Presenting:

The Value of Streamgage Information: A case study on culvert design and operations

by Emily Pindilli

DAAG Conference 2003

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The Value of Streamgage Information:
A case study on culvert design and operations

Emily Pindilli

Science and Decisions Center

U.S. Geological Survey

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1. BACKGROUND: Streamgages and their Benefits
2. CASE STUDY: Culvert Design and Operations
3. VALUE OF INFORMATION: Economic Methods
4. APPLICATION: Analysis of Limited Dataset
5. CONCLUSIONS: Lessons Learned and Next Steps

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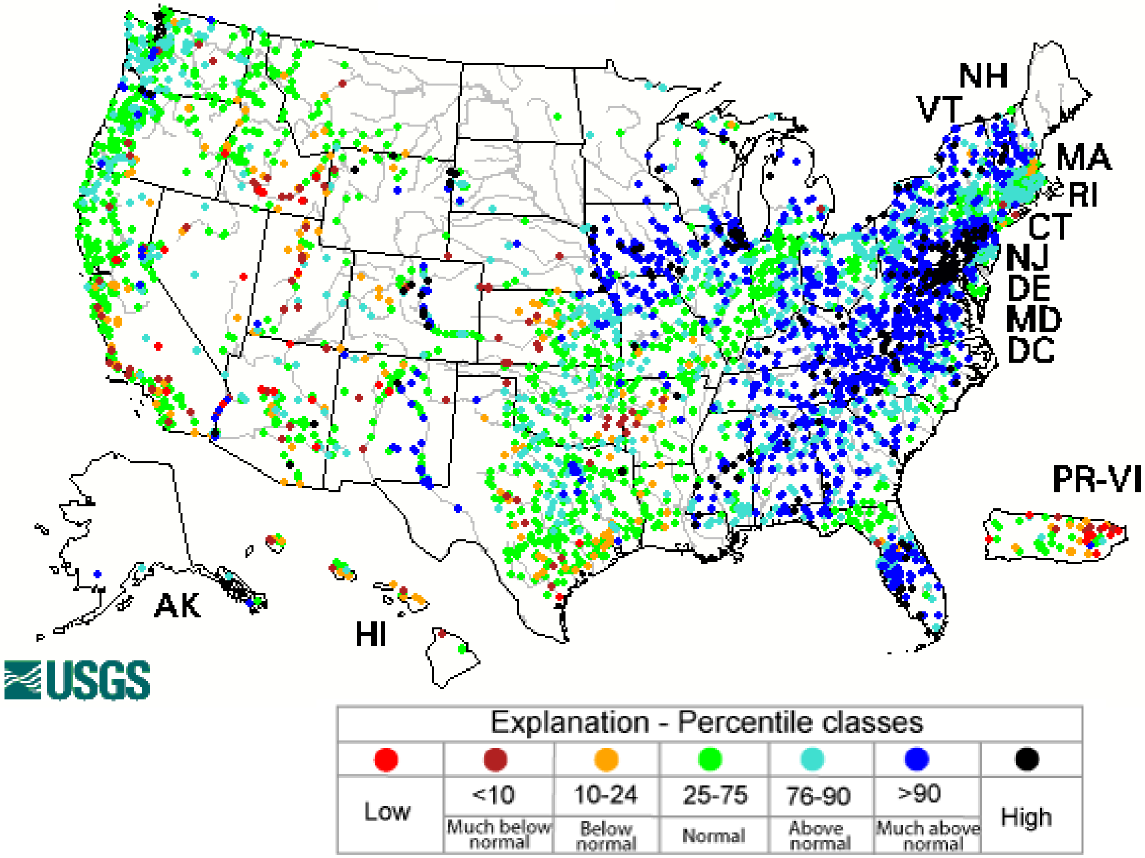
Streamgages Provide Critical Information

Real-time Streamflow Information



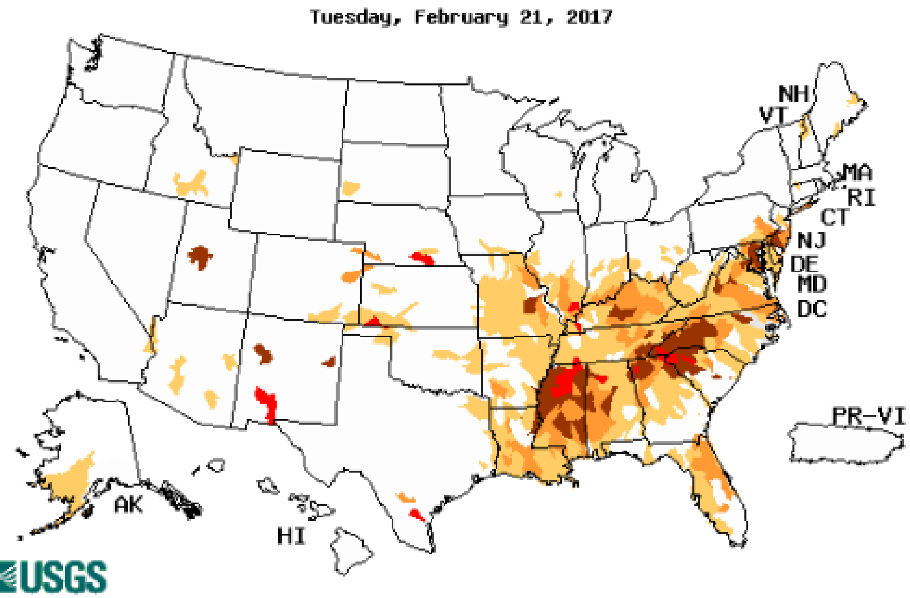
USGS Streamgage Network

- USGS network in operation since 1889
- National network of 7,600 gages
- Provides real-time and historical data on stream stage (height) and flow
- Information is readily and freely available

Predicting Droughts

Map of below normal 7-day average streamflow compared to historical streamflow for the day of year (United States)

State ▾



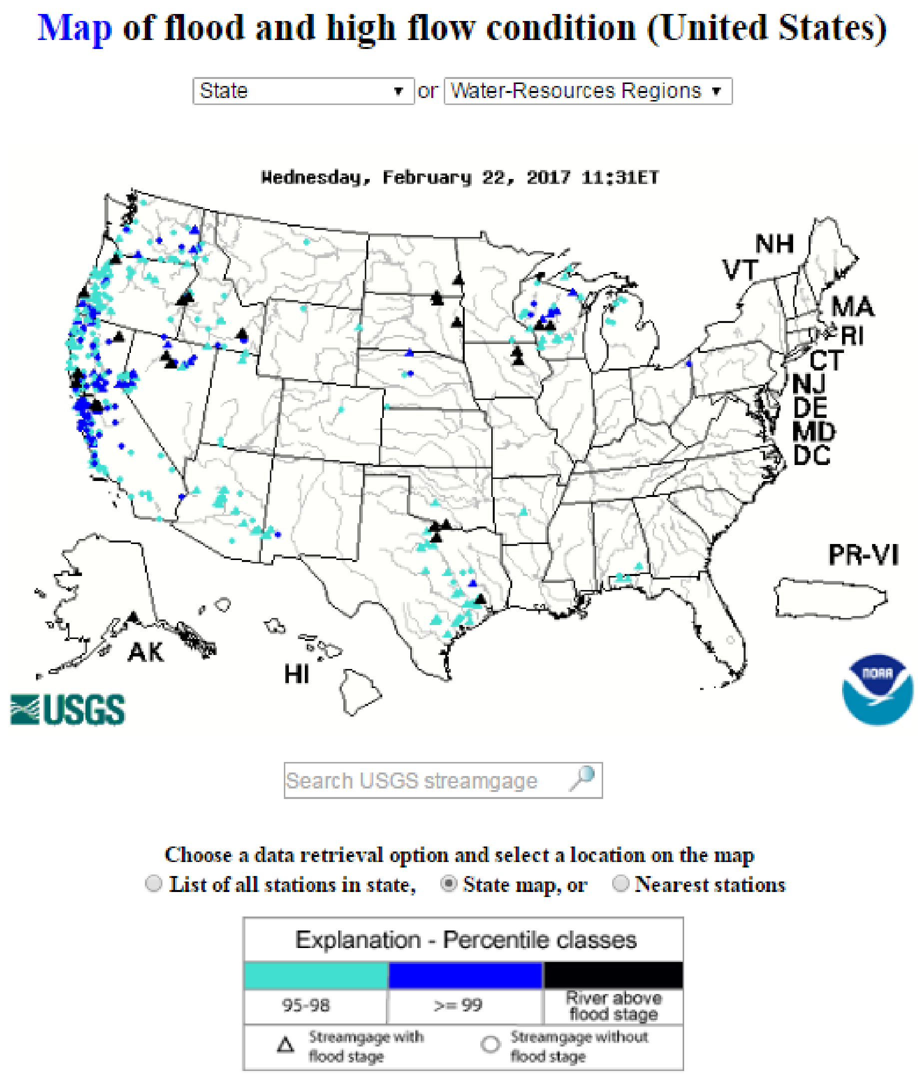
Choose a data retrieval option and select a state on the map

○ State DroughtWatch, ◉ State map

Explanation - Percentile classes				
Low	<=5	6-9	10-24	Insufficient data for a hydrologic region
Extreme hydrologic drought	Severe hydrologic drought	Moderate hydrologic drought	Below normal	

USGS

Forecasting Floods



USGS

Hazards

Photo: USGS

Photo: USGS

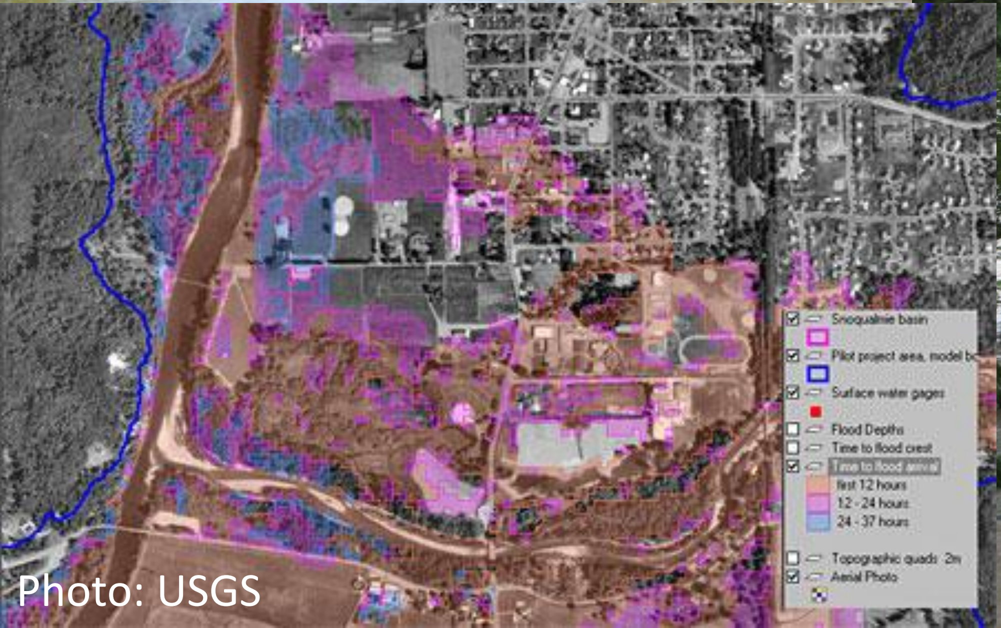


Photo: USGS

Photo: USGS

Infrastructure


Photo: USGS


Photo: DC Water


Photo: USGS


Photo: USGS

Water Allocation

Photo: USGS

Photo: USGS

Photo: USGS

Photo: USGS

Water Quality

Photo: USGS

Photo: USGS

Photo: USGS

Photo: USGS

Navigation and Recreation


Photo: USGS

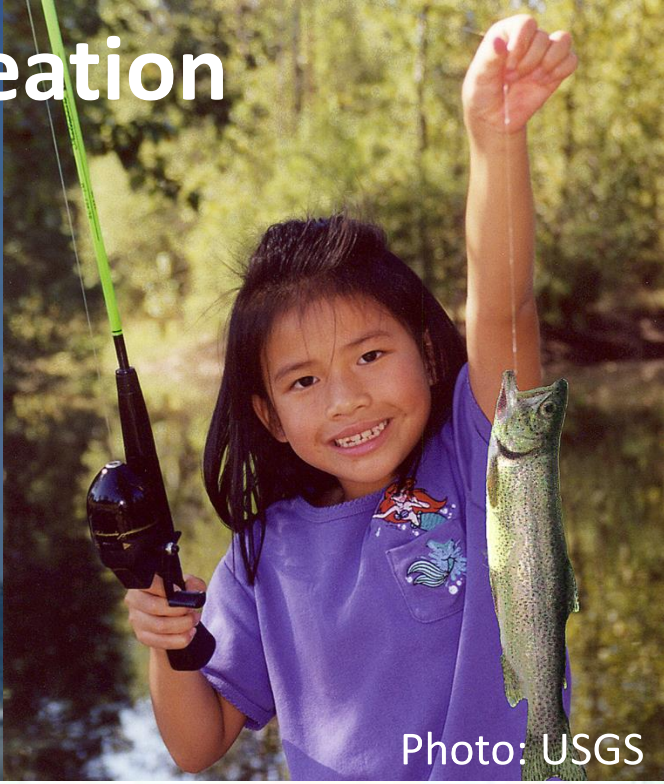


Photo: USGS


Photo: USGS


Photo: US Army Corp of Engineers

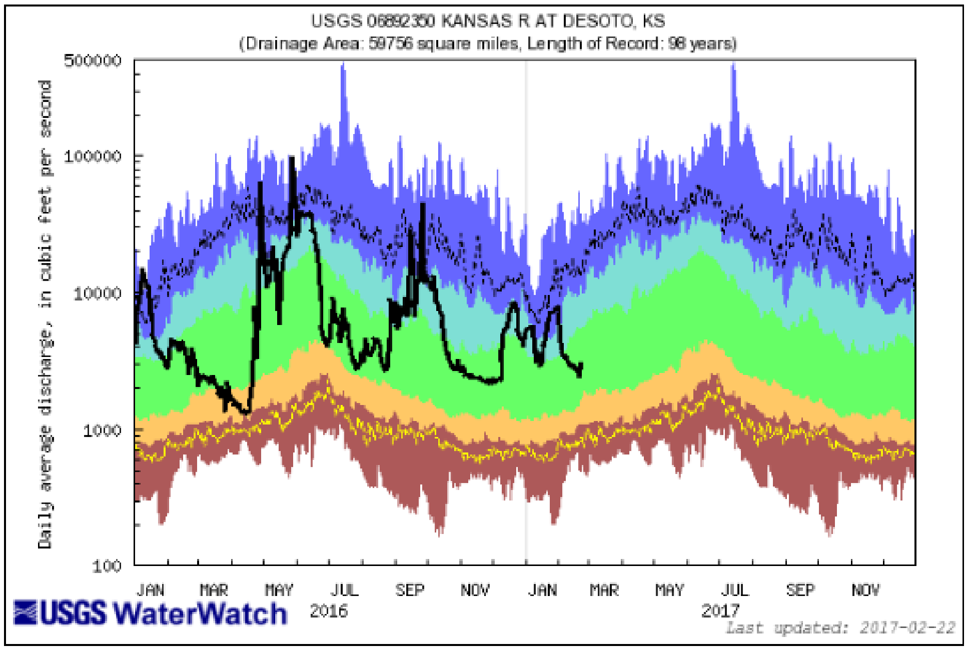
Detecting Trends

USGS Streamflow Duration Hydrograph Builder

Site Number 06892350 | Year: 2017 | No. of years: 2 | Flow: Daily | cfs | GO

5th and 95th percentiles: Line | Overlay | Year Type: Calendar Year | Output: Hydrograph

For some streams, flow statistics may have been computed from mixed regulated and unregulated flows; this can affect depictions of flow conditions.



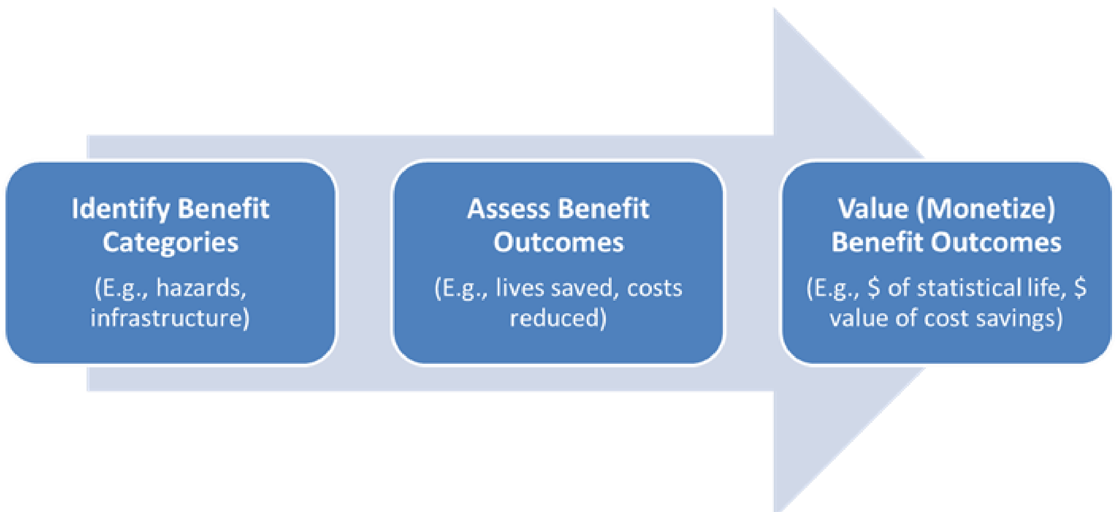
Explanation - Percentile classes							
lowest-10th percentile	5	10-24	25-75	76-90	95	90th percentile -highest	Flow
Much below Normal		Below normal	Normal	Above normal	Much above normal		

The Value of Benefits is Being Assessed

Application-by-Application Approach

- Benefits are being analyzed by application
- Monetization is focused on high magnitude impacts
- Values are aggregated to provide Total Economic Value*

*aggregated value will not capture 100% of benefits



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Culverts are Engineered to Protect Infrastructure

- A culvert is an engineered structure, i.e., a pipe, which is partially buried to allow surface water to flow underneath a roadway

- Engineering design relies on hydrology and hydraulics
  - Area precipitation
  - Over- and through-flow of surface water
  - Fluctuations in flow of river
  - Mechanics of water impact on structure

Example of a Culvert


Photo: USGS

Information is Needed to Design Culvert Capacity

- Water flow under various conditions must be derived to estimate capacity
  - Flow varies seasonally and annually

- Stream physical characteristics indicate ‘normal’ conditions; not flow for events which occur less frequently

- **Research Hypothesis:** increase in information (streamgage observations, in particular peak streamflow) will lead to optimization of culvert hydraulic capacity

Not all Information is Equivalent

Increasing Information

Bankfull Information	Regression Equations	Onsite Streamgage Data
• Early approaches relied heavily on bankfull measures and coefficients[1] • Study found bankfull data provides ~1.77 year storm recurrence; standard error of 51 percent for 100-year storm[2] • Another study estimated bankfull data only provides meaningful estimates of five-year storm or less[3]	• Relying on streamgages on similar stream segments with similar watershed characteristics • Availability varies with availability of similar watershed • Confidence varies with likeness of watershed	• Actual observations provides "best" (highest confidence) information • Confidence in accuracy flow during different recurrence events varies with streamgage history length

1. McEnroe, Bruce M. (2007). *Sizing of Highway Culverts and Bridges: A Historical Review of Methods and Criteria.* The University of Kansas, Report No. K-TRAN: KU-5-4.
2. U.S. Geological Survey (USGS). (2005). USGS. *Bankfull Characteristics of Ohio Streams and Their Relation to Peak Streamflows:* Scientific Investigations Report # 2005-5153. Available at: http://pubs.usgs.gov/sir/2005/5153/pdf/Bankfull_book.pdf
3. Wharton, G., N.W. Arnell, K.J. Gregory, and A.M Gurnell. (1989). *River Discharge Estimated from Channel Dimensions*. Journal of Hydrology. Volume 106 (3-4). 365–376 p.

There are Risks Associated with Design Flaws

- Culverts are oversized
  - Excess material, labor costs
- Culverts are undersized
  - Blowout events*
  - Overtopping events

*There are additional design factors such as material, shape, and length of the culvert, as well as degradation of the pipe or embankment that can cause or contribute to this risk, the analysis focused on overtopping events to be conservative.

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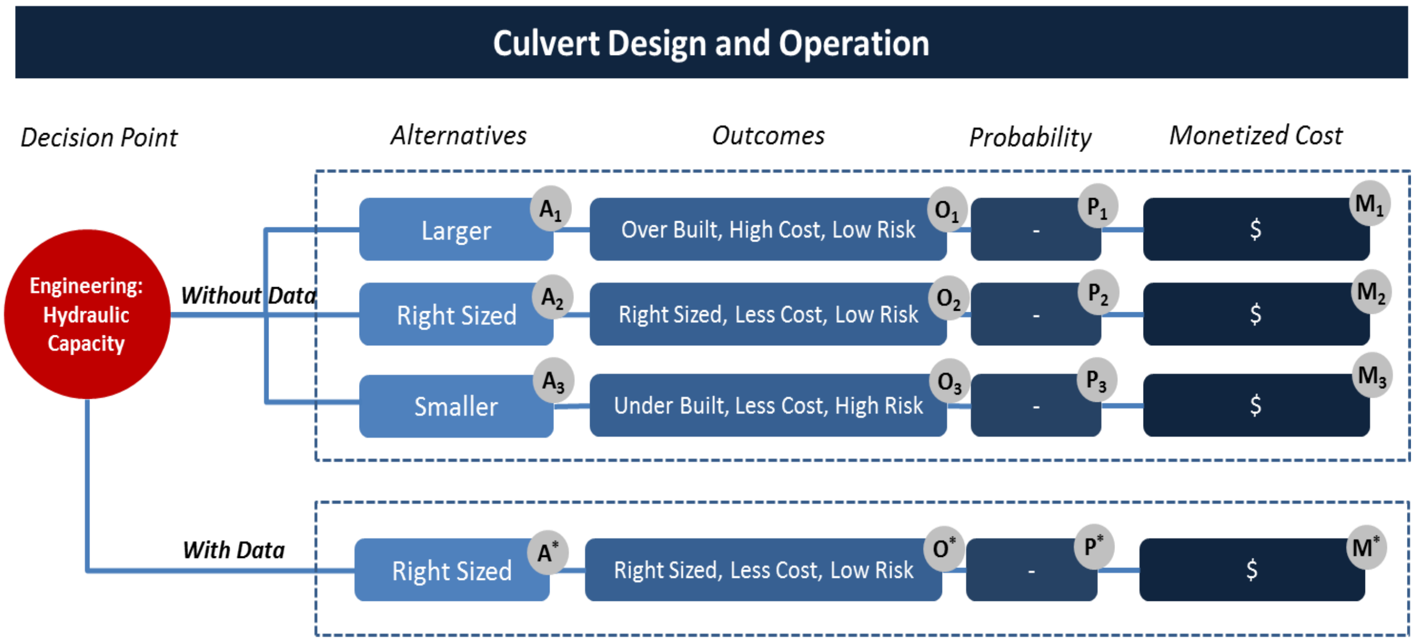
Deriving the Value of Streamgage Information: Bayesian Decision Trees

“Any one can make a culvert large enough, but it is the province of the engineer to design one of sufficient but not extravagant size”[1]



The Value of Information (VOI) can be derived from the decision tree as follows:

$$\left|(P^* \times M^*) - [(P1 \times M1) + (P2 \times M2) + (P3 \times M3)]\right| = VOI$$

1. Byrne, A.T. (1902). *A Treatise on Highway Construction,* fourth edition.

Analysis is Grounded in Research, Previously Collected Data

- Extensive Literature Review
  - Use of streamgage data for infrastructure
  - Culvert design, engineering, and operations
  - Incidence of blowouts, overtopping events, and other failures

- Outreach to Transportation Engineering Community
  - Department of Transportation Federal Highway Administration (Office of Bridges and Structures, Culvert Hydraulics Resource Center, Climate Adaptation Program)
  - Army Corp of Engineers
  - Academia (University of South Alabama, Colorado State University)
  - State Department of Transportations (Utah, Nebraska, Virginia, Vermont, Ohio, Connecticut)
  - Transportation Research Board
  - American Society of Civil Engineers
  - Engineering Consultants

- Outreach to Disaster Response Entities
  - Federal Emergency Management Agency (midwest region and national office)
  - Fish and Wildlife Service National Fish Passage Coordinator

Outcomes of Decision Paths are Quantified

- Overbuilt
  - Cost of construction and installation will outweigh benefits of risk reduction
  - Ohio DOT reported that new USGS regressions showed some culverts are oversized[1]

- Right sized
  - Construction and installation costs will equal damages avoided

- Underbuilt
  - Damages incurred due to insufficient hydraulic capacity on a periodic basis
  - Damage categories:

Direct Impacts	Costs	Variables
Flooding of adjacent property	Property damage (crops) Property damage (buildings)	Types of crops, value of crops Types of buildings, value of buildings and contents
Roadway flooding damage	Damage to pavement Damage to embankment	Material costs, labor costs Material costs, labor costs
Interruption of traffic	Increased travel time Increased travel distance	Duration of disruption Distance to avoid disruption Average daily traffic
Hazard to human life	Injury Value of a statistical life	Magnitude of injury Average daily traffic
Damage to stream and floodplain	Water quality impacts Loss of floodplain services	Damage extent, secondary impacts Types of services being impacted

1. Ohio Department of Transportation . (2013). Personal communication with Jeffrey Syar, PE, Administrator for the Office of Hydraulic Engineering in Ohio DOT.

Outcomes of Underbuilt Scenario are Monetized

- Damage costs are specified using multiple approaches:
  - Traditional cost estimation (property damage, cost of replacing pavement, embankment repairs)
  - Non-market costs use average estimated costs from authoritative sources (DOT rulemaking values) for travel time savings, travel distances, injuries and deaths
  - Values of water quality and floodplain services are highly dependent on location, not monetized in current analysis
- Economic Model is specified:

$$\text{Annual Cost Risk} = (\text{DamageCosts}_{100\text{-YearEvent}} * \text{AnnualRisk}_{100\text{YearEvent}}) + (\text{DamageCosts}_{50\text{-YearEvent}} * \text{AnnualRisk}_{50\text{YearEvent}}) + (\text{DamageCosts}_{25\text{-YearEvent}} * \text{AnnualRisk}_{25\text{YearEvent}}) + (\text{DamageCosts}_{10\text{-YearEvent}} * \text{AnnualRisk}_{10\text{YearEvent}}) + (\text{DamageCosts}_{5\text{-YearEvent}} * \text{AnnualRisk}_{5\text{YearEvent}})$$

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Application of Approach

Underbuilt Only

- Utilized a dataset by the Department of Transportation[1] on the cost of damages associated with overtopping events
  - Direct measures of 21 culvert overtopping events including actual peak flow and damage costs associated with roadway and embankment (low estimate of total cost)
  - Was possible to associate 2 of the incidents with streamgages (Castor River at Zalma State Highway 51, Bolilnger County, Missouri and San Francisco River at U.S. Highway 666 at Clifton, Arizona)
  - Downloaded historical peak flows and estimated exceedence values for 100, 50, 25, 10, and 5 year storm frequencies
  - Assumed cost of damages observed for the given streamflow could be applied as the unit cost for each cubic foot per second of volume above the 2-year storm hydraulic capacity

1. Department of Transportation, Federal Highway Administration (FHWA). (1987). *Development of a Methodology for Estimating Embankment Damage Due to Flood Overtopping.* Available at: http://isddc.dot.gov/OLPFiles/FHWA/009466.pdf.

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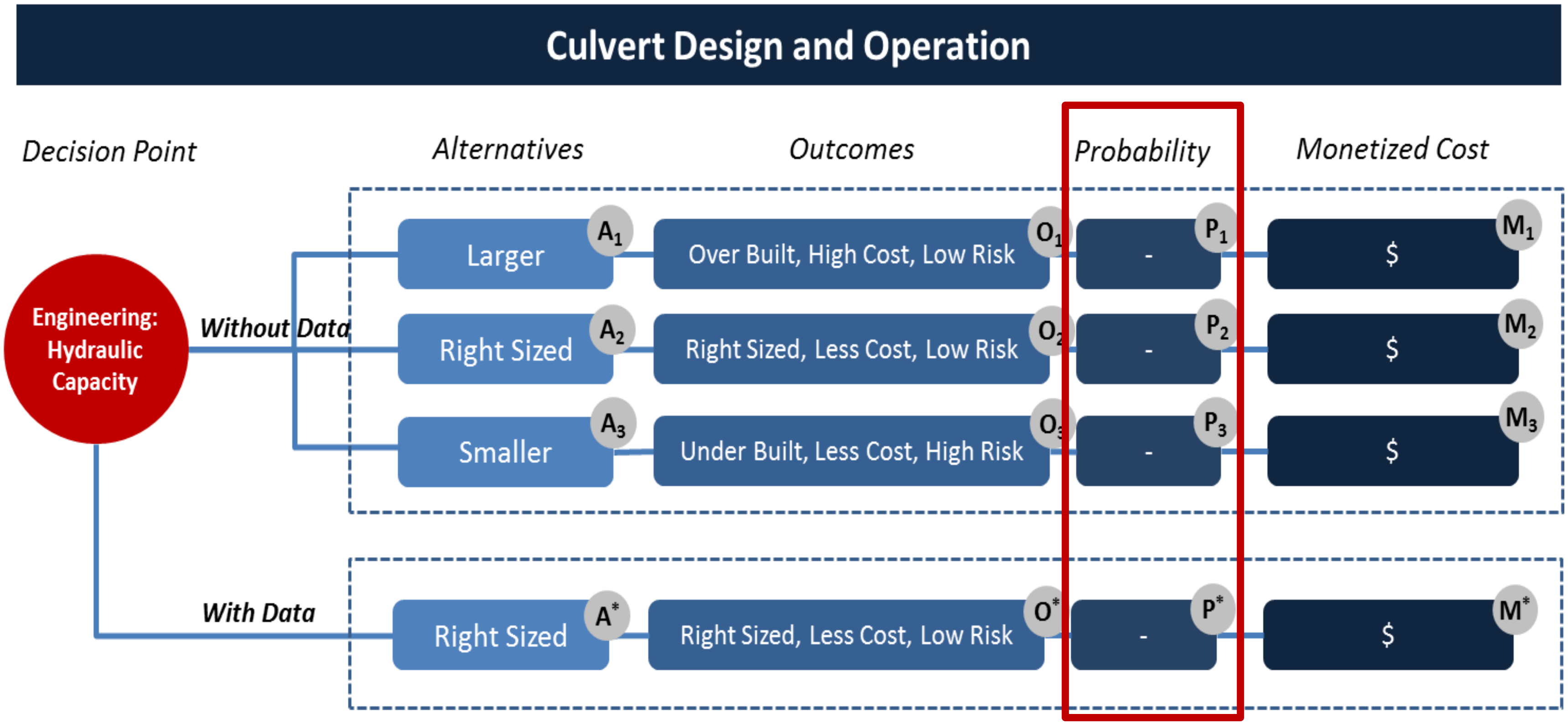
Lessons Learned

- Data, data, data – data may not be available where one might assume records are kept

- Lots of people love streamgages, but it is challenging to quantify value

- The use of data for culvert design and operations was evident in the literature and in talking with federal and state DOTs; however, it was difficult to assess the number that used actual streamgage data (onsite) versus regression equations or other alternatives

Ongoing Challenges



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Ongoing Challenges

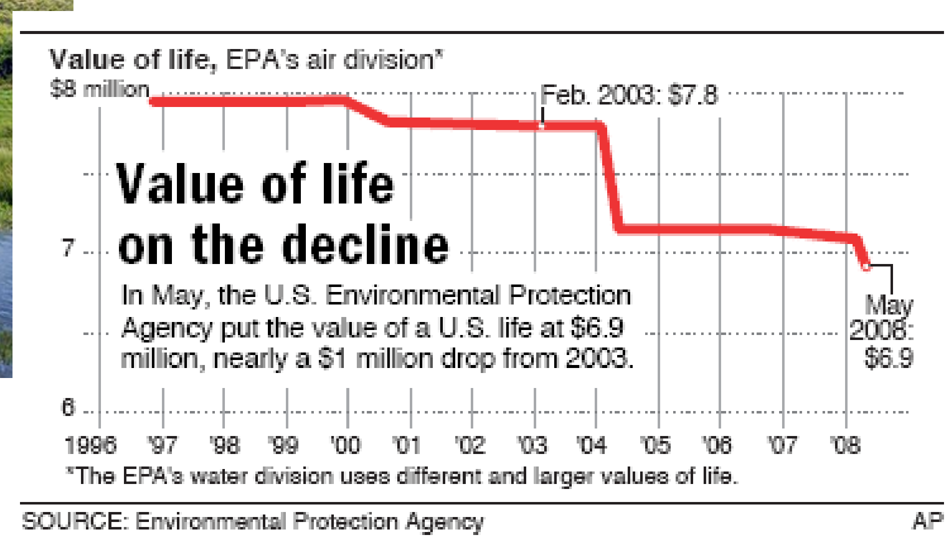
Increasing Information

Bankfull Information → Regression Equations → Onsite Streamgage Data

Ongoing Challenges

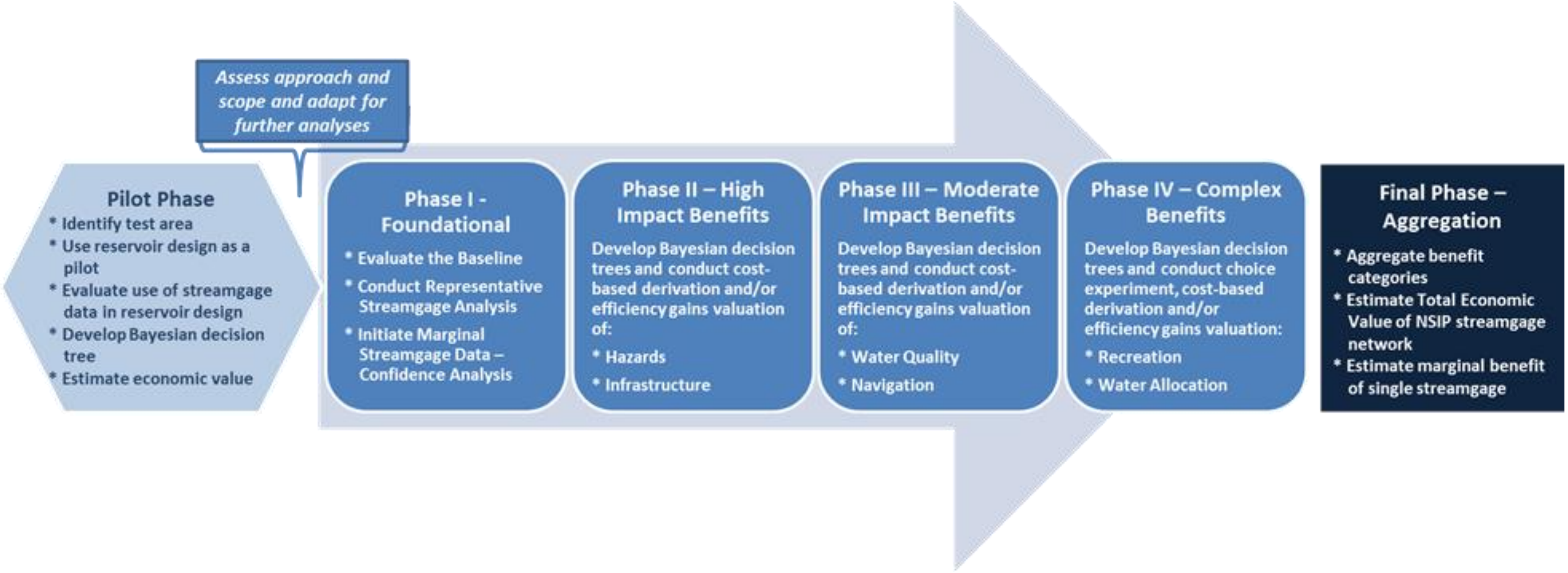
- Rigorous VOI studies are labor and resource intensive
- Non-market valuation


Photo: FWS



Next Steps

- Additional case studies are being conducted with the focus on water use and hydropower in the near-term



For More Information Contact:

Dr. Emily Pindilli
epindilli@usgs.gov
703-648-5732