Stormwater Modeling Committee
ASCE | EWRI

Model Calibration

EWRI Congress 2025
EPA SWMM5 Technical Workshop
Anchorage AK, May 18, 2025

Outline

- Model credibility (calibration, validation, and verification)
- Suggested model calibration methodology
- Monitoring program data review
- Project examples

EWRI Congress 2025, EPA SWMM5 Workshop -- Model Calibration

Model Credibility

Stormwater Modeling in Perspective

- A model is only an approximation of reality, results must be checked & verified
- Achieving a "perfect" calibration might not be worth the effort
- Consider "setting with some degree of intelligence" versus "calibration"

"All models are wrong, some are useful" – G. Box

"The scientist is interested in the right answer, the engineer in the best answer now"
– H. Golder

"All these prepositions are empirical. It is not possible to prove them mathematically… Fortunately, nature is not aware of this." – Johnstone and Cross, 1949

Model Credibility

- Calibration/validation/verification provides a reality check
- Compare results to observed behavior under a variety of conditions:
  - Calibration – measurements for a series of (often) smaller storm events
  - Validation – measurements or related information for small & large events
  - Verification – anecdotal information for the larger, less frequent design events
- Benefits of a calibrated model include:

To the modeler...

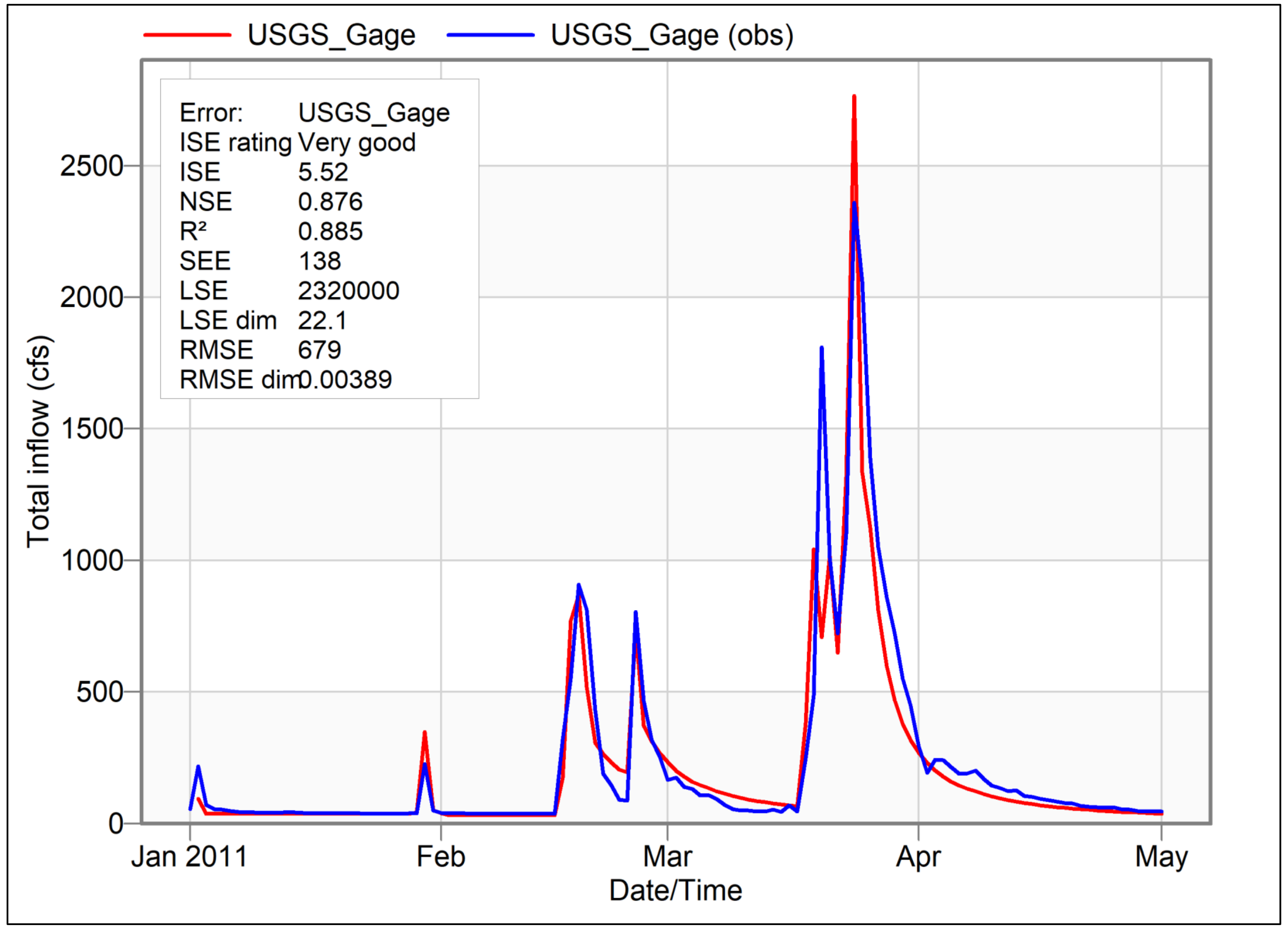
  - Better understanding of the modeled system
  - Improved confidence and reliability in model results

To the general public that we serve...

  - Model credibility
  - Wider acceptance of recommendations

Model Credibility

- Consider… Accurate Analysis vs. Acceptable Results
- It's not enough to be technically accurate, public officials and residents need assurance that your model produces acceptable results
- Showing results that match a memorable event will help to gain confidence more easily



Calibration Defined

- Rather than force-fitting the input parameters, several tasks are involved:
  - Examine/verify measured data
  - Conduct sensitivity analysis of model parameters
  - Develop calibration strategy and apply it
  - Validate model with additional information from historical events
  - Verify model for local design storm events
- Recognize that calibration results are only as accurate as rain/flow measurements
- Beware spending too much effort calibrating to bad rainfall or flow data!

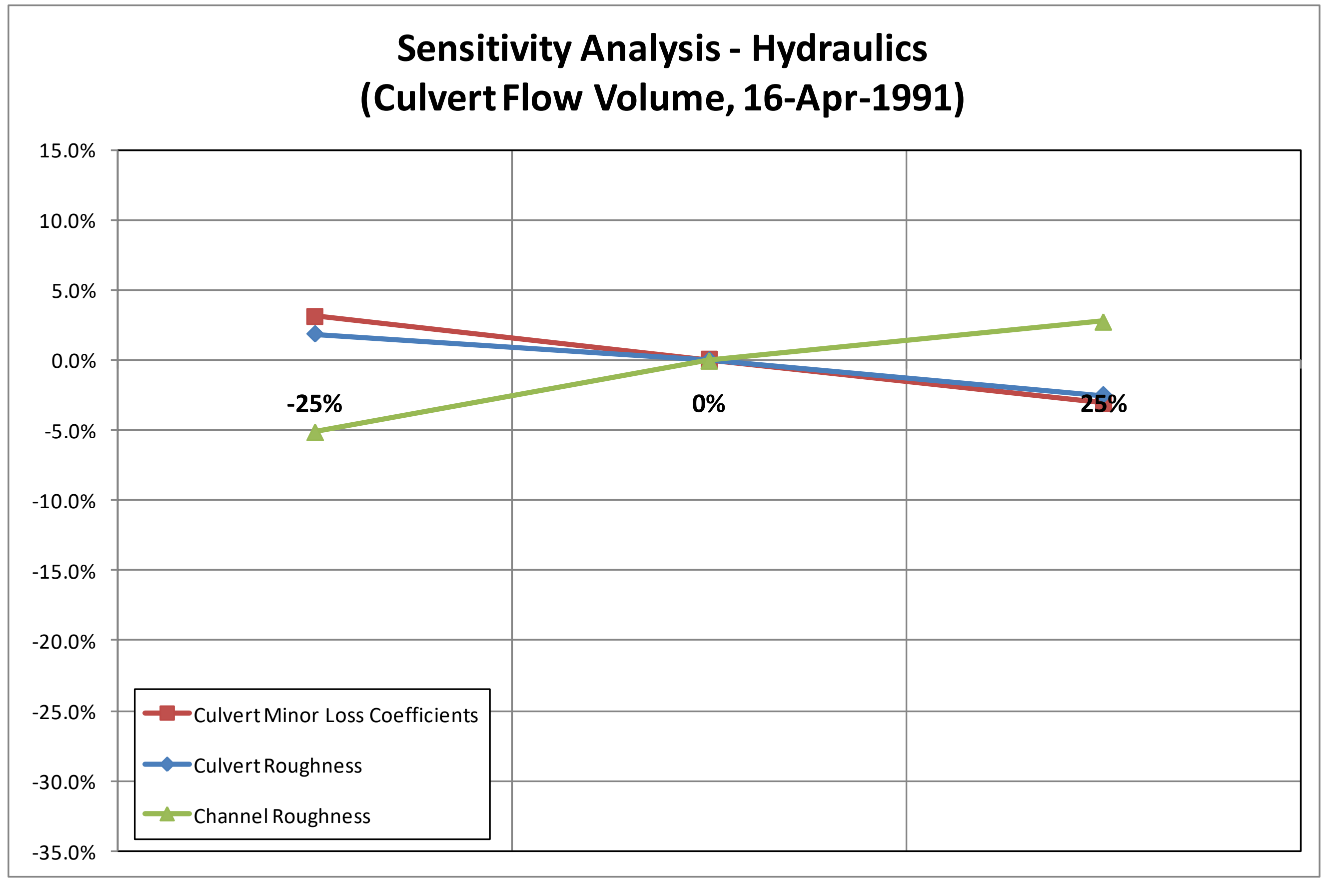
ASTM (Am. Soc. of Testing and Materials), 1984 Definitions:

Calibration: is a test of the model with known input and output information that is used to adjust or estimate factors for which data are not available.

Validation: is a comparison of model results with numerical data independently derived from experiments or observations of the environment.

Sensitivity Analysis

- Definition: input parameters are independently and systematically varied to identify incremental change
- Sensitivity analyses will:
  - Help modelers understand how their model responds to changes in input parameters
  - Guide the calibration strategy
  - Possibly help to identify data deficiencies
- Results will vary by:
  - Rainfall and antecedent moisture conditions
  - What's happening downstream
  - Initial and boundary conditions



Model Parameter	Computed Flow Volume (ft^3)			Computed Peak Flowrate (ft^3/s)		
	-25%	0%	25%	-25%	0%	25%
Hydrologic Model						
Imperviousness	-3.5%	0.0%	2.9%	-0.2%	0.0%	1.4%
Infiltration (Green-Ampt)	13.8%	0.0%	-31.1%	0.6%	0.0%	-5.0%
Overland Flow (Width & Slope)	-7.1%	0.0%	2.3%	-3.8%	0.0%	2.0%
Surface Roughness	2.0%	0.0%	-3.3%	0.8%	0.0%	-1.4%
Depression Storage	1.4%	0.0%	-1.8%	0.2%	0.0%	-0.3%
Hydraulic Model						
Culvert Minor Loss Coefficients	3.1%	0.0%	-3.1%	7.9%	0.0%	-6.4%
Culvert Roughness	1.9%	0.0%	-2.5%	7.2%	0.0%	-7.3%
Channel Roughness	-5.1%	0.0%	2.8%	2.5%	0.0%	-3.4%

Model Validation

- Independent check or "ground-truthing" of the calibrated model
- Sources of validation data:
  - High water marks, debris lines
  - Pump station records
  - Photographs, aerial photos
  - Flooding complaint records
  - Newspaper articles
  - Insurance claims
  - Results from other studies & reports

Model Verification

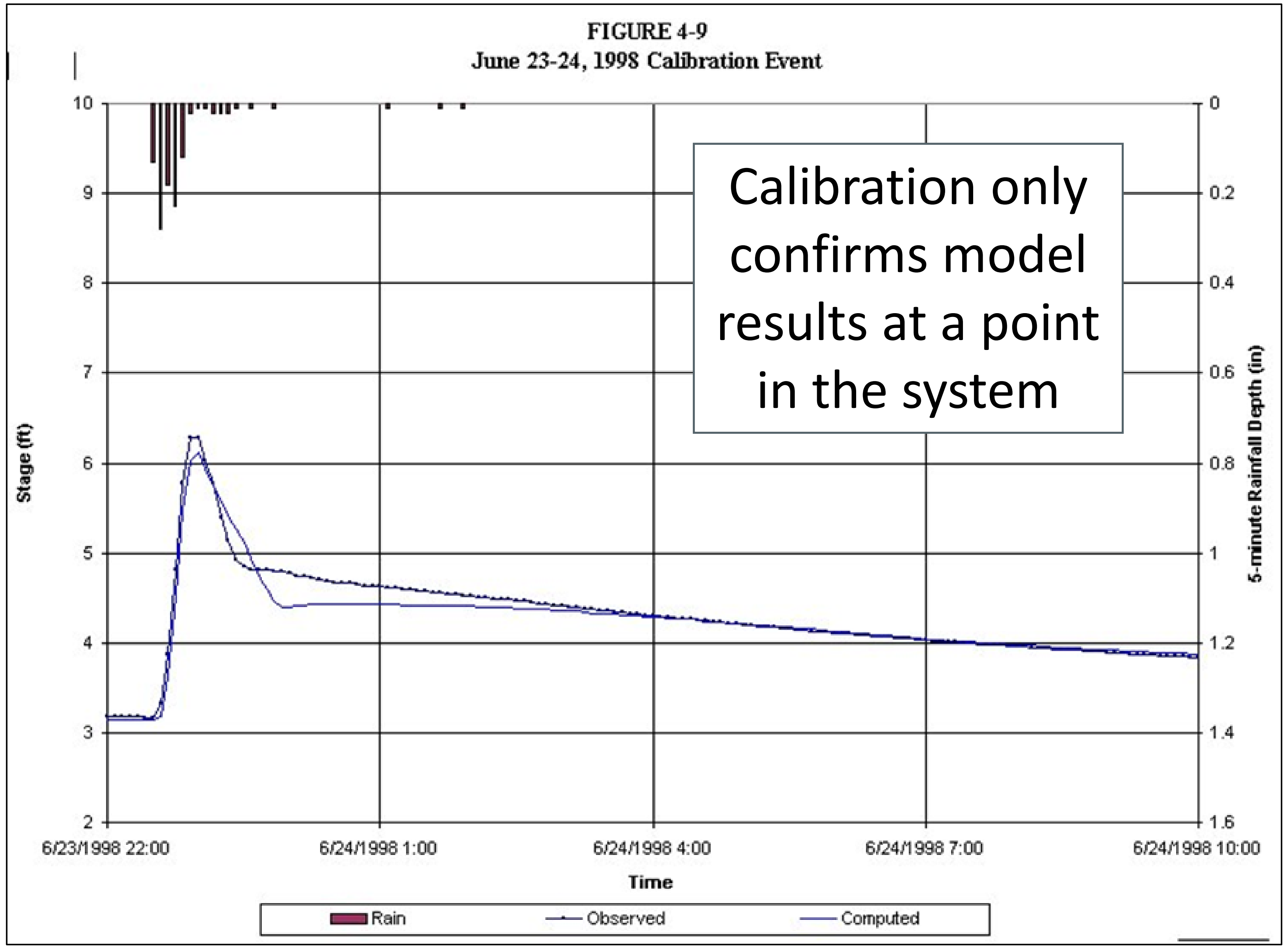
- Flow is contained in the pipe/channel during small storms
- But during the larger storm events…
  - Runoff overflows the pipe or channel banks
  - Streets and homes are flooded
  - Conveyance and storage properties are very different than low-flow conditions
- Calibration measurements may be biased to small storms, modelers therefore must validate/verify their model for the big storms
- Which requires modeling the “dual drainage” system…
  - Minor: active during all runoff producing events, it includes closed conduits (e.g., circular pipes and forcemains) and open channels (e.g., swales, roadside ditches, and creeks)
  - Major: active during the larger flood events when the minor system is overloaded (e.g., flooding in the curb/gutter along the road rights-of-way)

Verification (continued)

- Relate flooding occurrence to a design storm event:
  - Interview residents and/or staff who are familiar with the area and its history
  - Identify chronic flooding problem areas
  - Estimate return period of flooding (e.g., 2-yr road flooding, 25-yr building flooding) = "Level of Service" evaluation
  - Model should indicate similar flooding occurrences for design storm events
- Verification is not as objective or precise as calibration, but can lead to a credible model for high-flow conditions
- Calibration and validation only confirm model results at selected points, whereas verification using a system-wide evaluation covers the entire study area

Example…

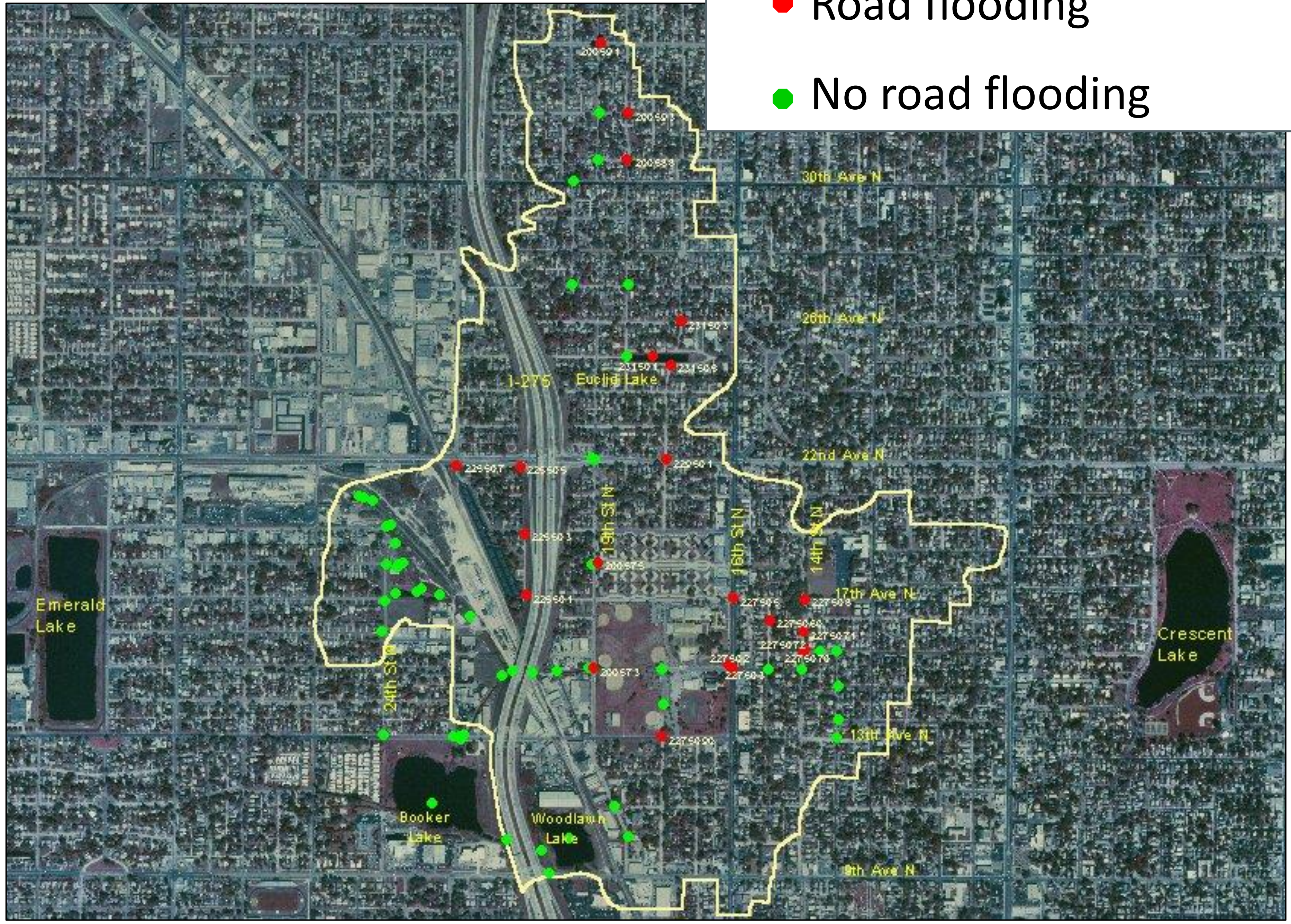
- Point calibration and system-wide verification



Calibration only confirms model results at a point in the system

Legend (25-yr Level of Service)

- Road flooding
- No road flooding



Suggested Calibration Methodology

Model Calibration Methodology

- Before you begin calibrating the model, check that:
  - Model is debugged, representative of your largest design storm event or loading condition
  - Measured data have been reviewed
  - Sensitivity analysis has identified sensitive and insensitive parameters
- Select candidate events:
  - Categorize by response type, seasonality, etc.
  - Separate into distinct flow regimes (e.g., small storms with flow in the main channel versus big storms that flow out-of-bank)
- Hierarchy of calibration parameters:
  - Calibrate the hydrology first (match runoff volume)
  - Hydraulics second (match peaks and timing)
  - Save the water quality for last

Suggested Methodology

1. Select events with impervious response
    - Only impervious surfaces contribute runoff
    - Intense, small volume storm events
2. Calibrate impervious area parameters
    - Imperviousness, overland flow width, and impervious initial abstractions
    - Match total volume and hydrograph shape (peak and timing)
3. Select events with pervious response
    - Both impervious and pervious surfaces contribute runoff
    - Steady rain, large volume storm events
4. Calibrate pervious area parameters
    - Infiltration parameters, pervious initial abstractions, pervious roughness
    - Match total volume and hydrograph shape

Suggested Methodology (continued)

5. Calibrate hydraulic parameters
   - Boundary conditions (tide, lake levels)
   - Base flow contributions (groundwater)
   - Channel/pipe roughness (vegetation, sediment)
   - Variable hydraulic conditions (blockage)

Suggested Methodology (continued)

6. Repeat steps 1-5 for all calibration events. The optimal set of calibration parameters will be based on how well you can:

   - Match total volume of flow
   - Match peak values of stage, flow, velocity
   - Match timing of the peaks
   - Match overall hydrograph shape

7. Validation

   - Test the worthiness of calibrated model parameters
   - Compare results to other flow or stage measurements

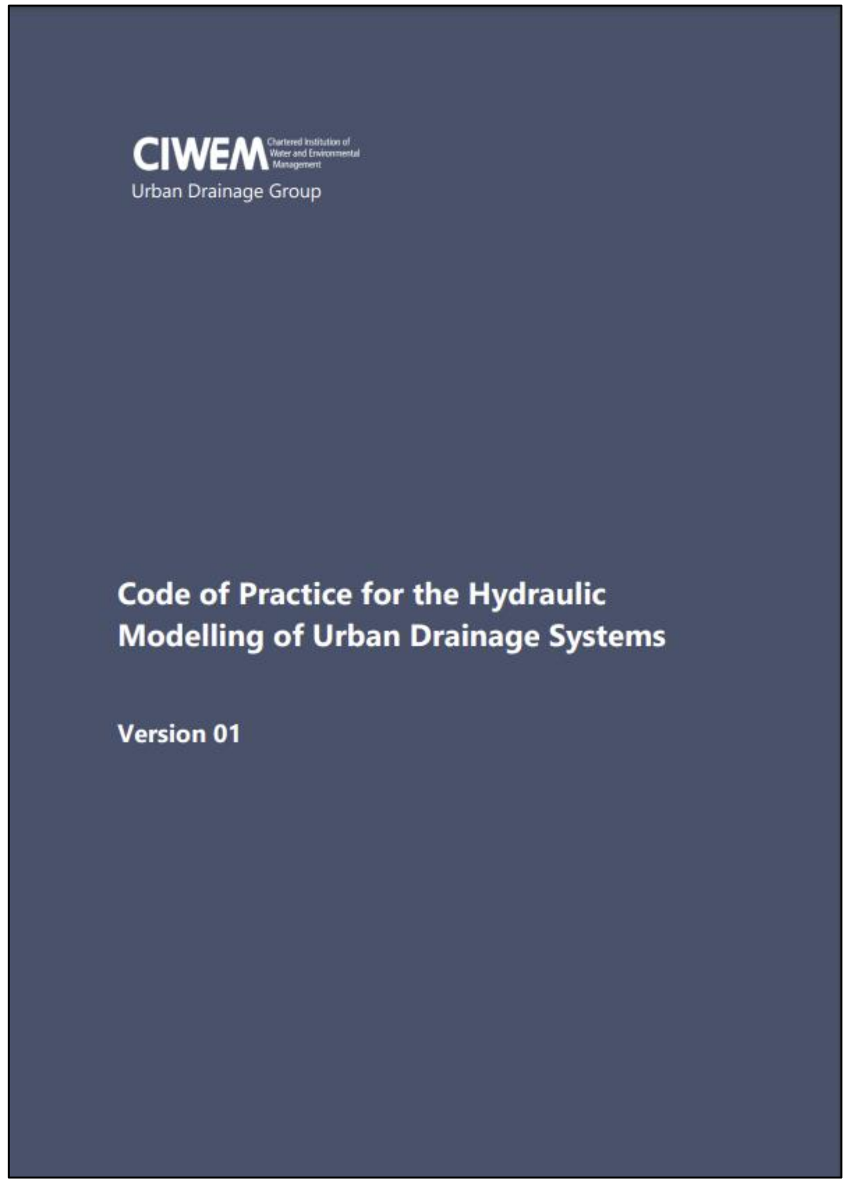
8. Verification

   - Test the worthiness of the calibrated/validated model
   - Compare to other anecdotal information for the really big events (i.e., where measurements may not be available)

When is a Model Calibrated?

- Criteria should be selected upfront, and possibly refined/negotiated during the calibration process
- For additional insight, see CIWEM Code of Practice at https://www.ciwem.org/
- This is what we used for a large master planning effort in northeast Ohio (c. 2004)…

Calibration Type	Data Type	Property	Tolerance
Hydrologic Calibration	ADS Flow Meter	Total Runoff Volume	-20 to +30%
Watershed-wide Flow and Volume Calibration	USGS Flow Meter	Peak Stage	+/- 1 foot
		Stage Hydrograph	Match general timing and shape characteristics
		Peak Flow Rate	-20 to +30%
		Total Flow Volume	-20 to +30%
		Flow Hydrograph	Match general timing and shape characteristics
	Regional Regression	Peak Flow Rate	-35 to +40% (for the 10-, 25-, 50-, and 100-yr events)
Hydraulic Calibration	High Water Marks	Peak Depth	+/- 1 foot
	FIS and Other Sources	Peak Head Loss	+/- 2 feet (at selected crossings for the 100-yr event)


CIWEM
Urban Drainage Group

Code of Practice for the Hydraulic Modelling of Urban Drainage Systems

Version 01

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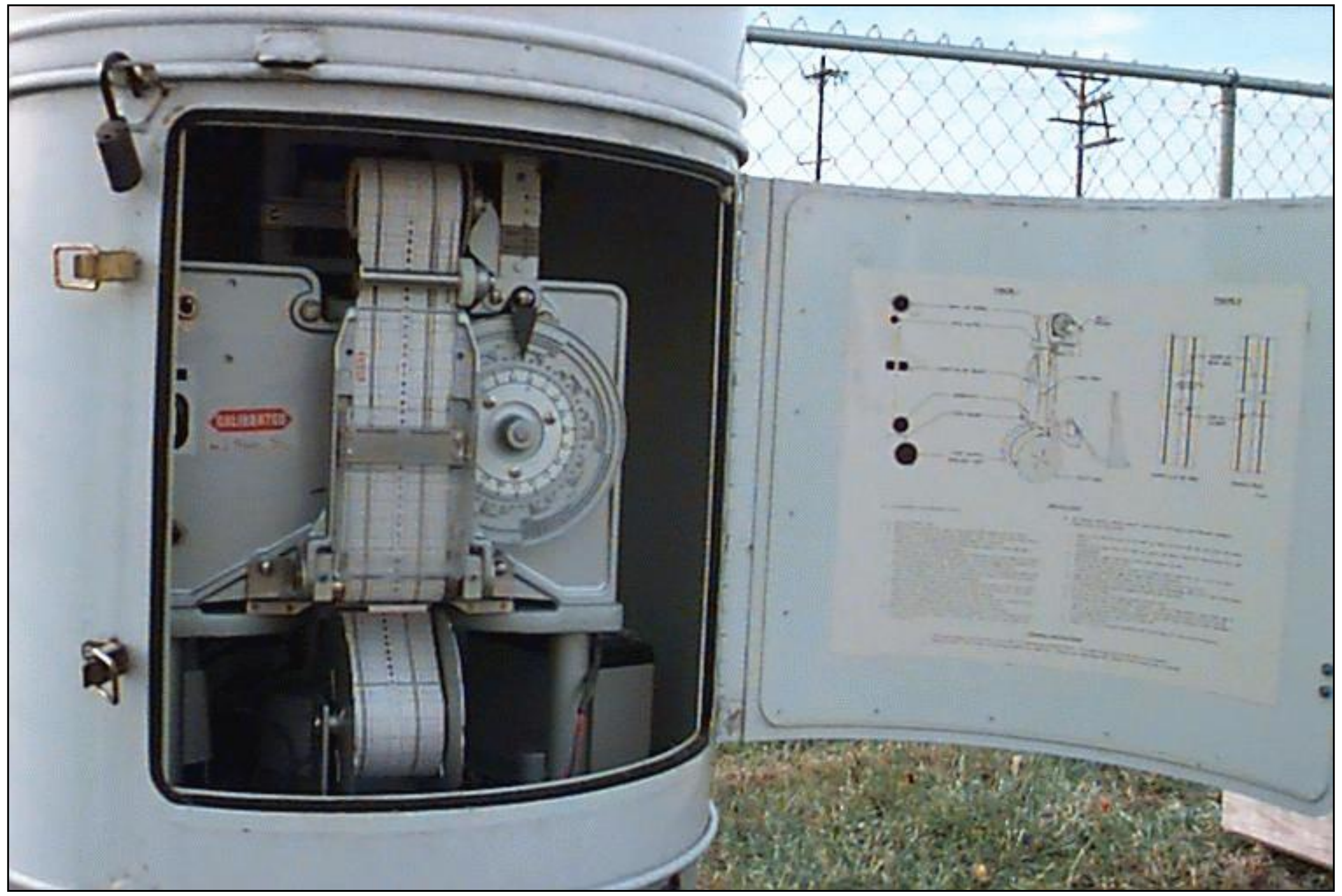
Monitoring Program Data Review

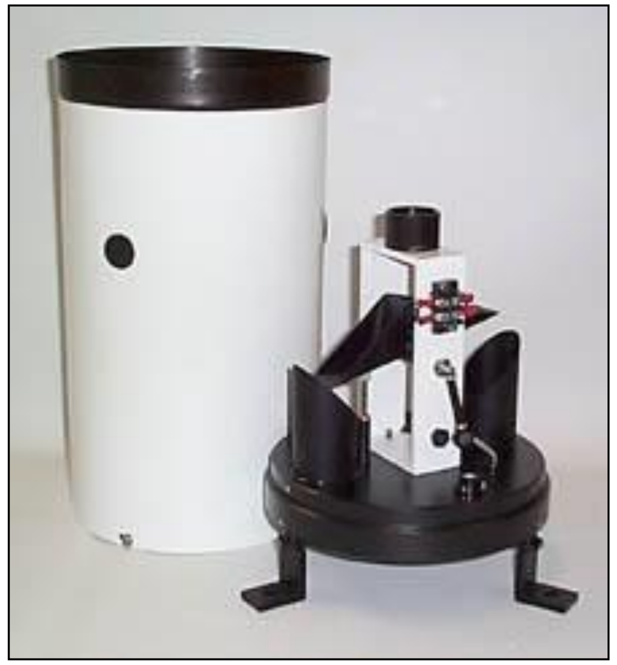
Verification of Measured Data

- Screening rainfall and flow monitoring data is a key activity that precedes the calibration effort
- Review with respect to:
    - Accuracy/quality
    - Extent of coverage (range of development type, drainage system characteristics, and hydrologic conditions)
    - Period of record
    - Selection of appropriate calibration datasets
- Improves model credibility by helping to ensure that imperviousness, for example, will not be improperly calibrated to make up for bad flow data

Rainfall Measurements

- Point representation of area-wide process
- Verify adequacy of rainfall data
  - Proximity to watershed (and orographic effects)
  - Number of gages
  - Extrapolate using daily gages and radar
  - Consider antecedent record
  - Operation and maintenance of equipment
- Standard (non-recording) rain gage
- Tipping bucket
  - Strip chart
  - Downloadable memory
  - Telemetry



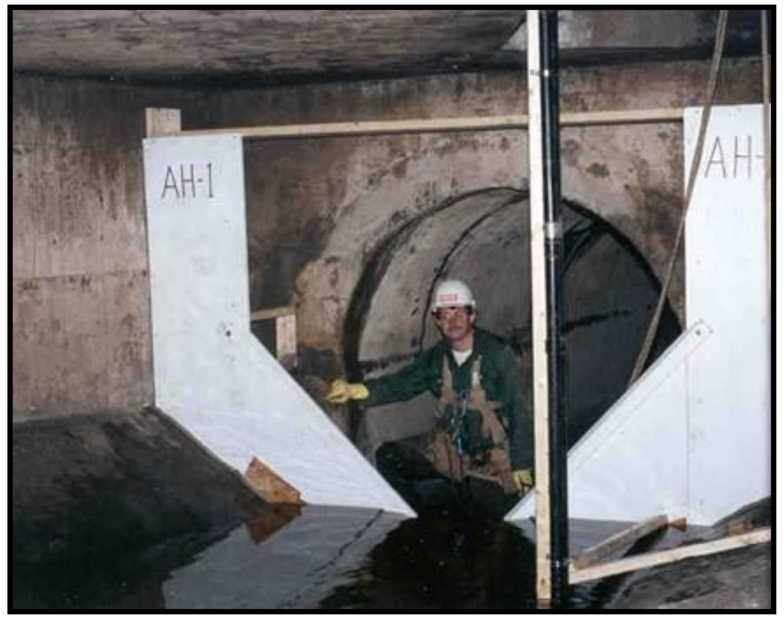


Rainfall Measurements (continued)

- Location considerations
  - Obstructions
  - Wind effects
  - Ground splash
  - Security
  - Freezing, etc.
- Operations & maintenance
  - Cleaning
  - Calibration
- Standard protocols at the state/federal level (and regional datasets from local governments, water management agencies, etc.)

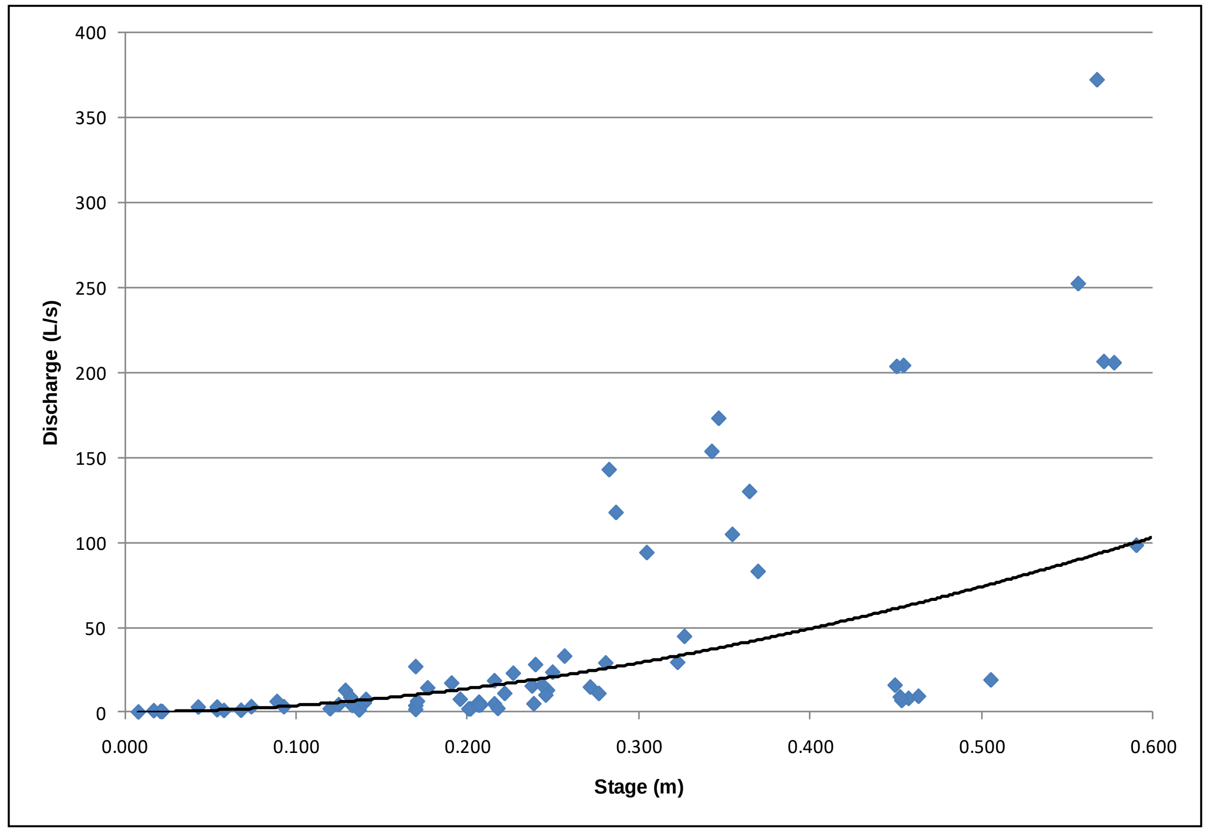
Flow Measurements

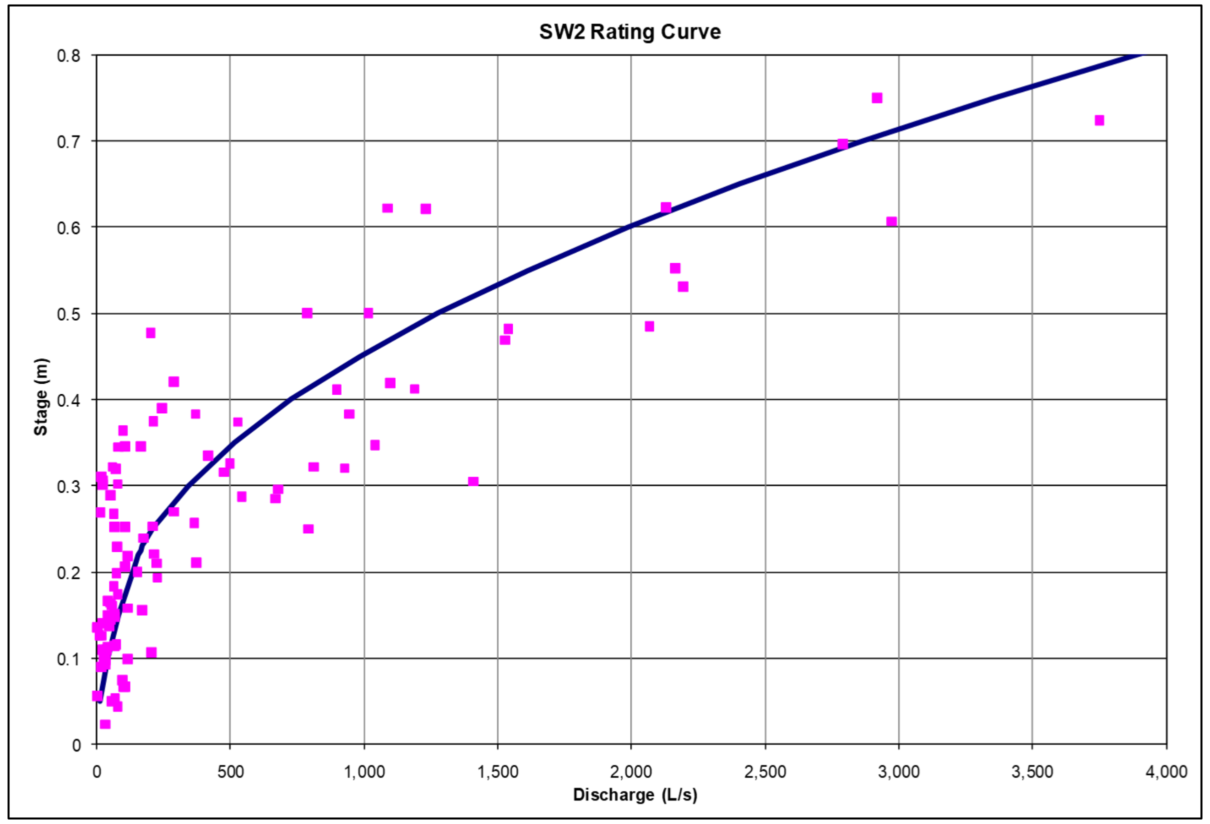
- Verify adequacy of discharge/stage data
  - Period and homogeneity of record
  - Seasonal effects (e.g., baseflow, vegetation)
  - Operation and maintenance of equipment
  - Measurement method (e.g., stage, single-valued rating curve, velocity and depth)
- And you never know what might happen during one of your calibration events…



Streamflow Rating Curves

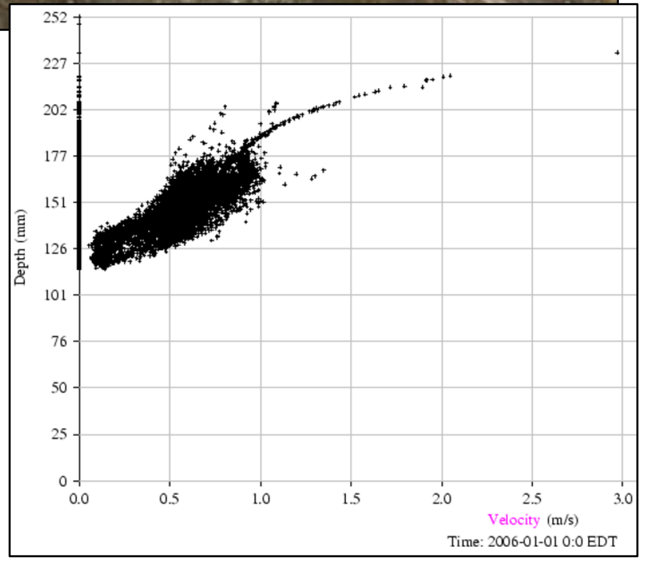
- These are site-specific stage-discharge relationships
  - By measuring stage, the corresponding flowrate is determined from the rating curve and recorded as part of the observed time-series data
- Developed from in-stream velocity-area measurements
  - Ideally from a wide range of flows in the channel
  - Should be updated when channel flow characteristics change
- Curves may not include large flood event flows, or may feature wide scatter in field measurements (which is not conducive to a single-valued curve)



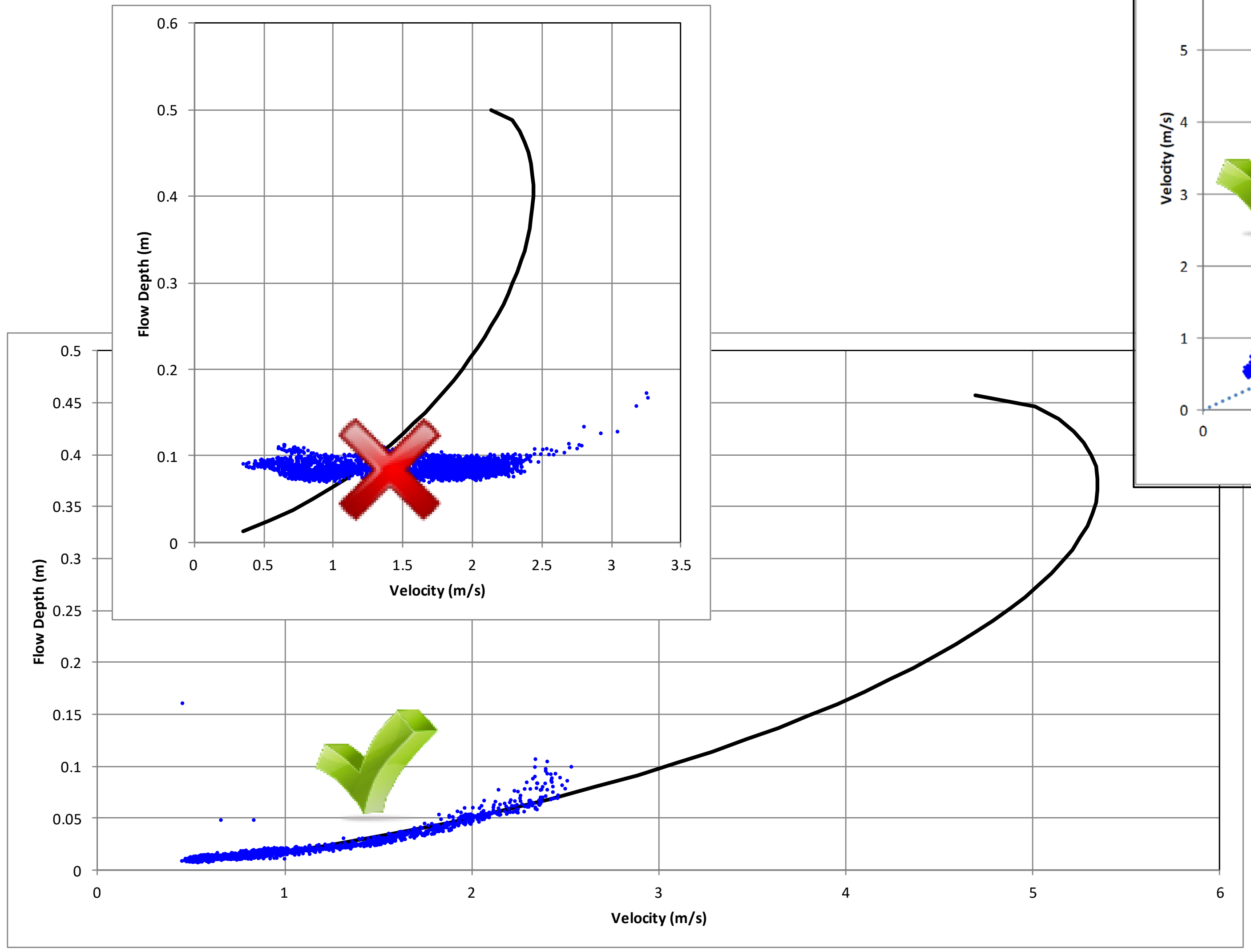


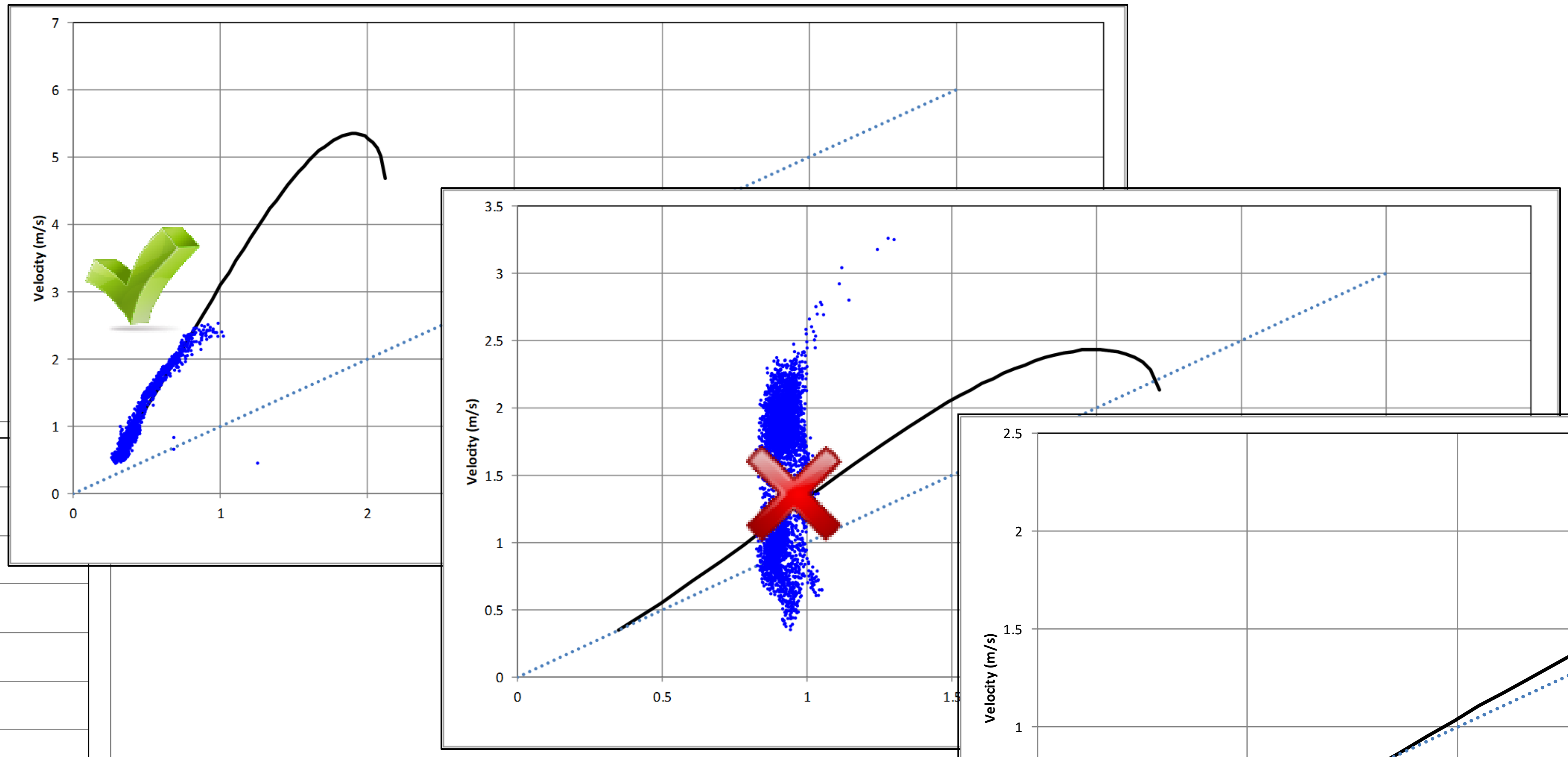
Sewer Flow Monitoring

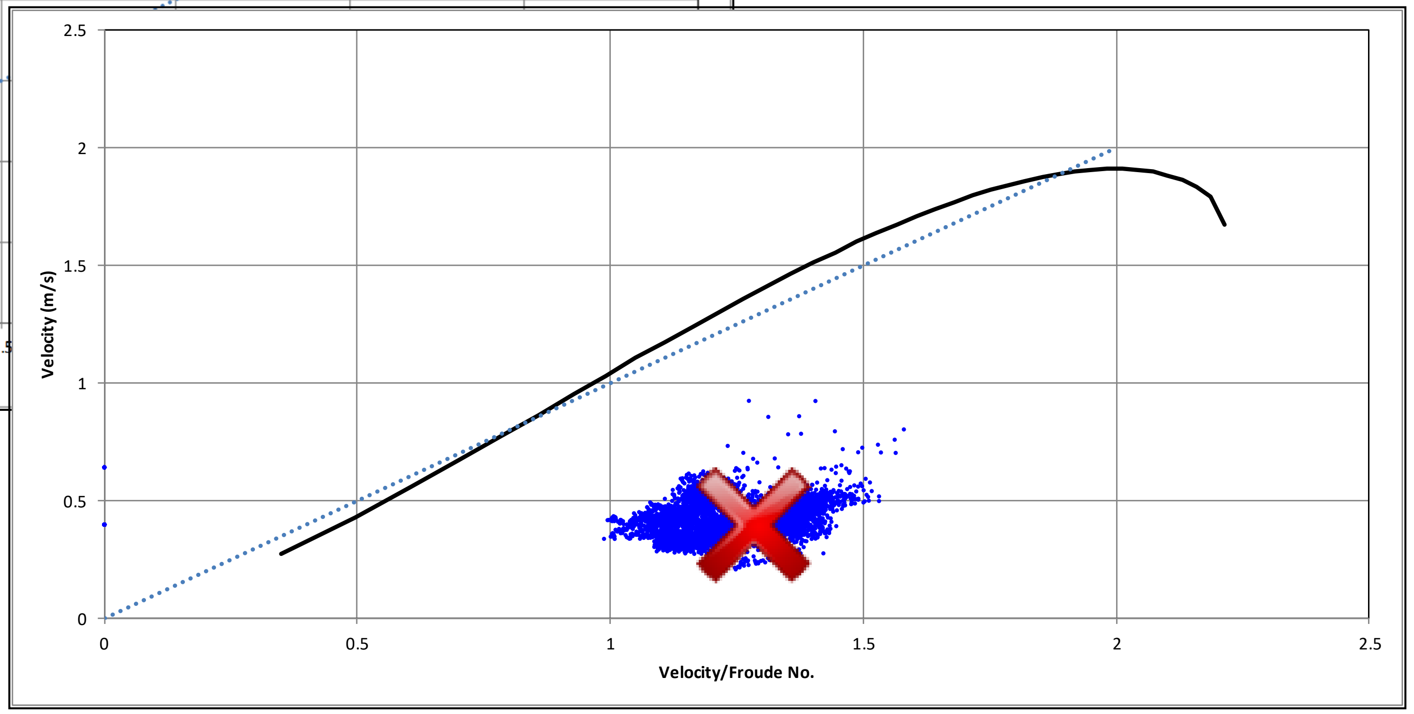
- Whether you hire a contractor or do it yourself, always check the data
- At a minimum, compare with Manning's formula
- Replace or move the meter if you have bad data!



Depth-Velocity plots







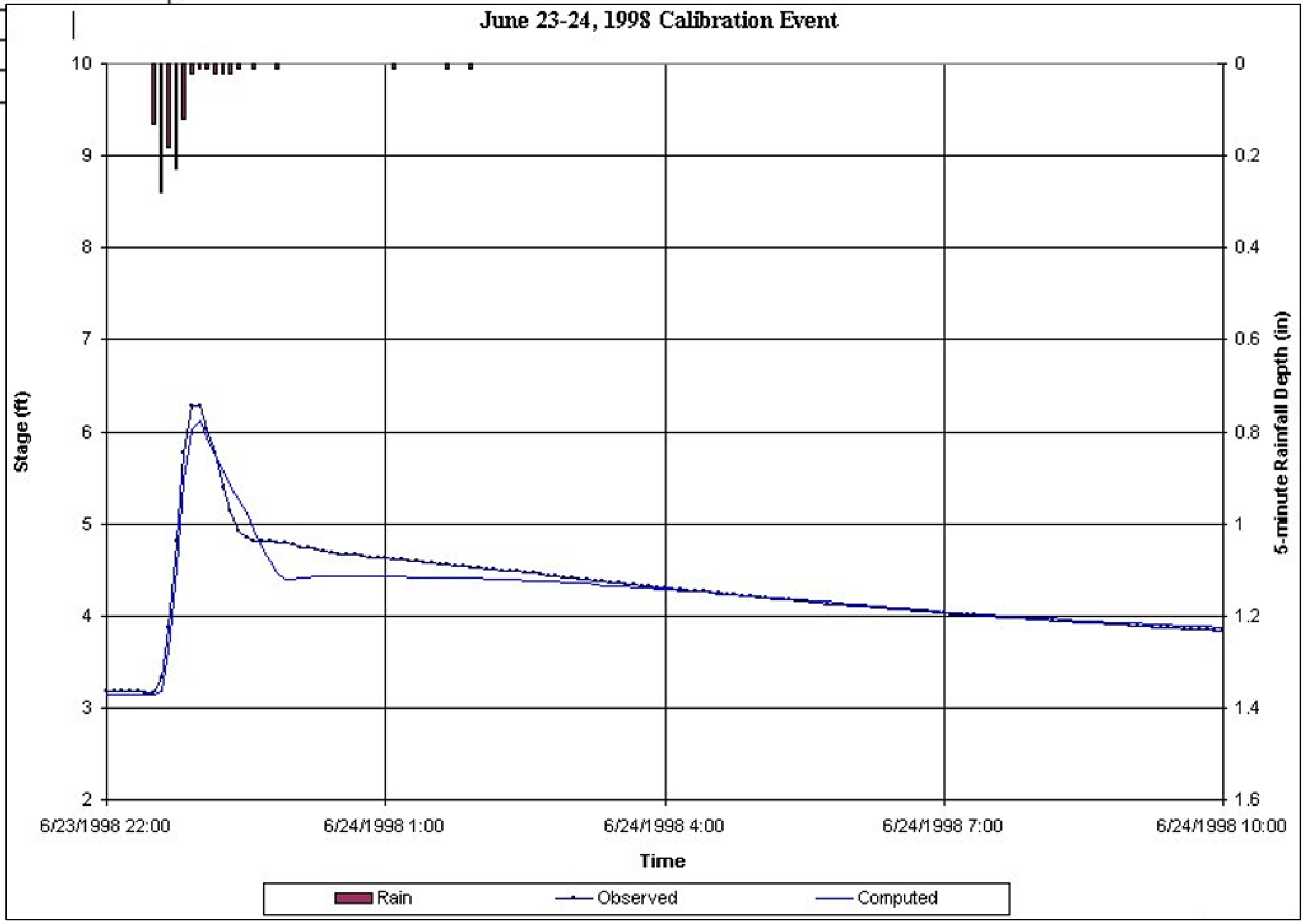
Velocity-Velocity÷ Froude plots

Model Calibration Examples

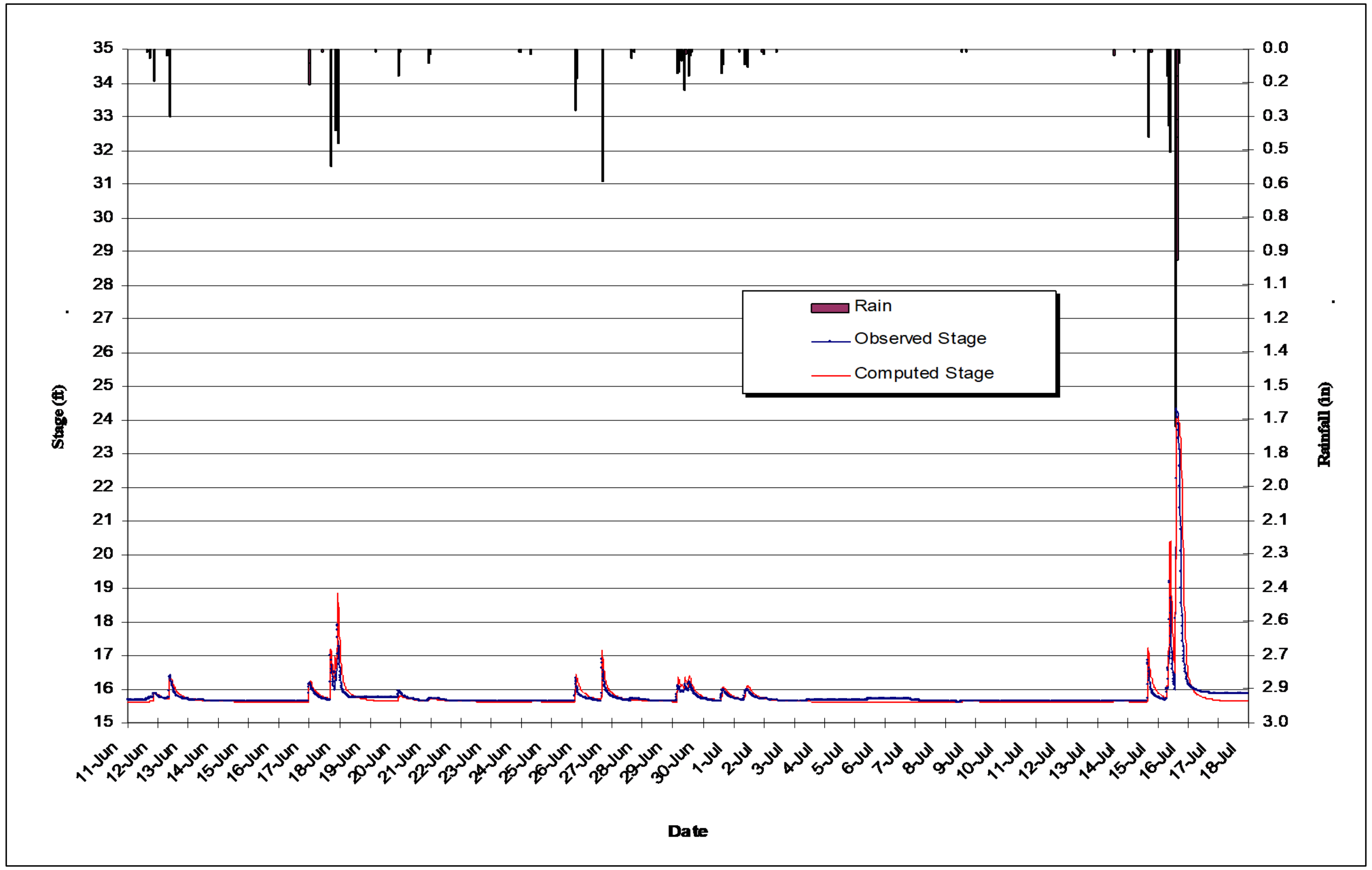
Single Event Examples

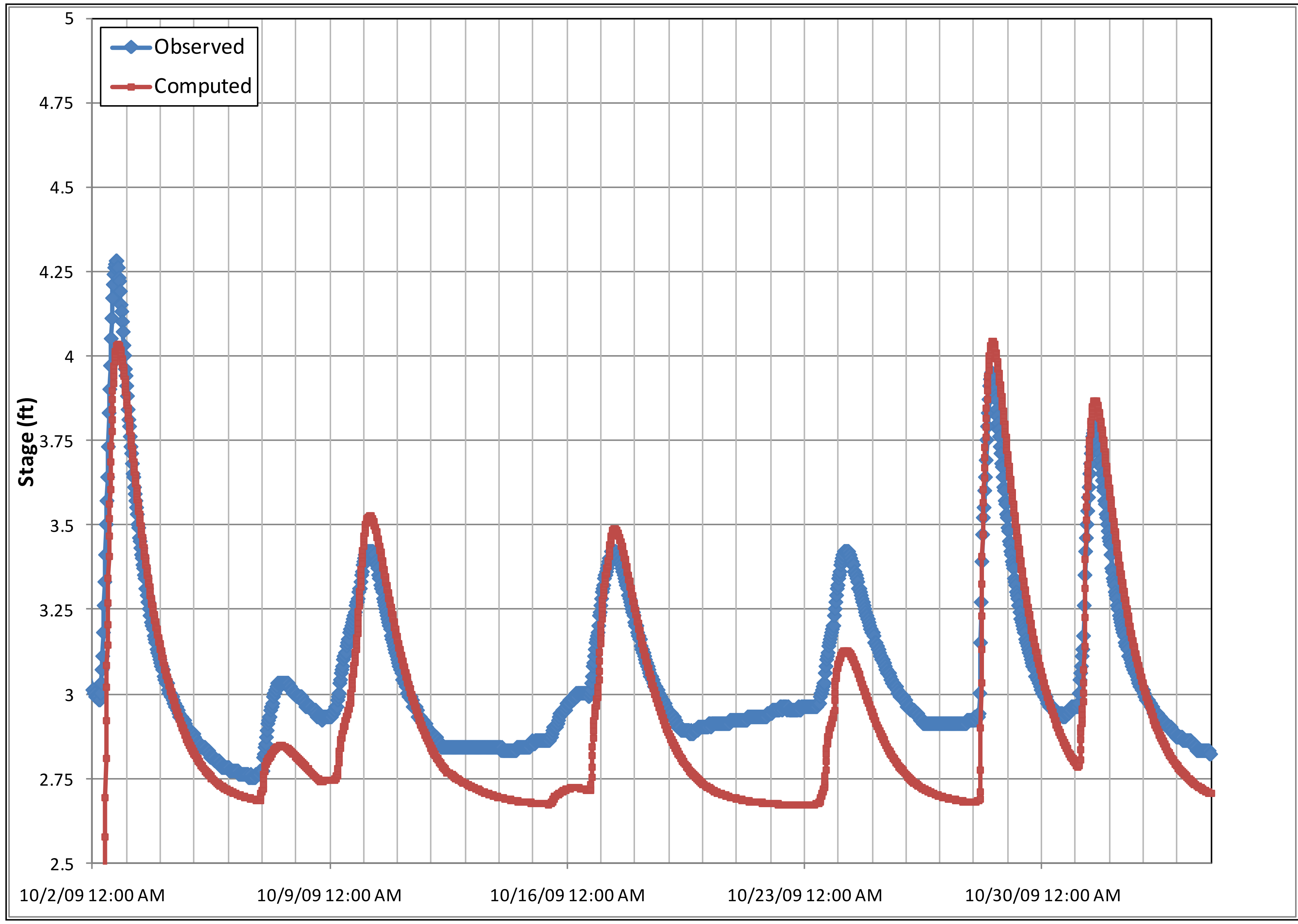
TABLE 4-3
City of St. Petersburg - Basin B Model Calibration
Summary of Calibration Results

Calibration Event Event Number	Start Date	Rainfall Volume (in)	Event Duration (hr)	Hydrologic Response Type	Antecedent Moisture Condition	Peak Stage (ft) Measured	Predicted	Diff	Comment
1	26-Dec-97	3.59	24	Pervious	Dry/Normal	6.9	6.6	-0.3	Receding limb is overpredicted
2	23-Jan-98	1.78	12	Impervious	Dry	6.0	5.8	-0.2	
3	2-Feb-98	2.32	12	Impervious	Dry	7.6	6.6	-0.9	Second peak is underpredicted
4	15-Feb-98	3.86	27	Pervious	Dry	6.9	6.2	-0.6	
5	19-Feb-98	3.84	12	Impervious	Wet	8.9	8.0	-0.9	Peaks under, receding limb overpredicted
6	18-Mar-98	4.54	42	Pervious	Dry	6.2	6.2	0.0	Receding limb is overpredicted
7	30-May-98	2.27	12	Impervious	Dry	7.8	6.3	-1.5	Non-uniform rainfall likely
8	22-Jun-98	0.98	12	Impervious	Dry	5.7	5.2	-0.5	Non-uniform rainfall likely
9	23-Jun-98	1.07	12	Impervious	Normal	6.3	6.1	-0.2	
10	31-Jul-98	1.27	12	Impervious	Dry	5.6	6.1	0.5	Non-uniform rainfall likely
							Average:	-0.4	(Does not include Event 7)



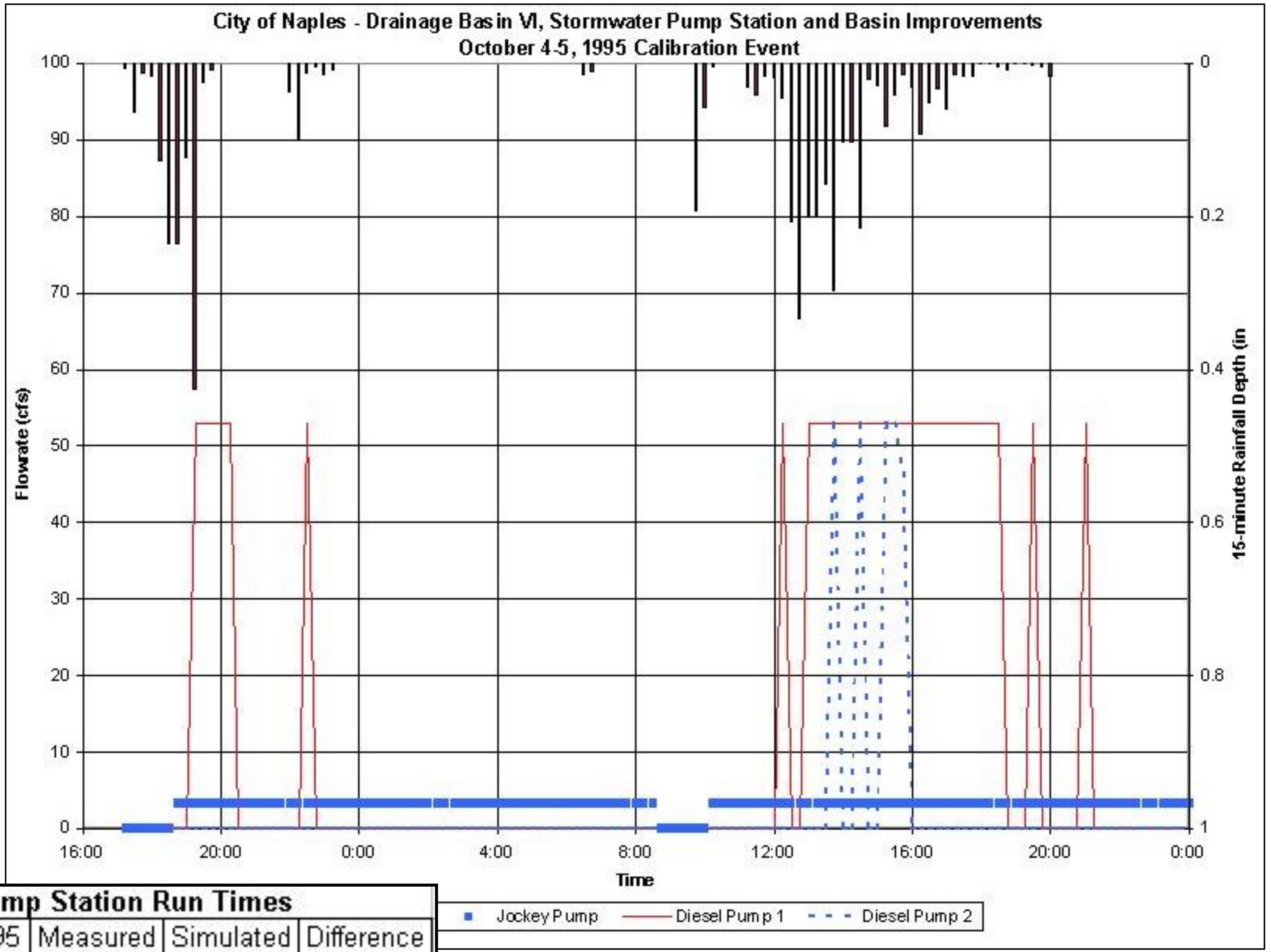
Continuous Simulation Examples



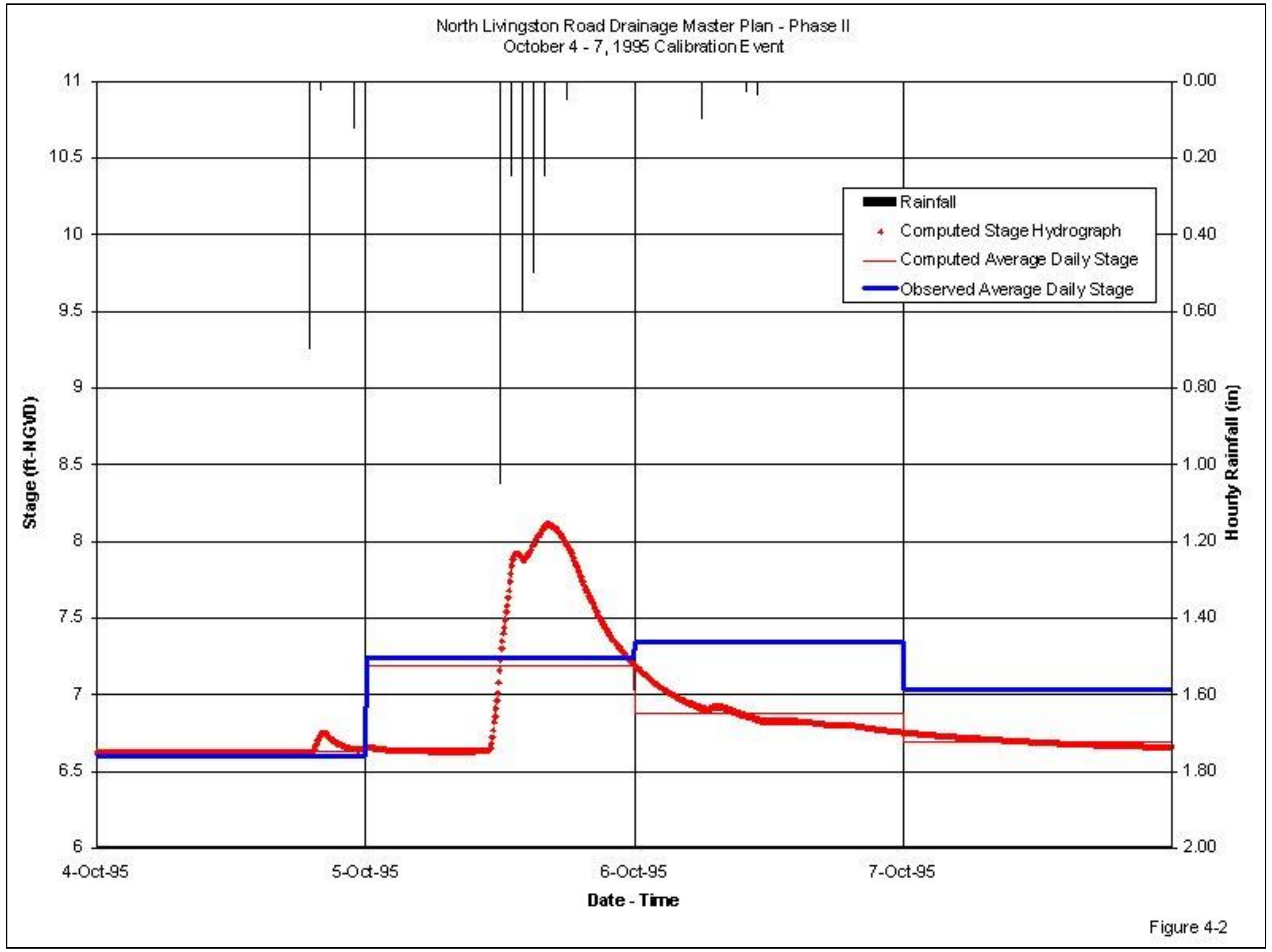


Calibration Affected by Measurement Limits

- In lieu of flow measurements, match pump run times
- Work with whatever time resolution is available…



Pump Station Run Times			
October 5, 1995	Measured	Simulated	Difference
Rainfall	2.90	2.87	-1%
Jockey Pump	22.34	22.5	1%
Diesel Pump 1	6.12	6.5	6%
Diesel Pump 2	1.53	1.25	-18%



Validation – Comparison to High Water Marks

Table 4-2
Myrtle Avenue Stormwater Improvement Project - Phase I
Model Validation Results
Comparison to Surveyed High Water Marks and Flooding Complaint Records (July 15, 2000 Storm Event)

Junction Name	Location (nearest street intersection)	Address (Building Name or Property Owner)	Peak Flood Stage Observed (ft-NGVD)	Peak Flood Stage Predicted (ft-NGVD)	Peak Flood Stage Difference (ft)
Prospect3	S. Prospect Ave. at Park St.	812 Park St. (Bob Lee's garage)	24.2	24.4	0.2
Prospect2	S. Prospect Ave. at Park St.	809 Park St. (Auto Parts)	24.3	24.4	0.0
SMyrtle19	S. Myrtle Ave. at Pierce St.	806 Pierce St. (Tack & Warren)	24.2	24.1	-0.1
Prospect10	S. Prospect Ave. at Court St.	825 Court St. (Bowen-Keppie Travel)	24.8	23.9	-0.9
Prospect11	S. Prospect Ave. at Chestnut St.	406 Prospect Ave. (David Levenreich Attorney)	24.8	24.6	-0.3
SMyrtle10	S. Myrtle Ave. at Pine St.	606 S. Myrtle Ave. (Scotty's)	24.9	25.1	0.1
SMyrtle9	S. Myrtle Ave. at Pine St.	703 S. Myrtle Ave.	25.5	25.1	-0.4
Prospect1	S. Prospect Ave. at Pierce St.	Prospect Ave./Pierce St. pump	23.8	24.0	0.3
SMyrtle22	S. Myrtle Ave. at Cleveland St.	811 Cleveland St. (Fiores Restaurant)	25.0	25.5	0.5
Chestnut14	Chestnut St. at S. Garden Ave.	Chestnut St. and Garden Ave.	25.6	25.4	-0.1
				Maximum	0.5
				Minimum	-0.9
				Average	-0.1

Notes:
1. Elevations and flooding depths have been rounded to the nearest tenth of a foot.
2. High water mark at Prospect10 (25.77 ft) was set to value at Prospect11 (24.80 ft) due to possible error or blocked inlets.

Figure 5-2

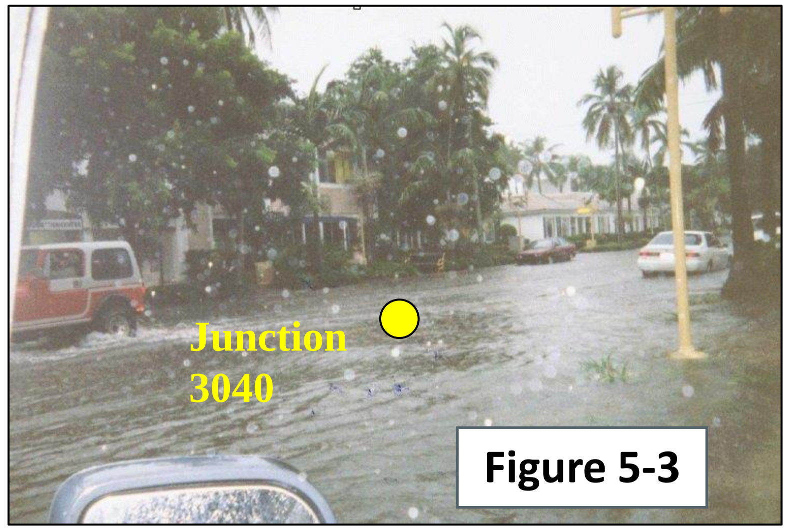


Figure 5-3

Table 5-2
City of Naples - Drainage Basin III, Stormwater Pump Station and System Improvements
5th Avenue South Model Validation - September 18-21, 1999

Junction Name	PSWMS Location	Road Crown Elevation (ft-NGVD)	Existing System: Peak Stage (ft-NGVD)	Existing System: Road Flooding (ft)	Existing System: Reference Photograph Figure No.	Comments
3002	Retention lake	4.4	4.5	0.1		
3004	Alley just north of retention lake	5.6	4.8		5-4	no visible street flooding is indicated
3020	East Lake Drive, just south of 5th Ave S	5.9	5.0			
3030	Intersection of East Lake Dr and 5th Ave S	6.5	6.2		5-2	minimal street flooding shown in photo
3040	Intersection of 6th St S and 5th Ave S	6.3	6.7	0.4	5-3	significant street flooding in photo
3042	Intersection of 6th St S and 4th Ave S	7.9	8.3	0.4		
3050	Intersection of 7th St S and 4th Ave S	8.0	8.3	0.3		
3060	Intersection of 6th St S and 3rd Ave S	9.5	9.5			

Validation – Match Chronic Flooding Problems

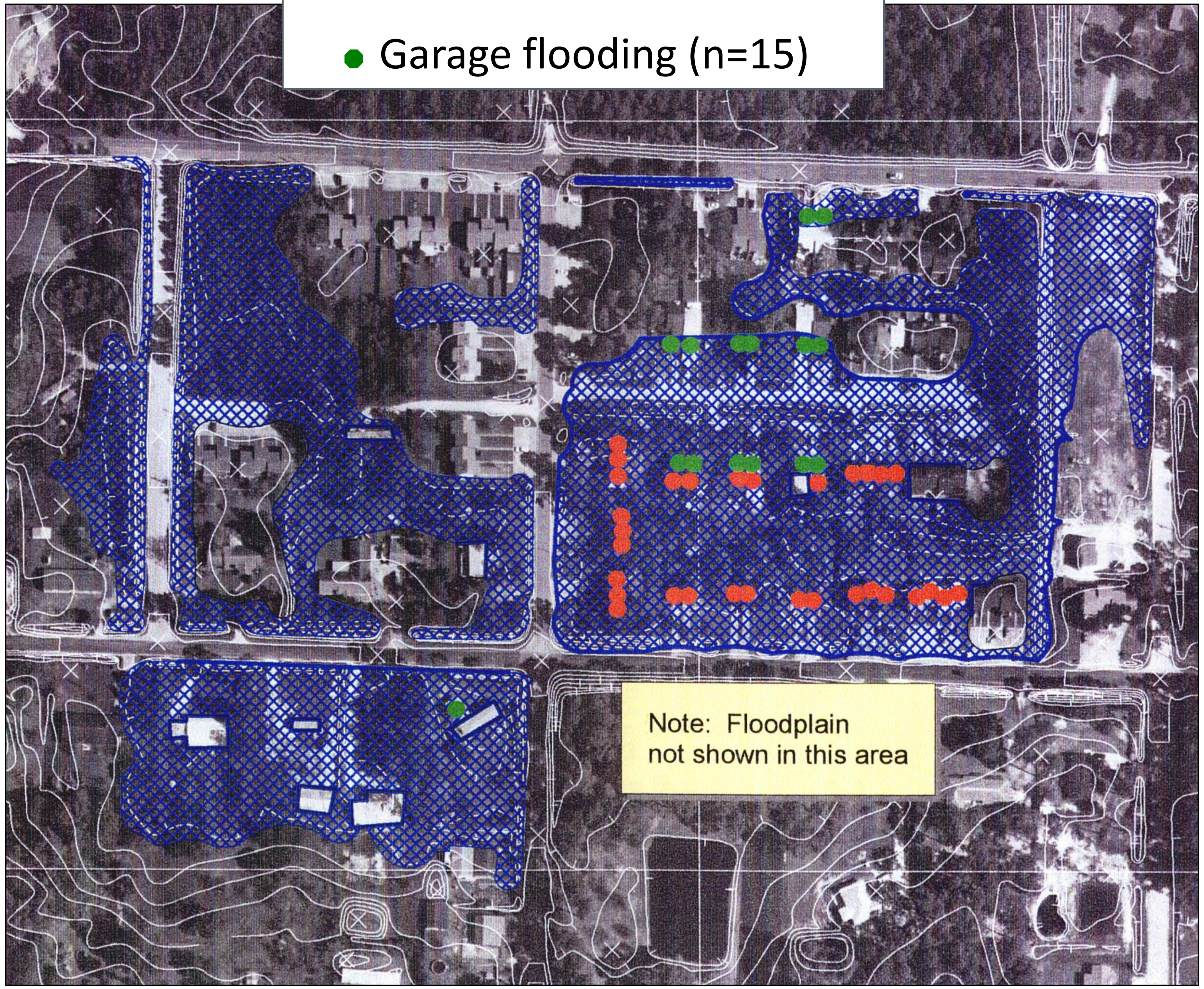
- Count the number of impacted structures

Bay County - East Hiland Park Stormwater Drainage Plan
Summary of Building Flooding Occurrences - Houses and Garages Within Study Area

Design Storm Event	Existing System House Flooding	Existing System Garage Flooding	Existing System Total	Recommended Alternative House Flooding	Recommended Alternative Garage Flooding	Recommended Alternative Total	Change
2-yr/24-hr	0	0	0	0	0	0	n/a
5-yr/24-hr	6	2	8	0	0	0	-100%
10-yr/24-hr	14	12	26	0	0	0	-100%
25-yr/24-hr	31	15	46	0	6	6	-87%
100-yr/24-hr	75	20	95	12	19	31	-67%

Legend (25-yr Design Storm)

- House flooding (n=31)
- Garage flooding (n=15)



Validation – Comparison to Previous Studies

- Compared to local USGS regression equations
- Compared to headloss through culverts as reported in FEMA Flood Insurance Study

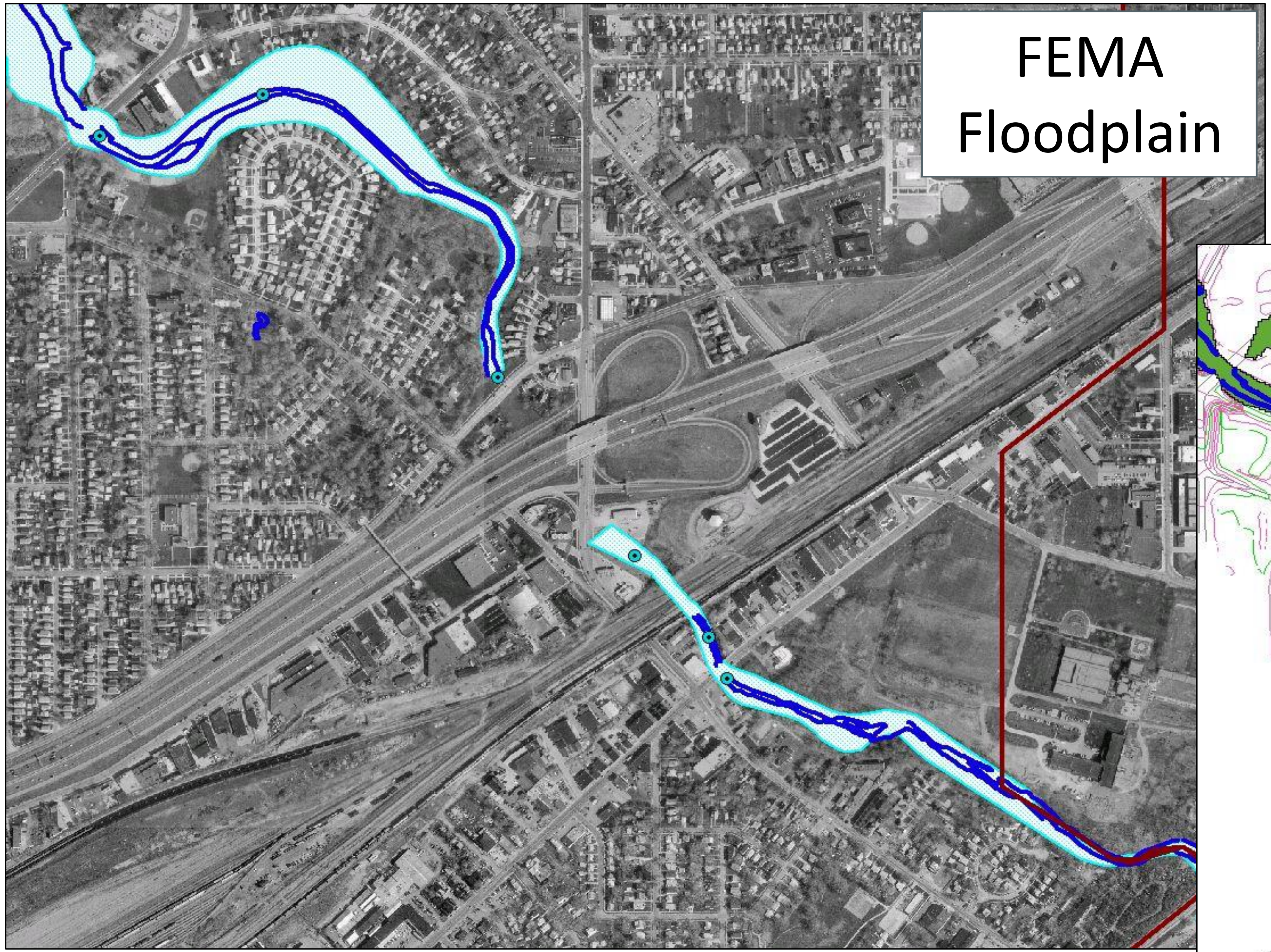
Location	Peak Flow (cfs)											
	10-Year Storm			25-Year Storm			50-Year Storm			100-Year Storm		
	USGS Regression	RIDE	% Difference	USGS Regression	RIDE	% Difference	USGS Regression	RIDE	% Difference	USGS Regression	RIDE	% Difference
Thames Rd. crossing, Bedford	468	556	19%	600	688	15%	714	780	9%	832	875	5%
Conrail crossing, Bedford	621	595	-4%	794	670	-16%	952	834	-12%	1,110	931	-16%
Confluence with Tinkers Creek, Walton Hills	1,033	1,260	22%	1,312	1,532	17%	1,576	1,857	18%	1,843	2,238	21%

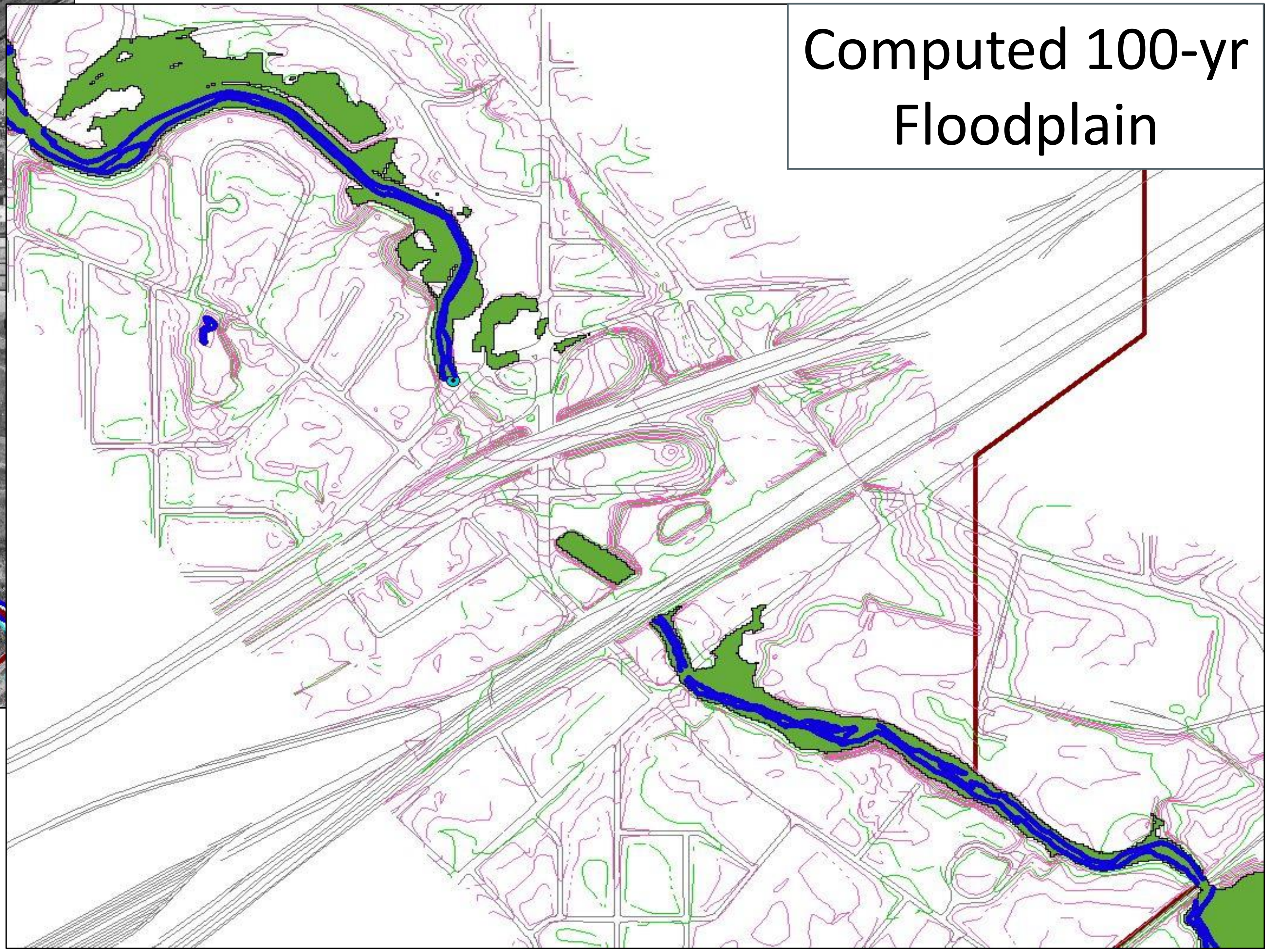
Notes:

1. These regression equations do not consider the effect of significant hydraulic constraints (e.g., stream crossings).
2. USGS determined the average standard error to be between 33 and 41 percent.

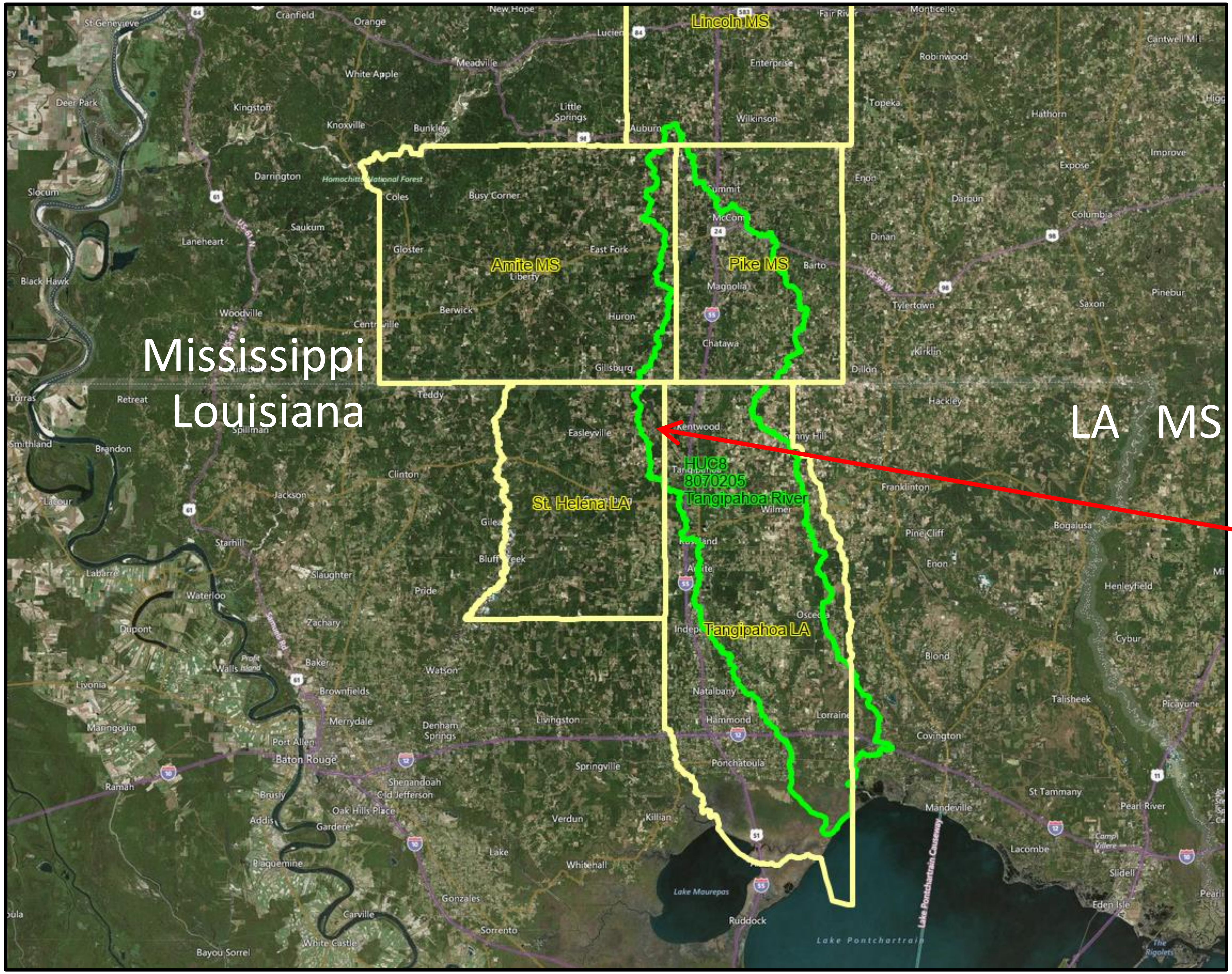
Location	Community	Tributary	Structure Head Loss (ft.)		
			FIS	RIDE	Difference
RR crossing	Euclid	Main Branch	1.8	2.6	0.8
Anderson Rd.	South Euclid	West Branch 3	5.7	4.0	-1.7
Telhurst Rd.	South Euclid	West Branch 3	2.0	1.2	-0.8
Anderson Rd.	South Euclid	West Branch 2	8.0	6.7	-1.3
Bishop Rd.	Highland Heights	East Branch 3A	2.3	0.2	-2.1
Cedar Rd.	Beachwood	West Branch 4	8.9	10.8	1.9
David-Myers Pkwy.	Beachwood	West Branch 4	1.4	0.9	-0.5
David-Myers Pkwy.	Beachwood	West Branch 4	3.2	2.3	-0.9

Validation – Match FEMA Floodplain



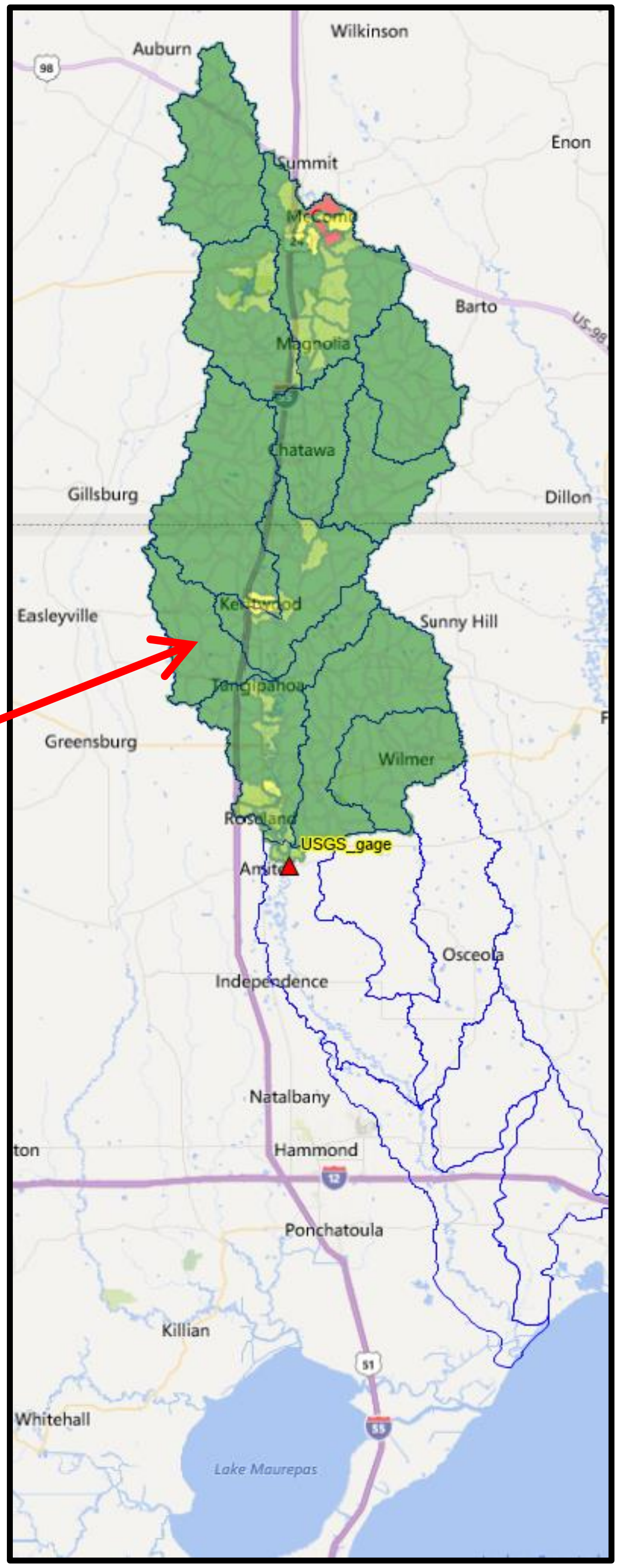


Calibration Example – Upper Tangipahoa River



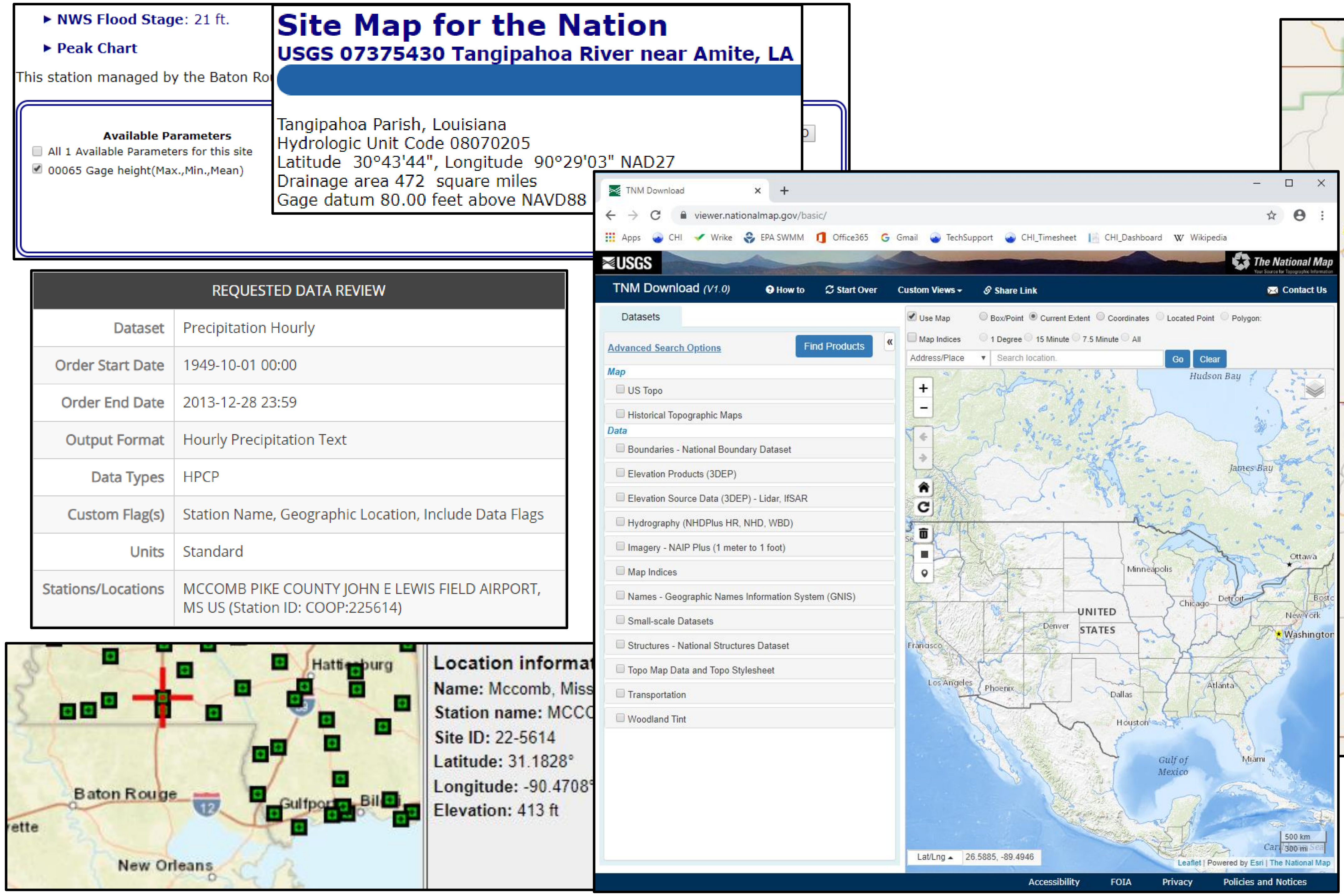
Upper Tangipahoa River watershed

Beaver Creek subwatershed

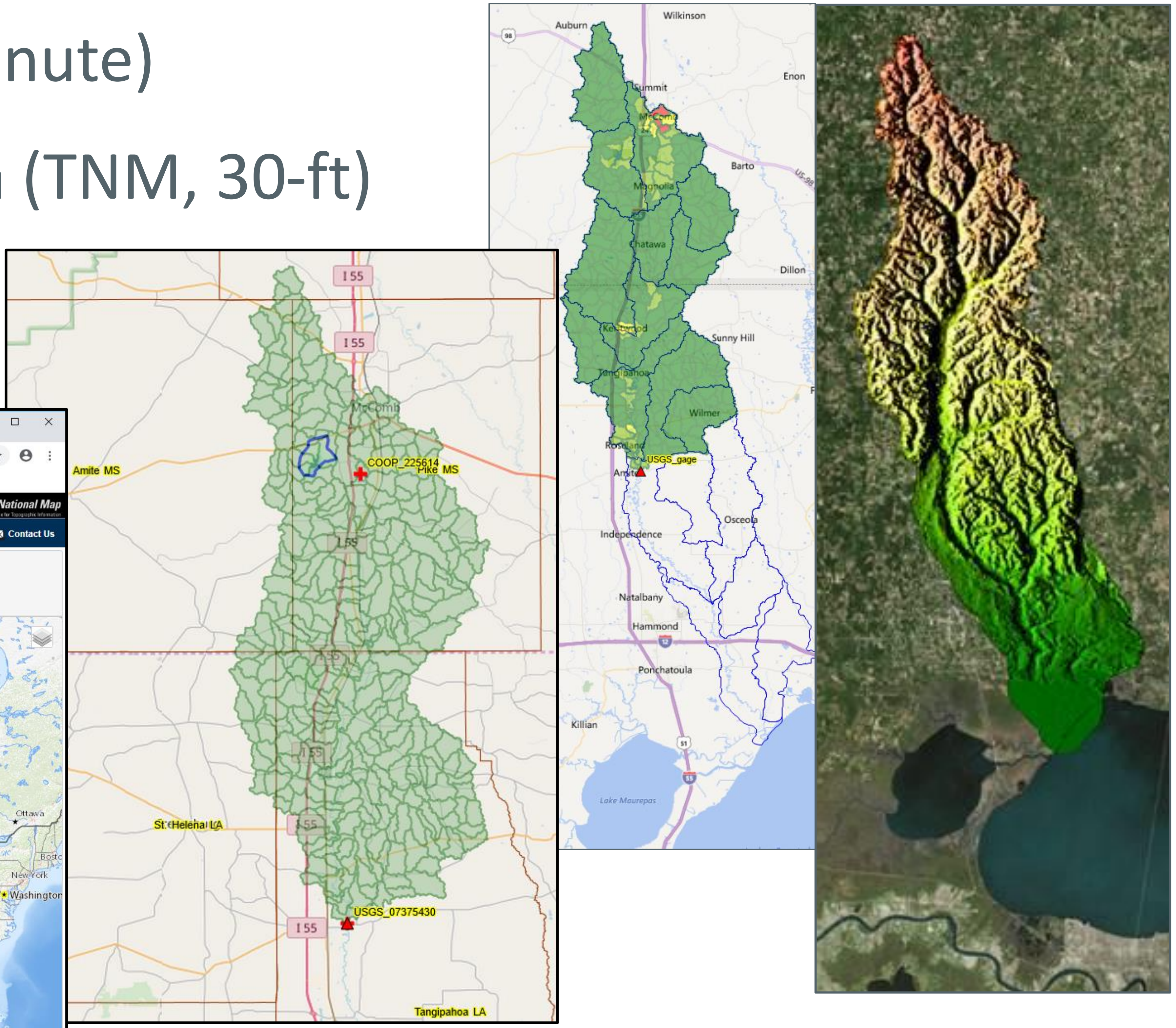


Rainfall, Flow, and Digital Topography Data

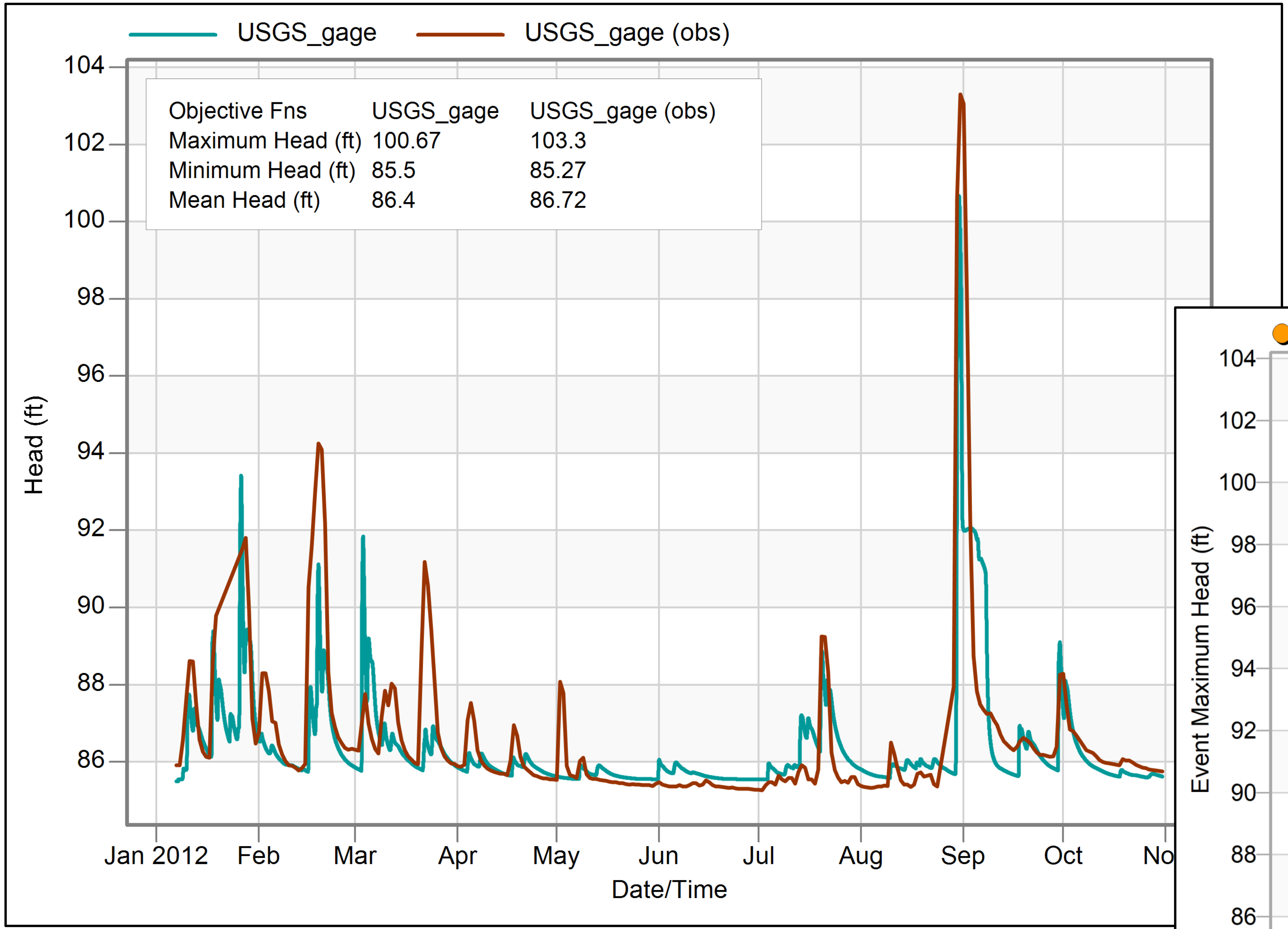
- NCEI rainfall data (HPCP hourly, ASOS 1-minute)
- USGS gage data (NWIS) and elevation data (TNM, 30-ft)

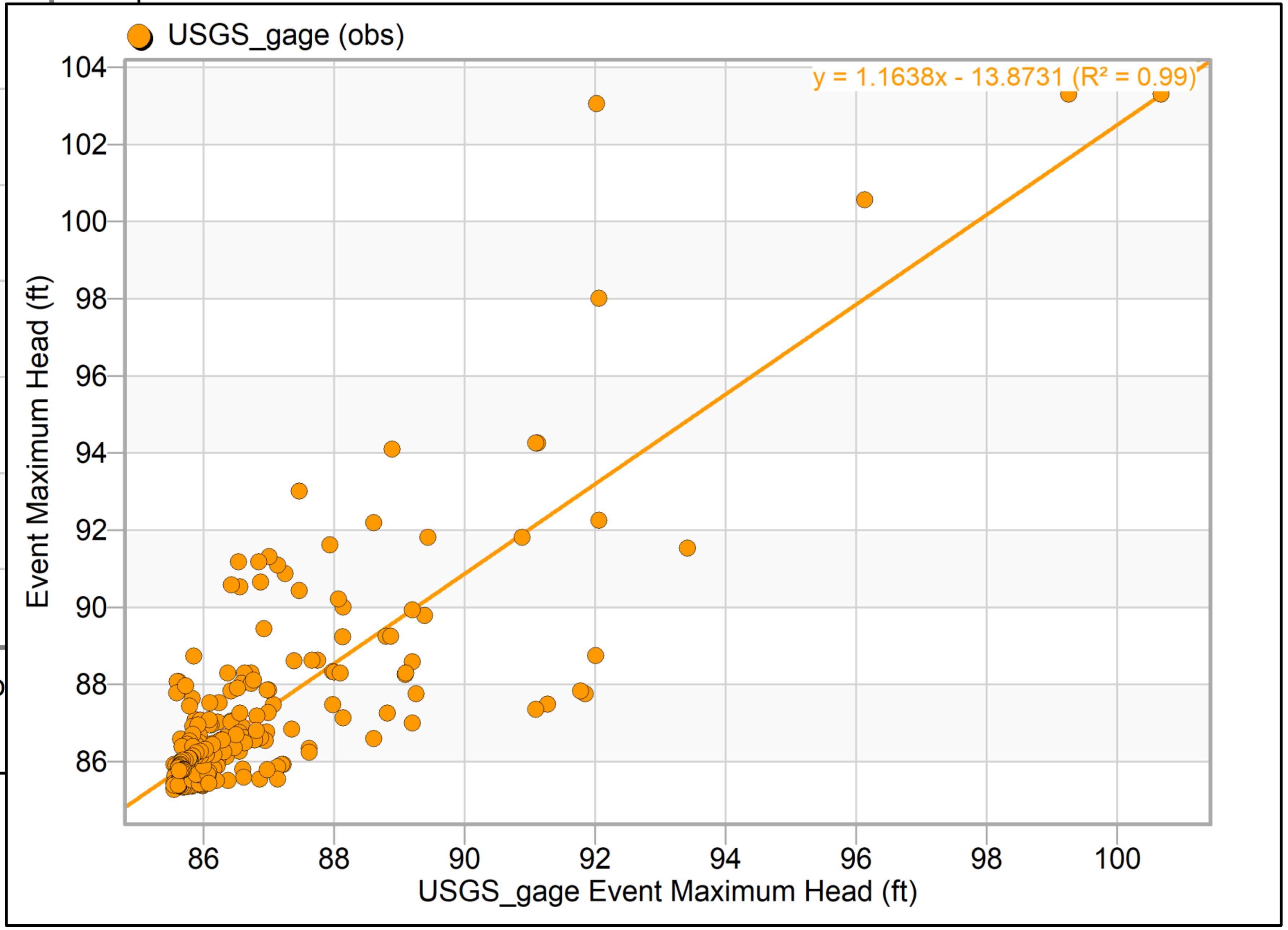


REQUESTED DATA REVIEW	
Dataset	Precipitation Hourly
Order Start Date	1949-10-01 00:00
Order End Date	2013-12-28 23:59
Output Format	Hourly Precipitation Text
Data Types	HPCP
Custom Flag(s)	Station Name, Geographic Location, Include Data Flags
Units	Standard
Stations/Locations	MCCOMB PIKE COUNTY JOHN E LEWIS FIELD AIRPORT, MS US (Station ID: COOP:225614)



Successful Calibration?

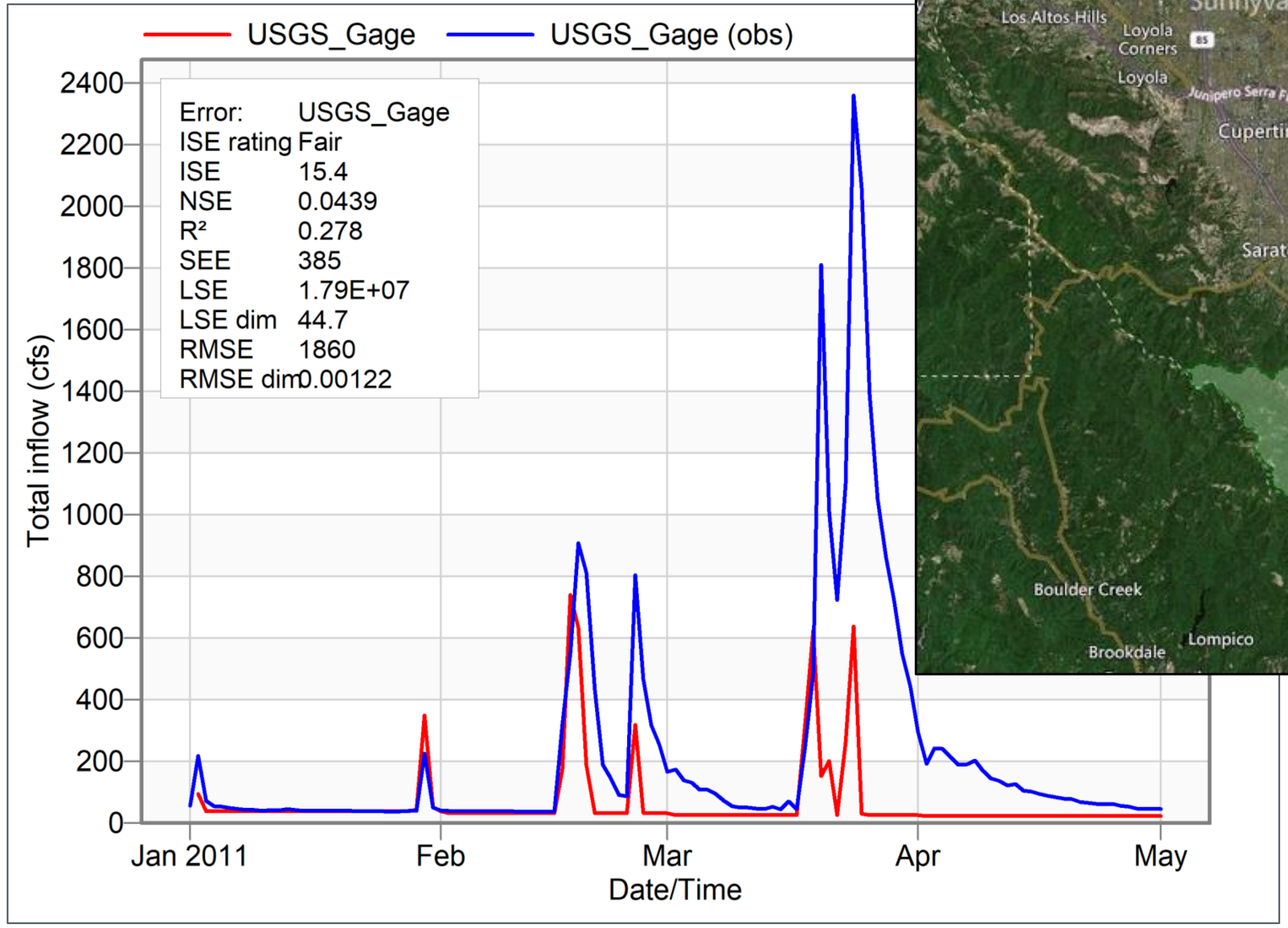


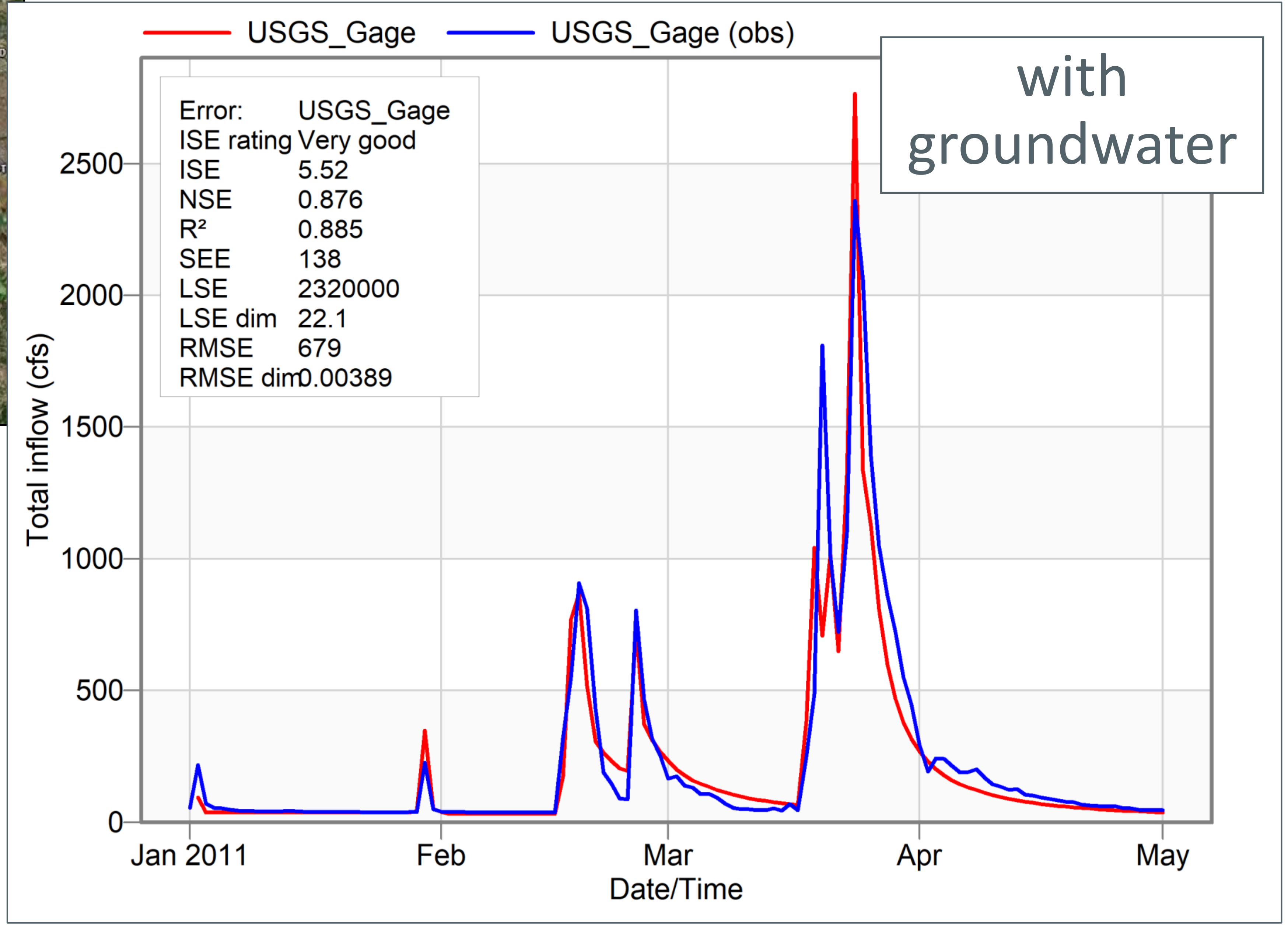


Results based on standard parameter values applied with NLCD database – further refinements would use SRTC tool

A Different Example

successful calibration?





with groundwater

NO! (don’t ignore groundwater)

Another Example…

Original “Calibrated” Groundwater Model

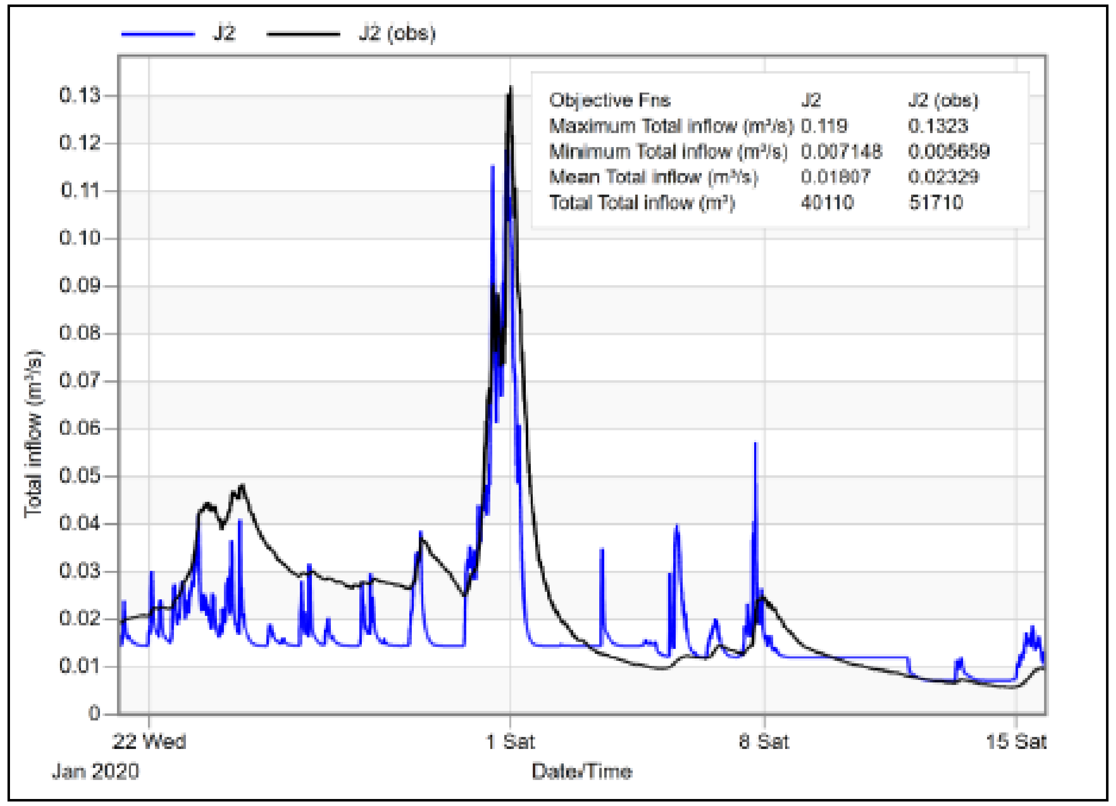


Figure 5 Computed vs Observed Flow Hydrographs in Cox Creek (January-February, 2020)

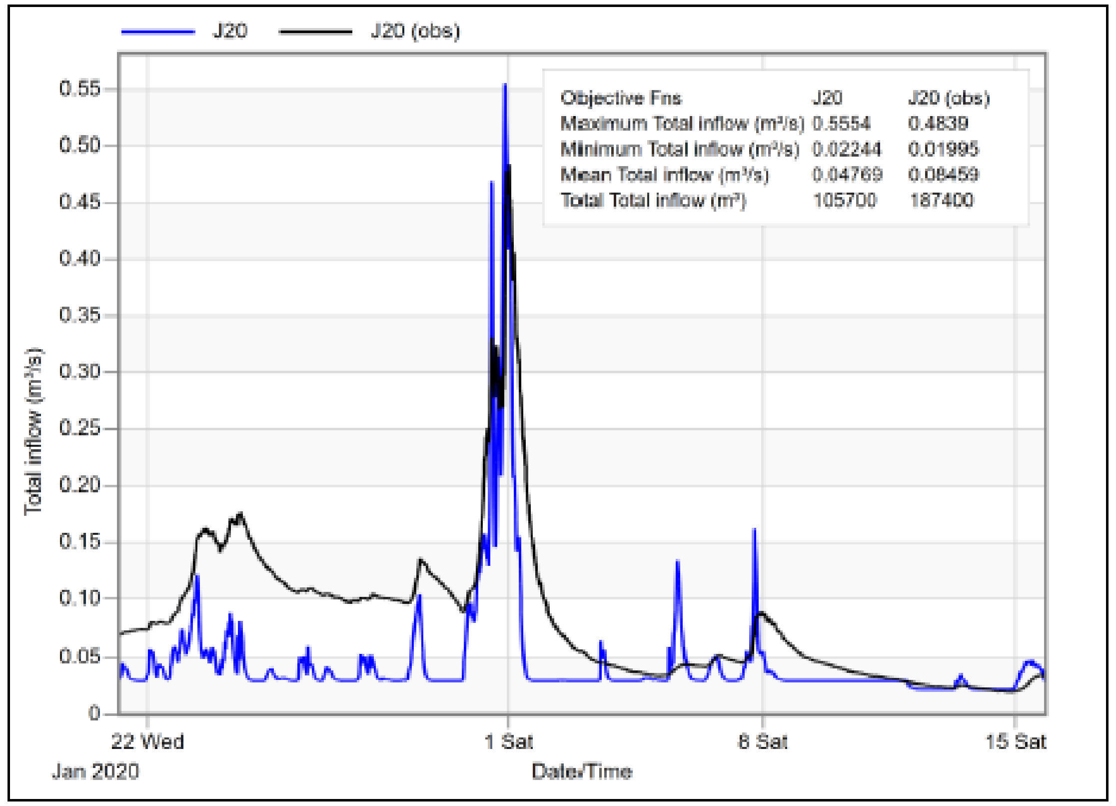


Figure 6 Computed vs Observed Flow Hydrographs in Jamieson Creek (January-February, 2020)

Revised Calibration

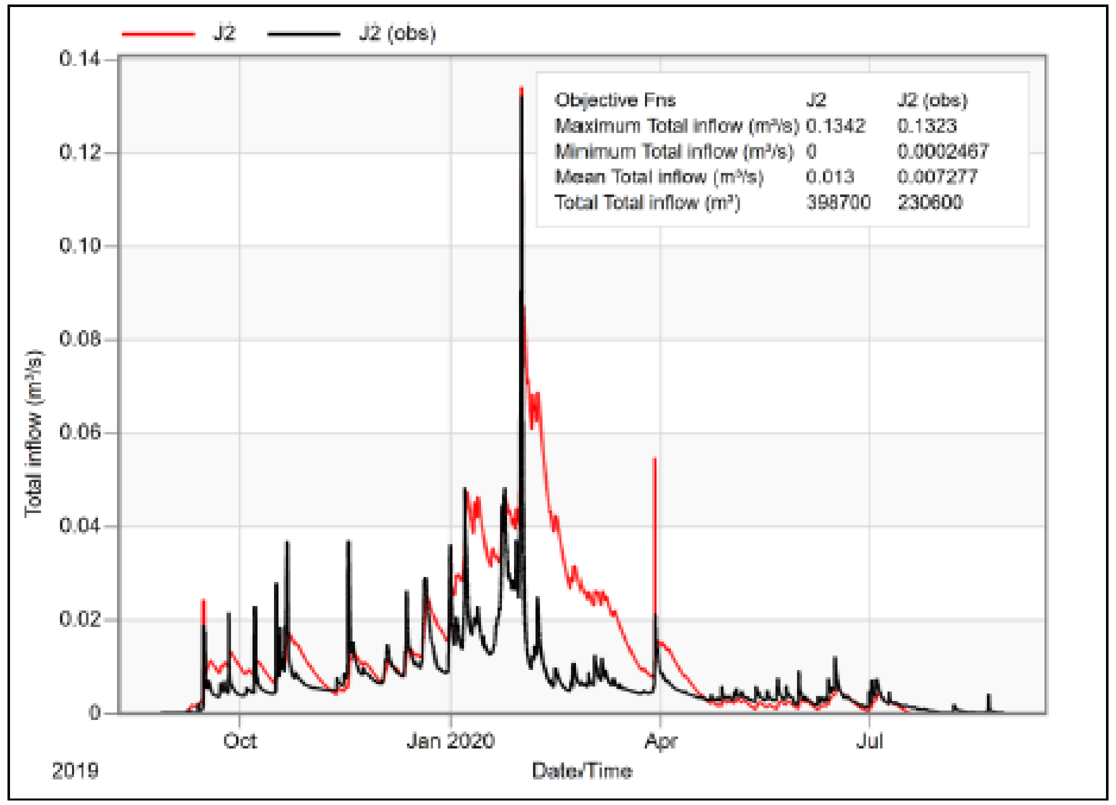


Figure 7 Computed vs Observed Flow Hydrographs in Cox Creek (model node J2)

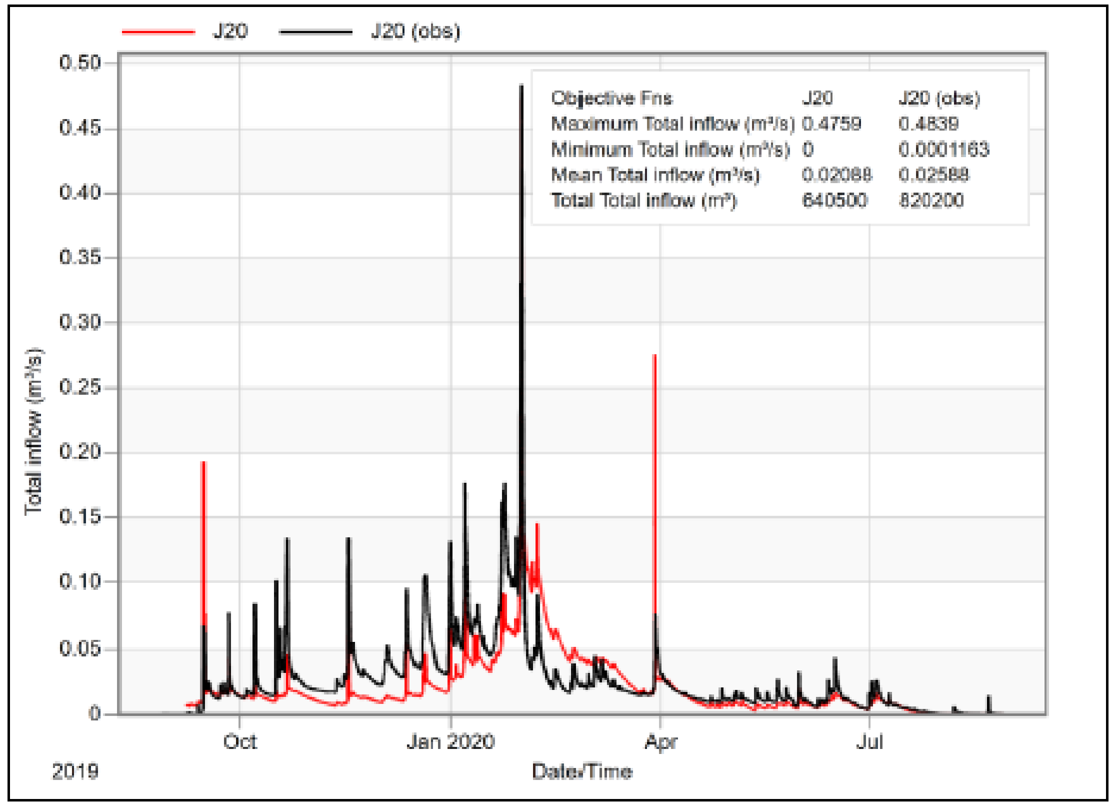
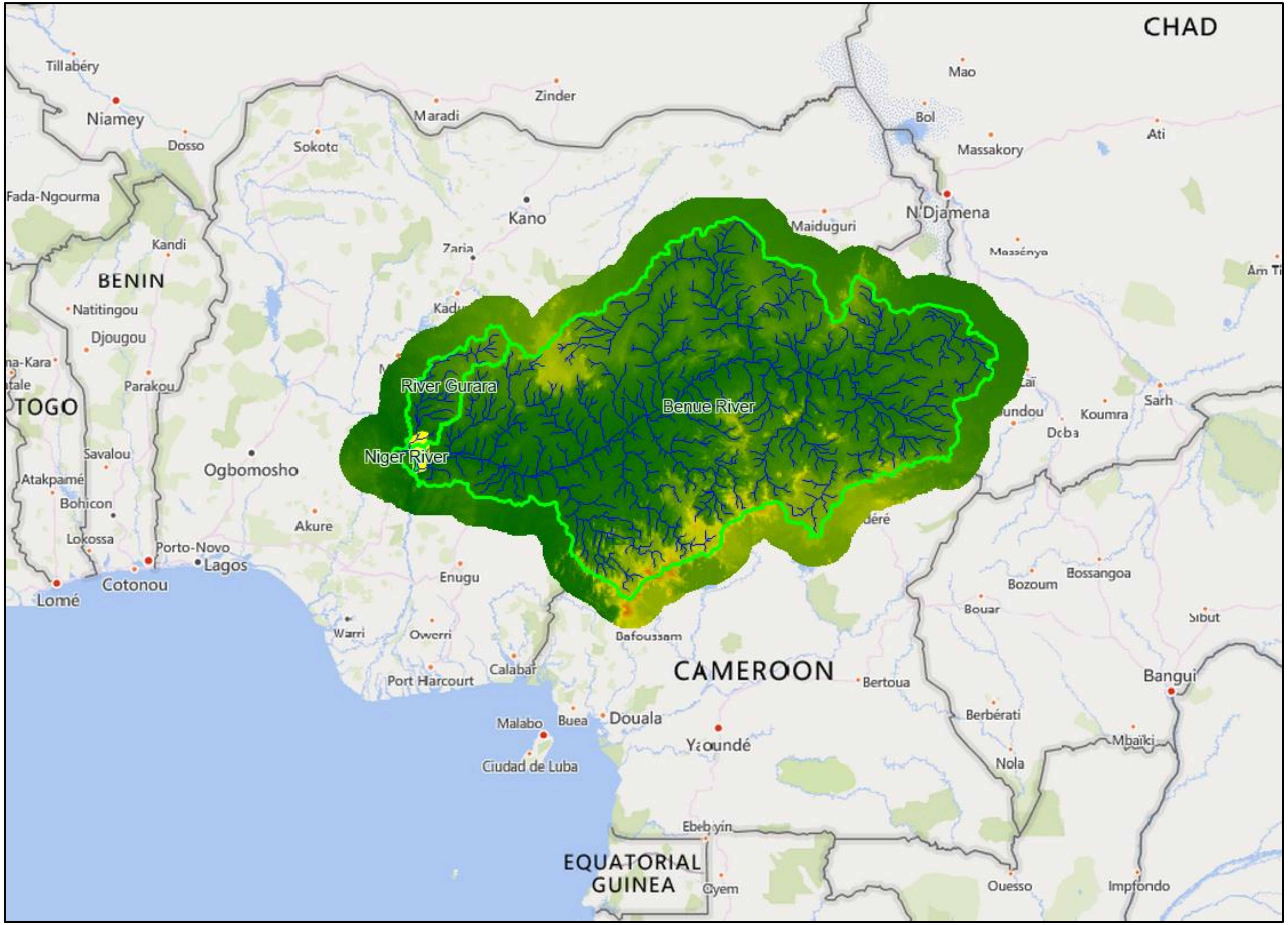


Figure 8 Computed vs Observed Flow Hydrographs in Jamieson Creek (model node J20)

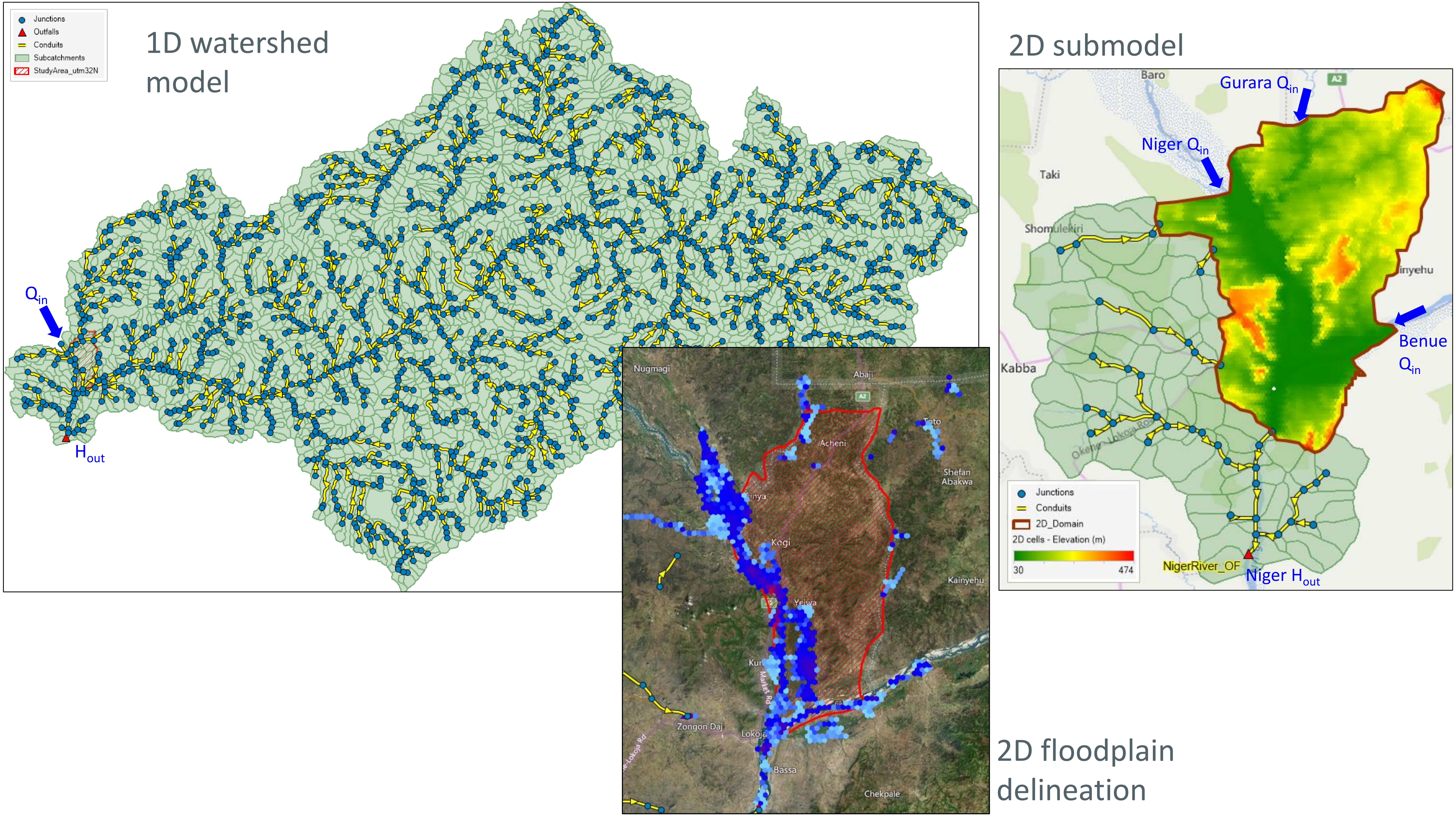
Yet Another Watershed…



Chronic flooding problem area in central Nigeria, at the confluence of three rivers:

- Niger River
- River Gurara
- Benue River

Note: Digital datasets often end at the country border, so data splicing/merging may be necessary



1D watershed model
Junctions
Outfalls
Conduits
Subcatchments
StudyArea_utm32N
Q_{in}
H_{out}
2D submodel
Gurara Q_{in}
Niger Q_{in}
Benue Q_{in}
Niger H_{out}
NigerRiver_OF
Baro
Taki
Kabba
Junctions
Conduits
2D_Domain
2D cells - Elevation (m)
30
474
2D floodplain delineation
Nugmagi
Abaji
Acheni
Kogi
Shefan Abakwa
Kainyehu
Zongon Daj
Lokoja
Basta
Chekpale

EWRI Congress 2025, EPA SWMM5 Workshop -- LID Modeling

Thank you for your attention… any questions?

Mike Gregory, P.Eng., PE   mike@chiwater.com

Stormwater Modeling Committee
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