Calibrating a Steady Flow Hydraulics Model

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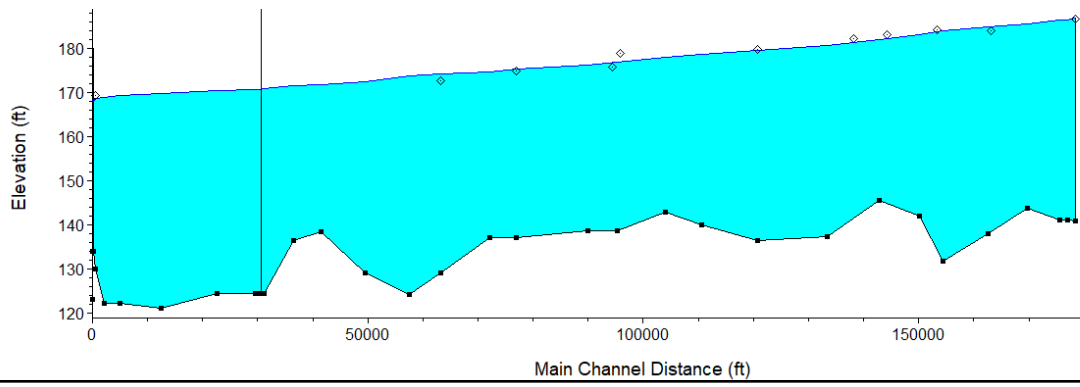
Calibration: A Definition

Calibration: adjusting uncertain model's parameters (e.g. roughness, ineffective flow areas, and hydraulic structure coefficients), *within reasonable ranges*, reproduces observed data to an acceptable accuracy.



Identifying Calibration Parameters

	Low Uncertainty	High Uncertainty
Low Sensitivity		
High Sensitivity		Calibration Parameters

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Top Five 1D Calibration Parameters

Common Calibration Parameters

- Hydrologic Data
- River and Floodplain Geometry
- Roughness Coefficients
- River and Floodplain Storage
- Hydraulic Structure Coefficients

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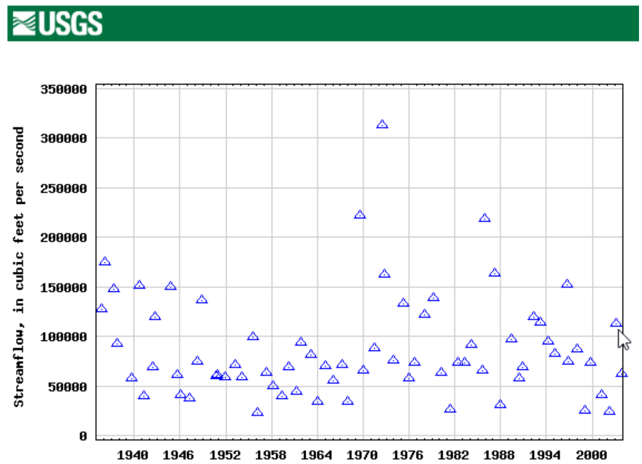
Greatest problem is inconsistency: model will reproduce one event but not another. Modeler must become a detective who identifies errors and inconsistencies in the input data and identifies possible geomorphic changes in the system. Once the modeler understands the system, the modeler must develop procedures that compensate for any shortcomings. This could include adding storage cells to simulate flooded areas.

Hydrologic Data

- Errors in the stage record
- Errors in the flow record
- Ungaged Areas
- High Water Marks



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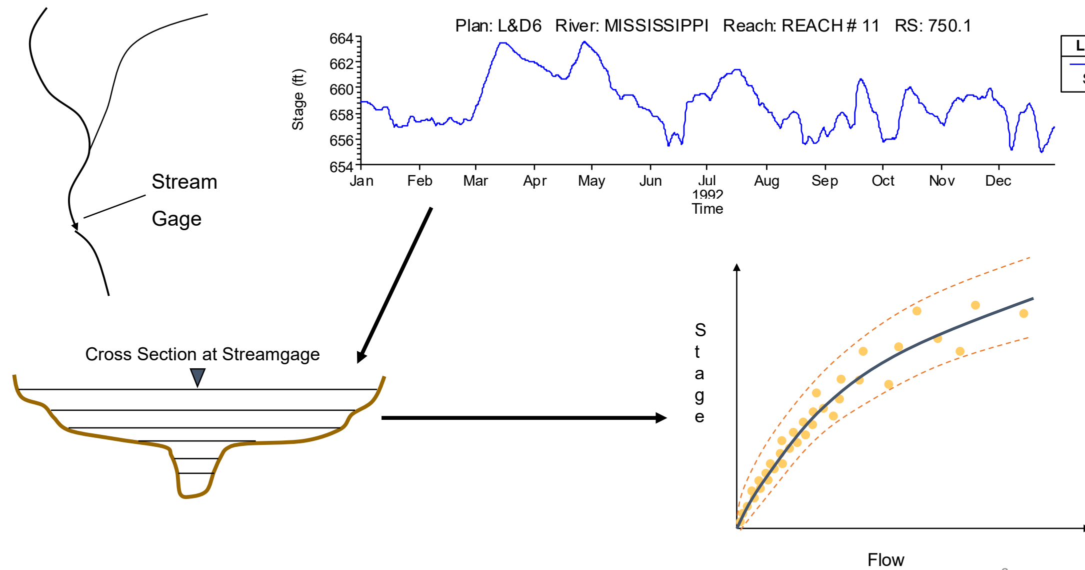
Stage Records

- Most accurate hydrologic input. Generally known within +/- 1.0 foot.

- Possible Errors:
  - Float gage gets stuck at a specific stage.
  - Recording systematically accumulates error with time.
  - Gage reader misses several days and guesses at stage recordings.
  - Error in the datum of the gage.

Stage Uncertainty at Stream gage Locations



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Flow Records

- Flow records are generally computed from observed stages using single valued rating curves. These rating curves are a best fit of measured data.
- USGS classifies very good flow measurements from a price current meter as +/- 5 percent.
- Discharge records for slope/area stations are at best +/- 10 percent of the true value.

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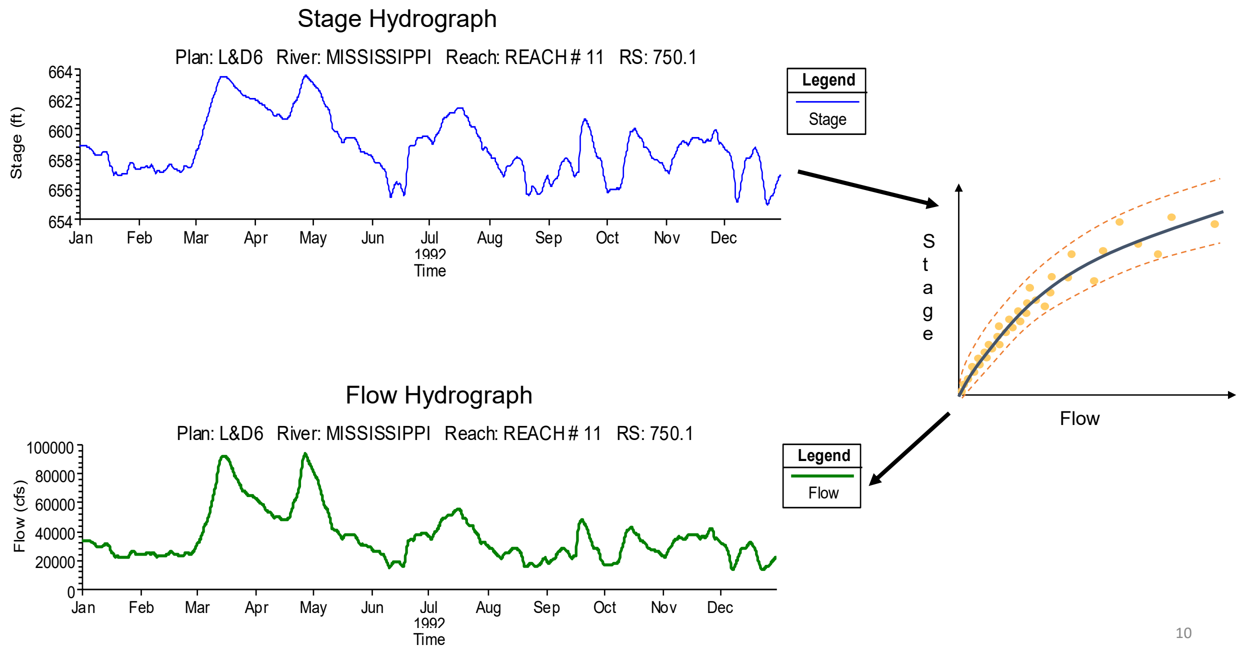
USGS classifies good flow measurements from Price current meters to be within ±5% of the true value. Some believe that this assumed error is optimistic. In any case, ±5%, on many river systems, translates into a stage error of ±1 foot. Acoustic velocity meters provide a continuous record, but the current USGS technique calibrates these meters to reproduce measurements from Price current meters, so the AVM is as accurate as the current meter. Boat measurements are always suspect. Newer techniques using acoustic velocity meters with three beams mounted on boats are thought to be much better. Published discharge records should also be scrutinized. Continuous discharge is computed from discharge measurements, usually taken at bi-weekly or monthly intervals and the continuous stage record. The measurements are compiled into a rating curve and the departures of subsequent measurements from the rating curve are used to define shifts. The shifts are temporary changes in the rating curve due to unsteady flow effects (looped rating curve) and short term geomorphic changes. The quality of the record depends on the frequency of discharge measurements and the skill of the hydrologist. The only way to tell is to compare the discharge measurements to the flow record. Still, if the measurements are infrequent, one can only apply the flow record to the model and see how well the stage record is reproduced. Remember! Most published flow records are in mean daily flow. The modeler must somehow assign time values to these records.

Flow Uncertainty at Stream gage Locations



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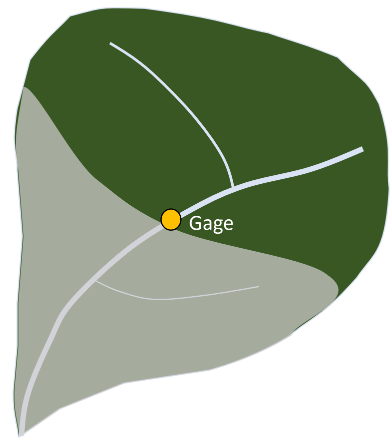
Ungaged Drainage Areas

- For the model to be accurate, it must have flow input from all of the contributing areas.
- In many studies a significant portion of the area is ungaged.
- Discharge from ungaged areas can be estimated from:
  - Hydrologic models.
  - Regional regression equations.
  - Flow from a gaged watershed with similar hydrologic characteristics, multiplied by a simple drainage area ratio.



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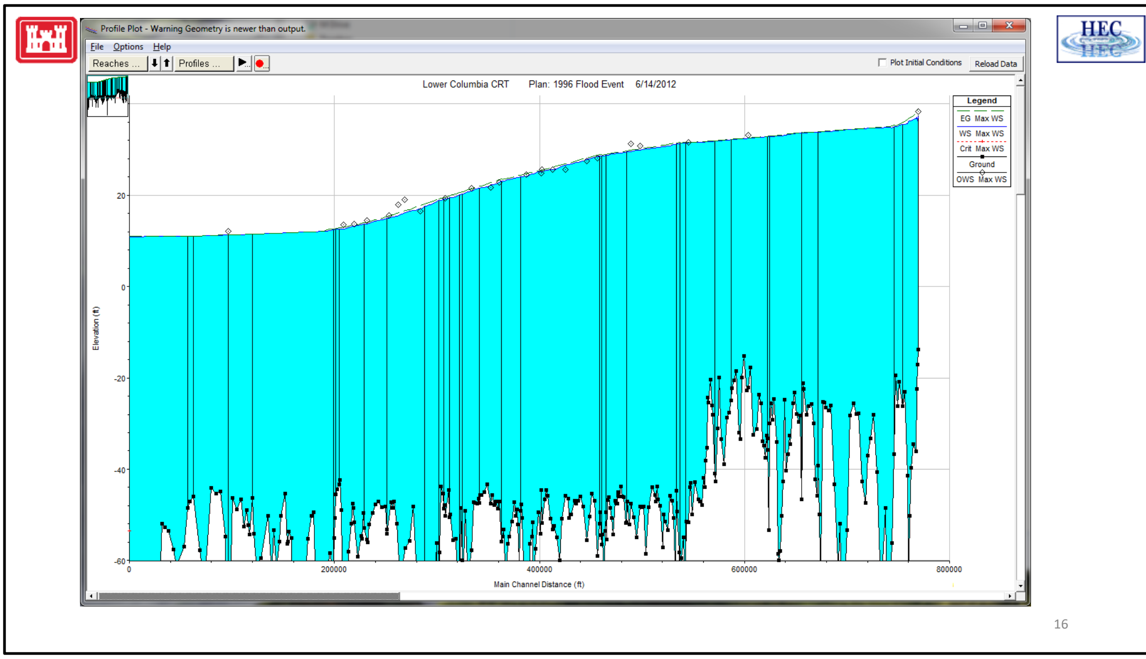
High Water Marks

- High water marks are estimated from the upper limit of stains and debris deposits found on buildings, bridges, trees, and other structures.
- Wind and wave actions can cause the debris lines to be higher than the actual water surface.
- Capillary action causes stains on buildings to migrate upward.
- High water marks in the overbank area are often higher than in the channel. Overbank water is moving slower and may be closer to energy gradeline.
- High water marks on bridge piers are often equal to the energy gradeline, not the average water surface.

These High water Marks were drawn on the side of a movie theater in the town of Rio California, along the Russian River, after each flood of significance. Some one also got very creative with the art work below each water line.

This is another High water mark along the Russian River in California. This was at an intersection of two roads, that could easily be found on a map/Terrain model for verification of the computed floodplain boundary for that event.

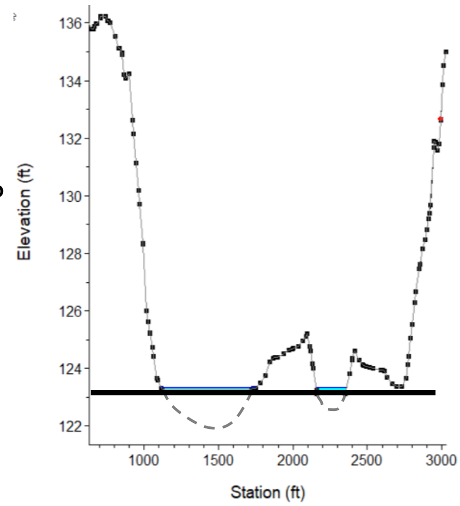
The green triangle with the black dot is a high water mark location obtained while talking to the Farmer who owns this land. This is another good example of a floodplain boundary high water mark.



Shown in the Figure above is a comparison between high water marks and the computed maximum water surface profile. Note the scatter in the high water marks, particularly around river station 230. Which mark is accurate?

River and Floodplain Geometry

- It is essential to have an adequate number of cross sections that accurately depict the channel and overbank geometry. This can be a great source of error when trying to calibrate.
- What is the accuracy level of the terrain data?
  - Surveyed Cross sections.
  - Aerial Survey Data (LIDAR, Stereo Imaging).
  - USGS DEM data.
- Does the Terrain Data include the channel data below the water surface?
- Are all hydraulic structures accurately depicted?



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Manning’s n values

- Make Initial Estimates of Manning’s n Values from Aerial Photos, Land use maps, and Field investigation using the following techniques:
  - Field observation (this requires experience).
  - Comparison with photos of calibrated streams.
  - Published documents with n values vs. land use types.
  - Channel n value formulas.
- Then Calibrate to any observed data that is available – Best Approach for obtaining Manning’s n values.

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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”.

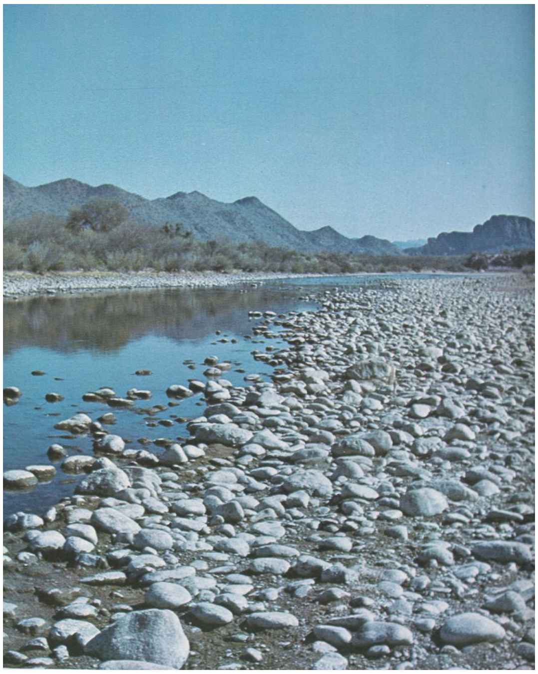
If an engineer is stuck in the office and has pictures or aerial photos, you can compare them to published documents. You can also used published documents that contain landuse types versus Manning’s n values. And you can rely on formulas which create a composite *n* value of the main channel based on the characteristics we talked about earlier. You can also use the hydraulic model itself and calibrate *n* values to observed profile data (i.e. gaged information and high water marks).

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

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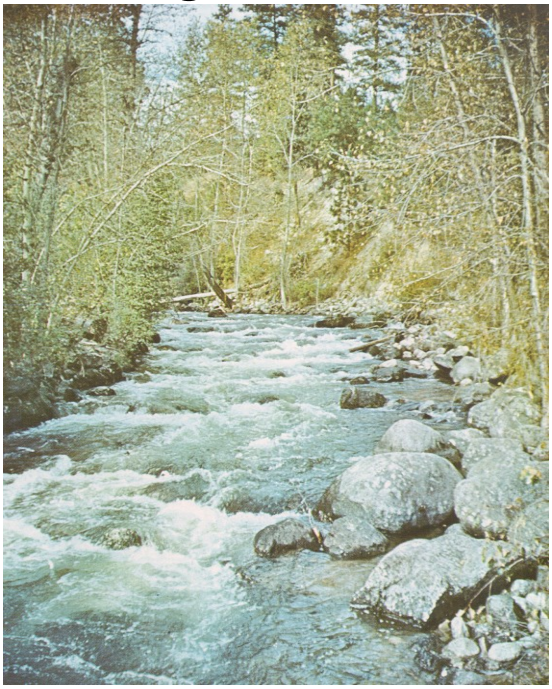
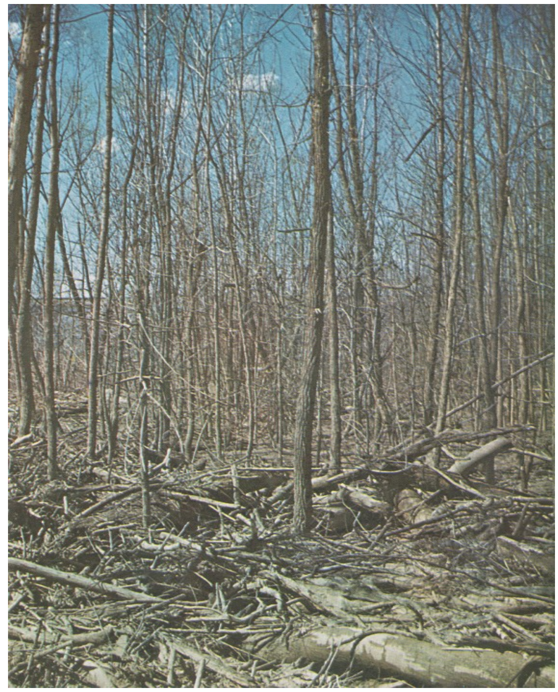
Manning's n values



$n =$ 0.075



$n =$ 0.097

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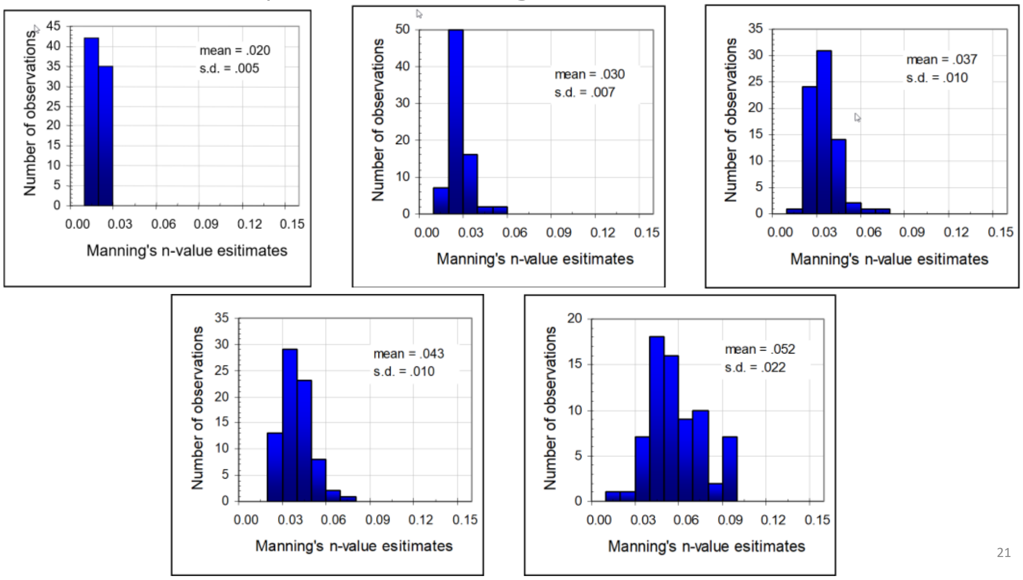
Uncertainty in Manning's n values



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Additional Uncertainty

- Obstructions:
  - Debris
    - Mud and Debris
    - Debris blockages
  - Ice
- Erosion/deposition, bed forms, and sediment concentration can all affect n values.

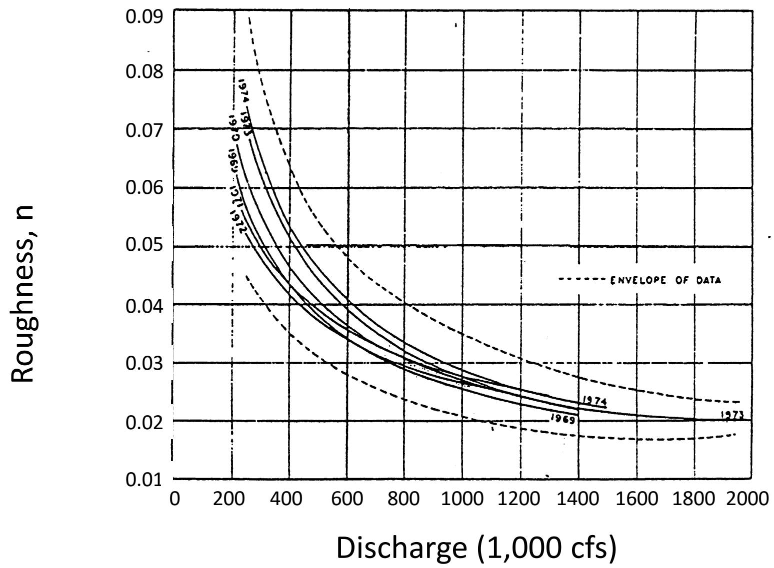
There are many additional factors that add uncertainty to a hydraulic model. More complicated hydraulic models require greater attention to detail. Hydraulic structures need scrutiny to decide upon coefficients – will the bridge be submerged or not during any event? It is also difficult to predict obstructions 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.

Roughness – Manning's n

- Generally, for a free flowing river, roughness decreases with increased stage and flow.
- However, if the banks of a river are rougher than the channel bottom (trees and brush), then the composite n value will increase with increased stage.
- Sediment and debris can also play an important role in changing the roughness.

Roughness vs. Discharge



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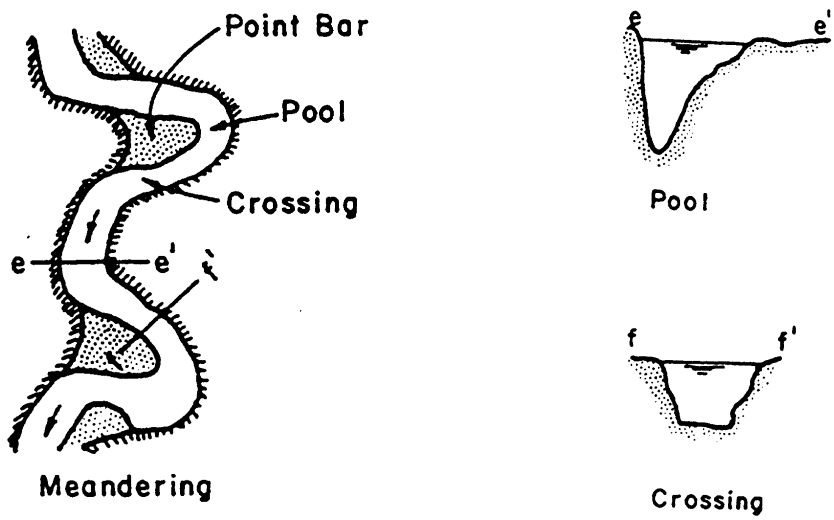
The Figure above shows decreasing Manning's n with increased discharge for the Mississippi River at Arkansas City.

Morphology of a Meandering River

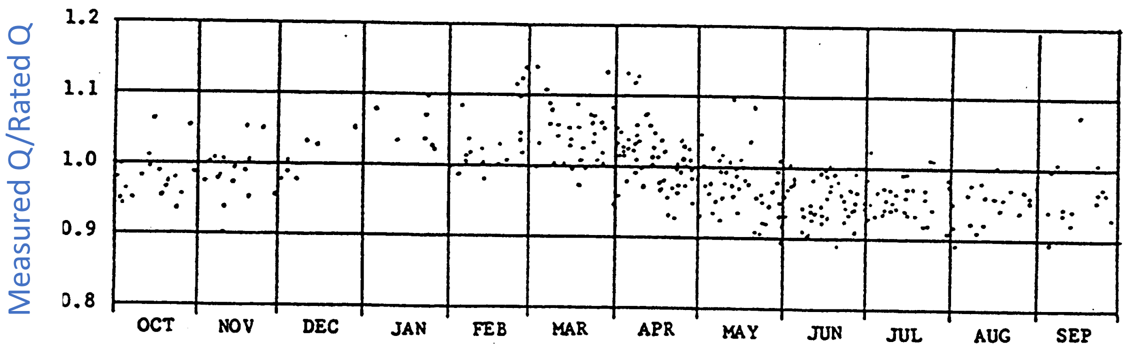


A typical meandering river is shown in the Figure above. Pools are at the outside of bends, and a typical pool cross-section is very deep. On the inside of the bend is a point bar. Crossings are between the meander bends. A typical crossing cross-section is much shallower and more rectangular than a pool cross-section.

Including cross sections at crossing locations is important to capture the high points of the low flow channel.

Manning's n values will often be higher in the crossing (riffles) than the pools.

Changes in Roughness due to Temperature (Large Rivers)



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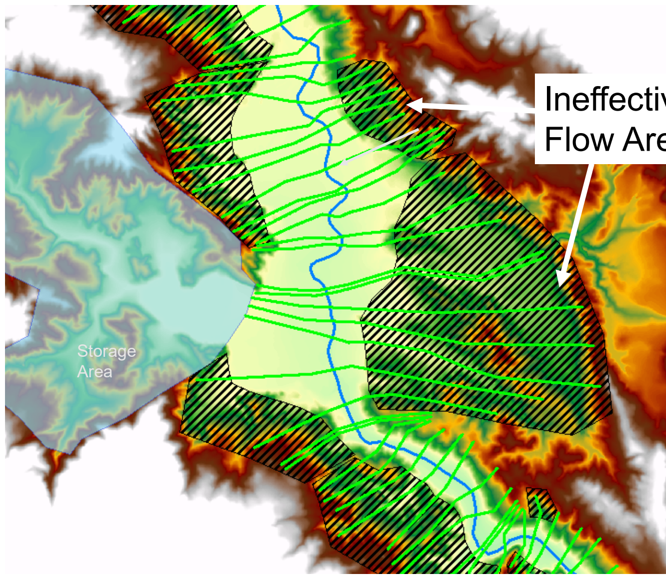
Bed forms change with water temperature. Because water is more viscous at lower temperatures, the water is more erosive, reducing the height and the length of the dunes. At higher temperatures, when the water is less viscous, the dunes are higher and of greater length. Since the larger dunes are more resistant to flow, the same flow will pass at a higher stage in the summer than in the winter. Larger streams such as the Mississippi River and the Missouri River show these trends. The Figure above shows the seasonal shift for the Mississippi River at St. Louis.

Cross Sectional Storage (Ineffective Flow Areas)

- Map all of the ineffective flow areas as polygons in the GIS (Topographic map).
- Or Map the active flood width on a topographic map (GIS Terrain model). The area outside of this should be treated as storage (Ineffective flow areas).
- Pay special attention to Ineffective flow areas around hydraulic structures such as Bridges; Culverts; Weirs; etc…

Example Ineffective Flow Areas



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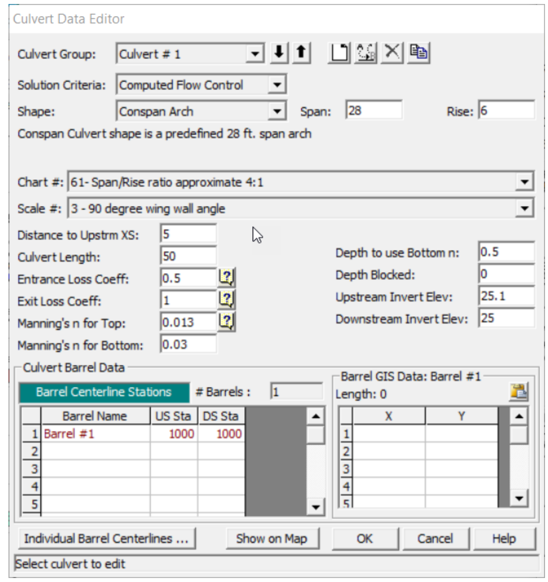
Hydraulic Structure Coefficients

- Hydraulic Coefficients at bridges and culverts tend to have a local effect on stage, and a minimum affect on the flow hydrograph.
- The effects of Inline weirs/spillways coefficients will depend upon the size of the structure.
- Lateral weir coefficients can have a significant role in the amount of water leaving the river system.



HEC-RAS Model Calibration Tools

- Manning's n value Input Tables.
- Flow Versus Roughness Factors Option.
- Graphical Plots
  - Profile plot.
  - Cross section plot.
- Tabular Output Tables.

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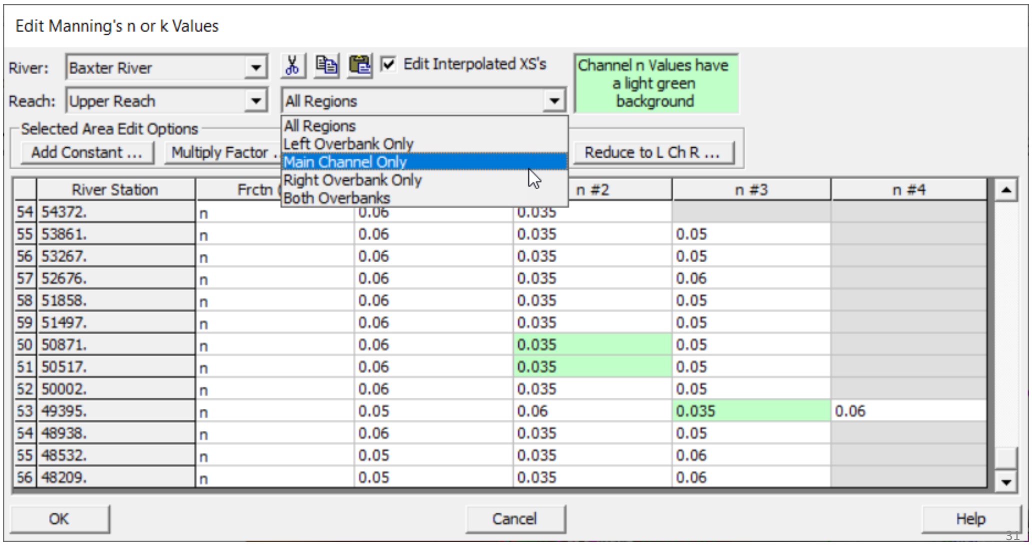
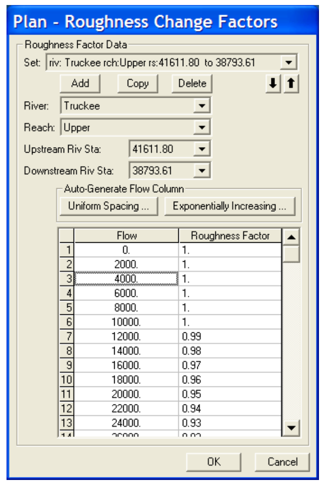
Manning's n Value Table



The Manning's n Table is available from the "Tables" menu on the Geometric Data editor in HEC-RAS. The table allows you to highlight portions of the table and then adjust all the highlighted values in a variety of ways, such as: add a constant, multiply by a factor, or change to a particular value. The table also allows you to display either all of the Manning's n vales across the cross section; just the left overbank values; just the main channel values (highlighted with a green background); just the right overbank values; or just the left and right overbank values. This table does not allow you to change the stationing of the Manning's n values (i.e. their location within the cross section).

Flow vs. Roughness Factors



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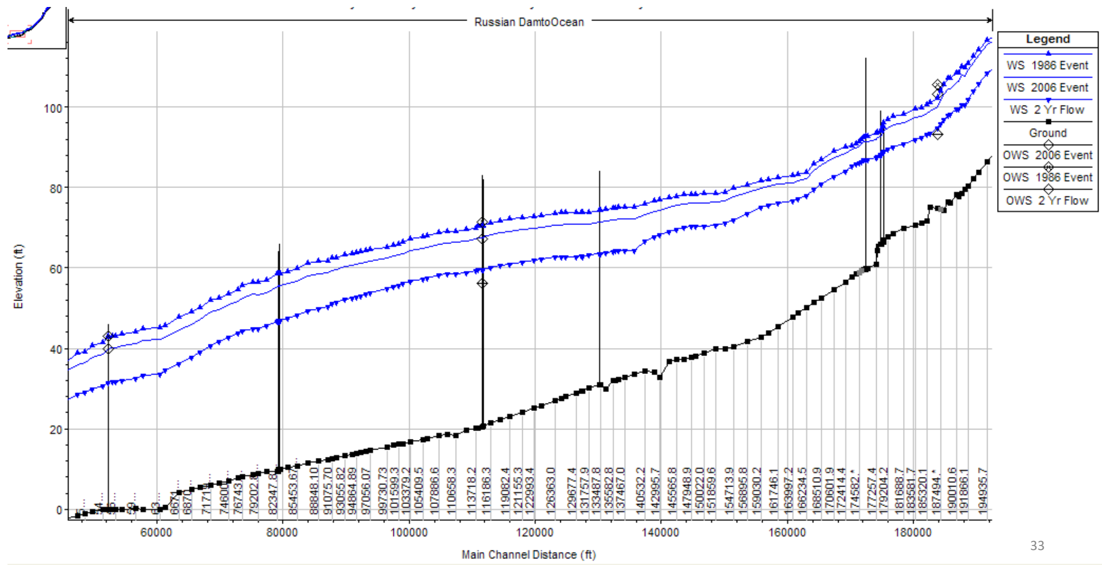
This option allows the user to adjust roughness coefficients with changes in flow. This feature is very useful for calibrating a steady or an unsteady flow model for flows that range from low to high. Roughness generally decreases with increasing flow and depth. This is especially true on larger river systems. This feature allows the user to adjust the roughness coefficients up or down in order to get a better match of observed data. To use this option, select Flow Roughness Factors from the Tools menu of the Geometric Data editor.

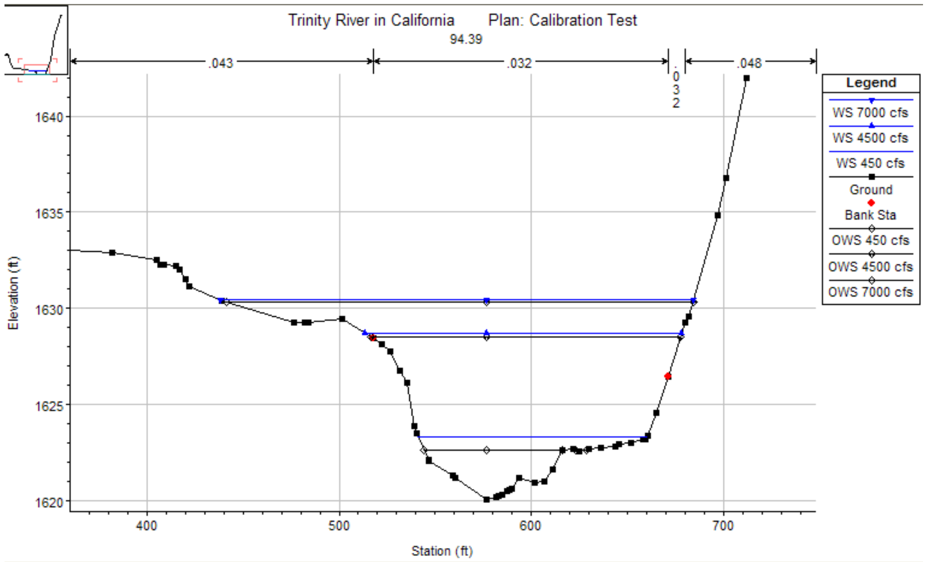
As shown in the Figure above, the user first selects a river, reach, and a range of cross sections to apply the factors to. Next, the user can either enter flow and roughness factors into the table directly, or they can use on of the two “Auto Generate Flow Column” buttons. Two options are available for auto generation of the flow column: one is based on equal increments of changing flow; the other is based on an exponentially increasing flow change rate.

Profile Plot with Observed Data



If the user enters Observed Data in the Steady Flow Data editor, when that profile is displayed, the observed values will be plotted on the profile plot.

Cross Section Plot with Observed Data



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If the user enters Observed Data in the Steady Flow Data editor, when that cross section location and profile is displayed, the observed values will be plotted on the cross section plot.

Tabular Output with Computed and Observed Water Surfaces

Profile Output Table - Calibration

File Options Std. Tables User Tables Locations Help

HEC-RAS Plan: Calibration River: Trinity Reach: Lew_DC — Reload Data

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Obs WS (ft)	Diff	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Wic (ft)
Lew_DC	95.03	450 cfs	500.00	1627.30	1629.75	1629.12	0.63	1629.87	0.002017	2.75	182.12	120.
Lew_DC	95.03	4500 cfs	5050.00	1627.30	1633.39	1633.25	0.14	1633.89	0.002460	5.65	893.54	228.
Lew_DC	95.03	7000 cfs	7450.00	1627.30	1634.54	1634.43	0.11	1635.17	0.002307	6.36	1173.86	268.
Lew_DC	94.99	450 cfs	500.00	1626.95	1628.32			1628.78	0.015268	5.46	91.60	99.
Lew_DC	94.99	4500 cfs	5050.00	1626.95	1632.37			1633.11	0.004091	6.89	734.98	233.
Lew_DC	94.99	7000 cfs	7450.00	1626.95	1633.82	1634.03	-0.21	1634.54	0.002902	6.81	1106.40	264.
Lew_DC	94.93	450 cfs	500.00	1623.23	1626.93	1627.15	-0.22	1627.05	0.001598	2.71	184.69	99.
Lew_DC	94.93	4500 cfs	5050.00	1623.23	1631.74	1631.65	0.09	1632.27	0.001601	6.32	1047.56	245.
Lew_DC	94.93	7000 cfs	7450.00	1623.23	1633.21	1633.19	0.02	1633.85	0.001561	7.14	1436.09	274.
Lew_DC	94.85	450 cfs	500.00	1620.15	1626.87			1626.90	0.000122	1.26	395.92	99.
Lew_DC	94.85	4500 cfs	5050.00	1620.15	1631.38			1631.77	0.000804	5.29	1170.07	245.
Lew_DC	94.85	7000 cfs	7450.00	1620.15	1632.82			1633.33	0.000893	6.20	1533.04	260.
Lew_DC	94.75	450 cfs	500.00	1623.39	1626.50	1626.67	-0.17	1626.69	0.005720	3.45	144.97	147.
Lew_DC	94.75	4500 cfs	5050.00	1623.39	1630.57	1630.22	0.35	1631.10	0.002216	5.85	881.38	218.
Lew_DC	94.75	7000 cfs	7450.00	1623.39	1632.07	1631.97	0.10	1632.68	0.001773	6.35	1221.77	240.

Observed Water Surface.

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User's can create their own tables using the Summary Table Output capability. In this example, "Standard Table 1" was selected, then it was modified by adding two new variables: "Obs WS" which is the observed water surface elevation, and "Diff" which is just the difference in the two previous fields (which in this case shows the difference between the computed and observed water surface elevations).

Steps to Follow in the Calibration Process

1. Run a range of observed discharges from low to high, depending on the purpose of the model.
2. Make sure you have defined the ineffective flow areas as accurate as possible before calibrating Manning's n values.
3. Start by calibrating main channel n values for low flows up to the bank full flow (generally the 1.5 – 2 yr flow).
4. Start downstream and work your way upstream (downstream computed water surfaces/energy effect computed upstream water surfaces).

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Steps to Follow in the Calibration Process - Continued

5. Modify n-values over consistent reaches rather than section by section. Look at reach slope, size of material, vegetation, etc…
6. After you think you have a good start on the main channel n values, calibrate higher events by adjusting overbank Manning's n values first. Then main channel adjustments if necessary .
7. Adjust hydraulic structure coefficients if observed data is available just upstream of the structure.
8. Fine tune calibration for stages low to high by using "Discharge-Roughness Factors" when and where appropriate.

Steps to Follow in the Calibration Process - Continued

9. Two sets of Geometry and Manning's n values may be necessary if significant seasonal affects are present (i.e. roughness in channel or overbanks is very different in winter vs. summer).
10. Verify the model calibration by running other flow events that were not used in the calibration process (if possible).
11. If further adjustment is deemed necessary from verification runs, make adjustments and re-run all events.

Calibration Suggestions and Warnings

- Do not force a calibration to fit with unrealistic Manning's n values and/or ineffective flow areas.

- Downstream boundary conditions can have a great affect on the computed water surface in the lower end of the model. If downstream boundary condition is unknown (i.e. using Normal Depth), make sure it is far enough downstream so it does not affect calibration where you do have observed data.

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Calibration Suggestions and Warnings - Continued

- Discrepancies may arise from a lack of quality cross section data, or not enough cross sections spaced at appropriate intervals.
- Calibration should be based on floods that encompass a wide range of flows (depending on purpose of the study).
- Accurately depicting significant flow changes along the river can significantly affect the model calibration.