Paleoflood Analyses for Probabilistic Flood Hazard Assessments—Approaches and Review Guidelines

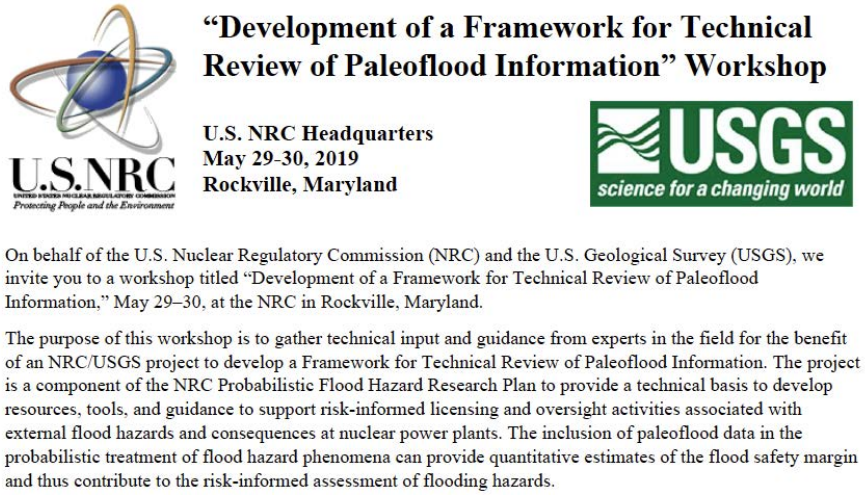
Tess Harden, Karen Ryberg, Jim O'Connor, Jonathan Friedman, Julie Kiang

U.S. Geological Survey

Nuclear Regulatory Commission, Probabilistic Flood Hazard Workshop, February 19-21, 2020

2019 Paleoflood Workshop

- USGS, NRC, USACE, Bureau of Reclamation, several universities
- Purpose of the workshop was to gather technical input and guidance from experts in the field for the benefit of a USGS Techniques and Methods Report.



"Development of a Framework for Technical Review of Paleoflood Information" Workshop

U.S. NRC Headquarters
May 29-30, 2019
Rockville, Maryland

On behalf of the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Geological Survey (USGS), we invite you to a workshop titled "Development of a Framework for Technical Review of Paleoflood Information," May 29–30, at the NRC in Rockville, Maryland.

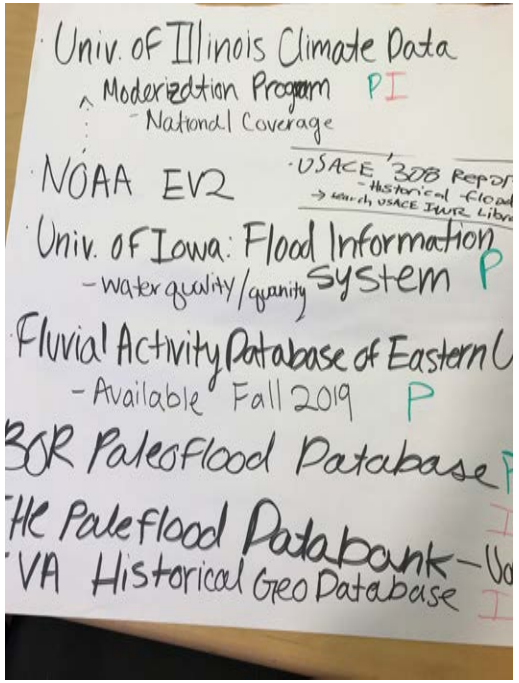
The purpose of this workshop is to gather technical input and guidance from experts in the field for the benefit of an NRC/USGS project to develop a Framework for Technical Review of Paleoflood Information. The project is a component of the NRC Probabilistic Flood Hazard Research Plan to provide a technical basis to develop resources, tools, and guidance to support risk-informed licensing and oversight activities associated with external flood hazards and consequences at nuclear power plants. The inclusion of paleoflood data in the probabilistic treatment of flood hazard phenomena can provide quantitative estimates of the flood safety margin and thus contribute to the risk-informed assessment of flooding hazards.

Workshop Motivation

- Paleoflood hydrology studies are an increasingly important tool for design and safer operation of critical infrastructure
  - Extending the effective flood record
  - Informing estimates of the magnitude and frequency of flooding hazards
- Standards of practice for conducting and reviewing such studies are lacking
  - Inhibits effective use in regulatory decision making.

Panel Discussions

- Uses of systematic, historical, and paleoflood data in PFHA—Probabilistic flood-hazard assessment
- Historical peak-flow data
- Determining floods from botanical evidence
- Sedimentological, stratigraphic, geochronological data
- Flow reconstruction
- Levels of review
- Databases



Paleoflood Analysis and Review Guidelines Document

- Document summarizes methods and techniques for preparation, gathering, evaluation, and interpretation of paleoflood information, including uncertainties, especially with respect to new statistical approaches available to efficiently use such data.
- Also provided is guidance on the levels of study appropriate for specific questions or issues as well as appropriate corresponding levels of technical review.

Included in analysis and review guidelines:

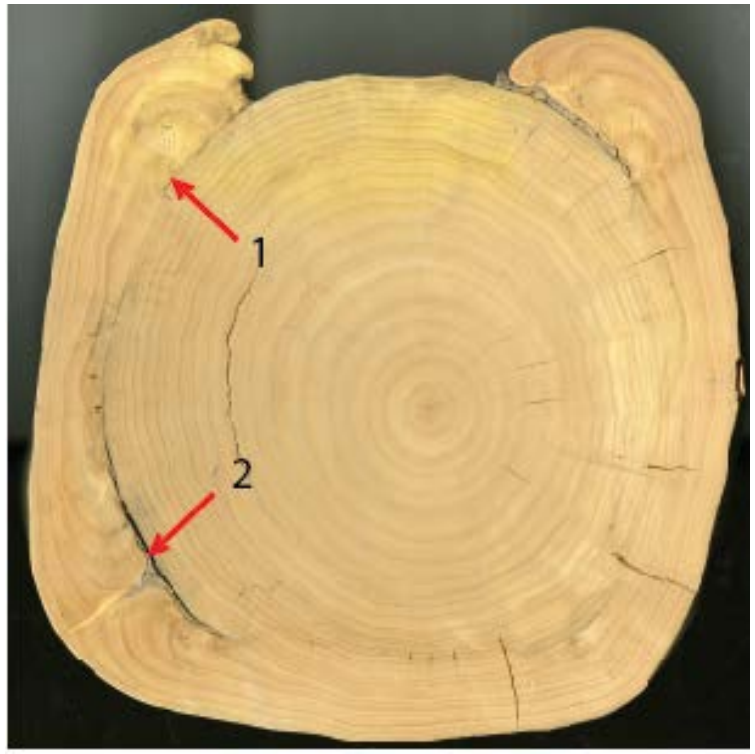
- Paleostage Indicators (PSI) and High water marks
  - Slack-water deposits
  - Site selection and stratigraphy
  - Age determination
    - Radiocarbon
    - Optically Stimulated Luminescence
    - Dendrochronology
    - Cesium-137
    - Lichenometry
    - Others
  - Overall Flood Chronology

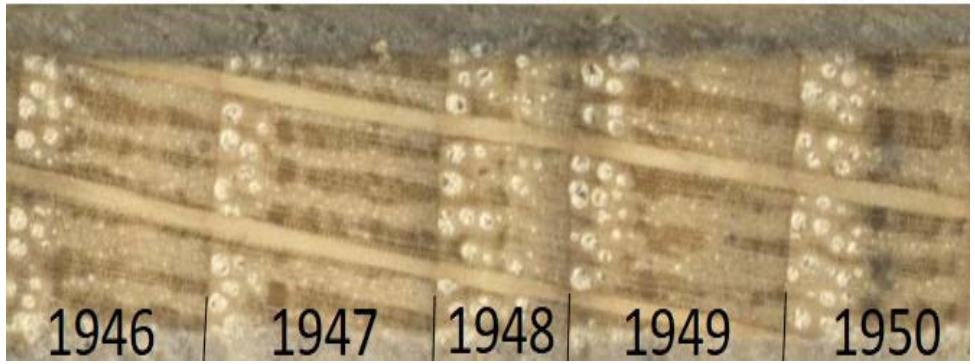
Included in analysis and review guidelines:

- Terrace and Floodplain deposits
  - Site selection and identification
  - Terraces as non-exceedance bounds
- Lake and Wetland Deposits
  - Site selection and identification of flood sequences
  - Stratigraphic analysis and age determination
- Uncertainties associated with paleostage indicators
- Stratigraphic uncertainties

Dendrochronology

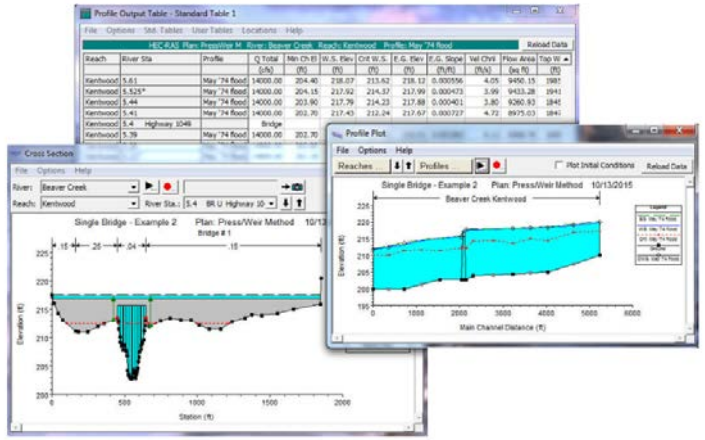
- Date and elevation of flood scars
- Death date of flooded trees
- Alteration of tree-ring anatomy by flooding and burial
- Flood-related anomaly in ring width
- Establishment of seedlings or vegetative sprouts following flood disturbance





Hydraulic Analysis

- **Common techniques for paleohydraulic calculation**
  - Manning's Equation
  - Critical Flow
  - Gradually Varied Flow
- **Channel geometry and roughness**
- **Flow directly from sedimentary deposits**
  - Based on thickness and grain size
  - Can be developed where the elevation of flood deposits is not likely to closely represent maximum flood stage.



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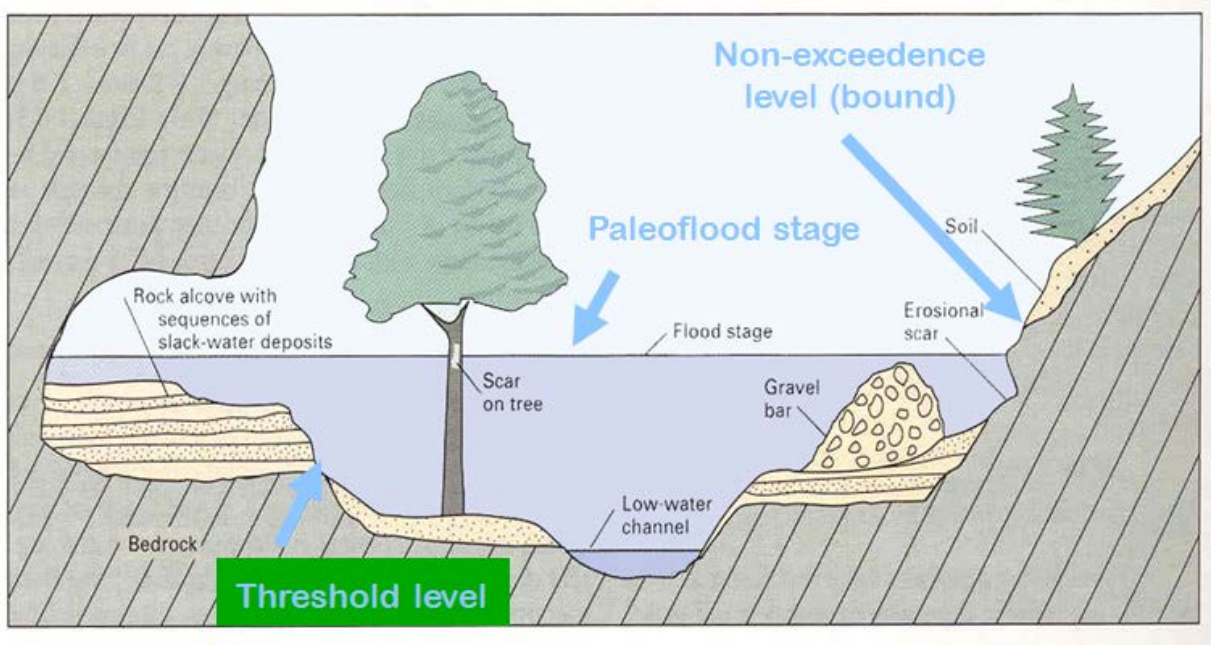
Flood-frequency Analysis

- Incorporating historical and paleoflood information into flood-frequency analysis
- Bulletin 17C
- Identification of perception thresholds and non-exceedance bounds



Paleoflood Analysis and Review Levels

- Three levels of paleoflood analyses and review for PFHAs.
- Boundaries are vague, and the scope and intensity of individual studies will vary depending on agency goals, guidelines, and objectives.
- This categorization helps organize discussion of levels of effort involved in conducting paleoflood studies as well as the degree of appropriate technical review.

Level 1

- Considered scoping level studies and are typically the first step in almost all paleoflood analyses.
- Purpose varies but typically level 1 studies:
  - 1) provide an initial screening of a local flood hazard issue,
  - 2) support nearby study or supply correlative information,
  - 3) serve as a feasibility assessment for a possible higher-level analysis,
  - 4) collect information for a regional flood assessment,
  - 5) or serve as a periodic review or update for site-specific flood hazard information
- If regional paleoflood information is available, Level 1 studies may not require a site visit.
- Uncertainty analyses are limited, and results may be preliminary.

Level 1 Review

- Preliminary scoping and project guidance may be solely determined by the project lead in accordance with the project purpose.
- Independent technical review of studies may be minimal, typically conducted by a subject matter expert or experts external to the project.
- A field review may not be required for this level.
- Commonly serve as feasibility studies to test the applicability of methods for a larger more comprehensive Level 2 or Level 3 study.

Level 2

- Improve flood frequency and magnitude estimates for a specific location, site hazard assessments and/or hydroclimate analysis.
- Involve a multidisciplinary team and one or more field campaigns to investigate paleoflood evidence at multiple sites on a single reach or multiple reaches of a river.
- Flood chronologies are supported by numeric dating methods.
- Step-backwater or 2D hydraulic modeling using high resolution topographic data support discharge estimates associated with flood evidence or non-exceedance bounds.
- Hydraulic modelling provides estimates of uncertainty through sensitivity to model uncertainties such as roughness, boundary conditions, etc.
- Flood–frequency analyses using gaged, historical and paleoflood information, including flow intervals, identification of perception thresholds, and non-exceedance bounds.

Level 2 Review

- May be guided by a technical steering committee composed of subject matter experts and stakeholders who can assist with project scoping and offer guidance in the initial planning stages of the paleoflood study.
- In-progress review may be overseen by a technical steering committee.
- In-field review of benchmark sites and accompanying interpretations.
- Technical review of the final report and conclusions typically involves a team of independent experts, including scientists and engineers with knowledge of all study components (for example, stratigraphy, dendrochronology, hydraulics, flood frequency analysis).
- Comprehensive record keeping, including field notes, photographs, and laboratory analyses will aid technical review.

Level 3

- Most comprehensive.
- Support regional and site-specific flood frequency and magnitude estimates to address broad flood hazard or hydroclimate issues.
- May support siting, design, or retrofits of critical infrastructure such as dams, levees and nuclear power plants.

Level 3 cont.

- Project components include those associated with a Level 2 analysis— rigorous development of stratigraphic records, systematic surveys and analysis of botanical flood evidence, historical flood research, hydraulic modeling, and frequency analysis involving all available information including perception thresholds and non-exceedance bounds.
- Level 3 studies, however, generally involve multiple river reaches and possibly multiple river basins.
- May also be supported by regional hydroclimate and paleoflood analyses to confirm reach- and basin-specific conclusions.
- Include rigorous uncertainty assessments encompassing all aspects (hydraulic, geochronologic, and statistical model analyses) and underlying assumptions.
- Conducted by multidisciplinary teams of researchers over the course of multiple field campaigns and for multiple reaches of the river or even multiple river basins.

Level 3 Review

- More intensive than the other 2 levels of study, especially for studies assessing hazards to critical facilities.
- A technical steering committee composed of national and/or international subject matter experts and stakeholders may be assembled during the initial planning stages of the project.
- Such a technical steering committee can offer specific guidance and help with project scoping and determination of formal reporting standards and data preservation requirements.
- The technical steering committee may also conduct in-process reviews and field inspections at benchmark sites.
- Final technical review may be conducted by an established and independent team of experts for all study components (stratigraphy, dendrochronology, hydraulics, flood frequency analysis).

Analysis and Review table for all three levels

	Study Level	Level 1	Level 2	Level 3
Paleoflood Study Attributes	Purpose	Initial hazard screening Regional flood assessment Feasibility assessment Periodic review/update for site hazard	Site specific flood-frequency and magnitude estimates Inspection finding Issue evaluation (NRC) Site hazard assessment Hydroclimatic analysis	Regional and site-specific flood-frequency and magnitude estimates Support siting, facility design, or retrofits of critical infrastructure. Broad-scale hydroclimatic analysis
	Typical activities	Incorporation of historical data flood-frequency Identification of non-exceedance bounds Identification of paleoflood evidence at a single site of interest Hydraulic computations, if done, use existing models or simple calculations Limited uncertainty analysis	Development of stratigraphic records Archival research for historical floods Systematic surveys and analysis of botanical flood evidence Hydraulic modeling Flood frequency analysis augmented by incorporation of historical and paleoflood information, including identification of perception intervals and non-exceedance bounds.	Similar as level 2 but involving several analysis reaches and possibly multiple river basins. Regional hydroclimatic and paleoflood analyses to support reach- and basin-specific analysis Rigorous uncertainty assessment, including assessment of hydraulic, geochronologic, and statistical model assumptions and uncertainties.
	Analysis effort	Few personnel Minimal (or no) field inspection	Multidisciplinary team Single or multiple field campaigns Single or multiple reaches	Multidisciplinary team(s) Multiple field campaigns Multiple reaches or river basins
	Examples	Black Hills Assessment Study 2014 USGS report for NRC Tennessee River Feasibility Study Jarrett studies	Tennessee River comprehensive study Deschutes River (Hosman and others, 2003) BOR examples	Harden and others (2011) Black Hills BOR AR Bowman Dam study Ballesteros Canova analysis in Spain
Technical oversight and review	Preliminary scoping and project guidance	Investigator determined in accordance with project purpose	Broad guidance and project scoping by technical steering committee Technical oversight of planning and execution by subject matter experts and stakeholders	Specific guidance and project scoping by technical steering committee including national and international subject-matter experts and stakeholders Establishment of formal reporting standards and data preservation requirements
	Concurrent review and project modification	Investigator determined in accordance with project purpose	In-process review and progress evaluation by technical steering committee of subject-matter experts Field review of critical study sites and interpretations	In-process review by formally established panel of subject matter experts (such as Consultant Review Board). Field inspection and independent evaluation of key sites.
	Final technical review	Independent technical review by general subject matter expert(s)	Technical review by team of independent subject-area experts, including expertise for all study components (i.e. stratigraphy, dendrochronology, hydraulics, flood frequency analysis)	Technical review by formally established team of independent and nationally or internationally recognized subject-area experts, including expertise for all study components (i.e. stratigraphy, dendrochronology, hydraulics, flood frequency analysis) Independent expert review of uncertainty and sensitivity analyses

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	Examples	O'Connor et al., 2014 Harden and O'Connor, 2017	Tennessee River comprehensive study Deschutes River (Hosman and others, 2003)	Harden et al. (2011) Black Hills BOR AR Bowman Dam study

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Reporting requirements

- Similar regardless of the level of study.
- Documenting all site and stratigraphic or botanic information, analysis steps, laboratory analyses and results, modeling approaches and associated uncertainty, and assumptions allows for study transparency and more thorough and objective review.
- Documentation should be sufficient to reproduce the flood frequency results.

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