Multi-Agency Development and Use of a Reservoir Model for the Fox Chain of Lakes using HEC-ResSim

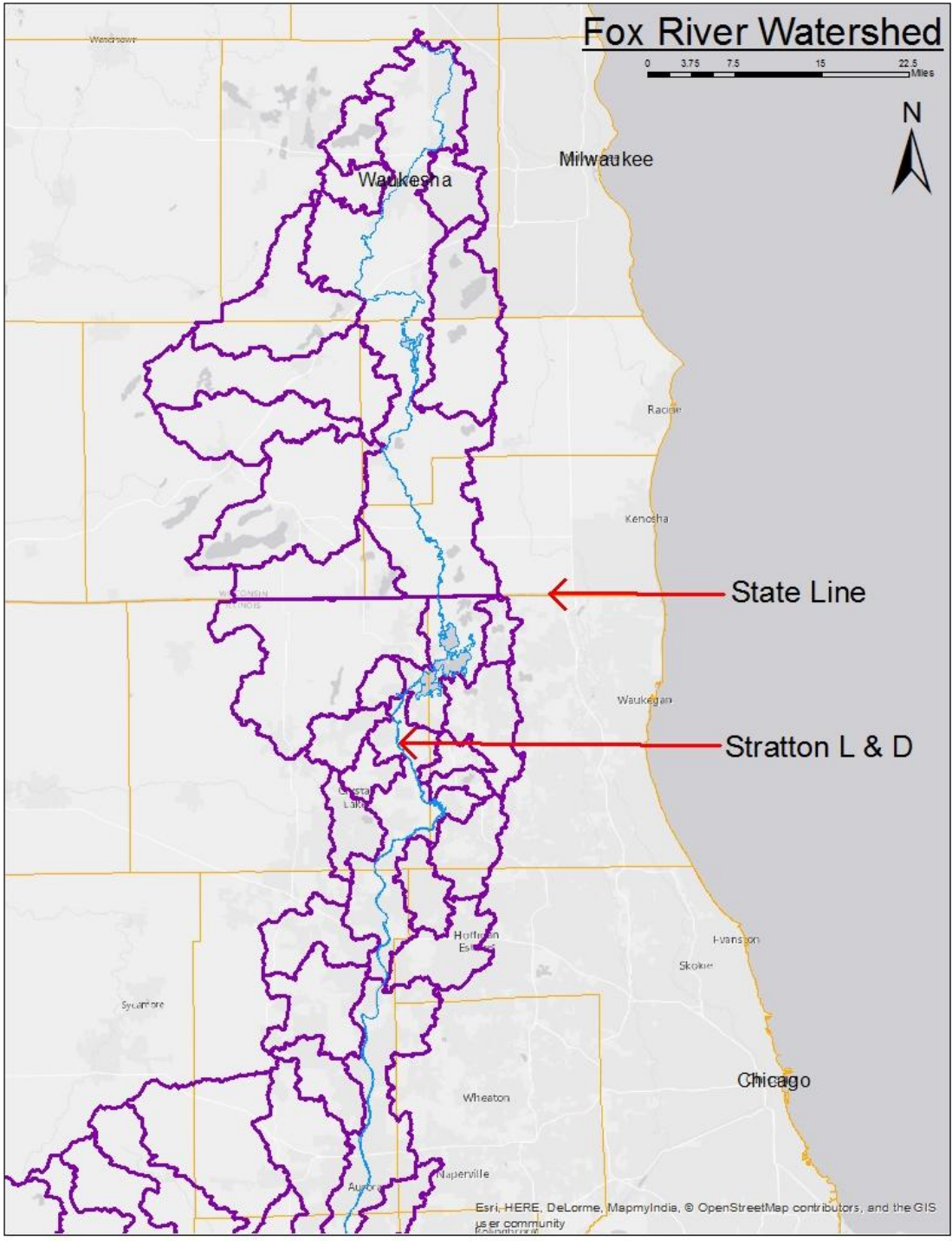
Brad Winters P.E., CFM – Illinois DNR/ Office of Water Resources

Marian Domanski, E.I.T. – U.S.G.S. / IL-IA Water Science Center

IDNR OWR

USGS science for a changing world

- Fox River drainage area is 2657 mi^2
- Drainage area in Wisconsin is 934 mi^2
- Drainage area at Stratton Lock & Dam is 1250 mi^2



William G. Stratton Lock and Dam

Sluice Gates

5 gates at 13.75 foot wide each

Hinged Crest Gate

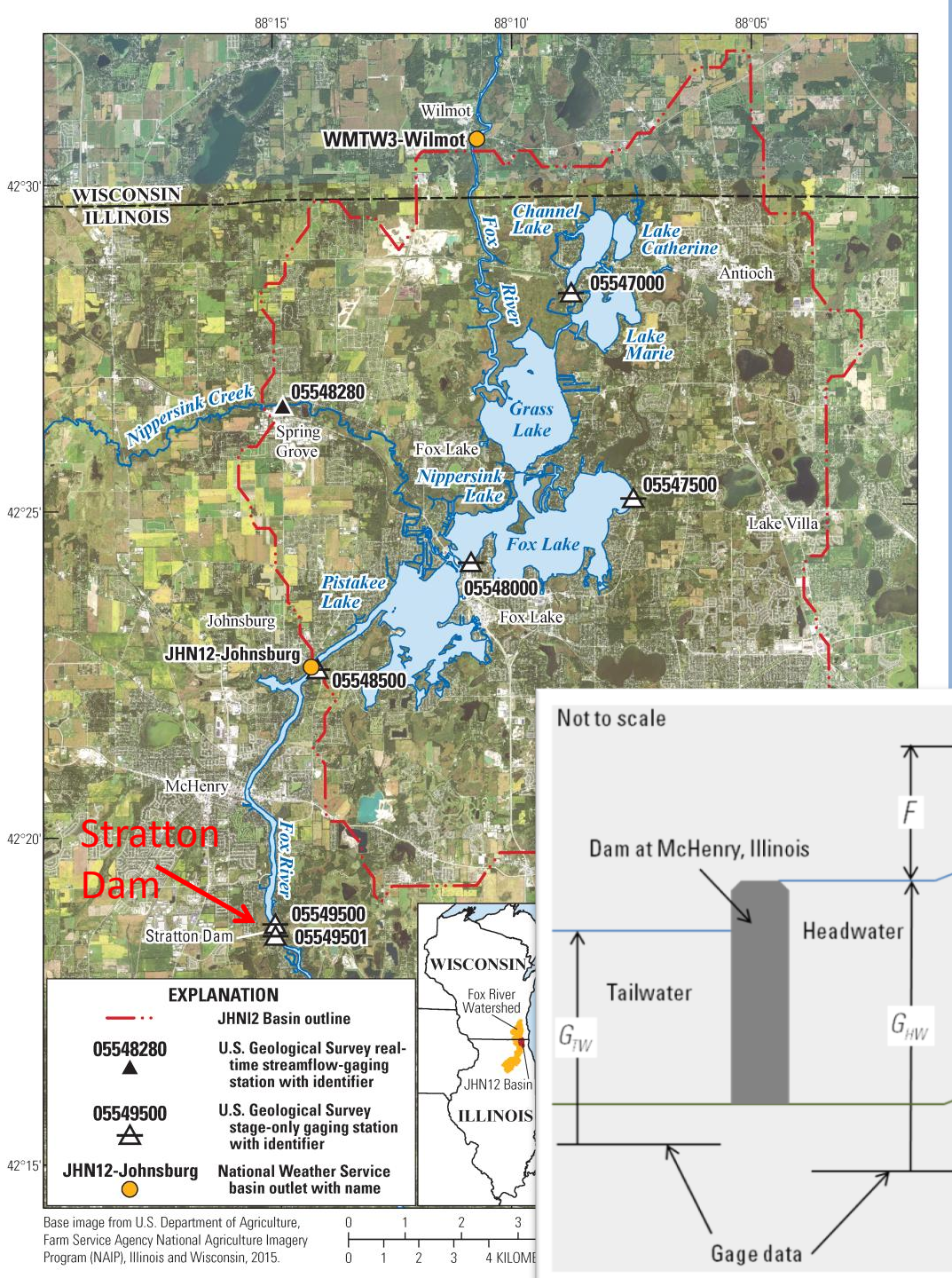
50 foot gate with movable crest, maximum 6.5 foot drop

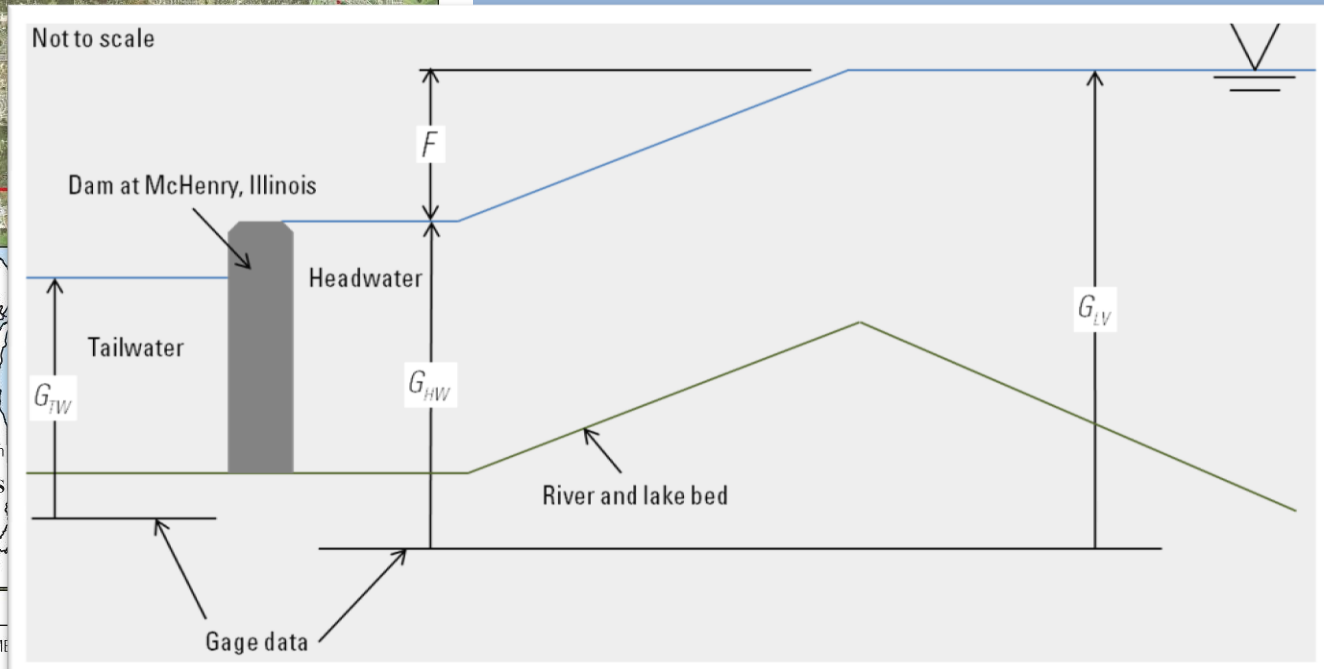
Spillway

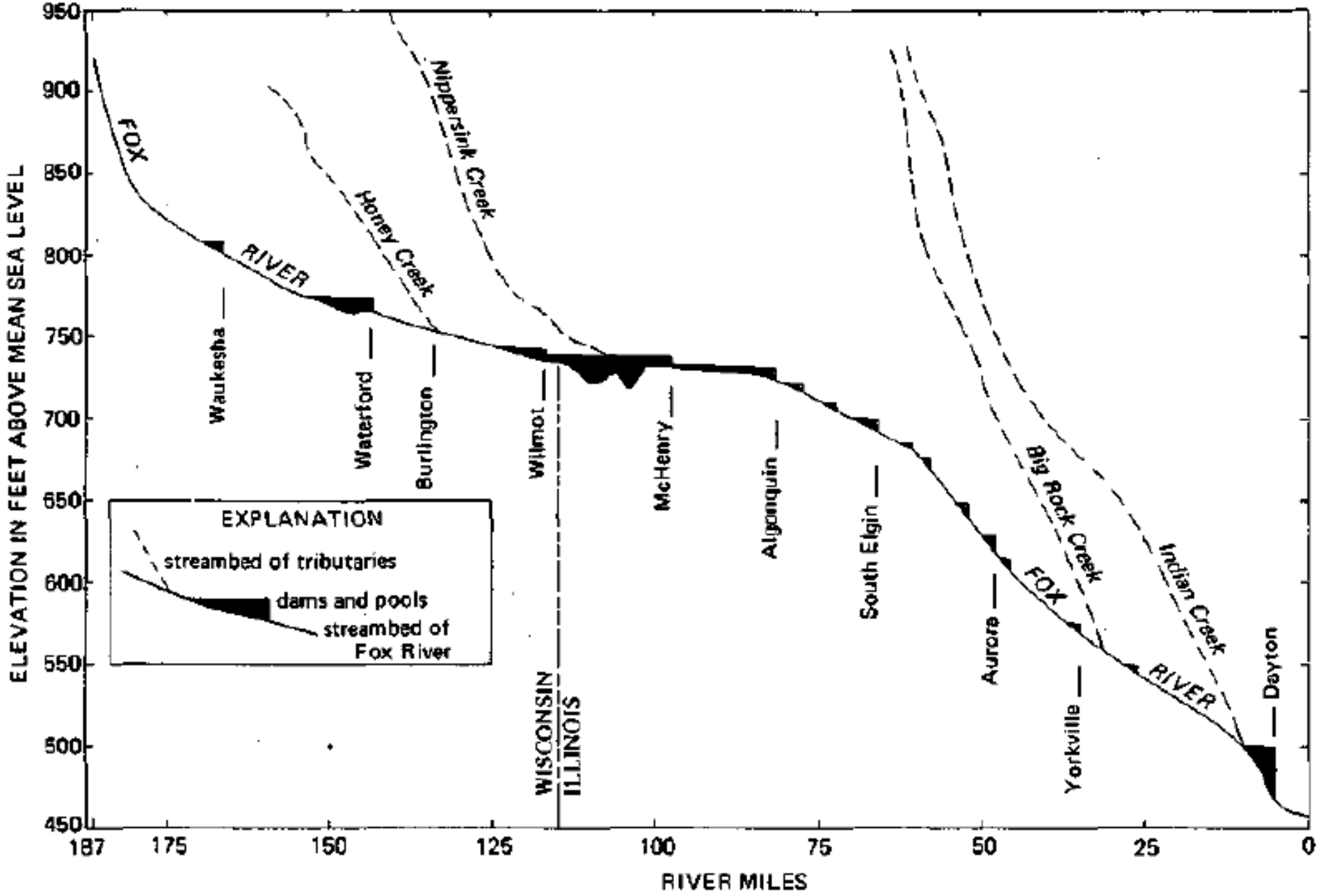
Length is 221 feet

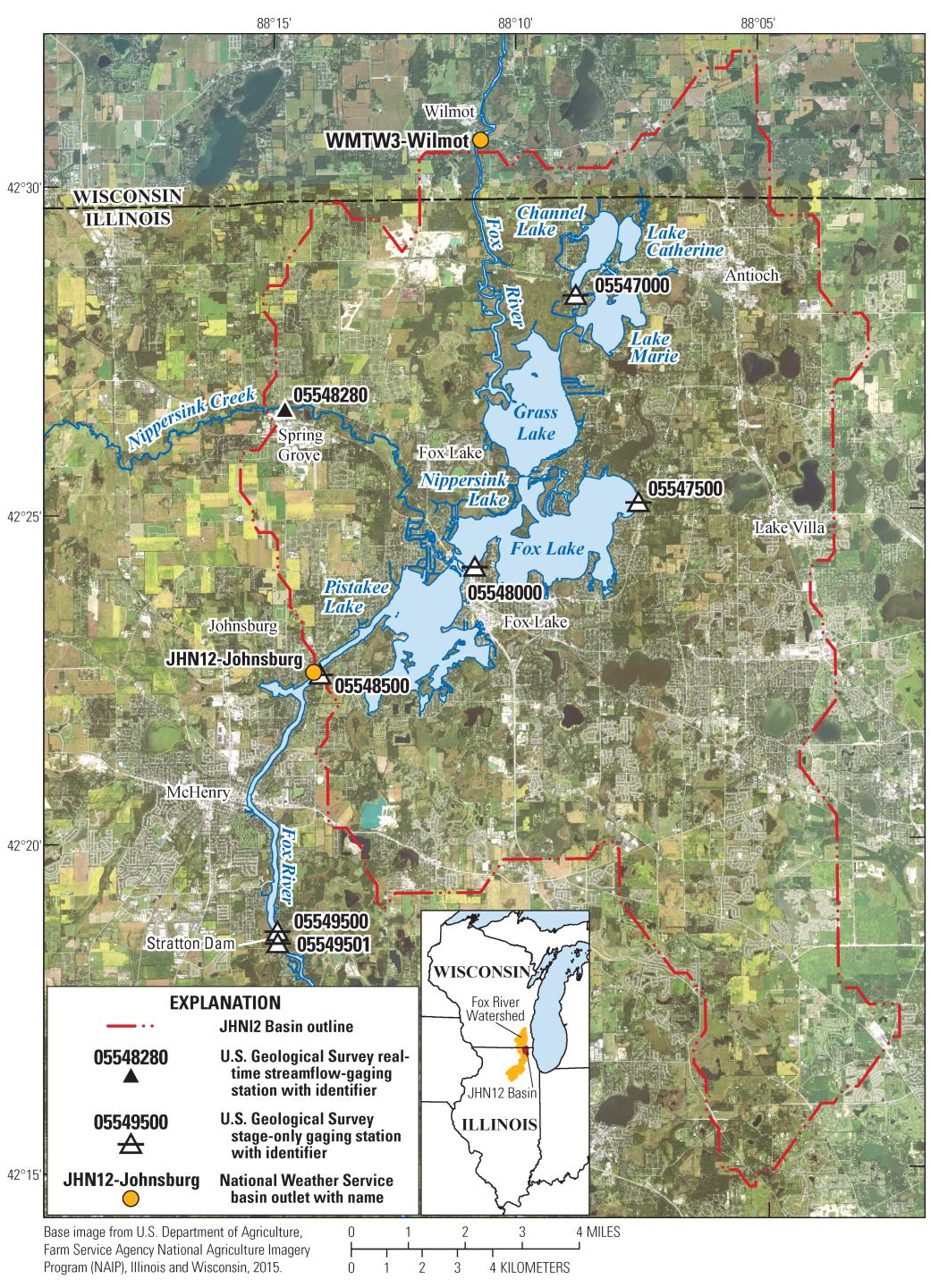
Lock

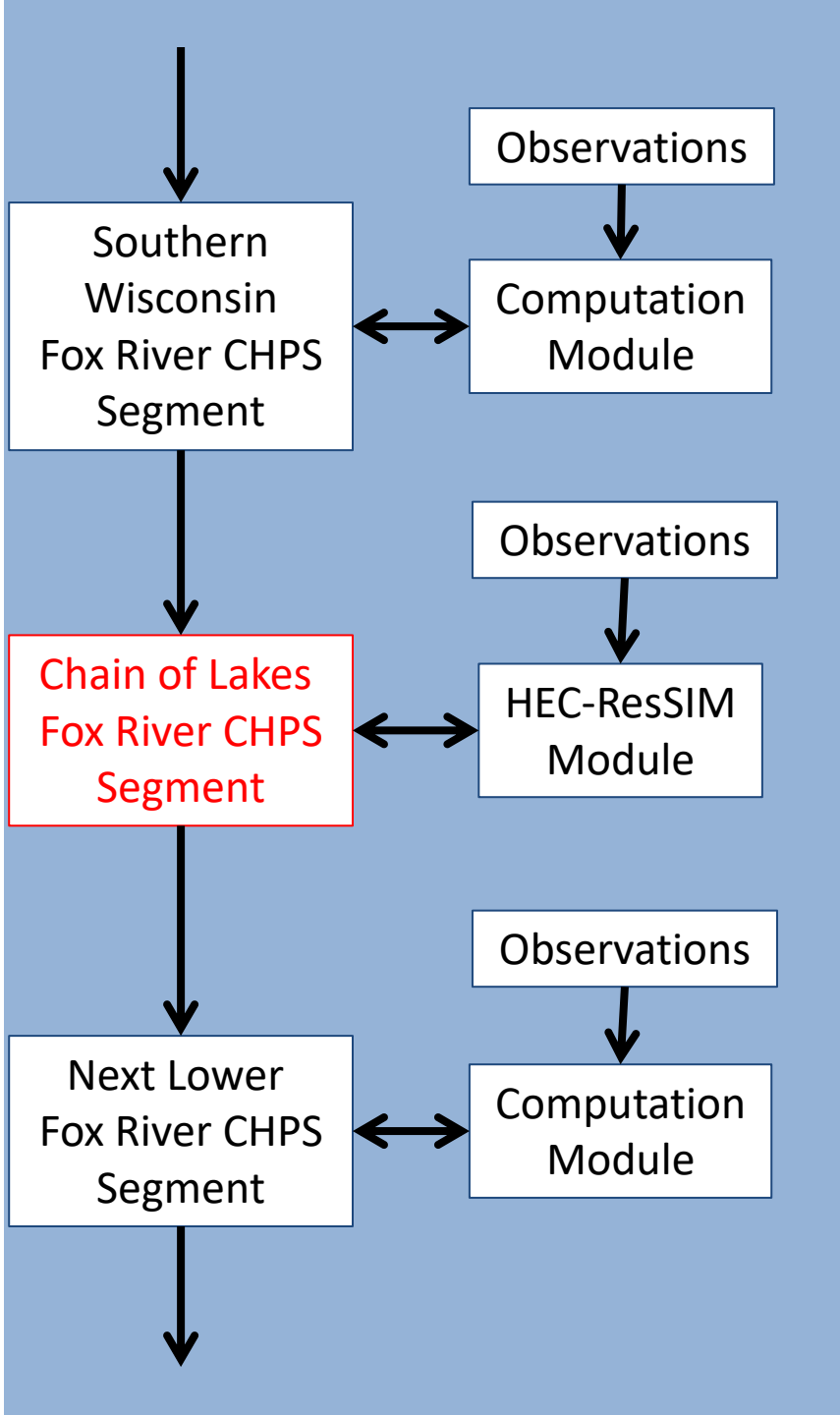
Length is 149 feet


88°15'
88°10'
88°05'
42°30'
42°25'
42°20'
42°15'
Wilmot
WMTW3-Wilmot
WISCONSIN
ILLINOIS
Channel Lake
Lake Catherine
Antioch
Fox River
05547000
Lake Marie
Grass Lake
05548280
Nippersink Creek
Spring Grove
Fox Lake
Nippersink Lake
05547500
Lake Villa
Fox Lake
05548000
Pistakee Lake
Johnsburg
Fox Lake
JHN12-Johnsburg
05548500
McHenry
Stratton Dam
Fox River
05549500
05549501
Stratton Dam
EXPLANATION
JHNI2 Basin outline
05548280
U.S. Geological Survey real-time streamflow-gaging station with identifier
05549500
U.S. Geological Survey stage-only gaging station with identifier
JHN12-Johnsburg
National Weather Service basin outlet with name
WISCONSIN
Fox River Watershed
JHN12 Basin
ILLINOIS
Base image from U.S. Department of Agriculture, Farm Service Agency National Agriculture Imagery Program (NAIP), Illinois and Wisconsin, 2015.
0 1 2 3
0 1 2 3 4 KILOME


Not to scale
F
Dam at McHenry, Illinois
Headwater
Tailwater
G_{TW}
G_{HW}
G_{LV}
River and lake bed
Gage data

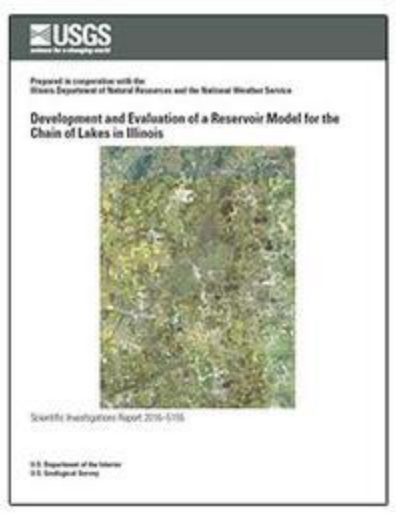

ELEVATION IN FEET ABOVE MEAN SEA LEVEL
950
900
850
800
750
700
650
600
550
500
450
187
175
150
125
100
75
50
25
0
RIVER MILES
FOX
RIVER
Nippersink Creek
Honey Creek
Big Rock Creek
Indian Creek
Waukesha
Waterford
Burlington
Wilmot
McHenry
Algonquin
South Elgin
Aurora
Yorkville
Dayton
WISCONSIN
ILLINOIS
EXPLANATION
streambed of tributaries
dams and pools
streambed of Fox River


88°15'
88°10'
88°05'
42°30'
42°25'
42°20'
42°15'
Wilmot
WMTW3-Wilmot
WISCONSIN
ILLINOIS
Channel Lake
Fox River
Lake Catherine
Antioch
05547000
Lake Marie
Grass Lake
Nippersink Creek
05548280
Spring Grove
Fox Lake
Nippersink Lake
05547500
Lake Villa
Fox Lake
05548000
Pistakee Lake
Fox Lake
Johnsburg
JHN12-Johnsburg
05548500
McHenry
Fox River
05549500
05549501
Stratton Dam
EXPLANATION
JHNI2 Basin outline
05548280
U.S. Geological Survey real-time streamflow-gaging station with identifier
05549500
U.S. Geological Survey stage-only gaging station with identifier
JHN12-Johnsburg
National Weather Service basin outlet with name
WISCONSIN
Fox River Watershed
JHN12 Basin
ILLINOIS
Base image from U.S. Department of Agriculture, Farm Service Agency National Agriculture Imagery Program (NAIP), Illinois and Wisconsin, 2015.
0 1 2 3 4 MILES
0 1 2 3 4 KILOMETERS


Observations
Southern Wisconsin Fox River CHPS Segment
Computation Module
Observations
Chain of Lakes Fox River CHPS Segment
HEC-ResSIM Module
Observations
Next Lower Fox River CHPS Segment
Computation Module

Modeling the Chain of Lakes using HEC-ResSim

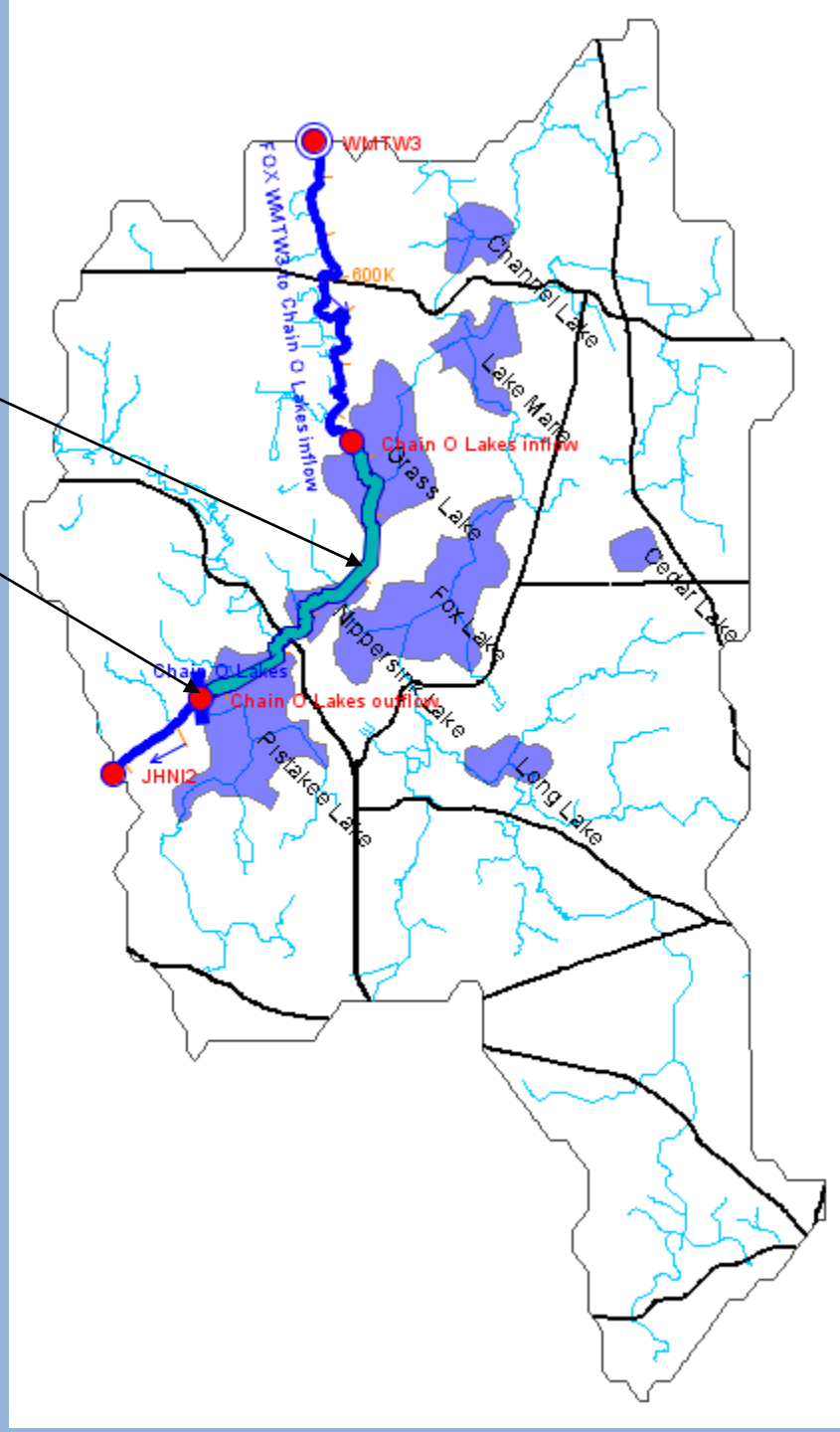
- HEC-ResSim modeling methodology
- Chain of Lakes model challenges
- Model evaluation



Domanski, M.M., 2017, Development and evaluation of a reservoir model for the Chain of Lakes in Illinois: U.S. Geological Survey Scientific Investigations Report 2016–5155, 21 p., https://doi.org/10.3133/sir20165155.

USGS

HEC-ResSim Reservoirs



- ResSim reservoirs are modeled with a dam at the outlet.
- The release capacity of the control structure at the dam is a function of the reservoir pool elevation.

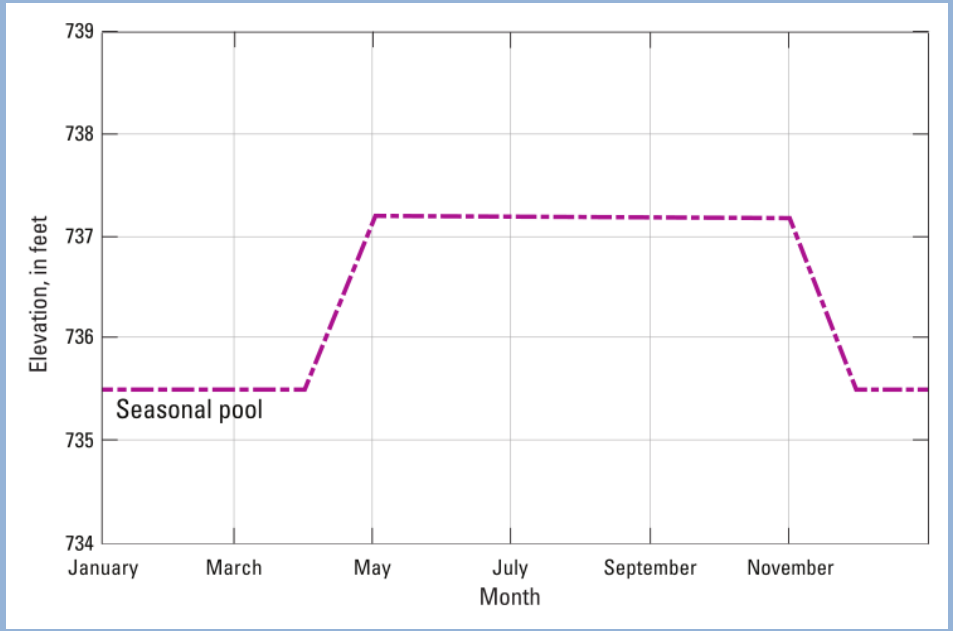
USGS

Guide Curve

Guide curve—A guide curve is a seasonally varying target pool elevation that describes the regulation plan for a reservoir.

Summer pool—From May 1 to November 1, the target elevation is 737.2 ft.

Winter pool—From December 1 to April 1, the target elevation is 735.5 ft.

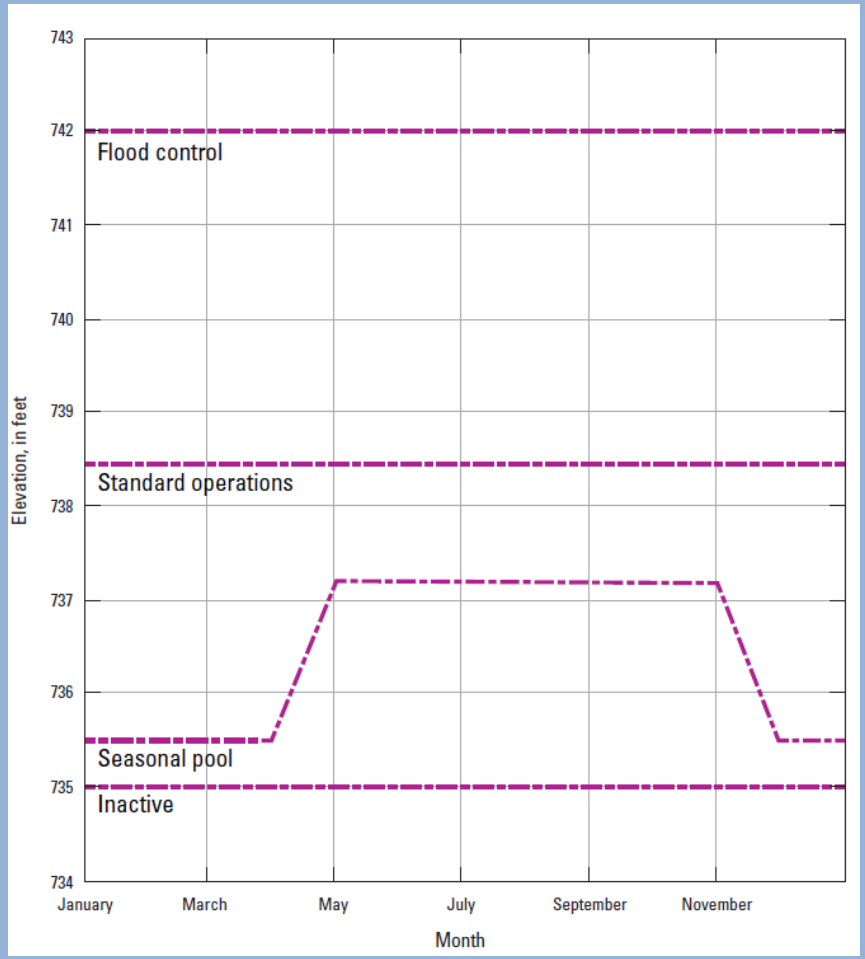


USGS

Operation Zones

Operation zone—Operation zones are operational subdivisions of the reservoir pool. Each operation zone is defined by an elevation curve describing the top of the zone.

- Flood control – 742 ft
- Standard operations – 738.45 ft
- Seasonal pool
  - Summer pool – 737.2 ft
  - Winter pool – 735.5 ft
- Inactive – 735 ft



USGS

Operation Rules

Operation rule—Operation rules represent the flow goals and constraints upon the releases for each operation zone of the operation set.

[Max, maximum; Q, flow; ft^3/s, cubic feet per second; Spec, specify; ft, feet; SL, sluice gate; HCG, hinged-crest gate]

Rule name	Description
Max Q 3000	Maximum discharge of 3,000 ft^3/s implemented during standard operations
Max Q ice jam	Maximum discharge of 1,100 ft^3/s implemented during ice jam operations
Low Q protection	Minimum release for low flow protection[1]
Spec 1800	Specify a discharge of 1,800 ft^3/s
Spec 2550	Specify a discharge of 2,550 ft^3/s
Spec 3000	Specify a discharge of 3,000 ft^3/s
Spec Q from 736.6 to 737.2	Specify a linearly increasing discharge from 1,800 ft^3/s to 3,000 ft^3/s between a pool elevation of 736.6 ft and 737.2 ft
Spec max SL capacity	Specify maximum discharge capacity with sluice gates fully opened
Spec max SL HCG capacity	Specify maximum discharge capacity with sluice and hinged-crest gates fully opened

[1]See page 48 of Illinois Department of Natural Resources, 2012, Operation of the Stratton and Algonquin Dams Fox River.

USGS

Operation Sets

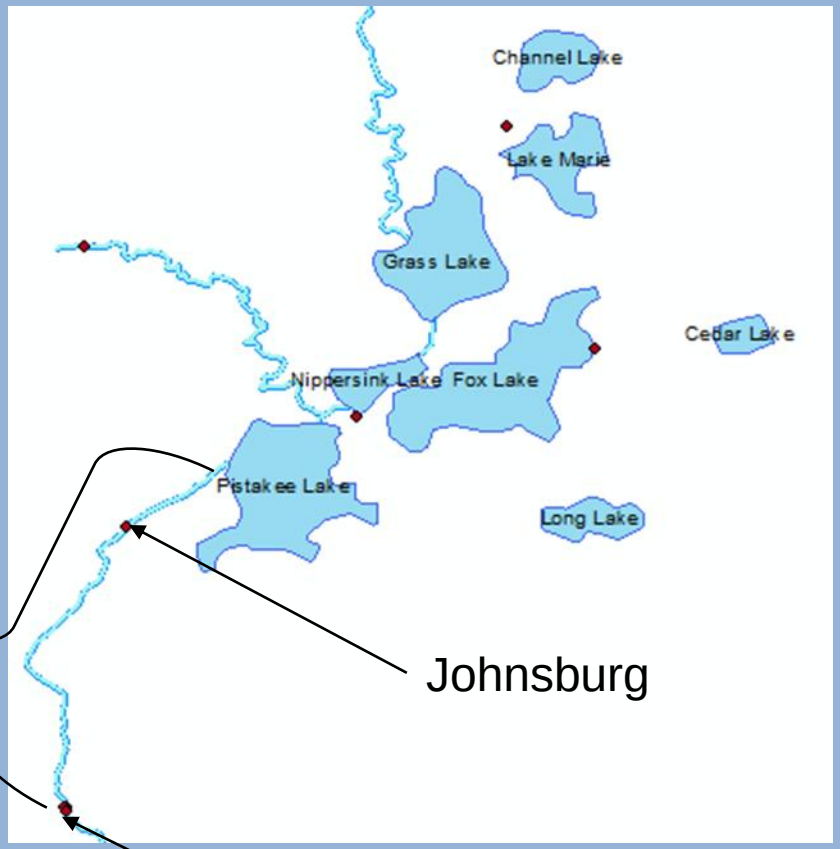
Operation set—An operation set is the operation plan or scheme upon which a reservoir bases its decisions regarding how much water to release at each time step of simulation run.

Operation set	Zone	Max Q 3000	Max Q ice jam	Low Q protection	Spec 1800	Spec 2550	Spec 3000	Spec Q from 736.6 to 737.2	Spec max SL capacity	Spec max SL HCG capacity
Physical limits	Flood control									
	Standard operations									
	Seasonal pool									
	Inactive									
Standard operations	Flood control								•	•
	Standard operations	•		•	•	•	•	•		•
	Seasonal pool			•						
	Inactive									
Ice jam operations	Flood control									
	Standard operations		•	•						
	Seasonal pool		•	•						
	Inactive									
Specify maximum capacity	Flood control									•
	Standard operations									•
	Seasonal pool									•
	Inactive									

USGS

Modeling the Chain of Lakes Reservoir

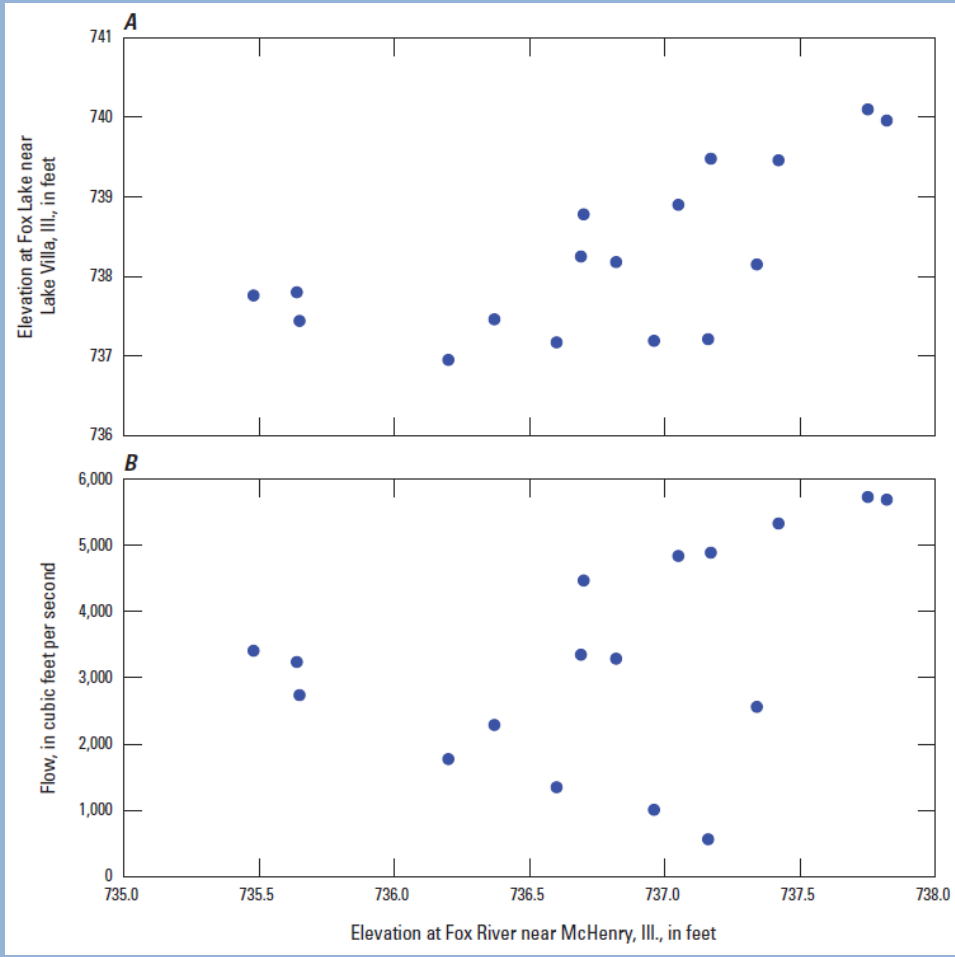
- Stratton Lock and Dam is the control structure for the reservoir.
- The reservoir outlet and Stratton Lock and Dam are separated by the Johnsburg chute.



USGS

Finding a Headwater Relation

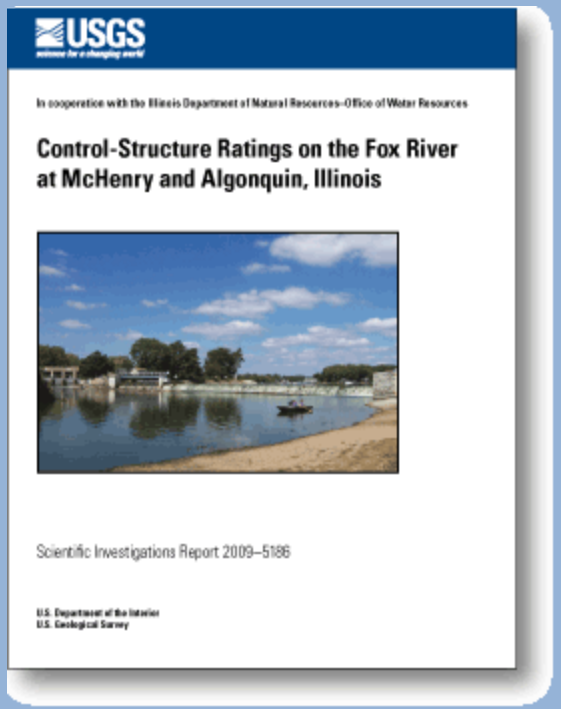
There is no simple relation to find headwater elevation at the control structure using flow or the reservoir pool elevation.



USGS

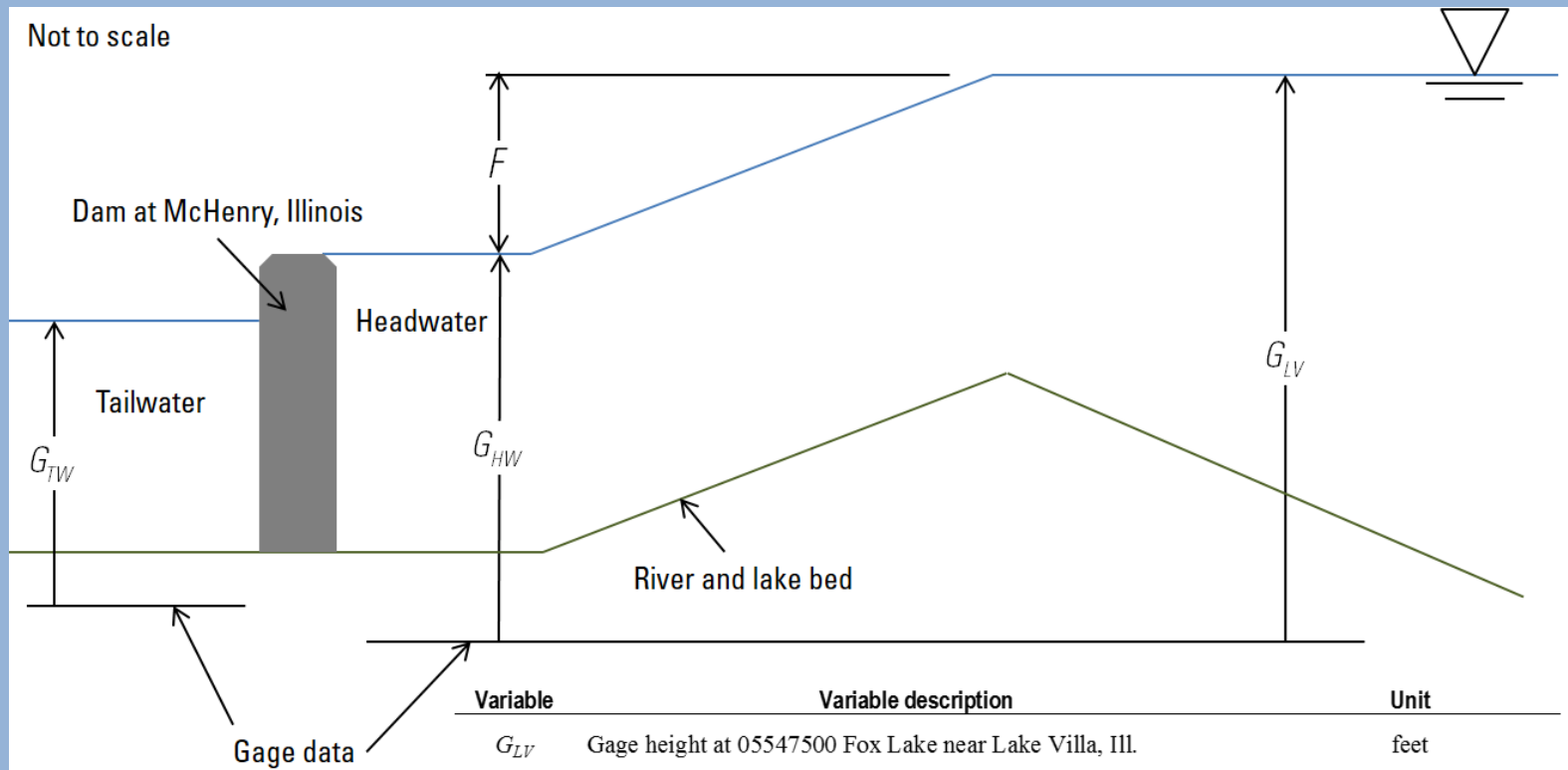
Modeling the Chain of Lakes Reservoir

- Problem:
  - Cannot model Chain of Lakes physical limits in HEC-ResSim using typical method
- Solution:
  - Model physical limits using rule scripts
  - Use control structure ratings



USGS

Linear Regression Variables



Variable	Variable description	Unit
G_{LV}	Gage height at 05547500 Fox Lake near Lake Villa, Ill.	feet
G_{TW}	Gage height at 05549501 Fox River (tailwater) near McHenry, Ill.	feet
F	Water-surface elevation fall	feet
Q	Flow	cubic feet per second

USGS

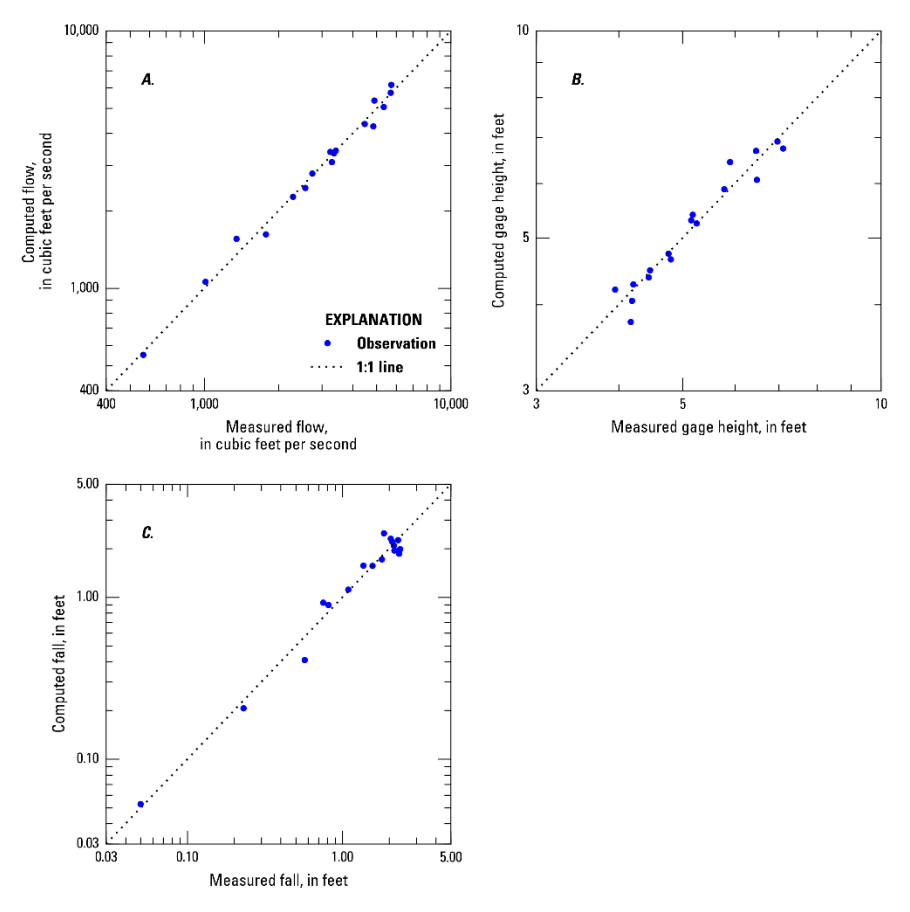
Headwater Regression Model

Headwater elevation is estimated using a gage height-flow-fall relation

$$F = 2.6755 \times 10^{-6} G_{LV}^{-3.3283} Q^{2.3158}$$

$$Z_{HW} = Z_{LV} - F$$

Using the pool elevation (Z_{LV}) and the reservoir release (Q) from the model to find headwater and tailwater elevations.



USGS

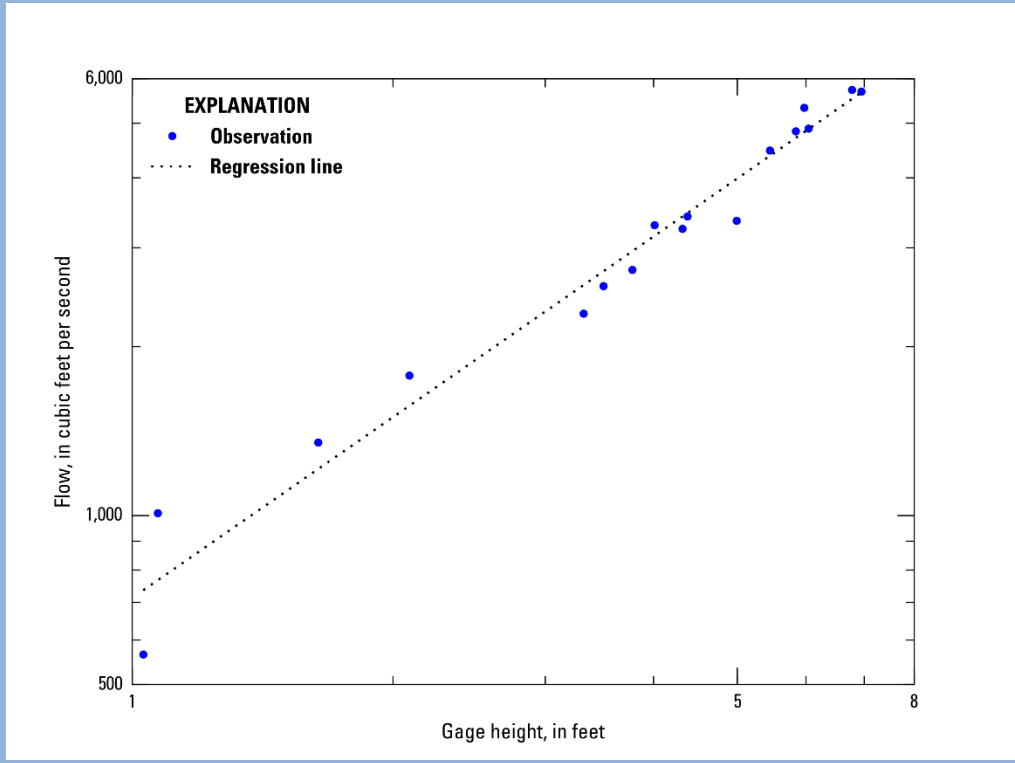
Tailwater Regression Model

Estimate tailwater elevation using a gage height-flow relation

$$G_{TW} = 2.1520 \times 10^{-3} Q^{0.93493}$$

$$Z_{TW} = G_{TW} + Z_{TW\ DATUM}$$

Using reservoir release (*Q*) from the model to find headwater and tailwater elevations.

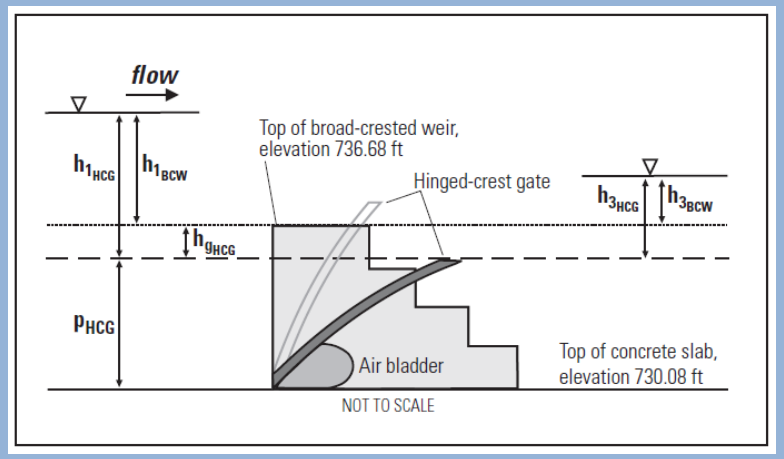


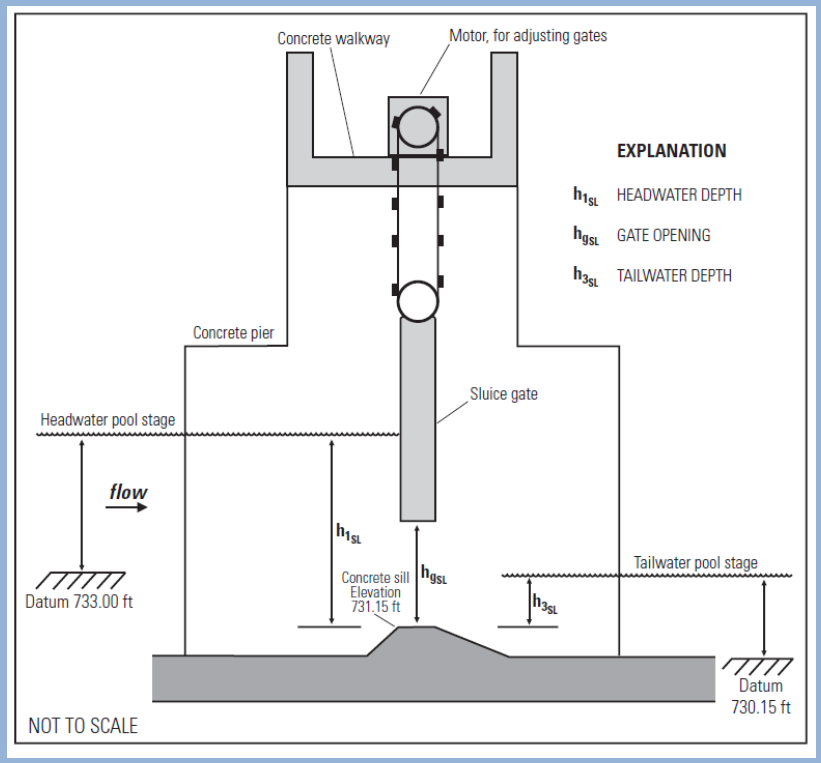
USGS

Physical limits
Structures

The estimated headwater and tailwater elevations are used to calculate maximum and minimum flow through the dam using the control structure ratings.

Maximum flow—fully open gates
Minimum flow—fully closed gates





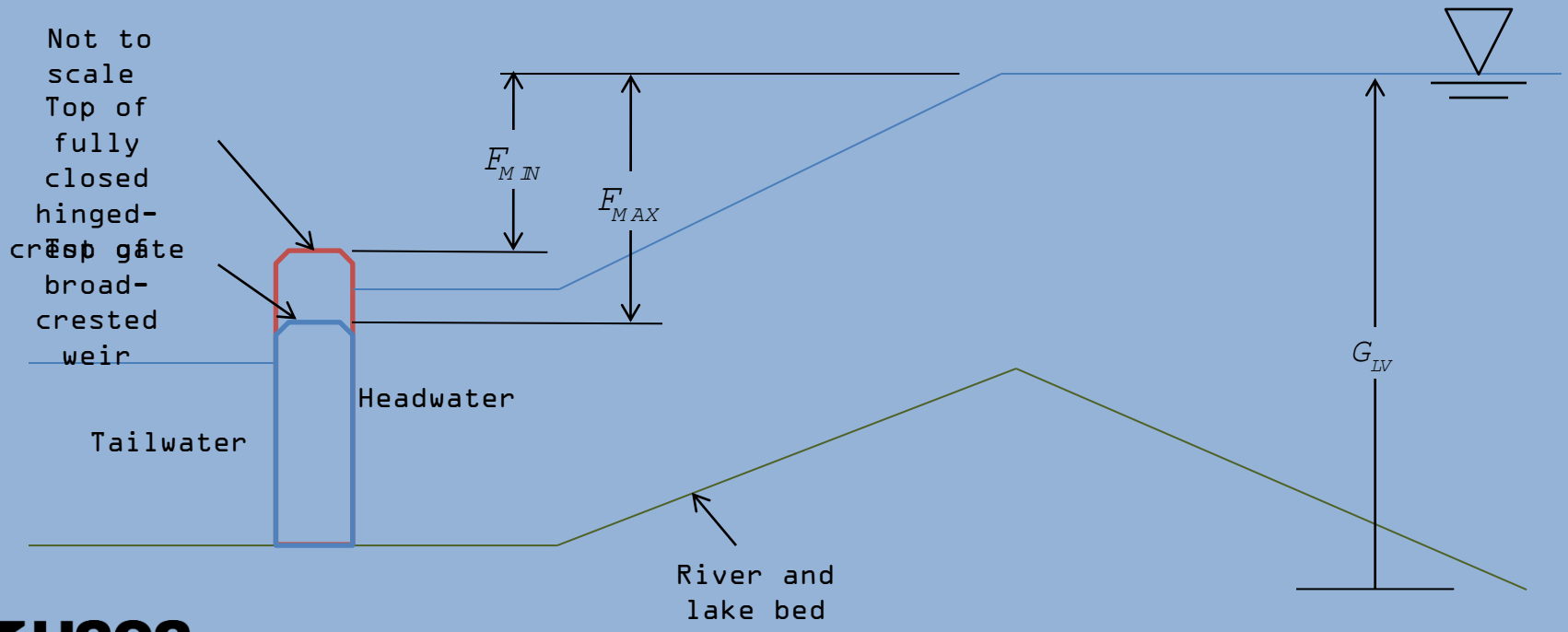
USGS

Physical limits
Fall

The limitation of fall was an important factor in modeling the reservoir. Limits on discharge based on fall are set using the gage height-flow-fall relation.

$$Q_{MAX} = 254.86 G_{LV}^{1.4372} F_{MAX}^{0.43181}$$

$$Q_{MIN} = 254.86 G_{LV}^{1.4372} F_{MIN}^{0.43181}$$



USGS

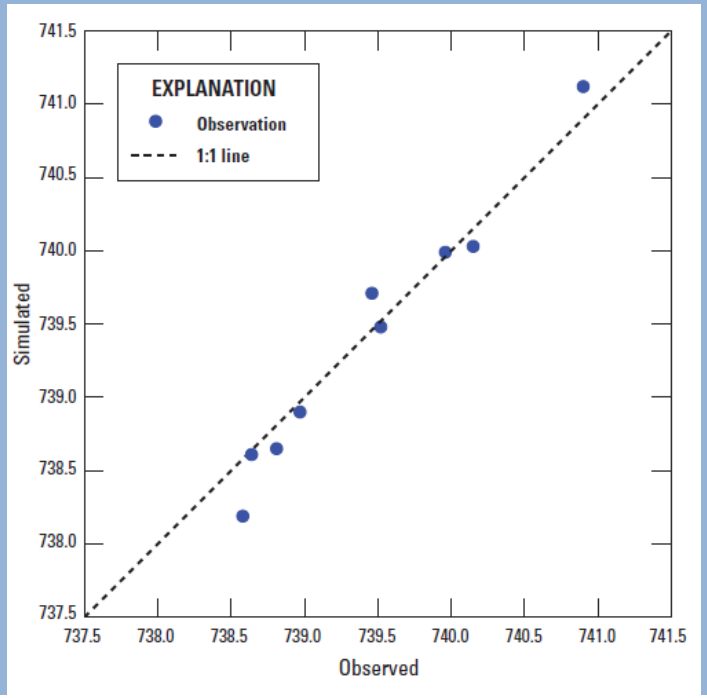
Physical Limit Rules

[Min, minimum; Q, flow; BCW, broad-crested weir; HCG, hinged-crest gate; Max, maximum; SL, sluice gate]

Description	Rule name
Minimum uncontrolled flow	Min Q BCW HCG
Minimum flow from minimum fall	Min Q from fall
Maximum controlled and uncontrolled flow	Max Q BCW HCG SL
Maximum flow from maximum fall	Max Q from fall

USGS

Model performance



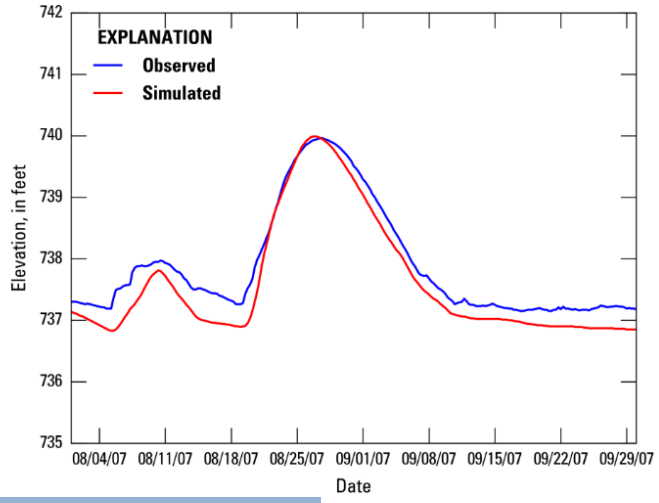
[ft, feet; hr, hour]

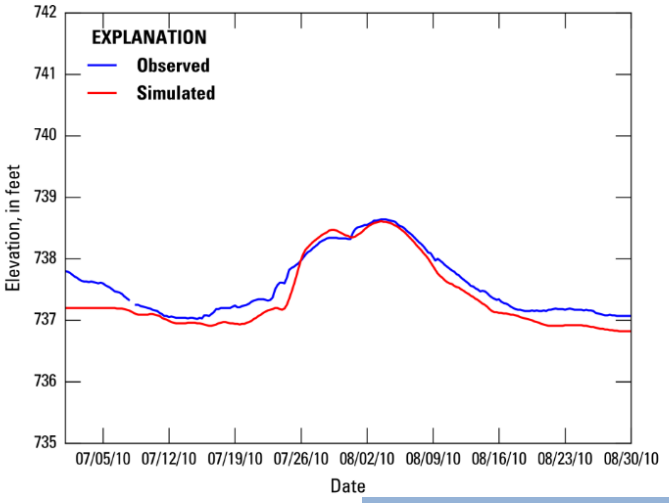
Simulated		Observed		Simulated minus observed	
Date and time	Elevation (ft)	Date and time	Elevation (ft)	Time (hr)	Elevation (ft)
05/27/2004 12:00 a.m.	739.71	05/28/2004 12:00 p.m.	739.46	-36	0.25
08/26/2007 6:00 p.m.	739.99	08/27/2007 12:00 p.m.	739.96	-18	0.03
04/15/2008 12:00 a.m.	739.48	04/15/2008 6:00 p.m.	739.52	-18	-0.04
06/18/2008 6:00 a.m.	740.03	06/18/2008 6:00 p.m.	740.15	-12	-0.12
05/03/2009 12:00 a.m.	738.90	05/04/2009 12:00 p.m.	738.97	-36	-0.07
06/23/2009 6:00 p.m.	738.19	06/23/2009 12:00 p.m.	738.58	6	-0.39
08/03/2010 12:00 p.m.	738.61	08/03/2010 12:00 p.m.	738.64	0	-0.03
04/21/2013 6:00 p.m.	741.12	04/22/2013 6:00 p.m.	740.90	-24	0.22
06/29/2013 6:00 p.m.	738.65	07/01/2013 12:00 p.m.	738.81	-42	-0.16

USGS

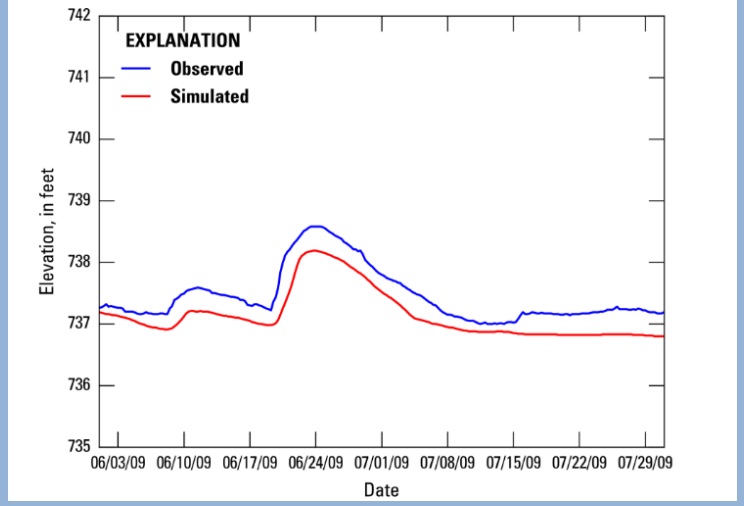
Model Performance

Least error in peak elevation prediction (+/- 0.03 ft)





Most error in peak elevation prediction (-0.39 ft)

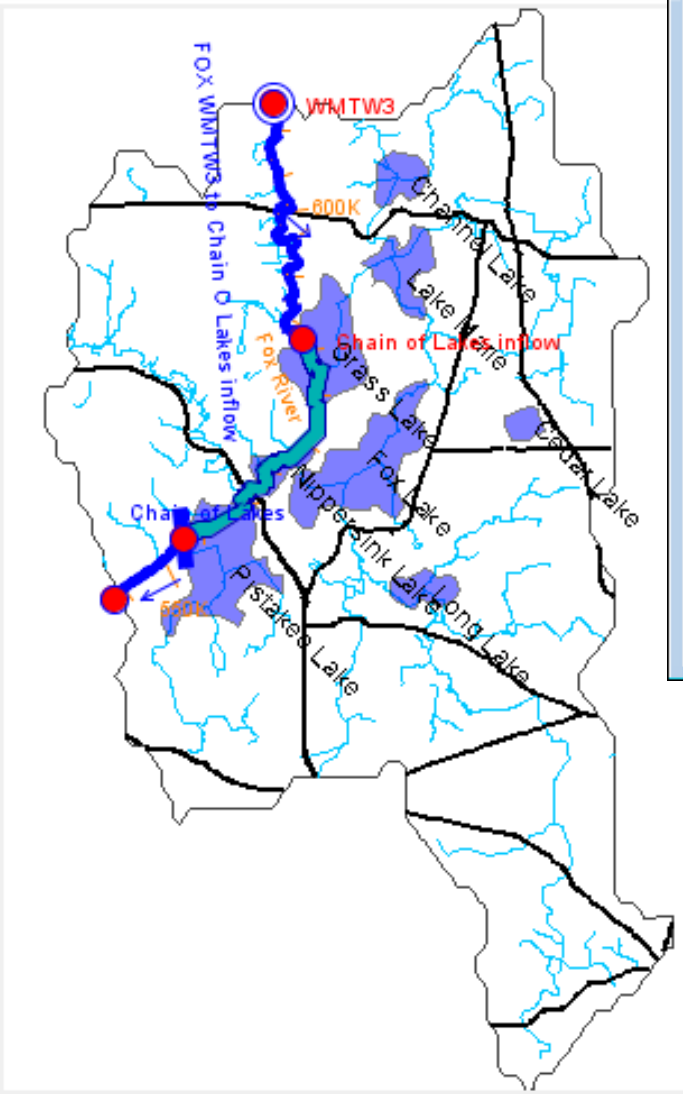


USGS

HEC-ResSim 3.1 - Chain_of_Lakes

File Edit View Simulation Alternative Reports Tools Help

Module: Simulation



Scripts

Edit gate settings

Export CSV

Export DSS

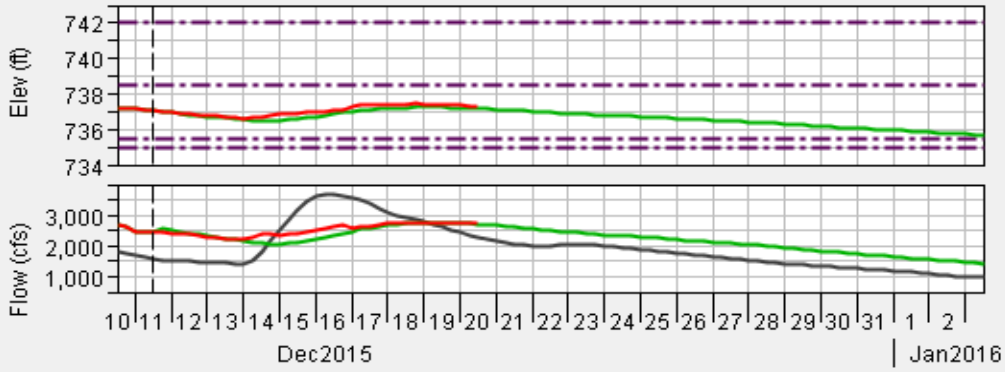
Run forecast

ResSim Compute Complete for QIIFF-----0

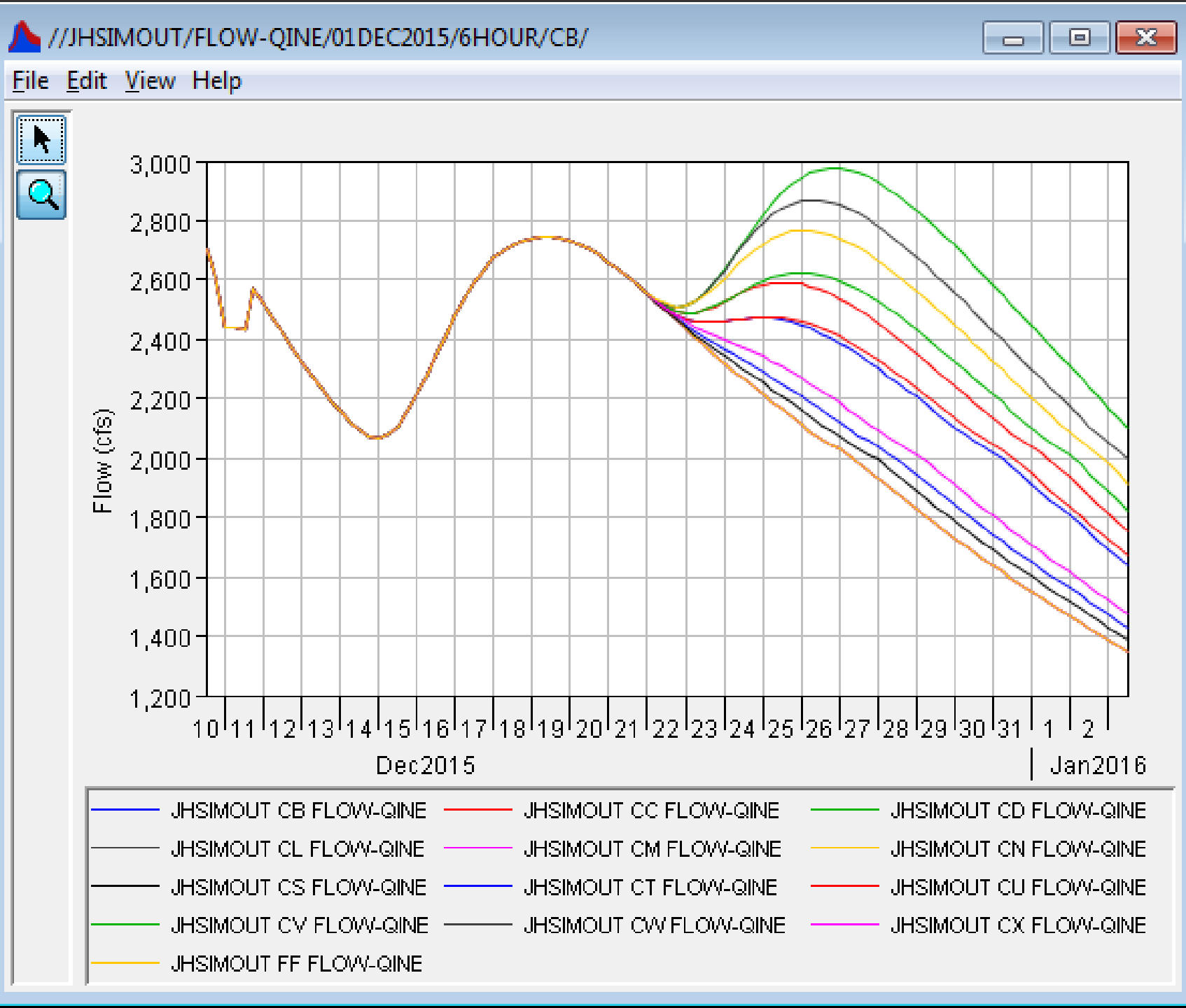
...

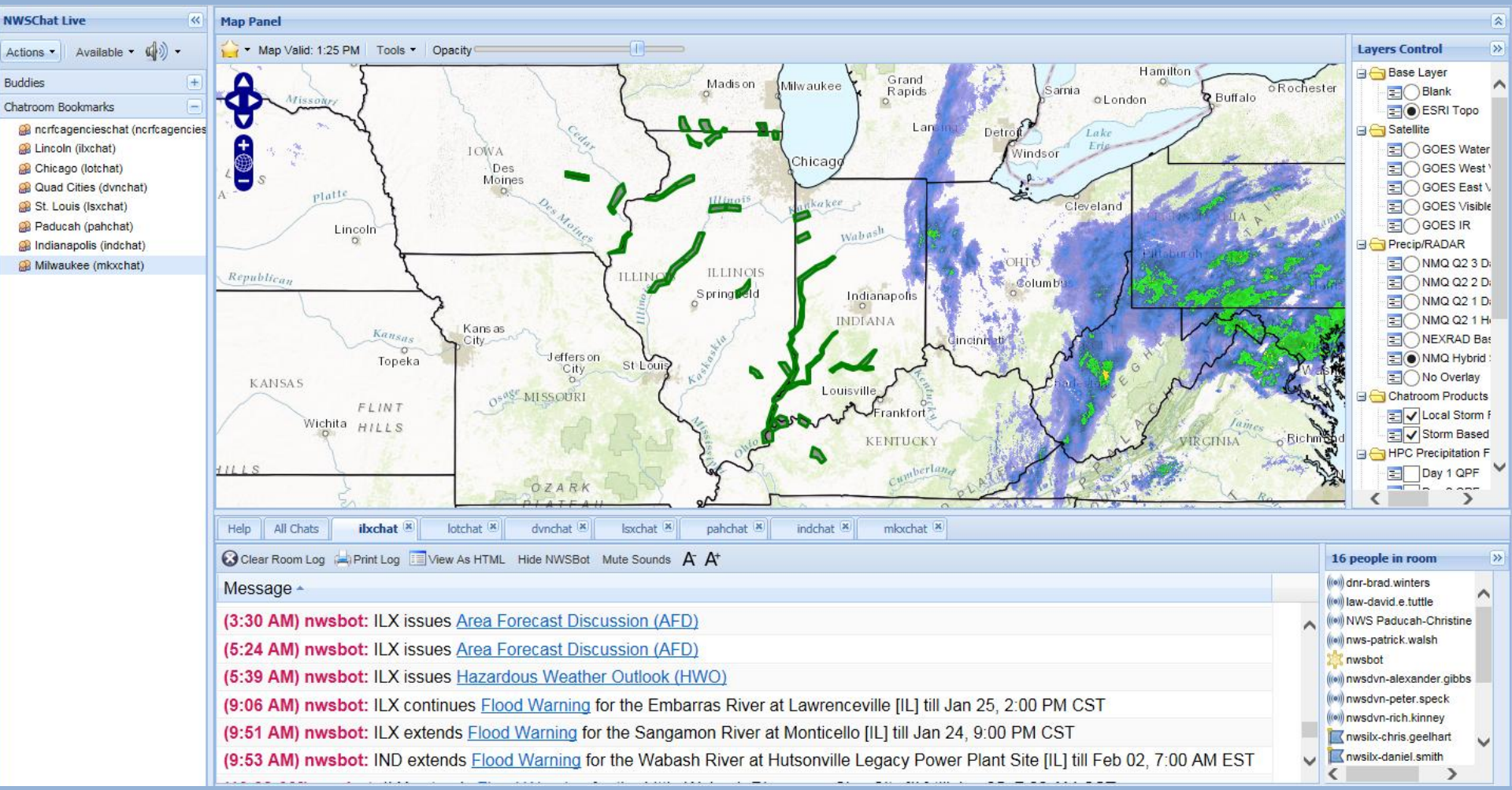
Default Plot - Chain of Lakes, 3:13PM

File Edit Plot View



Chain of Lakes-Flood Control.QIICB-----0.Elev-ZONE.6HOUR
Chain of Lakes-Seasonal pool.QIICB-----0.Elev-ZONE.6HOUR
Chain of Lakes-Inactive.QIICB-----0.Elev-ZONE.6HOUR
Chain of Lakes-Standard operations.QIICB-----0.Elev-ZONE.6HOUR
Chain of Lakes-Pool.QIICB-----0.Elev.6HOUR
FLVI2.OBS.ELEV.6HOUR
Time of Simulation
Chain of Lakes-Pool.QIICB-----0.Flow-IN.6HOUR
Chain of Lakes-Pool.QIICB-----0.Flow-OUT.6HOUR
MHYI2.OBS.FLOW.6HOUR


//JHSIMOUT/FLOW-QINE/01DEC2015/6HOUR/CB/
File Edit View Help
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
Flow (cfs)
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2
Dec2015
Jan2016
JHSIMOUT CB FLOW-QINE
JHSIMOUT CC FLOW-QINE
JHSIMOUT CD FLOW-QINE
JHSIMOUT CL FLOW-QINE
JHSIMOUT CM FLOW-QINE
JHSIMOUT CN FLOW-QINE
JHSIMOUT CS FLOW-QINE
JHSIMOUT CT FLOW-QINE
JHSIMOUT CU FLOW-QINE
JHSIMOUT CV FLOW-QINE
JHSIMOUT CW FLOW-QINE
JHSIMOUT CX FLOW-QINE
JHSIMOUT FF FLOW-QINE


NWSChat Live
Actions
Available
Buddies
Chatroom Bookmarks
ncrfcagencieschat (ncrfcagencies
Lincoln (ilxchat)
Chicago (lotchat)
Quad Cities (dvnchat)
St. Louis (lsxchat)
Paducah (pahchat)
Indianapolis (indchat)
Milwaukee (mkxchat)
Map Panel
Map Valid: 1:25 PM
Tools
Opacity
Layers Control
Base Layer
Blank
ESRI Topo
Satellite
GOES Water
GOES West
GOES East
GOES Visible
GOES IR
Precip/RADAR
NMQ Q2 3 D
NMQ Q2 2 D
NMQ Q2 1 D
NMQ Q2 1 H
NEXRAD Bas
NMQ Hybrid
No Overlay
Chatroom Products
Local Storm
Storm Based
HPC Precipitation F
Day 1 QPF
Madison
Milwaukee
Grand Rapids
Hamilton
Sarnia
London
Buffalo
Rochester
Detroit
Windsor
Chicago
Cleveland
Lincoln
Des Moines
IOWA
ILLINOIS
Springfield
Indianapolis
INDIANA
OHIO
Columbus
Cincinnati
Kansas City
Topeka
Jefferson City
St Louis
KANSAS
MISSOURI
FLINT HILLS
Wichita
Louisville
Frankfort
KENTUCKY
VIRGINIA
OZARK PLATEAU
Missouri
Cedar
Platte
Des Moines
Illinois
Kaskaskia
Wabash
Republican
Kansas
Osage
Ohio
Cumberland
Help
All Chats
ilxchat
lotchat
dvnchat
lsxchat
pahchat
indchat
mkxchat
Clear Room Log
Print Log
View As HTML
Hide NWSBot
Mute Sounds
Message
(3:30 AM) nwsbot: ILX issues Area Forecast Discussion (AFD)
(5:24 AM) nwsbot: ILX issues Area Forecast Discussion (AFD)
(5:39 AM) nwsbot: ILX issues Hazardous Weather Outlook (HWO)
(9:06 AM) nwsbot: ILX continues Flood Warning for the Embarras River at Lawrenceville [IL] till Jan 25, 2:00 PM CST
(9:51 AM) nwsbot: ILX extends Flood Warning for the Sangamon River at Monticello [IL] till Jan 24, 9:00 PM CST
(9:53 AM) nwsbot: IND extends Flood Warning for the Wabash River at Hutsonville Legacy Power Plant Site [IL] till Feb 02, 7:00 AM EST
16 people in room
dnr-brad.winters
law-david.e.tuttle
NWS Paducah-Christine
nws-patrick.walsh
nwsbot
nwsdvn-alexander.gibbs
nwsdvn-peter.speck
nwsdvn-rich.kinney
nwsilx-chris.geelhart
nwsilx-daniel.smith

Questions?

Special thanks to: