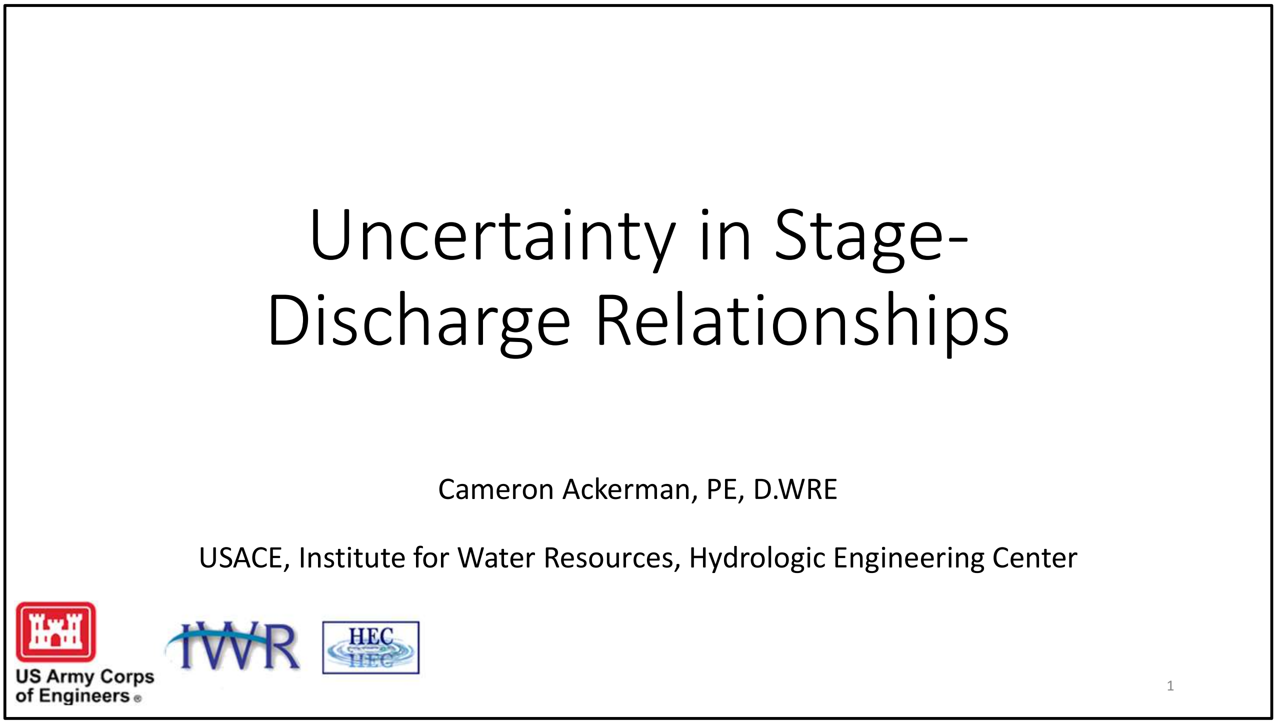

Uncertainty in Stage-Discharge Relationships

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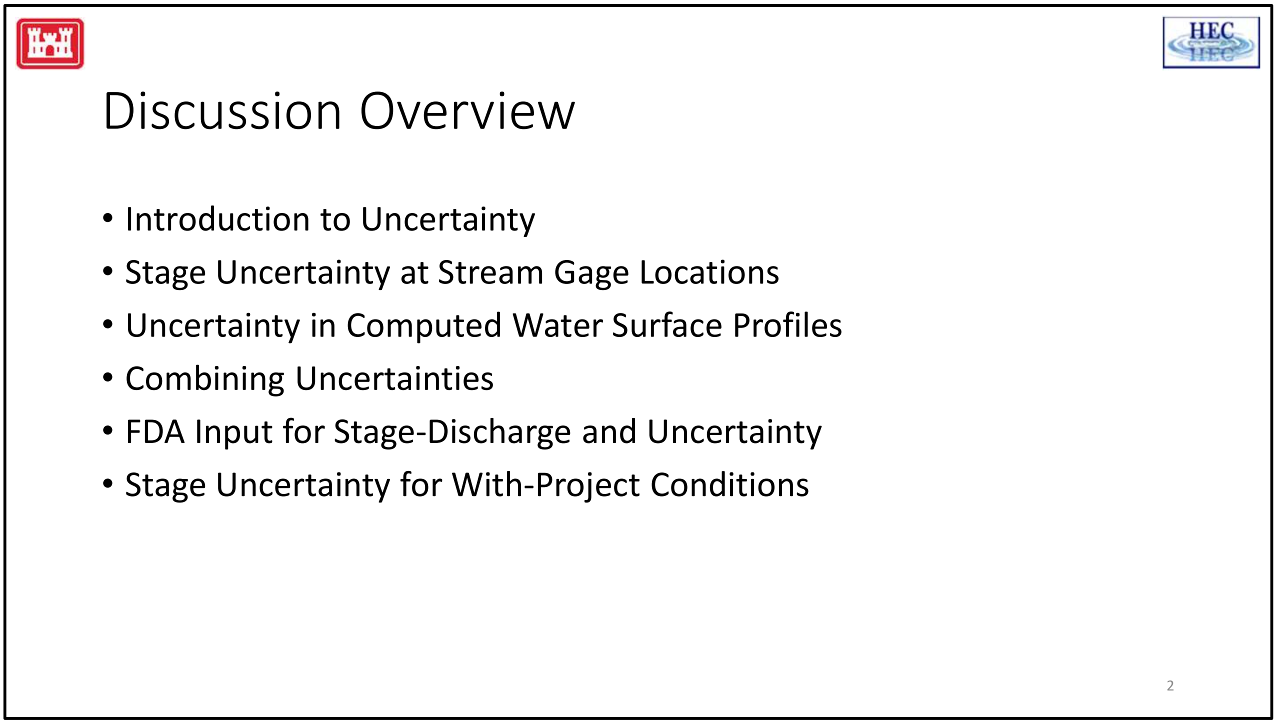
USACE, Institute for Water Resources, Hydrologic Engineering Center

In this presentation we will discuss Uncertainty in Stage-Discharge Relationships for performing Risk Based Flood Damage Analysis.

Much of this presentation, data, and methods were developed by Gary Brunner (and can be found in Chapter 3 of EM 1619)

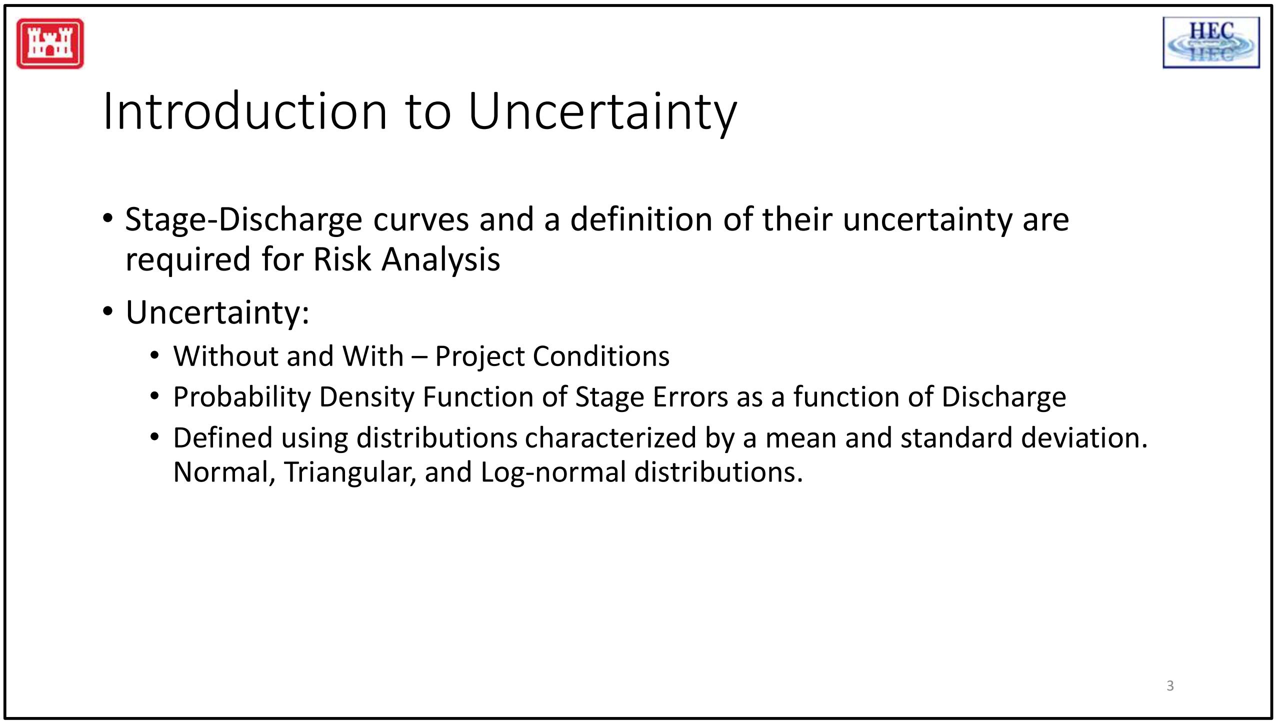


Discussion Overview

- Introduction to Uncertainty
- Stage Uncertainty at Stream Gage Locations
- Uncertainty in Computed Water Surface Profiles
- Combining Uncertainties
- FDA Input for Stage-Discharge and Uncertainty
- Stage Uncertainty for With-Project Conditions

In this presentation we will provide you with
-an introduction to stage-discharge uncertainty
-discuss stage uncertainty as it pertains to stream gage locations
-discuss uncertainty related to computed water surface profiles and combining stage uncertainties

- Show how to input a stage-discharge function with uncertainty into HEC-FDA
- And discuss it use for evaluating with-project conditions



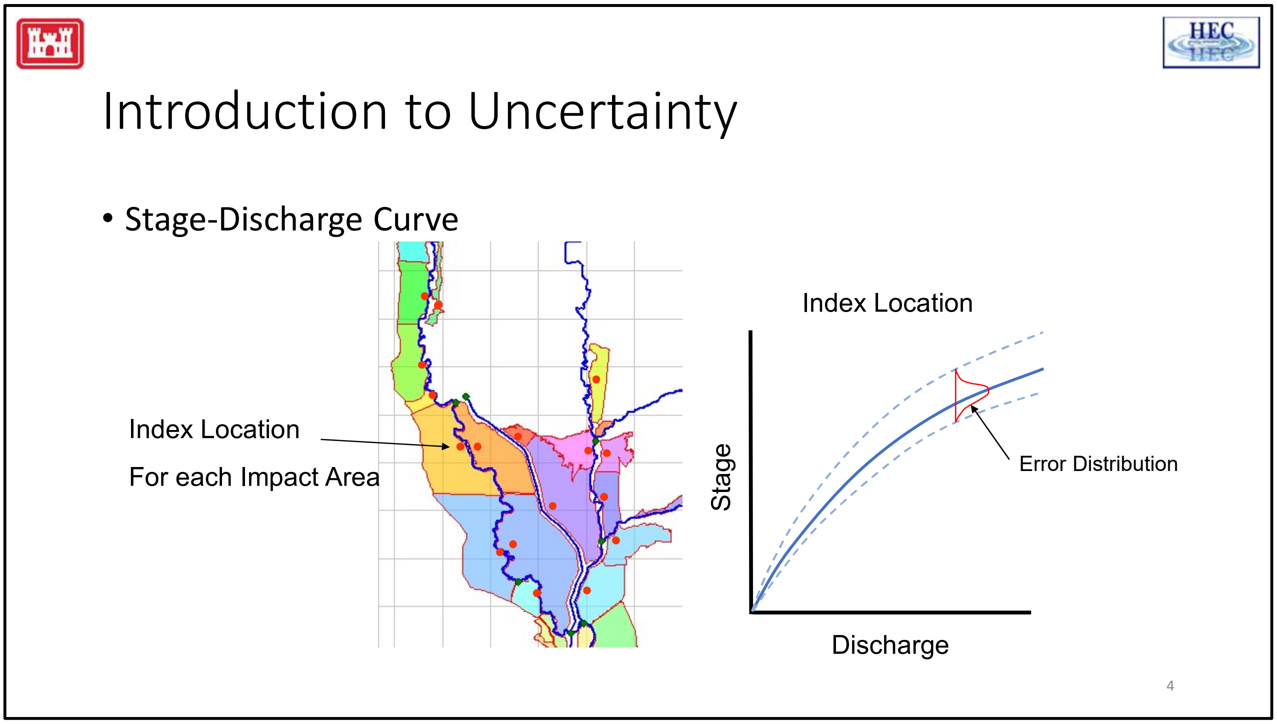
Introduction to Uncertainty

- Stage-Discharge curves and a definition of their uncertainty are required for Risk Analysis
- Uncertainty:
  - Without and With – Project Conditions
  - Probability Density Function of Stage Errors as a function of Discharge
  - Defined using distributions characterized by a mean and standard deviation. Normal, Triangular, and Log-normal distributions.

Corps Guidance requires Risk Analysis be performed for any planning study. In order to perform risk based analysis, we need to have stage-discharge curves and a definition of their uncertainty.

At a minimum, you must perform analysis for the existing conditions (without- project) and the with–project conditions

Because we must create a relationship for out with-project conditions, we most likely will need to develop a river hydraulics model to develop a mean stage-discharge relationship and define the uncertainty about the rating with a Probability Density Function. This PDF is characterized by a mean and standard deviation using either a normal, triangular or log-normal distribution.



Introduction to Uncertainty

- Stage-Discharge Curve

Impact areas are used by FDA to group (or aggregate) structures together when considering flood damage.
Flood damage throughout an impact area is aggregated to specific location called index locations.
Impact areas defined by economic type (such as agriculture vs urban)
and further by hydraulics conditions such that the water surface can be used consistently (constant slopes, river formations, etc.)

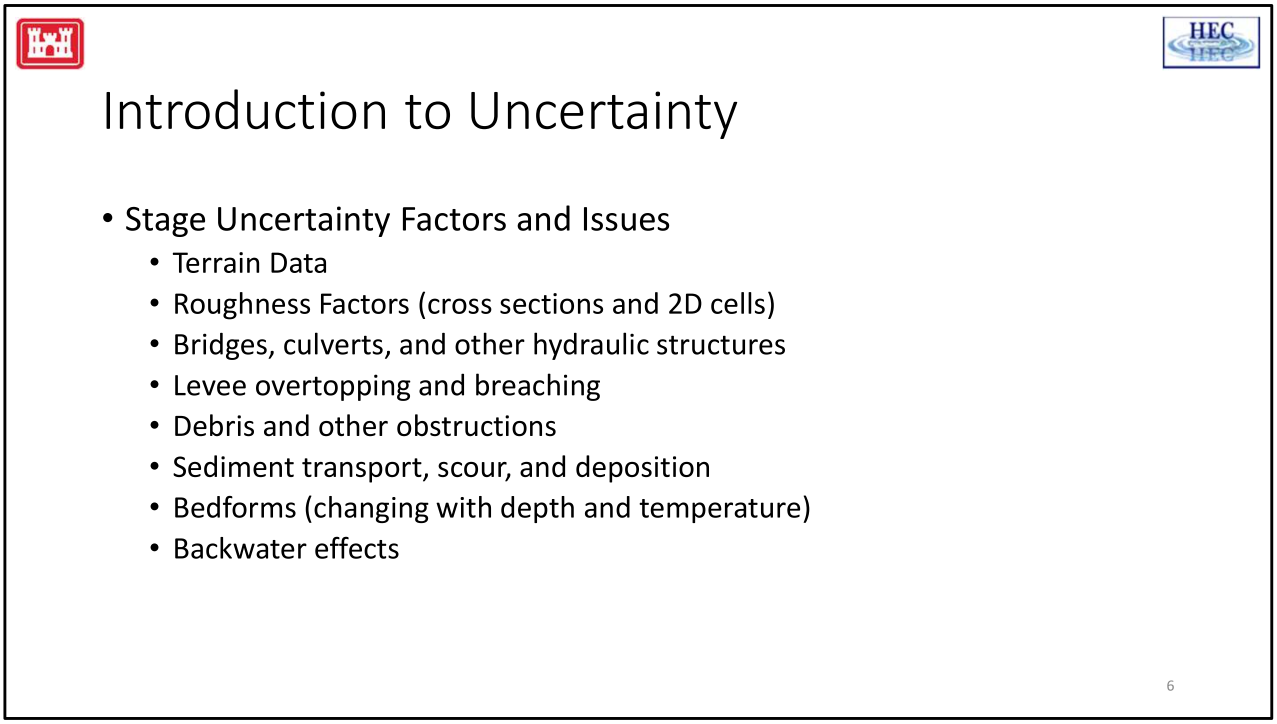
For risk and uncertainty calculations it is necessary to aggregate damages to the index location, in order to be able to quantify the uncertainty in the calculations. This is due to the fact that risk and uncertainty calculations require thousands of iterations (normally 10000 or more) using Monte Carlo Simulation procedures to determine the risk and uncertainty. Therefore Stage-Discharge relationships with uncertainty bands are required as input to each of the index locations.

The objective of this this discussion is to explore how we can determine the uncertainty in Stage-Discharge relationships (Observed and computed), which ultimately will be used in the calculation of flood damages and risk and uncertainty calculations.

Introduction to Uncertainty

- Develop Stage-Discharge Curves by the following methods:
  - Measured Stream flow Data (gaged locations)
  - Computed Water Surface Profiles
    - Steady-flow analysis
    - Unsteady-flow analysis
    - Movable-bed analysis
    - Multi-dimensional modeling

We can develop Stage-Discharge curves from observed/measured data or by computed water surface profiles.
Typically, don’t have a long enough record to used observed data, so we have to compute water surface profile information through river hydraulics modeling to develop Stage-Discharge information.
Modeling can be performed through steady-flow analysis, unsteady-flow or multi-dimensional modeling



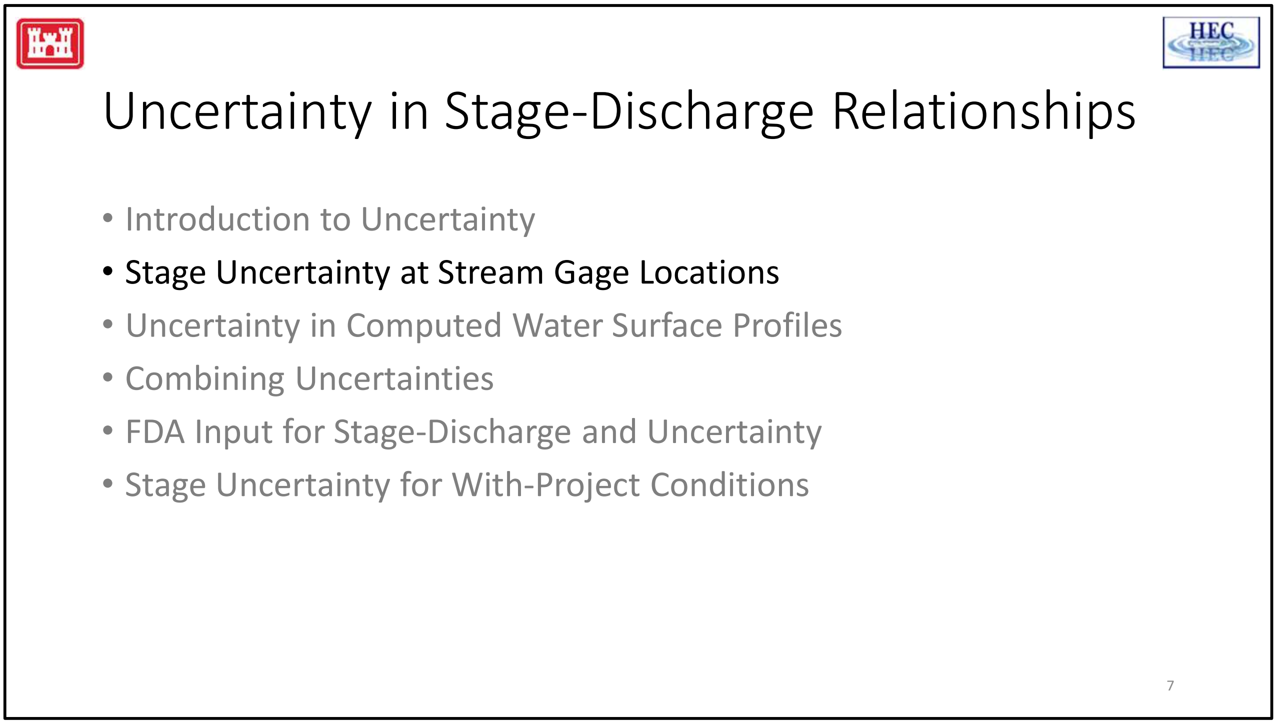
Introduction to Uncertainty

- Stage Uncertainty Factors and Issues
  - Terrain Data
  - Roughness Factors (cross sections and 2D cells)
  - Bridges, culverts, and other hydraulic structures
  - Levee overtopping and breaching
  - Debris and other obstructions
  - Sediment transport, scour, and deposition
  - Bedforms (changing with depth and temperature)
  - Backwater effects

Because modelling is likely to be performed to develop the stage-discharge relationship, it is important to identify and attempt to quantify the uncertainty associated with modelling parameters.

These modelling parameters likely to affect results are:

Terrain Data
Roughness Factors (cross sections and 2D cells)
Hydraulic structures such as Bridges and culverts
Levee overtopping and breaching
Debris and other obstructions
Sediment transport, scour, and deposition
Bedforms (changing with depth and temperature)
Backwater effects



Uncertainty in Stage-Discharge Relationships

- Introduction to Uncertainty
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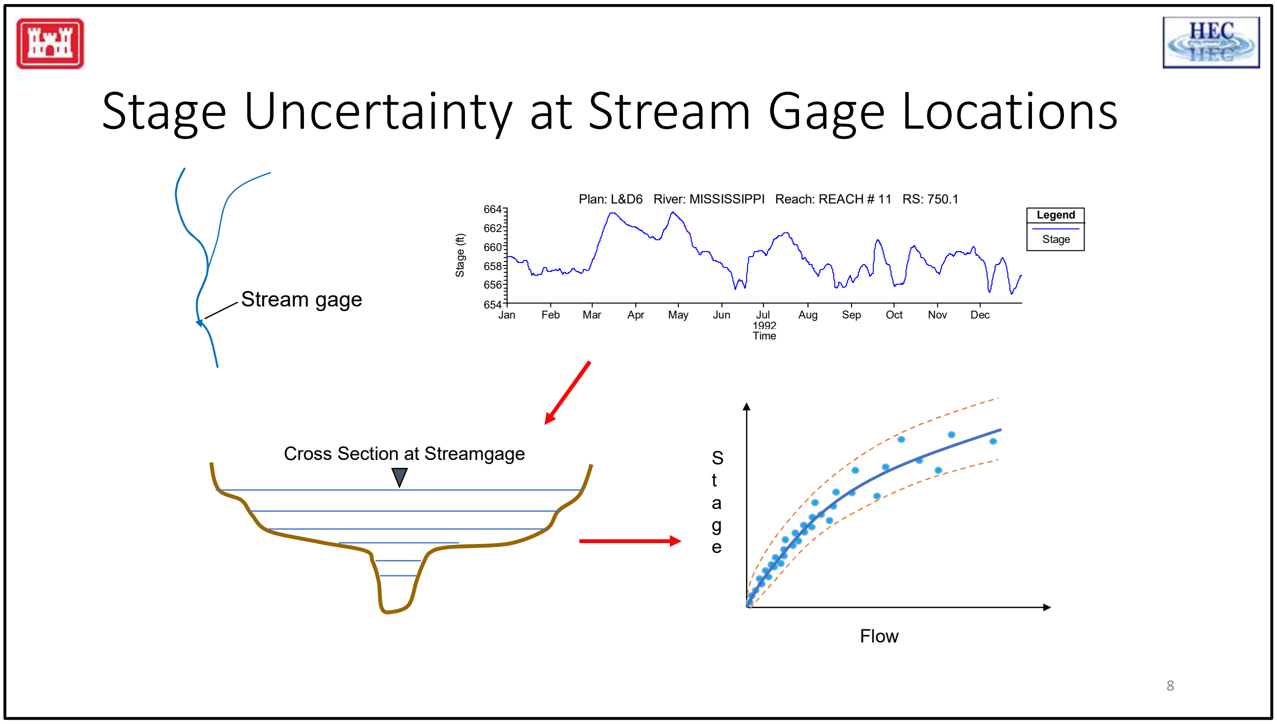
We will now discuss uncertainty in observed data at stream gage locations

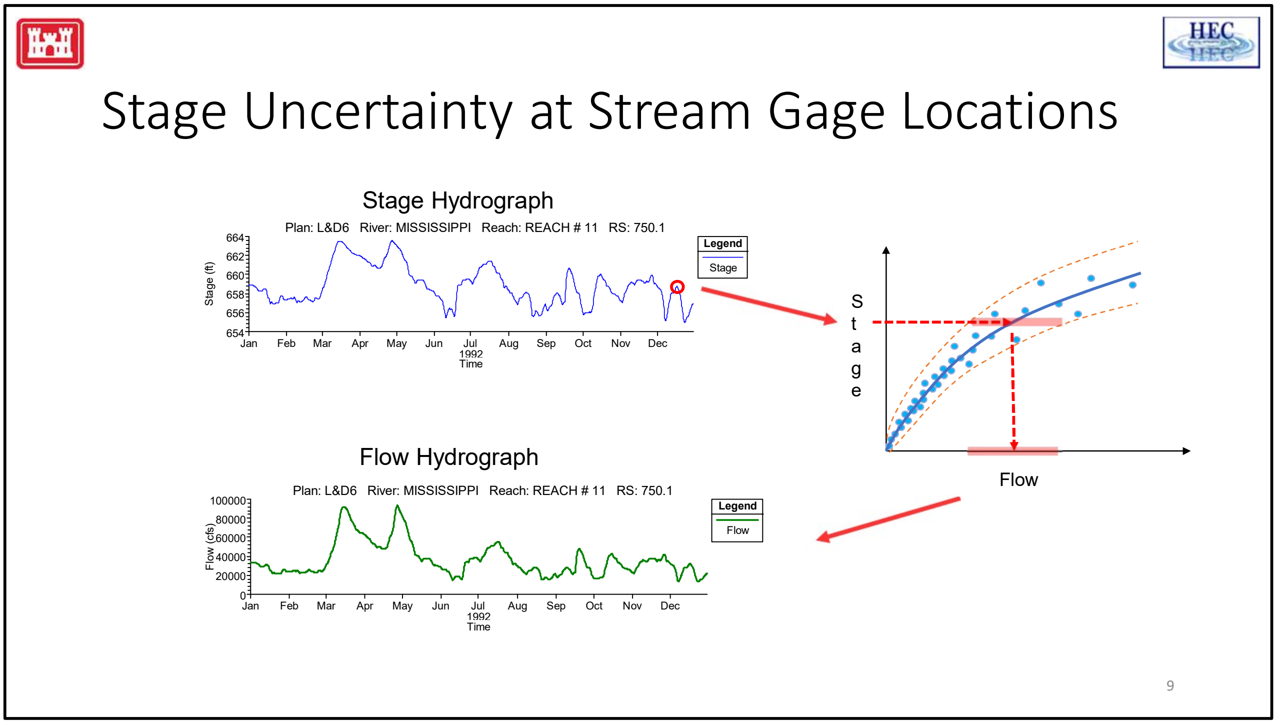


Stage Uncertainty at Stream Gage Locations

The development of a rating curve is performed by the USGS a selection location on a river. It is constructed based on a collection of observed water surface elevations and velocity measurements for a giving cross section. To construct an accurate rating, you must have enough measurements to characterize the range of flows.

However, there is measurement uncertainty both with the measuring device, reading the device, possibility that the cross section is shape is changing, slope of the water surface is changing / looping the rating curve due the shape of the hydrograph or backwater effects.

The blue dots represent observed stage and resultant computed flow for the observations at the gage location. The line represents the computed mean rating curve for the location.

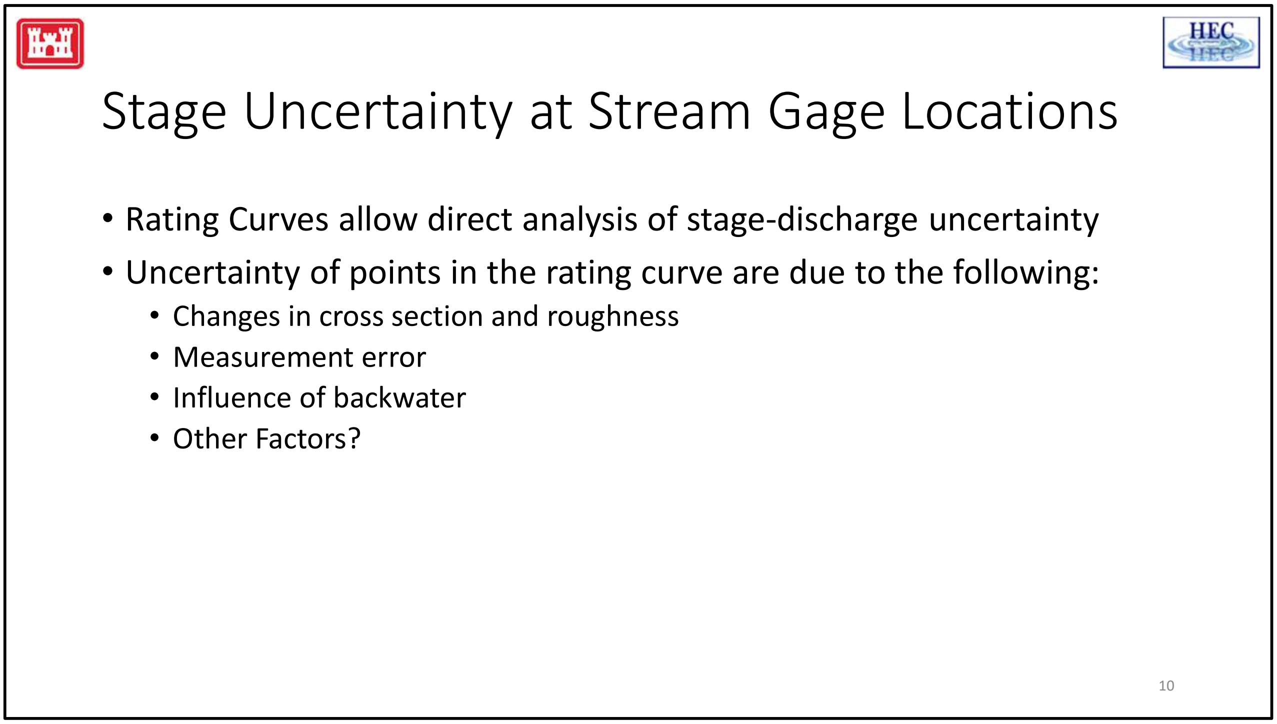


Stage Uncertainty at Stream Gage Locations

Uncertainty with the published data. Once the USGS has a published rating of Stage vs Flow, it then uses that rating curve to publish future data collection.
During a flow event, they may record a stage at a gage and then publish the observed flow.

This observed flow is then NOT measured but computed based on the stage and the MEAN rating curve.

When performing a hydraulic study, the modeler should download the measure points and get an idea for how accurate the data are – how much to trust the rating curve.

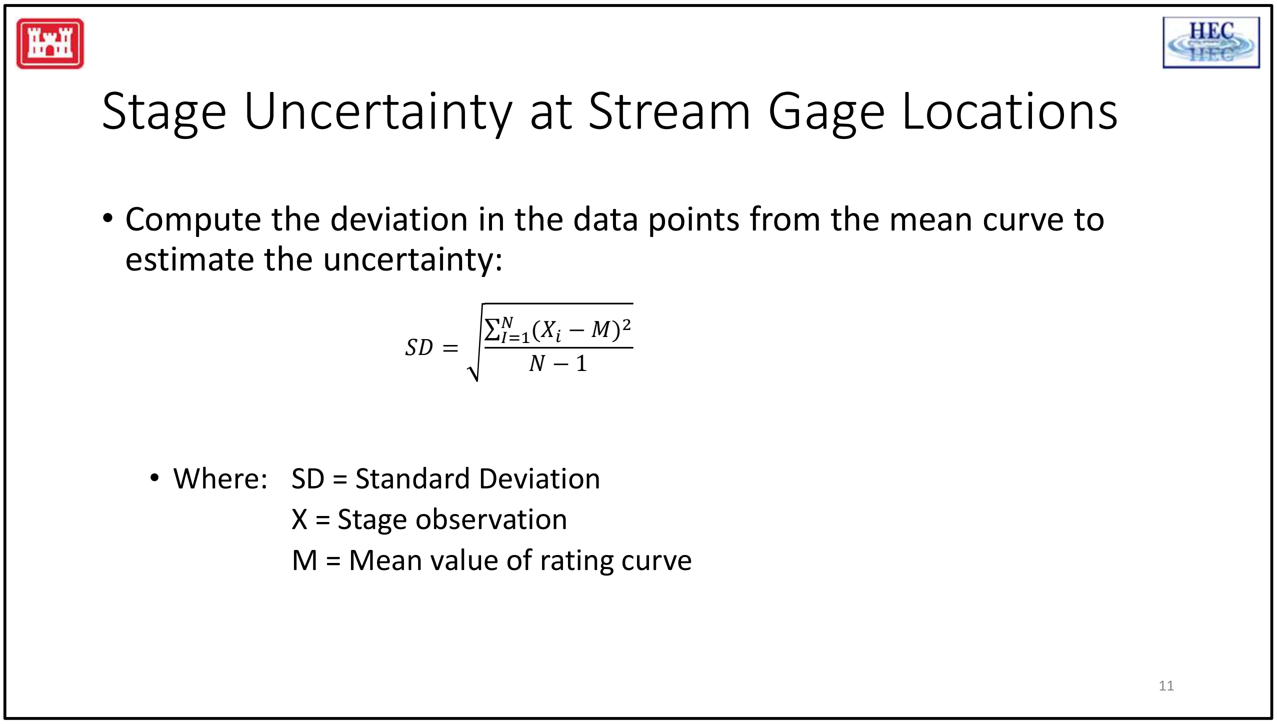


Stage Uncertainty at Stream Gage Locations

- Rating Curves allow direct analysis of stage-discharge uncertainty
- Uncertainty of points in the rating curve are due to the following:
  - Changes in cross section and roughness
  - Measurement error
  - Influence of backwater
  - Other Factors?

Summary of uncertainty in developing and use of a rating curve for published data.

-Changes in the cross section overtime and during a flow event.
-Changes to surface roughness during the flow event and seasonally
-Errors in measurement
-Downstream influences resulting in backwater affect
-Loop in rating due to the shape of the hydrograph (is it rising or falling)



Stage Uncertainty at Stream Gage Locations

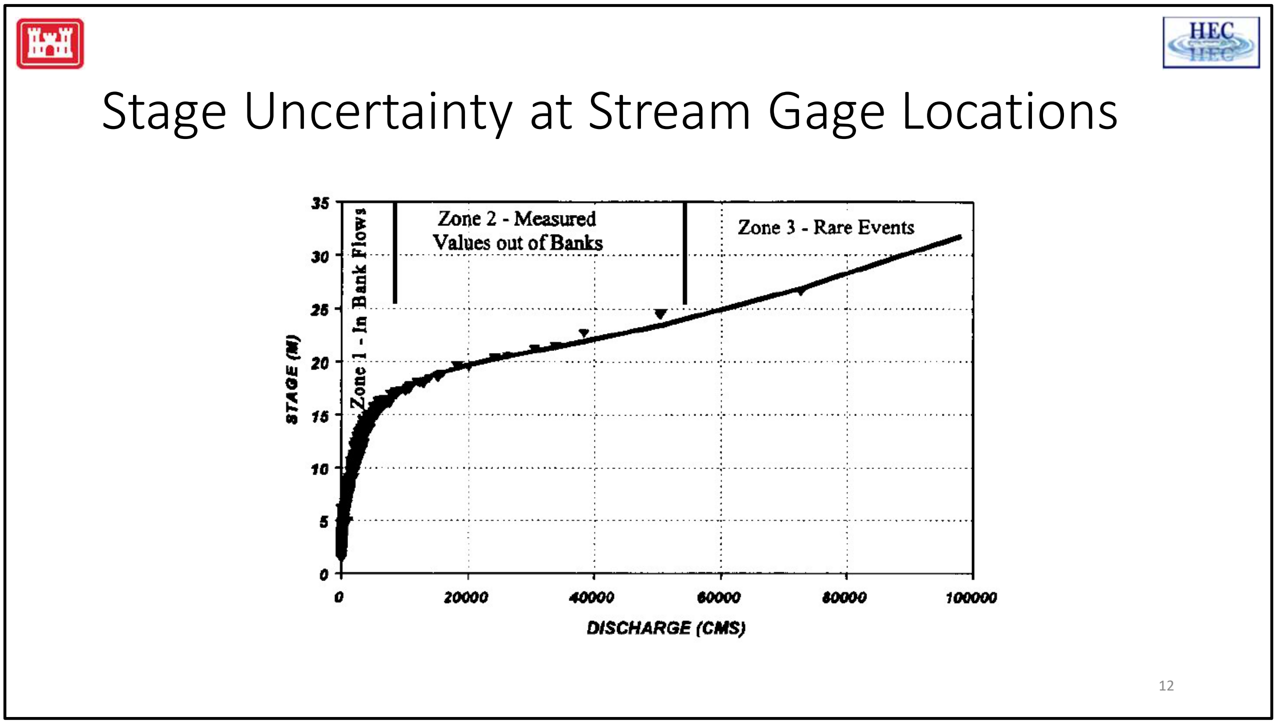
- Compute the deviation in the data points from the mean curve to estimate the uncertainty:

$$SD = \sqrt{\frac{\sum_{I=1}^{N}(X_i - M)^2}{N-1}}$$

- Where:
  SD = Standard Deviation
  X = Stage observation
  M = Mean value of rating curve

If all you have is a stream gage rating curve, you can use the observed data point and compute the deviation in the uncertainty from the mean rating curve.

This would be done based on ranges of flows that have a consistent relationship based on flow and geometry interaction (in bank, floodplain, etc).



Stage Uncertainty at Stream Gage Locations

The standard deviation about the mean curve should be computed in zones along the curve. The standard deviation will normally be smaller at low flows, and then increase with increases in flow rate.

Want to compute the uncertainty for various flows (here shown for 3 different flow zones).

Uncertainty in Stage-Discharge Relationships

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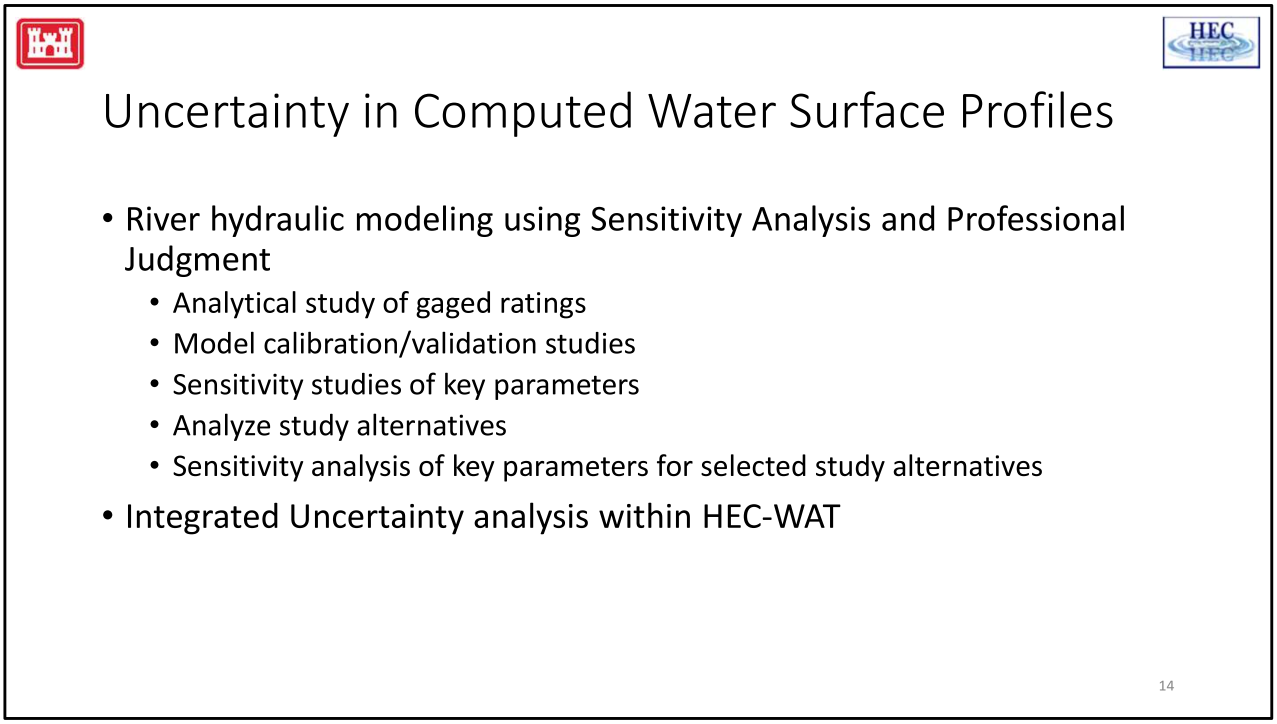
We will now discuss uncertainty in computed water surface profiles based on hydraulic modeling.



Uncertainty in Computed Water Surface Profiles

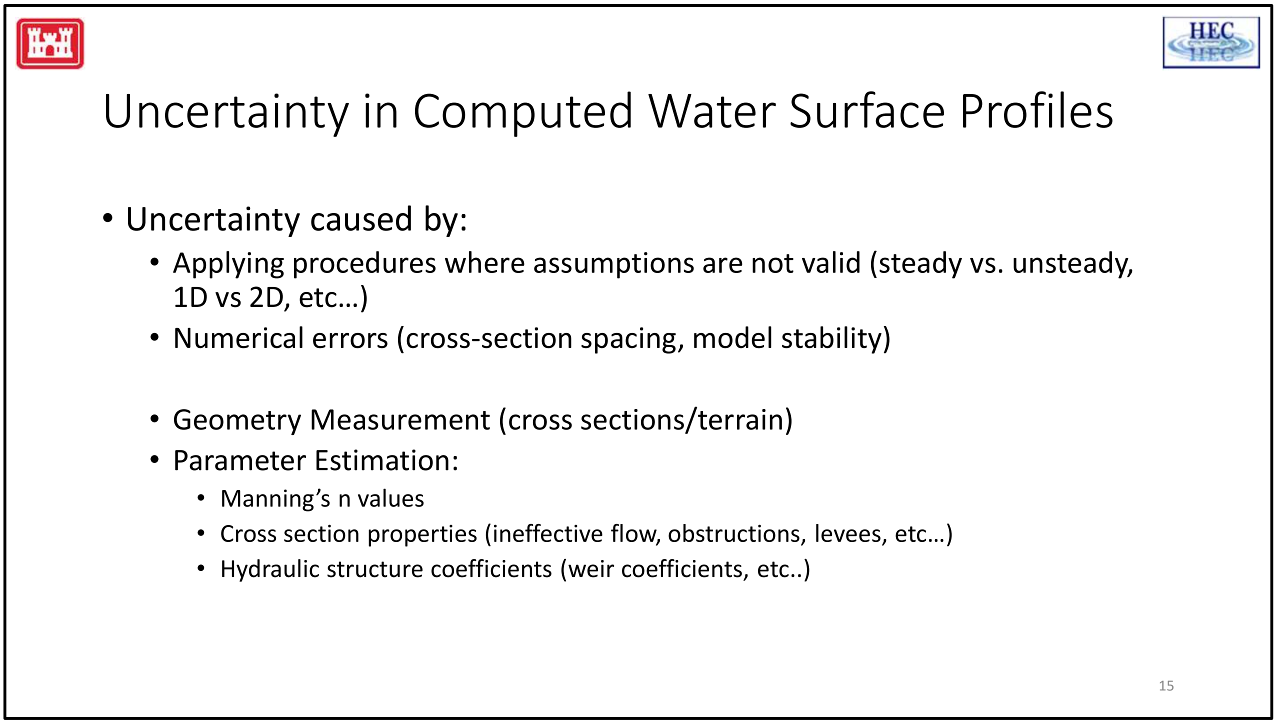
- River hydraulic modeling using Sensitivity Analysis and Professional Judgment
  - Analytical study of gaged ratings
  - Model calibration/validation studies
  - Sensitivity studies of key parameters
  - Analyze study alternatives
  - Sensitivity analysis of key parameters for selected study alternatives
- Integrated Uncertainty analysis within HEC-WAT

River hydraulic modeling using sensivity analysis and professional judgement is performed by

-evaluating data from gaged ratings

- Performing a model calibration and validation to a range flow events
- Performing a sensitivity analysis of key parameters
- Analyzing study alternatives and model sensitivity to those models

In a more complicated uncertainty analysis, the HEC-WAT can be used to drive the perturbations of all of the significant model parameters driving uncertainty



Uncertainty in Computed Water Surface Profiles

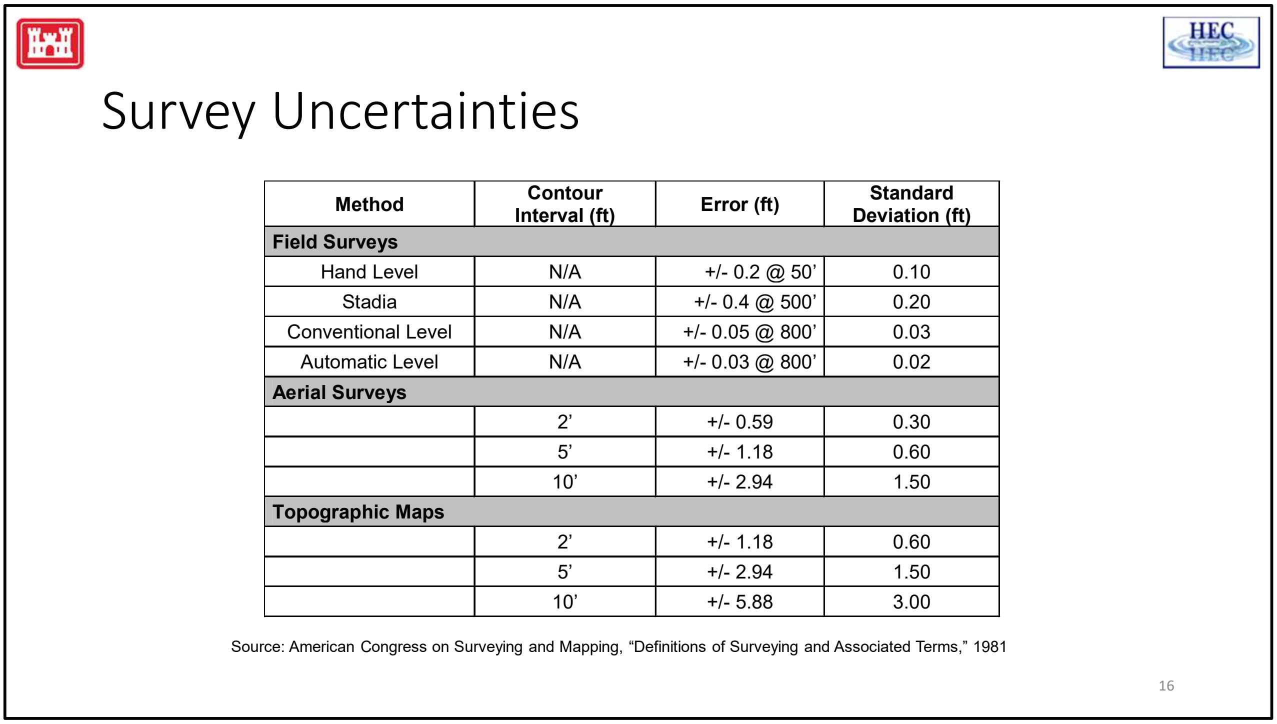
- Uncertainty caused by:
  - Applying procedures where assumptions are not valid (steady vs. unsteady, 1D vs 2D, etc…)
  - Numerical errors (cross-section spacing, model stability)

  - Geometry Measurement (cross sections/terrain)
  - Parameter Estimation:
    - Manning's n values
    - Cross section properties (ineffective flow, obstructions, levees, etc…)
    - Hydraulic structure coefficients (weir coefficients, etc..)

Uncertainty in computed water surface profiles from hydraulic models is caused by:
- Applying incorrect procedures
- And numerical errors due to cross section spacing and model stability

Hydraulic modeler trained to identify the appropriate modeling method to utilize and develop sound models.

However, there is uncertainty in data collection and parameter estimation.
The main factors that affect model uncertainty come from
- Measurement of Geometry data such as cross sections and terrain
- And Parameters such as Manning's n values, cross section properties (such as ineffective flow areas, levees), and hydraulic structure coefficients (weir, gate, culvert coefficients).



Survey Uncertainties

Method	Contour Interval (ft)	Error (ft)	Standard Deviation (ft)
Field Surveys			
Hand Level	N/A	+/- 0.2 @ 50’	0.10
Stadia	N/A	+/- 0.4 @ 500’	0.20
Conventional Level	N/A	+/- 0.05 @ 800’	0.03
Automatic Level	N/A	+/- 0.03 @ 800’	0.02
Aerial Surveys			
	2’	+/- 0.59	0.30
	5’	+/- 1.18	0.60
	10’	+/- 2.94	1.50
Topographic Maps			
	2’	+/- 1.18	0.60
	5’	+/- 2.94	1.50
	10’	+/- 5.88	3.00

Source: American Congress on Surveying and Mapping, “Definitions of Surveying and Associated Terms,” 1981

Based on published data on the uncertainty in terrain data based on various survey methods,
HEC sought to take the data to develop a regression equation to describe the uncertainty in computed Water Surface Elevations based on the accuracy of the Terrain.
Gary Brunner, used the data for Monte Carlo Analysis to perturbate 1D hydraulic model cross sections assuming a level of survey accuracy to run 10,000 events.
The results could then be used to see how the water surface elevations accuracy was affected.

Survey and mapping accuracy of data >> an equation for uncertainty simply based on the UNCERTAINTY in the TERRAIN.

*This data is from 1981 and probably should be updated. Terrain accuracy should probably increase as survey technology has improved, thereby reducing overall uncertainty.

Standard Deviation of Error in WS Elevation due to Uncertainty in the underlying Terrain

- Traditional Field Surveying Methods:

$$SD = 0.0$$

- Aerial Spot Elevations (Photogrammetry and Lidar):

$$SD = 0.0657 \times S_0^{0.592} \times S_n^{0.738}$$

- USGS Topographic Data (DEM’s):

$$SD = 0.484 \times S_o^{0.345} \times S_n^{1.095}$$

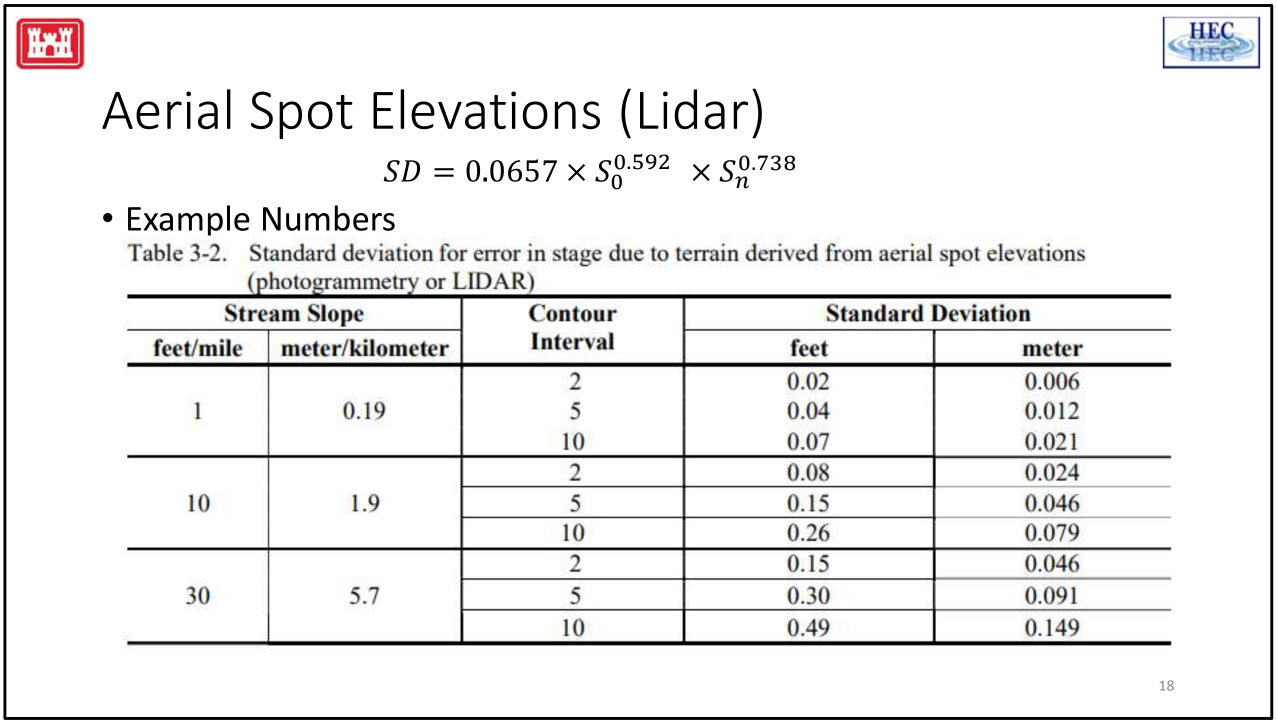
If cross sections and first floor elevations are obtained from traditional survey methods, then the user can assume the Standard deviation of the error in computing the water surface elevation, due to the terrain data, is zero.

If terrain data are derived from aerial spot elevations (photogrammetry or lidar), or USGS topographic Maps (DEM’s), then the regression equations shown above can be used to estimate the standard deviation of error in computed water surface elevations due to the accuracy of the terrain data.

Where: SD = Standard Deviation (ft) of the error in the computed water surface elevation due solely to the accuracy of the terrain data and the slope of the stream.

S_0 = Slope of the stream in ft/mile.

S_n = The standardized survey accuracy being analyzed – the contour interval 2-, 5-, 10-feet divided by 10. (i.e. if the data is considered to be accurate to the 2 foot contour interval then $S_n = 2/10 = 0.2$).



Aerial Spot Elevations (Lidar)

$$SD = 0.0657 \times S_0^{0.592} \times S_n^{0.738}$$

- Example Numbers

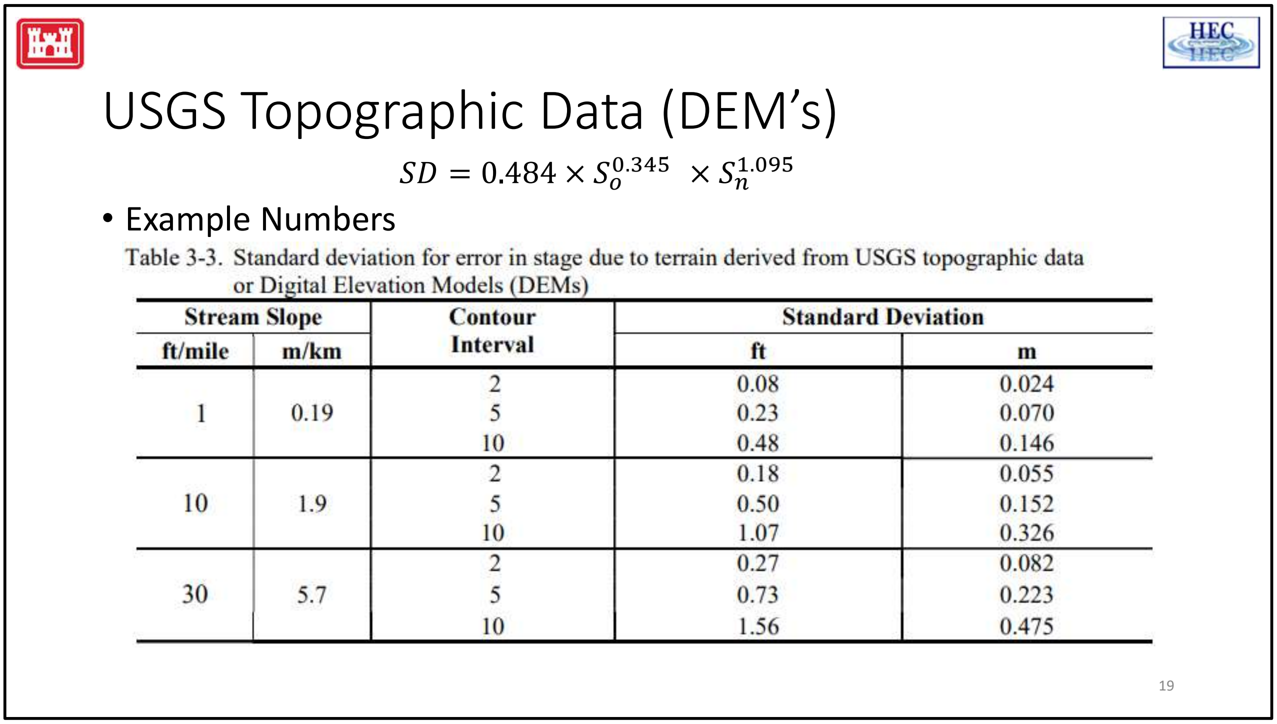
Table 3-2. Standard deviation for error in stage due to terrain derived from aerial spot elevations (photogrammetry or LIDAR)

Stream Slope		Contour Interval	Standard Deviation	
feet/mile	meter/kilometer		feet	meter
1	0.19	2	0.02	0.006
		5	0.04	0.012
		10	0.07	0.021
10	1.9	2	0.08	0.024
		5	0.15	0.046
		10	0.26	0.079
30	5.7	2	0.15	0.046
		5	0.30	0.091
		10	0.49	0.149

Note: The above regression equations were derived from data with the following ranges:

Contour Interval accuracy from 2 to 10 feet.
Stream slopes from 0.5 ft/mi t0 106 ft/mi

If these equations are applied to values outside the range of this data, the user must ensure that the resulting Standard Deviations are reasonable and not wild due to extrapolation of the regression equations.



USGS Topographic Data (DEM's)

$$SD = 0.484 \times S_o^{0.345} \times S_n^{1.095}$$

- Example Numbers

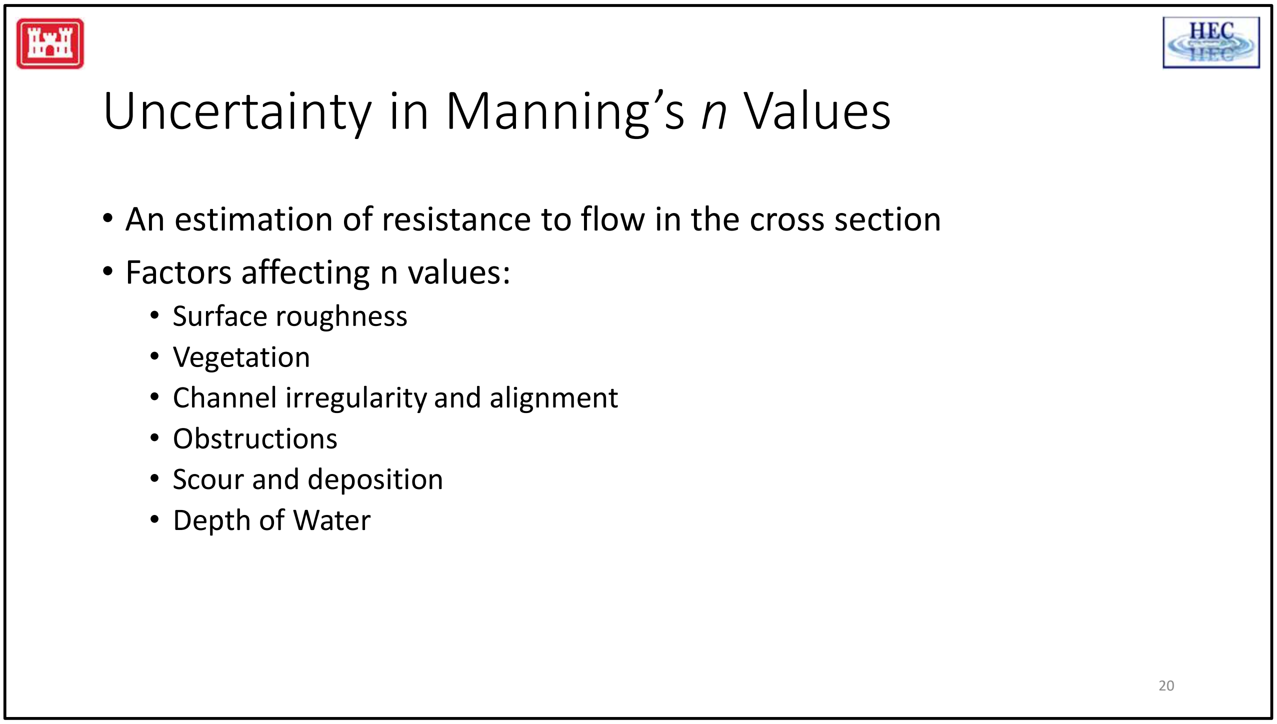
Table 3-3. Standard deviation for error in stage due to terrain derived from USGS topographic data or Digital Elevation Models (DEMs)

Stream Slope		Contour Interval	Standard Deviation	
ft/mile	m/km		ft	m
1	0.19	2	0.08	0.024
		5	0.23	0.070
		10	0.48	0.146
10	1.9	2	0.18	0.055
		5	0.50	0.152
		10	1.07	0.326
30	5.7	2	0.27	0.082
		5	0.73	0.223
		10	1.56	0.475

Note: The above regression equations were derived from data with the following ranges:

Contour Interval accuracy from 2 to 10 feet.
Stream slopes from 0.5 ft/mi t0 106 ft/mi

If these equations are applied to values outside the range of this data, the user must ensure that the resulting Standard Deviations are reasonable and not wild due to extrapolation of the regression equations.



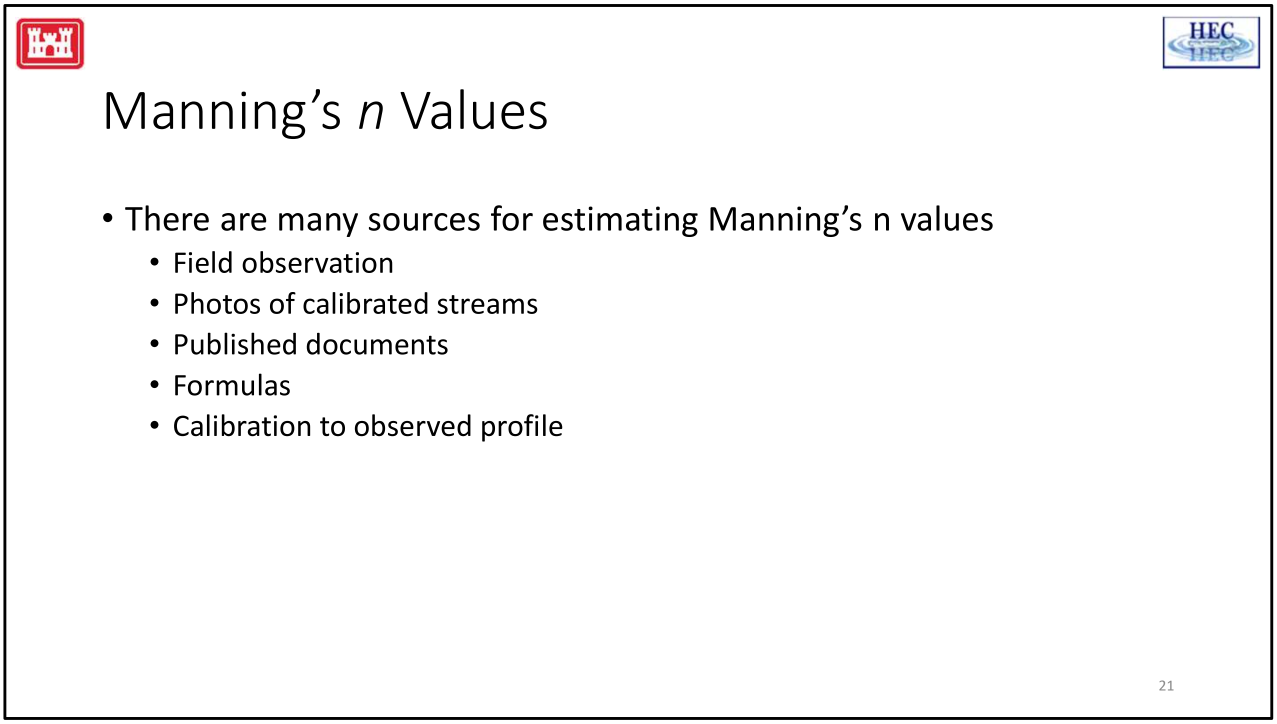
Uncertainty in Manning’s *n* Values

- An estimation of resistance to flow in the cross section
- Factors affecting n values:
  - Surface roughness
  - Vegetation
  - Channel irregularity and alignment
  - Obstructions
  - Scour and deposition
  - Depth of Water

Manning’s *n* values are a measure of resistance to flow in the channel.
Several factors affect *n* values. A description of the many are provide below.

1. Surface roughness – this refers to the size of the material in the bed of the cross section. The *n* value for fines such as silt and clay will be less than that for coarse material such as gravels or boulders. When the bed material is fine the *n* value is relatively unaffected by change in flow stage. When the material is large, the *n* value can be quite high, particularly during low and high stage. At low stage boulders produce obstructions, at high stage energy goes into moving the bed.
2. Vegetation – vegetation can greatly affect *n* values. This may lead to seasonal *n* values, where *n* value are small during winter when the branches are barren, to very high during spring leaf-out. Values may vary by depth based on branching patterns and plant flexibility.
3. Channel irregularity and alignment – channels that are highly irregular in cross section will increase surface roughness compared with those that do not have sand bars, ridges, depressions, and holes and humps. Moreover, a channel that has sharps bends will give higher *n* values than those having smooth curvature.
4. Obstructions – the presence of debris, ice, bridge piers,and other obstructions will increase *n* values.
5. Scour and deposition – silting may take a rough, irregular channel and make it smooth, while scour may create a more irregular channel, thereby affecting surface roughness. Further, energy will be lost during scour, increasing an *n* value.
6. Depth of Water – It has been shown that Manning’s n values can vary with the depth of water

due to the roughness height being relative to the depth of the water.



Manning’s *n* Values

- There are many sources for estimating Manning’s n values
  - Field observation
  - Photos of calibrated streams
  - Published documents
  - Formulas
  - Calibration to observed profile

There are many sources for estimating Manning’s *n* values.

The best method is to have an experienced hydraulic engineer making observations in the field. But as the saying goes: “it takes experience to get experience”.

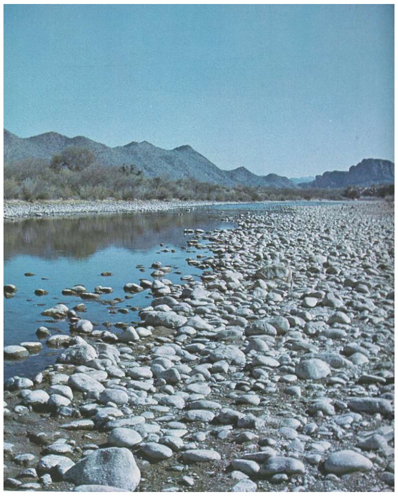
If an engineer is stuck in the office and has pictures, you can compare them to published documents. Or you can rely on formulas which create a composite *n* value based on the characteristics we talked about earlier. You can also use the hydraulic model itself and calibrate *n* values to observed profile data.

In the end, good engineers use all of the methods together to finalize *n* values.

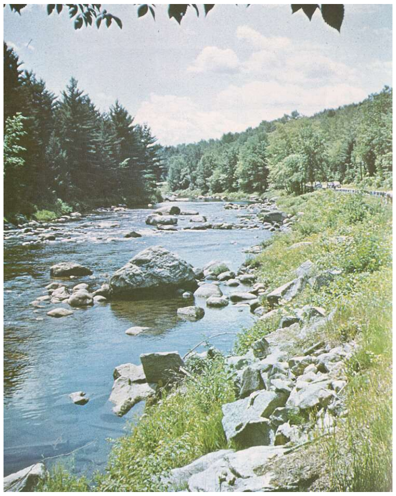
References for estimating Manning’s n values:

1. Chow, VT, 1959. Open-Channel Hydraulics, McGraw-Hill, Inc., USA.
2. Barnes, HH, 1967. Roughness Characteristics of Natural Channels, Geological Survey Water-Supply Paper 1849, USGS.
3. Phillips, JV and TL Ingersoll, 1998. Verification of Roughness Coefficients for Selected Natural and Constructed Stream Channels in Arizona, USGS Professional Paper 1584, USGS.
4. Hicks, DM and PD Mason, 1991. Roughness Characteristics of New Zealand Rivers, Water Resources Survey, New Zealand.

Manning’s *n* Values

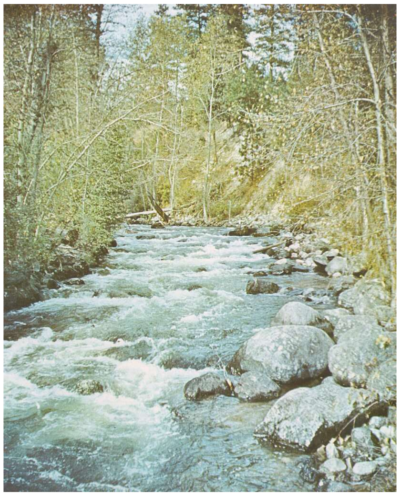


n = 0.032

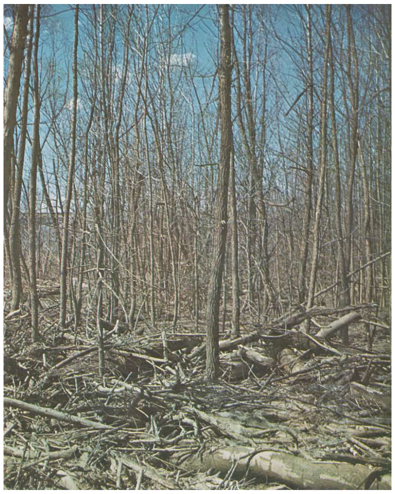


n = 0.055

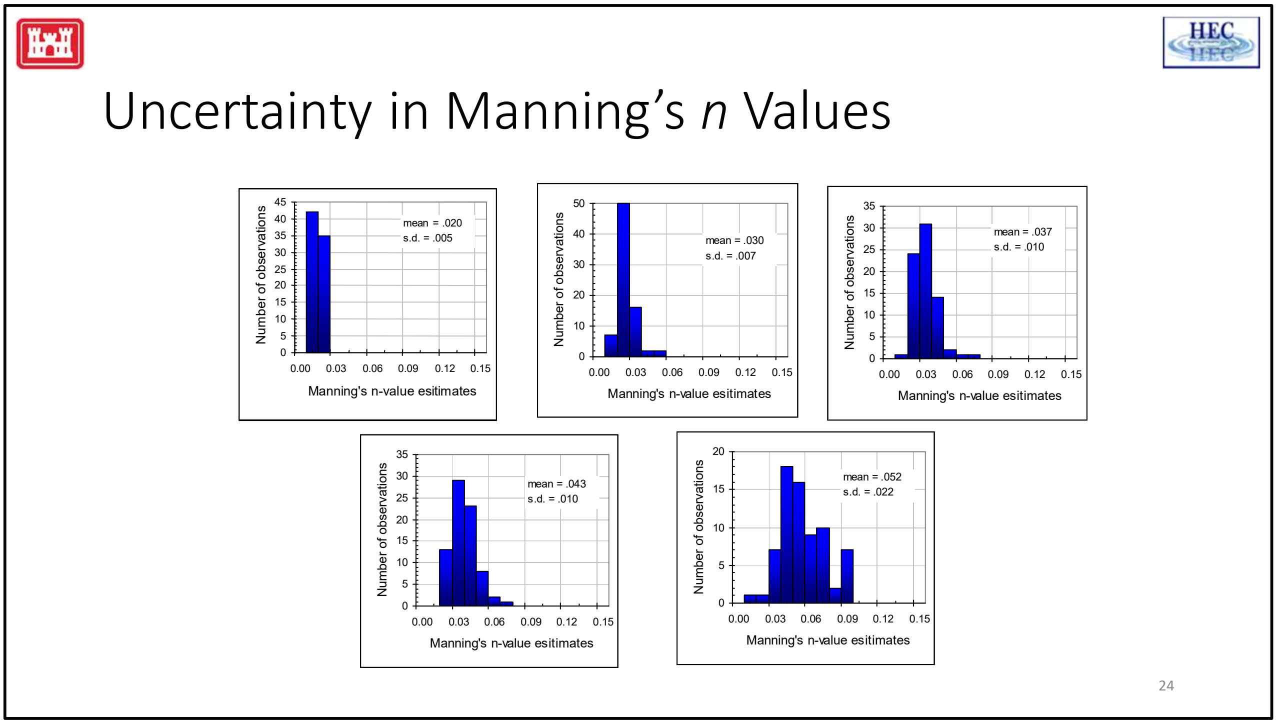
Manning’s *n* Values



$n = 0.075$



$n = 0.097$

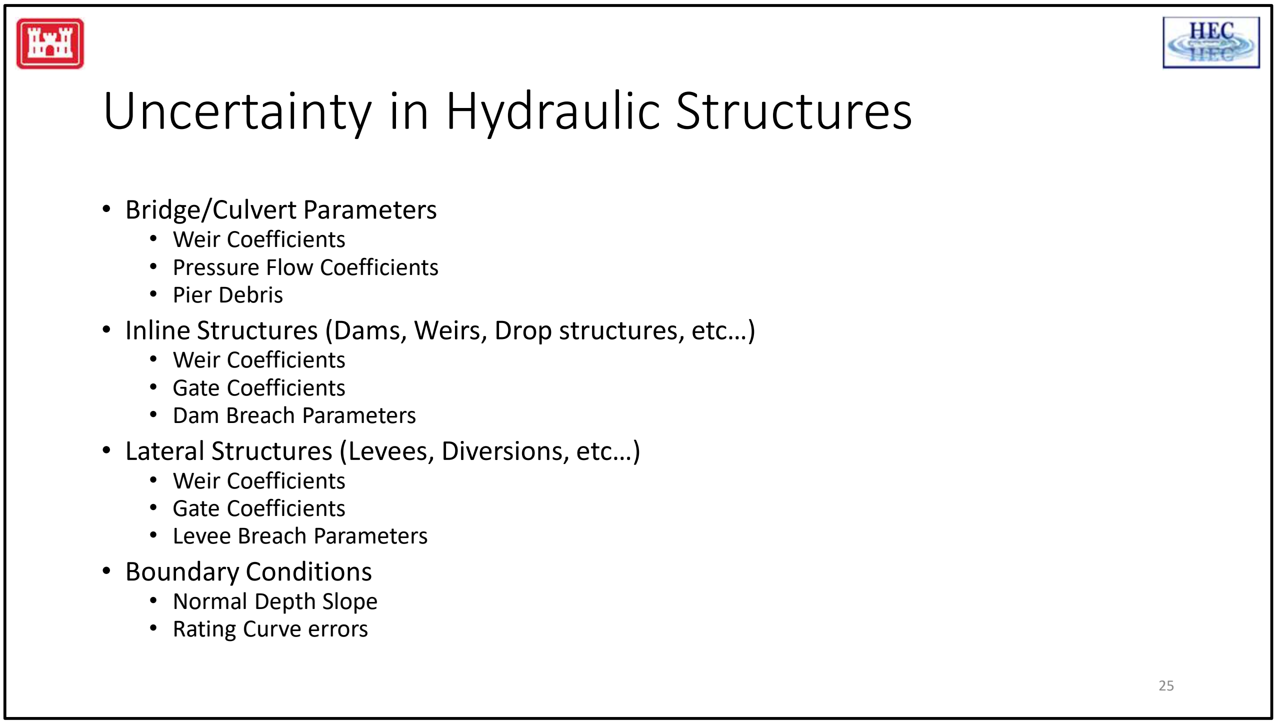


Uncertainty in Manning's *n* Values

These charts are adopted from an HEC research document (RD-26).

Statistics are derived from surveyed engineers. Engineers were shown various river channel cross sections (all are from different streams) and asked to estimate the Manning's *n* value for each of them. Note that the Standard Deviation for the the estimates decreases as the *n* value decrease. What does this tell us about estimating roughness coefficients?

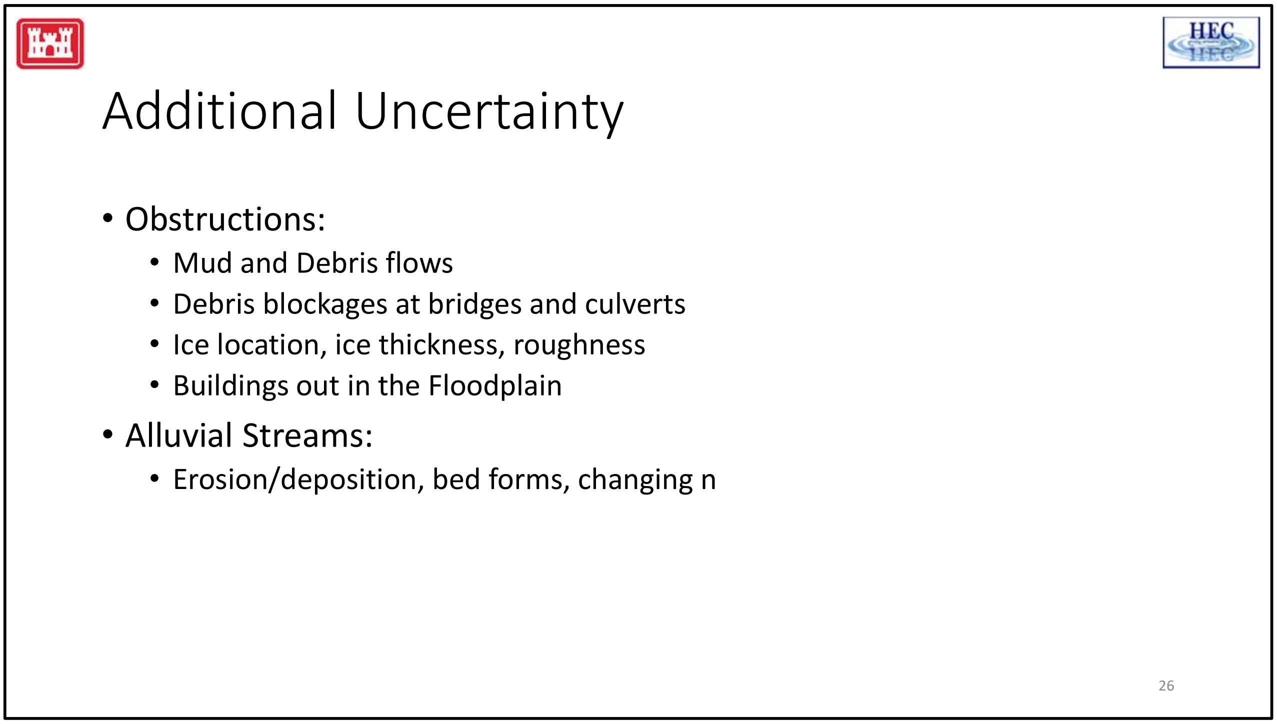
To start with, it is not easy and for any cross section you can get quite a bit of variability in estimates from experienced people. This is due to the tremendous cross-sectional variability.
Second, there is more knowledge and calibrated studies on low *n* value channels. A typical main channel *n* value is 0.035, but if you were to show engineers a concrete lined channel all *n* values would fall between 0.012 and 0.016 (there would be very, very little variability in responses).



Uncertainty in Hydraulic Structures

- Bridge/Culvert Parameters
  - Weir Coefficients
  - Pressure Flow Coefficients
  - Pier Debris
- Inline Structures (Dams, Weirs, Drop structures, etc…)
  - Weir Coefficients
  - Gate Coefficients
  - Dam Breach Parameters
- Lateral Structures (Levees, Diversions, etc…)
  - Weir Coefficients
  - Gate Coefficients
  - Levee Breach Parameters
- Boundary Conditions
  - Normal Depth Slope
  - Rating Curve errors

Other things that MAY need to be considered in the sensitivity



Additional Uncertainty

- Obstructions:
  - Mud and Debris flows
  - Debris blockages at bridges and culverts
  - Ice location, ice thickness, roughness
  - Buildings out in the Floodplain
- Alluvial Streams:
  - Erosion/deposition, bed forms, changing n

There are many additional factors that add uncertainty to a hydraulic model. More complicated a hydraulic models require greater attention to detail. Hydraulic structures need scrutiny to decide upon coefficients – will the bridge be submerged or not during any event? It is also difficult to predict obstructions to flow developing. Will a debris or ice jam occur during a given flow? Where will it occur? And what will it look like? All are questions that need to be addressed.

We also don't model the bed moving. In reality, the river bed may be eroding or aggregating. How will this affect my results? The river may pick up large amounts of the bed, thereby increasing the volume moving downstream.

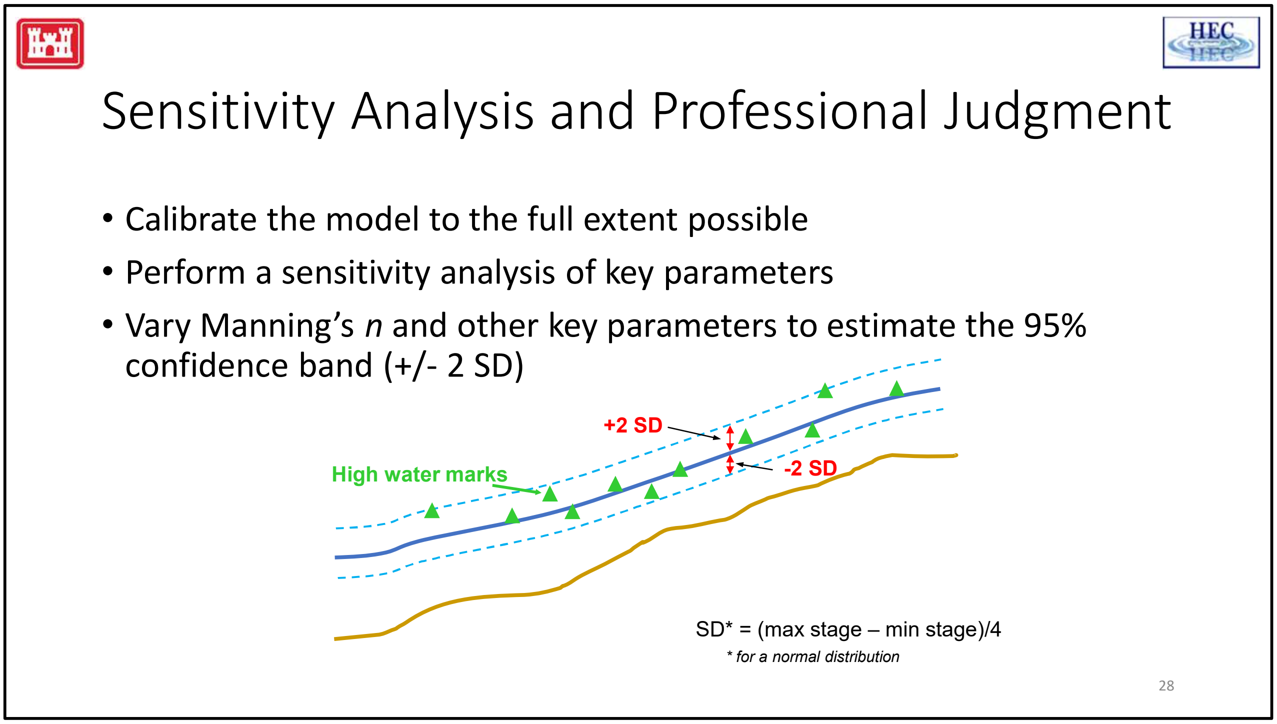
Influences of Backwater

- Caused by natural constrictions and/or hydraulic structures.
- Effect is more pronounced in flatter streams
- Rating Curves tend to be looped

- May need to develop stage-frequency relationships instead of flow-frequency and stage-discharge. Consider using HEC-WAT for this type of analysis.

Generally, people do hydrology and have uncertainty-flow relationship.

In extremely flat areas with backwater, you may need to look at it as Stage-Frequency. This can be accomplished using the Monte-Carlo Analysis with the HEC-WAT framework.



Sensitivity Analysis and Professional Judgment

- Calibrate the model to the full extent possible
- Perform a sensitivity analysis of key parameters
- Vary Manning's *n* and other key parameters to estimate the 95% confidence band (+/- 2 SD)

SD* = (max stage – min stage)/4

** for a normal distribution*

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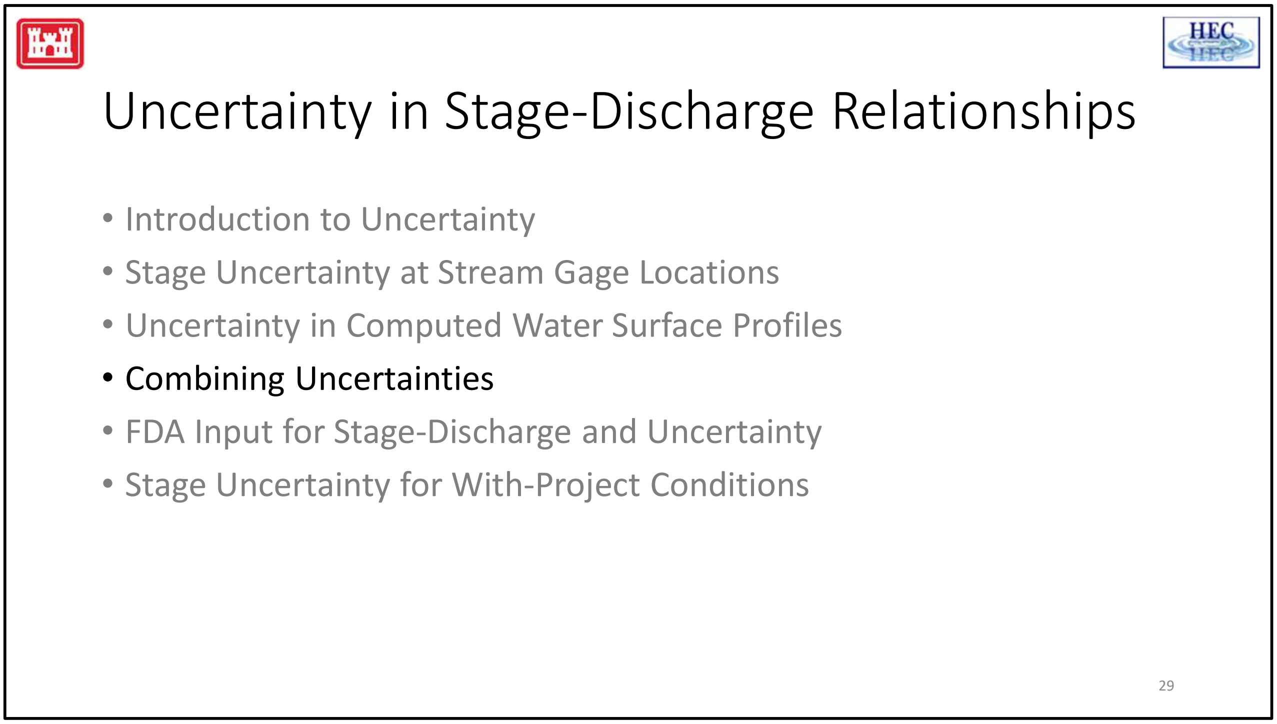
Once the hydraulic model is calibrated, the hydraulic engineer should perform sensitivity analysis to estimate the profile bounds. The sensitivity analysis is performed for the full range of events, in order to capture the uncertainty for the entire rating curve.

For a given flow, the calibrated profile is considered the engineer's best estimate of the water surface. High water marks and local system knowledge are used as sample data and lend confidence in resultant water surface profiles. Manning's *n* values are then scaled up and down based on engineering judgment to envelope the engineer's uncertainty. When estimating a range of values for Manning's n values, the engineer should remember that they are trying to estimate a range that represents the 95% confidence interval of the Manning's n values. This same principle is also applied to any other key parameters that will affect the results of the model (hydraulic structure coefficients, debris, ice, etc…).

The difference in elevation at each cross section is considered to bound the water surface with 95% confidence.
This difference is taken to equal 4 standard deviations (S) about the mean. So SD for a normal distribution is calculated as:
SD = (MaxStage – MinStage) / 4



Uncertainty in Stage-Discharge Relationships

- Introduction to Uncertainty
- Stage Uncertainty at Stream Gage Locations
- Uncertainty in Computed Water Surface Profiles
- Combining Uncertainties
- FDA Input for Stage-Discharge and Uncertainty
- Stage Uncertainty for With-Project Conditions

Conjoining Uncertainties for Total Uncertainty

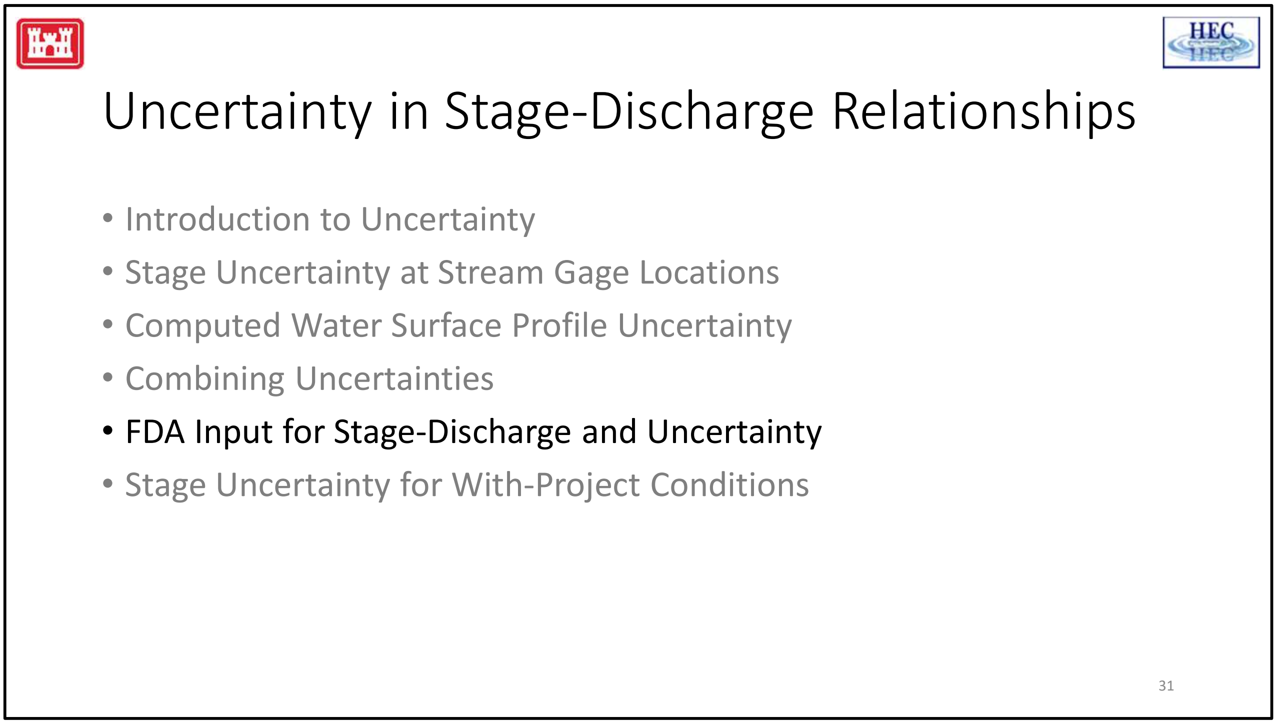
- Total water surface elevation uncertainty is computed using the following equation:

$$SD_t = \sqrt{SD_{terrain}^2 + SD_{model}^2 + SD_{natural}^2}$$

Where:
SD_t = Total standard deviation of uncertainty in computed water surface elevations
$SD_{terrain}$ = Standard deviation of water surface error due to uncertainty in terrain data.
SD_{model} = Standard deviation of water surface error due to uncertainty in the hydraulic model parameters
$SD_{natural}$ = Standard deviation of water surface error due to uncertainty caused by natural variability

Natural variability may include water surface error due to changes in bed forms, temperature, unsteady flow effects, hydraulic roughness changes due to season seasonal variations, changes in channel shape during the event, as well as other factors that were not specifically address in the model uncertainty analysis.

Do all the modeling due to fixed bed, but if there is variability do to bed movement, you could add in the SDnatural here (anything you didn't already include)



Uncertainty in Stage-Discharge Relationships

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- Computed Water Surface Profile Uncertainty
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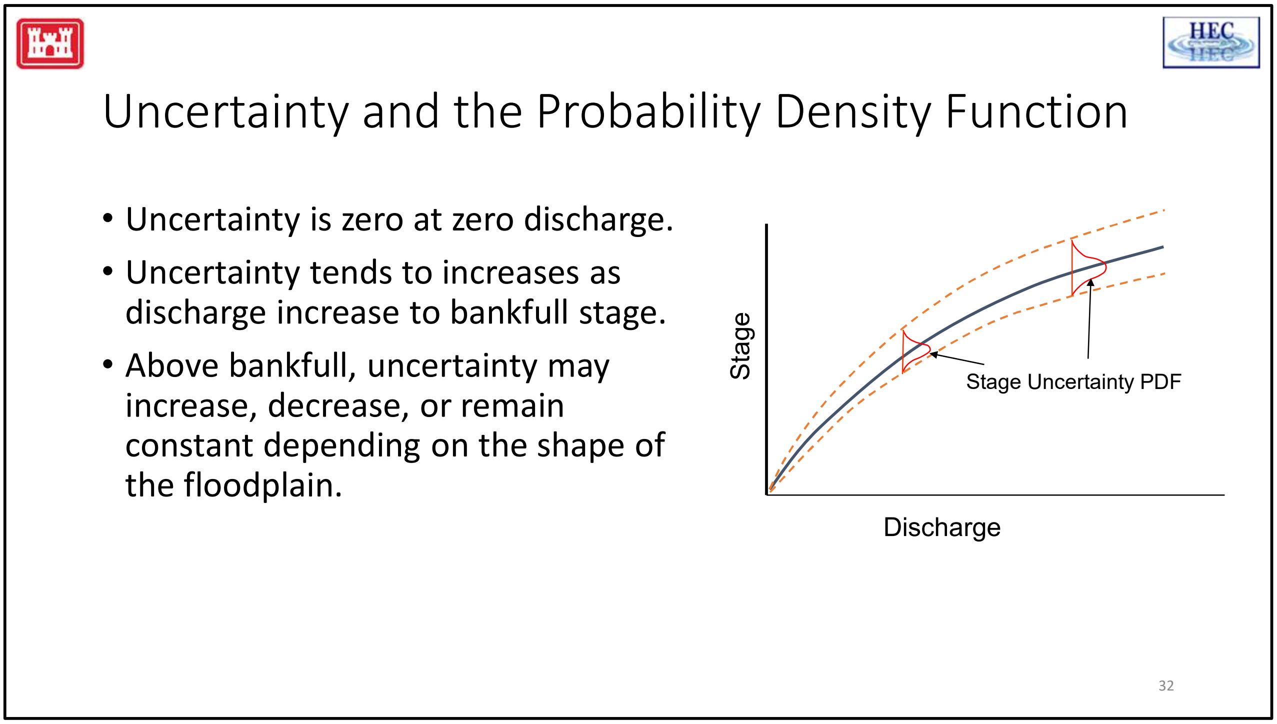
- Stage Uncertainty for With-Project Conditions

We will now discuss inputting Stage-Discharge information with Uncertainty into HEC-FDA
And evaluating without and with-project conditions

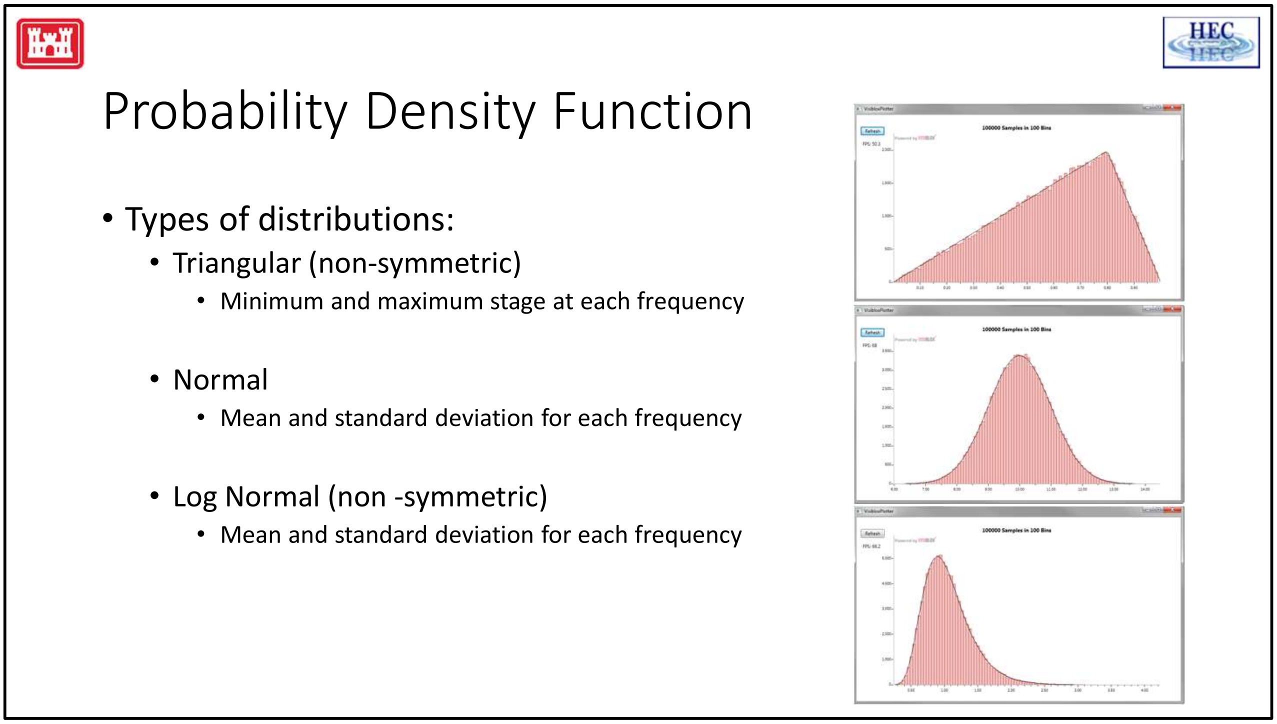


Uncertainty and the Probability Density Function

- Uncertainty is zero at zero discharge.
- Uncertainty tends to increases as discharge increase to bankfull stage.
- Above bankfull, uncertainty may increase, decrease, or remain constant depending on the shape of the floodplain.

Thus far we have discussed the development of creating a stage-discharge function and attempting to define the uncertainty with a Probability Density Function.
The bounds of the PDF are defined based engineers sensitivity and professional judgement.

What we notice is that the stage uncertainty is zero at zero flow and tends to increase as flow increases. As flow gets larger the uncertainty MAY get larger or remain constant based on the shape of the floodplain.



Probability Density Function

- Types of distributions:
  - Triangular (non-symmetric)
    - Minimum and maximum stage at each frequency
  - Normal
    - Mean and standard deviation for each frequency
  - Log Normal (non -symmetric)
    - Mean and standard deviation for each frequency

The PDF can be represented through different statistical distributions.
We are familiar with the Normal distribution from a basic introduction to statistics, but there are other distributions we can use to describe the stage-discharge PDF. Each distribution is described a bit differently.

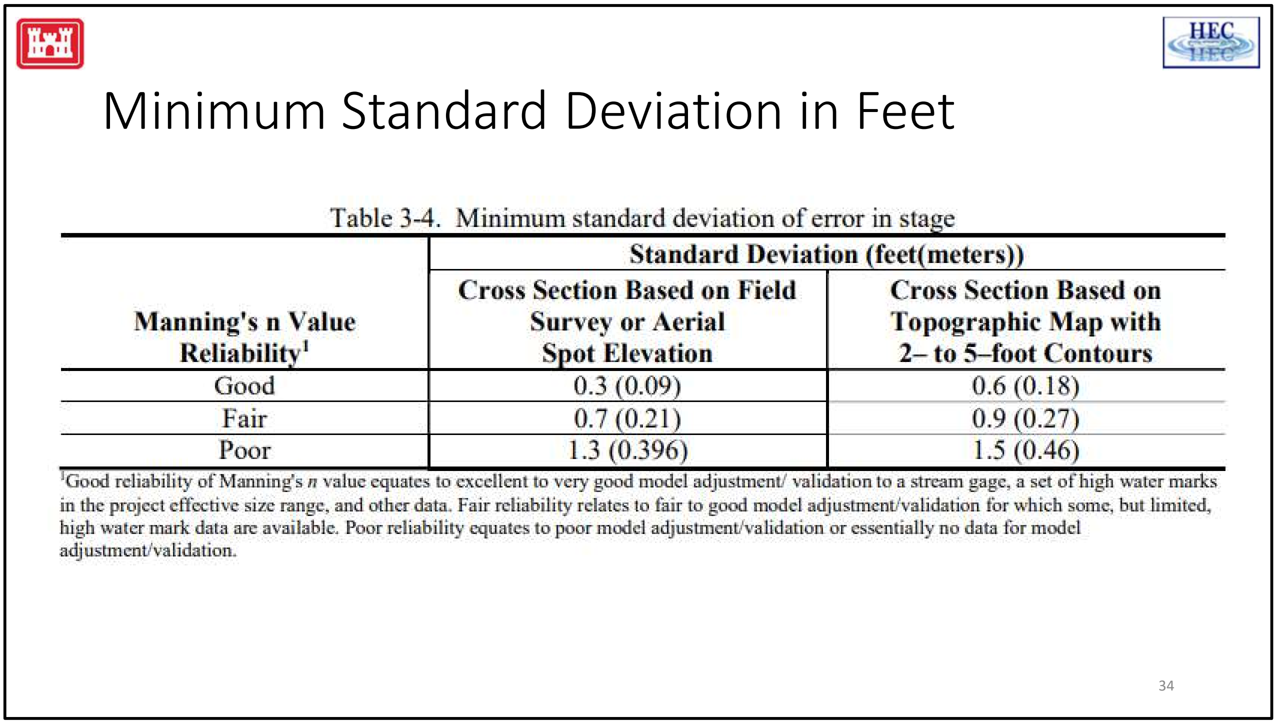
The distributions are:

Triangular Distribution: A two-parameter bounded probability distribution defined by the minimum stage and maximum stage.

Normal Distribution: A two-parameter probability distribution defined by the mean and standard deviation. A symmetrical "bell shaped" curve applicable to many kinds of data sets where values are equally likely to be greater than or less than the mean. Also called a Gaussian distribution. The distribution is truncated at plus and minus three standard deviations from the mean.

Log Normal Distribution: A two-parameter probability distribution defined by the mean and standard deviation. A non-symmetrical distribution applicable to many kinds of data sets where the majority (more than half) of values are less than the mean but values greater than the mean can be extreme, such as with streamflow data. The distribution is truncated at three standard deviations. The Standard deviation is computed by taking the logs of the stages from the sensitivity analysis, then subtracting the high stage from the low stage and dividing by four, to get a standard deviation in log space.

As hydraulic engineers, we prefer the triangular distribution because, as we discussed previously, we have more confidence in the minimum water surface profile and typically have less confidence in the maximum water surface profile. Therefore, the uncertainty distribution better fits the triangular distribution.



Minimum Standard Deviation in Feet

Table 3-4. Minimum standard deviation of error in stage

	Standard Deviation (feet(meters))	
Manning's n Value Reliability[1]	**Cross Section Based on Field Survey or Aerial Spot Elevation**	**Cross Section Based on Topographic Map with 2– to 5–foot Contours**
Good	0.3 (0.09)	0.6 (0.18)
Fair	0.7 (0.21)	0.9 (0.27)
Poor	1.3 (0.396)	1.5 (0.46)

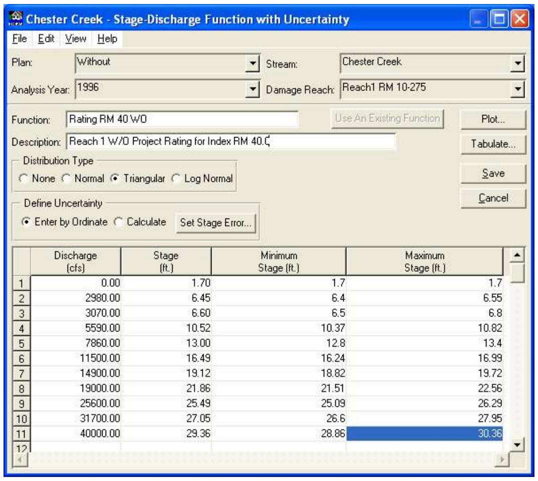
[1] Good reliability of Manning's *n* value equates to excellent to very good model adjustment/ validation to a stream gage, a set of high water marks in the project effective size range, and other data. Fair reliability relates to fair to good model adjustment/validation for which some, but limited, high water mark data are available. Poor reliability equates to poor model adjustment/validation or essentially no data for model adjustment/validation.

When evaluating the uncertainty for you stage-discharge relationship, first consult this table of Minimum Standard Deviations from EM 1110-2-1619. TABLE 5-2.

We have previously discussed variety of methods for determining the standard deviation of error in the stage, derived from computed water surface profiles, using hydraulic models. Whichever method is used, the standard deviation of error generated should be checked against the Table above. The Table above is intended to provide consistency in USACE risk analyses and sets minimum limits that should be used, when computed values come out lower than the minimums. In other words, the values of standard deviation in stage errors, from computed water surface profiles, should never be less than the values shown in the Table above. The values in the Table above represent standard deviations of error in stage, at design level discharges (for example the stages associated with the p=0.01 event). Standard deviations for events less than the design level, will decrease as you go towards a zero flow. Standard deviations for events greater than design levels may be equal to or higher than what is shown the Table above.

FDA Input for Flow-Stage Uncertainty

- Triangular Distribution
- Enter Min/Max WSE



Plan: Without

Stream: Chester Creek

Analysis Year: 1996

Damage Reach: Reach1 RM 10-275

Function: Rating RM 40 WO

Description: Reach 1 W/O Project Rating for Index RM 40.0

Distribution Type: ○ None ○ Normal ● Triangular ○ Log Normal

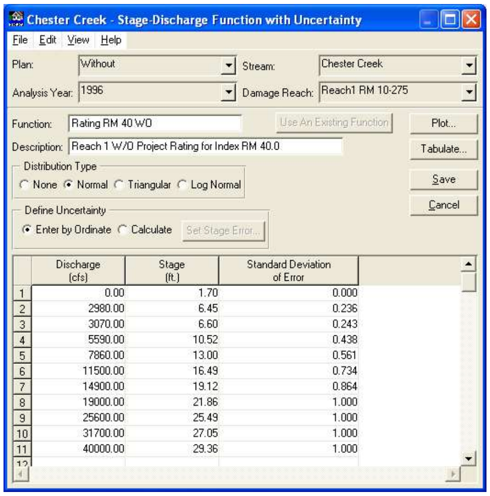
Define Uncertainty: ● Enter by Ordinate ○ Calculate

	Discharge (cfs)	Stage (ft.)	Minimum Stage (ft.)	Maximum Stage (ft.)
1	0.00	1.70	1.7	1.7
2	2980.00	6.45	6.4	6.55
3	3070.00	6.60	6.5	6.8
4	5590.00	10.52	10.37	10.82
5	7860.00	13.00	12.8	13.4
6	11500.00	16.49	16.24	16.99
7	14900.00	19.12	18.82	19.72
8	19000.00	21.86	21.51	22.56
9	25600.00	25.49	25.09	26.29
10	31700.00	27.05	26.6	27.95
11	40000.00	29.36	28.86	30.36
12				

Error values developed by hydraulic methods
Next Lecture

FDA Input for Flow-Stage Uncertainty

- Normal Distribution
- Compute SD from Min/Max WSE



Plan: Without

Stream: Chester Creek

Analysis Year: 1996

Damage Reach: Reach1 RM 10-275

Function: Rating RM 40 WO

Description: Reach 1 W/O Project Rating for Index RM 40.0

Distribution Type: ○ None ● Normal ○ Triangular ○ Log Normal

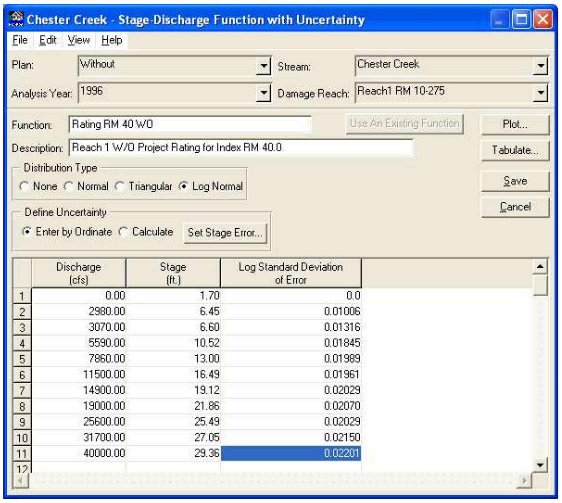
Define Uncertainty: ● Enter by Ordinate ○ Calculate

	Discharge (cfs)	Stage (ft.)	Standard Deviation of Error
1	0.00	1.70	0.000
2	2980.00	6.45	0.236
3	3070.00	6.60	0.243
4	5590.00	10.52	0.438
5	7860.00	13.00	0.561
6	11500.00	16.49	0.734
7	14900.00	19.12	0.864
8	19000.00	21.86	1.000
9	25600.00	25.49	1.000
10	31700.00	27.05	1.000
11	40000.00	29.36	1.000

Error values developed by hydraulic methods
Next Lecture

FDA Input for Flow-Stage Uncertainty

- Log Normal Distribution
- Compute the Log of SD



Plan: Without

Stream: Chester Creek

Analysis Year: 1996

Damage Reach: Reach1 RM 10-275

Function: Rating RM 40 WO

Description: Reach 1 W/O Project Rating for Index RM 40.0

Distribution Type: ○ None ○ Normal ○ Triangular ● Log Normal

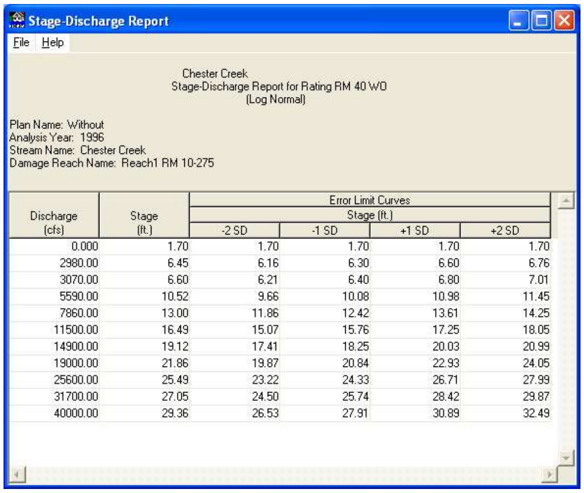
Define Uncertainty: ● Enter by Ordinate ○ Calculate

	Discharge (cfs)	Stage (ft.)	Log Standard Deviation of Error
1	0.00	1.70	0.0
2	2980.00	6.45	0.01006
3	3070.00	6.60	0.01316
4	5590.00	10.52	0.01845
5	7860.00	13.00	0.01989
6	11500.00	16.49	0.01961
7	14900.00	19.12	0.02029
8	19000.00	21.86	0.02070
9	25600.00	25.49	0.02029
10	31700.00	27.05	0.02150
11	40000.00	29.36	0.02201
12			

Error values developed by hydraulic methods
Next Lecture

Stage-Discharge Table

- FDA Summary Input Table



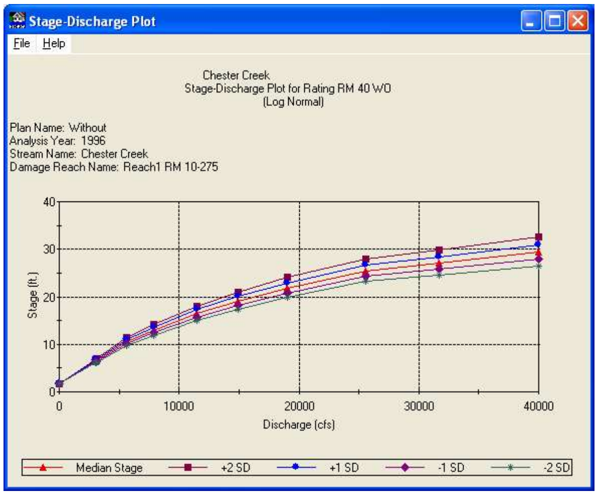
Chester Creek
Stage-Discharge Report for Rating RM 40 WO
(Log Normal)

Plan Name: Without
Analysis Year: 1996
Stream Name: Chester Creek
Damage Reach Name: Reach1 RM 10-275

Discharge (cfs)	Stage (ft.)	Error Limit Curves Stage (ft.) -2 SD	-1 SD	+1 SD	+2 SD
0.000	1.70	1.70	1.70	1.70	1.70
2980.00	6.45	6.16	6.30	6.60	6.76
3070.00	6.60	6.21	6.40	6.80	7.01
5590.00	10.52	9.66	10.08	10.98	11.45
7860.00	13.00	11.86	12.42	13.61	14.25
11500.00	16.49	15.07	15.76	17.25	18.05
14900.00	19.12	17.41	18.25	20.03	20.99
19000.00	21.86	19.87	20.84	22.93	24.05
25600.00	25.49	23.22	24.33	26.71	27.99
31700.00	27.05	24.50	25.74	28.42	29.87
40000.00	29.36	26.53	27.91	30.89	32.49

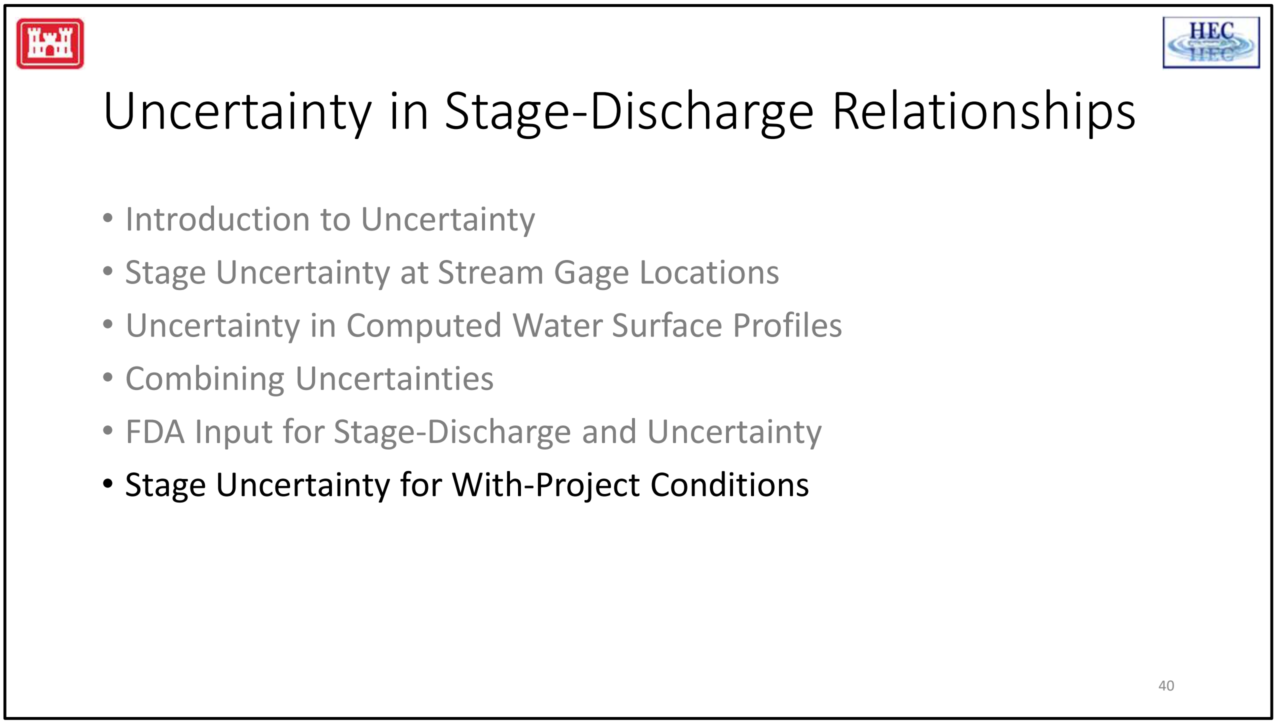
Stage-Discharge Plot

- FDA Summary Input Plot



Chester Creek
Stage-Discharge Plot for Rating RM 40 WO
(Log Normal)

Plan Name: Without
Analysis Year: 1996
Stream Name: Chester Creek
Damage Reach Name: Reach1 RM 10-275



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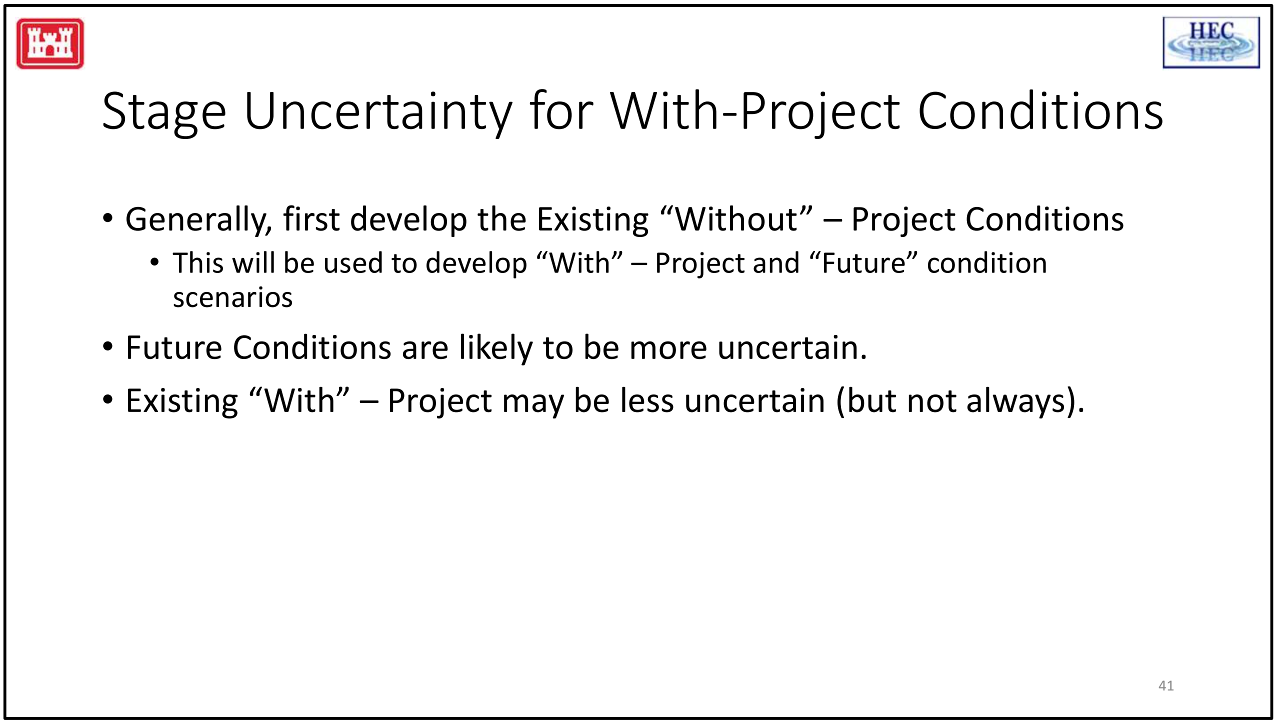

Stage Uncertainty for With-Project Conditions

- Generally, first develop the Existing “Without” – Project Conditions
  - This will be used to develop “With” – Project and “Future” condition scenarios
- Future Conditions are likely to be more uncertain.
- Existing “With” – Project may be less uncertain (but not always).

Now that we have an understanding of uncertainty in computed water surface elevations, planning studies requires that we apply the evaluation to study alternatives.
Risk and uncertainty analysis can then be performed on the preferred alternatives.