AWS Free Webinar: 7 April 2021

Developing Rating Curves
from measurements and models

Presented by:

Dr. John Fenton

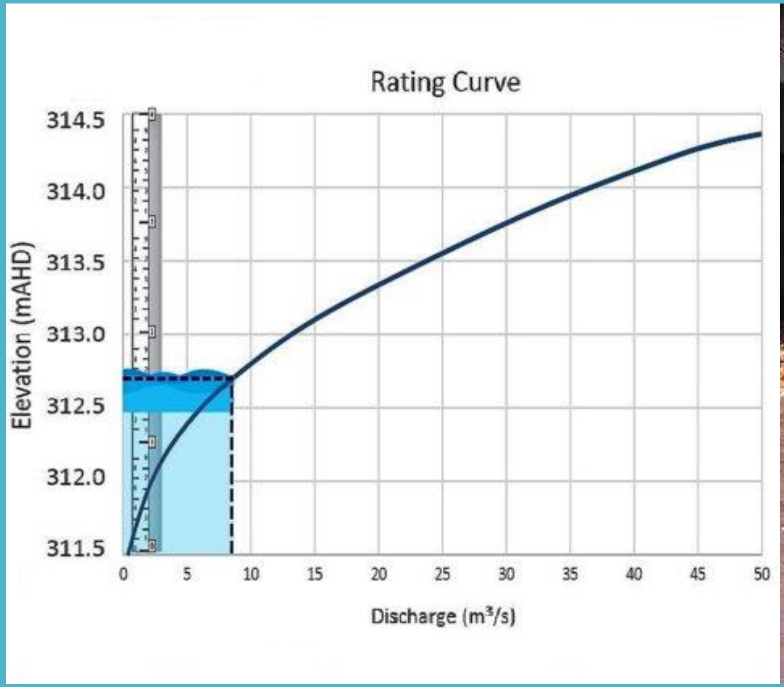
Vienna University of Technology

Dr. Robert Keller

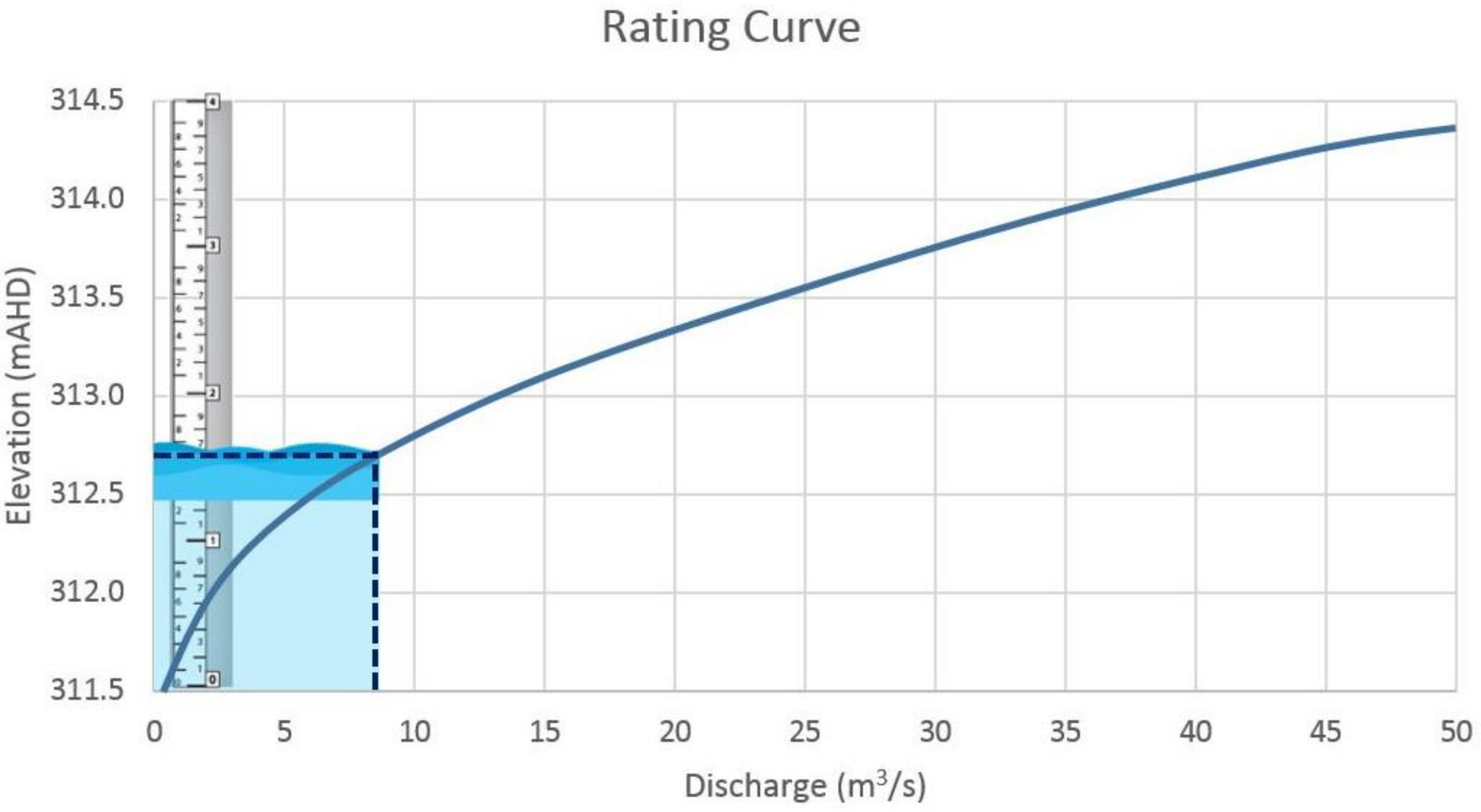
Monash University

Krey Price

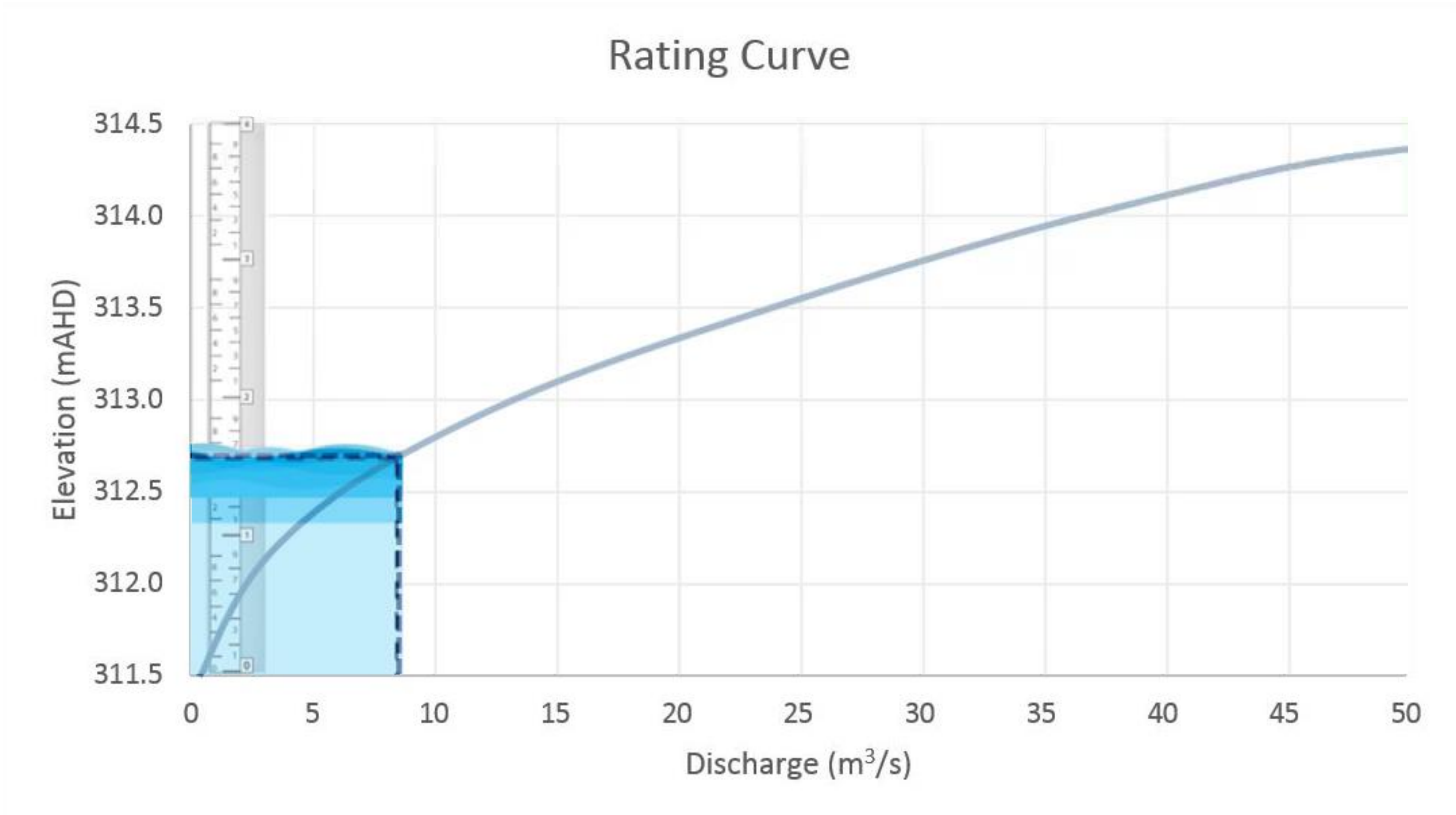
Surface Water Solutions



aws Australian Water School



Rating Curve
Elevation (mAHD)
314.5
314.0
313.5
313.0
312.5
312.0
311.5
0
5
10
15
20
25
30
35
40
45
50
Discharge (m³/s)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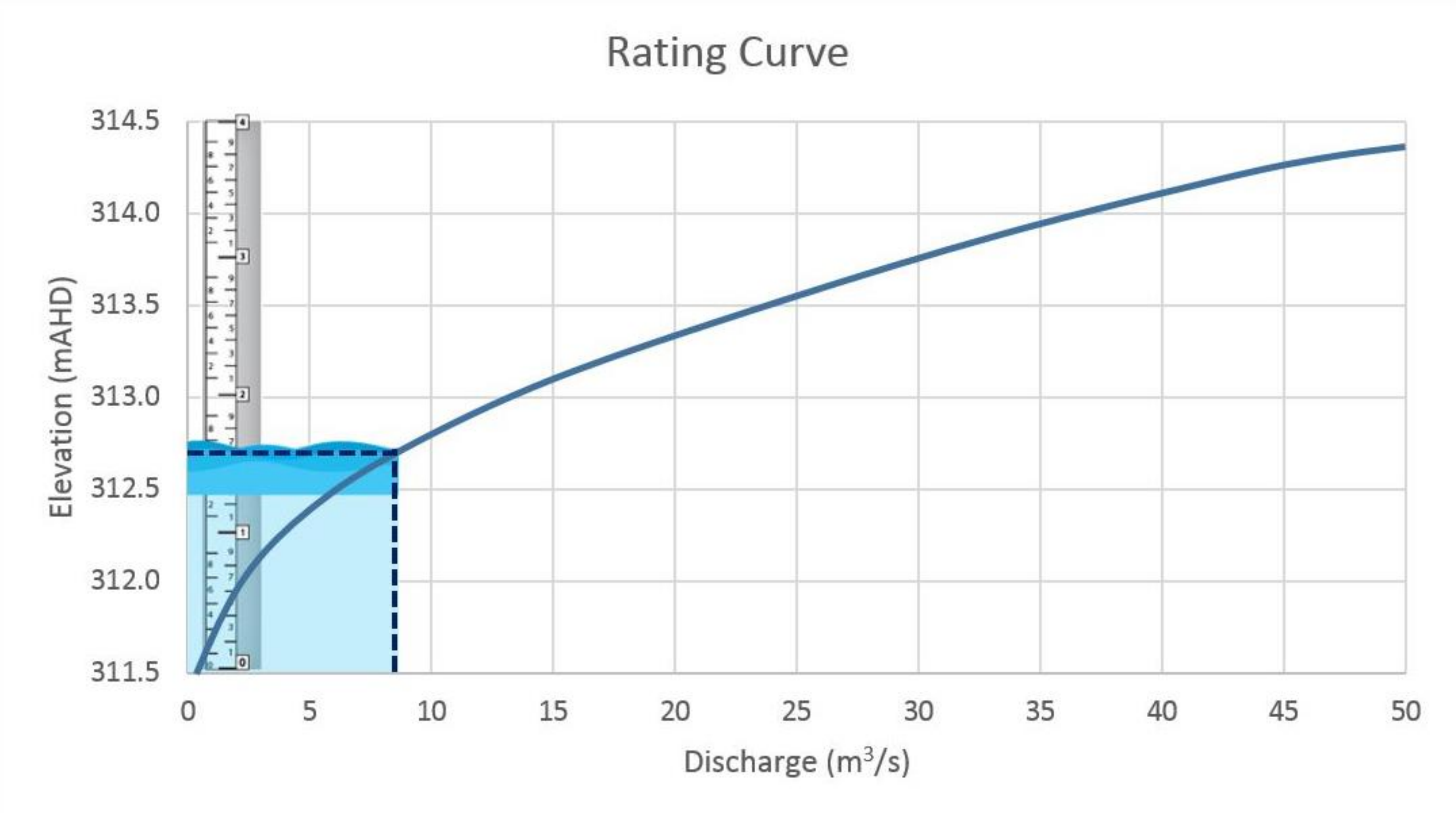

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15
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Discharge (m3/s)

hydro.gov.au

What is Hydrography

Hydrography is the branch of applied sciences which deals with the measurement and description of the physical features of oceans, seas, coastal areas, lakes and rivers, as well as with the prediction of their change over time, for the primary purpose of safety of navigation and in support of all other marine activities, including economic development, security and Defence, scientific research, and environmental protection.

WHY IS HYDROGRAPHY IMPORTANT?

In addition to supporting safe and efficient navigation of ships, hydrography underpins almost every other activity associated with the sea, including:

- resource exploitation (e.g.: fishing, minerals)
- environmental protection and management
- maritime boundary delimitation
- national marine spatial data infrastructures
- recreational boating
- maritime defence and security
- tsunami flood and inundation modelling
- coastal zone management
- tourism
- marine science

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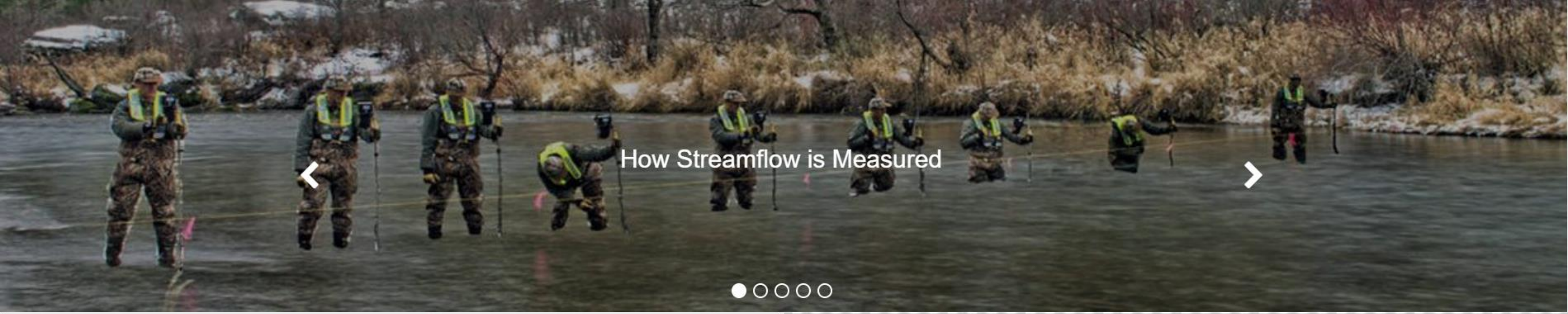
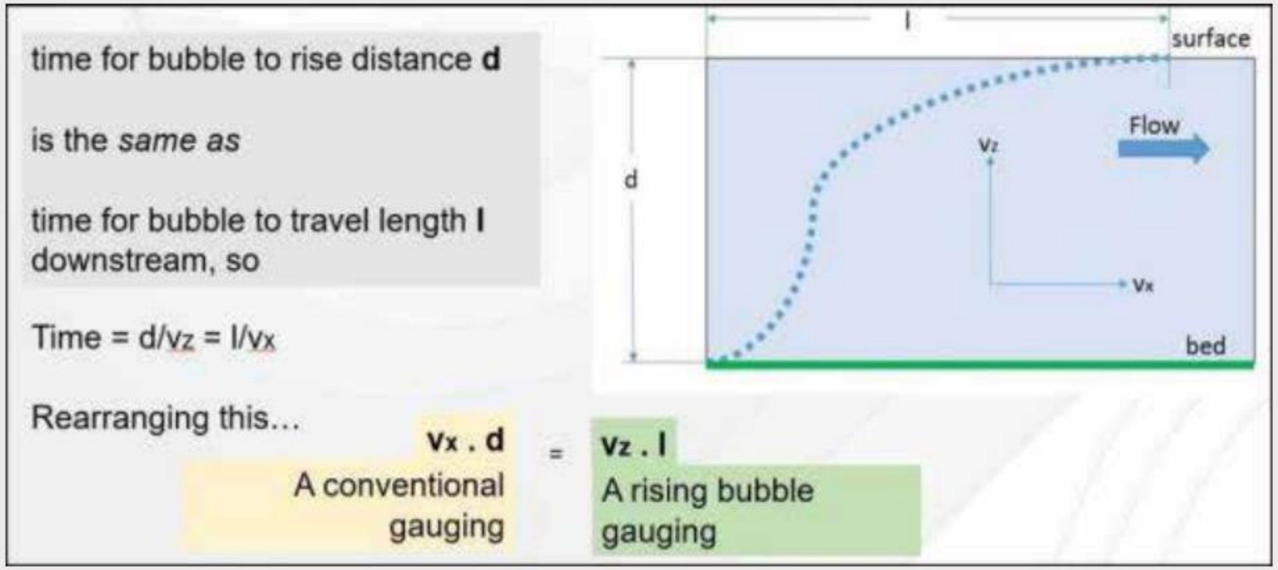
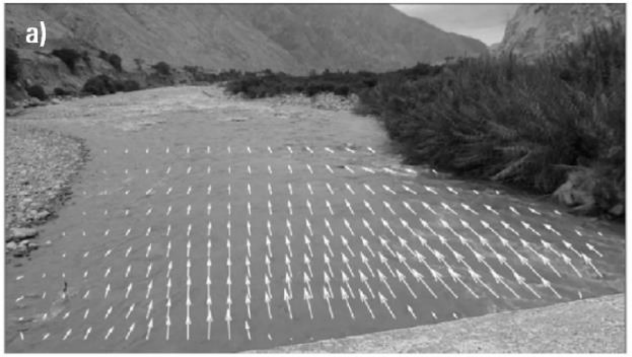
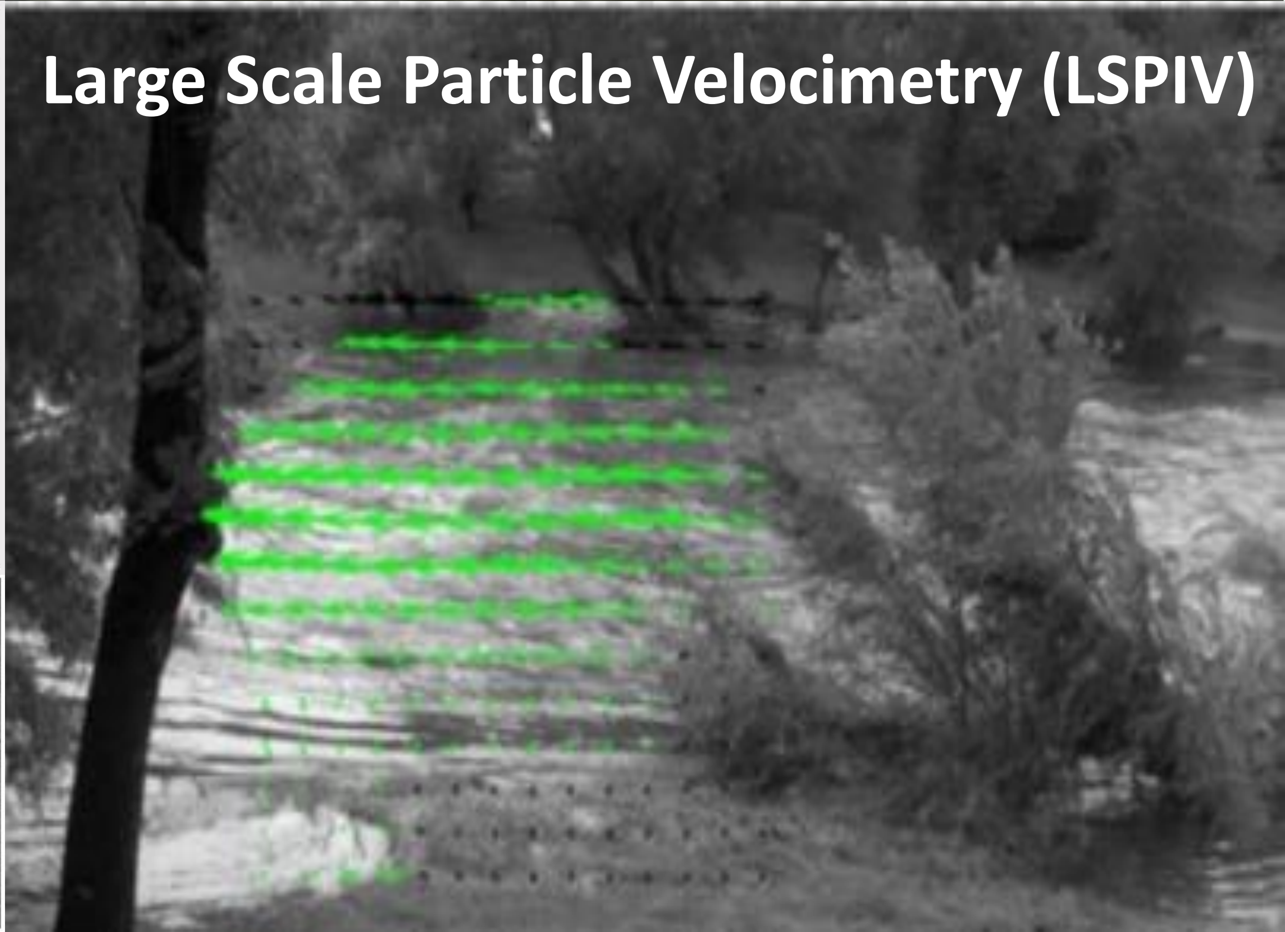

How Streamflow is Measured


time for bubble to rise distance d
is the same as
time for bubble to travel length l
downstream, so
Time = d/vz = l/vx
Rearranging this…
vx . d
A conventional
gauging
=
vz . l
A rising bubble
gauging
l
surface
d
Flow
vz
vx
bed

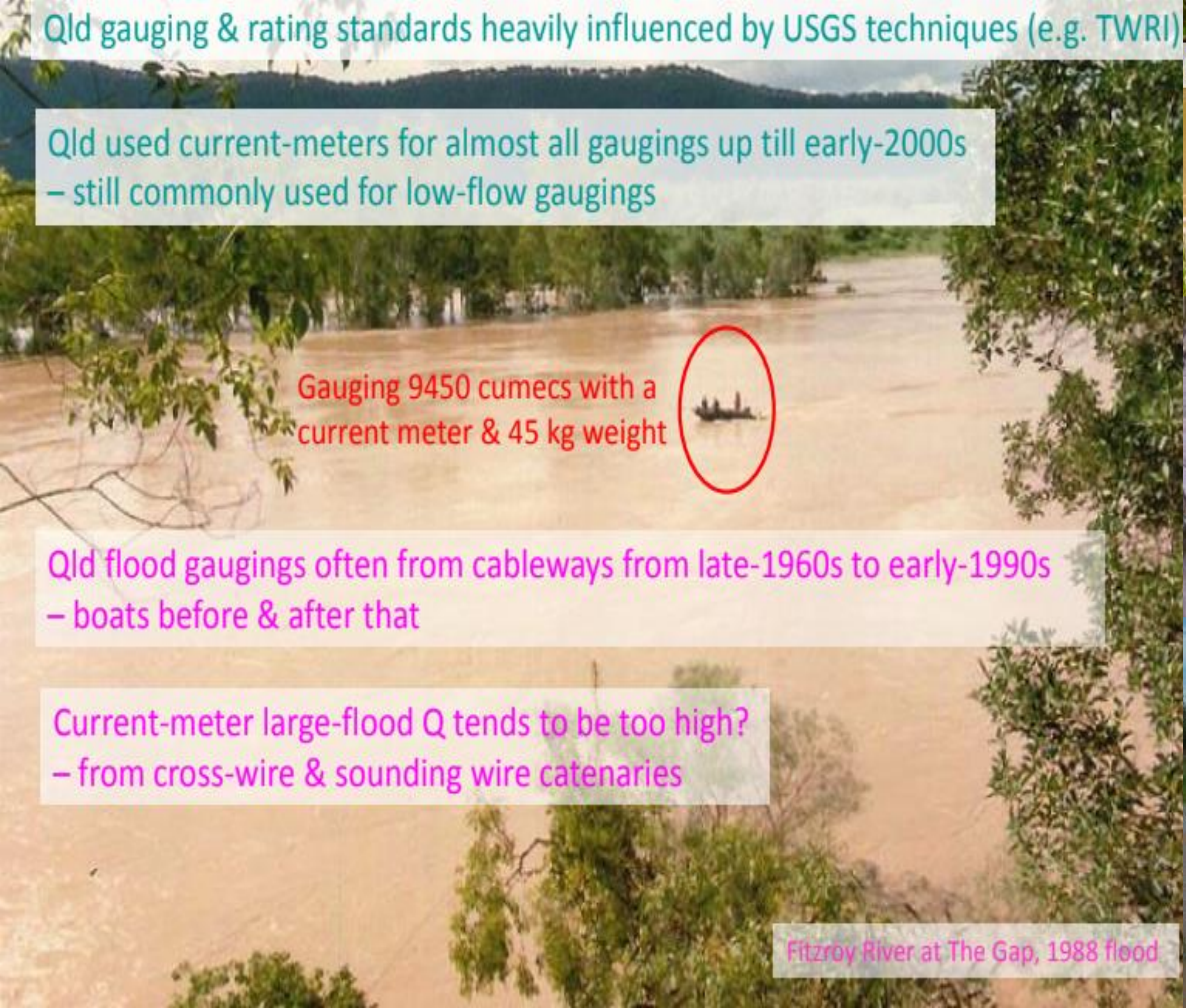

a)


b)


Large Scale Particle Velocimetry (LSPIV)

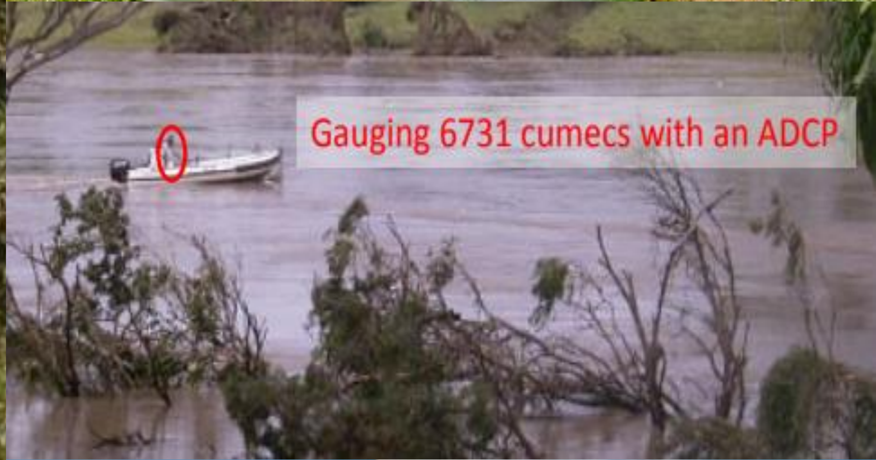
Qld gauging & rating standards heavily influenced by USGS techniques (e.g. TWRI)

Qld used current-meters for almost all gaugings up till early-2000s
– still commonly used for low-flow gaugings



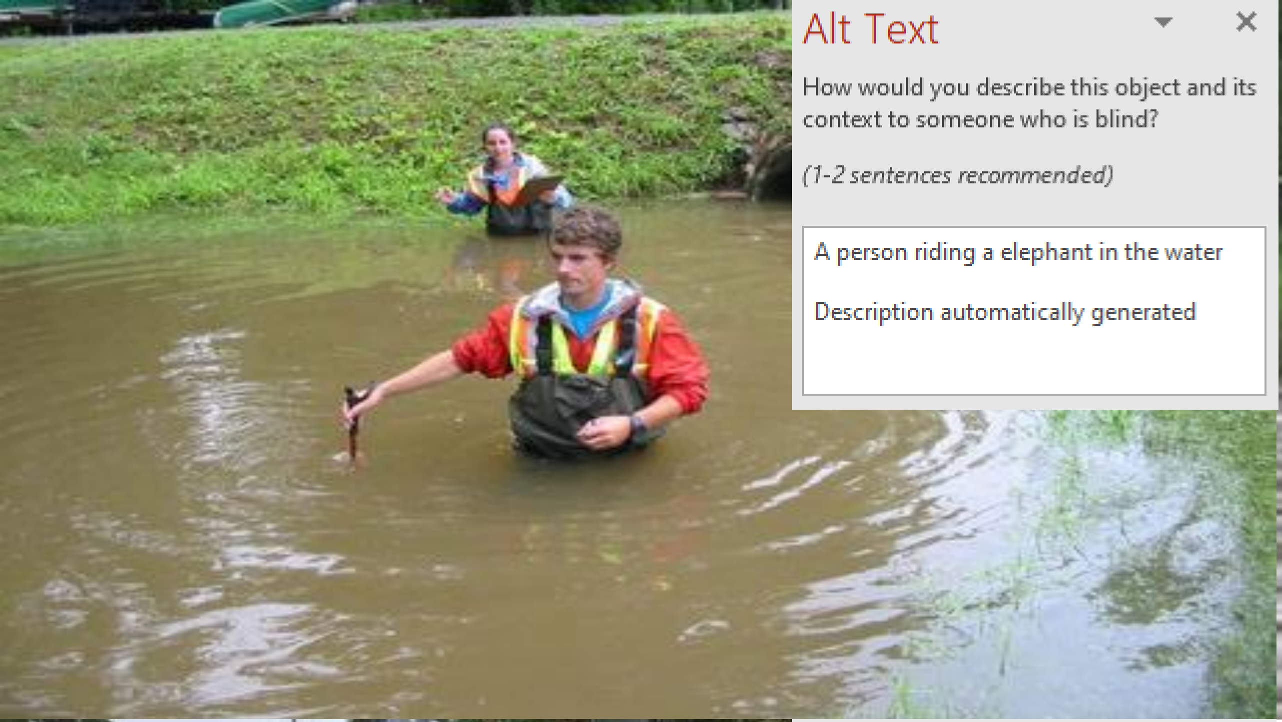
Qld flood gaugings often from cableways from late-1960s to early-1990s
– boats before & after that

Current-meter large-flood Q tends to be too high?
– from cross-wire & sounding wire catenaries

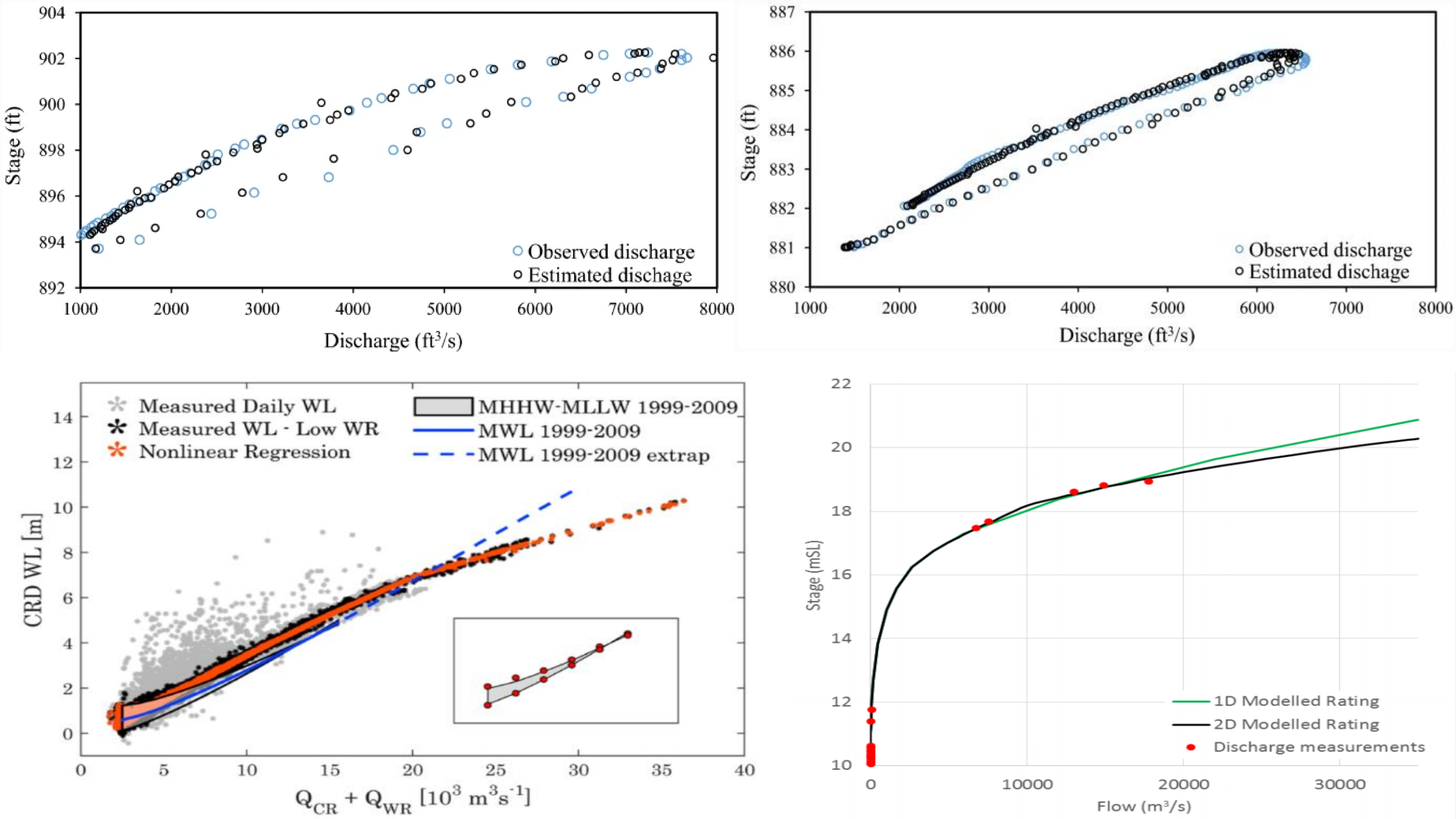


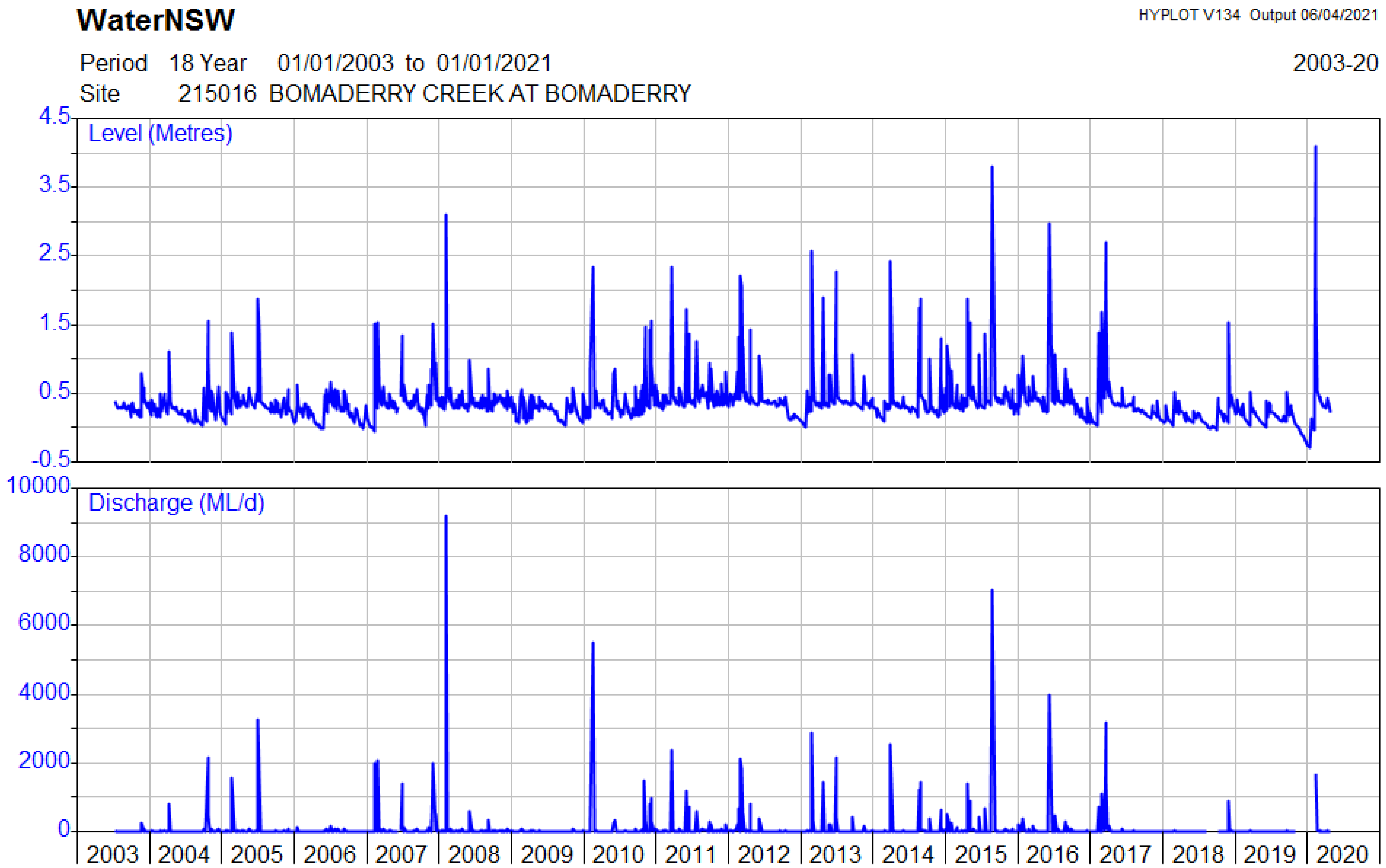
Bull sharks, crocodiles

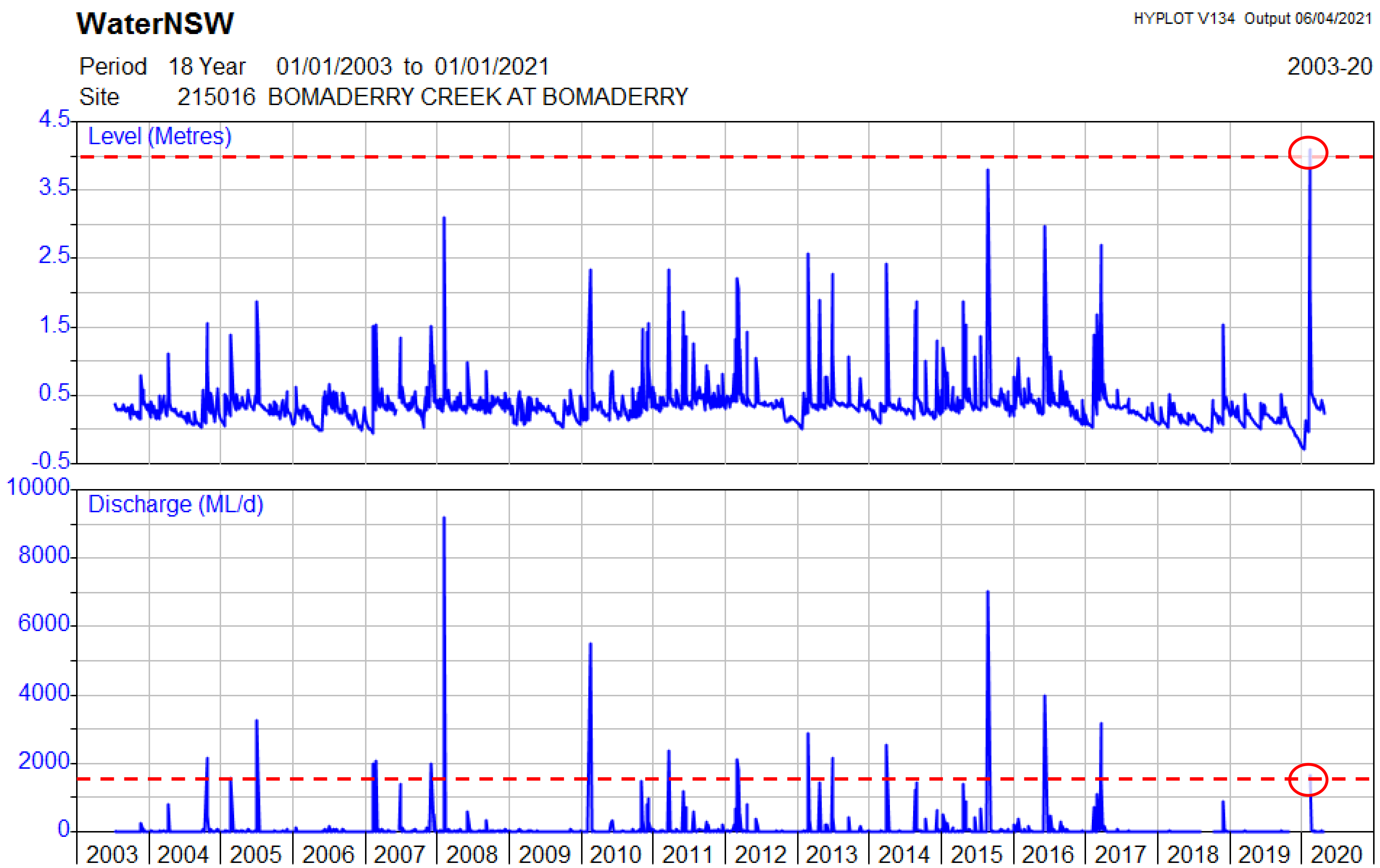




Alt Text
How would you describe this object and its context to someone who is blind?
(1-2 sentences recommended)
A person riding a elephant in the water
Description automatically generated


Alt Text
How would you describe this object and its context to someone who is blind?
(1-2 sentences recommended)
A red fire hydrant covered in snow
Description automatically generated


Stage (ft)
Discharge (ft³/s)
Observed discharge
Estimated dischage
Stage (ft)
Discharge (ft³/s)
Observed discharge
Estimated dischage
Measured Daily WL
Measured WL - Low WR
Nonlinear Regression
MHHW-MLLW 1999-2009
MWL 1999-2009
MWL 1999-2009 extrap
CRD WL [m]
$Q_{CR} + Q_{WR}$ [10^3 m^3s^{-1}]
Stage (mSL)
Flow (m³/s)
1D Modelled Rating
2D Modelled Rating
Discharge measurements


WaterNSW
HYPLOT V134 Output 06/04/2021
Period 18 Year 01/01/2003 to 01/01/2021
2003-20
Site 215016 BOMADERRY CREEK AT BOMADERRY
Level (Metres)
4.5
3.5
2.5
1.5
0.5
-0.5
Discharge (ML/d)
10000
8000
6000
4000
2000
0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020



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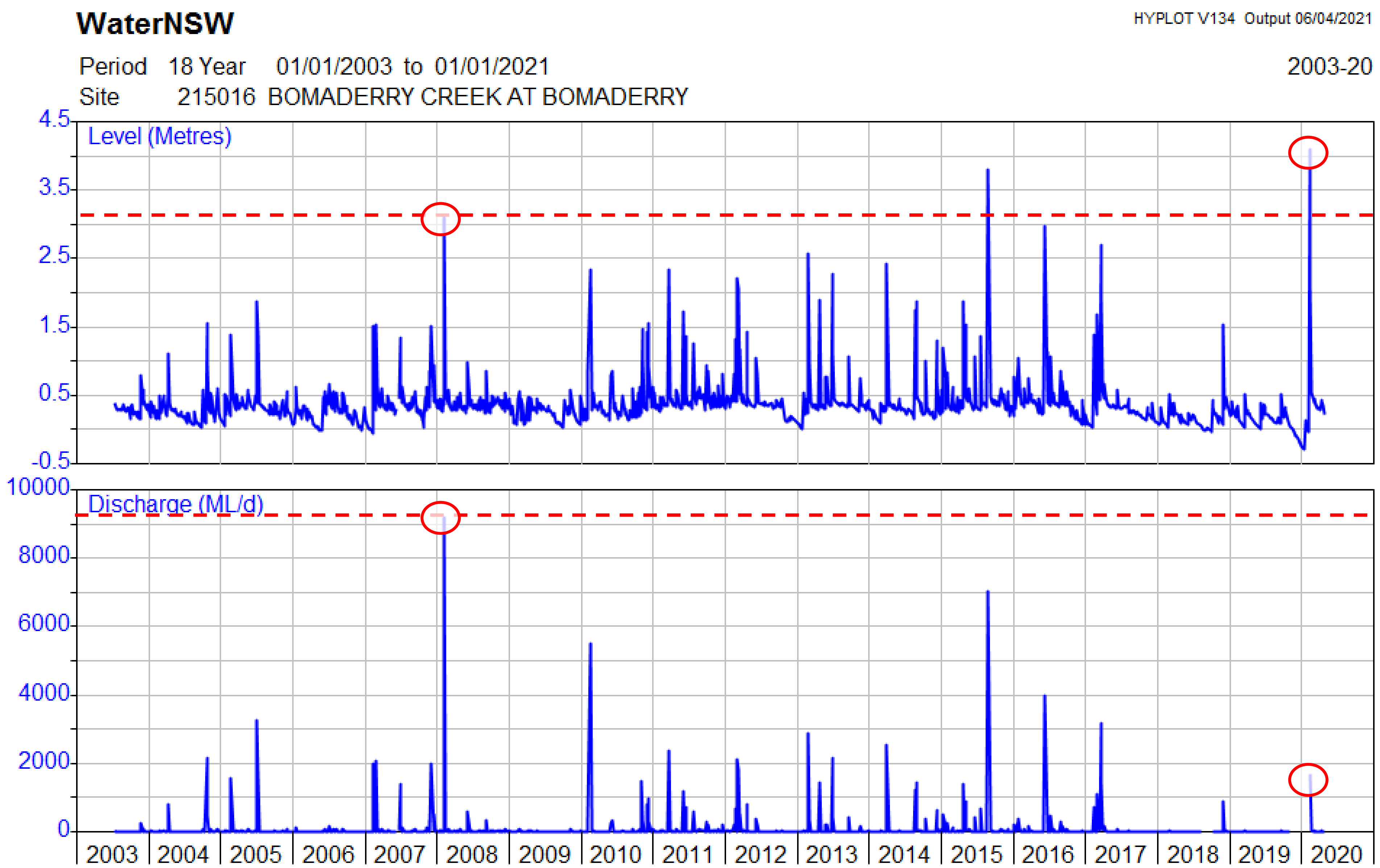
8000
6000
4000
2000
0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020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10000
8000
6000
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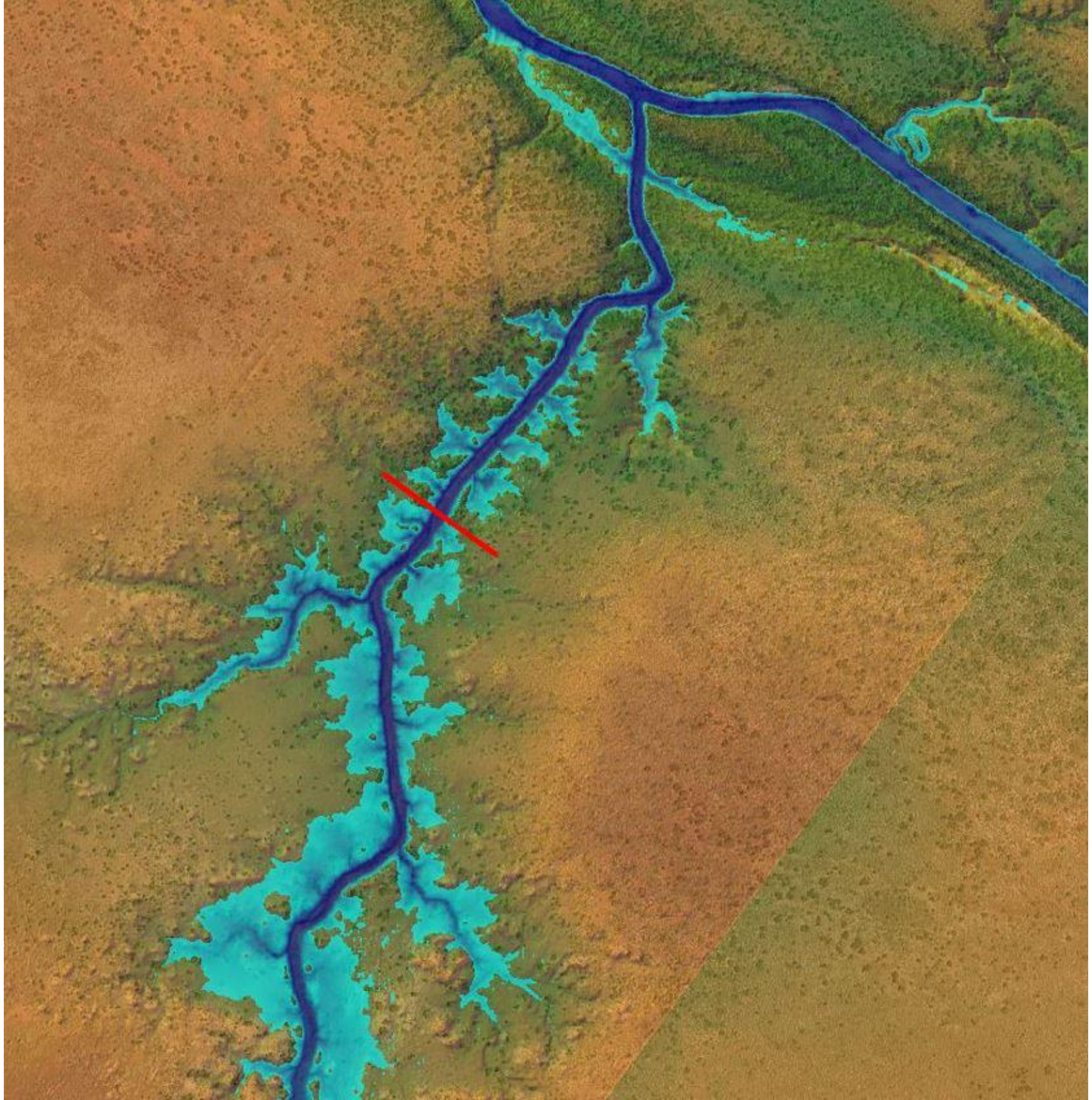
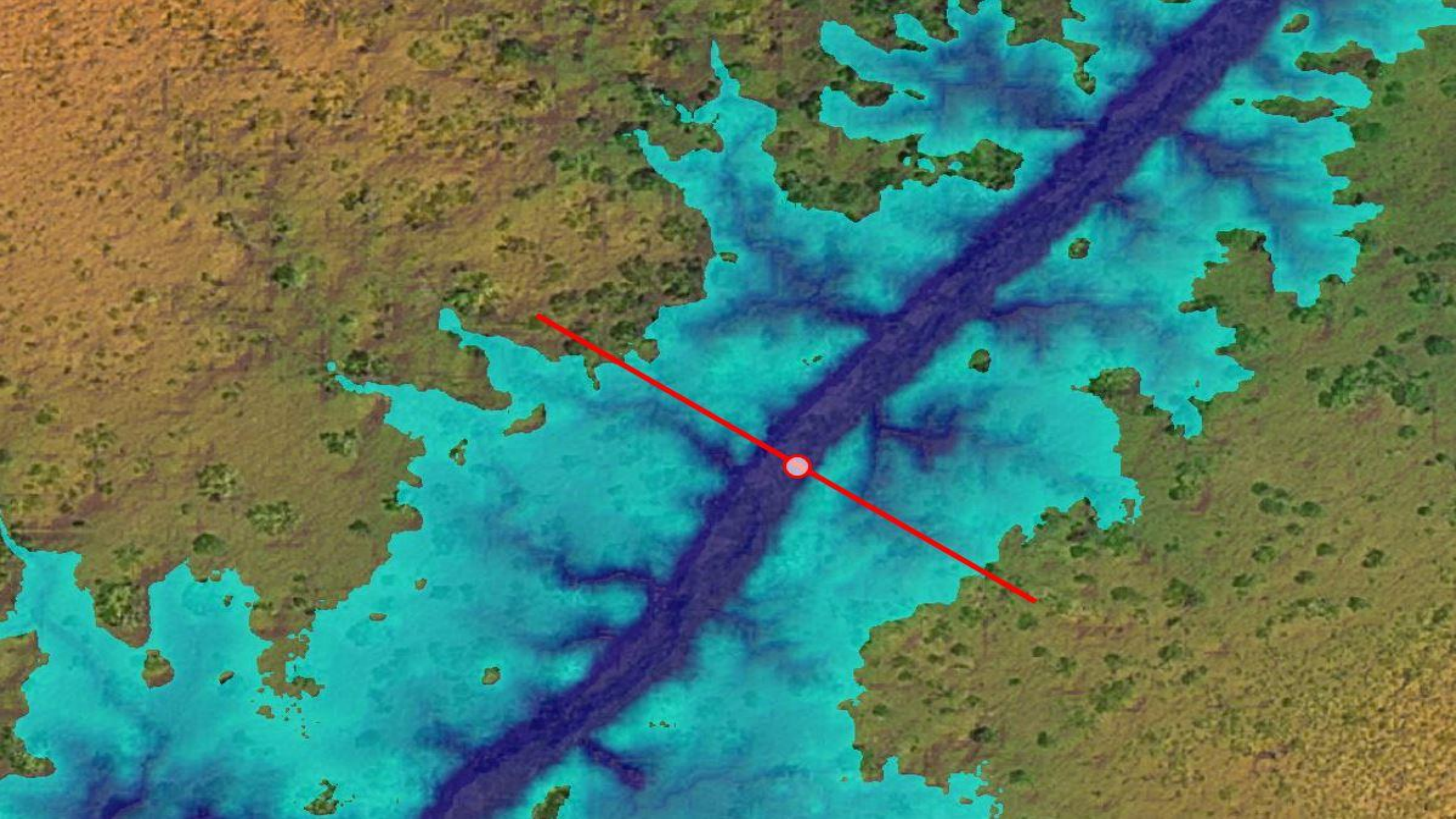
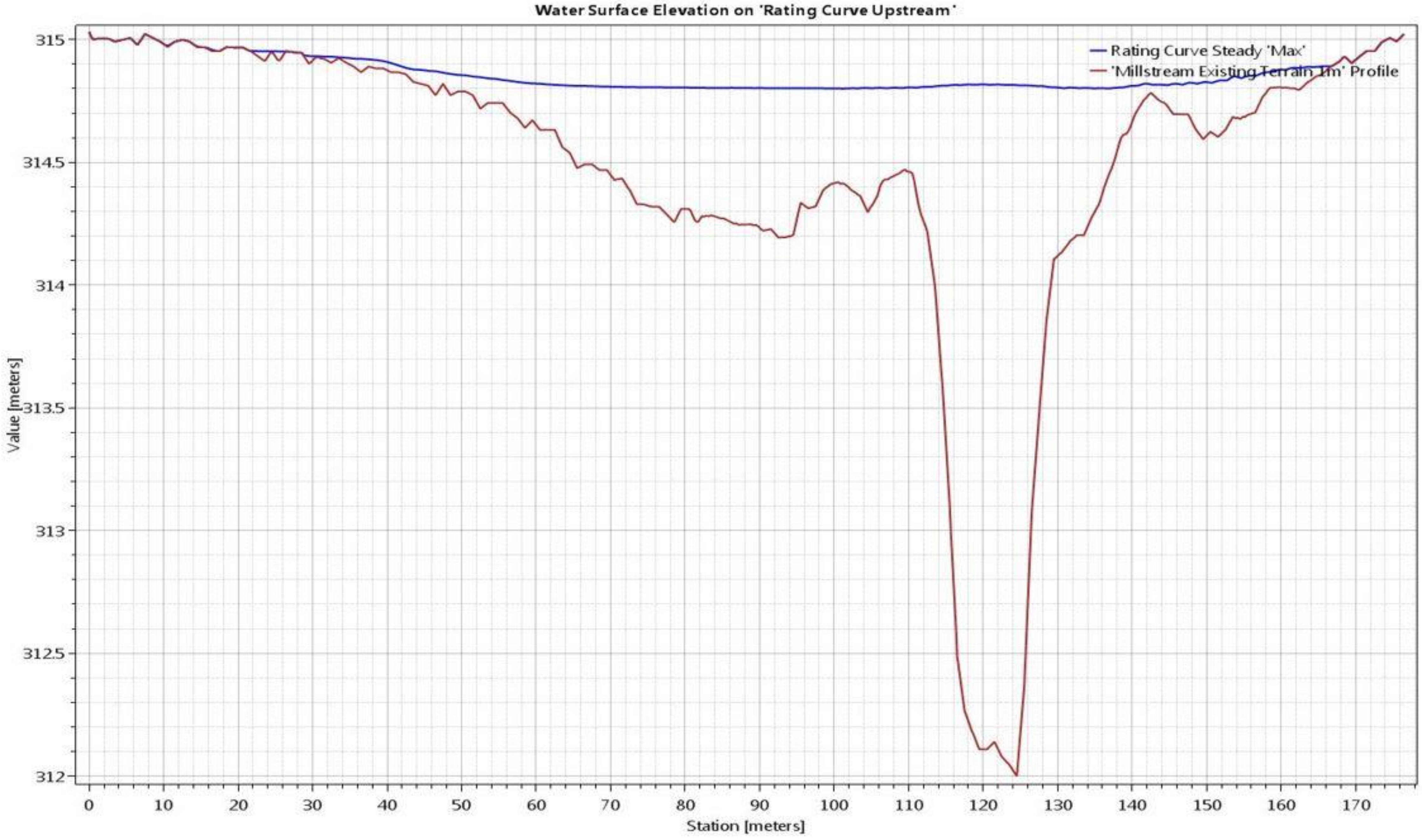
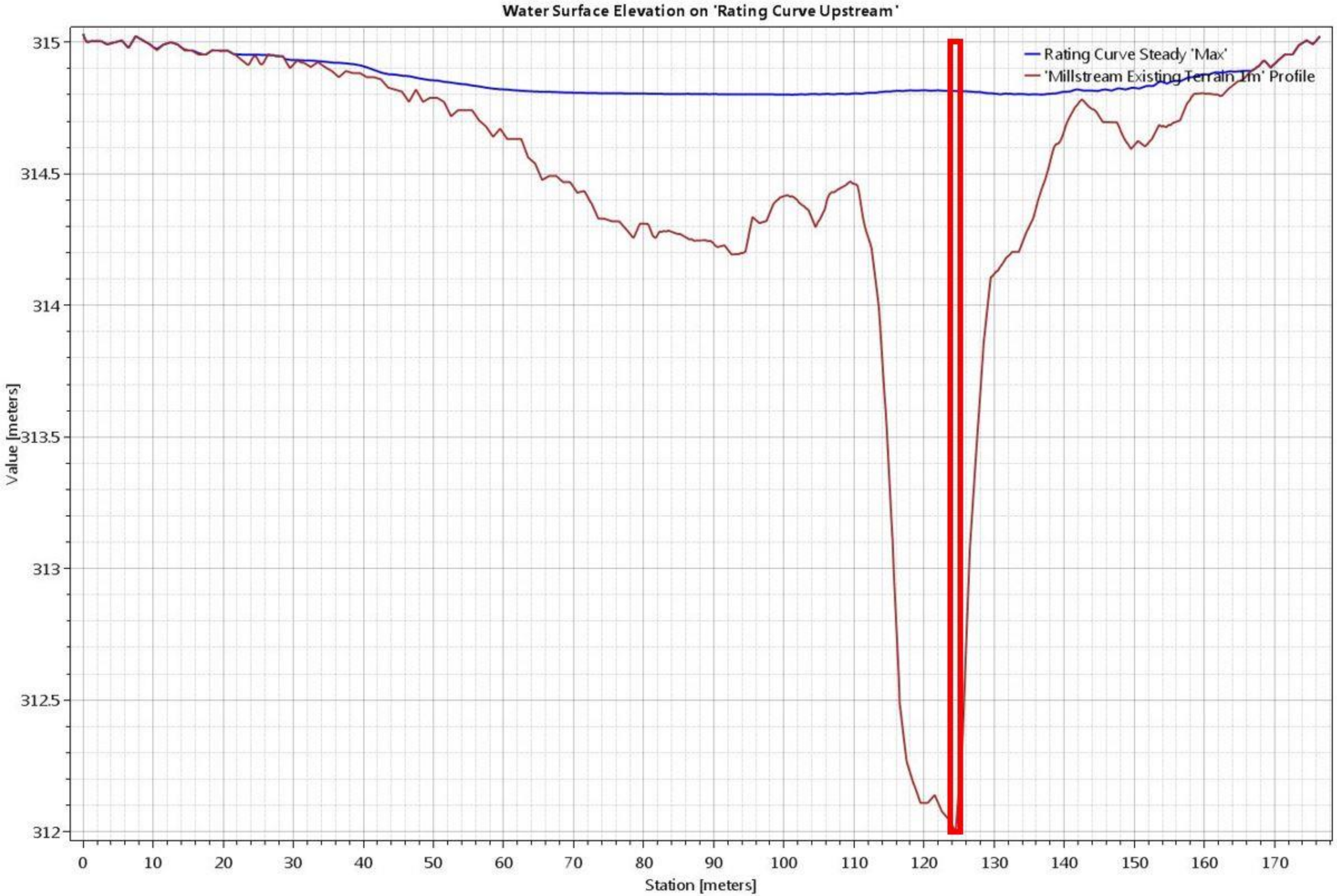
2000
0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020



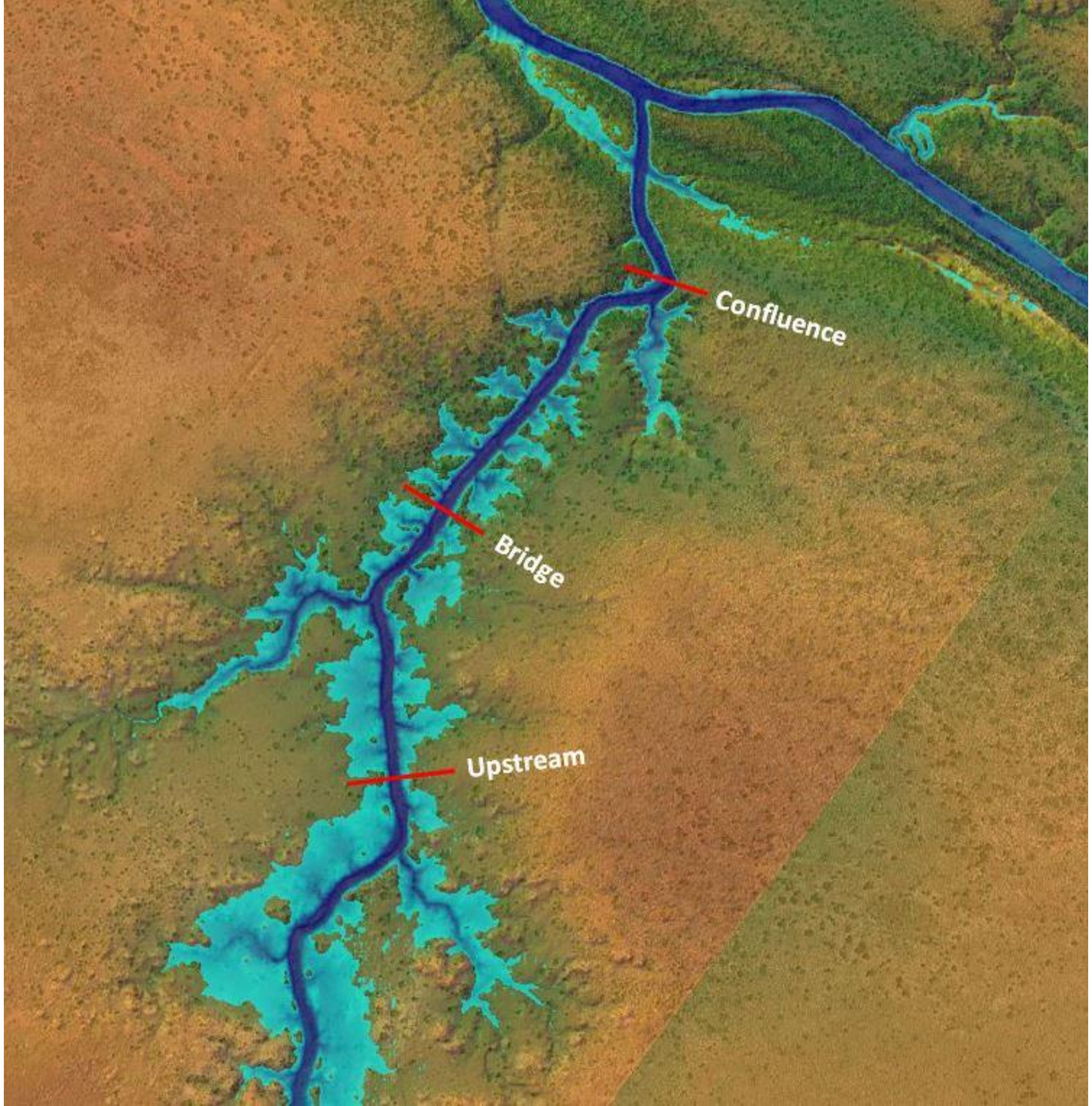


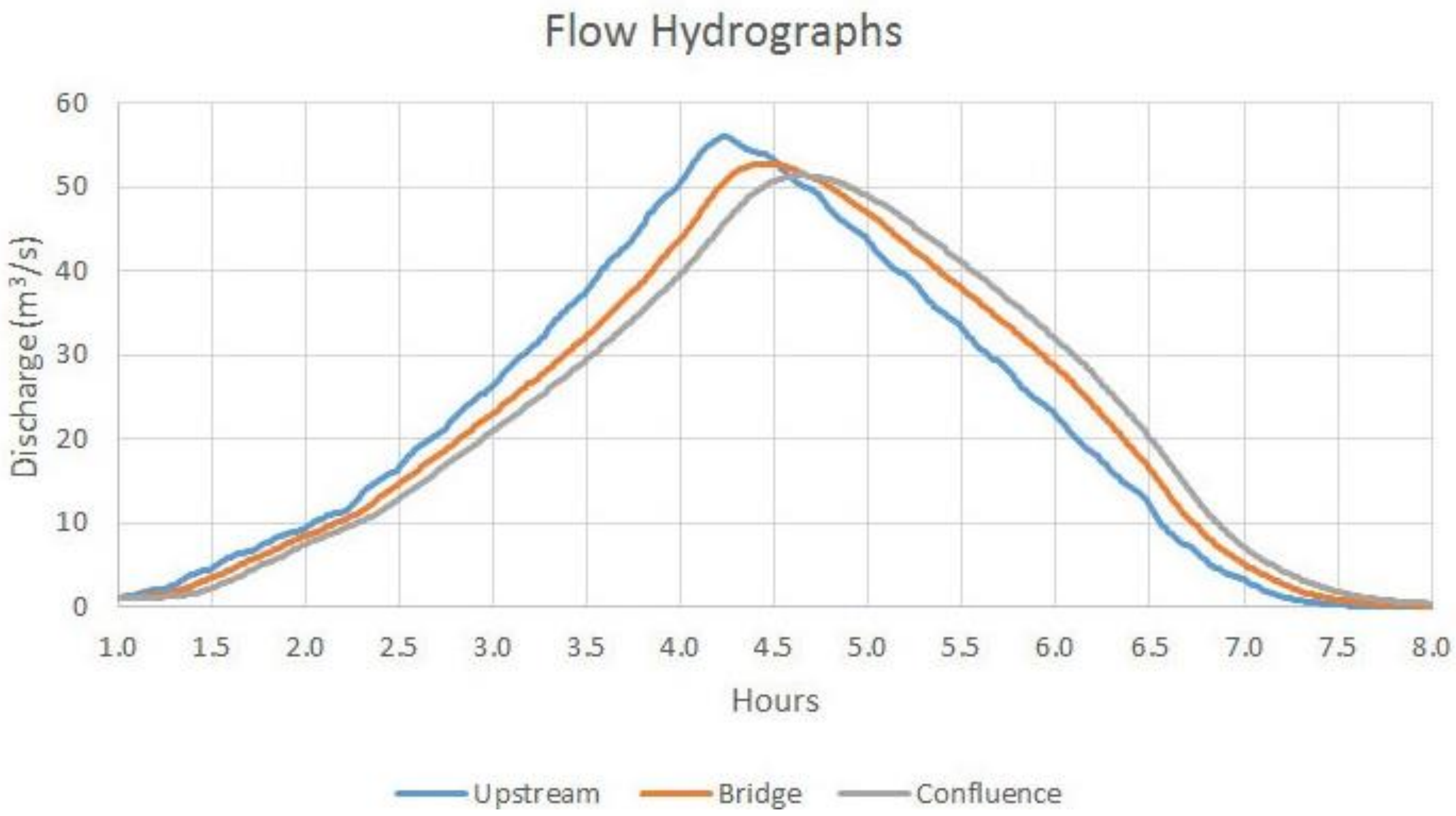


Water Surface Elevation on 'Rating Curve Upstream'
Rating Curve Steady 'Max'
'Millstream Existing Terrain 1m' Profile
Value [meters]
Station [meters]
315
314.5
314
313.5
313
312.5
312
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170

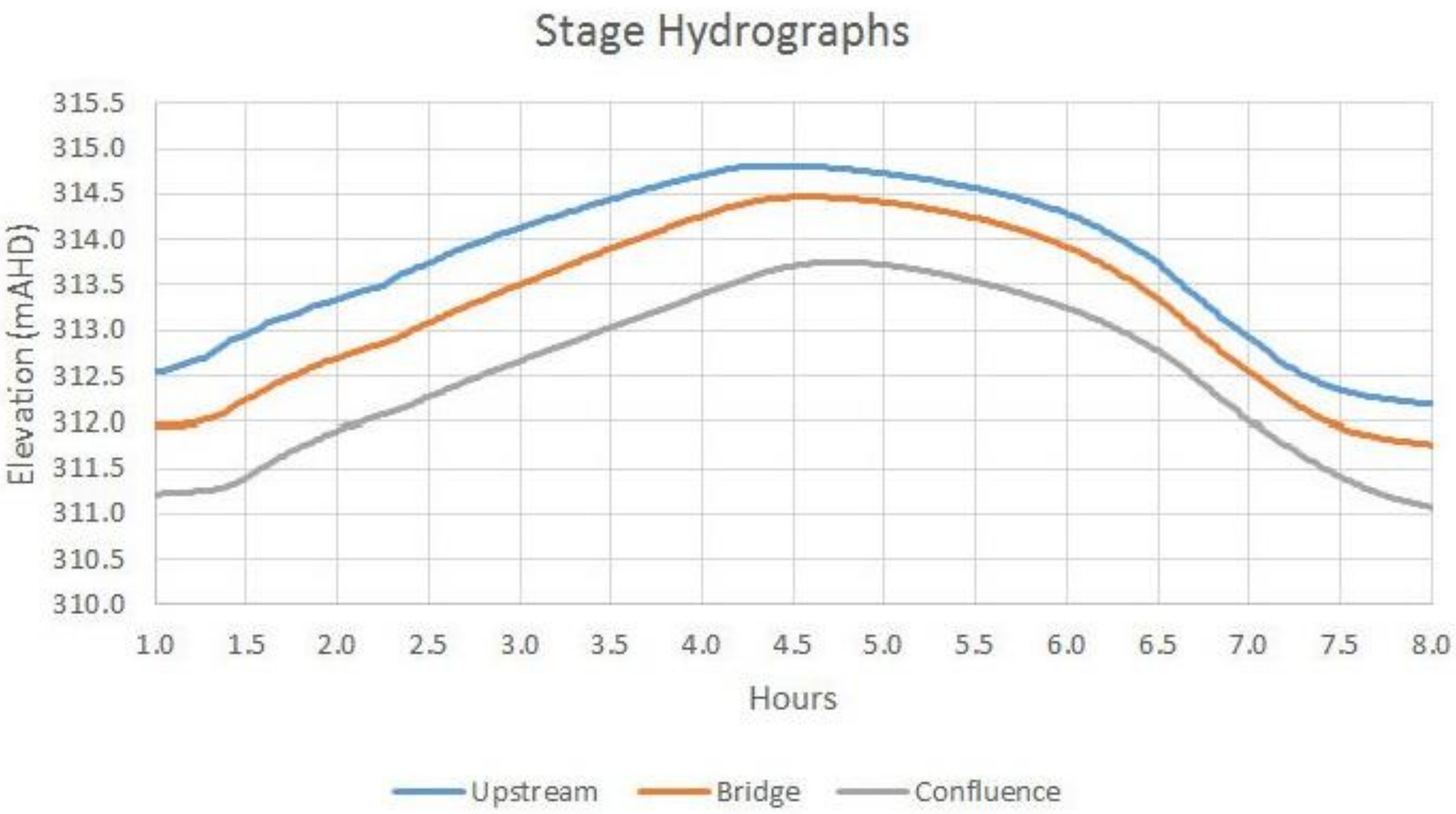


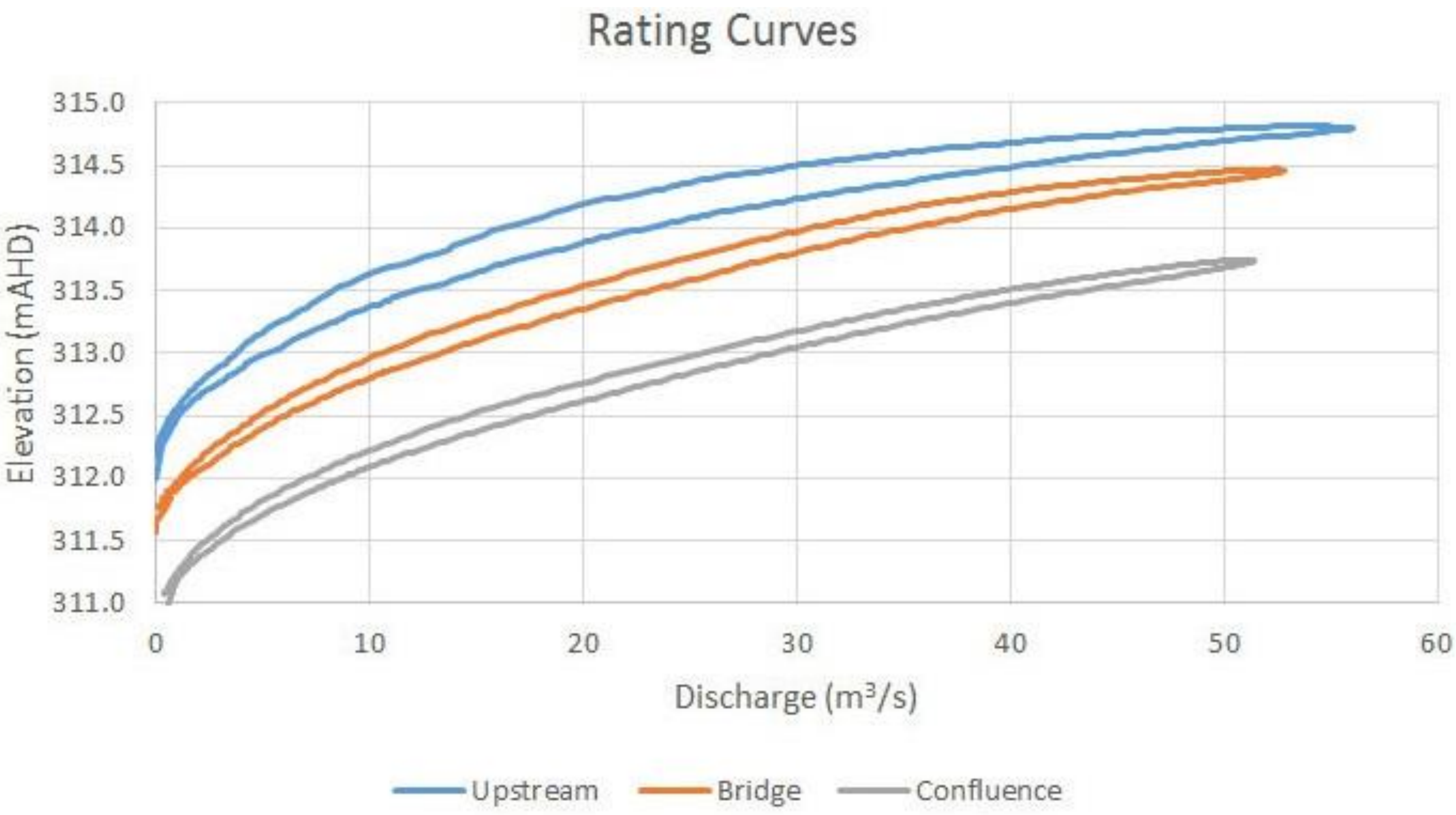
Water Surface Elevation on 'Rating Curve Upstream'
Rating Curve Steady 'Max'
'Millstream Existing Terrain Tin' Profile
Value [meters]
Station [meters]
315
314.5
314
313.5
313
312.5
312
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170


Confluence
Bridge
Upstream



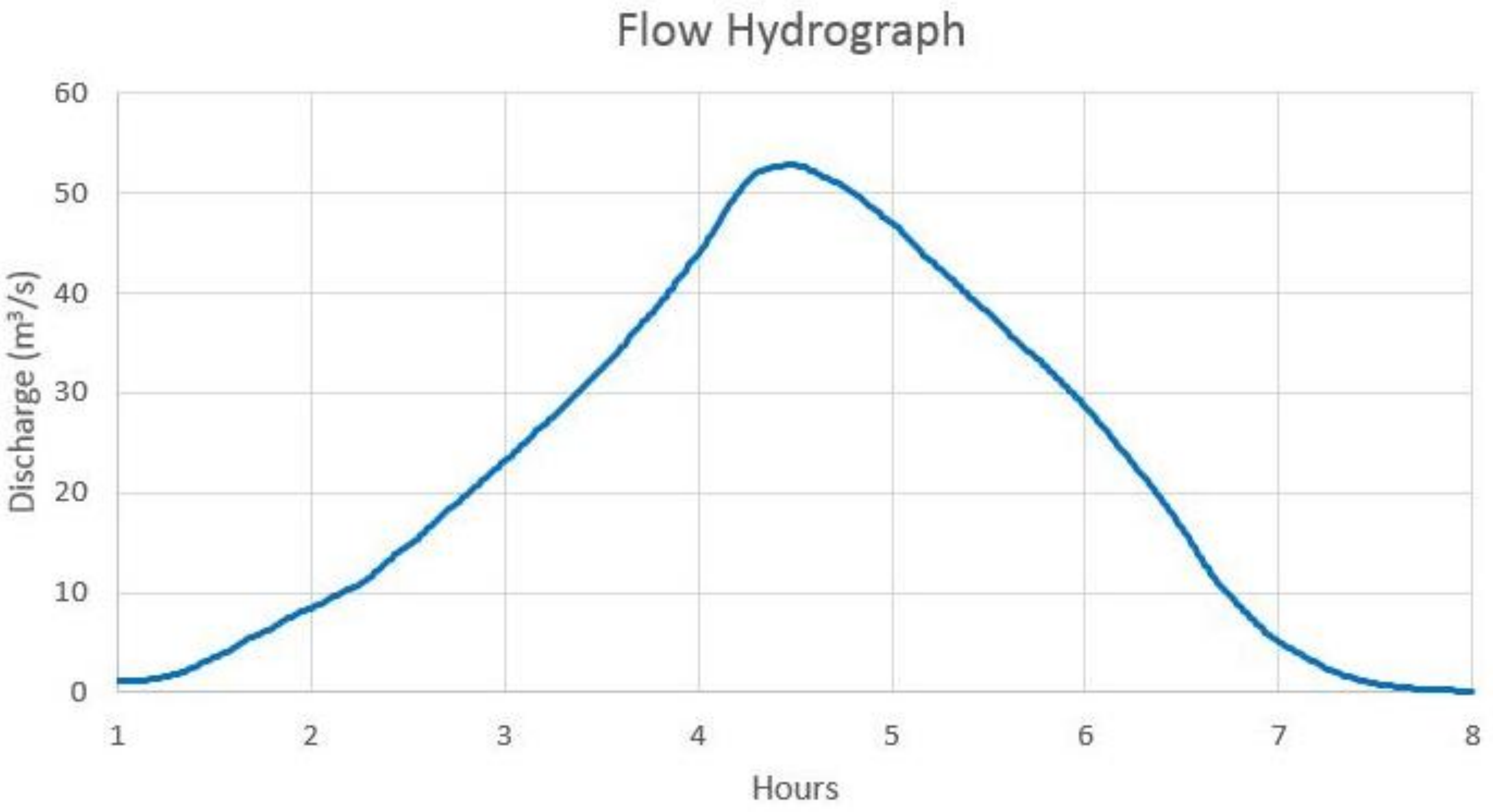
Flow Hydrographs
Discharge (m3/s)
0
10
20
30
40
50
60
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
Hours
Upstream
Bridge
Confluence


Stage Hydrographs
Elevation (mAHD)
315.5
315.0
314.5
314.0
313.5
313.0
312.5
312.0
311.5
311.0
310.5
310.0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
Hours
Upstream
Bridge
Confluence


Rating Curves
315.0
314.5
314.0
313.5
313.0
312.5
312.0
311.5
311.0
Elevation (mAHD)
0
10
20
30
40
50
60
Discharge (m³/s)
Upstream
Bridge
Confluence

Flow Hydrograph

Time (Hours)	Discharge (m^3/s)	Stage (m AHD)
1.00	1.21	311.96
1.10	1.43	311.98
1.20	1.86	312.04
1.30	2.60	312.12
1.40	3.55	312.25
1.50	4.50	312.34
1.60	5.62	312.46
1.70	6.47	312.54
1.80	6.66	312.55
1.90	6.87	312.57
2.00	7.03	312.58



Stage Hydrograph

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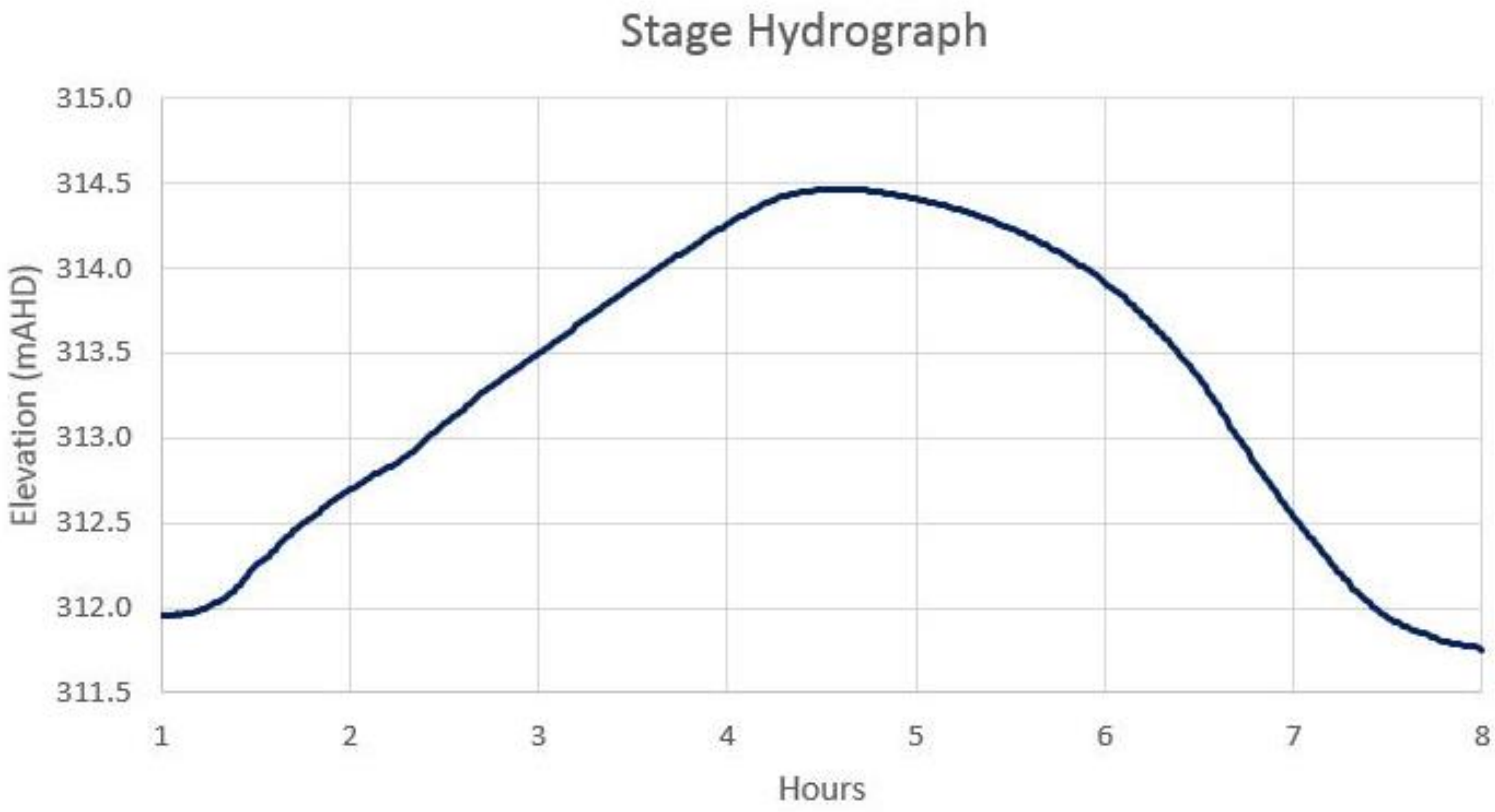

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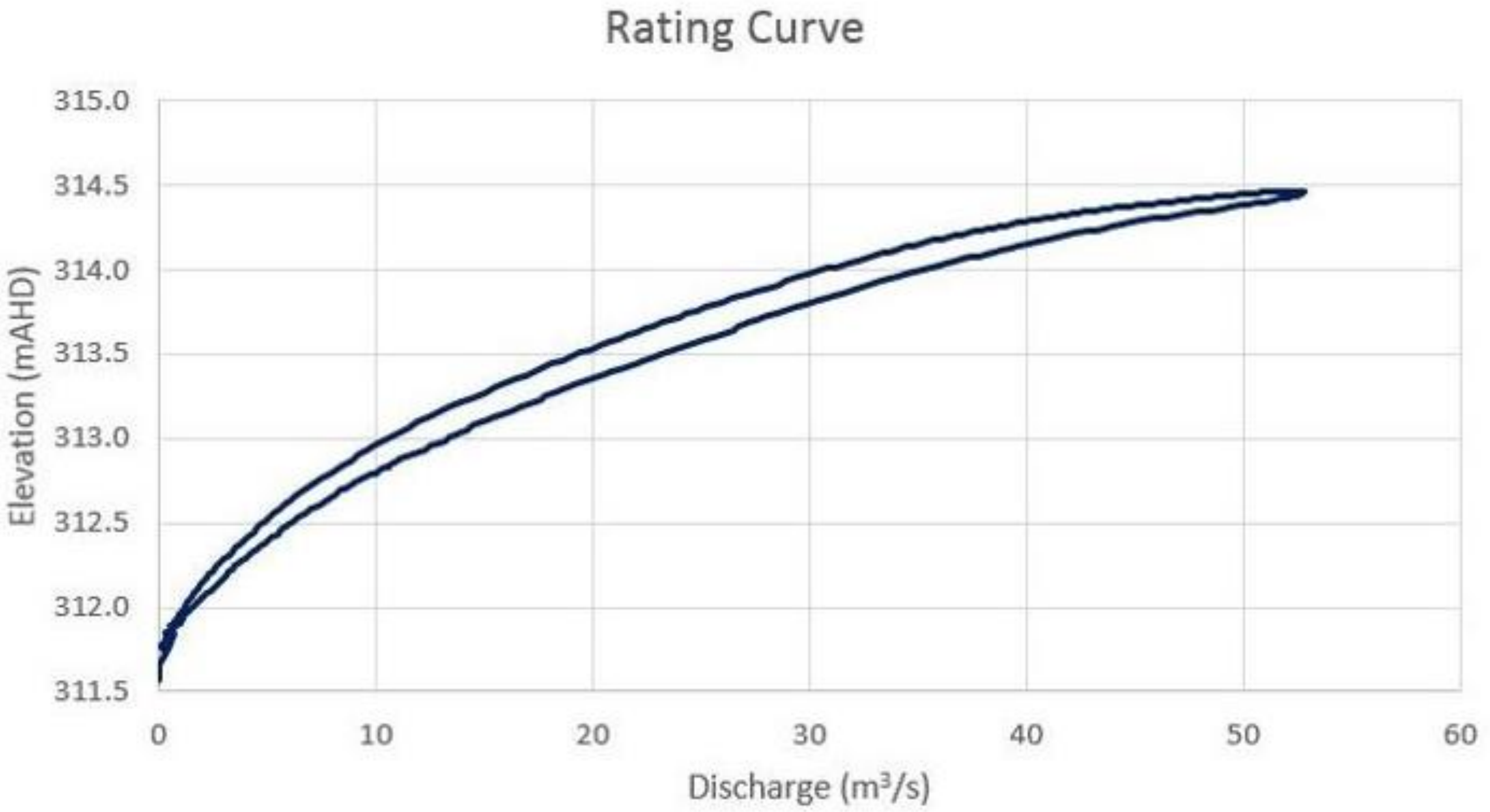

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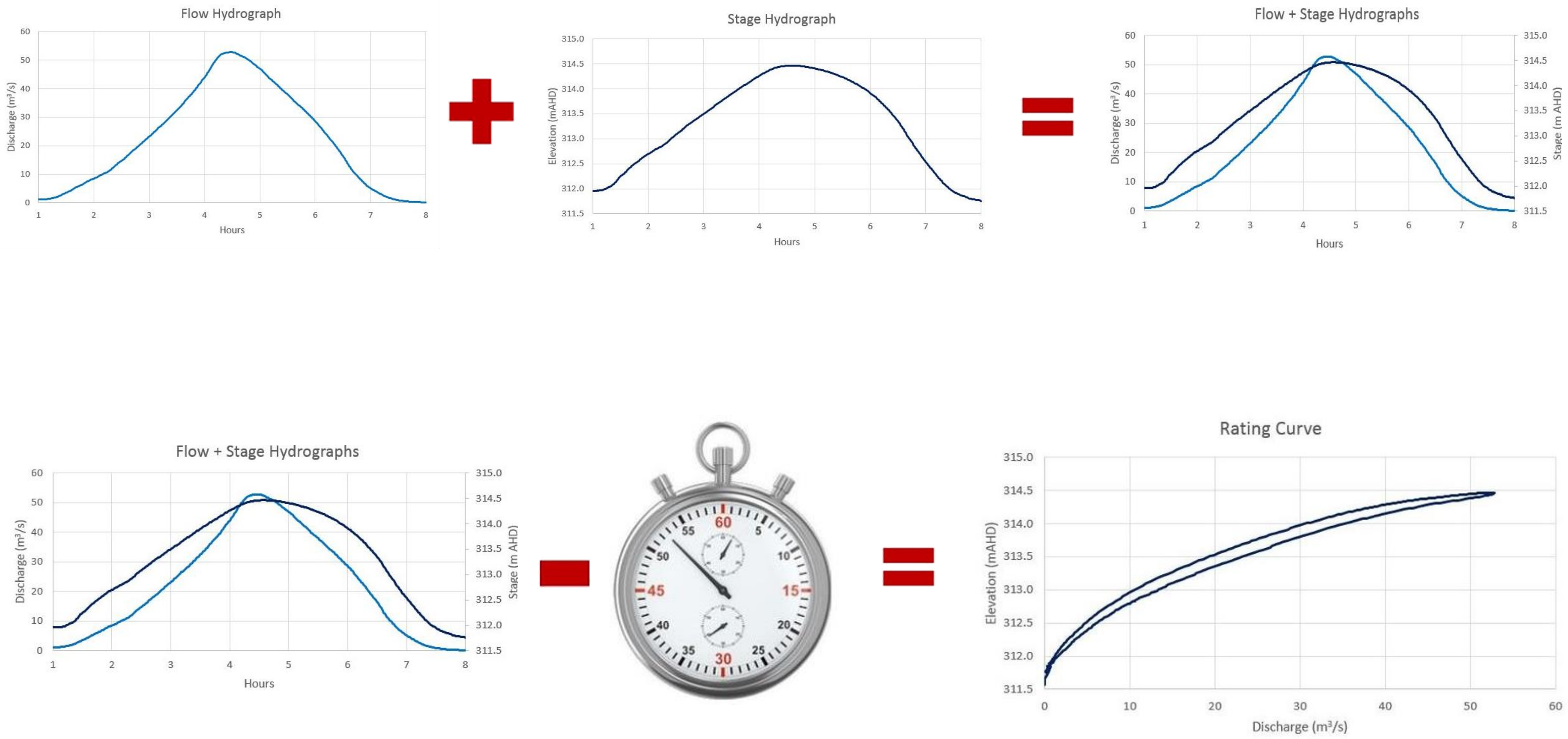
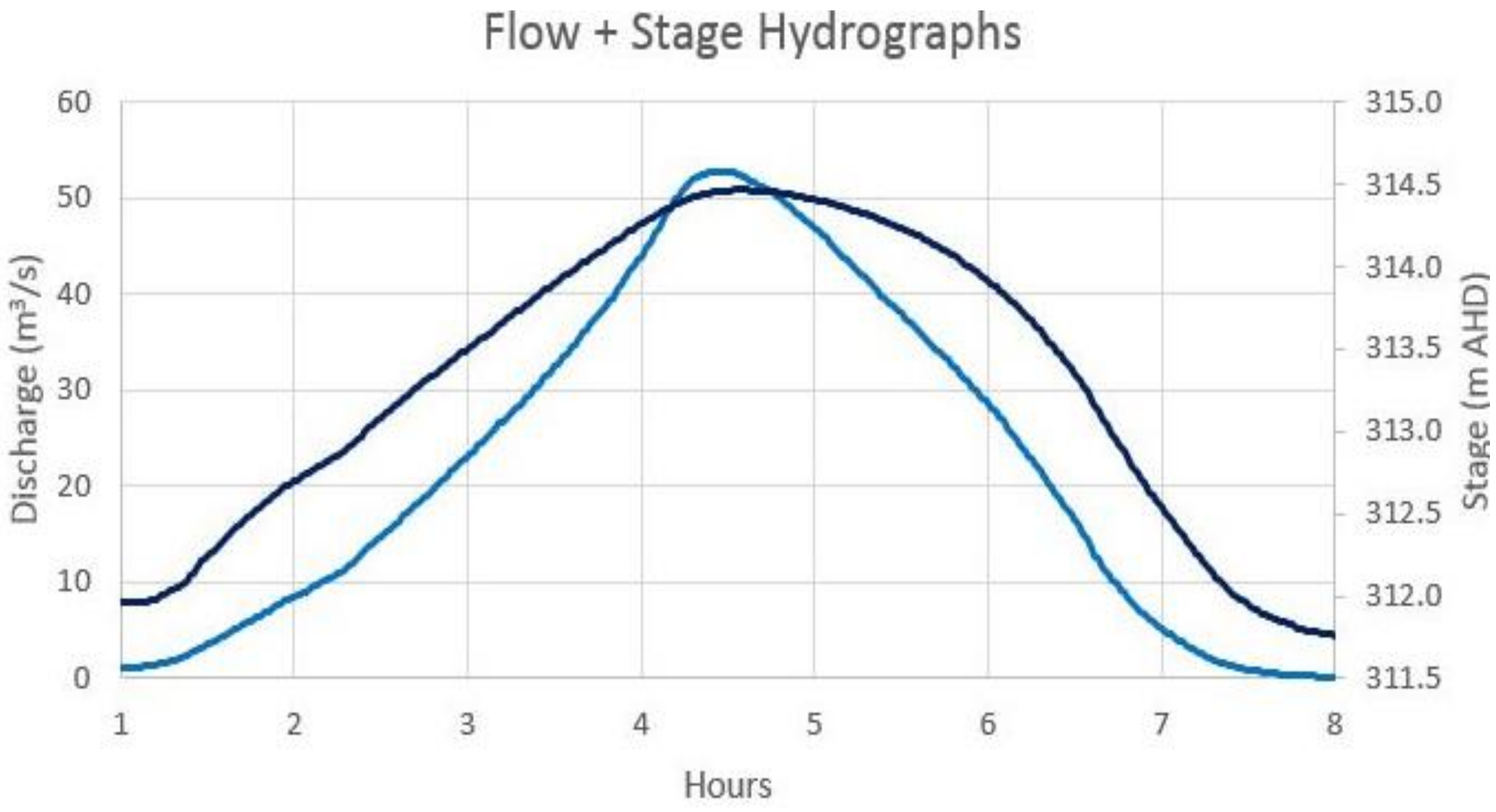
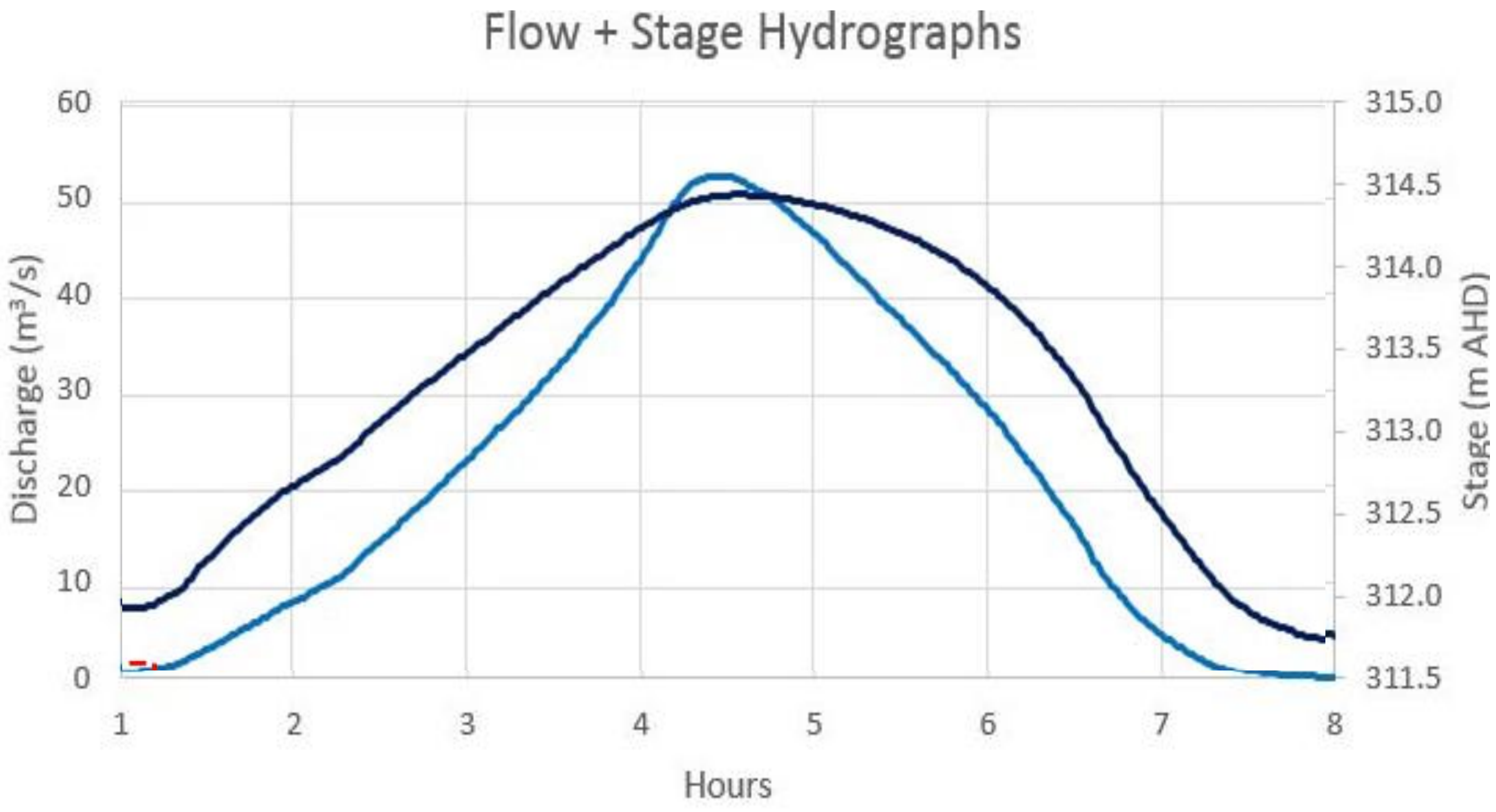
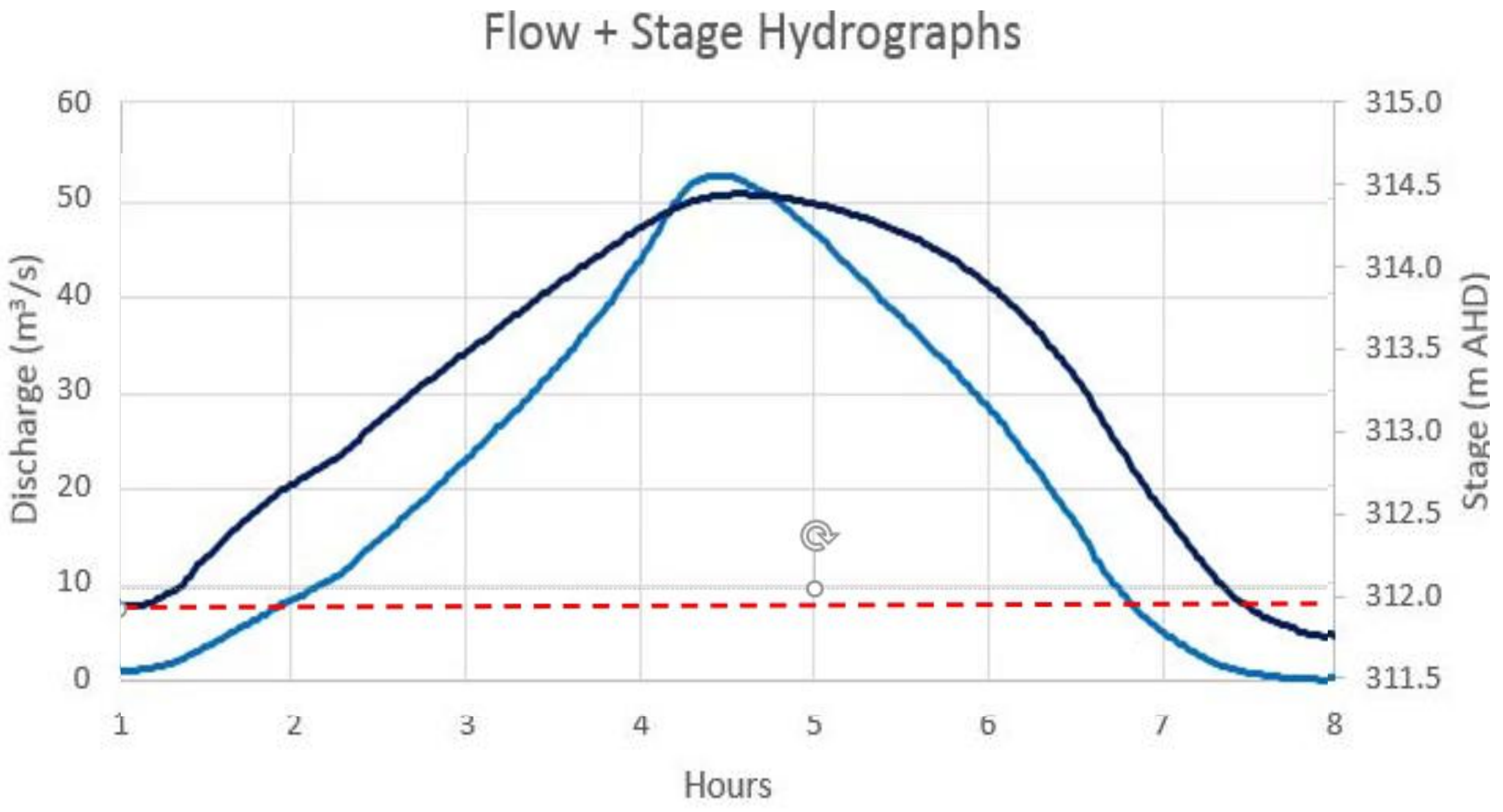

Flow Hydrograph
Discharge (m³/s)
Hours
Stage Hydrograph
Elevation (mAHD)
Hours
Flow + Stage Hydrographs
Discharge (m³/s)
Stage (m AHD)
Hours
Flow + Stage Hydrographs
Discharge (m³/s)
Stage (m AHD)
Hours
60
15
30
45
Rating Curve
Elevation (mAHD)
Discharge (m³/s)

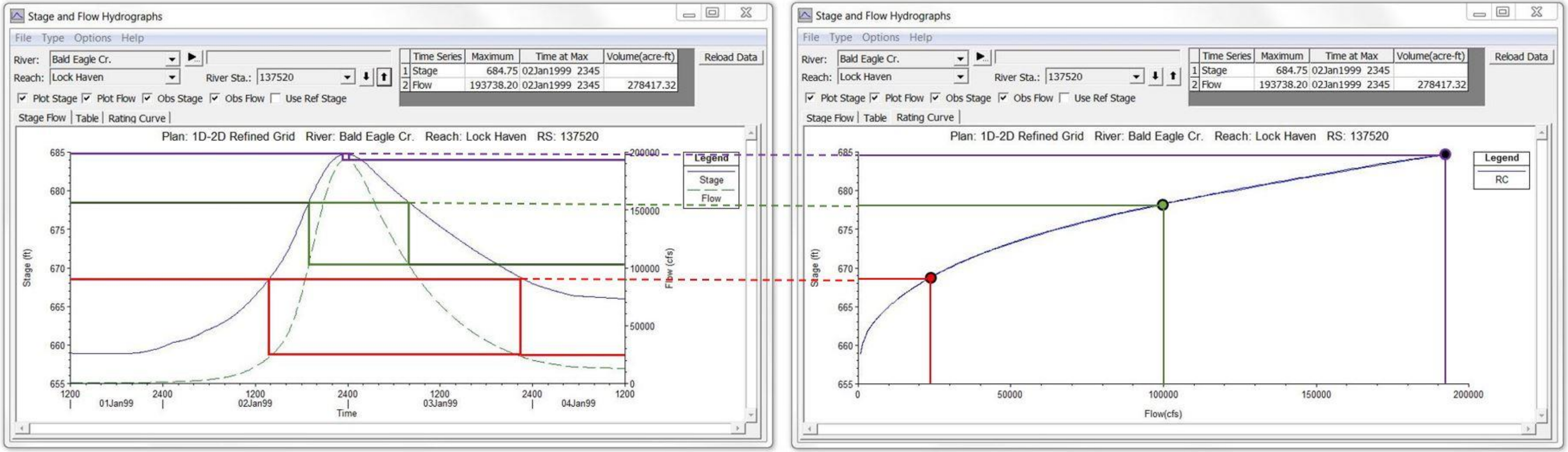

Flow + Stage Hydrographs
Discharge (m³/s)
Stage (m AHD)
Hours
60
50
40
30
20
10
0
315.0
314.5
314.0
313.5
313.0
312.5
312.0
311.5
1
2
3
4
5
6
7
8

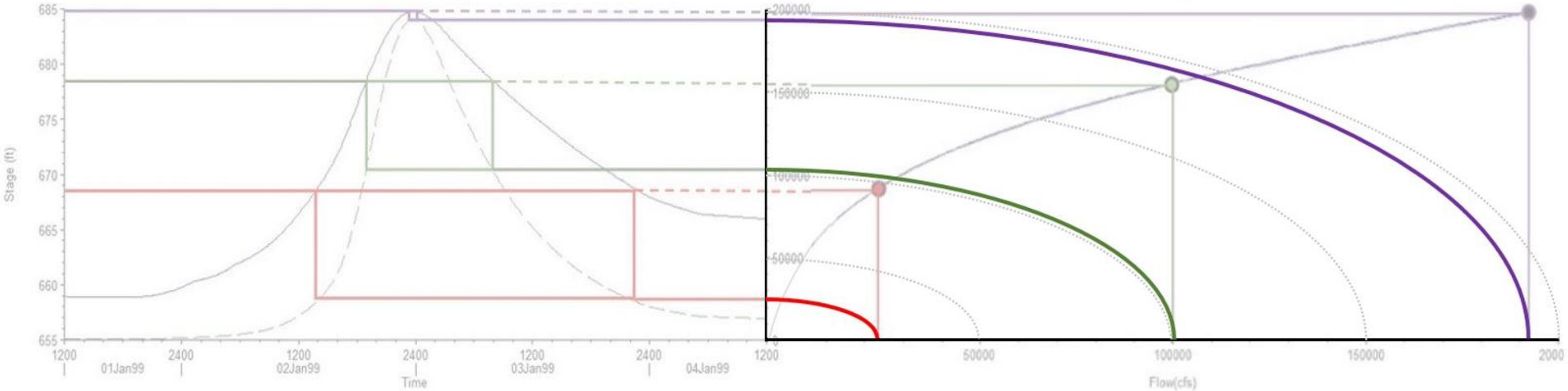


Flow + Stage Hydrographs
Discharge (m³/s)
Stage (m AHD)
Hours
0
10
20
30
40
50
60
311.5
312.0
312.5
313.0
313.5
314.0
314.5
315.0
1
2
3
4
5
6
7
8

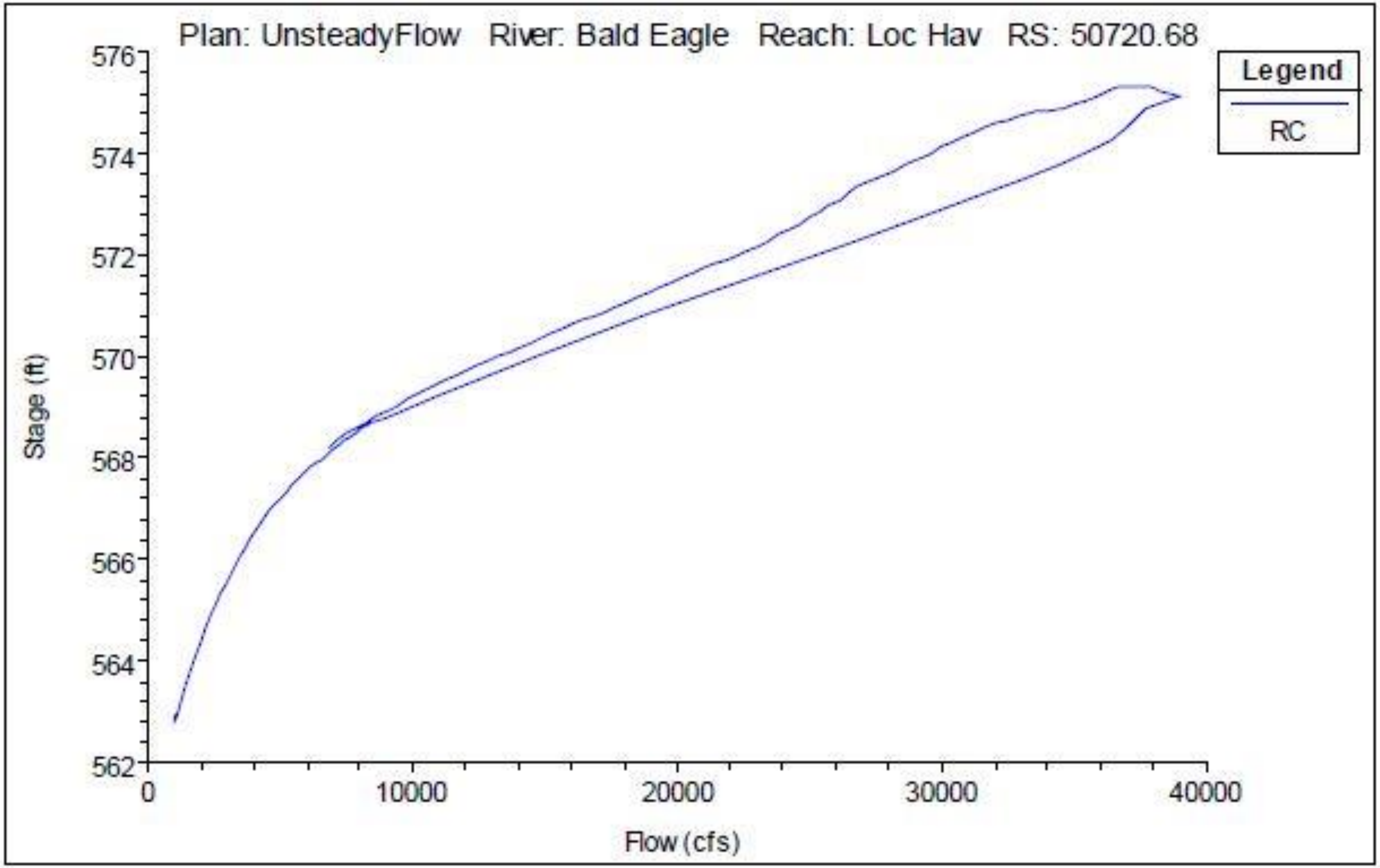


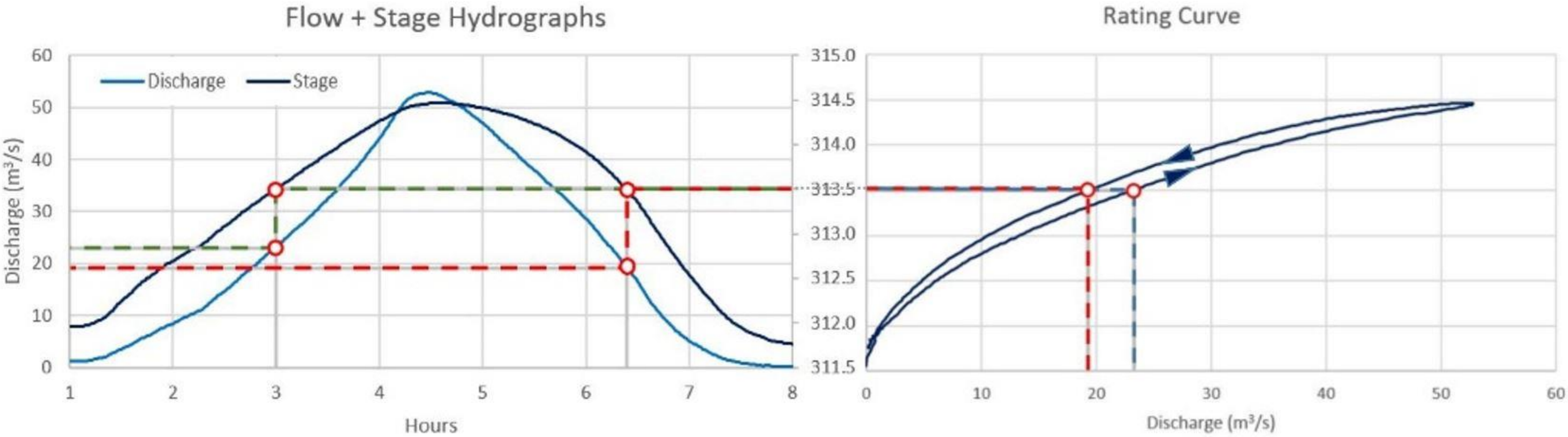
Flow + Stage Hydrographs
Discharge (m³/s)
Stage (m AHD)
Hours
60
50
40
30
20
10
0
315.0
314.5
314.0
313.5
313.0
312.5
312.0
311.5
1
2
3
4
5
6
7
8


Stage and Flow Hydrographs
File Type Options Help
River: Bald Eagle Cr.
Reach: Lock Haven
River Sta.: 137520
Reload Data
Time Series | Maximum | Time at Max | Volume(acre-ft)
1 Stage 684.75 02Jan1999 2345
2 Flow 193738.20 02Jan1999 2345 278417.32
Plot Stage
Plot Flow
Obs Stage
Obs Flow
Use Ref Stage
Stage Flow
Table
Rating Curve
Plan: 1D-2D Refined Grid River: Bald Eagle Cr. Reach: Lock Haven RS: 137520
Stage (ft)
Flow (cfs)
Time
01Jan99
02Jan99
03Jan99
04Jan99
Legend
Stage
Flow
Flow(cfs)
RC

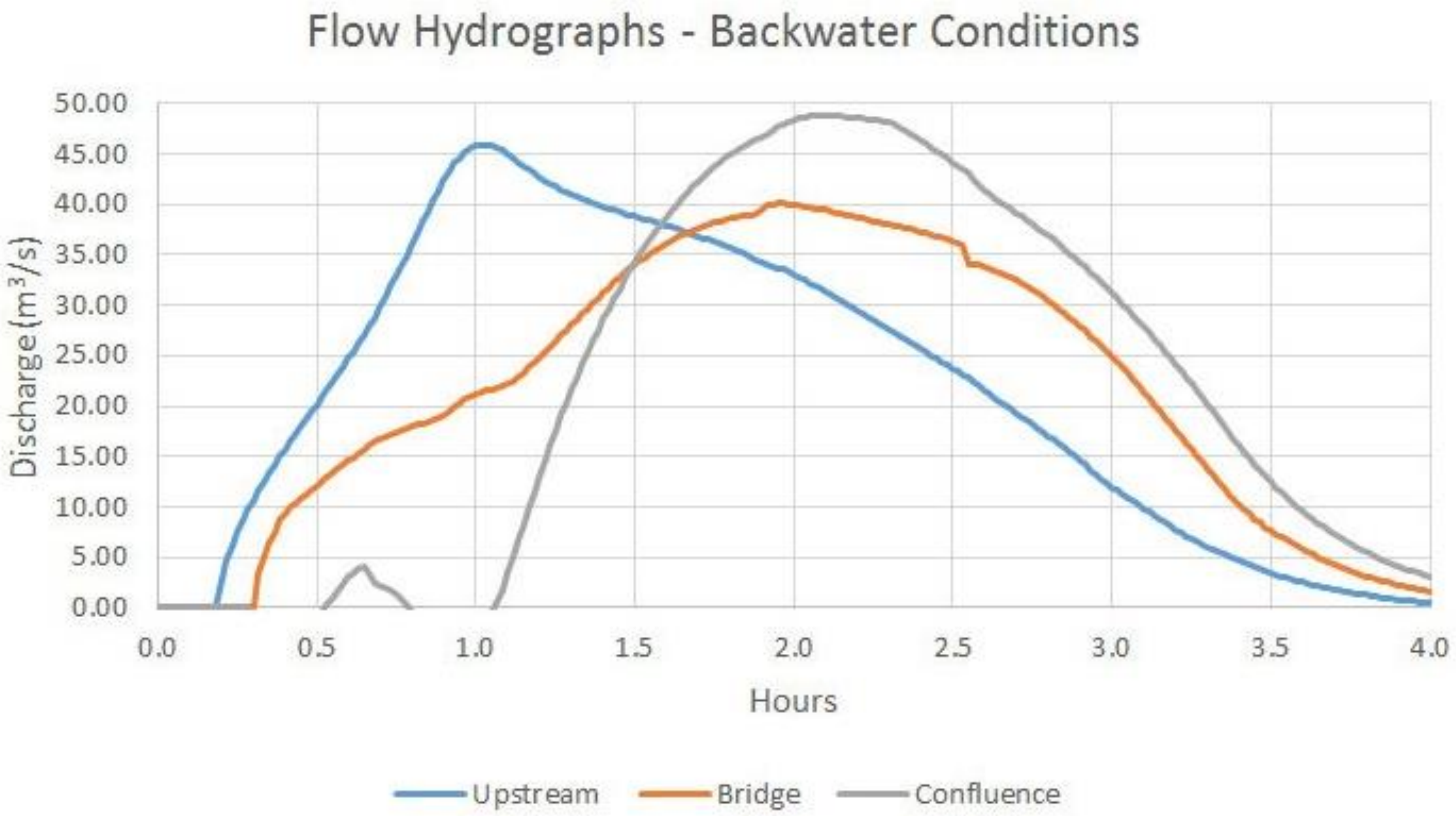


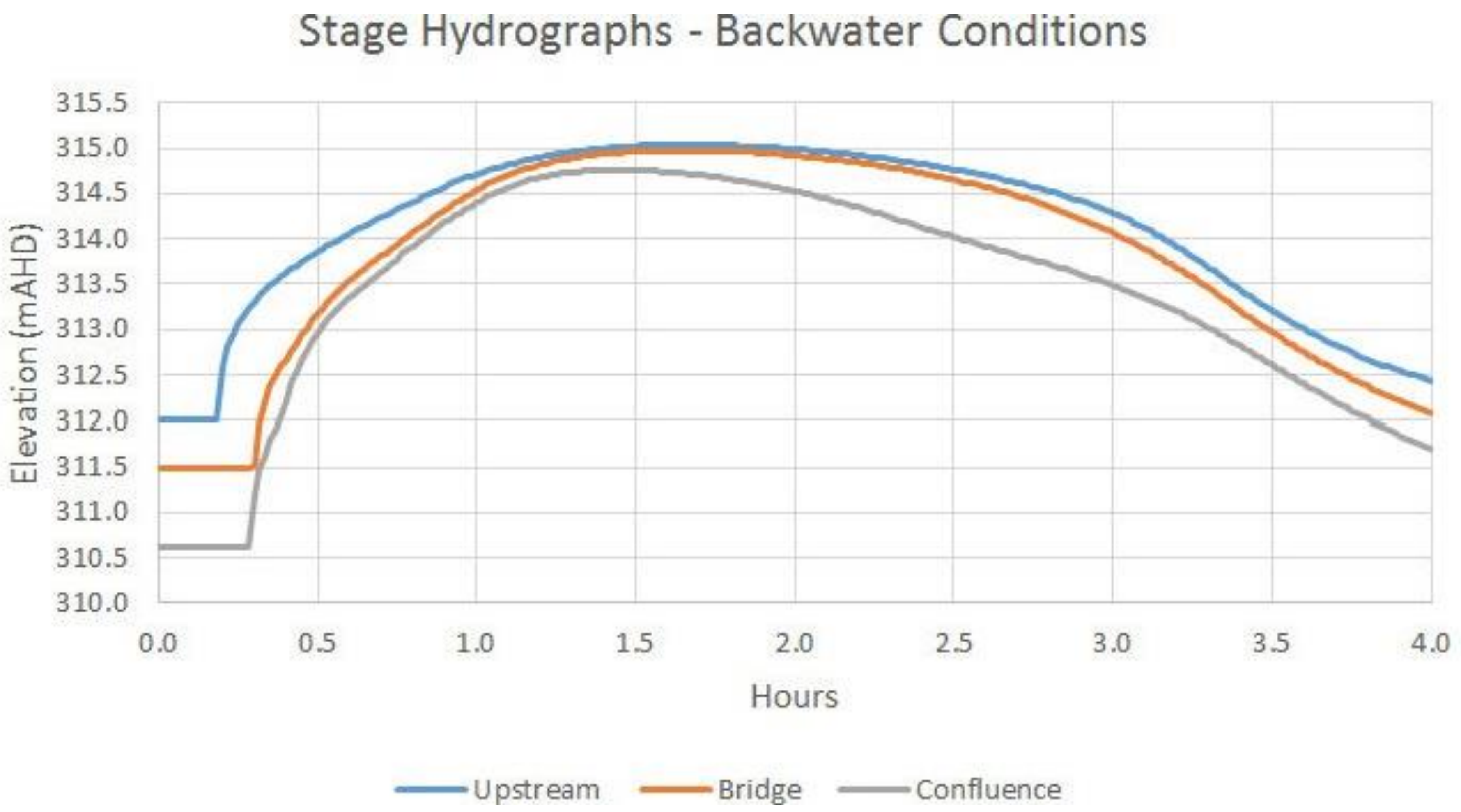
685
680
675
670
665
660
655
Stage (ft)
1200
01Jan99
2400
1200
02Jan99
2400
1200
03Jan99
2400
04Jan99
1200
Time
200000
150000
100000
50000
0
50000
100000
150000
2000
Flow(cfs)

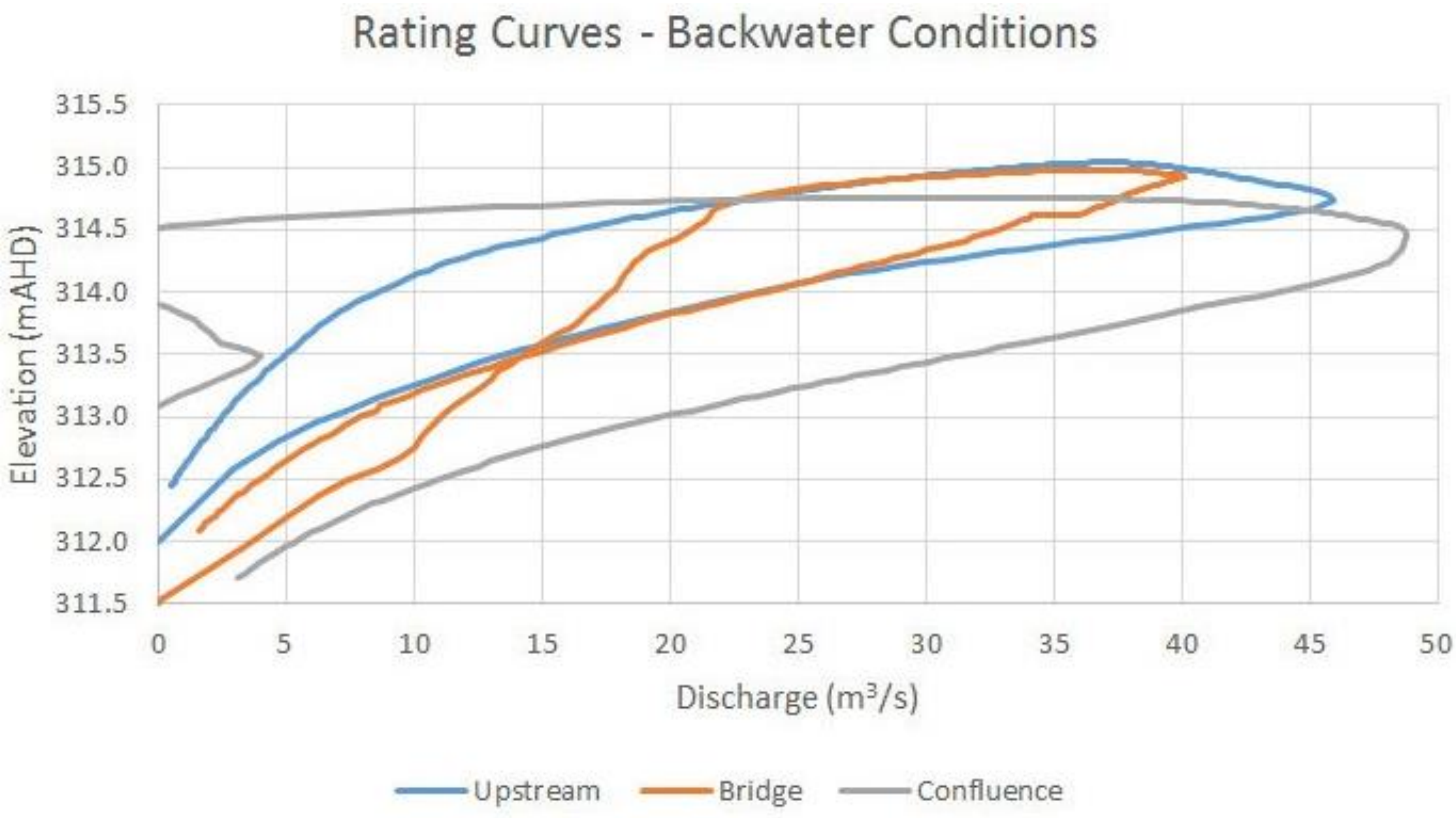

Plan: UnsteadyFlow River: Bald Eagle Reach: Loc Hav RS: 50720.68
Legend
RC
Stage (ft)
576
574
572
570
568
566
564
562
0
10000
20000
30000
40000
Flow (cfs)

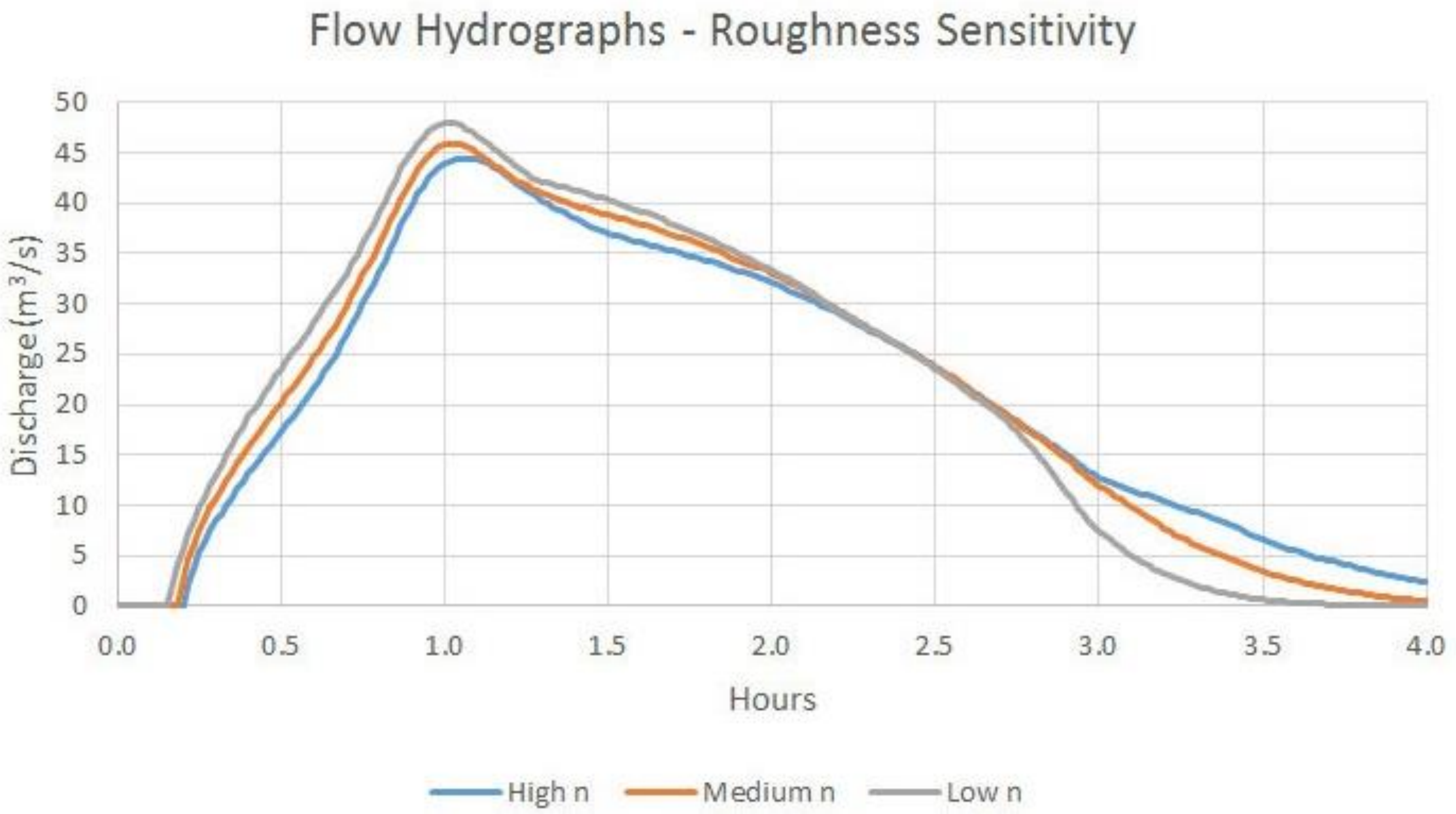


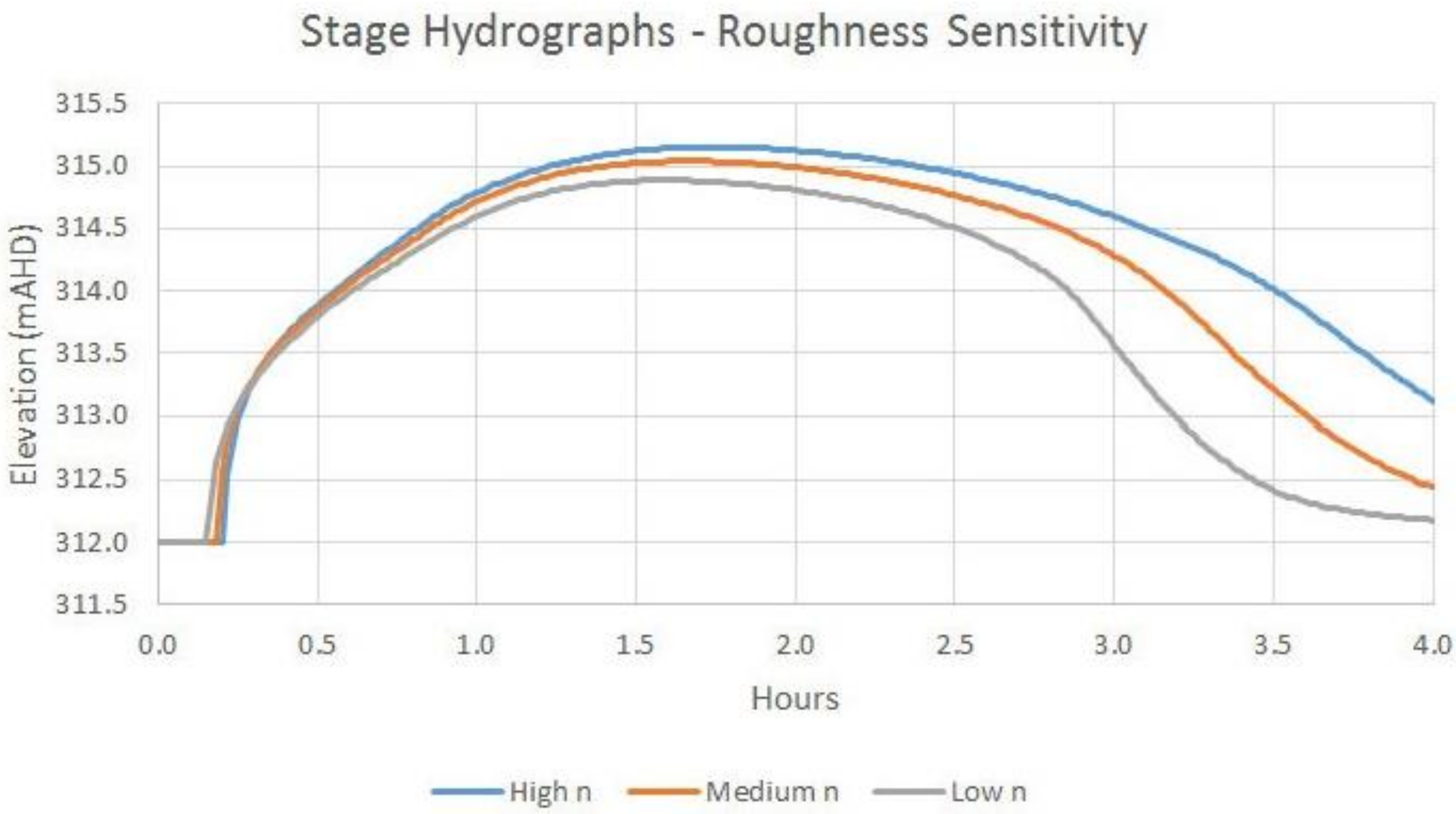
Flow + Stage Hydrographs
Discharge
Stage
Discharge (m³/s)
Hours
0
10
20
30
40
50
60
1
2
3
4
5
6
7
8
Rating Curve
311.5
312.0
312.5
313.0
313.5
314.0
314.5
315.0
0
10
20
30
40
50
60
Discharge (m³/s)

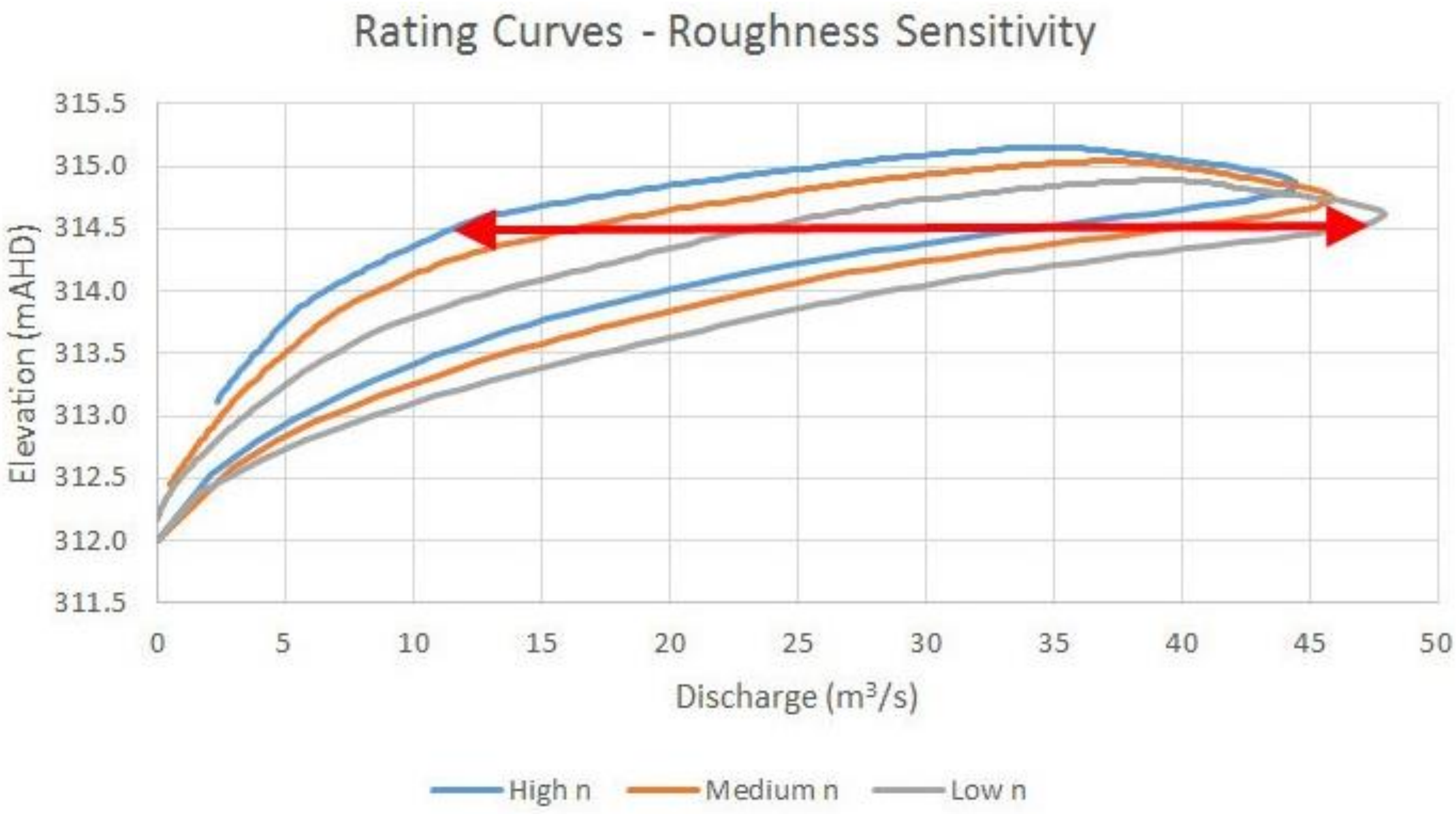

Flow Hydrographs - Backwater Conditions
Discharge (m3/s)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Hours
Upstream
Bridge
Confluence


Stage Hydrographs - Backwater Conditions
Elevation (mAHD)
315.5
315.0
314.5
314.0
313.5
313.0
312.5
312.0
311.5
311.0
310.5
310.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Hours
Upstream
Bridge
Confluence


Rating Curves - Backwater Conditions
315.5
315.0
314.5
314.0
313.5
313.0
312.5
312.0
311.5
Elevation (mAHD)
0
5
10
15
20
25
30
35
40
45
50
Discharge (m³/s)
Upstream
Bridge
Confluence


Flow Hydrographs - Roughness Sensitivity
Discharge (m3/s)
50
45
40
35
30
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Hours
High n
Medium n
Low n


Stage Hydrographs - Roughness Sensitivity
Elevation (mAHD)
315.5
315.0
314.5
314.0
313.5
313.0
312.5
312.0
311.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Hours
High n
Medium n
Low n


Rating Curves - Roughness Sensitivity
315.5
315.0
314.5
314.0
313.5
313.0
312.5
312.0
311.5
Elevation (mAHD)
0
5
10
15
20
25
30
35
40
45
50
Discharge (m³/s)
High n
Medium n
Low n

$$Q = \frac{1.49}{n} * A * R^{\frac{2}{3}} * S^{\frac{1}{2}}$$

Where:

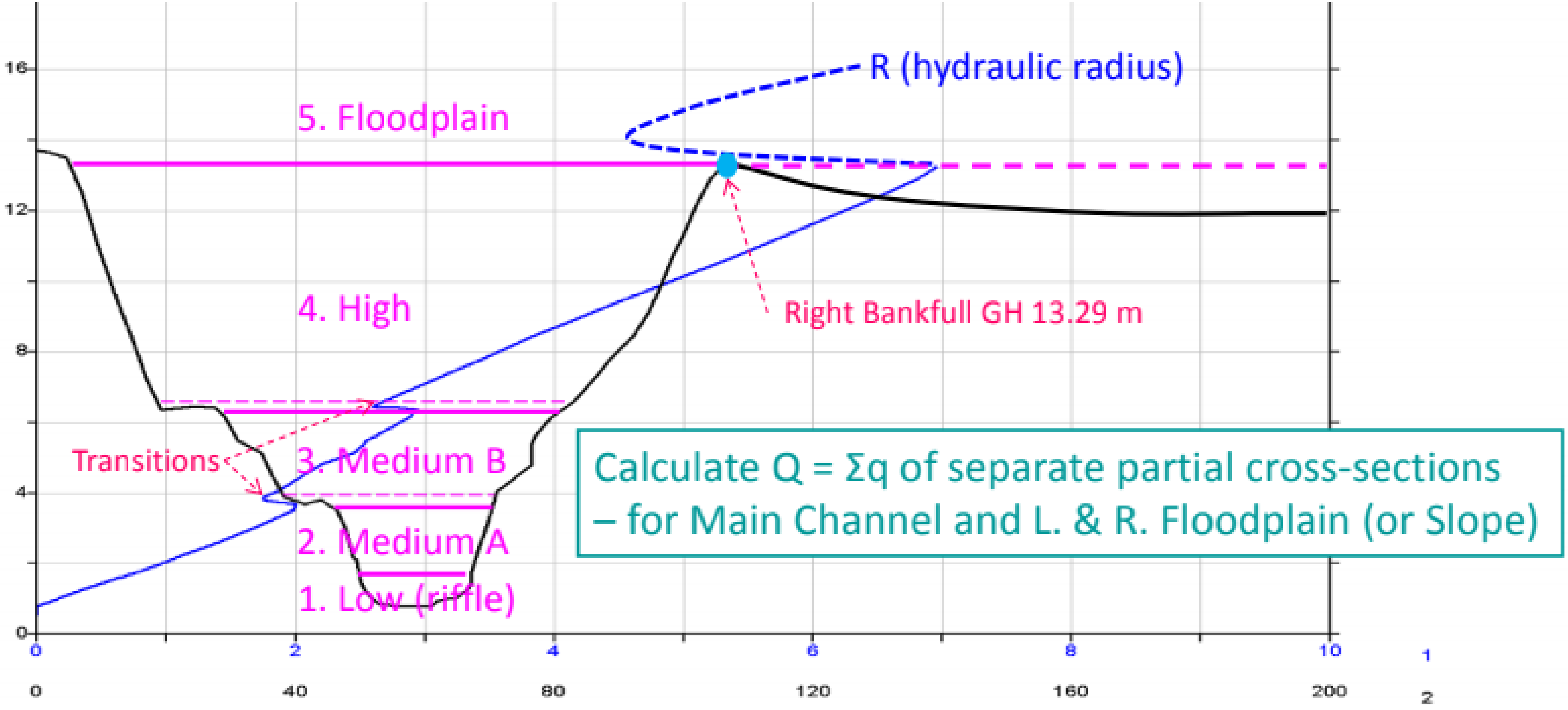
Q = Flow Rate, (cfs)

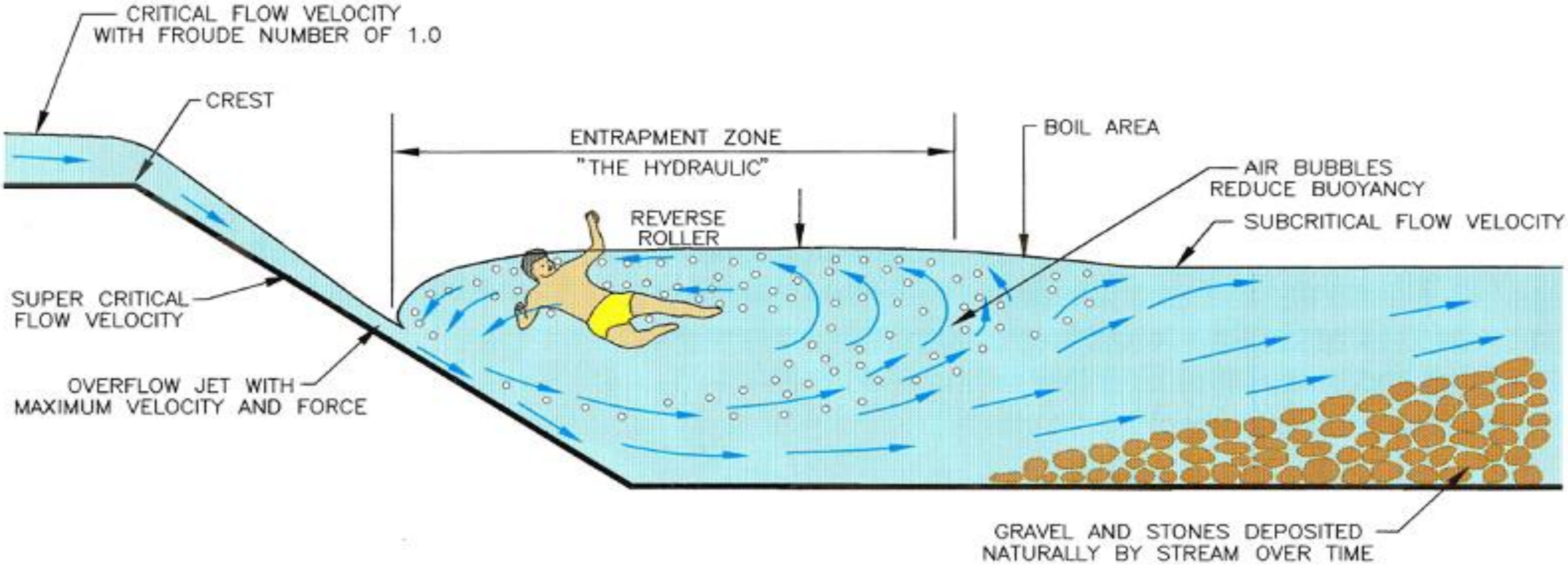
n = Manning's Roughness Coefficient (unitless)

A = Flow Area, (sf)

R = Hydraulic Radius, (ft)

S = Slope of Energy Gradient, (ft/ft)

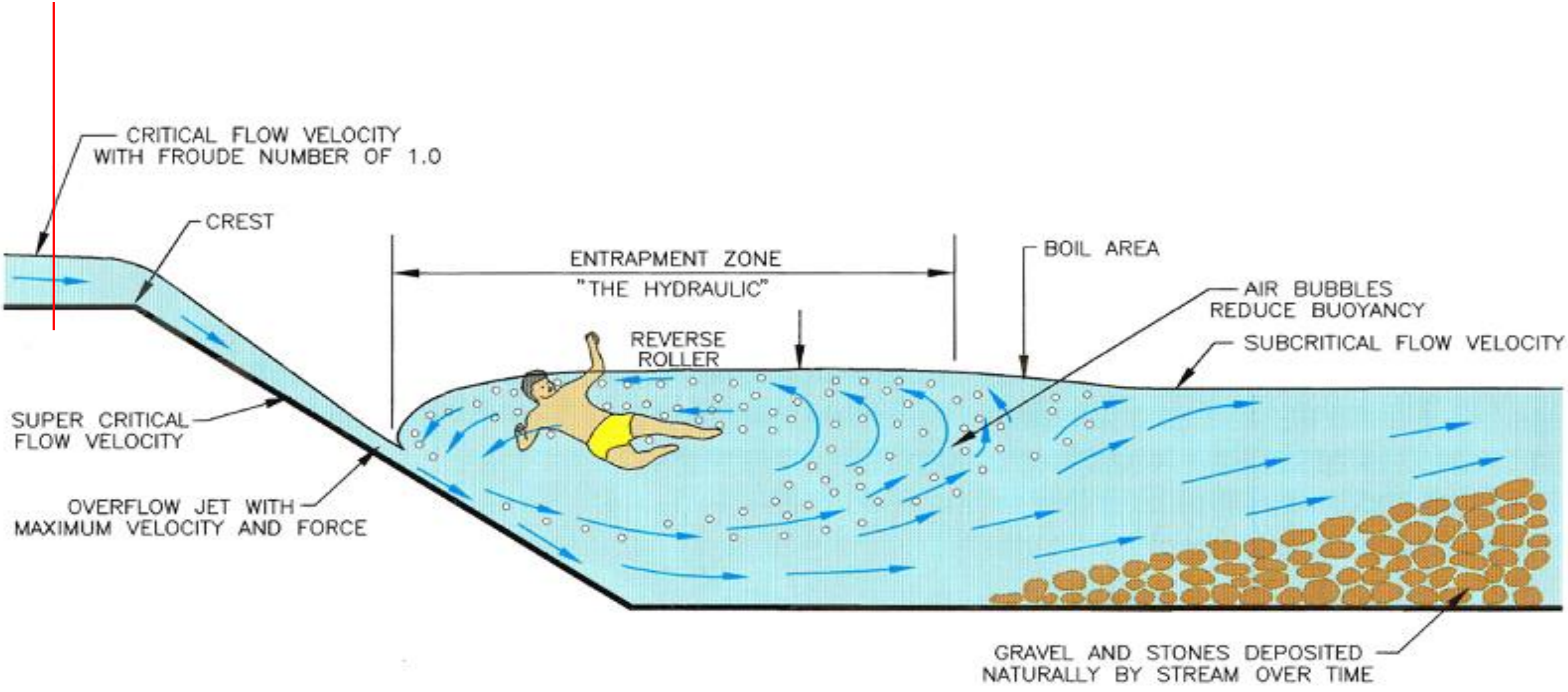




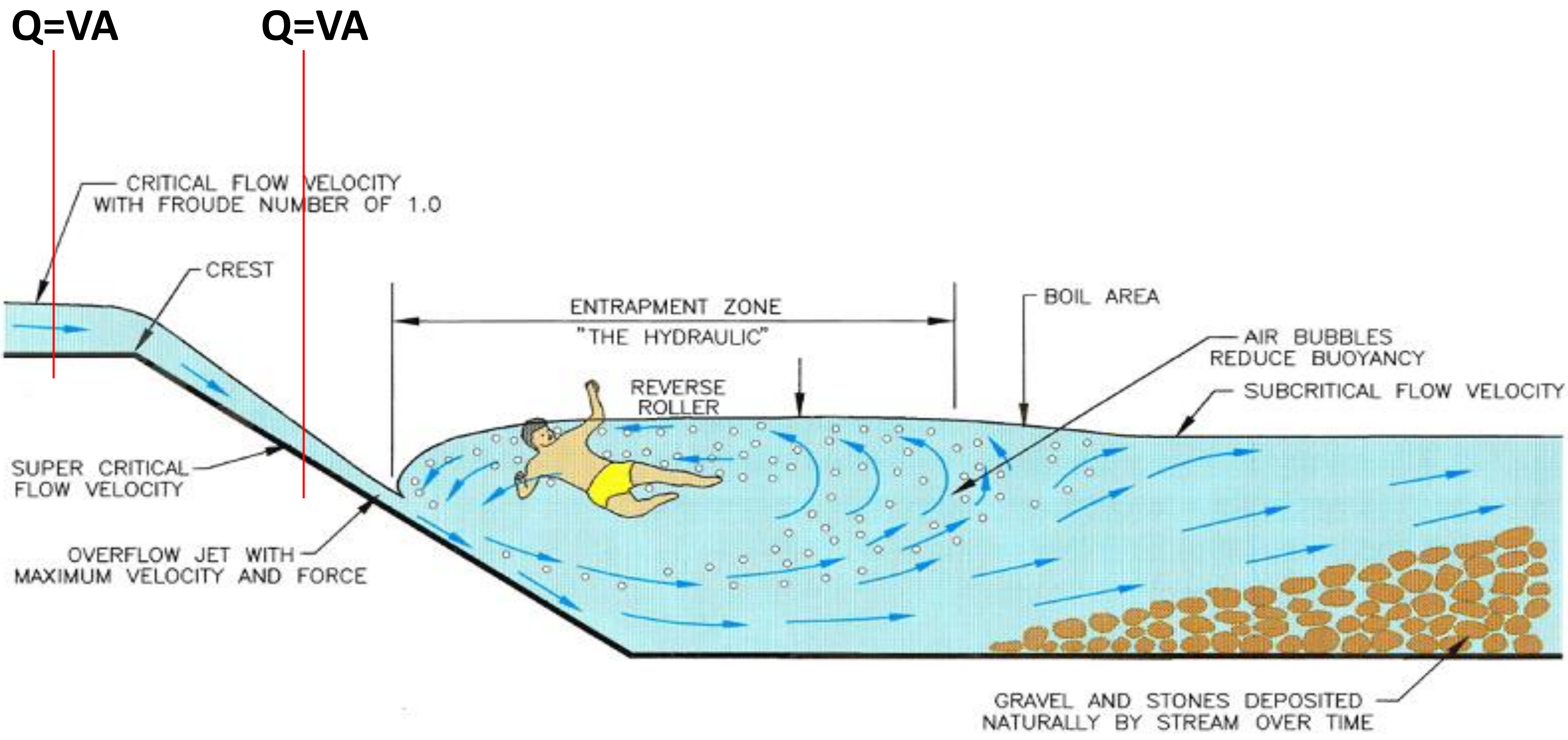
Courtesy of Wright Water Engineers, Inc. and ASDSO.

Source: Wright, Kenneth R., Kelly, Jonathan M., Houghtalen, Robert J., & Bonner, Mark R. "Emergency Rescues at Low-Head Dams." Paper presented at Dam Safety 1995, the 12th annual conference of the Association of State Dam Safety Officials, Atlanta, GA, September 1995.

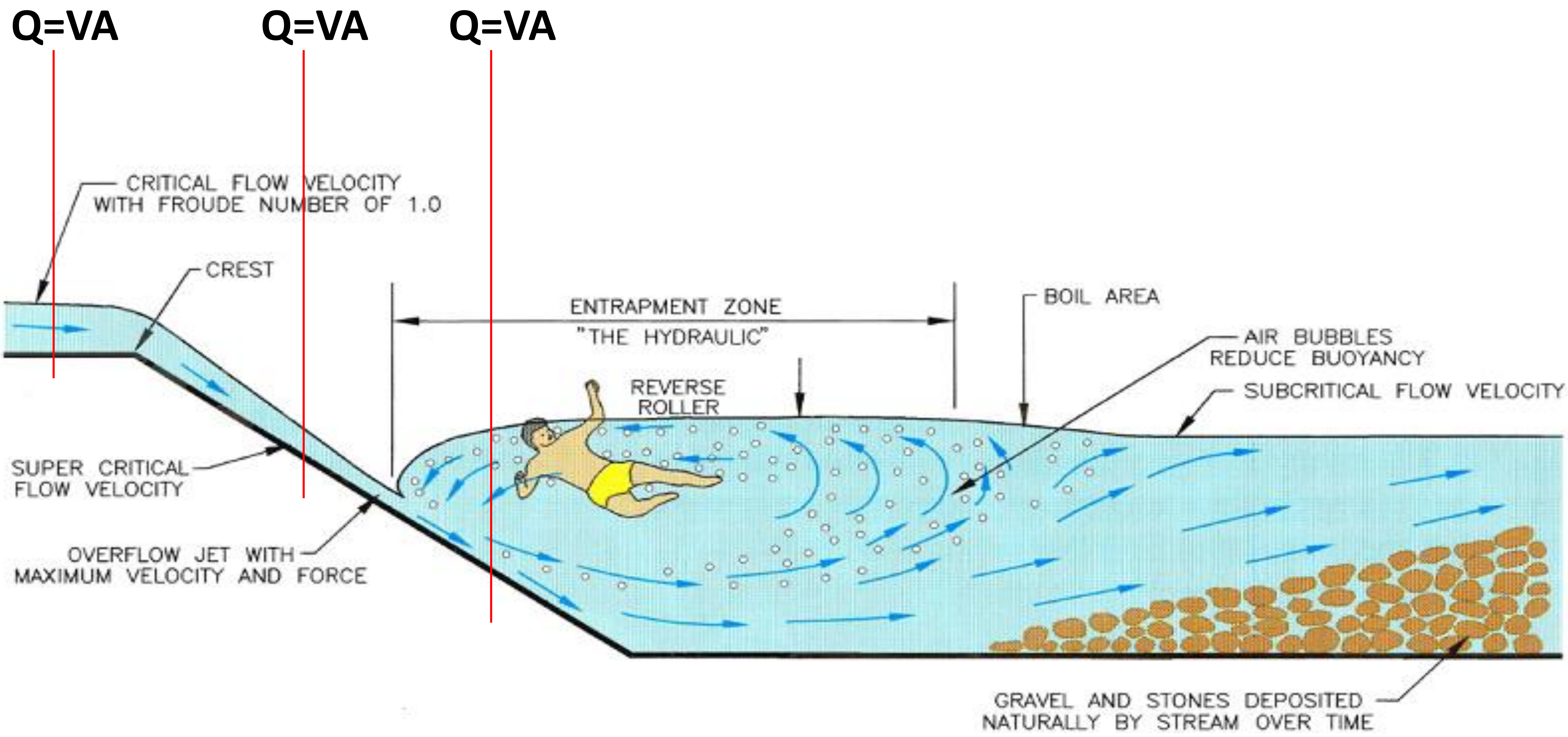
Q=VA



Courtesy of Wright Water Engineers, Inc. and ASDSO.
Source: Wright, Kenneth R., Kelly, Jonathan M., Houghtalen, Robert J., & Bonner, Mark R. "Emergency Rescues at Low-Head Dams." Paper presented at Dam Safety 1995, the 12th annual conference of the Association of State Dam Safety Officials, Atlanta, GA, September 1995.

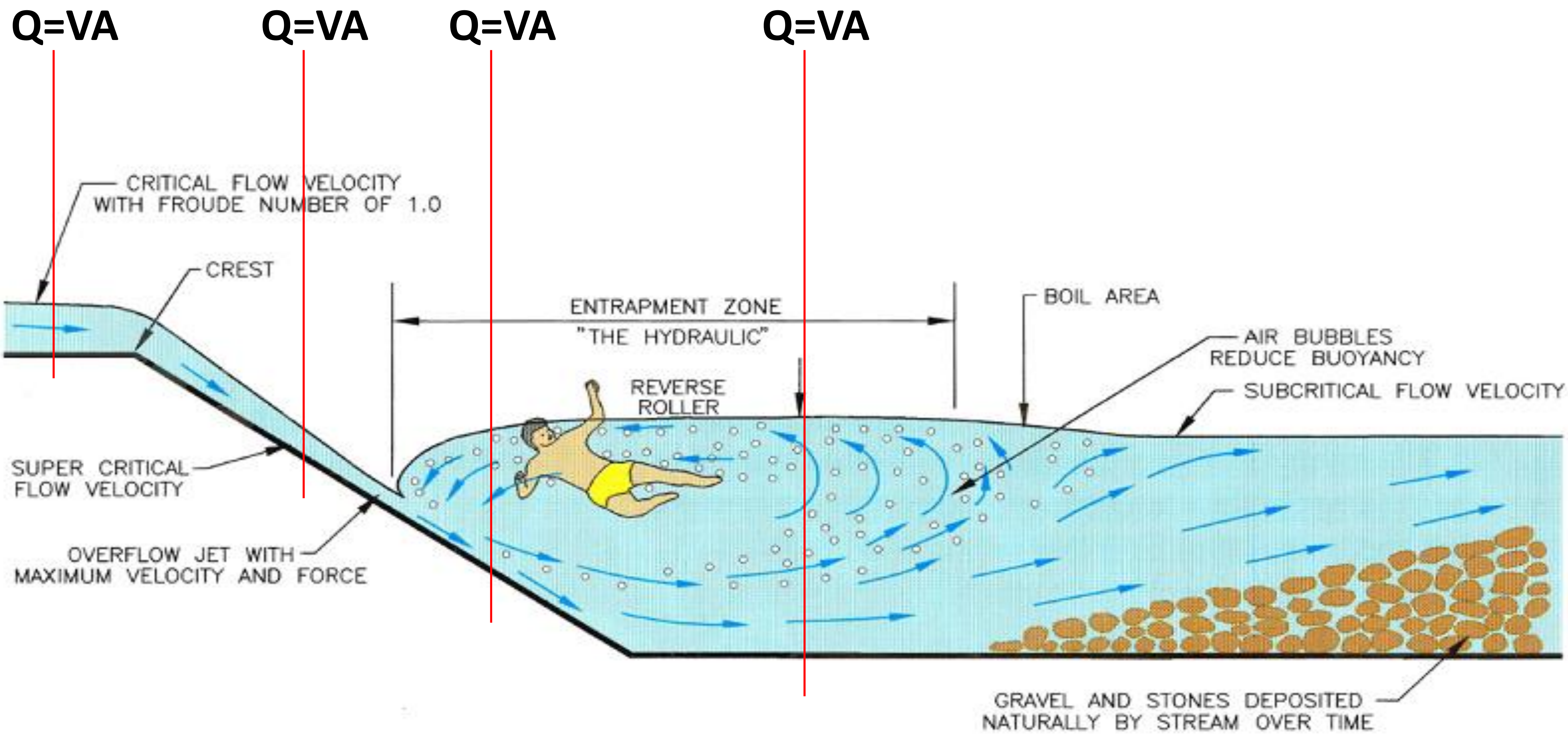


Courtesy of Wright Water Engineers, Inc. and ASDSO.
Source: Wright, Kenneth R., Kelly, Jonathan M., Houghtalen, Robert J., & Bonner, Mark R. "Emergency Rescues at Low-Head Dams." Paper presented at Dam Safety 1995, the 12th annual conference of the Association of State Dam Safety Officials, Atlanta, GA, September 1995.

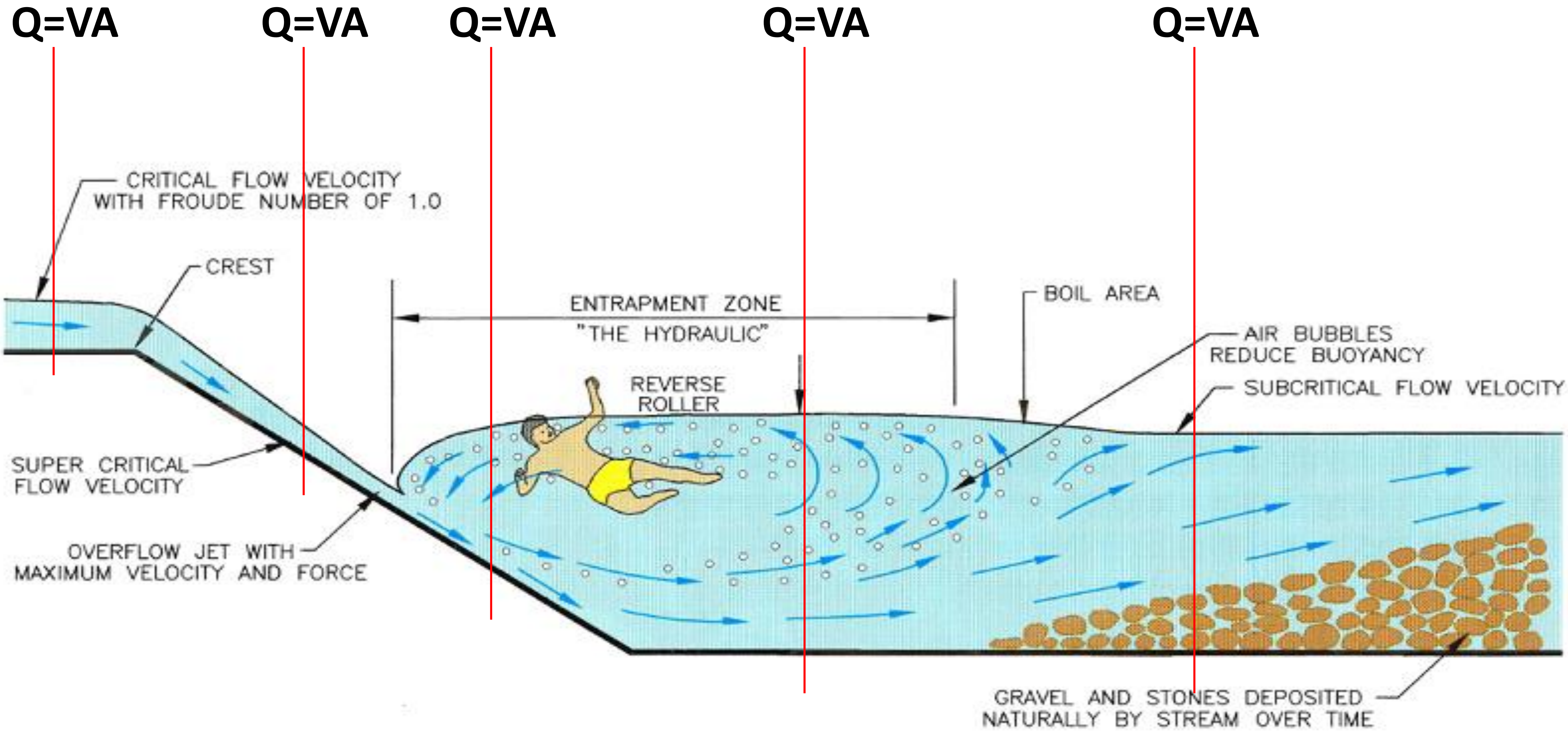


Courtesy of Wright Water Engineers, Inc. and ASDSO.

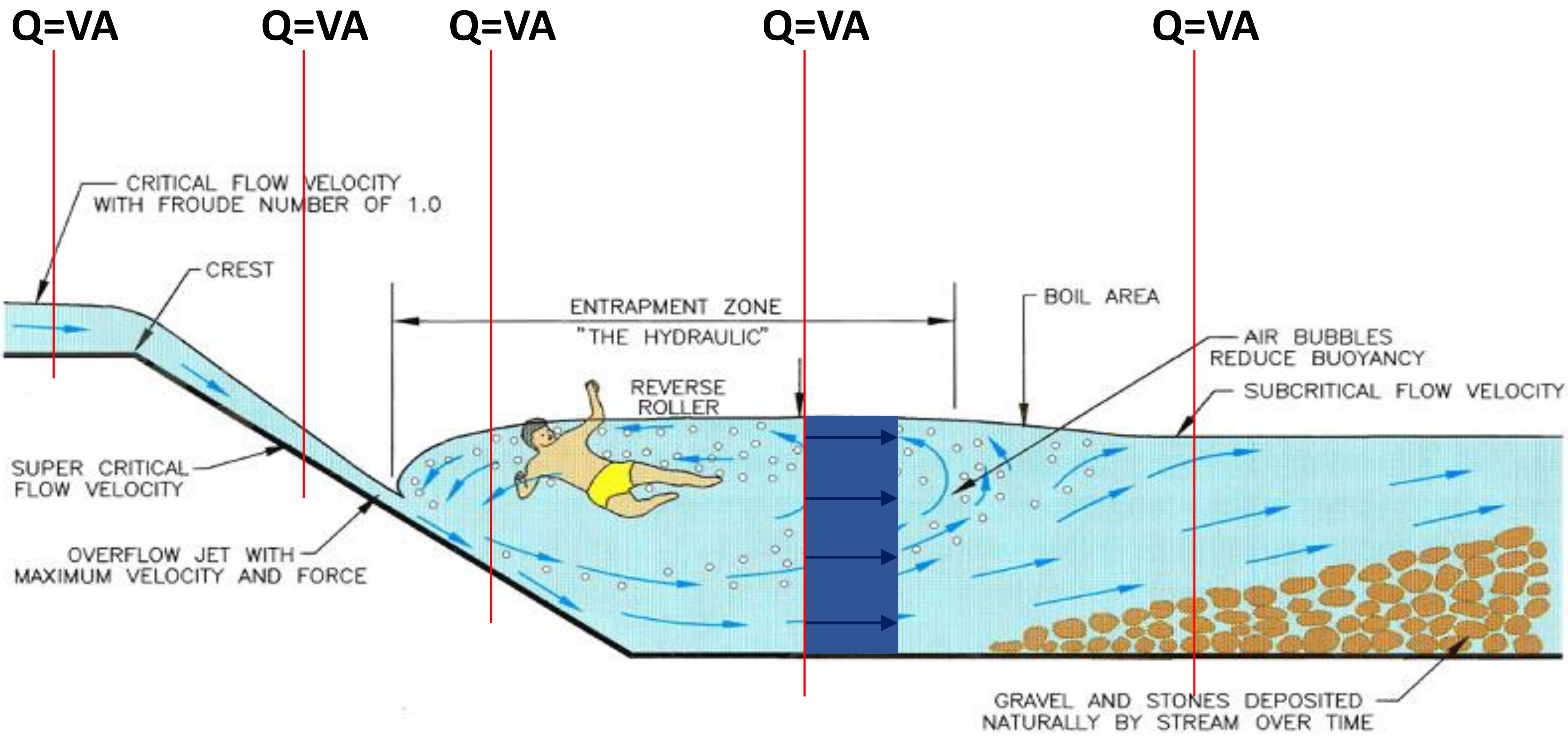
Source: Wright, Kenneth R., Kelly, Jonathan M., Houghtalen, Robert J., & Bonner, Mark R. "Emergency Rescues at Low-Head Dams." Paper presented at Dam Safety 1995, the 12th annual conference of the Association of State Dam Safety Officials, Atlanta, GA, September 1995.



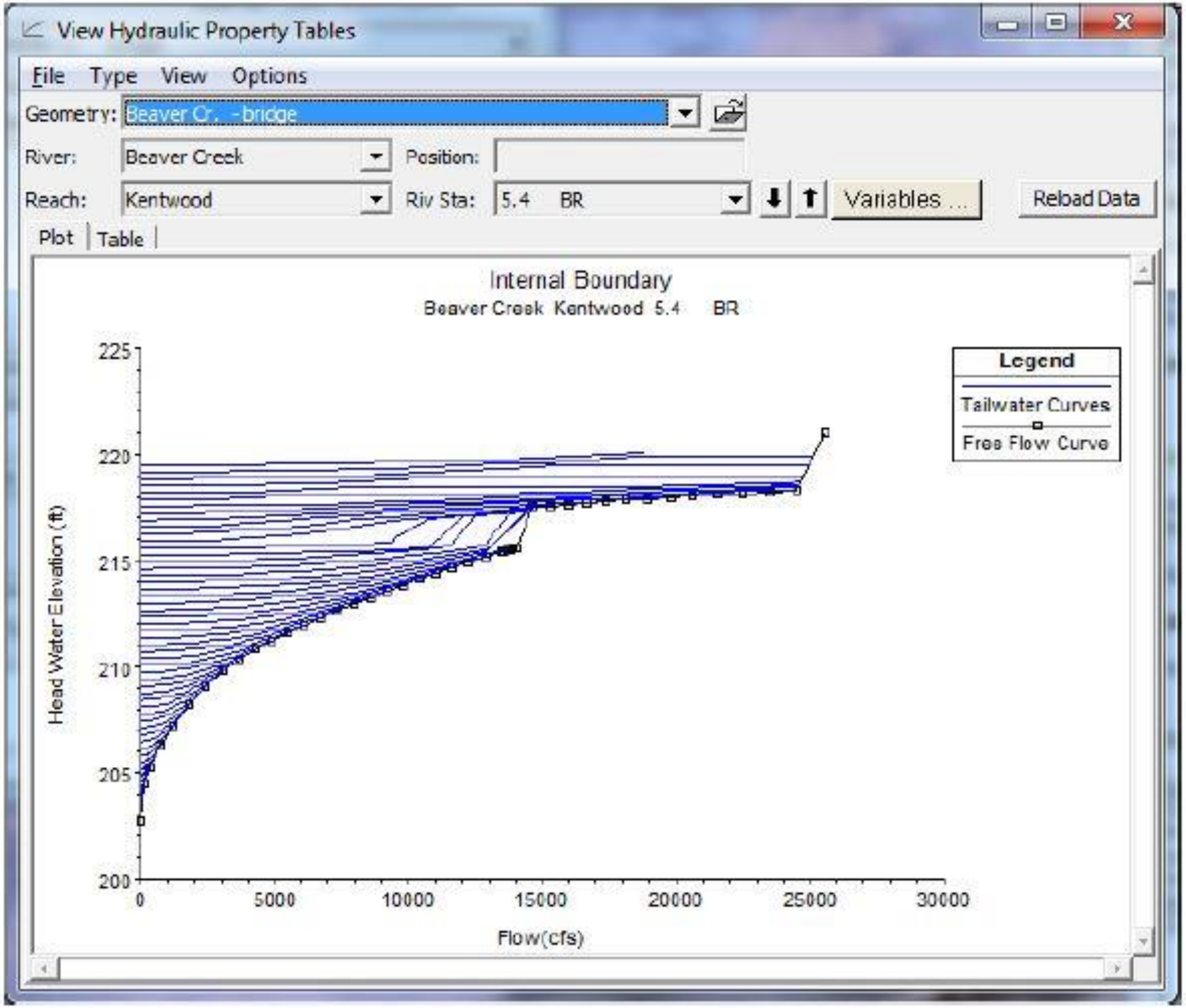
Courtesy of Wright Water Engineers, Inc. and ASDSO.
Source: Wright, Kenneth R., Kelly, Jonathan M., Houghtalen, Robert J., & Bonner, Mark R. "Emergency Rescues at Low-Head Dams." Paper presented at Dam Safety 1995, the 12th annual conference of the Association of State Dam Safety Officials, Atlanta, GA, September 1995.

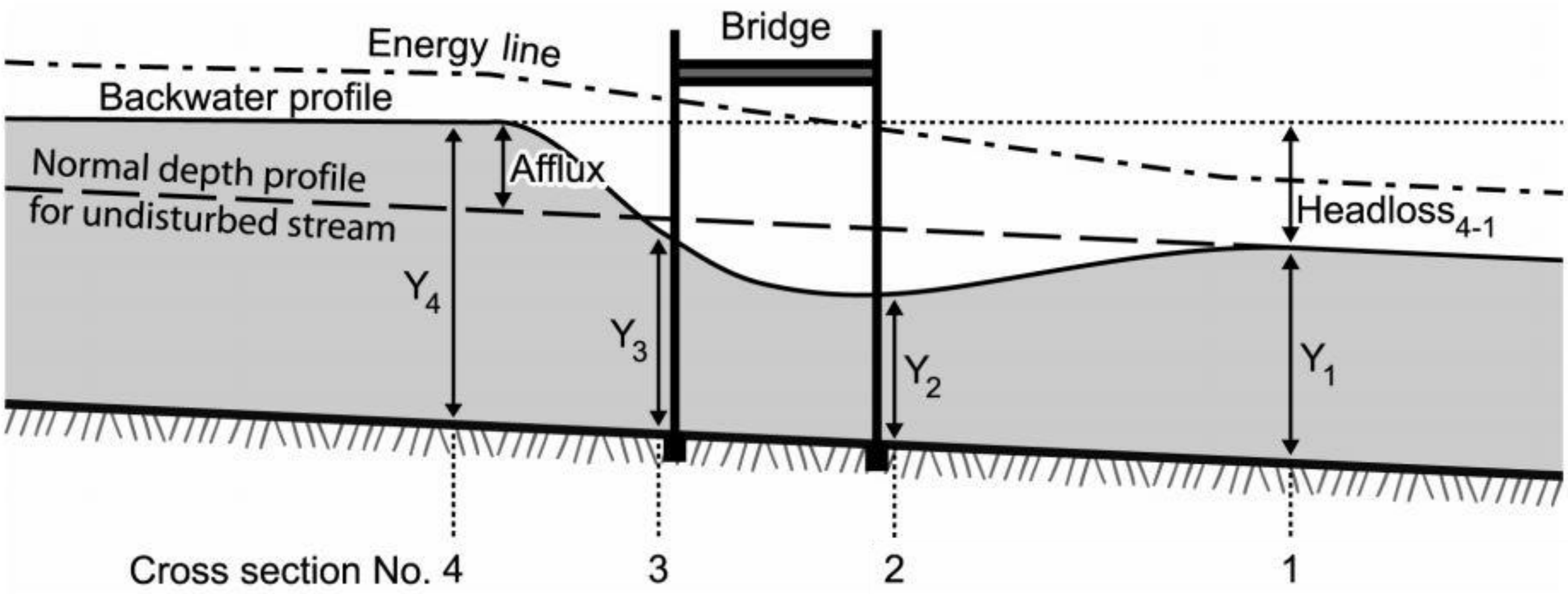


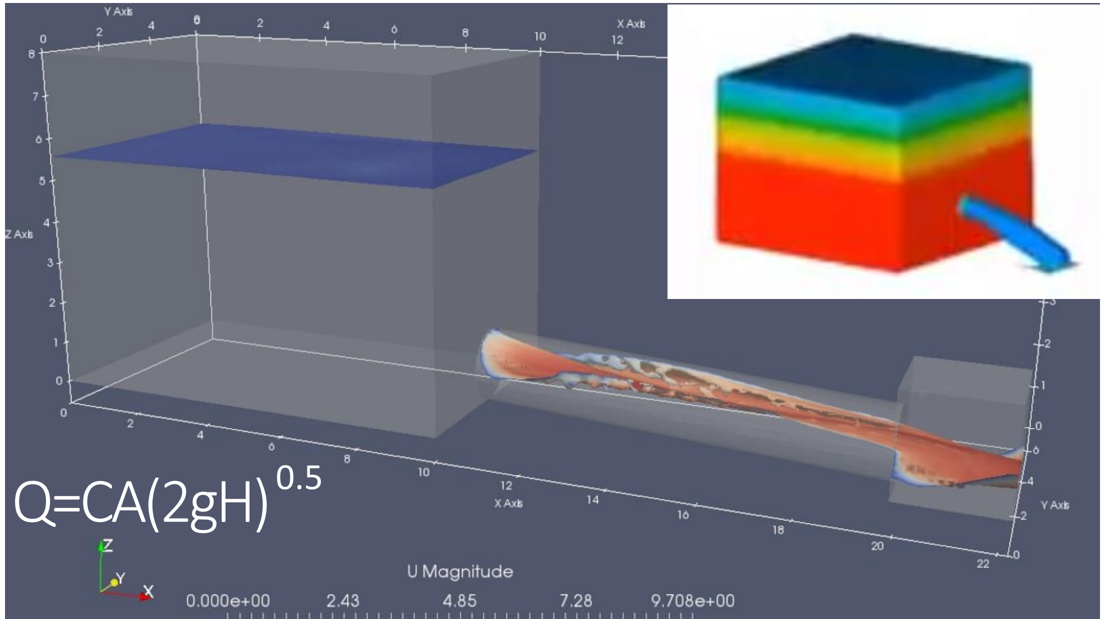
Courtesy of Wright Water Engineers, Inc. and ASDSO.
Source: Wright, Kenneth R., Kelly, Jonathan M., Houghtalen, Robert J., & Bonner, Mark R. "Emergency Rescues at Low-Head Dams." Paper presented at Dam Safety 1995, the 12th annual conference of the Association of State Dam Safety Officials, Atlanta, GA, September 1995.



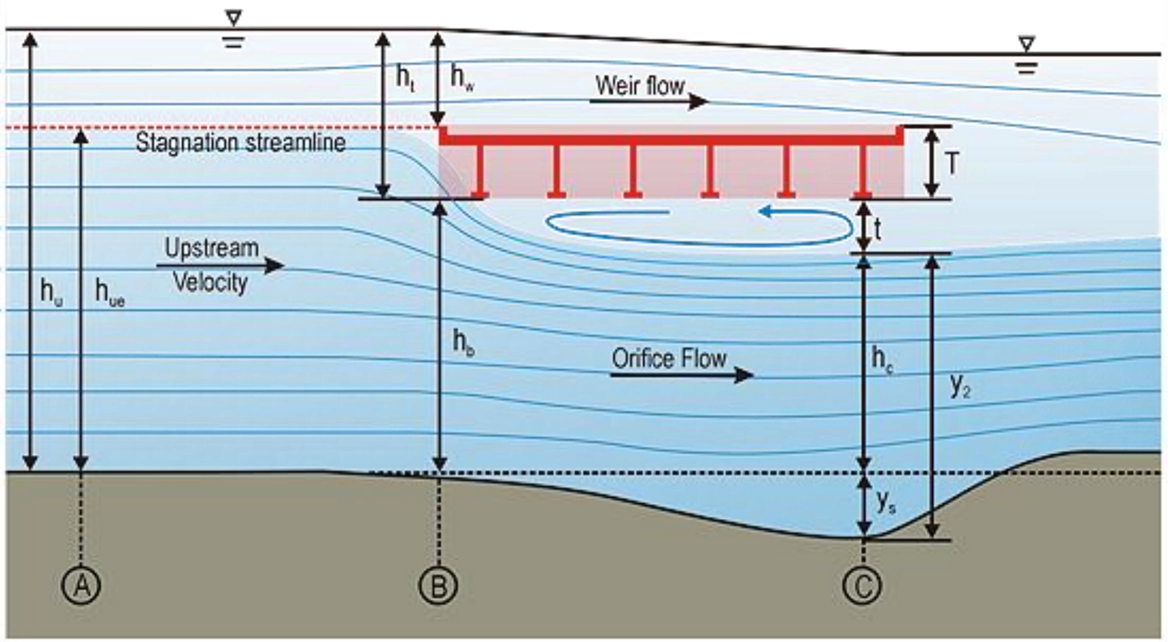
Courtesy of Wright Water Engineers, Inc. and ASDSO.
Source: Wright, Kenneth R., Kelly, Jonathan M., Houghtalen, Robert J., & Bonner, Mark R. "Emergency Rescues at Low-Head Dams." Paper presented at Dam Safety 1995, the 12th annual conference of the Association of State Dam Safety Officials, Atlanta, GA, September 1995.

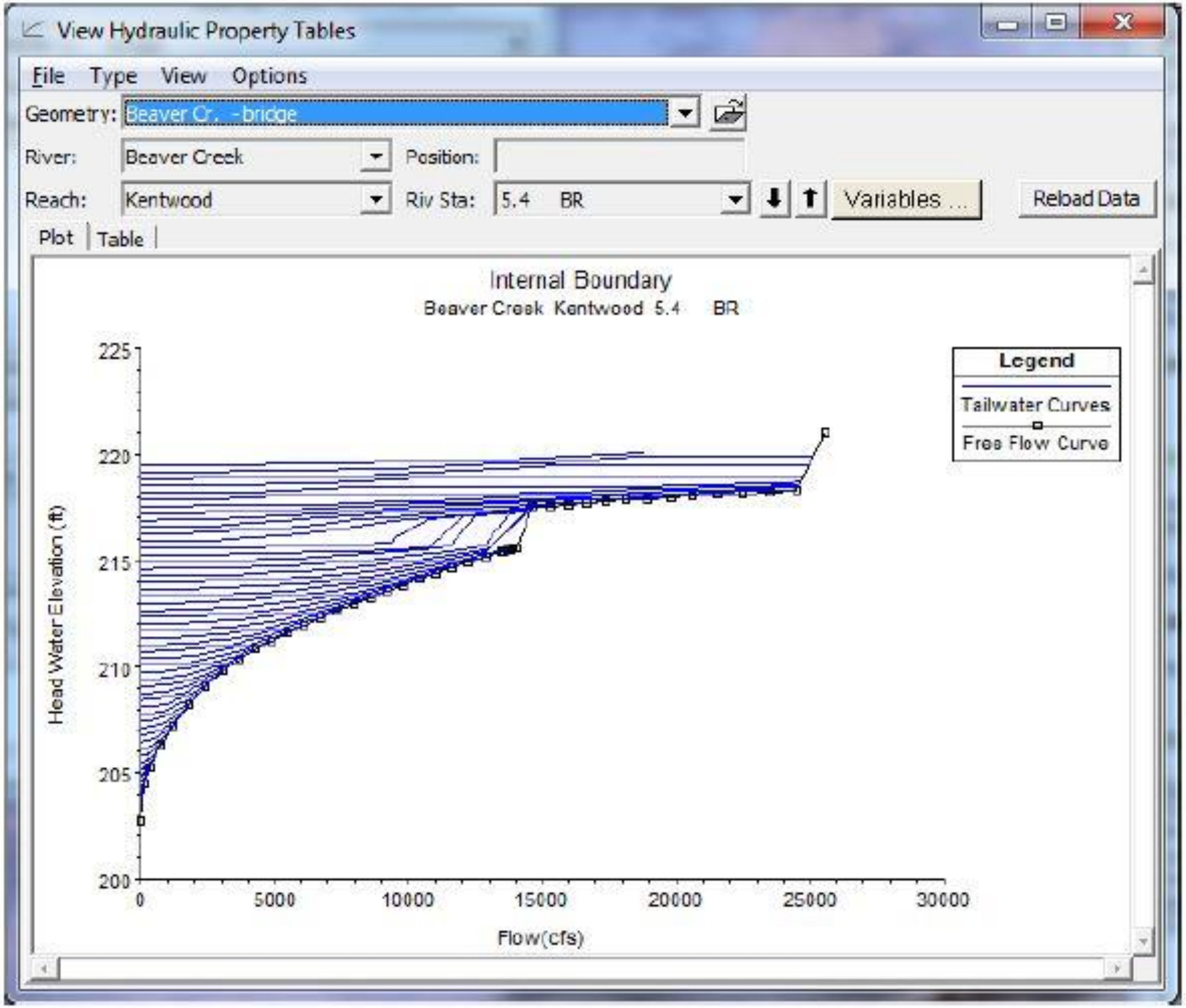

View Hydraulic Property Tables
File Type View Options
Geometry: Beaver Cr. - bridge
River: Beaver Creek
Position:
Reach: Kentwood
Riv Sta: 5.4 BR
Variables ...
Reload Data
Plot
Table
Internal Boundary
Beaver Creek Kentwood 5.4 BR
Legend
Tailwater Curves
Free Flow Curve
Head Water Elevation (ft)
225
220
215
210
205
200
0
5000
10000
15000
20000
25000
30000
Flow(cfs)


Bridge
Energy line
Backwater profile
Afflux
Normal depth profile
for undisturbed stream
Headloss$_{4-1}$
Y_4
Y_3
Y_2
Y_1
Cross section No. 4
3
2
1

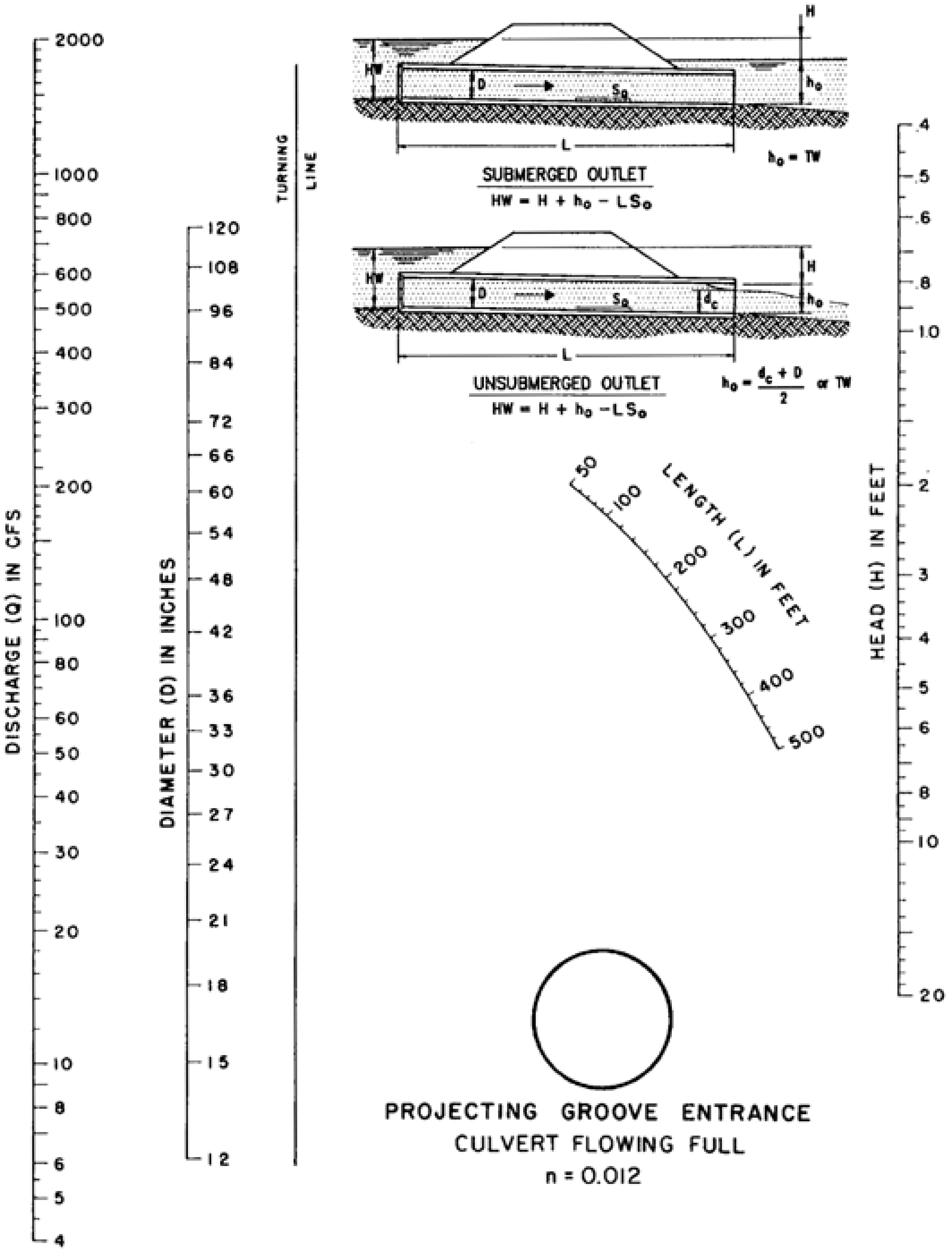

Y Axis
X Axis
Z Axis
U Magnitude
0.000e+00
2.43
4.85
7.28
9.708e+00

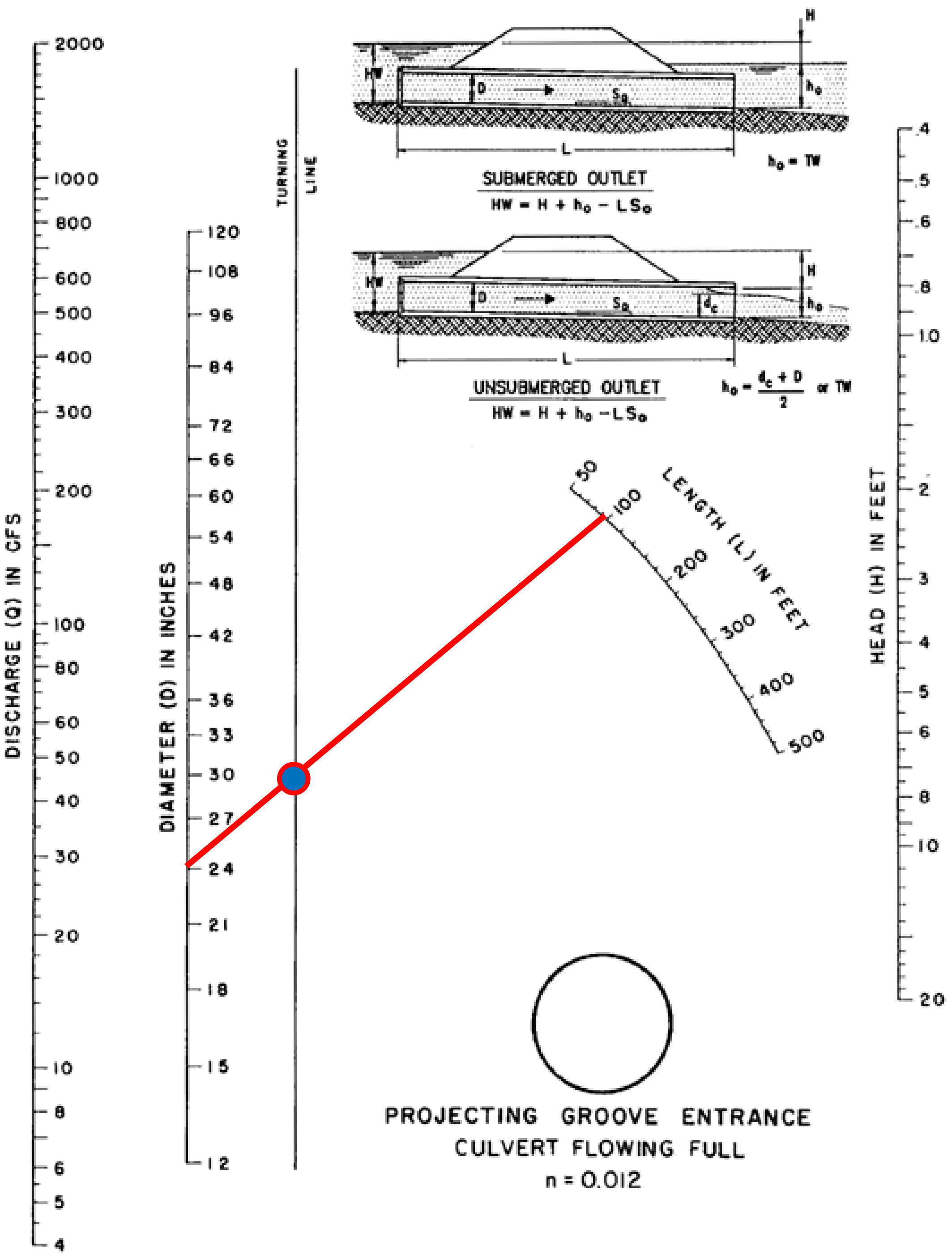
$$Q=CA(2gH)^{0.5}$$


h_t
h_w
Weir flow
Stagnation streamline
T
t
Upstream
Velocity
h_u
h_{ue}
h_b
Orifice Flow
h_c
y_2
y_s
A
B
C

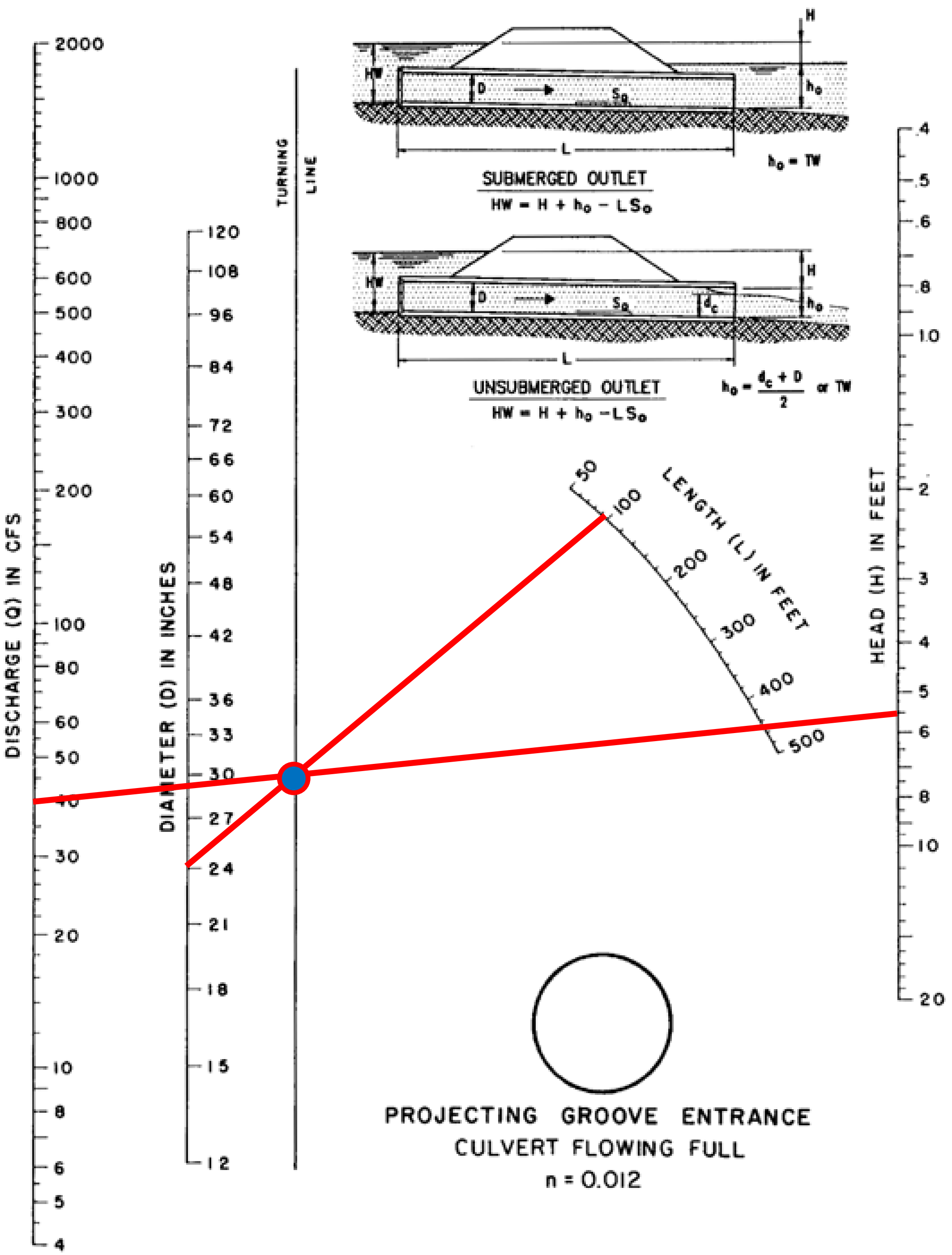


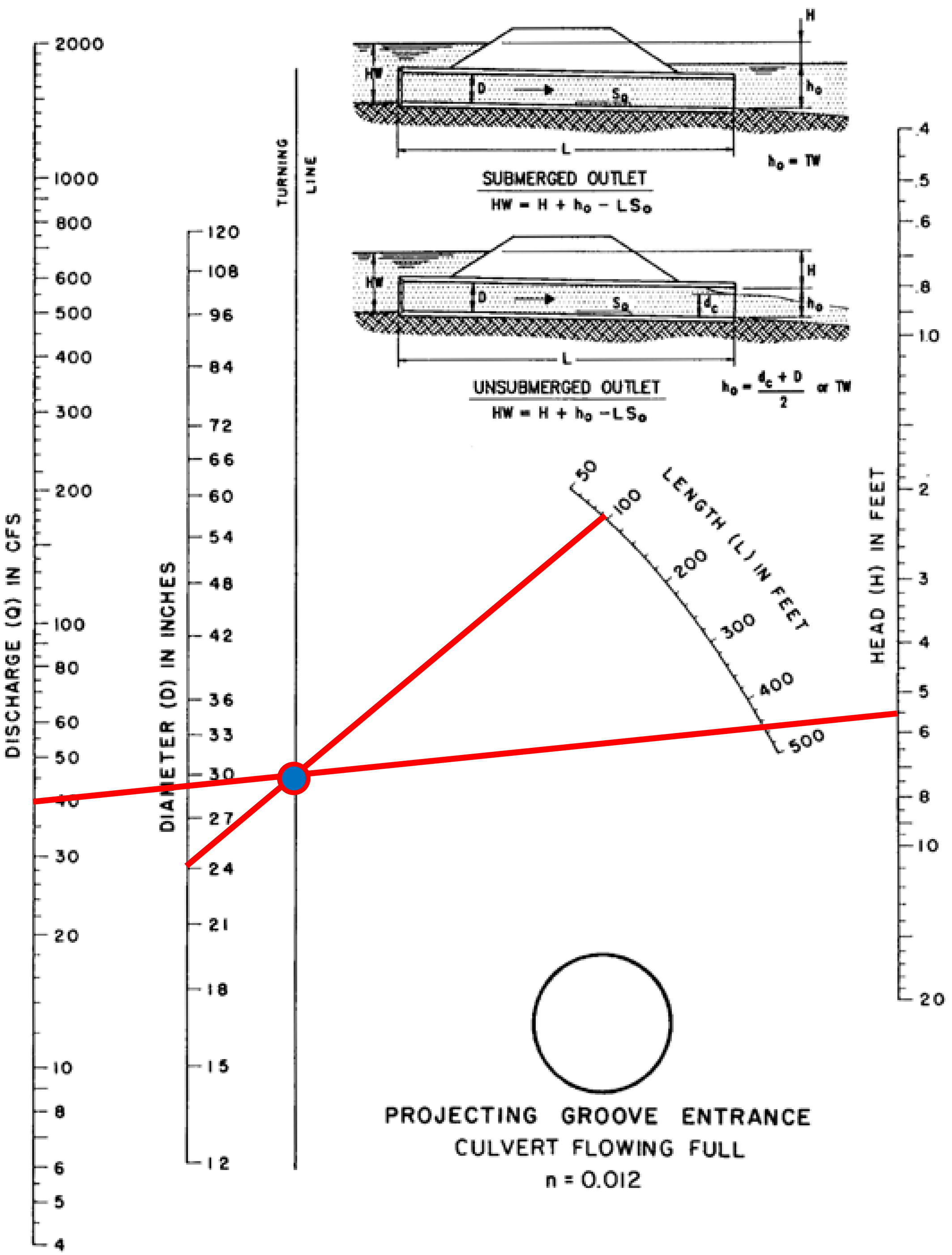
View Hydraulic Property Tables
File
Type
View
Options
Geometry:
Beaver Cr. - bridge
River:
Beaver Creek
Position:
Reach:
Kentwood
Riv Sta:
5.4 BR
Variables ...
Reload Data
Plot
Table
Internal Boundary
Beaver Creek Kentwood 5.4 BR
Legend
Tailwater Curves
Free Flow Curve
Head Water Elevation (ft)
Flow(cfs)
225
220
215
210
205
200
0
5000
10000
15000
20000
25000
30000


SUBMERGED OUTLET
HW = H + h₀ − LS₀
h₀ = TW
UNSUBMERGED OUTLET
HW = H + h₀ − LS₀
h₀ = (d_c + D)/2 or TW
DISCHARGE (Q) IN CFS
DIAMETER (D) IN INCHES
TURNING LINE
LENGTH (L) IN FEET
HEAD (H) IN FEET
PROJECTING GROOVE ENTRANCE
CULVERT FLOWING FULL
n = 0.012

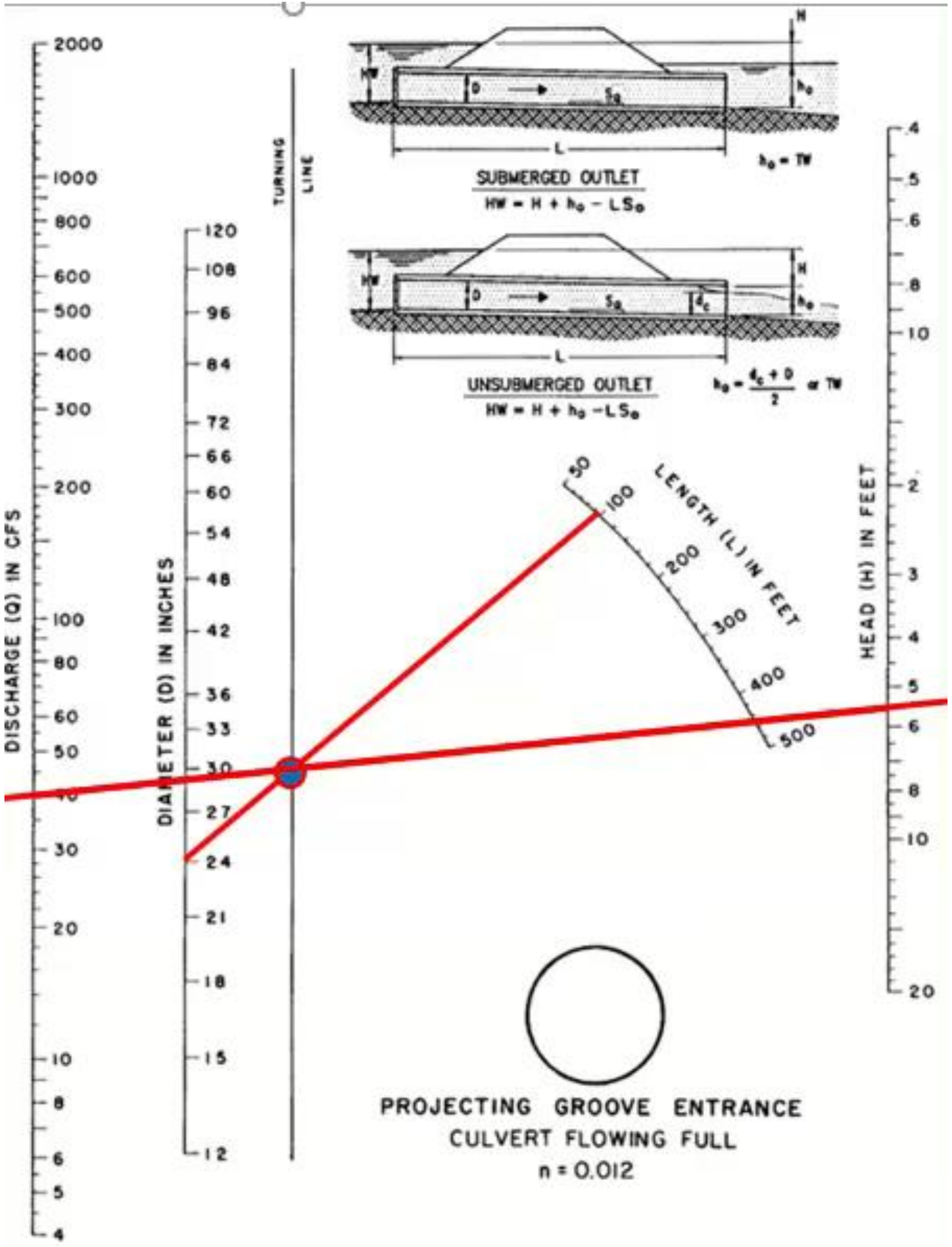


SUBMERGED OUTLET
HW = H + h₀ − LS₀
h₀ = TW
UNSUBMERGED OUTLET
HW = H + h₀ − LS₀
h₀ = (d_c + D)/2 or TW
TURNING LINE
DISCHARGE (Q) IN CFS
DIAMETER (D) IN INCHES
LENGTH (L) IN FEET
HEAD (H) IN FEET
PROJECTING GROOVE ENTRANCE
CULVERT FLOWING FULL
n = 0.012

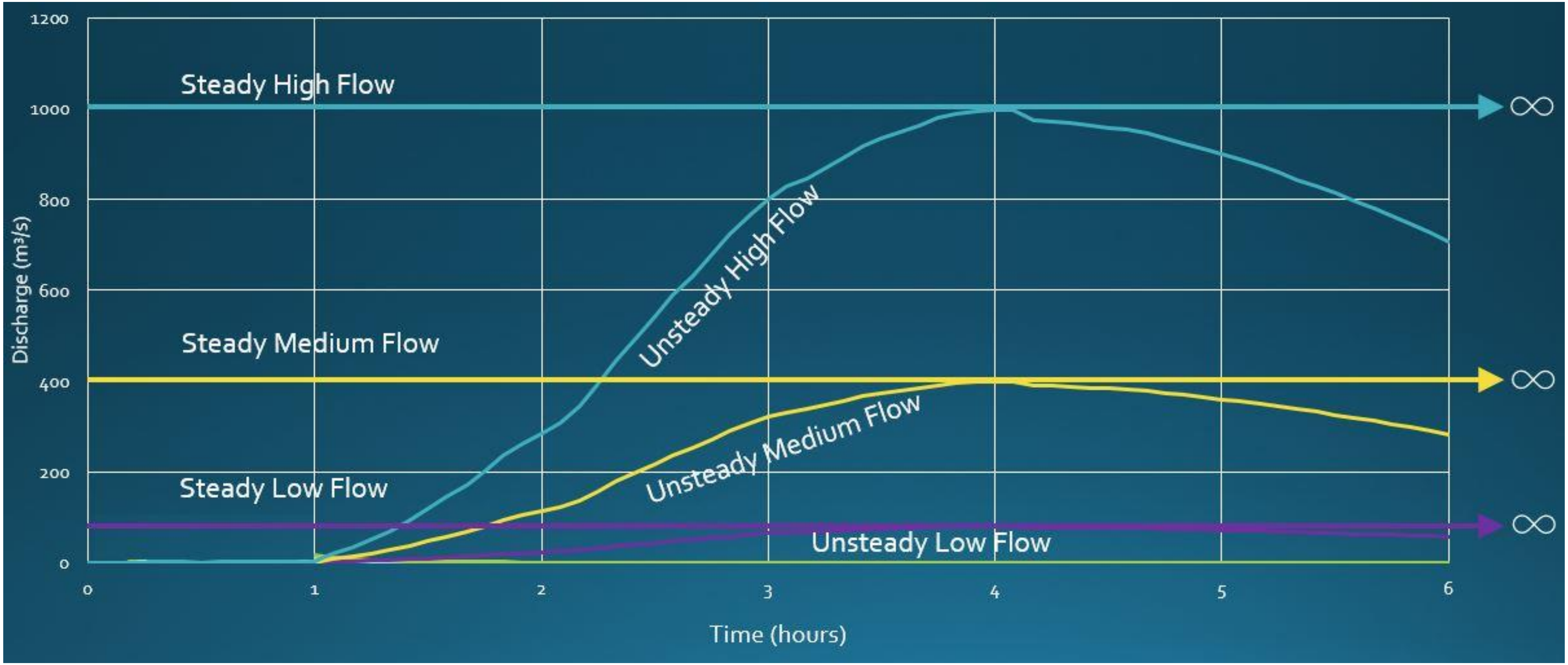

SUBMERGED OUTLET
HW = H + h_o − LS_o
h_o = TW
UNSUBMERGED OUTLET
HW = H + h_o − LS_o
h_o = (d_c + D)/2 or TW
TURNING LINE
DISCHARGE (Q) IN CFS
DIAMETER (D) IN INCHES
LENGTH (L) IN FEET
HEAD (H) IN FEET
PROJECTING GROOVE ENTRANCE
CULVERT FLOWING FULL
n = 0.012



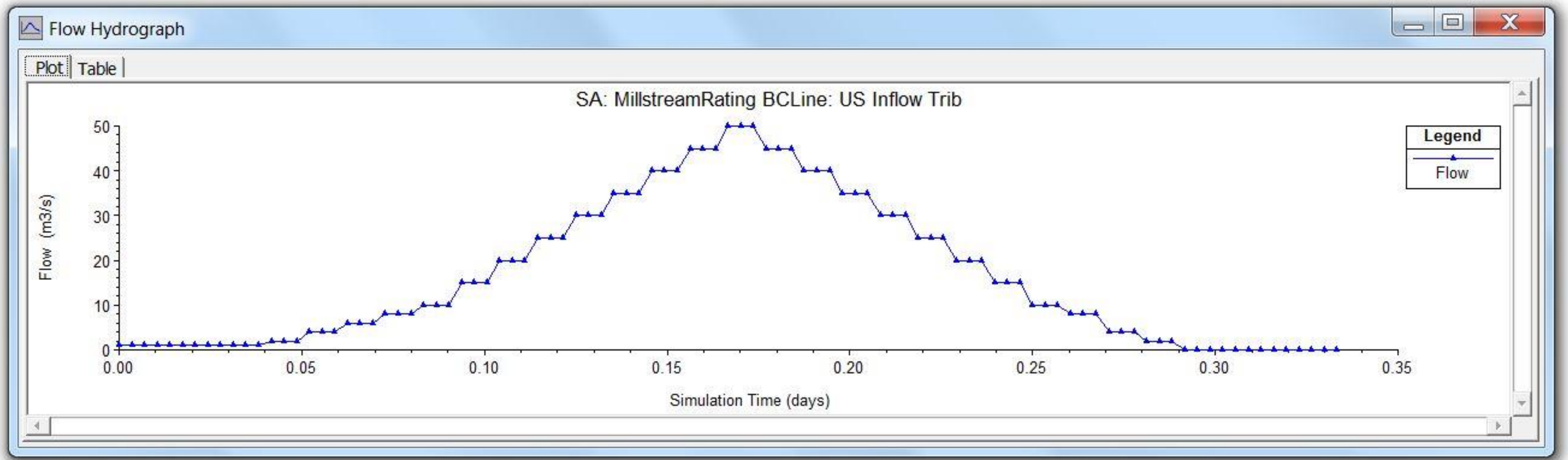
SUBMERGED OUTLET
HW = H + h_o − LS_o
h_o = TW
UNSUBMERGED OUTLET
HW = H + h_o − LS_o
h_o = (d_c + D)/2 or TW
DISCHARGE (Q) IN CFS
DIAMETER (D) IN INCHES
TURNING LINE
LENGTH (L) IN FEET
HEAD (H) IN FEET
PROJECTING GROOVE ENTRANCE
CULVERT FLOWING FULL
n = 0.012

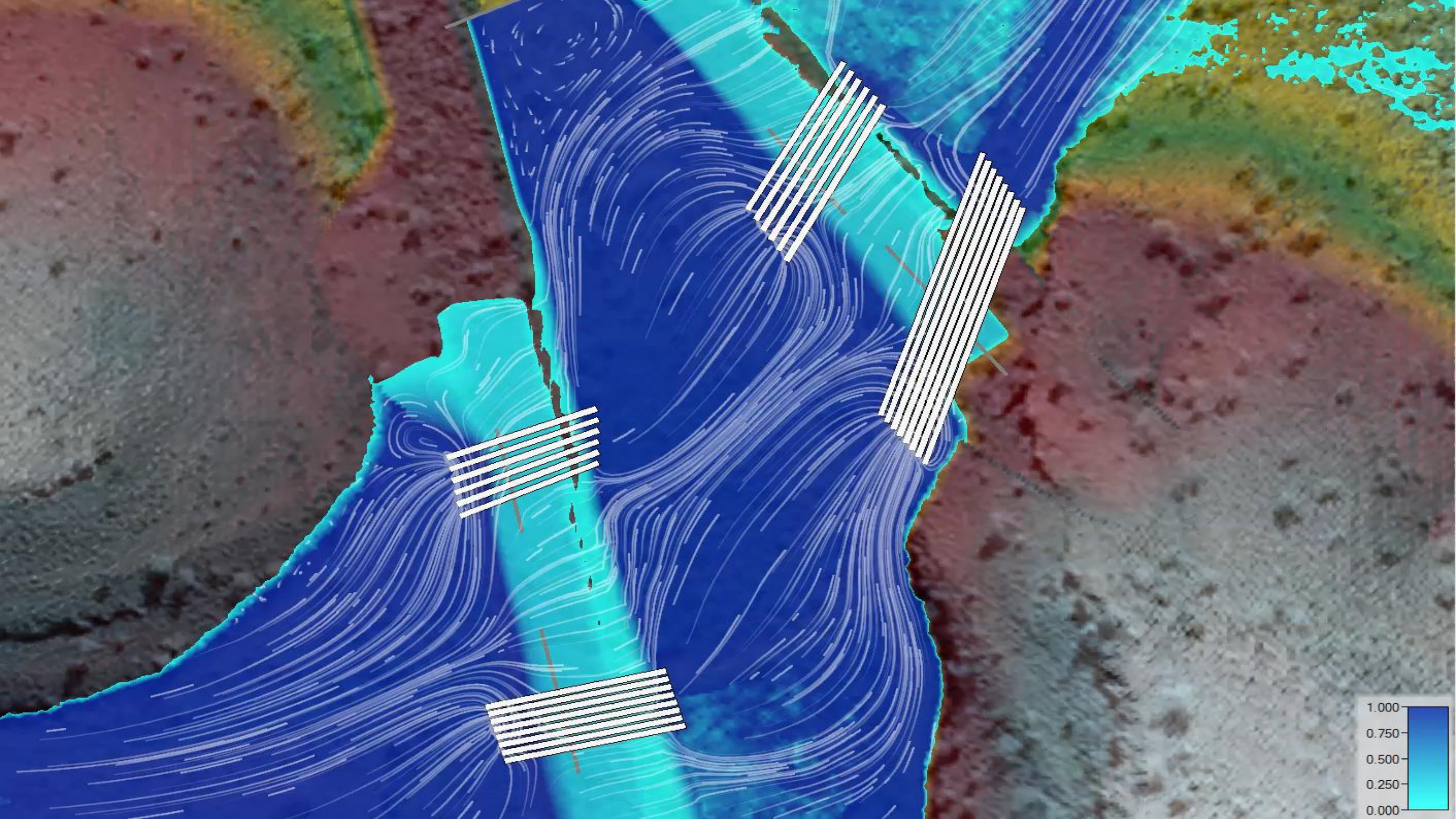


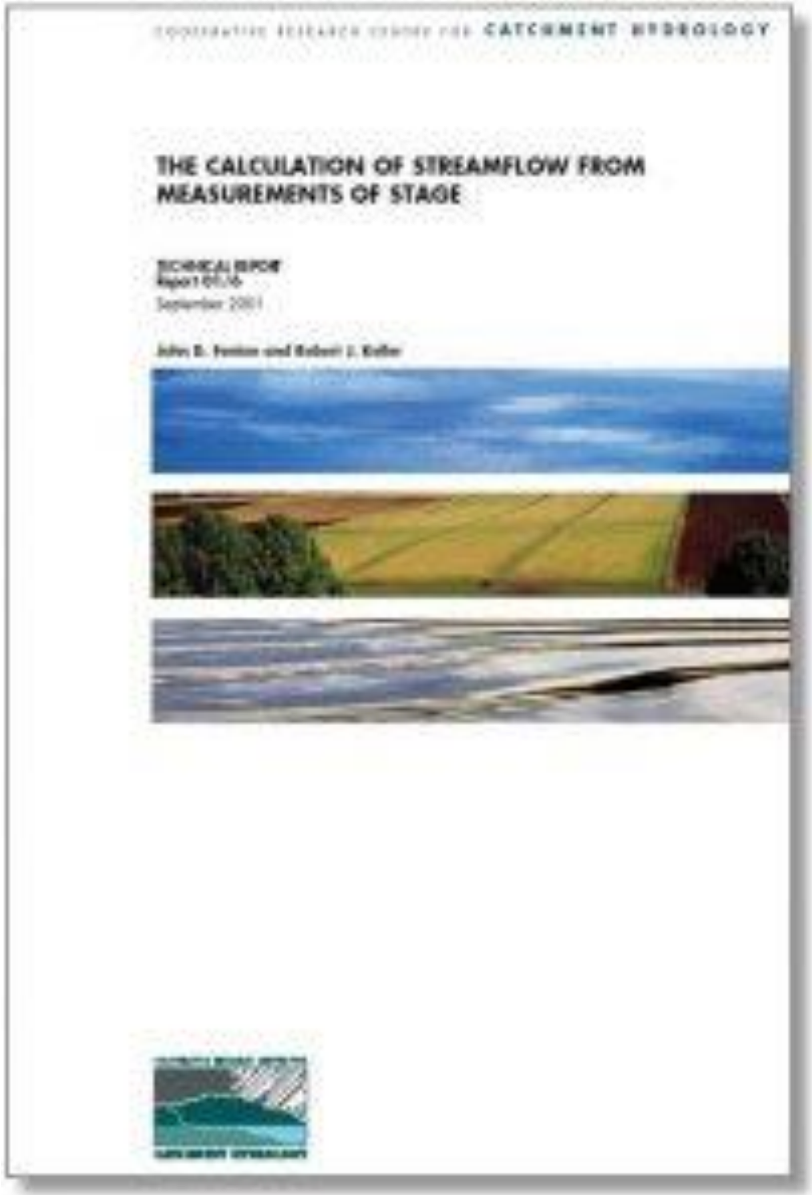
SUBMERGED OUTLET
HW = H + h_o − LS_o
h_o = TW
UNSUBMERGED OUTLET
HW = H + h_o − LS_o
h_o = (d_c + D)/2 or TW
DISCHARGE (Q) IN CFS
DIAMETER (D) IN INCHES
TURNING LINE
LENGTH (L) IN FEET
HEAD (H) IN FEET
PROJECTING GROOVE ENTRANCE
CULVERT FLOWING FULL
n = 0.012



1200
1000
800
600
400
200
0
Discharge (m³/s)
Steady High Flow
Unsteady High Flow
Steady Medium Flow
Unsteady Medium Flow
Steady Low Flow
Unsteady Low Flow
∞
∞
∞
0
1
2
3
4
5
6
Time (hours)


Flow Hydrograph
Plot
Table
SA: MillstreamRating BCLine: US Inflow Trib
Flow (m3/s)
50
40
30
20
10
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Simulation Time (days)
Legend
Flow


1.000
0.750
0.500
0.250
0.000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Research papers

On the generation of stream rating curves

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ARTICLE INFO

This manuscript was handled by Marco Borga, Editor-in-Chief, with the assistance of Yasuto Tachikawa, Associate Editor

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Discharge measurement
Streamgauging
Rating curves
Rivers
Velocity measurements

ABSTRACT

Traditional methods for the calculation of rating curves from measurements of water level and discharge are criticised as being limited and complicated to implement, such that manual methods are still often used. Two methods for automatic computation are developed using least-squares approximation, one based on polynomials and the other on piecewise-continuous splines. Computational problems are investigated and procedures recommended to overcome them. Both methods are found to work well and once the parameters for a gauging station have been determined, rating data can be processed automatically. For some streams, ephemeral changes of resistance may be important, evidenced by scattered or loopy data. For such cases, the approximation methods can be used to generate a rating envelope as well, allowing the routine calculation also of maximum and minimum expected flows. Criticism is made of current shift curve practices. Finally, the approximation methods allow the specification of weights for the data points, enabling the filtering of data, especially decreasing the importance of points with age and allowing the computation of a rating curve for any time in the past or present.

1. Introduction

A rating curve is a relationship between the discharge Q of a stream and h, the stage or surface elevation, so that when routine measurements of stage at a gauging station are made, the flow can be estimated. The curve is calculated from a number of (h, Q) rating data points from that station, using relatively infrequent measurements of the velocity distribution, cross-section, and stage of the stream.

relationship $Q(h)$ over the whole range of data, in general it is not. It is an over-simplification of the real hydraulics at many gauging stations. Such a formula is valid for an infinitely-wide weir in infinitely-deep water or for uniform flow in an infinitely-wide rectangular channel. There is no reason for a real rating curve to follow such a function closely. Insufficient knowledge of hydraulics has led to a too-great belief in the power function, on one hand by practitioners, and on the other by theoreticians in related disciplines. This has led to complicated

tonyladson

Hydrology, Natural Resources and R

Rating curve resources

1 Reply

Hydrologists are often interested in the highest flows and that means we are using the upper limits of rating tables where uncertainty is large.

Below are some links that explain how rating curves are developed and potential issues with current practice.

Rating Curves: National Environmental Monitoring Standards (New Zealand)

Fenton, J. D. and Keller, R. J. (2001) The calculation of streamflow from measurements of stage. Cooperative Research Centre for Catchment Hydrology. Technical report 01/6. (link)

USGS

- How streamflow is measured
- Buchanan, T. J. and Somers, W. P. (1969) Discharge measurements at gaging stations. U. S. Geological Survey Techniques of Water-Resources Investigations Book 3, Chapter A8, pp. 65. (link)

John Fenton's papers

- Rating curves: Part 1 – correction for surface slope
- Rating curves: Part 2 – representation and approximation
- Generating stream rating curves from data

The NZ Hydrological Society Ratings Workshop 2016

- Australian Rating Curves – Ray Maynard

Stu Hamilton's blog at Aquatic Informatics

- Rating curves, blind men, an Elephant and the Goldilocks Principle
- Stage-discharge rating curves – geophysics or religion?
- Extreme gauging – how to extend rating curves with confidence
- Rating curves workshop – International best practices explored in New Zealand

Stu Hamilton's Whitepaper: 5 Best Practices for Building Better Stage-Discharge Rating Curves.

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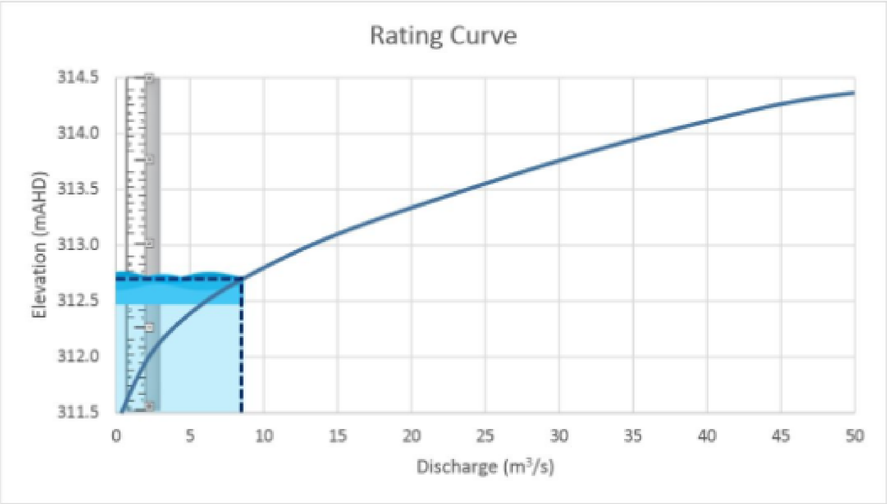
Rating Curves Part 1

Introduction

This article focusses on rating curves in 1D and 2D HEC-RAS models. We'll start by extracting stage-discharge rating curves from HEC-RAS and then focus on refining the data that feeds into the rating curve. In the end, we're looking for a graphical or tabular representation of the relationship between water surface elevation and discharge rate as shown here:



You may run across some rating curves that have the axes reversed, but I prefer to keep stage on the vertical axis since I find it simpler to picture the water surface rising and falling at a gauge like