Decoding the Hysteretic Behavior of Hydraulic Variables in Lowland Rivers with Multivariate Monitoring Approaches

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Abstract

This paper demonstrates that the multivariate monitoring methods are capable to underpin the systematic investigation of the hysteretic behavior occurring during gradually-varied flows. For this purpose, we present simultaneous measurements of stage, index velocity, and free-surface slope acquired continuously with high-frequency sampling instruments deployed at several river gauging sites exposed to a range of storm magnitudes. The experimental evidence reveals intrinsic features of unsteady open-channel flow mechanics that are hinted by pertinent governing equations but rarely substantiated with in-situ measurements. The illustrations are intentionally made for fluvial waves propagating at sites located in lowland areas where the relationships among flow variables are most likely displaying hysteretic loops and phasing in the hydraulic variable progression. The set of presented measurements highlights that: a) the hysteretic behavior is apparent in both time-independent and time-dependent graphical representations of any two of the hydraulic variables; b) the severity of the hysteresis is commensurate with the geomorphic, hydraulic, and hydrological characteristics of the measurement site; and c) there is a pressing need for changing the flow paradigms currently used in tracking flow variables during gradually-varied flows. Also discussed are research needs associated with flow hysteresis for advancing the understanding of the mechanisms underlying the movement and storage of water in the lowland river environments as well as for increasing the accuracy of streamflow monitoring, modeling, and forecasting.

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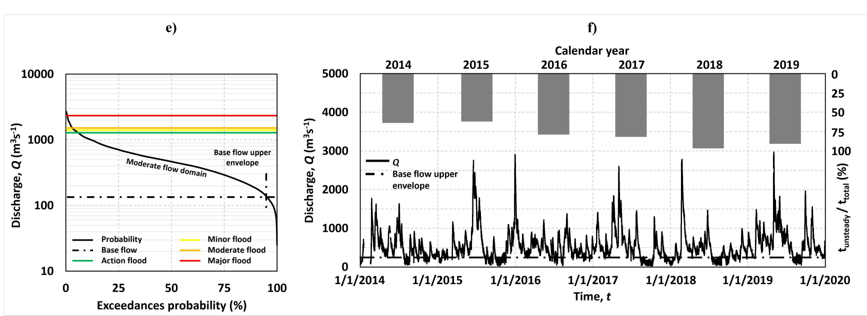
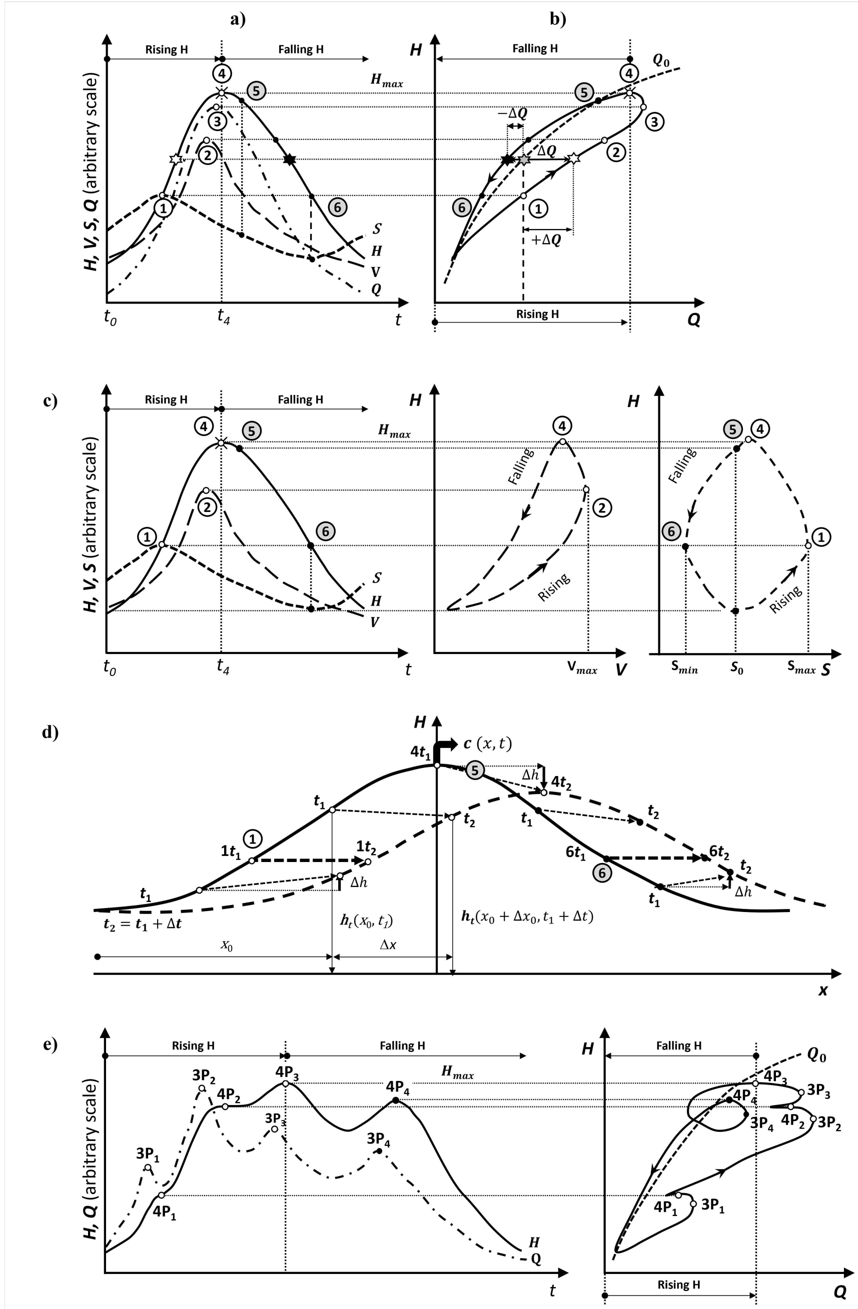
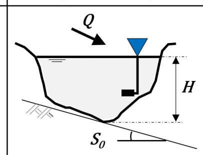
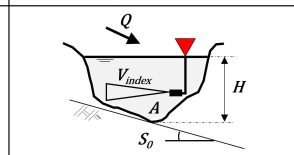
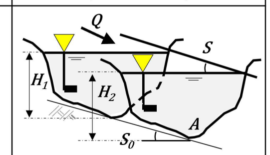
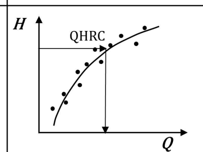
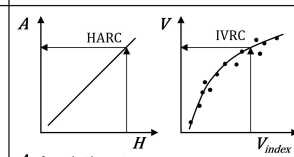
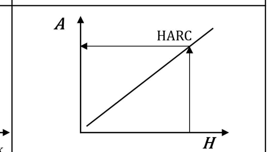
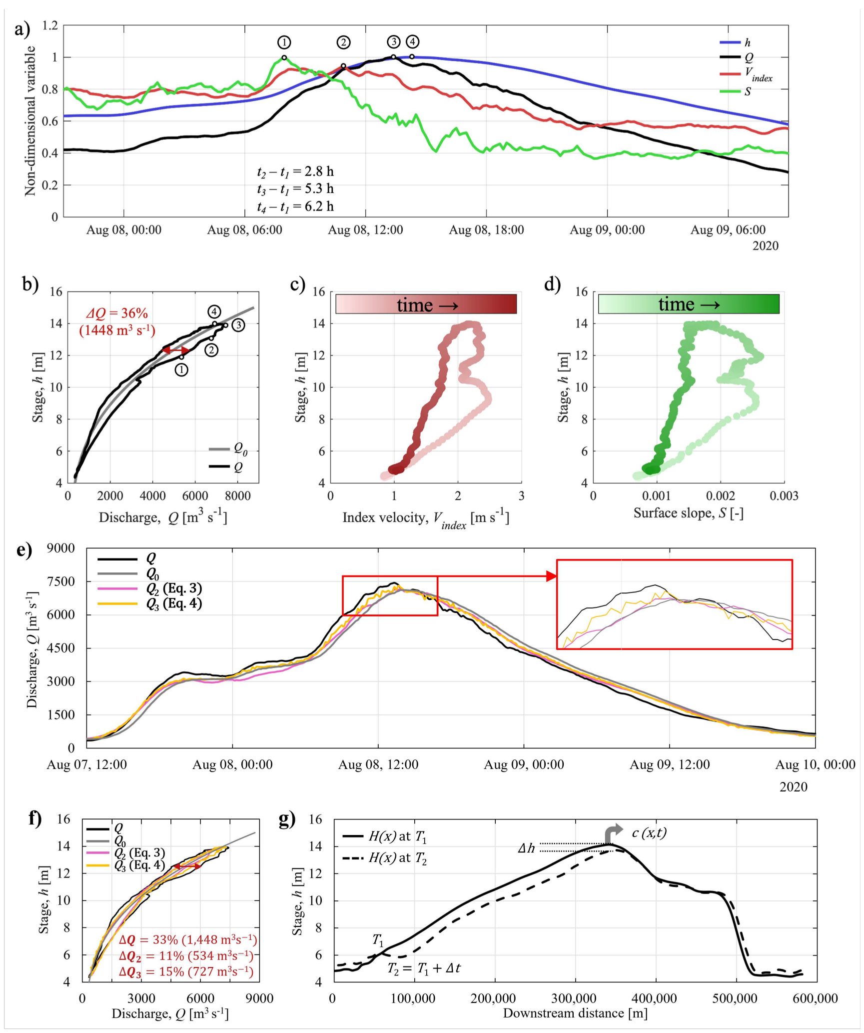
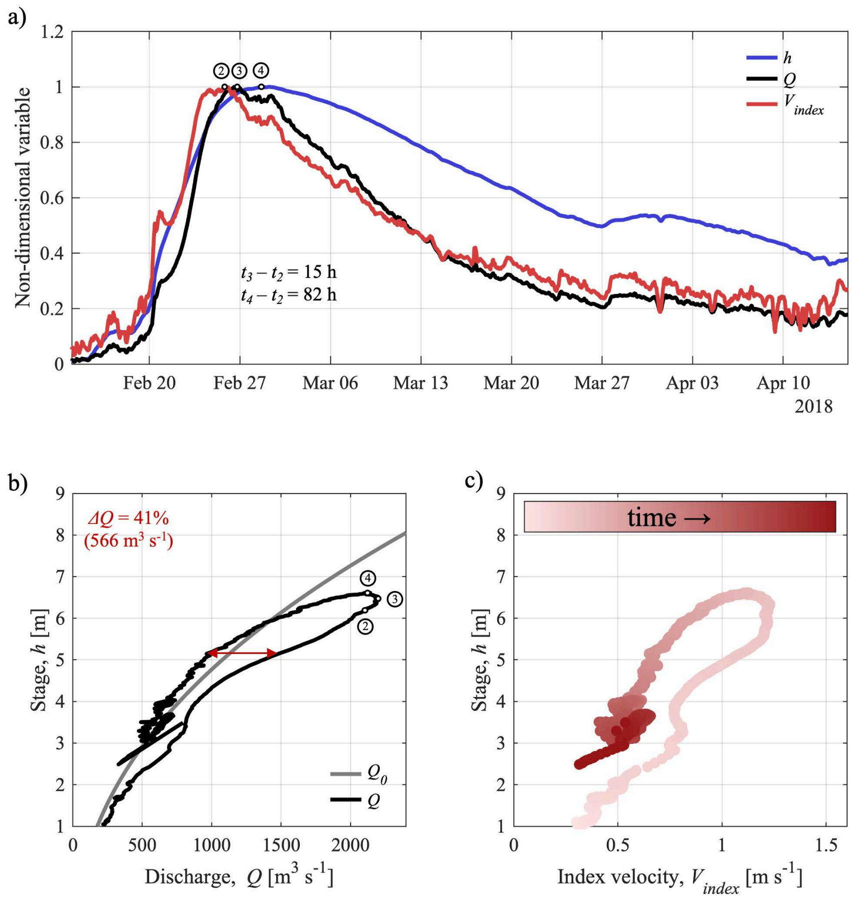
1. `Manuscript (Hydrological processes in lowlands and plains)_V02.docx` available at https://authorea.com/users/772316/articles/857097-decoding-the-hysteretic-behavior-of-hydraulic-variables-in-lowland-rivers-with-multivariate-monitoring-approaches



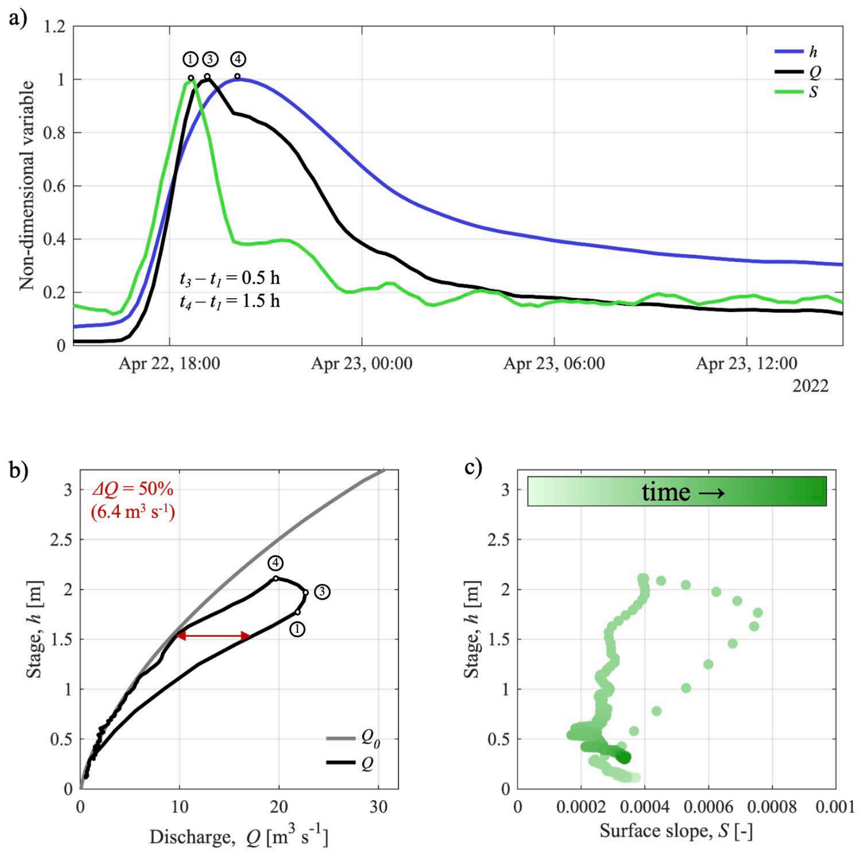

a)
b)
c)
d)
e)
Rising H
Falling H
H, V, S, Q (arbitrary scale)
H, V, S (arbitrary scale)
H, Q (arbitrary scale)
H_{max}
Q_0
$-\Delta Q$
ΔQ
$+\Delta Q$
t_0
t_4
Falling
Rising
V_{max}
S_{min}
S_0
S_{max}
$c\ (x,t)$
$4t_1$
$4t_2$
$1t_1$
$1t_2$
$6t_1$
$6t_2$
Δh
$t_2 = t_1 + \Delta t$
$h_t(x_0, t_1)$
$h_t(x_0 + \Delta x_0, t_1 + \Delta t)$
x_0
Δx
$3P_1$
$3P_2$
$3P_3$
$3P_4$
$4P_1$
$4P_2$
$4P_3$
$4P_4$

Method/ Specifications	Stage-discharge method (HQRC)	Index-velocity method (IVRC)	Continuous slope-area (CSA)
Continuously measured	Surface stage, H (one location)	Surface stage, H; Index-velocity, V_{index} (one location)	Free-surface slope, S (two locations)
Experimental arrangement			
Supporting rating(s)	 Q - from direct measurements	 A - from bathymetry survey; $V = Q/A$; Q from direct measurements	 A - from bathymetry survey
Q estimation	$H \rightarrow$ QHRC $\rightarrow Q$	$H \rightarrow$ HARC $\rightarrow A$; $V_{index} \rightarrow$ IVRC $\rightarrow Q = A \cdot V$	$Q = {}^{1}/_{n} AR^{2/3}S^{1/2}$ (SI units)

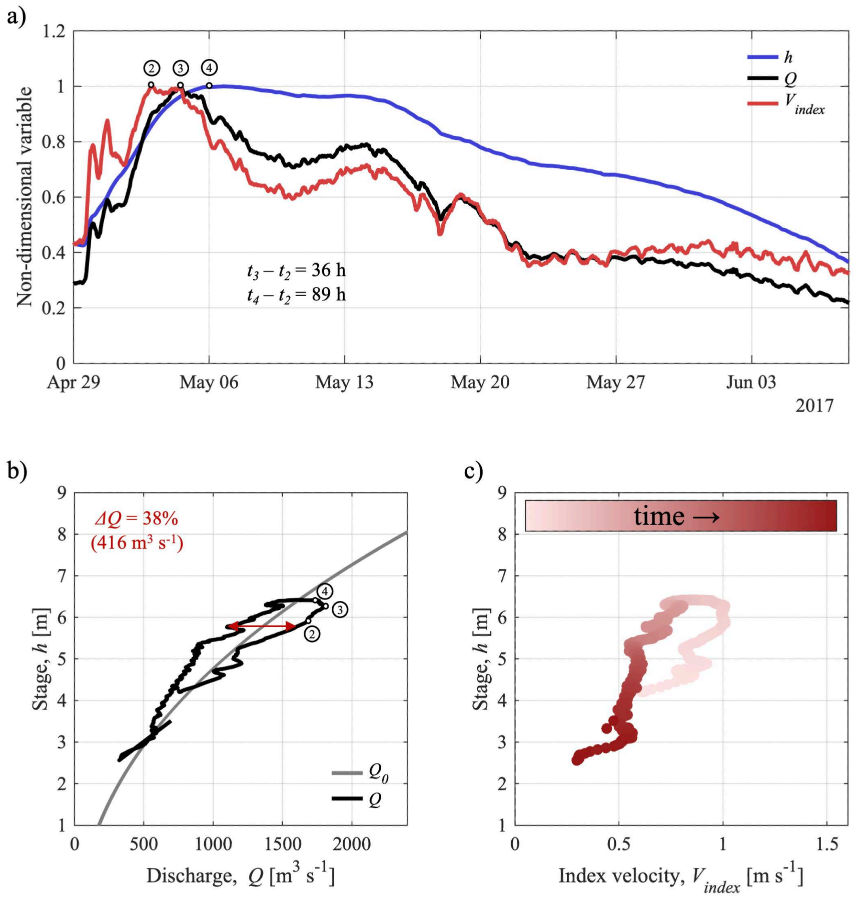




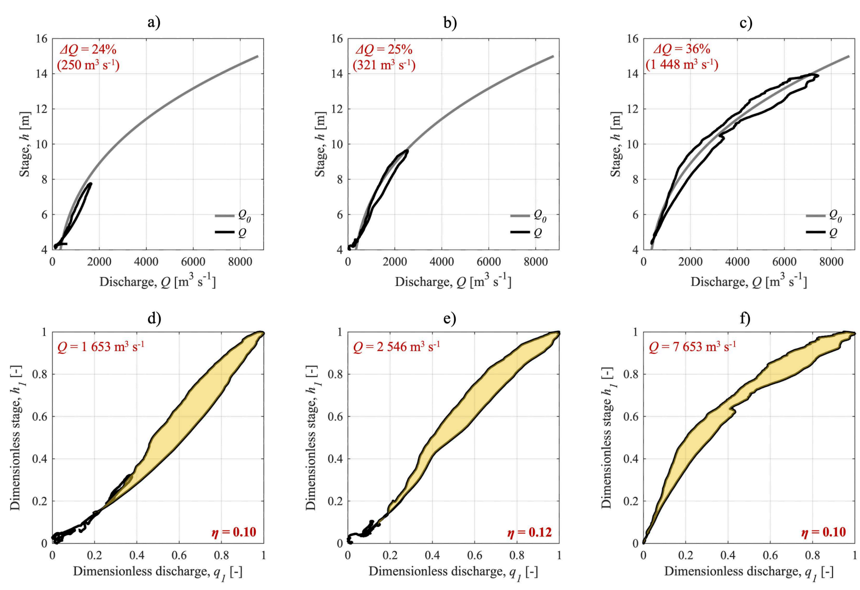
a)
b)
c)
h
Q
V index
Non-dimensional variable
t3 – t2 = 15 h
t4 – t2 = 82 h
Feb 20
Feb 27
Mar 06
Mar 13
Mar 20
Mar 27
Apr 03
Apr 10
2018
ΔQ = 41%
(566 m3 s-1)
Stage, h [m]
Discharge, Q [m3 s-1]
Q0
Q
time →
Index velocity, V index [m s-1]



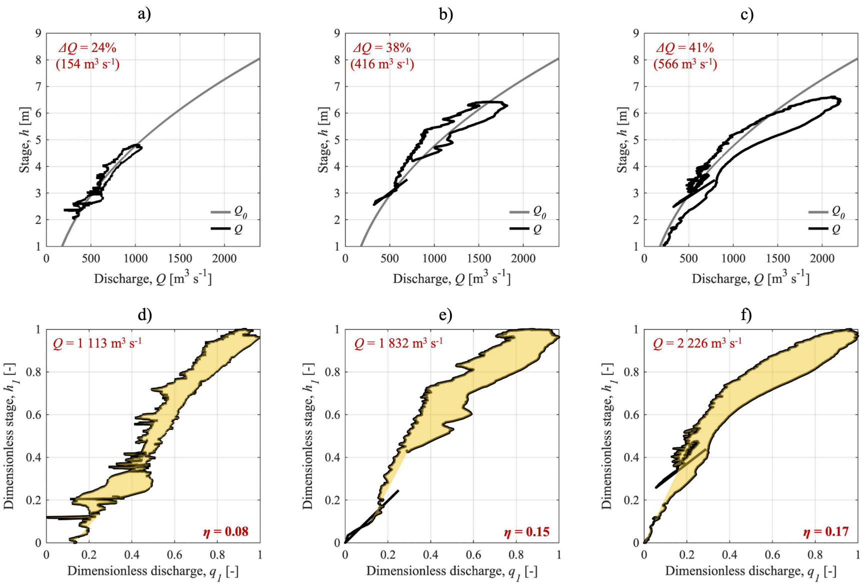
a)
Non-dimensional variable
h
Q
S
$t_3 - t_1 = 0.5$ h
$t_4 - t_1 = 1.5$ h
Apr 22, 18:00
Apr 23, 00:00
Apr 23, 06:00
Apr 23, 12:00
2022
b)
$\Delta Q = 50\%$
(6.4 m³ s⁻¹)
Stage, h [m]
Discharge, Q [m³ s⁻¹]
Q_0
Q
c)
time →
Stage, h [m]
Surface slope, S [-]

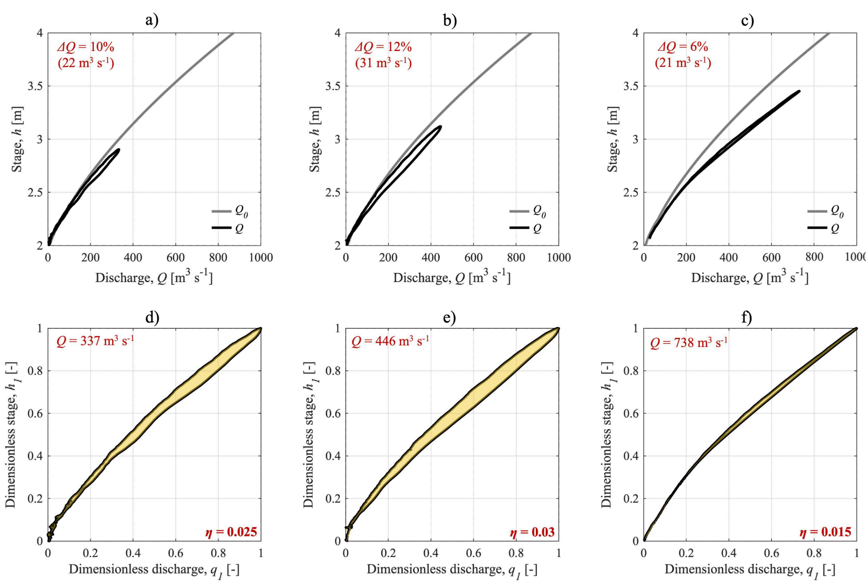


a)
Non-dimensional variable
h
Q
V index
$t_3 - t_2 = 36$ h
$t_4 - t_2 = 89$ h
Apr 29
May 06
May 13
May 20
May 27
Jun 03
2017
b)
ΔQ = 38%
(416 m³ s⁻¹)
Stage, h [m]
Discharge, Q [m³ s⁻¹]
Q0
Q
c)
time →
Stage, h [m]
Index velocity, V index [m s⁻¹]



a)
ΔQ = 24%
(250 m³ s⁻¹)
b)
ΔQ = 25%
(321 m³ s⁻¹)
c)
ΔQ = 36%
(1 448 m³ s⁻¹)
Stage, h [m]
Discharge, Q [m³ s⁻¹]
Q0
Q
d)
Q = 1 653 m³ s⁻¹
η = 0.10
e)
Q = 2 546 m³ s⁻¹
η = 0.12
f)
Q = 7 653 m³ s⁻¹
η = 0.10
Dimensionless stage, h1 [-]
Dimensionless discharge, q1 [-]





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