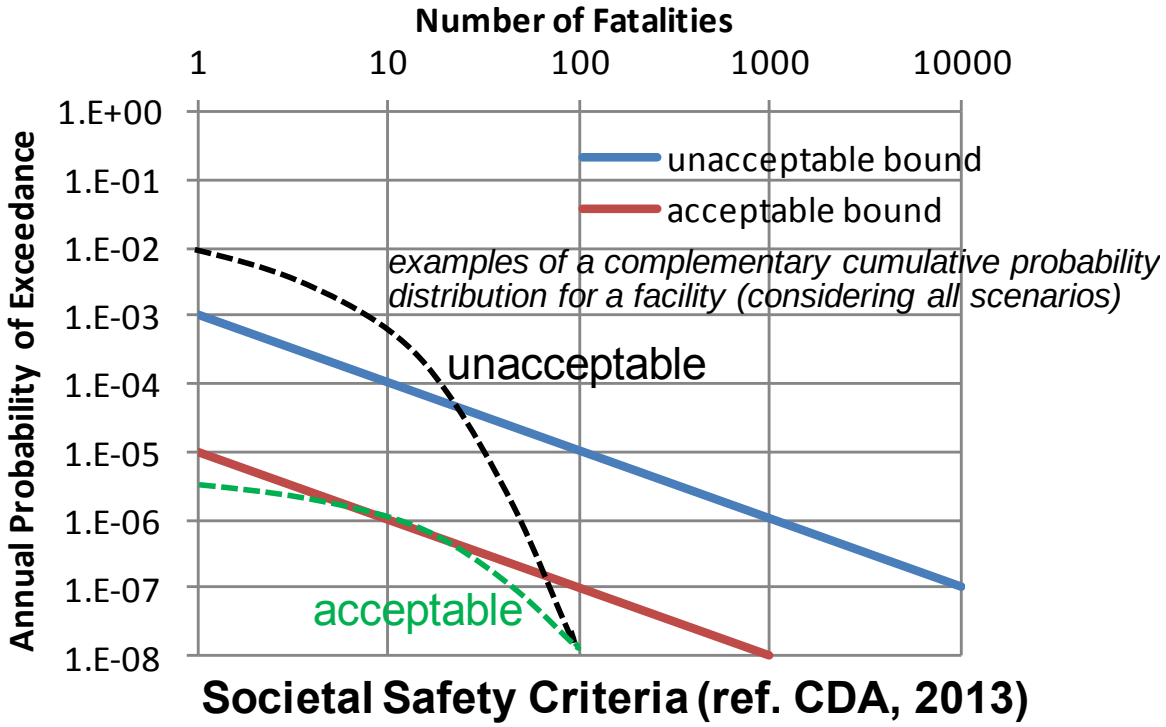

21 Jan 2014

Colliery Dam (Nanaimo BC) Risk Assessment

by Dr. Bill Roberds

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Develop Colliery Dams (Nanaimo BC) Plan

- **13 Dec 2013 Meeting**
  - **Objectives -** identify *optimal* dam rehab option plan
  - **Criteria -** including (but not limited to) *safety* and *financial performance*
  - **Process -** conduct *risk assessment* to appropriately evaluate potential performance (rather than worst-case scenario) of any plan, per recent *dam safety guidelines*
  - **Risk assessment**
    - *performance model* translates *inputs* ➔ *outputs*
    - inherent uncertainties in inputs and in model result in uncertainties in outputs
    - quantify uncertainty in terms of *probability*
    - assess probability *objectively* or *subjectively*

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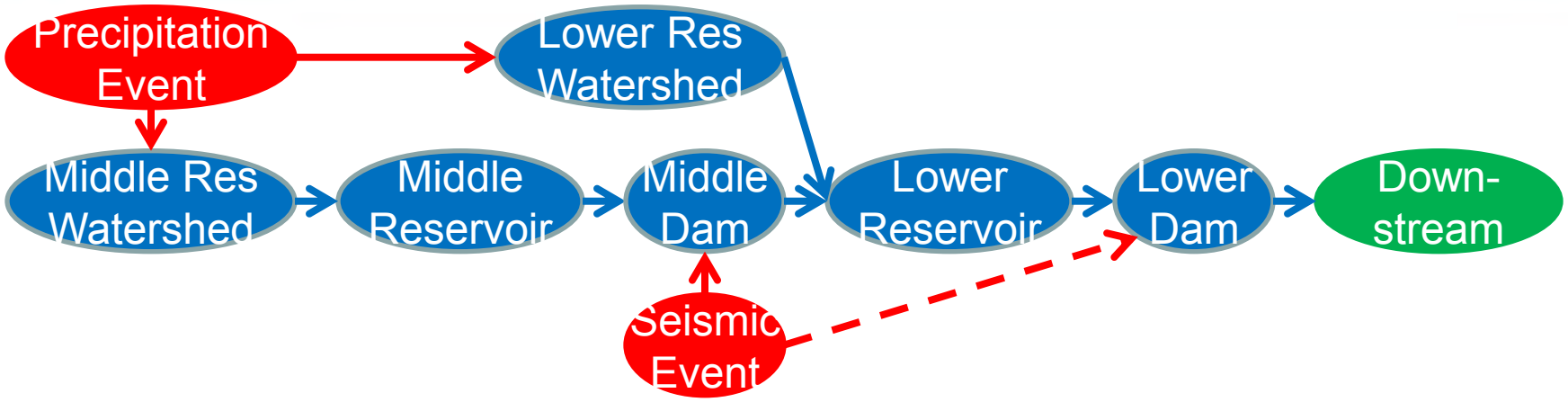
Colliery Dam System: Elements



- People/property/critical functions/etc. might exist within each element, but especially “downstream”
- Outflow from Lower Dam can cause inundation downstream that might affect those people/property/critical functions/etc.
  - outflow from Lower Dam
  - consequences (safety and financial) of Lower Dam outflow

Lower Dam Release

- ***Lower Dam outflow model***
  - Lower Dam reservoir level
  - Lower Dam reservoir inflow
    - Lower Dam res. watershed
      - Precipitation
      - Runoff
    - Middle Dam release ➔
  - Lower Dam storage capacity / spillway release / overtopping release
    - Undamaged
    - Damaged
      - Breach by overtopping
      - Seismic collapse
      - Other (e.g., piping)

- ***Middle Dam outflow model***
  - Middle Dam reservoir level
  - Middle Dam reservoir inflow
    - Middle Dam res. Watershed
      - Precipitation
      - Runoff
  - Middle Dam storage capacity / spillway release / overtopping release
    - Undamaged
    - Damaged
      - Breach by overtopping
      - Seismic collapse
      - Other (e.g., piping)

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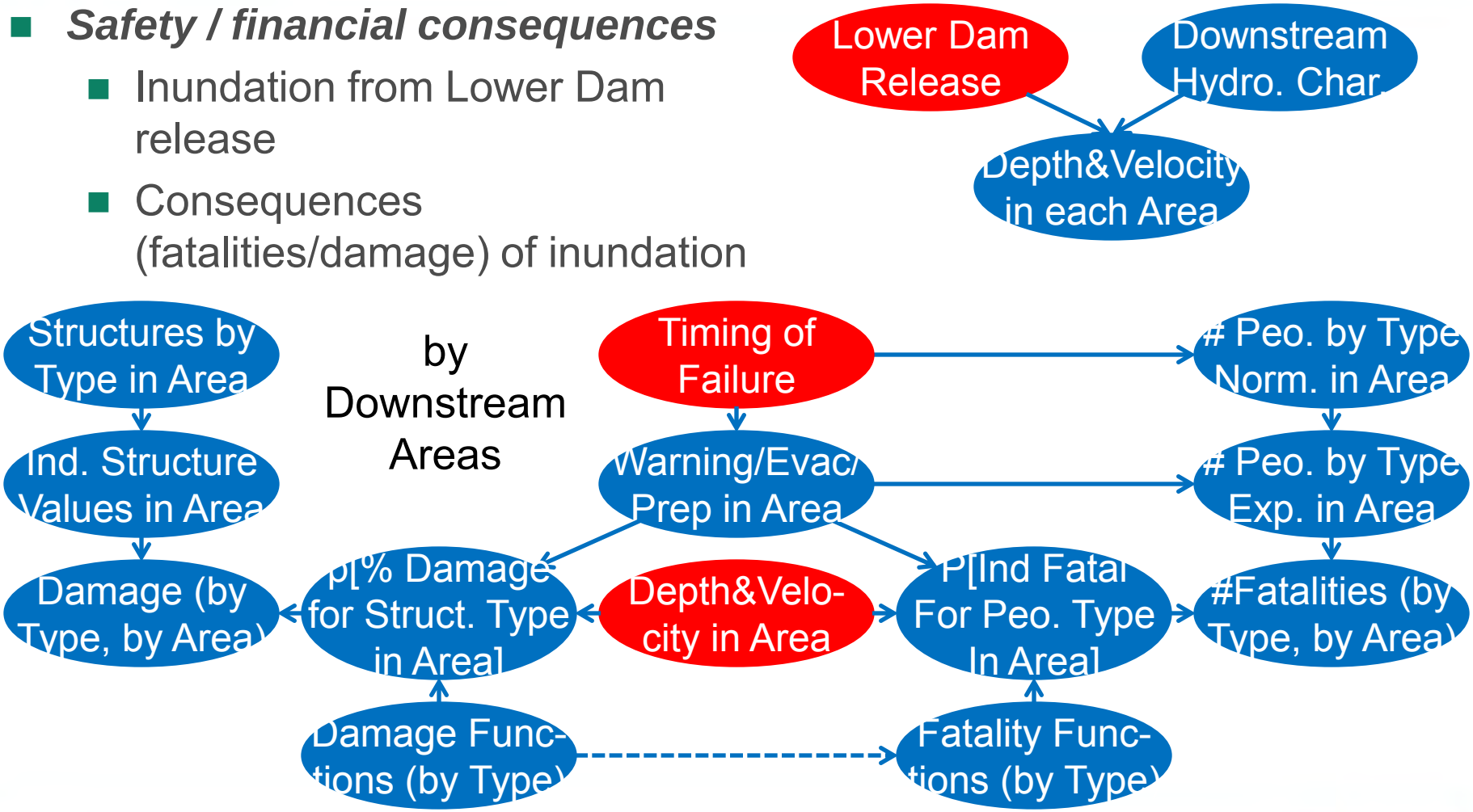
Downstream Consequences

- ***Safety / financial consequences***
  - Inundation from Lower Dam release
  - Consequences (fatalities/damage) of inundation



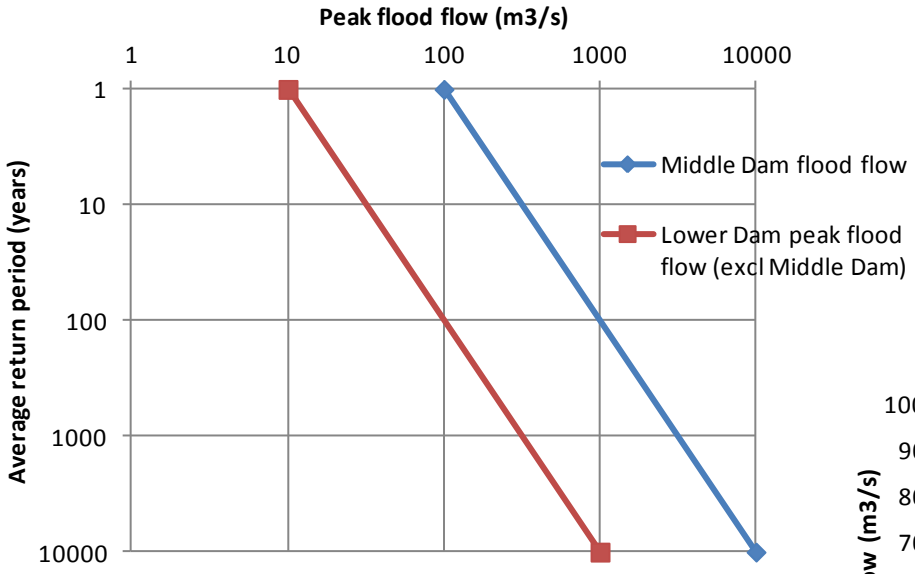
Risk Inputs (1 of 10)

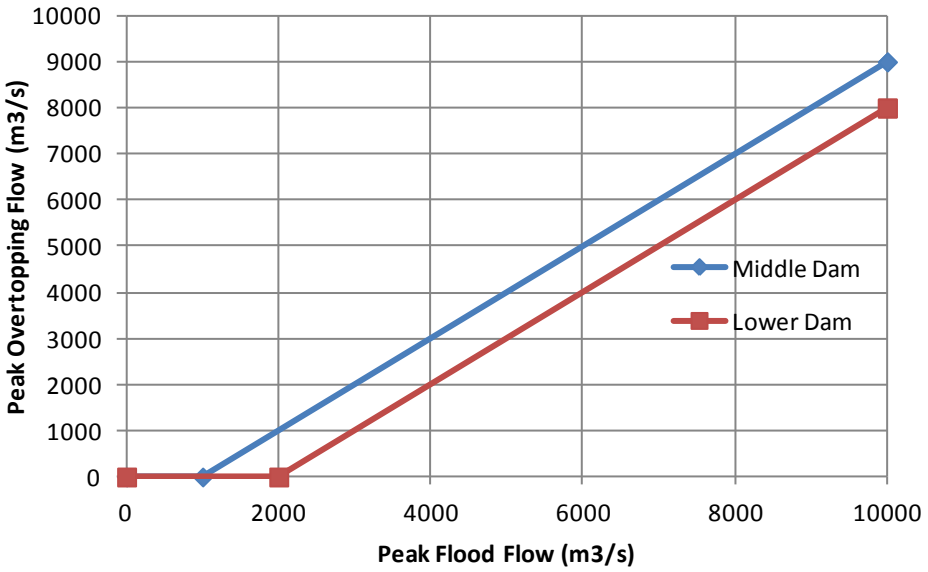
- **Precipitation/Hydrology/Reservoir Inflow**
  - Exceedance Frequency – Magnitude (flow rate/duration) for inflow
    - Middle Dam reservoir inflow
    - Lower Dam reservoir inflow (excl Middle Dam reservoir inflow)

  Status: We have precipitation frequency and hydrographs from previous studies, but will refine hydrographs (e.g., considering Nanaimo Parkway culvert) and subjectively assess uncertainties.
- **Reservoir Storage/Hydraulics/Outflow**
  - Storage(m^3)—depth (m) – spillway (+ leakage) release (flow rate/duration) – overtopping release (flow rate/duration) relationships
    - Middle Dam
    - Lower Dam

  Status: We have these relationships (rating curves) from previous studies, but will refine them (e.g., considering Nanaimo Parkway culvert and spillway hydraulics) and subjectively assess uncertainties.

Hypothetical Example Inputs





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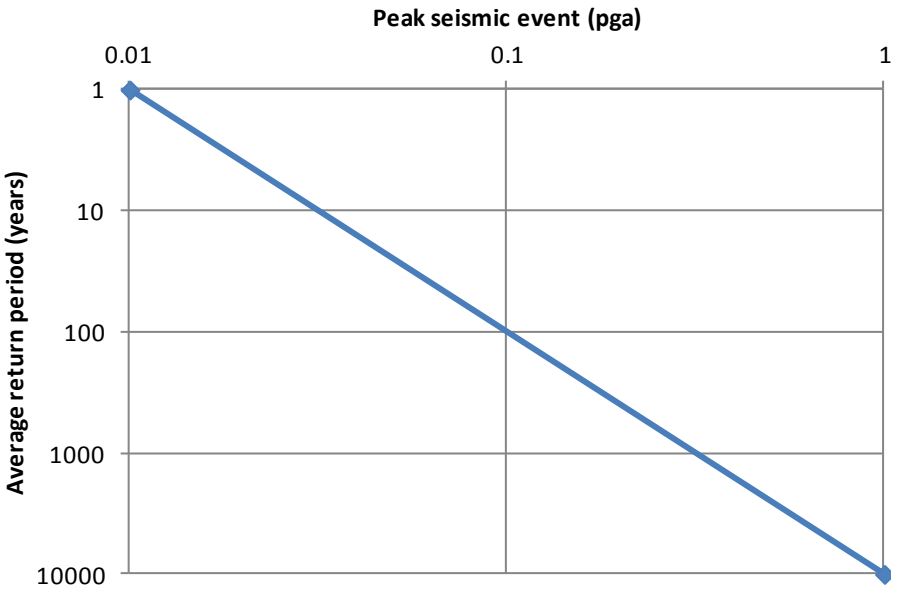
Risk Inputs (2 of 10)

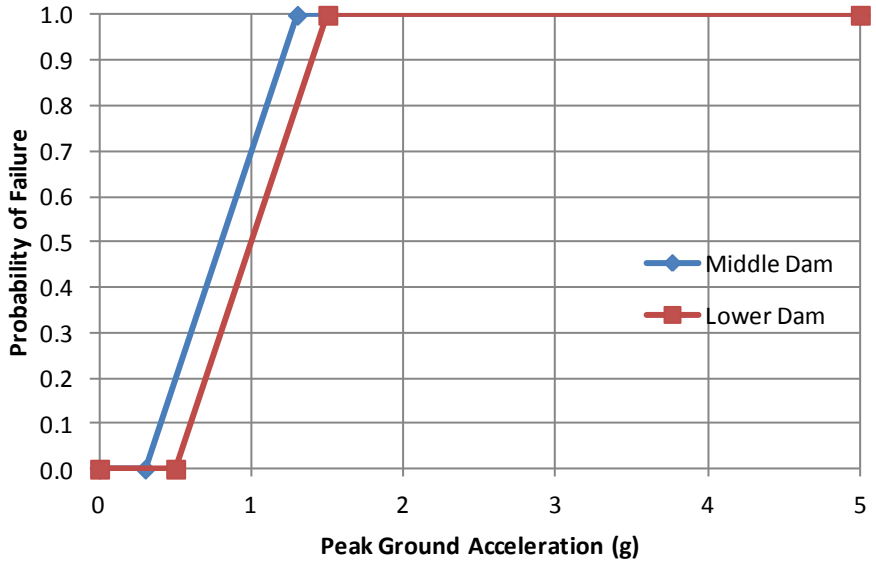
- **Seismic Load**
  - Exceedance Frequency – Magnitude (pga) relationship

    Status: We have this relationship from previous studies, but need to develop site-specific seismic inputs and subjectively assess uncertainties.
- **Dam "Failure"**
  - Dam failure – seismic (pga) relationship
    - Middle Dam
    - Lower Dam

    Status: We have "performance" of each dam for several pga values from previous studies. However, we will collect additional geotechnical data from the ongoing investigation (geophysics & drilling), which will be used to develop parameters for re-analysis. We need performance at several pga's for each dam (also considering previous results) in order to subjectively develop the complete relationship (by interpolation/extrapolation), and subjective assessments of: a) the uncertainty in modeled performance; and b) the probability of failure - performance relationship and the uncertainty in that relationship. Note: not differentiating degree of dam failure.

Hypothetical Example Inputs





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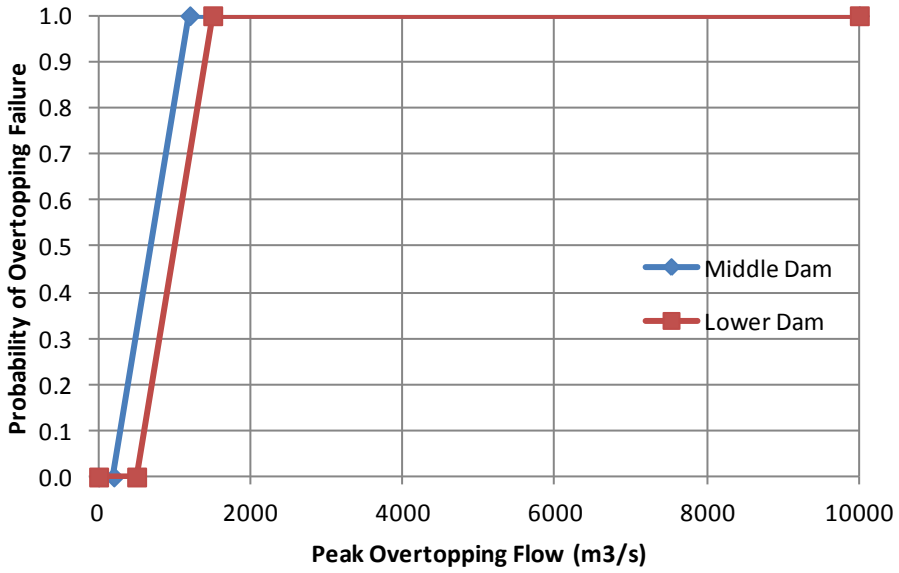
Risk Inputs (3 of 10)

- **Dam "Failure" (cont.)**
  - Dam failure/breach – overtopping (flow rate/duration) relationship
    - Middle Dam
    - Lower Dam

    Status: We do not have any overtopping "breach" analyses for either dam from previous studies. We need breach analyses at several overtopping values for each dam in order to subjectively develop the complete relationship (by interpolation/extrapolation), and subjective assessment of the uncertainty in that relationship.
  - Dam failure/breach – other causes (e.g., piping) relationship
    - Middle Dam
    - Lower Dam

    Status: We do not have any other failure analyses for either dam from previous studies nor reliable models to do such analyses. We need subjective assessment of probability of dam failure by other causes (not seismic or overtopping, e.g., piping).

Hypothetical Example Inputs



Risk Inputs (4 of 10)

- **Lower Dam Release**
  - Magnitude (flow rate/duration) for no Lower Dam failure in combination with
    - No Middle Dam failure
    - Middle Dam overtopping failure
    - Middle Dam seismic failure
    - Middle Dam failure by other causes (e.g., piping)

  Status: We have the magnitude of releases for each dam in the absence of dam failure from previous studies, but will confirm and need subjective assessments of the uncertainties in those releases (done elsewhere).

Risk Inputs (5 of 10)

- **Lower Dam Release (cont.)**
  - Magnitude (flow rate/duration) for Lower Dam overtopping failure in combination with
    - No Middle Dam failure
    - Middle Dam overtopping failure
    - Middle Dam seismic failure
    - Middle Dam failure by other causes (e.g., piping)

  Status: We do not have any overtopping "breach" analyses to determine the magnitude of release for either dam if breached, from previous studies. We need breach analyses at several overtopping values for each dam (done elsewhere) in order to subjectively develop the complete relationship (by interpolation/extrapolation) of dam release magnitude to overtopping value, and subjective assessment of the uncertainty in that relationship, for each dam.

Risk Inputs (6 of 10)

- **Lower Dam Release (cont.)**
  - Magnitude (flow rate/duration) for Lower Dam seismic failure in combination with
    - No Middle Dam failure
    - Middle Dam overtopping failure NA
    - Middle Dam seismic failure
    - Middle Dam failure by other causes (e.g., piping) NA

  Status: We do not have any analyses to determine the magnitude of release for either dam if it fails due to a seismic event, from previous studies. We need to subjectively assess dam release magnitude if the dam fails due to a seismic event and the uncertainty in that release, for each dam.

Risk Inputs (7 of 10)

- **Lower Dam Release (cont.)**
  - Magnitude (flow rate/duration) for Lower Dam failure by other causes (e.g., piping) in combination with
    - No Middle Dam failure
    - Middle Dam overtopping failure NA
    - Middle Dam seismic failure NA
    - Middle Dam failure by other causes (e.g., piping) NA

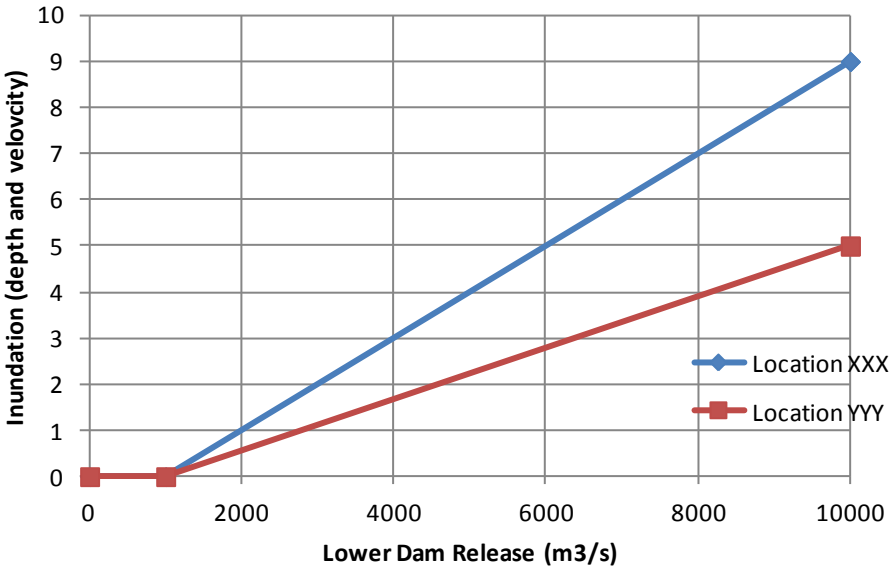
  Status: We do not have any analyses to determine the magnitude of release for either dam if it fails due to some other cause besides overtopping or seismic event (e.g., piping), from previous studies. We need to subjectively assess dam release magnitude if the dam fails due to some other cause besides overtopping or seismic event (e.g., piping), and the uncertainty in that release, for each dam.

Risk Inputs (8 of 10)

- **Downstream Inundation**
  - Downstream inundation (depth/velocity/location) – Lower Dam release (flow rate/duration) relationship

    Status: We can get downstream inundation values at relevant locations for several Lower Dam releases from previous studies, but we need additional analyses for other Lower Dam releases in order to subjectively develop the complete relationship (by interpolation/extrapolation), and subjective assessment of the uncertainty in that relationship.

Hypothetical Example Inputs



Risk Inputs (9 of 10)

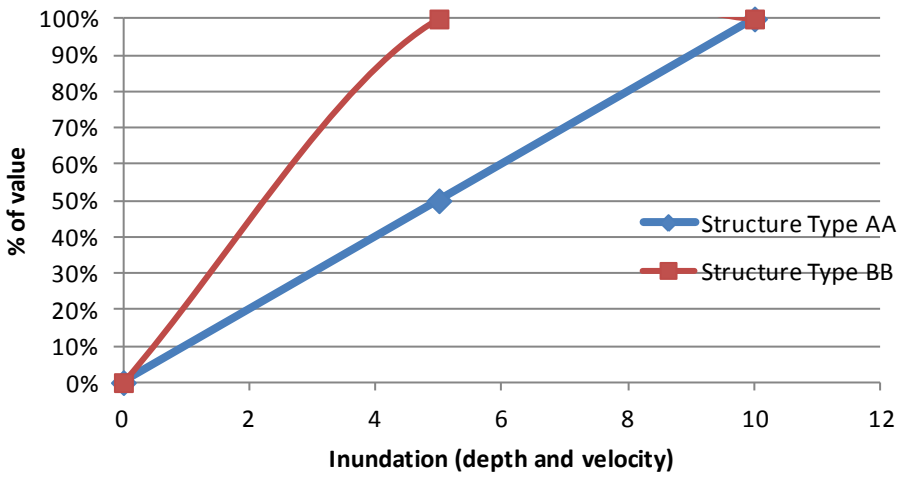
- **Downstream consequences**
  - Downstream consequences – downstream inundation (depth/velocity/location) - warning (failure mode related) relationship
    - Properties/facilities
      - Downstream properties and facilities (type, location, value, and occupant type/number)
      - Damage (% of value) – inundation (depth/velocity) – warning relationship by type
      - Individual casualty (occupant probability) – damage (% of value) – warning relationships by type
    - Population (outside of property/facilities)
      - Downstream populations (type, location and number)
      - Individual casualty (by type) – inundation (depth/velocity) – warning by type

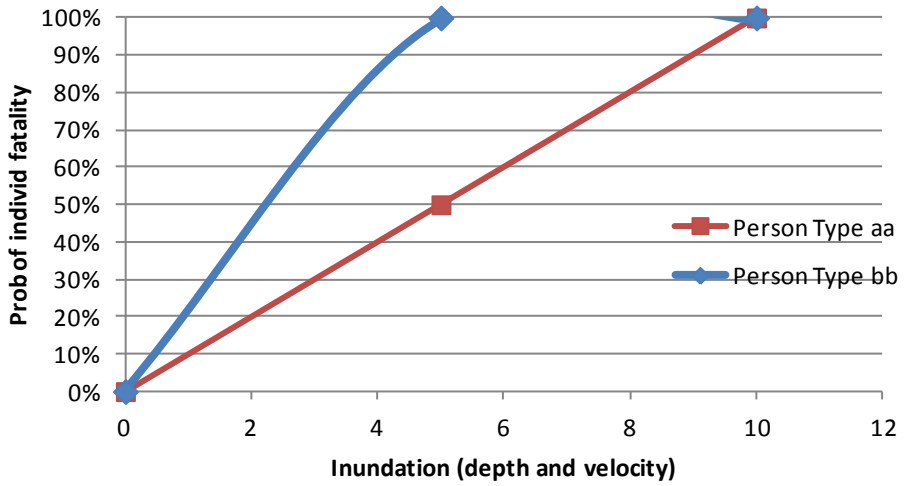
Risk Inputs (10 of 10)

- **Downstream consequences (cont.)**

  Status: We can get relatively current inventory (type, location, value, number) of downstream property/facilities and populations from previous studies, but we need to confirm and project into future when a failure might occur, and subjectively assess uncertainties in those values. We have the damage – inundation and individual casualty – inundation relationships from previous studies, but still need to subjectively assess effectiveness of warning and individual casualty – damage relationship, and the uncertainty in all those relationships.

Hypothetical Example Inputs





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Risk Model

- Algorithms (outputs from inputs in chains) implemented in *MS Excel* with *@Risk* (commercial add-in) to do probabilistic analysis:
  - Inputs expressed probabilistically (representing their uncertainties)
  - Outputs calculated probabilistically (representing their uncertainties) via *Monte Carlo simulation* (many possible sets of input values are generated, each with known probability, from which outputs with known probability are generated)
- Simulation Sequence:

  Maximum precipitation and seismic events

  ➔ Dam(s) failure mode (each with particular lower dam release, timing and warning/no warning)

  ➔ Downstream inundation and downstream population/property

  ➔ Downstream damage and casualties
- *Status:* In development

Thank you!

Questions?