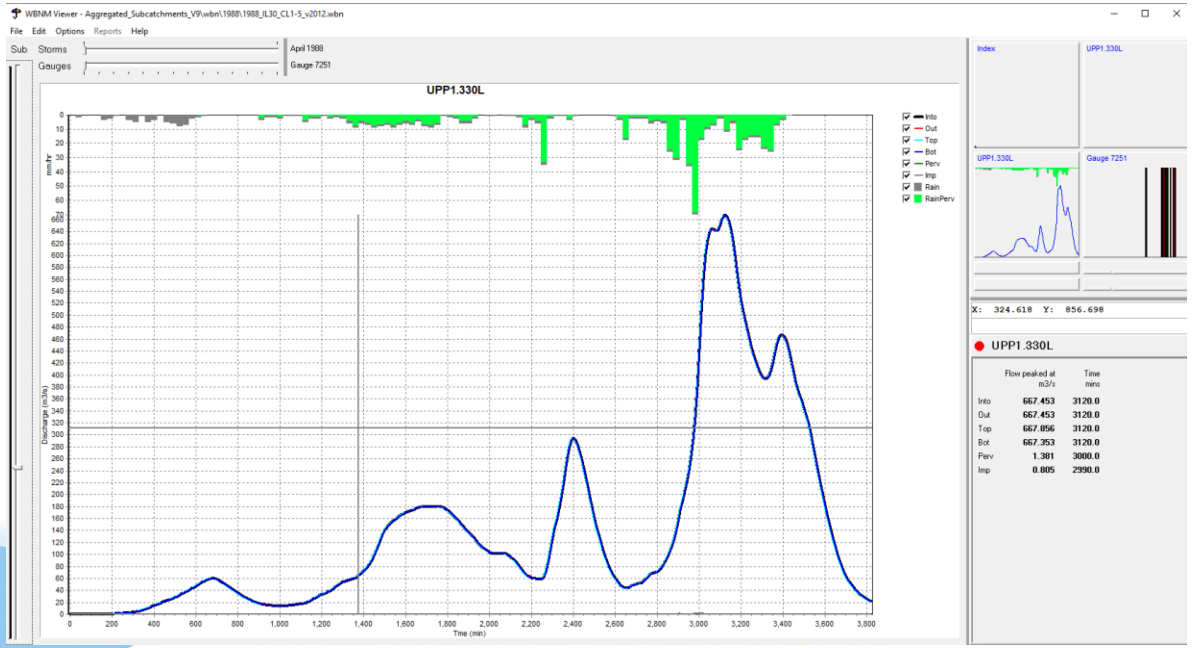
- Introduction, course layout
- Fundamental issues
- Approaches
- Data
- Risk based design
- Climate Change
- Questions

Course Outline

Date	Title and Links
15th April	Webinar: ARR Essentials
27th May	ARR Live Course #1: Rainfall Design Inputs
24th June	ARR Live Course #2: Flood Frequency Analysis
22nd July	ARR Live Course #3: Hydrologic Modelling Applications
2nd September	ARR Live Course #4: Flood Hydraulics
30th September	ARR Live Course #5: Design Estimation
28th October	ARR Live Course #6: Extreme Events
11th November	ARR Live Course #7: Urban Approaches
9th December	ARR Live Course #8: Urban Flood Modelling

What to expect from the 8 sessions

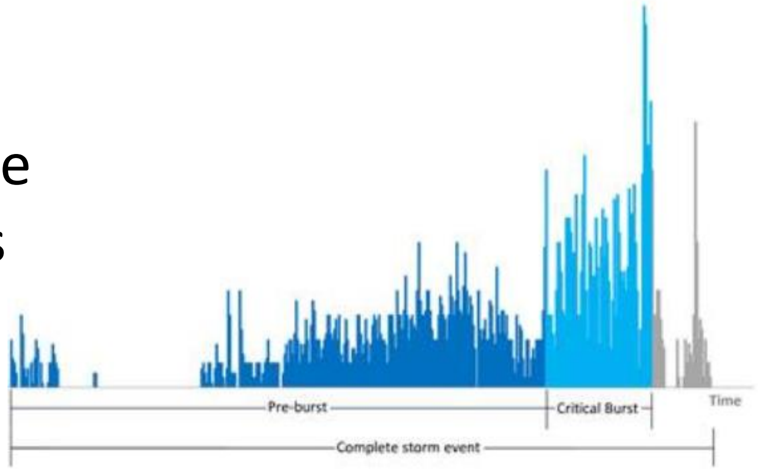
- Practical advice
- How to guide to ARR
- Worked examples

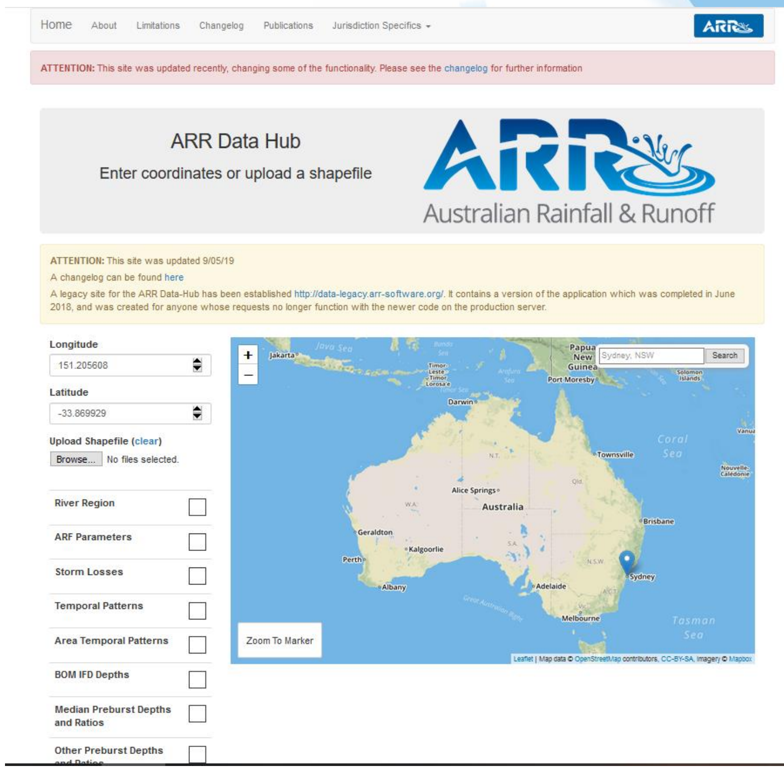


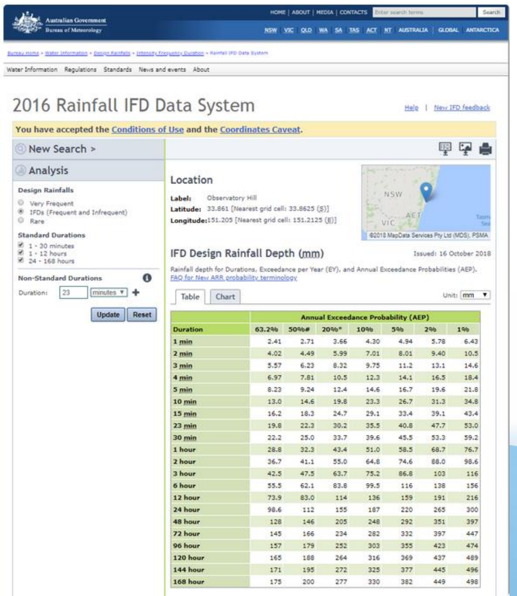

ARR
Live Training Series
Course One
Rainfall Design Inputs

Rainfall Design Inputs

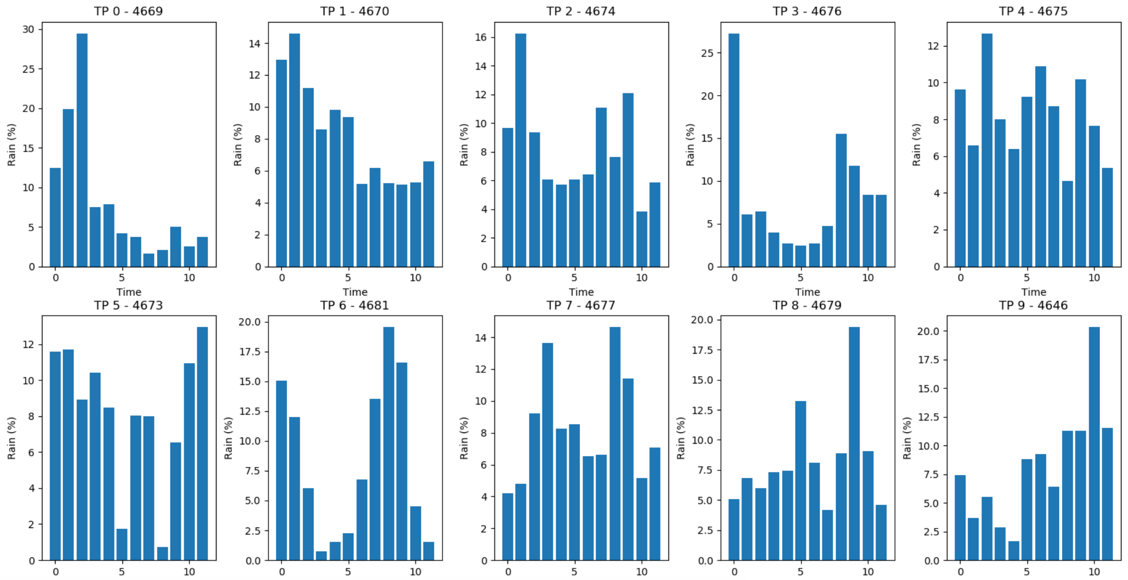
- Pre-burst
- how to select which temporal pattern to use
- Areal reduction factors
- Spatially distributing rainfall

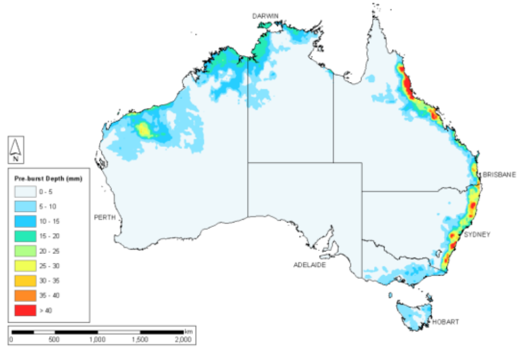






	Annual Exceedance Probability (AEP)						
Duration	63.2%	50%#	20%*	10%	5%	2%	1%
1 min	2.41	2.71	3.66	4.30	4.94	5.78	6.43
2 min	4.02	4.49	5.99	7.01	8.01	9.40	10.5
3 min	5.57	6.23	8.32	9.75	11.2	13.1	14.6
4 min	6.97	7.81	10.5	12.3	14.1	16.5	18.4
5 min	8.23	9.24	12.4	14.6	16.7	19.6	21.8
10 min	13.0	14.6	19.8	23.3	26.7	31.3	34.8
15 min	16.2	18.3	24.7	29.1	33.4	39.1	43.4
23 min	19.8	22.3	30.2	35.5	40.8	47.7	53.0
30 min	22.2	25.0	33.7	39.6	45.5	53.3	59.2
1 hour	28.8	32.3	43.4	51.0	58.5	68.7	76.7
2 hour	36.7	41.1	55.0	64.8	74.6	88.0	98.6
3 hour	42.5	47.5	63.7	75.2	86.8	103	116
6 hour	55.5	62.1	83.8	99.5	116	138	156
12 hour	73.9	83.0	114	136	159	191	216
24 hour	98.6	112	155	187	220	265	300
48 hour	128	146	205	248	292	351	397
72 hour	145	166	234	282	332	397	447
96 hour	157	179	252	303	355	423	474
120 hour	165	188	264	316	369	437	489
144 hour	171	195	272	325	377	445	496
168 hour	175	200	277	330	382	449	498

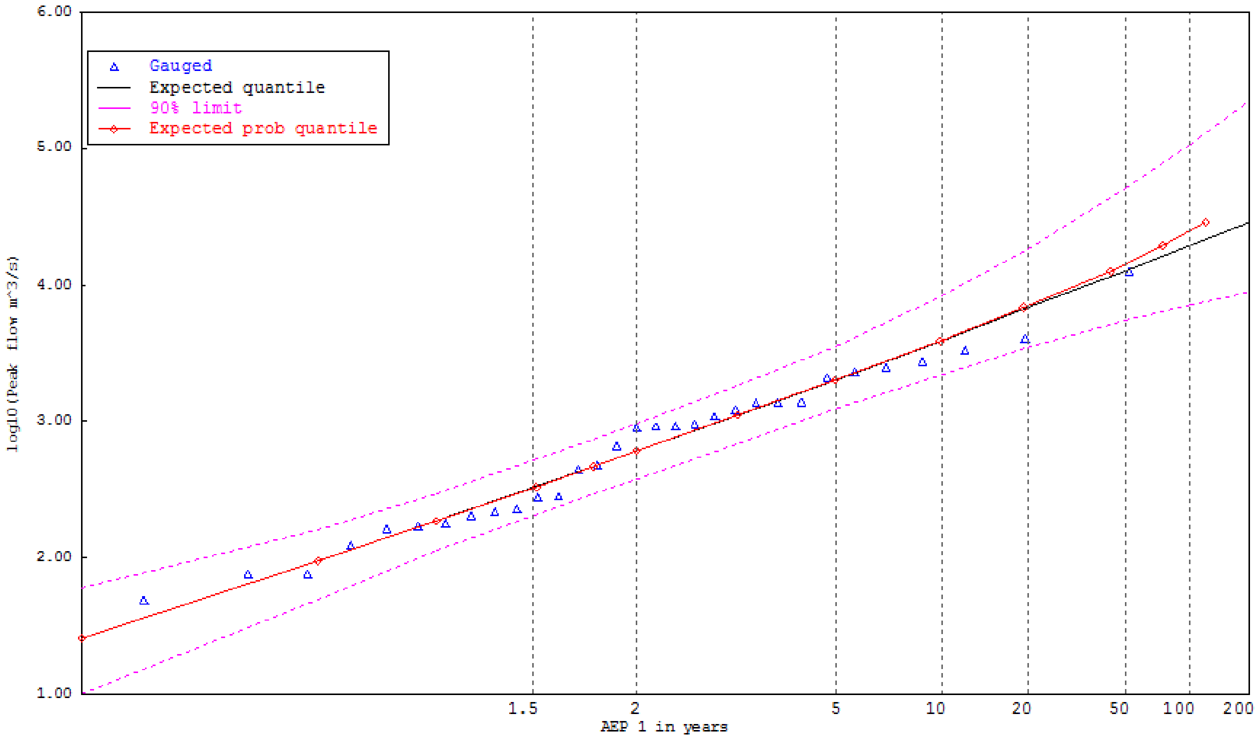


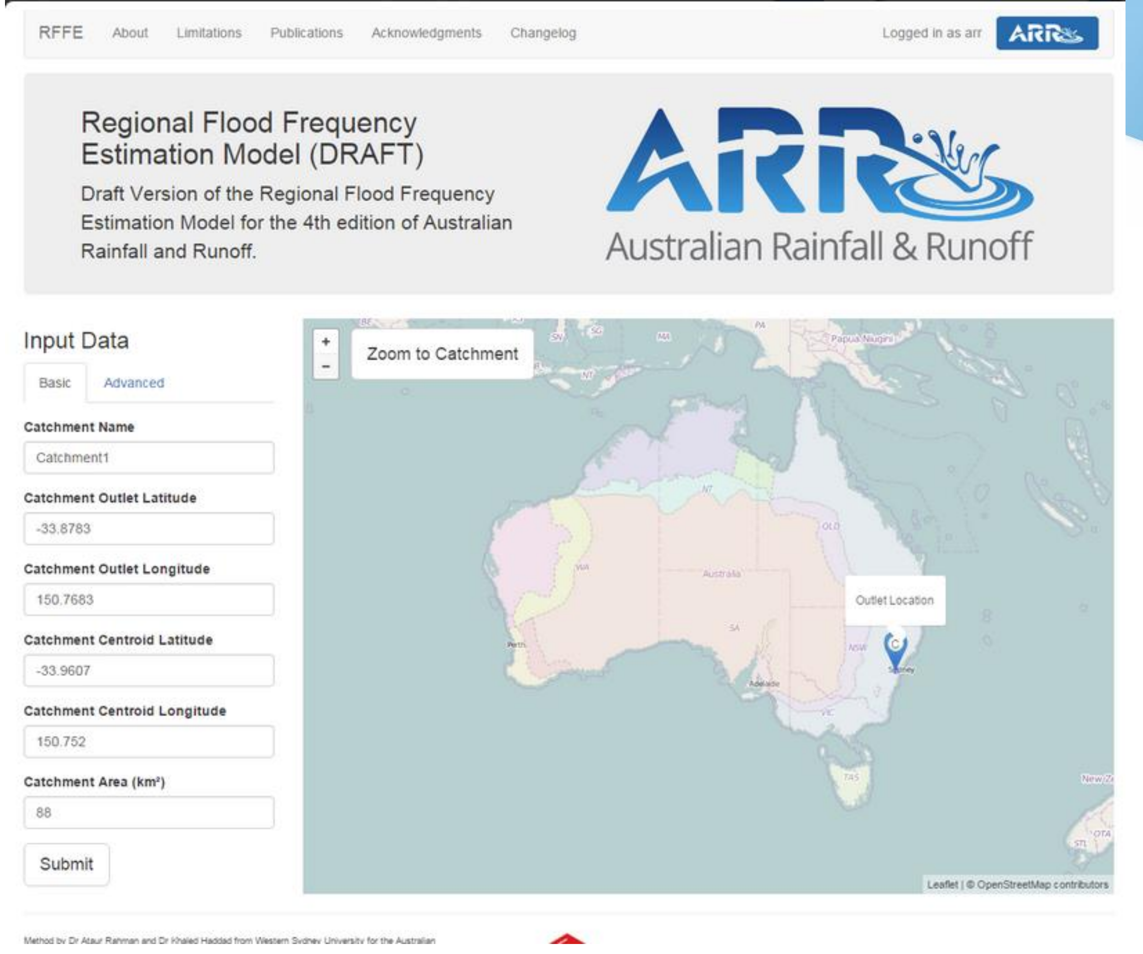



ARR
Live Training Series
Course Two
Flood Frequency Analysis

RFFE and FFA

- Practical applications of FLIKE
- Including historical data and thresholds
- RFFE – current enhancements
- When will the arid zone be back online





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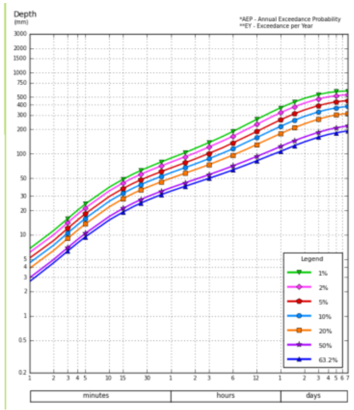
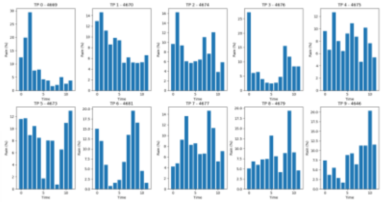
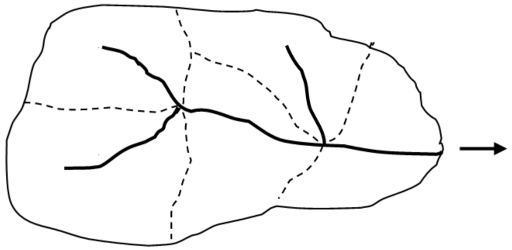
ARR
Live Training Series
Course Three
Hydrologic Modelling Applications

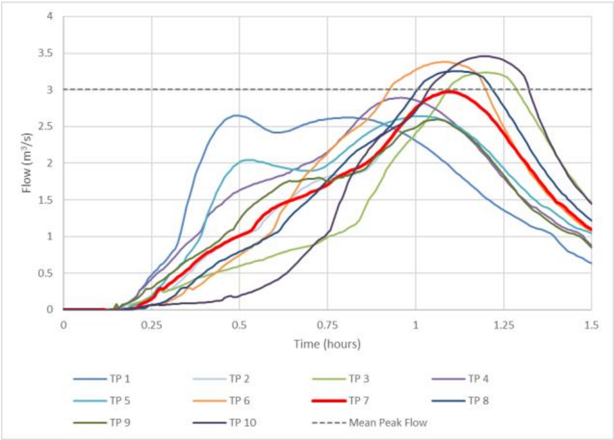
Hydrologic modelling applications

- Worked example from design inputs to design flows









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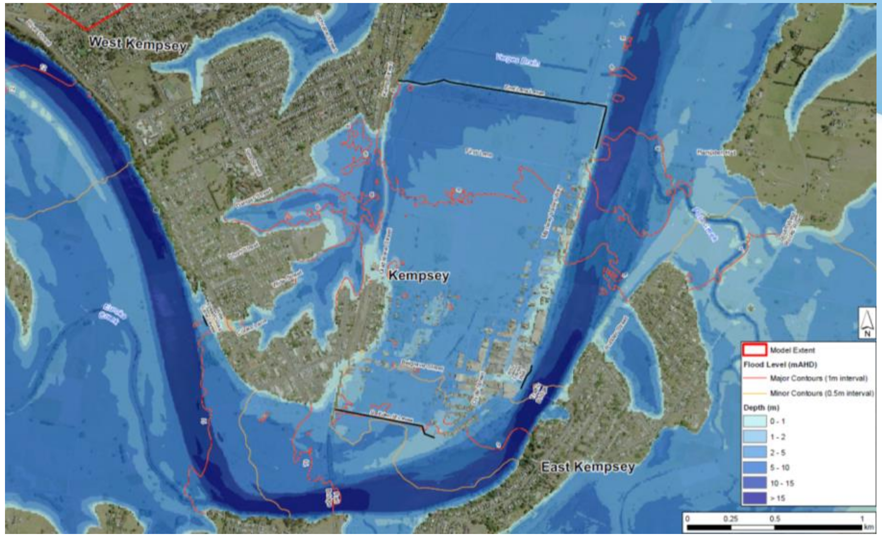
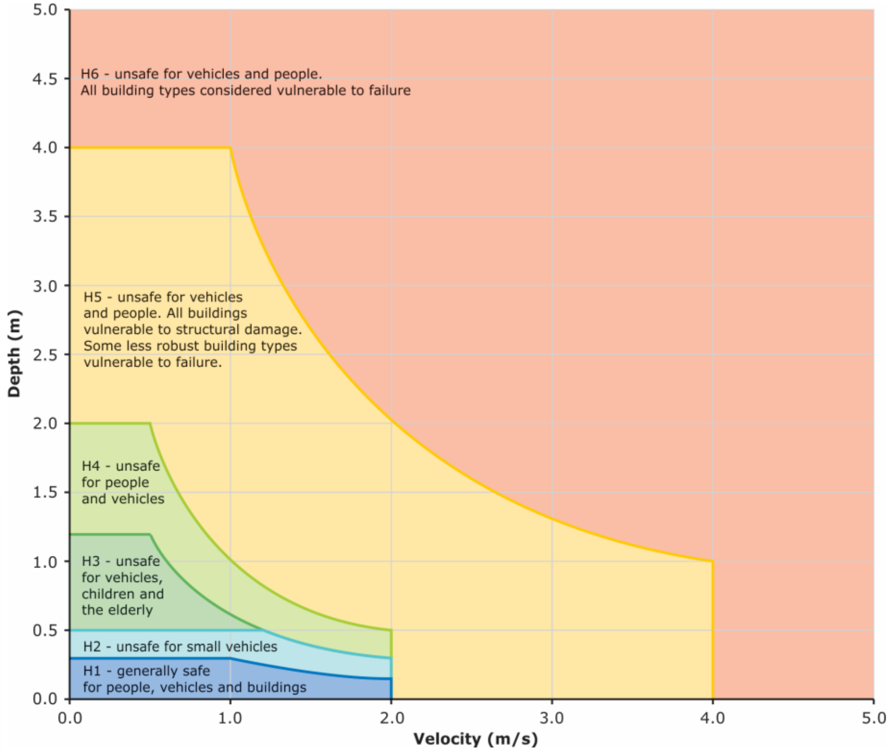
Flood Hydraulics

- A practical blockage example and its application
- Hazard
- Bridges






ARR
Live Training Series
2
1
Course Five
Design Estimation

Design estimation

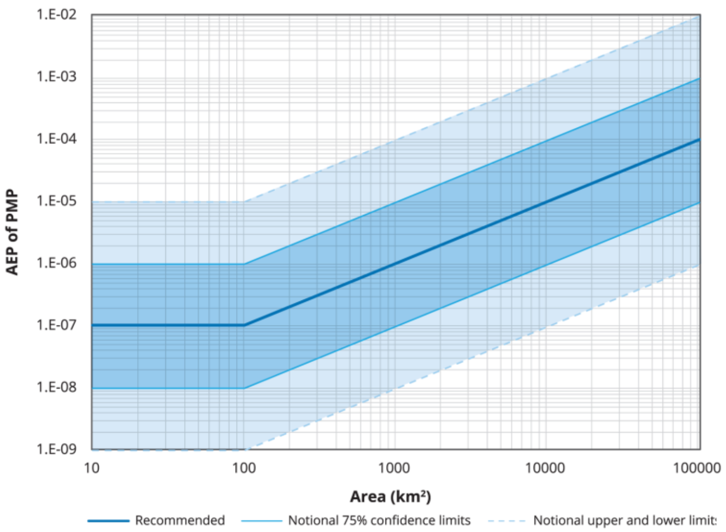
- Comparison of different methods
- Using the results from course 2 and 3
- Principles of calibration
- Model selection

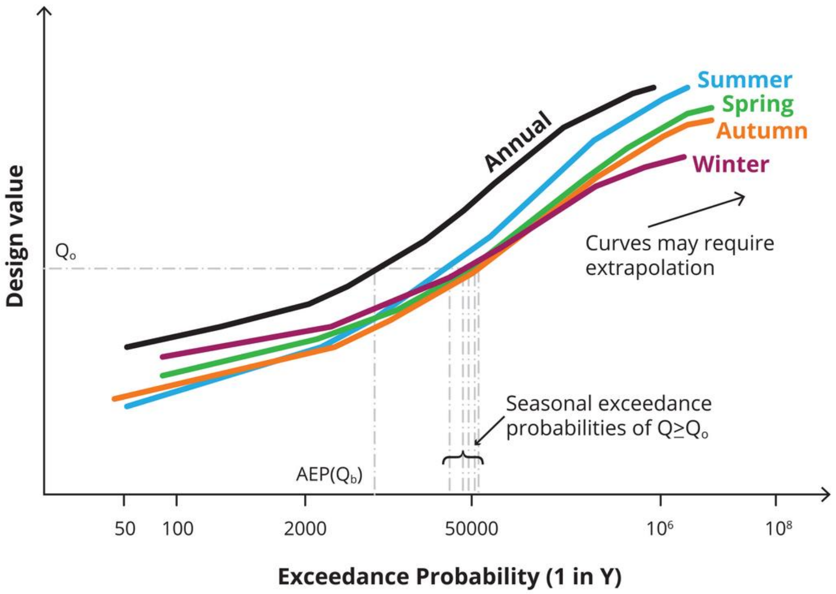
	Simple Event	Ensemble Event	Monte Carlo Event	Continuous Simulation
Hydrologic Inputs	Design rainfalls (ie rainfall depth for given burst duration and annual exceedance probability)			Observed (or synthetic) time series of rainfall and evaporation
Hydrologic variability	Fixed patterns of rainfall and other inputs	Ensemble of *N* temporal patterns	Ensemble (or distribution) of temporal patterns, losses, and other factors.	As represented in the time series of inputs – if not in time series then not represented
Model	Event-based model based on routing rainfall excess through catchment storage (see Book 5 for details of technique)			Model of catchment processes influencing runoff generation
Framework	Single simulation for each combination of rainfall depth and AEP	*N* simulations for each combination of rainfall depth and AEP ($N \approx 10$)	Stochastic sampling of input distributions using continuous or stratified domain (potentially thousands of simulations)	Continuous simulation at time step for *N* years
Flood AEP	Assumed same as input rainfall		Statistical analysis of joint probabilities (eg frequency analysis of maxima or Total Probability Theorem)	Computed from frequency analysis of *N* annual maxima
Flood magnitude	Single estimate derived from each set of inputs	Simple average (or median) of *N* simulations		
ARR guidance	Book 4, Sect 3.2.2	Book 4, Sect 3.2.3	Book 4, Sect 3.2.4	Book 4, Sect 3.3

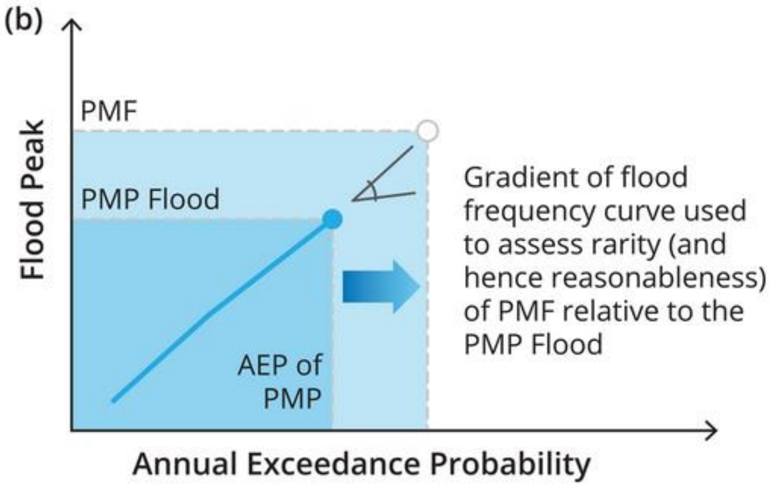

ARR
LIVE TRAINING SERIES
COURSE SIX
EXTREME EVENTS

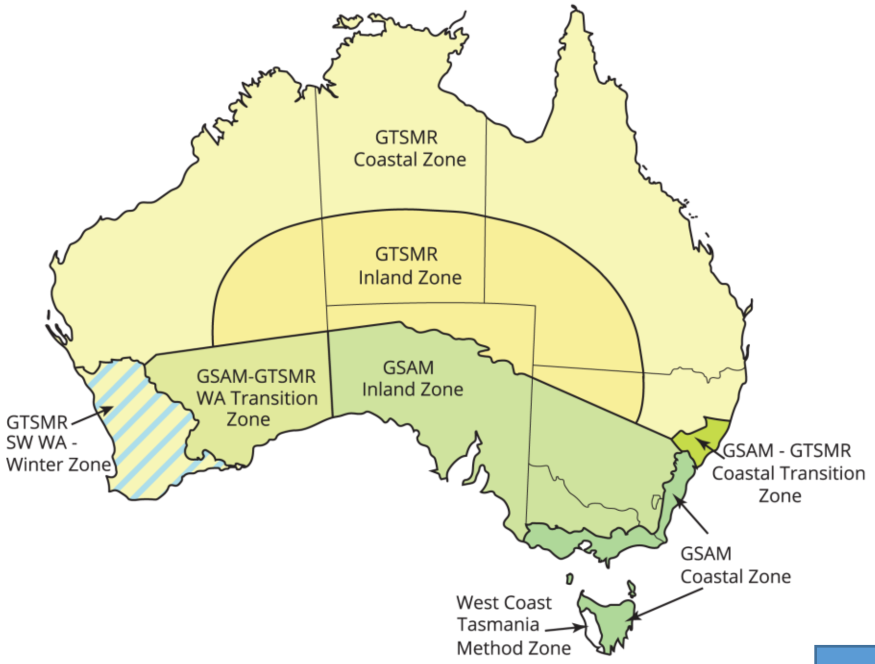
Extreme Events

- understanding of how extreme rainfalls are derived
- how to derive extreme rainfall for applications including the sizing of spillways for large dams and design of major structures in flood risk areas
- what temporal patterns to use with rare rainfall
- Correct PMF Terminology





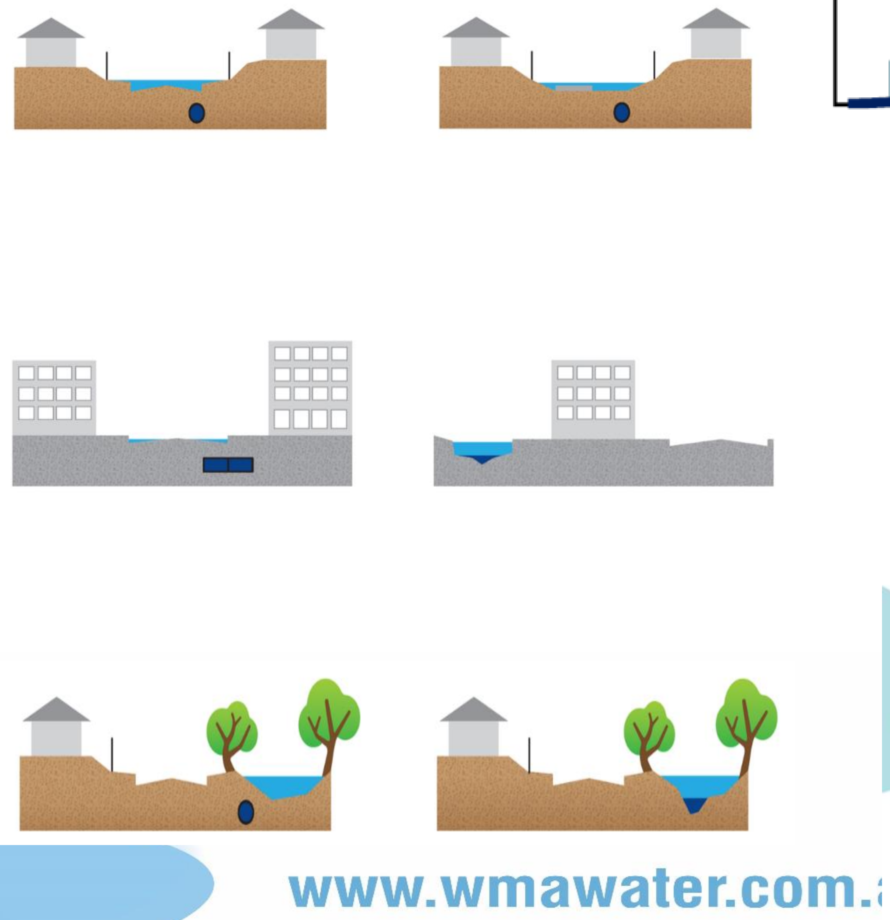


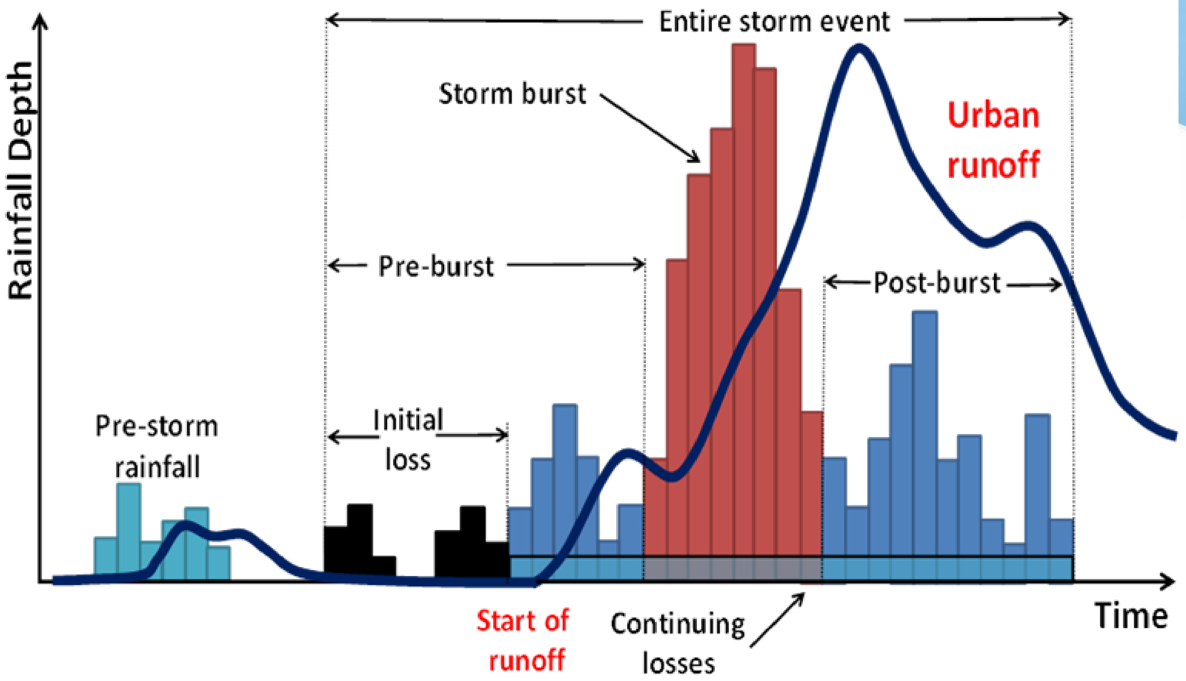


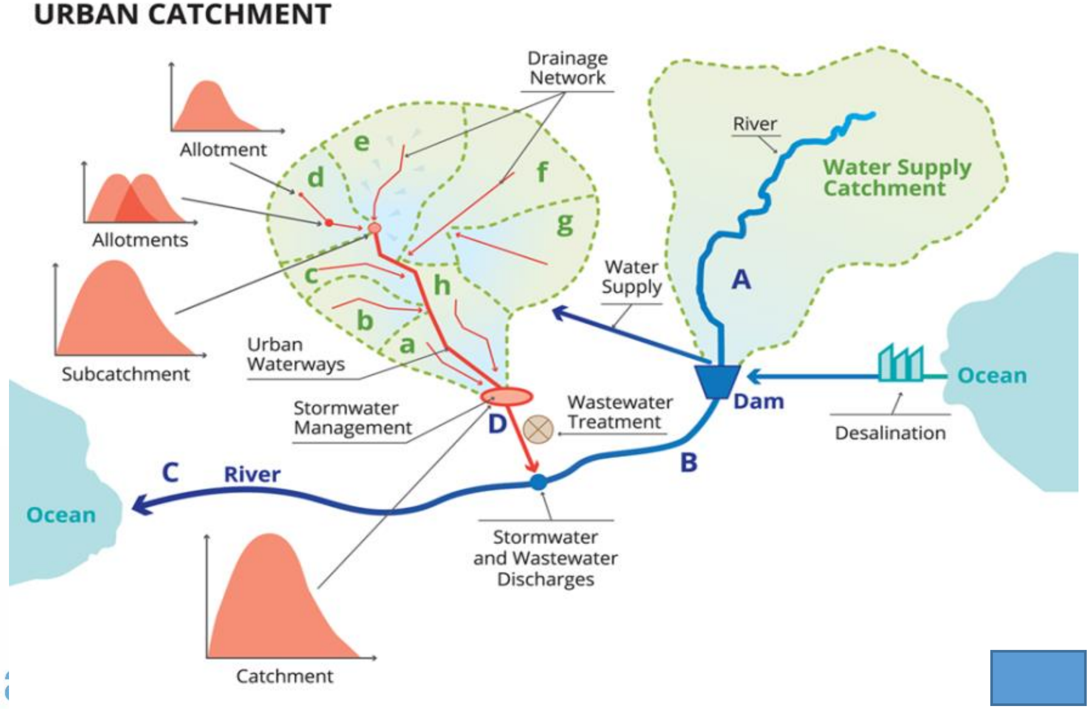

ARR
LIVE TRAINING SERIES
COURSE SEVEN
URBAN APPROACHES

Urban approaches

- Urban theory







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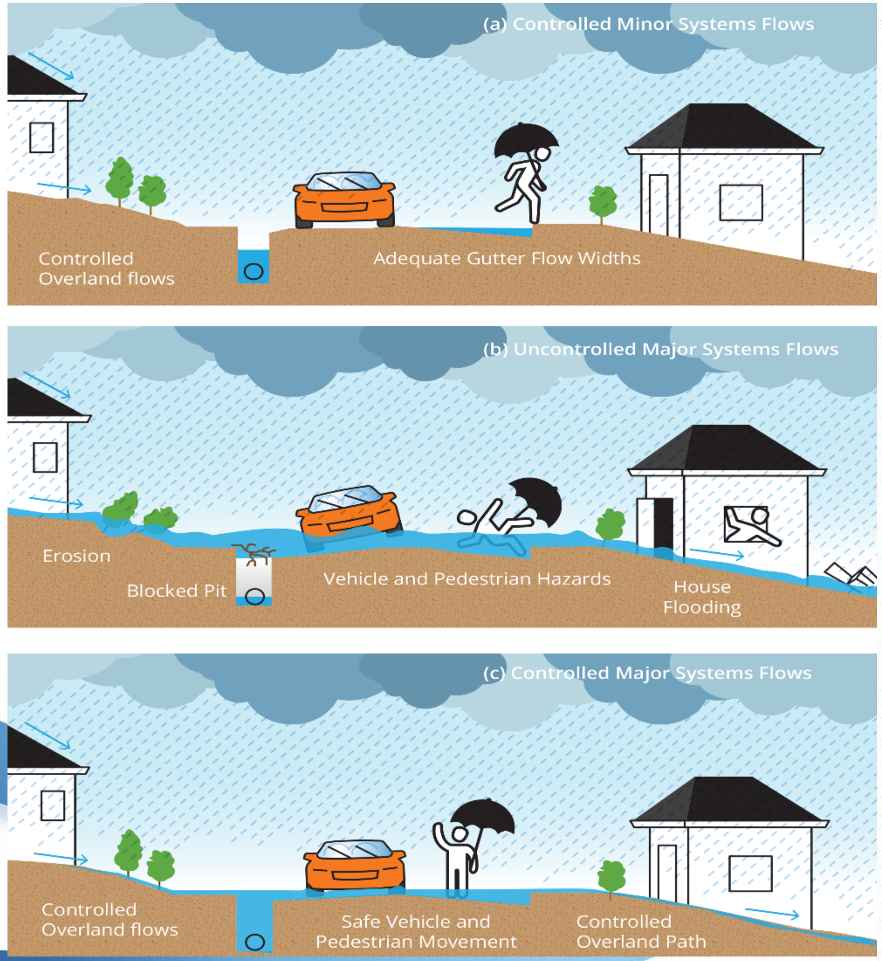
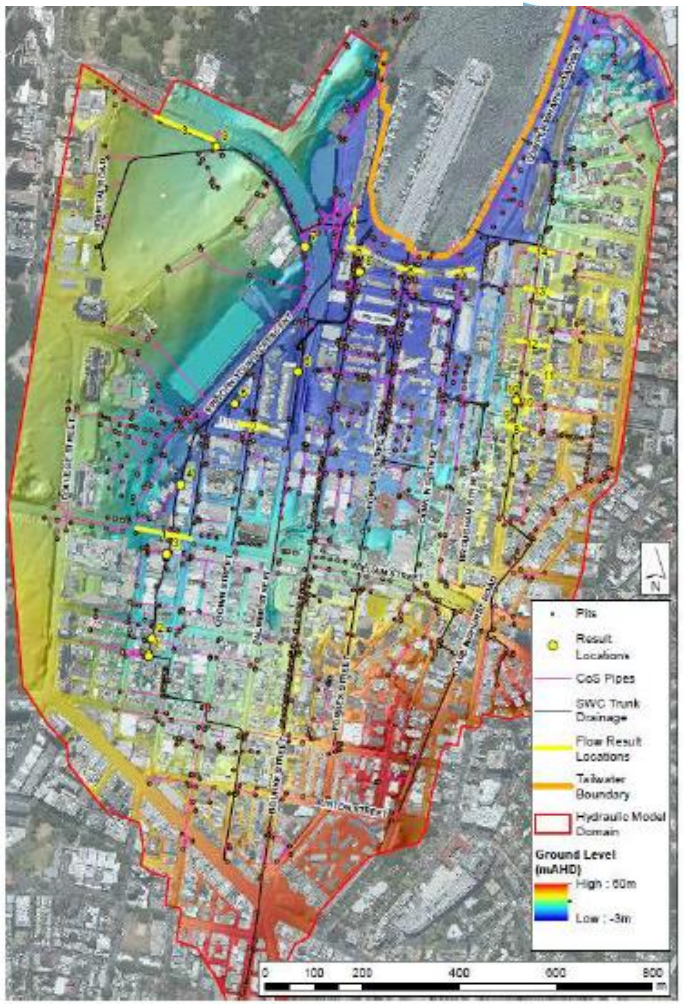
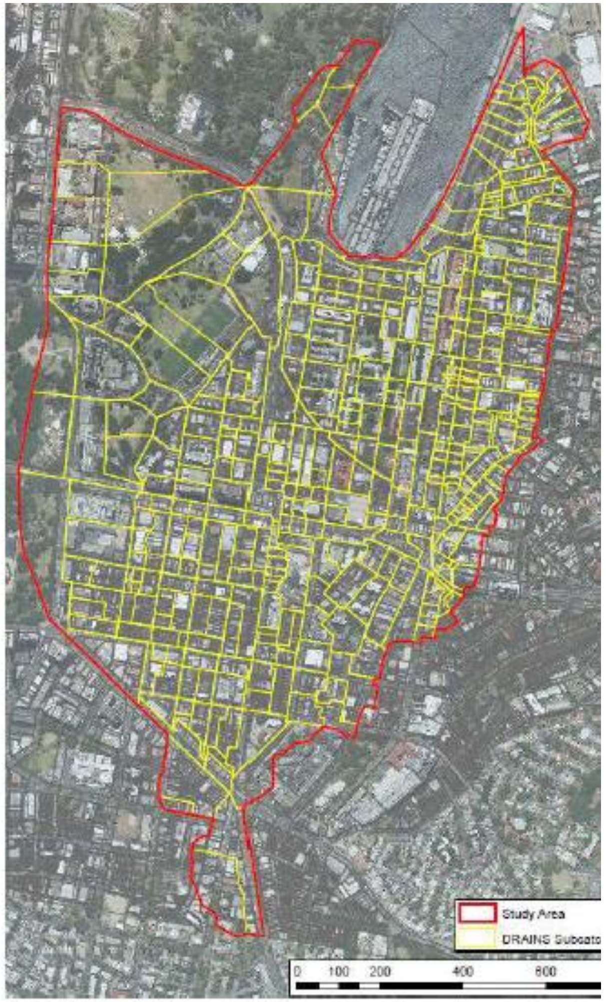
Urban Flood Modelling

- Hands on worked example
- Direct rainfall







Those dates again…

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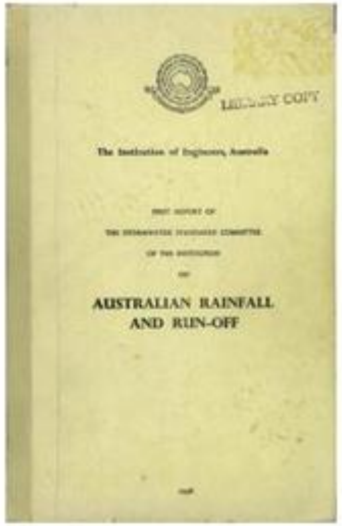
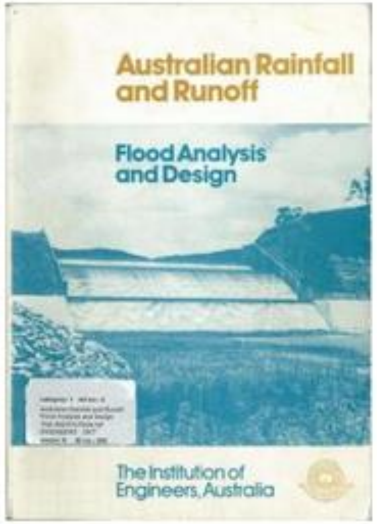
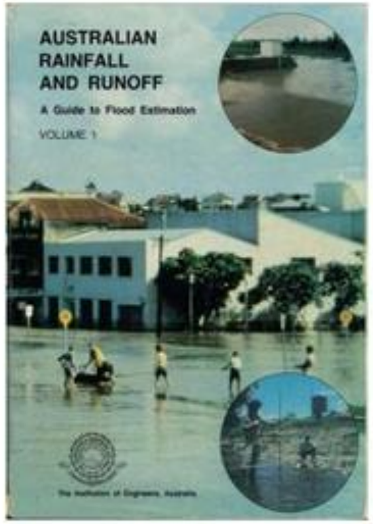
History

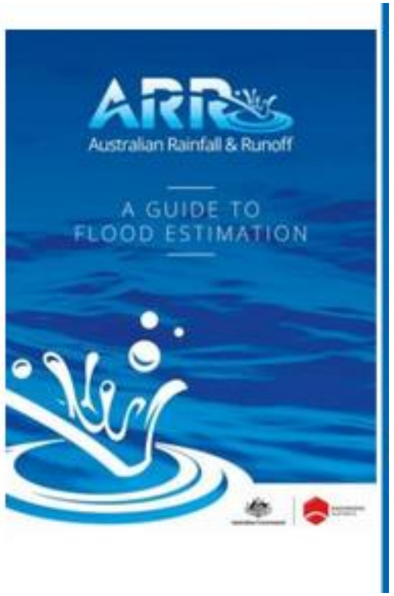
Australian Rainfall & Runoff

- 1958 (version 1)
- 1977 (version 2)
- 1987 (version 3)
- 1999 (version 3.1 update for extreme floods)
- 2016/2019 (version 4)









Big Changes In Practice

- Ensemble and Monte Carlo approaches to better capture variability
- Move away from simple burst approaches
- Less reliance on the rational method
- RFFE method
- Incorporation of Climate change
- Incorporation of blockage of hydraulic structures

Key changes in ARR design inputs

Design Input	ARR 1987	ARR 2016
Intensity Frequency Duration (IFD)	Used BoM rainfall gauges Presented as static A2 maps	Uses BoM and other agency gauges Online
Areal Reduction Factors (ARF)	Based on USA data Not available for long durations	Based on Australian data
Losses	Based on jurisdictional based advice (personal communication only)	National advice for rural and urban catchments
Baseflow	Methods but no ungauged catchment advice	Australia wide advice
Temporal Patterns	Average Variability Method Peak Burst Patterns for less than 30 year average recurrence interval (ARI) and rarer than 30 year ARI	Temporal patterns based on historic records, multi pattern for each design quantile and complete storms, with pre burst considered.

ARR 2019 Changes to Terminology

- How we use probability terms.
- Difference between design and actual events.
- Uncertainty.

Terminology

- Probability concepts are fundamental to the flood estimation problem.
- Effective communication of the concepts is essential for understanding and acceptance.
- Concerns with terminology cover.
    - Clarity of meaning.
    - Technical correctness.
    - Practicality and acceptability.

Clarity of Meaning

- Recurrence interval and return period are often misinterpreted by the community and even by technical experts.
- Floods occur randomly and years of above average flooding can be clustered.
- The average recurrence interval refers to the average occurrence, and not the period of time between occurrences.
- Therefore these terms are confusing and even possibly misleading.

Terminology

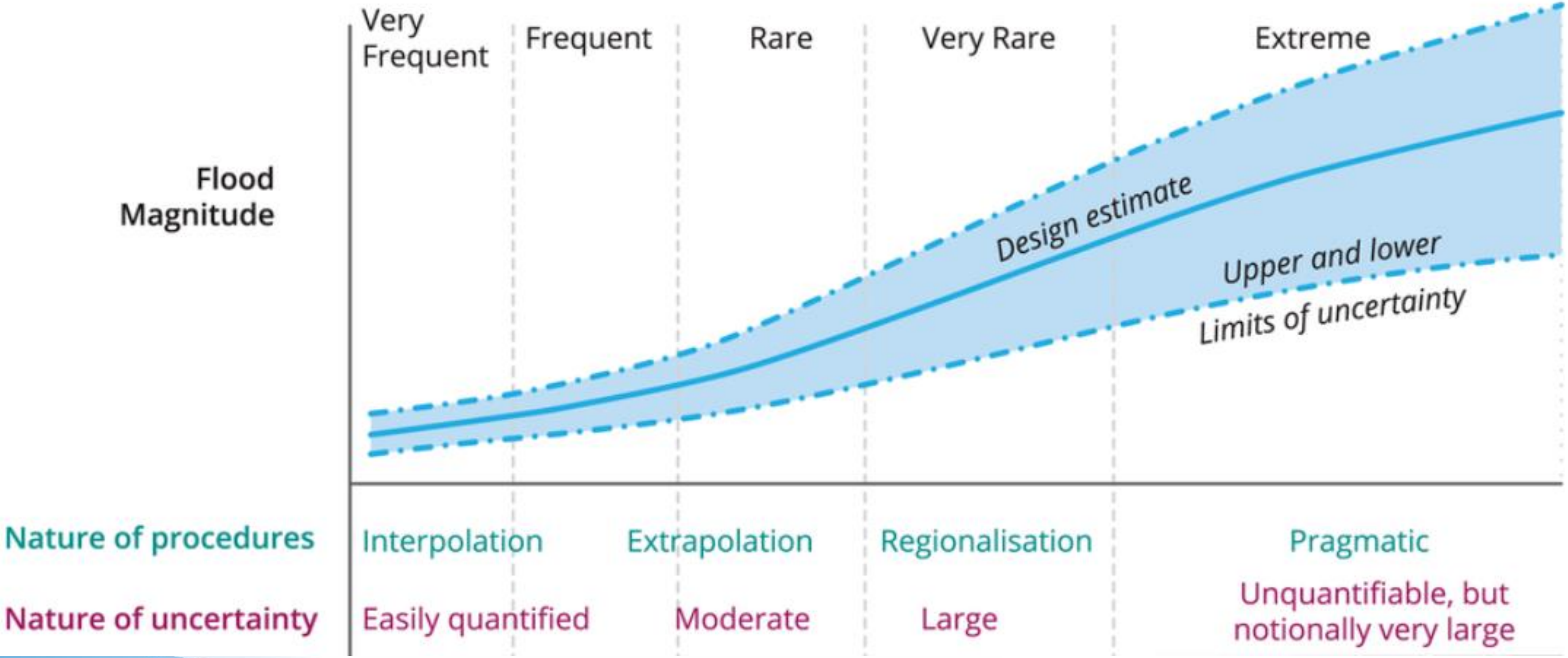
- Average Recurrence Interval (ARI) no longer recommended.
- Use Annual Exceedance Probability (AEP).
- Exceedances per Year (EY) for frequent events to deal with seasonality.
- Correct 1 in X AEP not 1 in X years AEP

Frequency Descriptor	EY	AEP (%)	AEP (1 in x)	ARI
Very Frequent	12			
	6	99.75	1.002	0.17
	4	98.17	1.02	0.25
	3	95.02	1.05	0.33
	2	86.47	1.16	0.5
	1	63.21	1.58	1
Frequent	0.69	50	2	1.44
	0.5	39.35	2.54	2
	0.22	20	5	4.48
	0.2	18.13	5.52	5
	0.11	10	10	9.49
Rare	0.05	5	20	19.5
	0.02	2	50	49.5
	0.01	1	100	99.5
Very Rare	0.005	0.5	200	199.5
	0.002	0.2	500	499.5
	0.001	0.1	1000	999.5
	0.0005	0.05	2000	1999.5
Extreme	0.0002	0.02	5000	4999.5
			↓	
			PMP/ PMP Flood	

Use of more recent methods and information

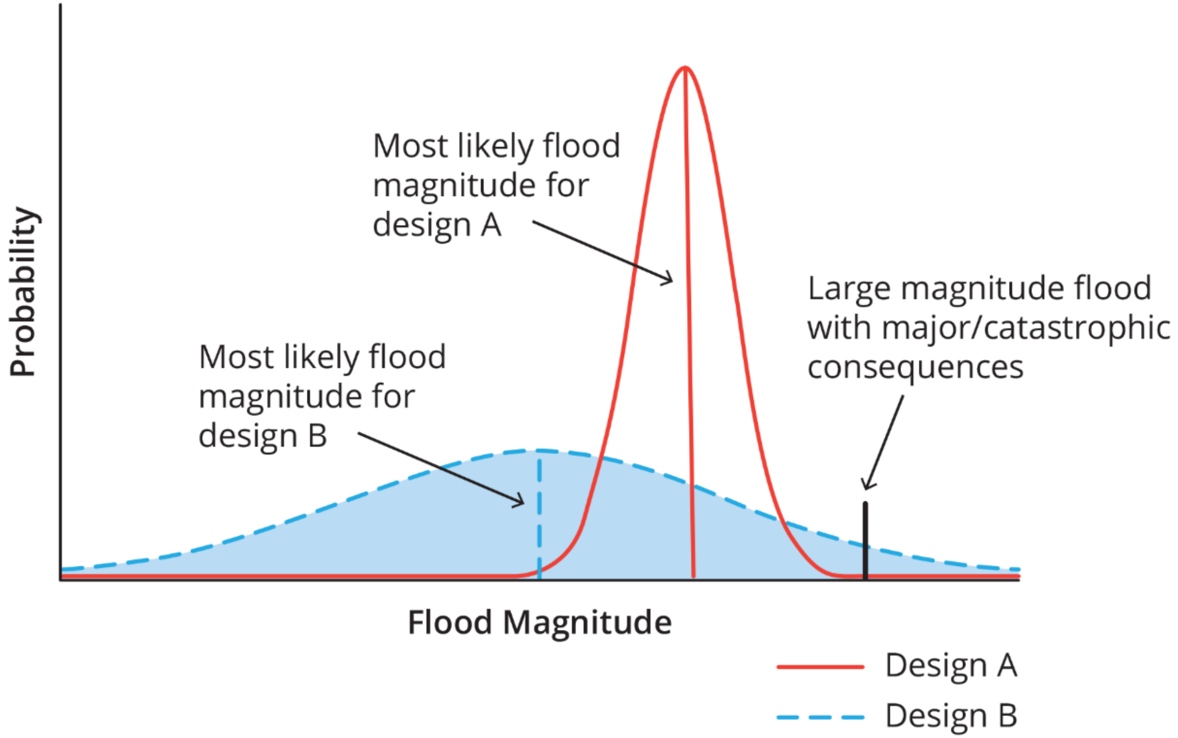
- In development of this guidance, it was recognised that knowledge and information availability is not fixed and that future research and applications will develop new techniques and information. This is particularly relevant in applications where techniques have been extrapolated from the region of their development to other regions and where efforts should be made to reduce large uncertainties in current estimates of design flood characteristics.
- Therefore, where circumstances warrant, designers have a duty to use other procedures and design information more appropriate for their design flood problem. The authorship team of this edition of Australian Rainfall and Runoff believe that the use of new or improved procedures should be encouraged, especially where these are more appropriate than the methods described in this publication.

Frequency Descriptors & Uncertainty



Uncertainty

- Formally acknowledge the uncertainty inherit in design methods
- Recommends the use of alternative methods
- Use risk based design not just probability based

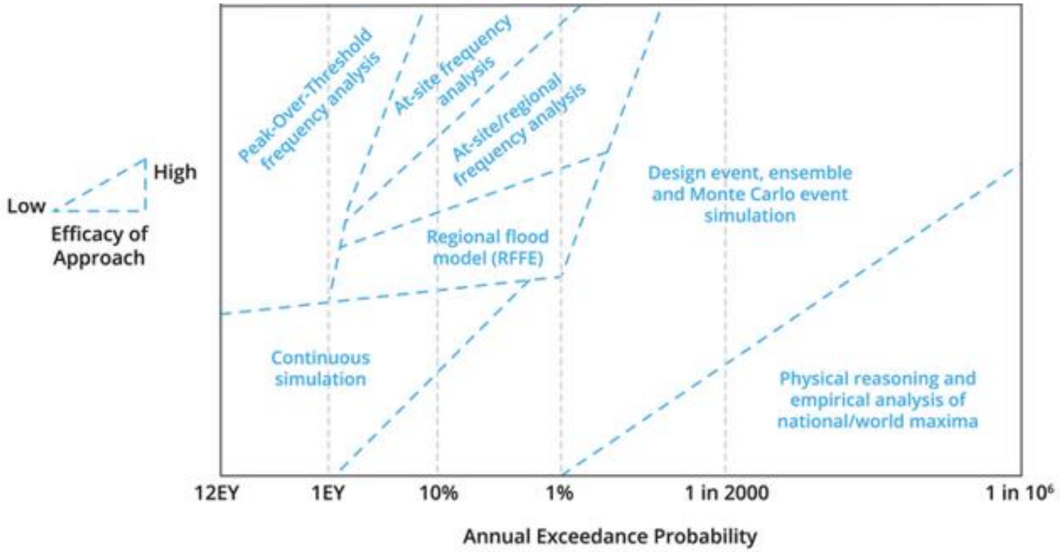


Update Of Existing Studies

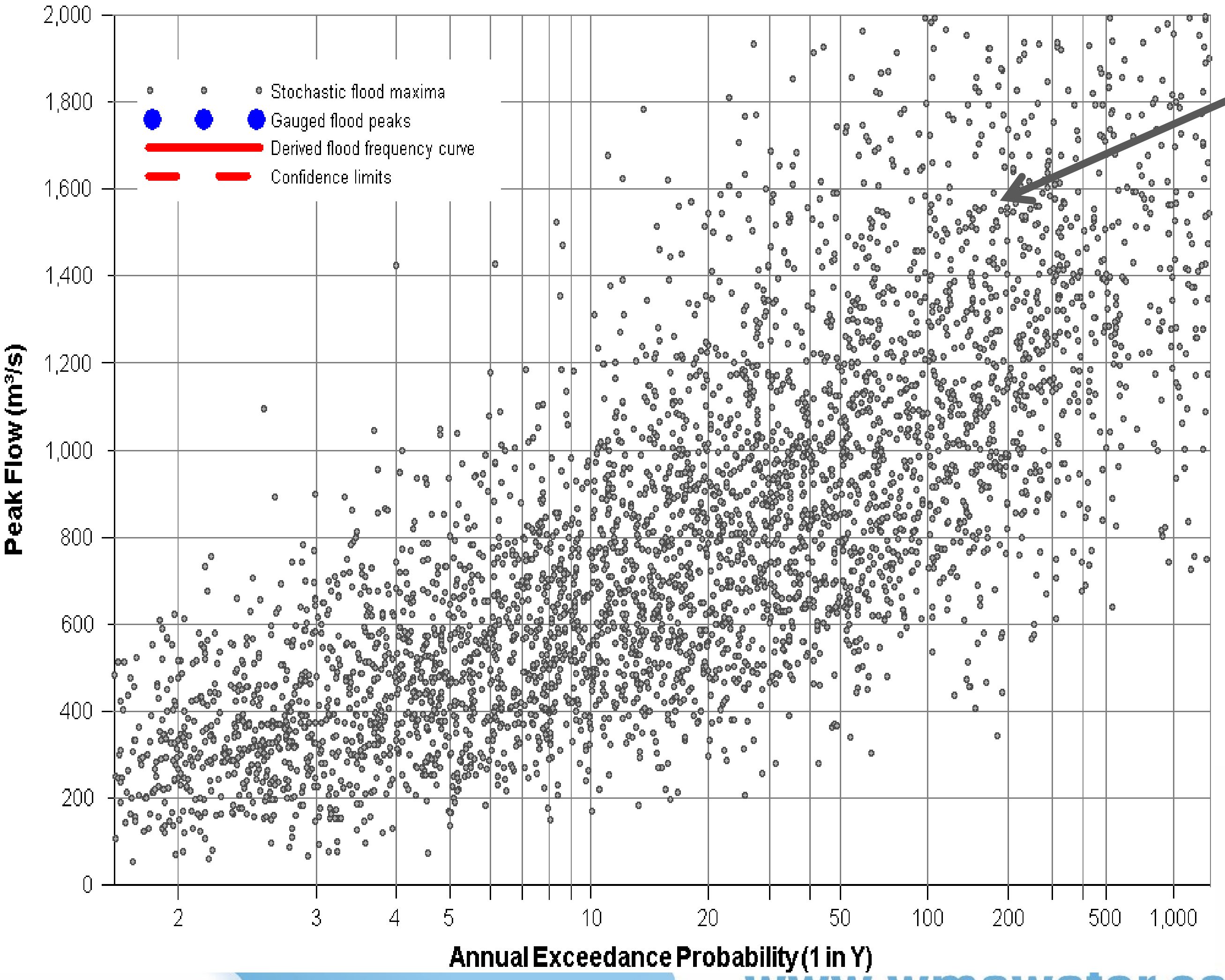
- With the publication of ARR 2019, do existing studies need to be updated (immediately)?
- Not necessarily.
- This is particularly the case where flood frequency analysis has been used and where there is adequate calibration data.
- Results from ARR 2019 should be more reliable and defensible than those that have used ARR 1987.
- Each case should be reviewed however to confirm the expected changes.

Approaches

- Two main classes of estimation methods:
  - Flood-data based
  - Rainfall based
- Each class of methods has variety of approaches
- ARR Book 1 Ch 3 describes which method is best suited for which purpose

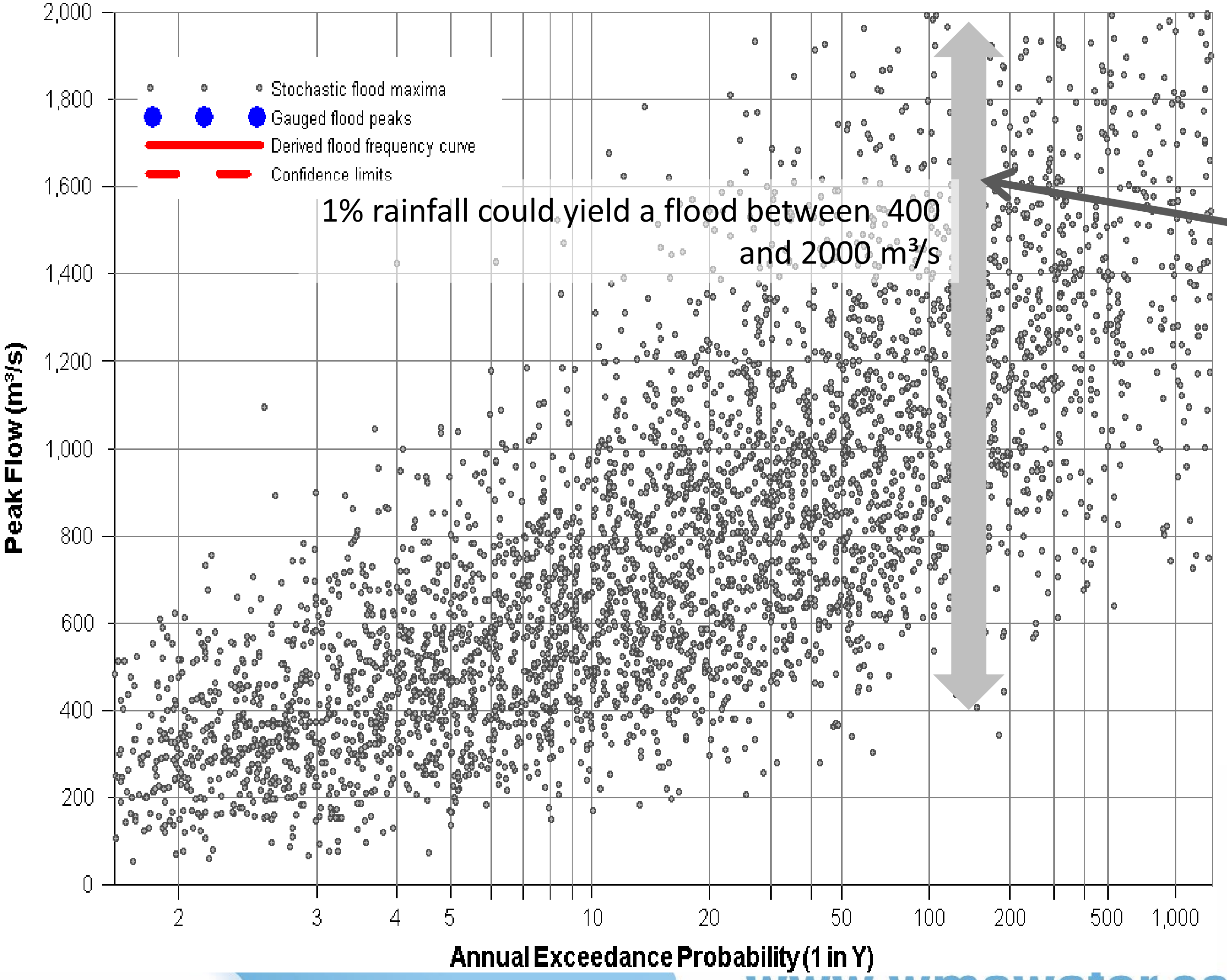


The Nature Of The Problem



Possible flood peaks resulting from rainfall of a given AEP

The Nature Of The Problem



- Possible flood peaks resulting from rainfall of a given AEP

- Wide range due to variation in antecedent conditions, losses, temporal patterns, spatial patterns

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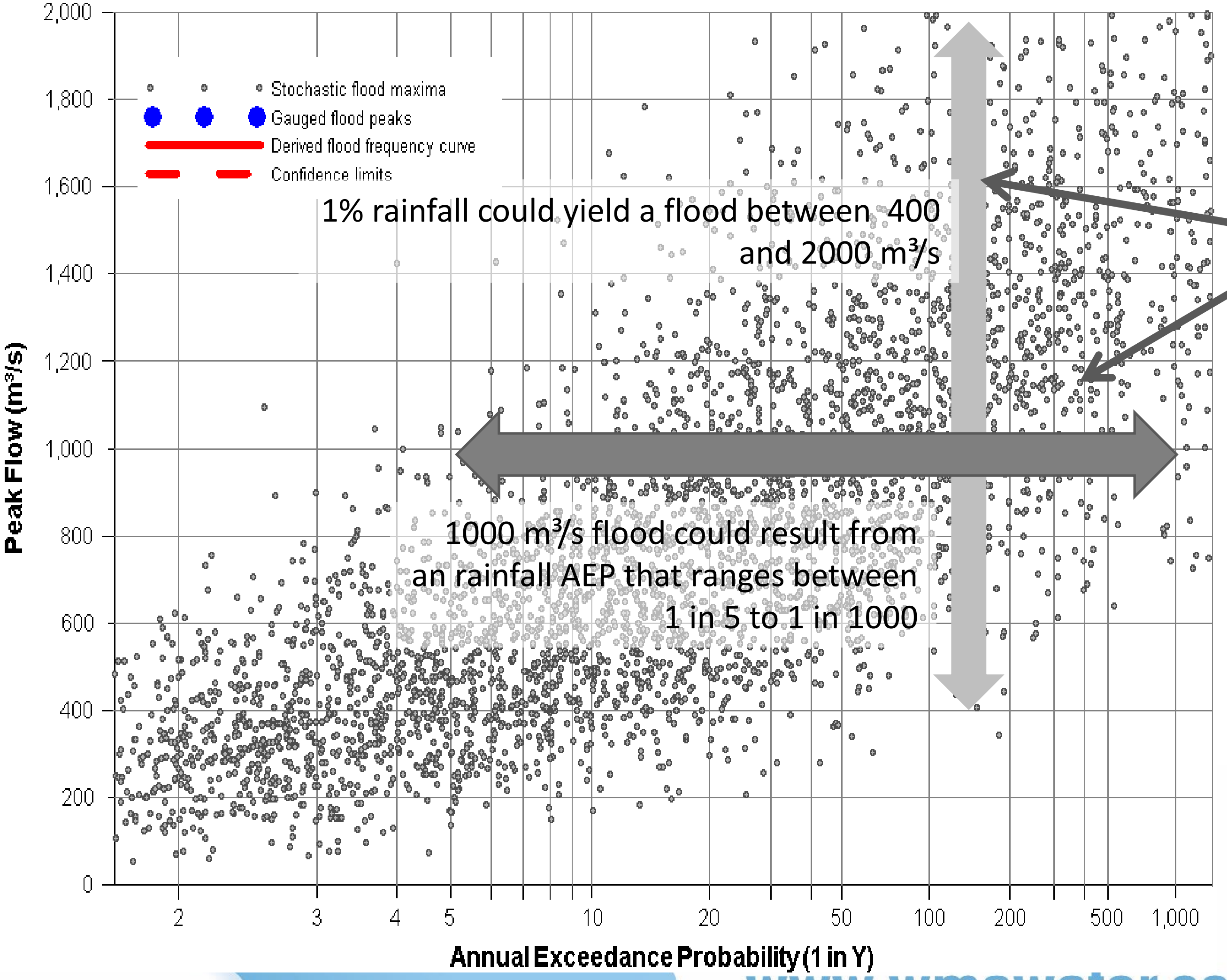

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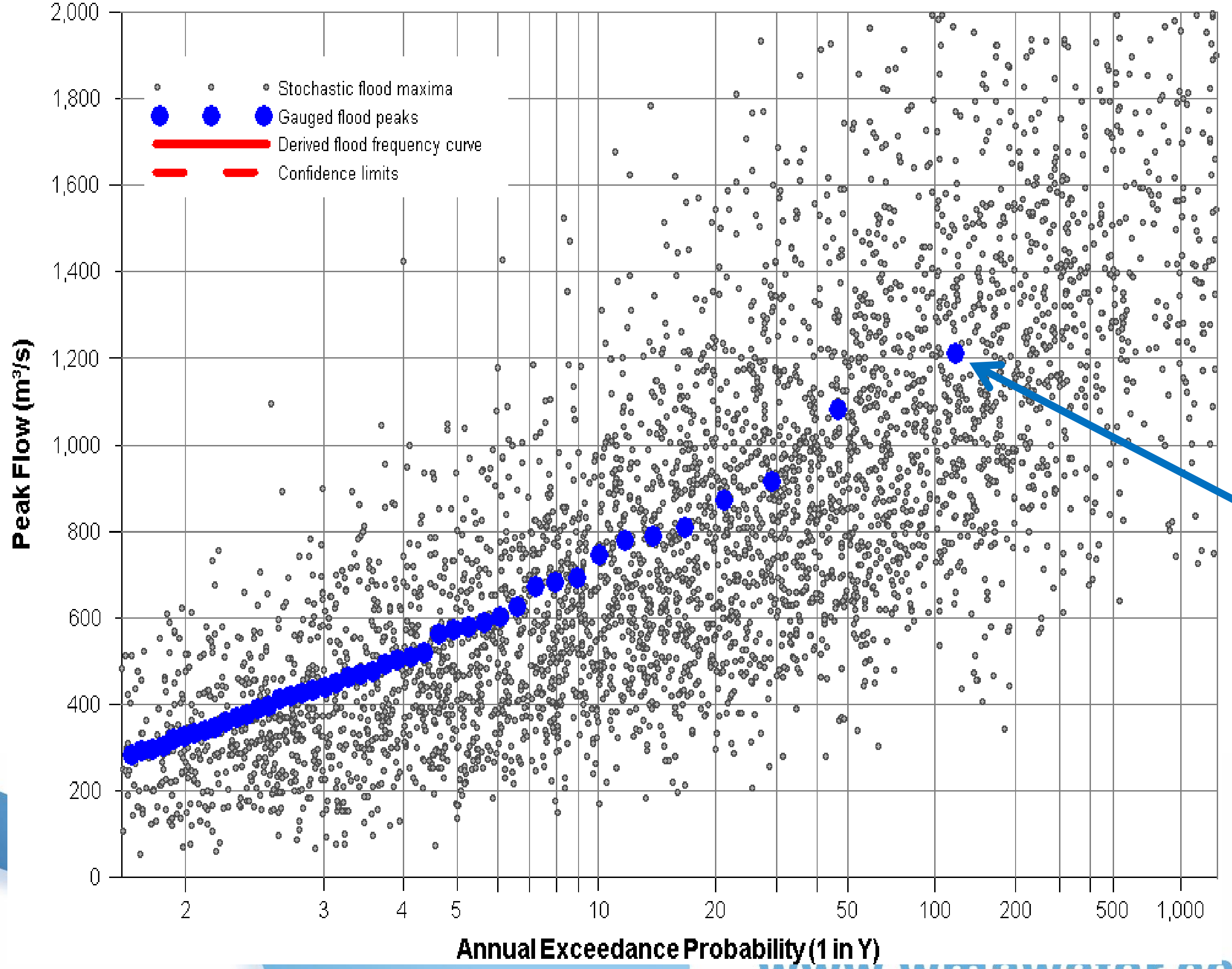

- Possible flood peaks resulting from rainfall of a given AEP

- Wide range due to variation in antecedent conditions, losses, temporal patterns, spatial patterns

- Annual flood maxima from gauged record

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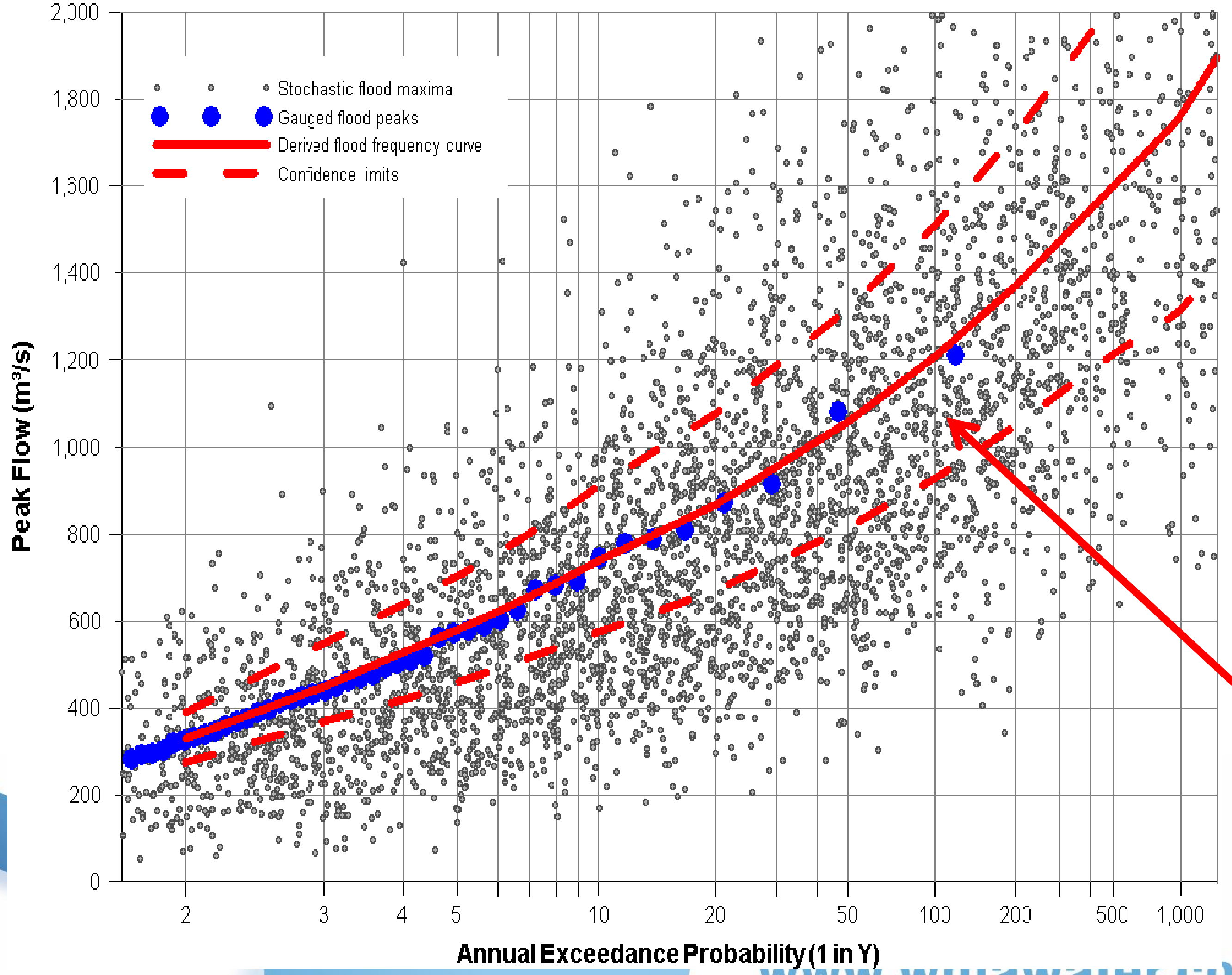
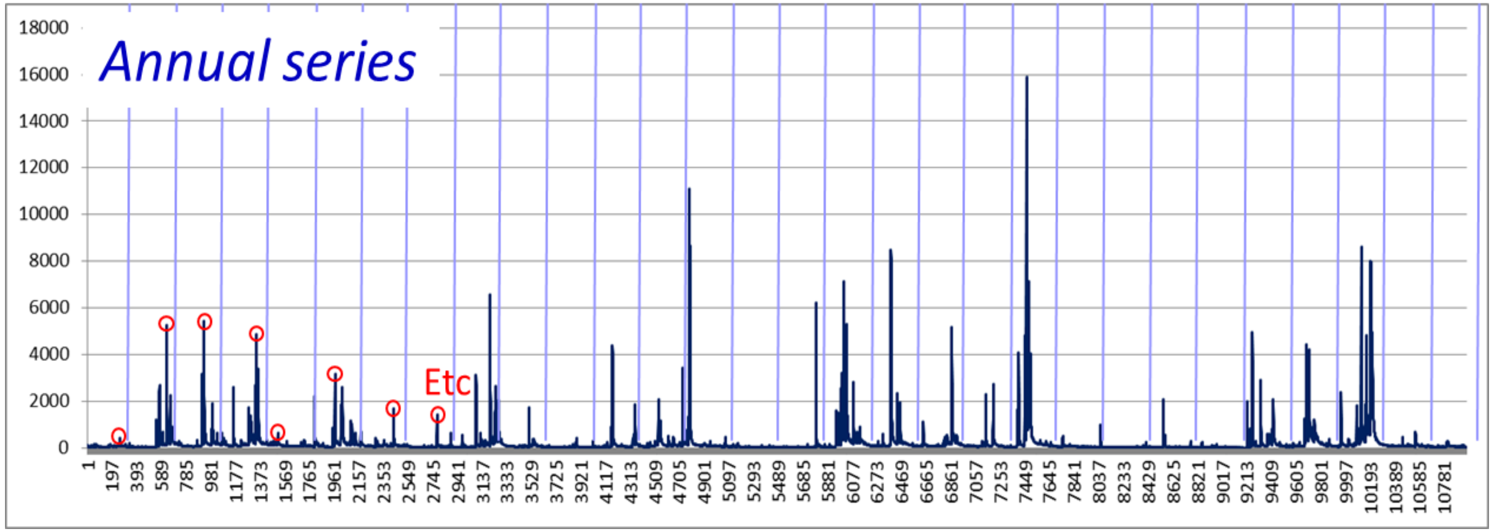


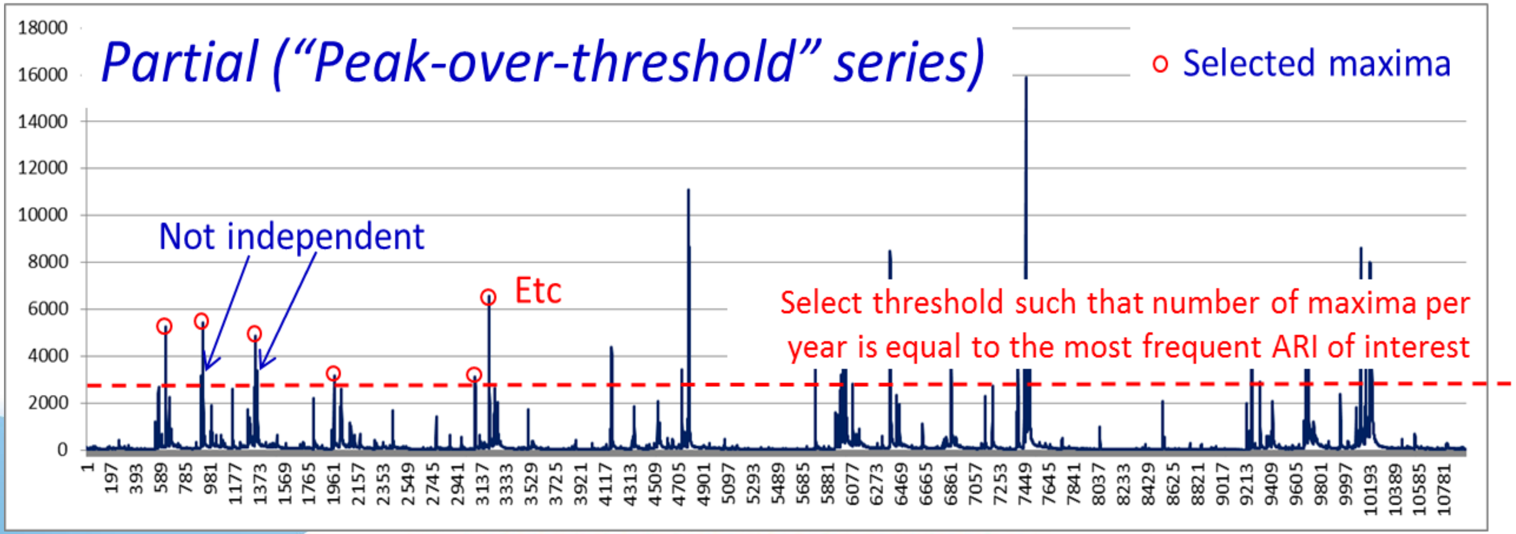
- Possible flood peaks resulting from rainfall of a given AEP
- Wide range due to variation in antecedent conditions, losses, temporal patterns, spatial patterns
- Annual flood maxima from gauged record
- Best estimate of probability model fitted to annual maxima .. with confidence limits

Basic Approaches

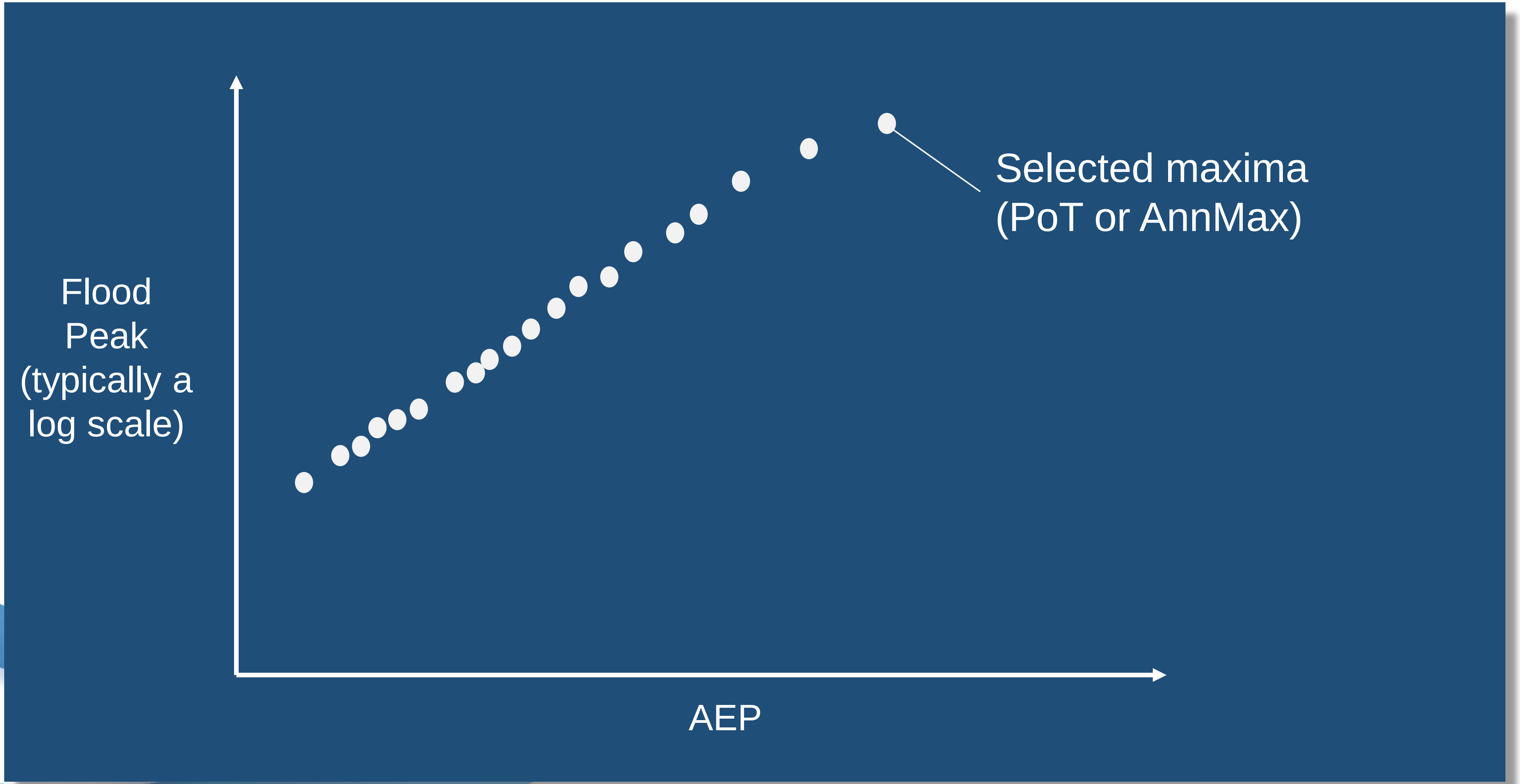
- Flood data based procedures (Book 3)
  - Partial series analysis (Book 3, Ch 2)
  - At-site frequency analysis (Book 3, Ch 2)
  - Regional flood procedures (Book 3, Ch 3)
- Rainfall based procedures (Books 4, 5)
  - Event-based simulation (Book 4, Ch 3)
    - Simple design event, ensemble, Monte Carlo
  - Continuous simulation (Book 4, Ch 3.3)

Sampling of Maxima





Fitting A Distribution



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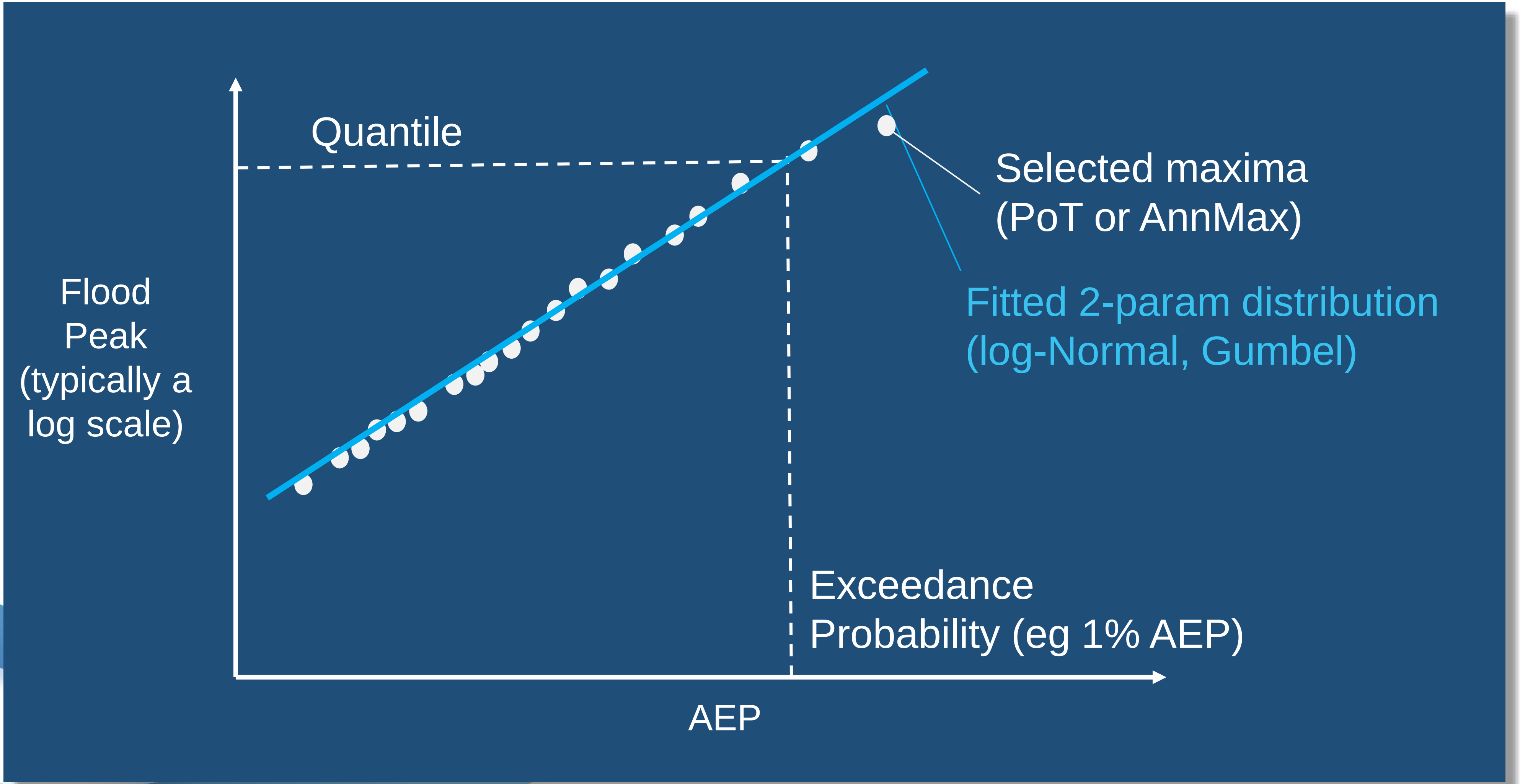

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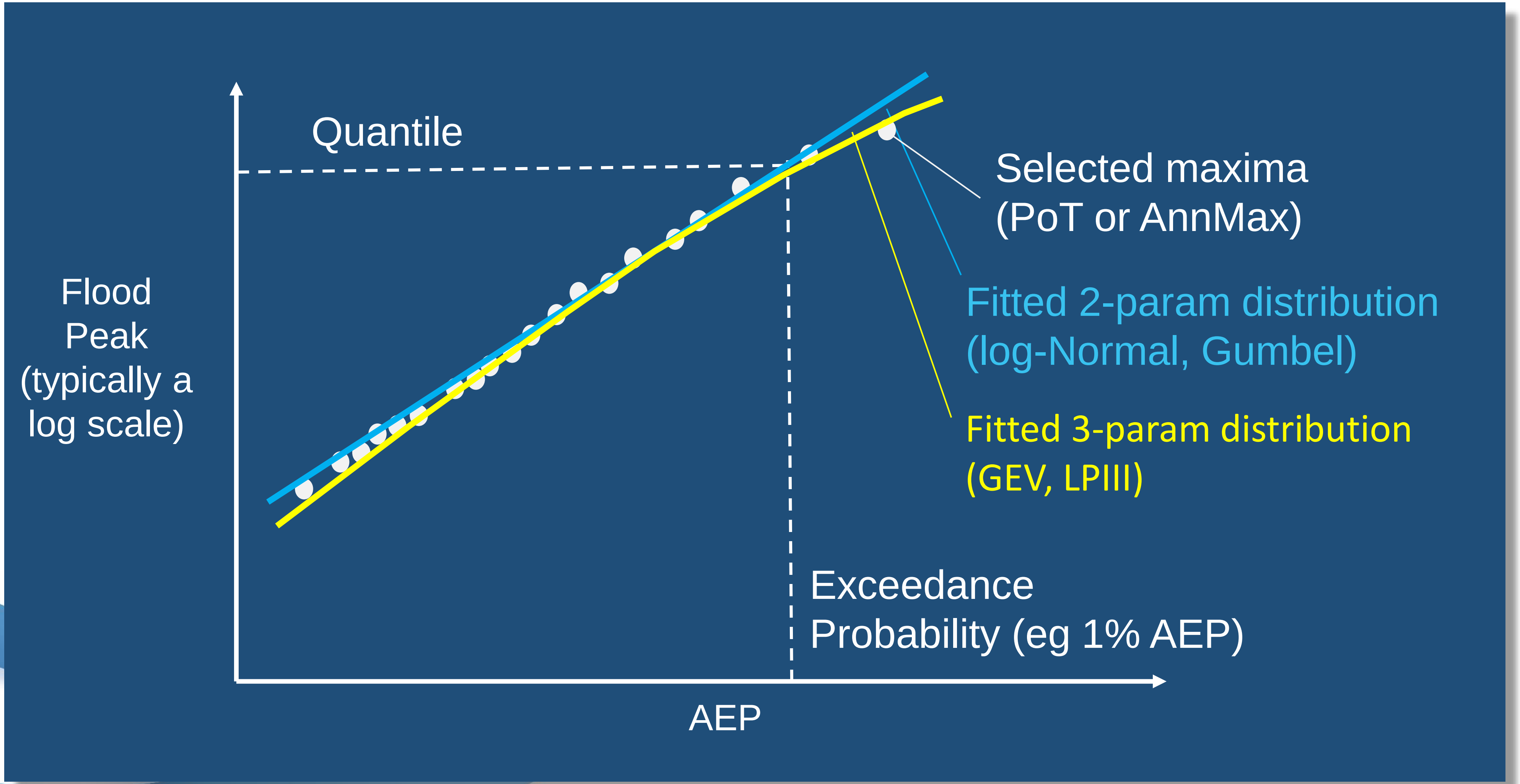


Extrapolation rule of thumb: limit extrapolation to twice record length

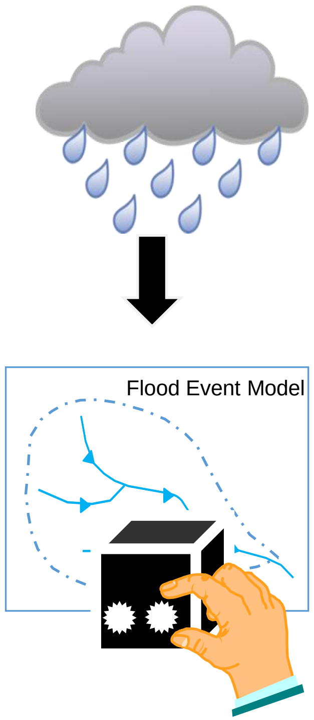
Rainfall-based Methods

Rainfall (infilled and distributed in time and space over whole catchment) – historic or “design”

Rainfall-based Methods

Rainfall (infilled and distributed in time and space over whole catchment) – historic or “design”

Fit (or adopt) parameters of a suitable flood event model



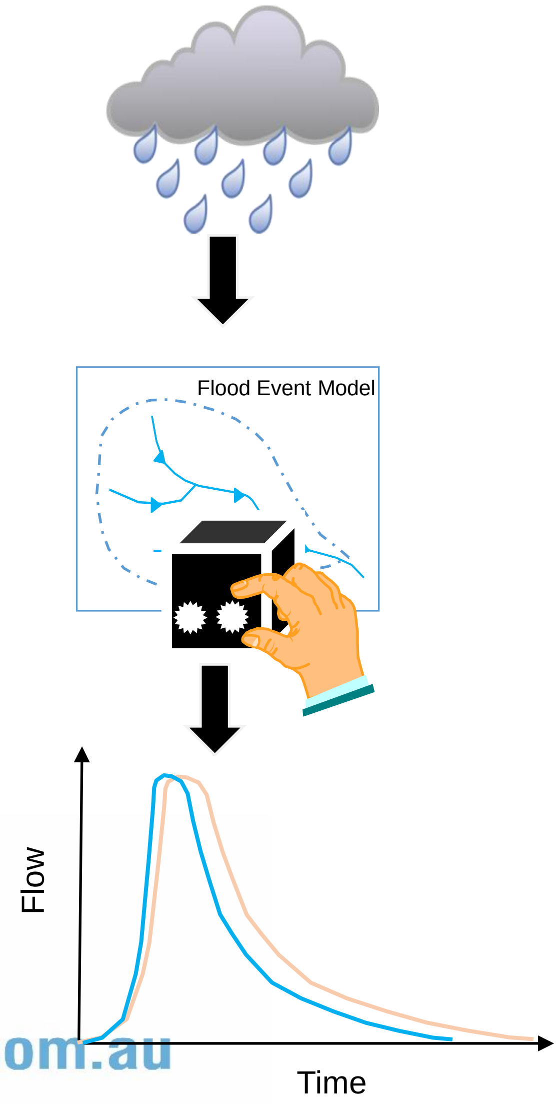
Rainfall-based Methods

Rainfall (infilled and distributed in time and space over whole catchment) – historic or “design”

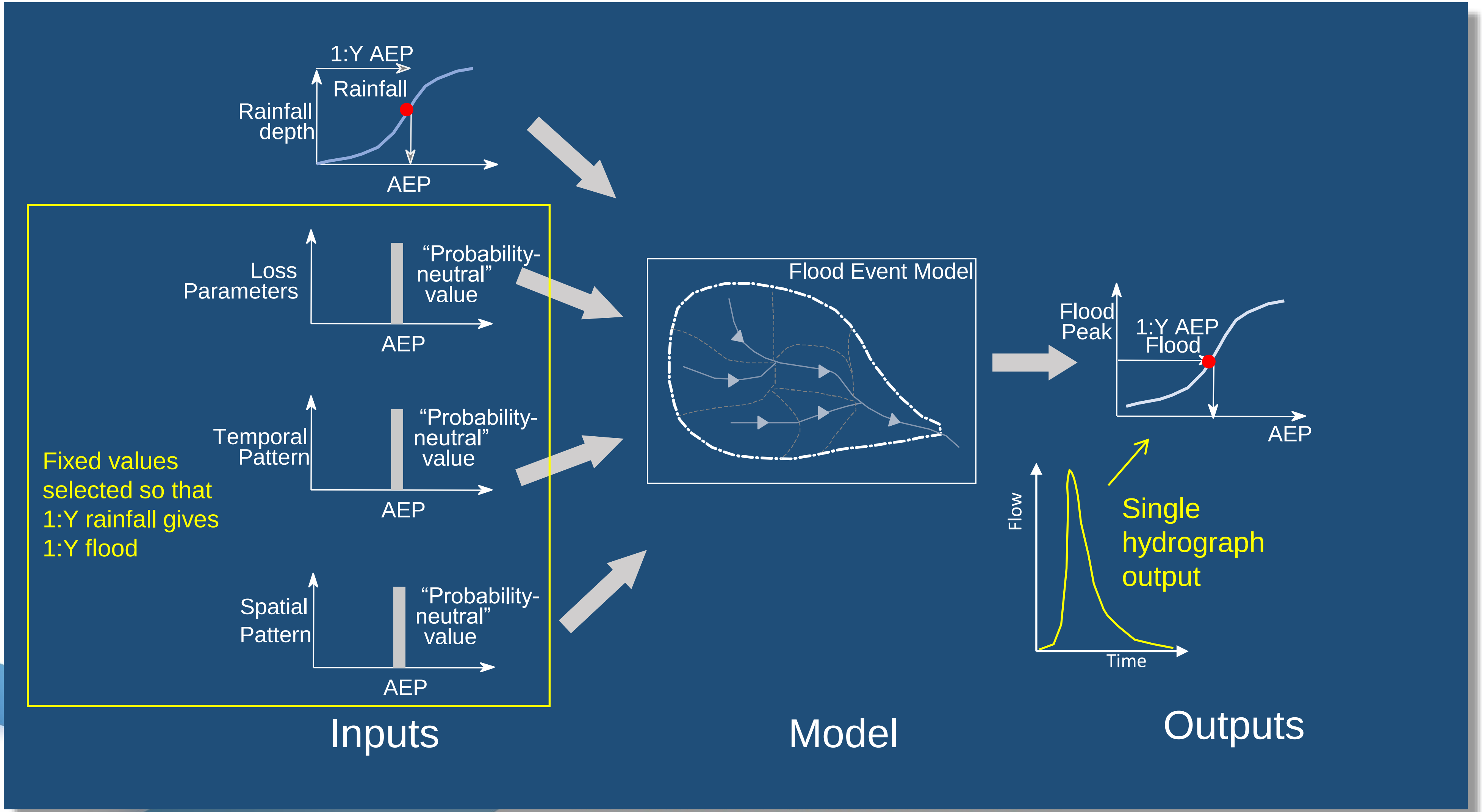
Fit (or adopt) parameters of a suitable flood event model

Calibration: obtain match between historical and simulated flood hydrographs

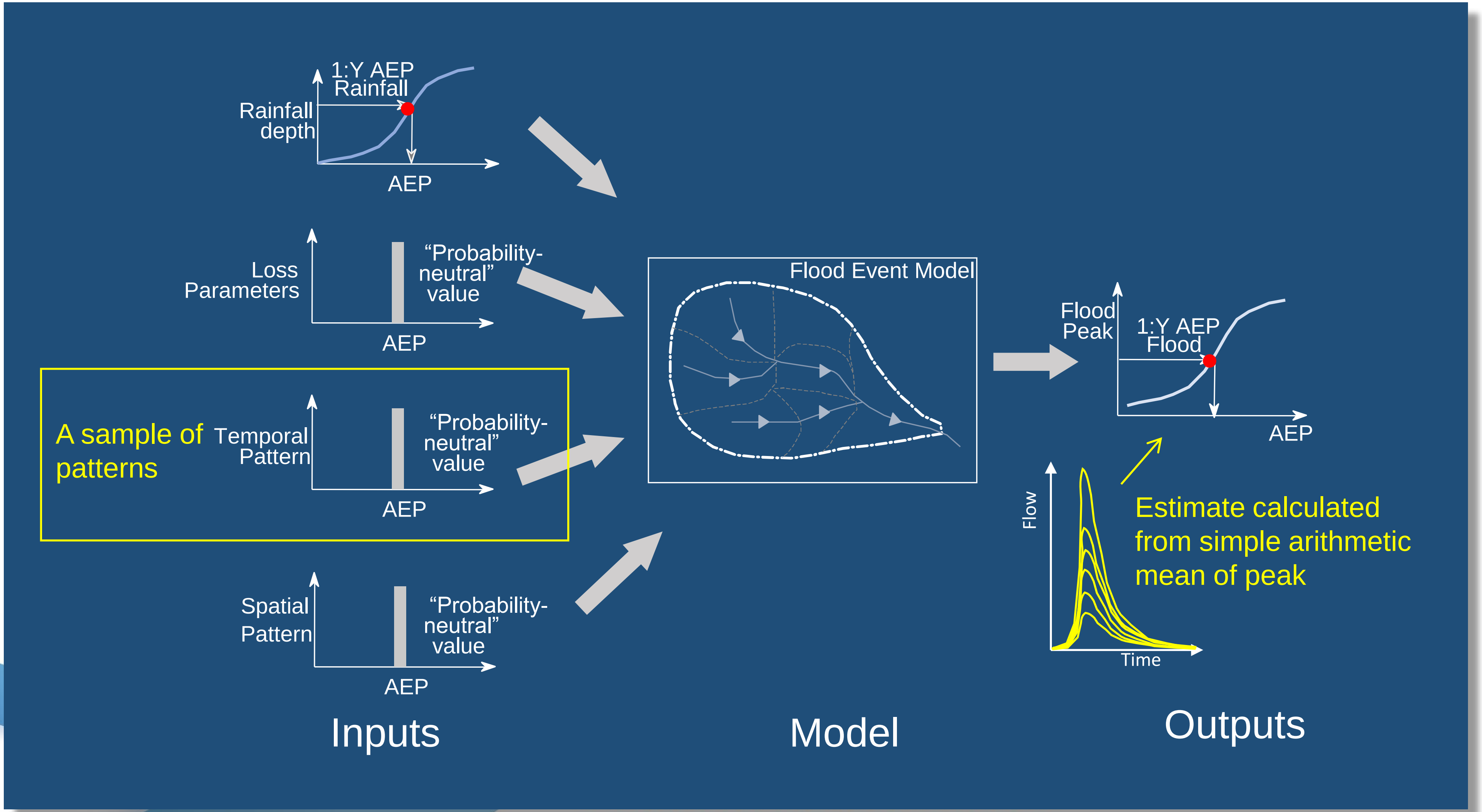
Design: simulate hydrographs for different AEPs



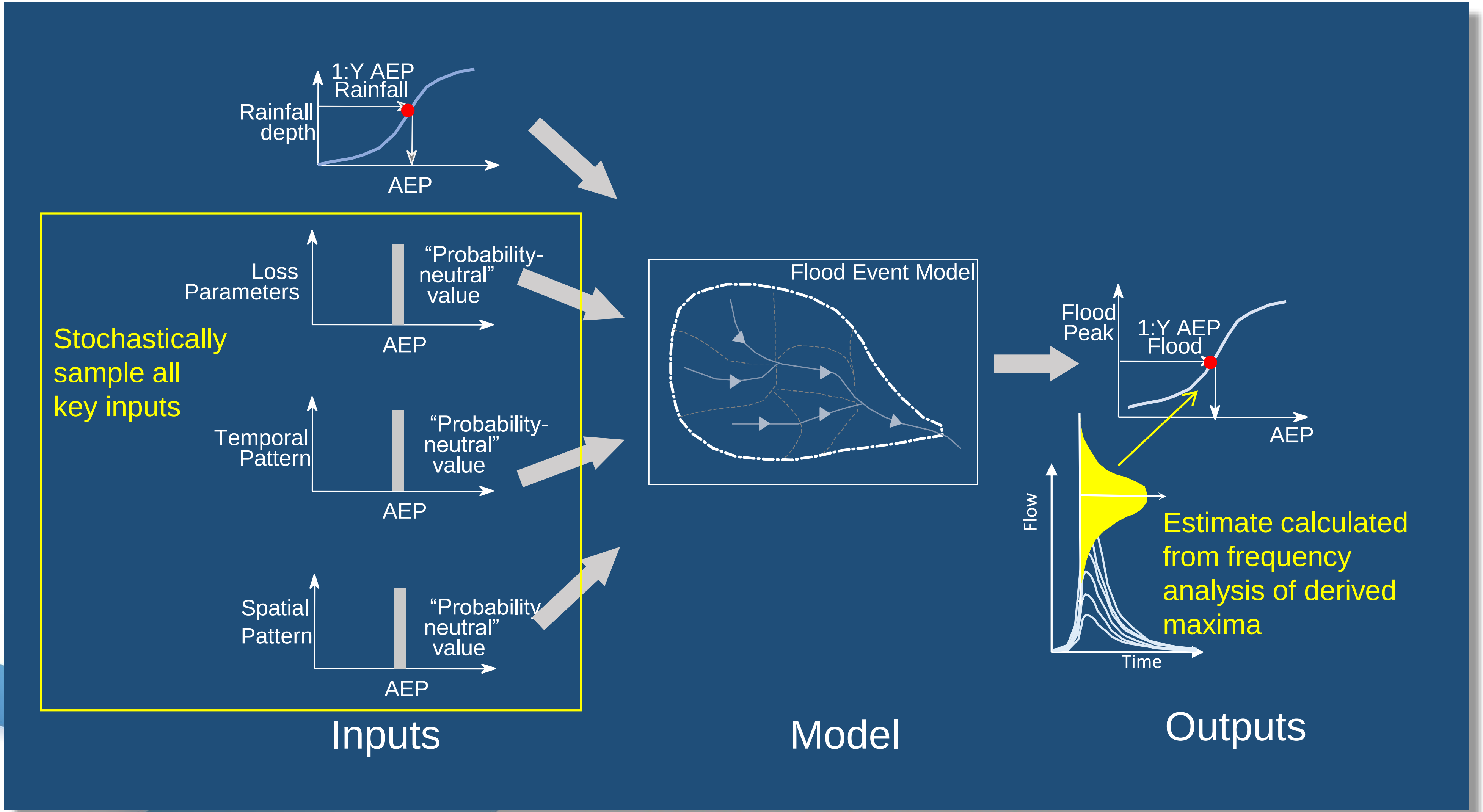
Simple Event Approach



Ensemble Event Approach



Monte Carlo Event Approach



Rainfall-based Procedures

	Simple Event	Ensemble Event	Monte Carlo Event	Continuous Simulation
Hydrologic Inputs	Design rainfalls (ie rainfall depth for given burst duration and annual exceedance probability)			Observed (or synthetic) time series of rainfall and evaporation
Hydrologic variability	Fixed patterns of rainfall and other inputs	Ensemble of *N* temporal patterns	Ensemble (or distribution) of temporal patterns, losses, and other factors.	As represented in the time series of inputs – if not in time series then not represented
Model	Event-based model based on routing rainfall excess through catchment storage (see Book 5 for details of technique)			Model of catchment processes influencing runoff generation
Framework	Single simulation for each combination of rainfall depth and AEP	*N* simulations for each combination of rainfall depth and AEP (N≈10)	Stochastic sampling of input distributions using continuous or stratified domain (potentially thousands of simulations)	Continuous simulation at time step for *N* years
Flood AEP	Assumed same as input rainfall		Statistical analysis of joint probabilities (eg frequency analysis of maxima or Total Probability Theorem)	Computed from frequency analysis of *N* annual maxima
Flood magnitude	Single estimate derived from each set of inputs	Simple average (or median) of *N* simulations		
ARR guidance	Book 4, Sect 3.2.2	Book 4, Sect 3.2.3	Book 4, Sect 3.2.4	Book 4, Sect 3.3

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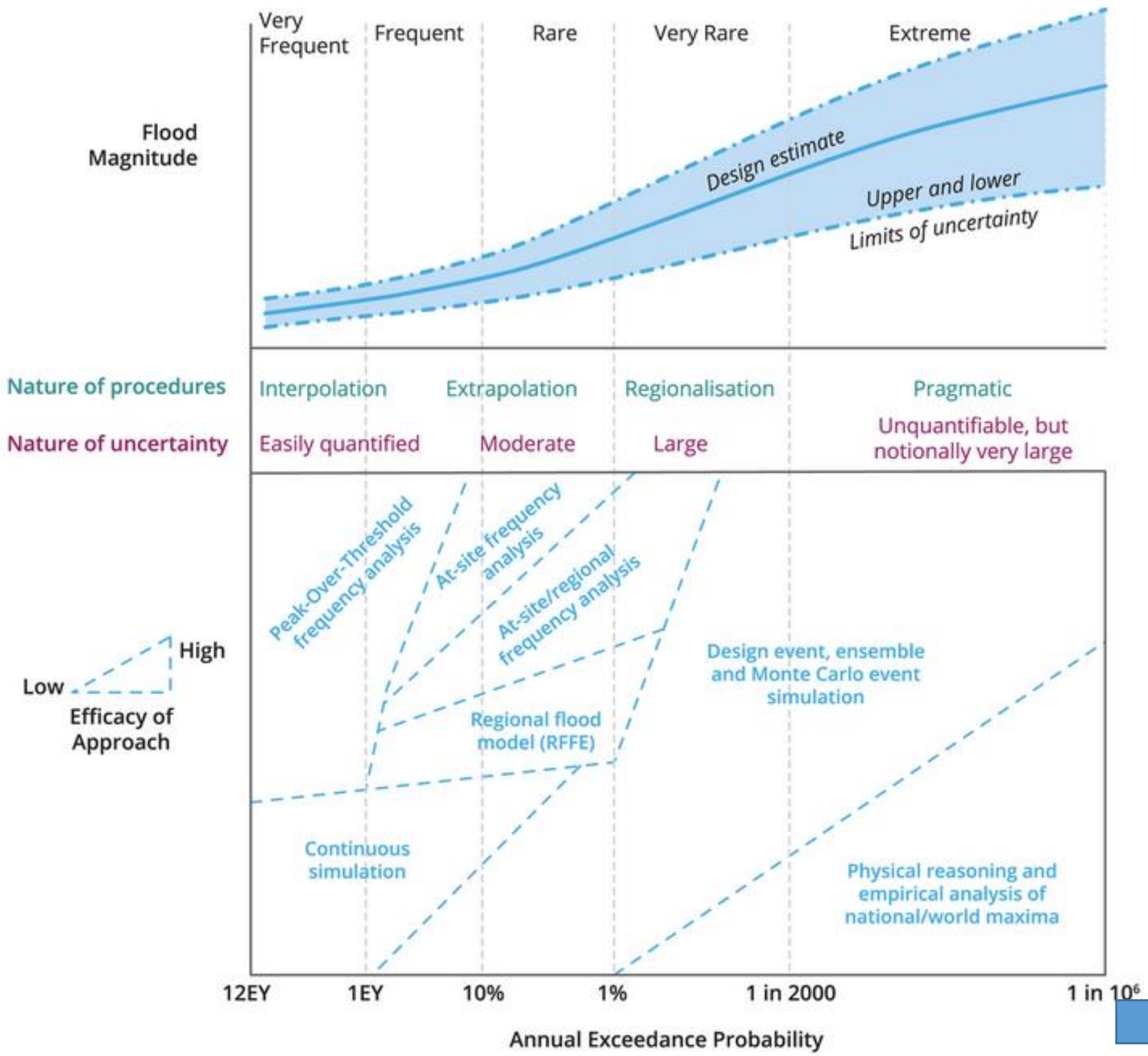
Summary Of Applicability Of Rainfall-based Procedures

Method	Advantages	Limitations	Comments on Applicability
Continuous simulation	• Well suited to assessing flood risk in complex systems that are sensitive to flood volume • Most applicable to range of very frequent to frequent events	• Difficult to parameterise model to correctly reproduce the frequency of flood exceedance in manner that adequately captures shape of observed hydrographs	• Useful for hindcasting streamflows for sites with short periods of record • Model parameters not easily transposed to ungauged locations
Design event	• Long tradition of use thus familiar to most practitioners	• Difficult to demonstrate that probability-neutrality is achieved	• Little justification to use this simplistic method with currently available computing resources, but suited to derivation of preliminary estimates.
Ensemble event	• Simple means of minimising probability bias for modest level of effort • Well suited to accommodating single source of hydrologic variability in simple catchments	• Not suited to considering multiple sources of hydrologic variability or other joint-probability influences • Difficult to determine if probability bias remains in the estimates	• Provides easy transition for practitioners familiar with design event method • The required sets of ensemble temporal patterns are now available
Monte Carlo event	• Rigorous means of deriving expected probability estimates for range of factors considered • Readily extended to consider multiple sources of variability and additional joint-probability factors (both anthropogenic and natural)	• Requires specialist skills to develop bespoke solutions and thus dependent on availability of software • For more complex applications care needs to be taken to ensure correlations between dependent factors are appropriately considered	• Non-dimensional loss distributions and temporal pattern ensembles are now available • The expected probability estimates account for hydrologic variability not parameter uncertainty as the necessary information on governing distributions is generally not available.

Relevance of different approaches



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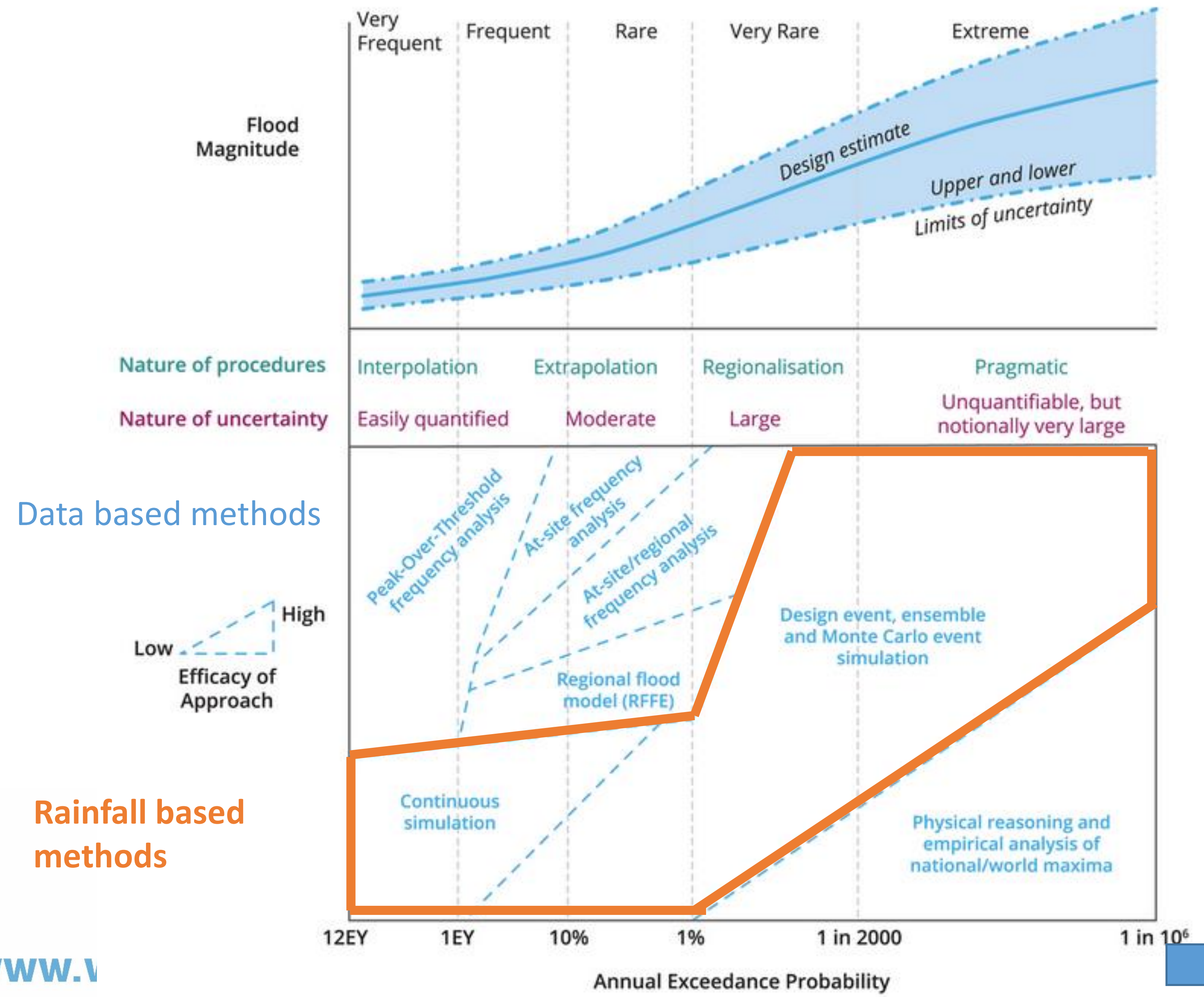
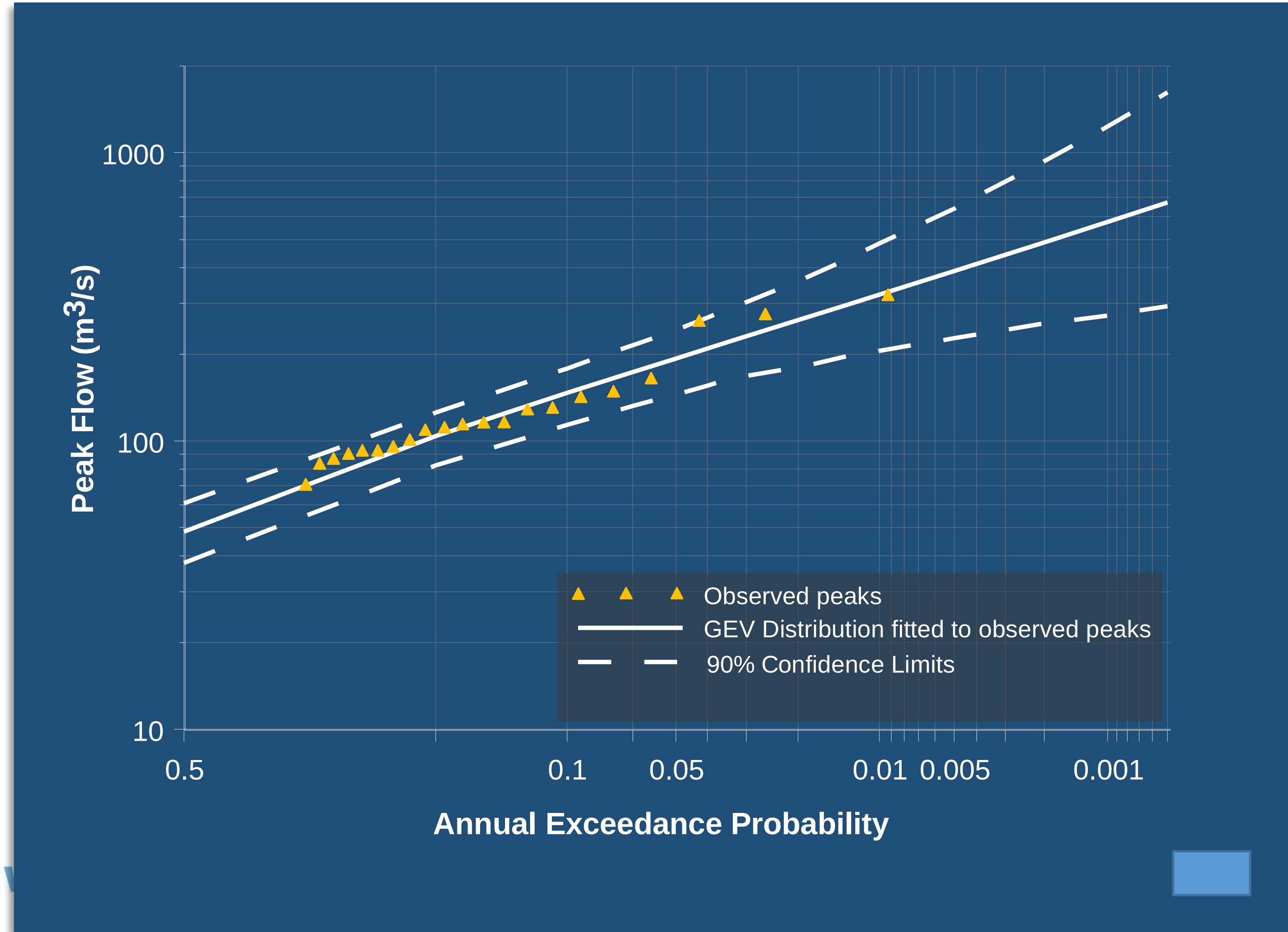
Relevance of different approaches



Reconciliation And Adoption Of Best Estimate

- Compare and reconcile estimates from different methods



Reconciliation And Adoption Of Best Estimate

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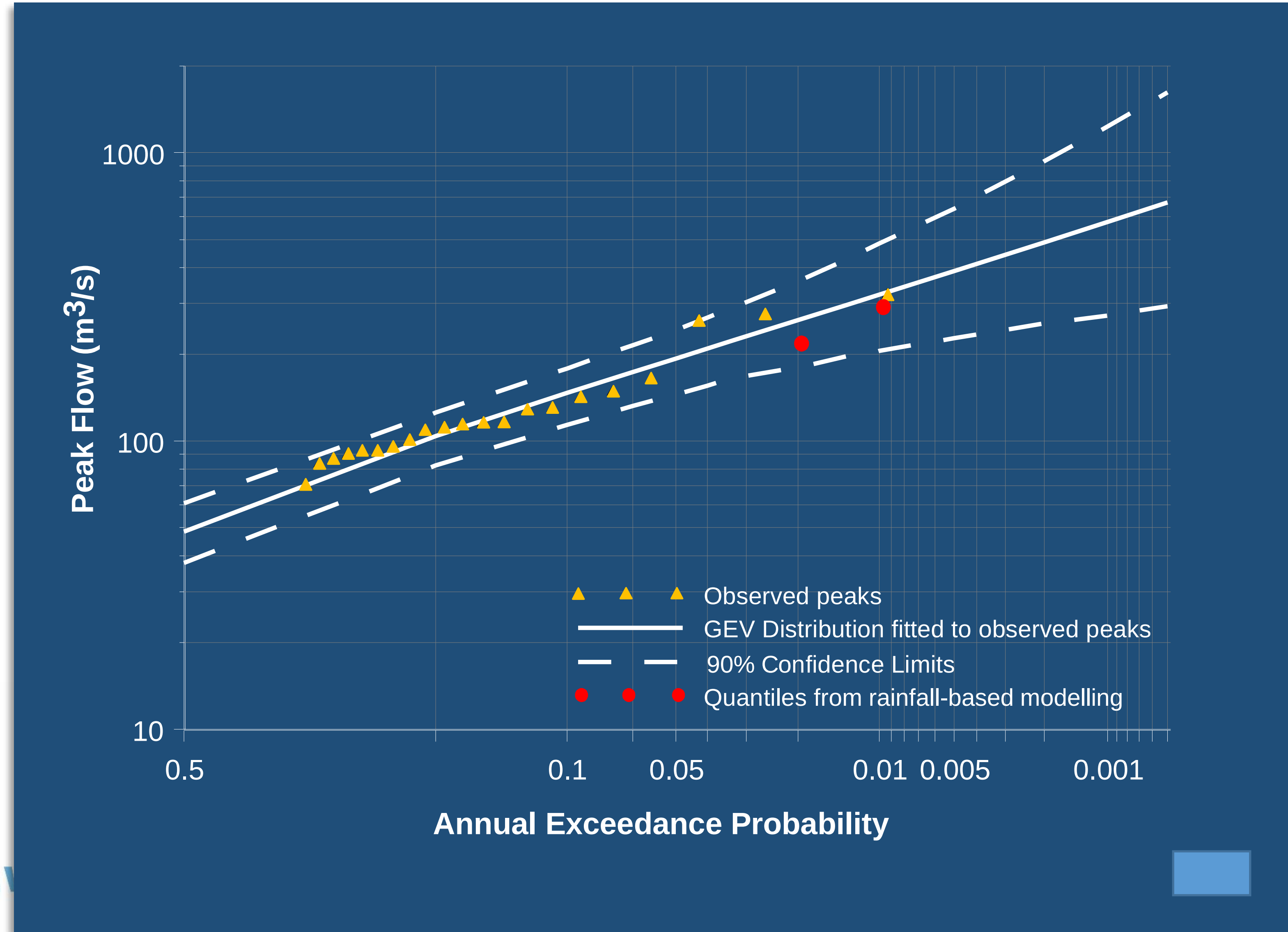

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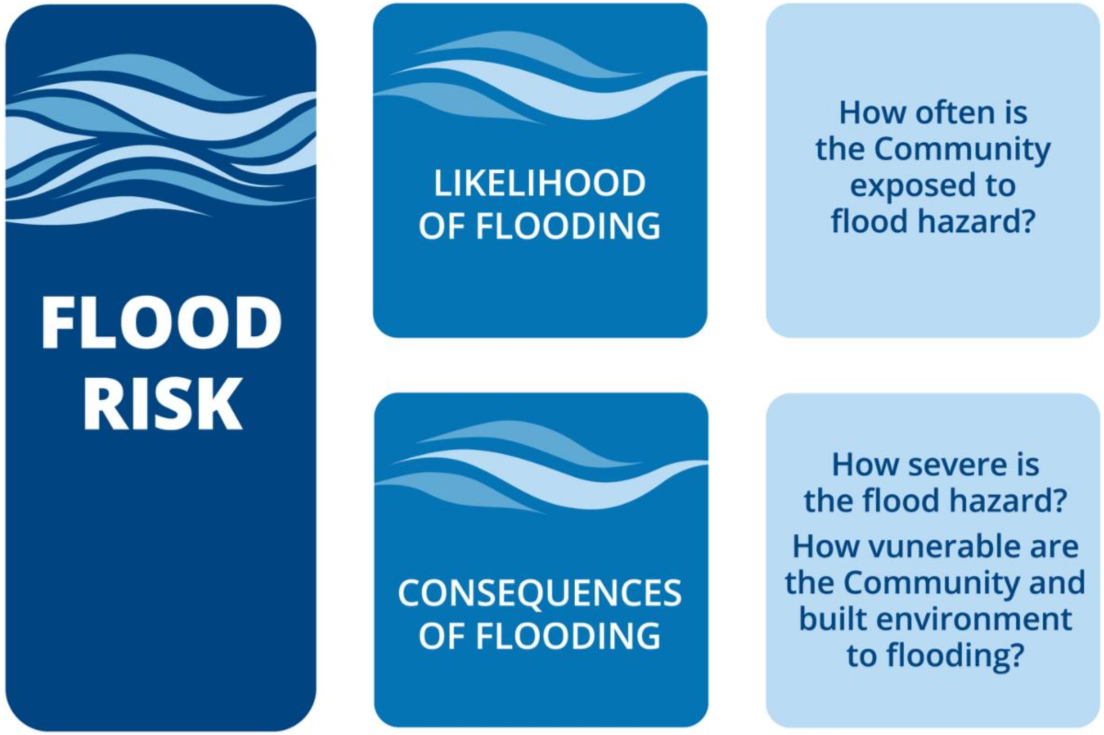
Data

- ARR 2019 places renewed emphasis on data

- ***"Practitioners need to utilise as much local information, even if this is anecdotal and limited, as possible to reduce this risk"***

Risk-based Design

- Industry is moving to risk based design and away from probability based design
- Flood risk results from human use of the floodplain
- Flood risk affects
  - Life safety
  - Assets and the economy
  - Community
  - Environment



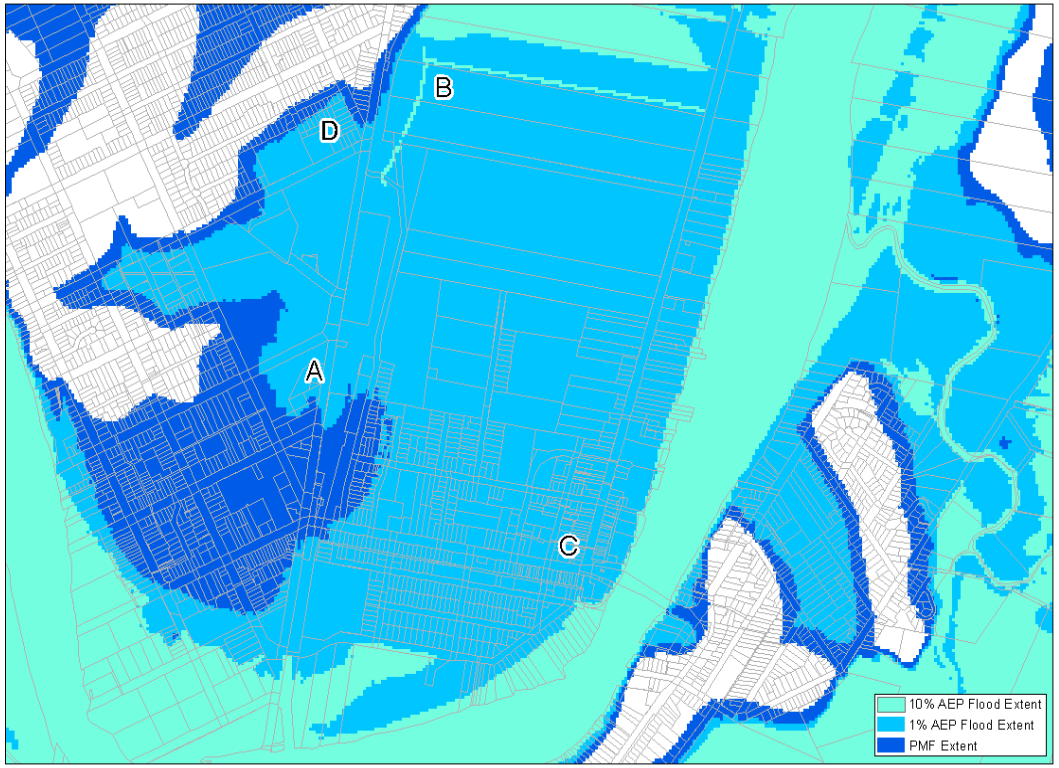
See Book 1, Chapter 5

Risk Analysis

Risk estimation leads to informed decision making

Systematic approach to understanding nature and level of risk:

- Probability of flooding
- Nature of the hazard (depth, velocity etc)
- Consequences



Standards Based Design

Managing risk by probability and restricting consequences

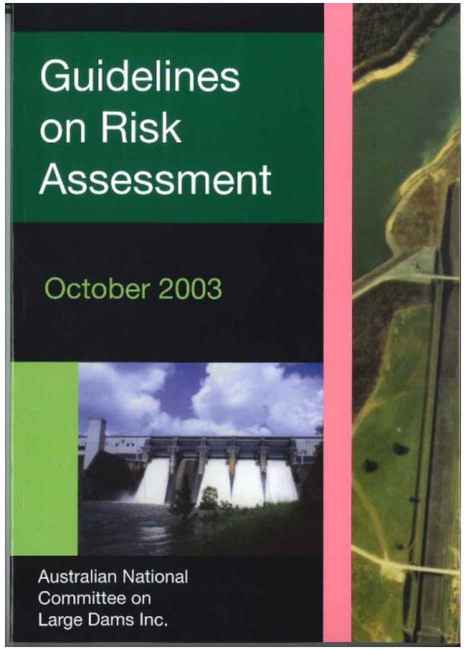
- 1% (1 in 100) floor and planning levels – most state and local authorities
- 0.05% (1 in 2000) bridge service life – Austroads
- Level of service – eg. Design of a road so that each crossing is open in a 1 in 50 AEP event

Problems With Design Standards

- Clusters consequences just above the standard – floor levels
- Does not consider residual risk
- Blunt tool – no consideration of costs or consequences

Risk Based Decision Making

- Examples of guidelines transitioning to risk based design:
- Dams – ANCOLD
- Short term structures
- Critical infrastructure



Climate Change

- ARR 1987 acknowledged the emerging understanding of climate change and associated risks
- National guidance provided based on advice from an expert group including CSIRO, BOM and various academic experts.

Climate change – Impacts on flooding

The major areas where climate change will impact flooding are:

- Design rainfall intensity-frequency-duration.
- Storm type, frequency and depth.
- Rainfall spatial and temporal patterns.
- Antecedent conditions.
- Changes in sea level.
- The joint probability of storm surge and flood producing rainfall.

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- Storm type, frequency and depth.
- Rainfall spatial and temporal patterns.
- Antecedent conditions.
- Changes in sea level.
- The joint probability of storm surge and flood producing rainfall.

Rainfall changes

- A warming climate leads to an increase in the water holding capacity of the air, which causes an increase in the atmospheric water vapour that supplies storms, resulting in more intense precipitation.
- Climate change is likely to increase the intense part of storms

Antecedent conditions

- Changes in the patterns of precipitation and evaporation will lead to changes in antecedent conditions prior to flood events, affecting soil moisture and thus loss rates in the catchment.
- Potential evaporation is projected to increase almost everywhere on a global scale due to an increase in the water-holding capacity of the atmosphere with higher temperatures combined with little projected change in relative humidity.

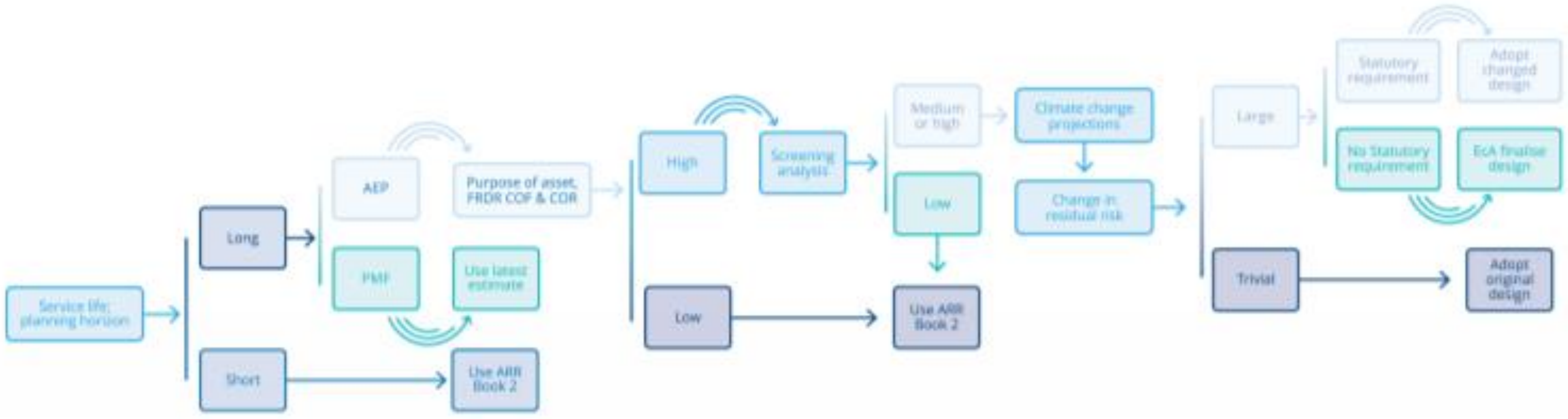
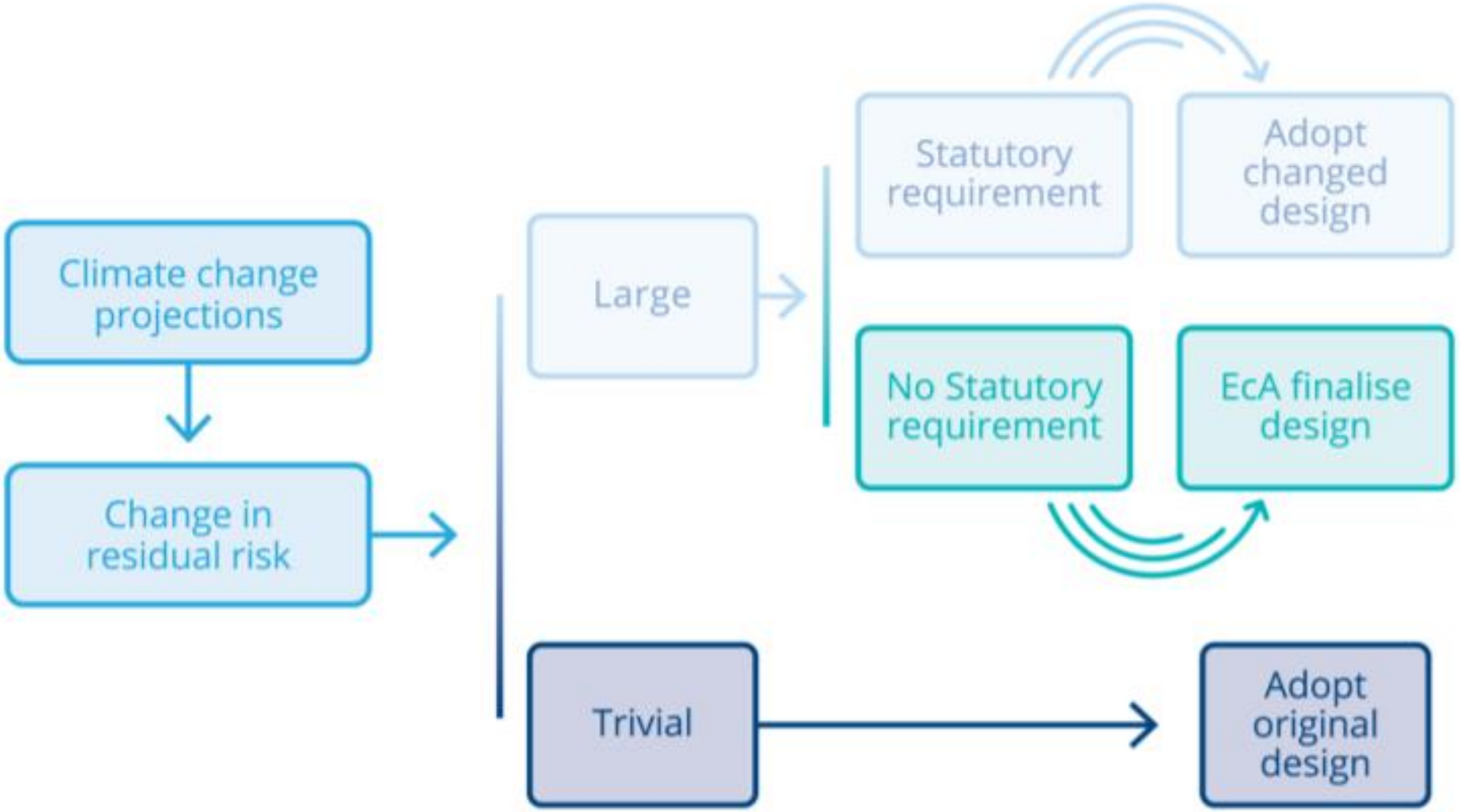


Figure 1.6.2. Decision Tree for Incorporating Climate Change in Flood Design


Climate change projections
Change in residual risk
Large
Statutory requirement
Adopt changed design
No Statutory requirement
EcA finalise design
Trivial
Adopt original design

NRM clusters

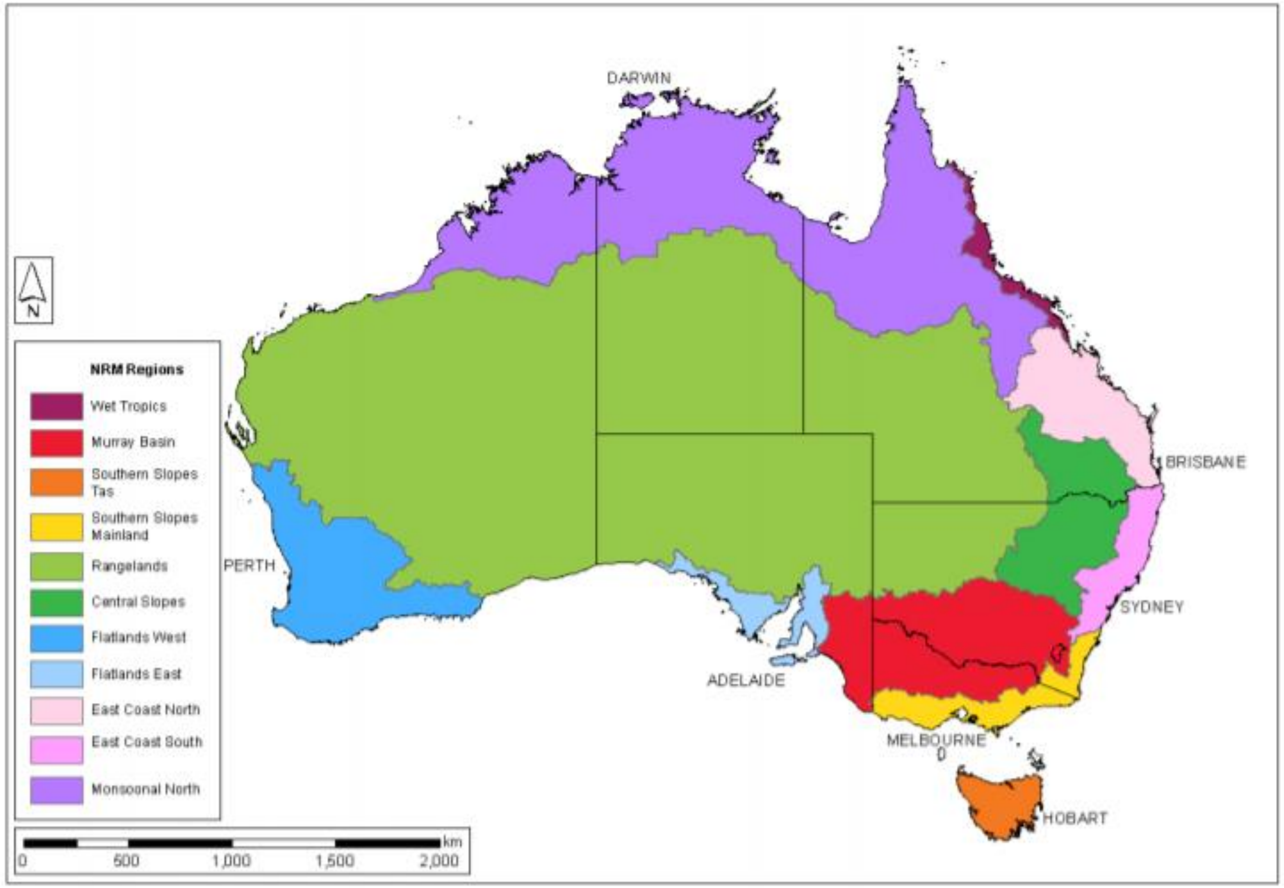


Figure 1.6.1. Locations of Natural Resource Management Clusters

Climate change rainfall increases from the ARR data hub

Interim Climate Change Factors

	RCP 4.5	RCP6	RCP 8.5
2030	0.869 (4.3%)	0.783 (3.9%)	0.983 (4.9%)
2040	1.057 (5.3%)	1.014 (5.1%)	1.349 (6.8%)
2050	1.272 (6.4%)	1.236 (6.2%)	1.773 (9.0%)
2060	1.488 (7.5%)	1.458 (7.4%)	2.237 (11.5%)
2070	1.676 (8.5%)	1.691 (8.6%)	2.722 (14.2%)
2080	1.810 (9.2%)	1.944 (9.9%)	3.209 (16.9%)
2090	1.862 (9.5%)	2.227 (11.5%)	3.679 (19.7%)

Layer Info

Time Accessed	07 July 2020 10:12PM
Version	2019_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values. These have been updated to the values that can be found on the climate change in Australia website.

- Increase the rainfall not flow
- Currently no advice on PMP

Guide to arr-software.org

Home ARR Guidebook Project Reports

ARR Services Index

Australian Rainfall & Runoff

ARR Services Index

- Data Hub: https://data.arr-software.org
- Legacy Data Hub: https://data-legacy.arr-software.org
- RFFE: https://rffe.arr-software.org
- Joint Probability: https://p18.arr-software.org
- ARR Guidebook: https://www.arr-software.org/arrdocs
- Project Reports: https://www.arr-software.org/project-reports

Key Links

Document

http://arr.ga.gov.au/

IFD

http://www.bom.gov.au/water/designRainfalls/revised-ifd/

Data Hub

http://data.arr-software.org/

RFFE

http://rffe.arr-software.org/

Interaction of coastal and ocean flooding

http://p18.arr-software.org/

Questions ?