iemisc: Comparing Other Hydraulic Software Output to iemisc's Manningtrap for Critical Conditions

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Introduction

This document compares the results for 2 examples for a trapezoidal channel with a critical state for the FHWA Hydraulic Toolbox Version 4.4, Dr. Xing Fang's open channel flow calculator, and Irucka Embry's `iemisc` [https://CRAN.R-project.org/package=iemisc] Manningtrap_critical function.

Replicate the R code without the images

Note: If you wish to replicate the R code below, then you will need to copy and paste the following commands in R first (to make sure you have all the of the required packages):

```
install.packages(c("install.load", "iemisc", "pander", "data.table"))
# install the packages and their dependencies
```

```
# load the required package
install.load::load_package("iemisc", "pander", "data.table")
```

Critical State Description

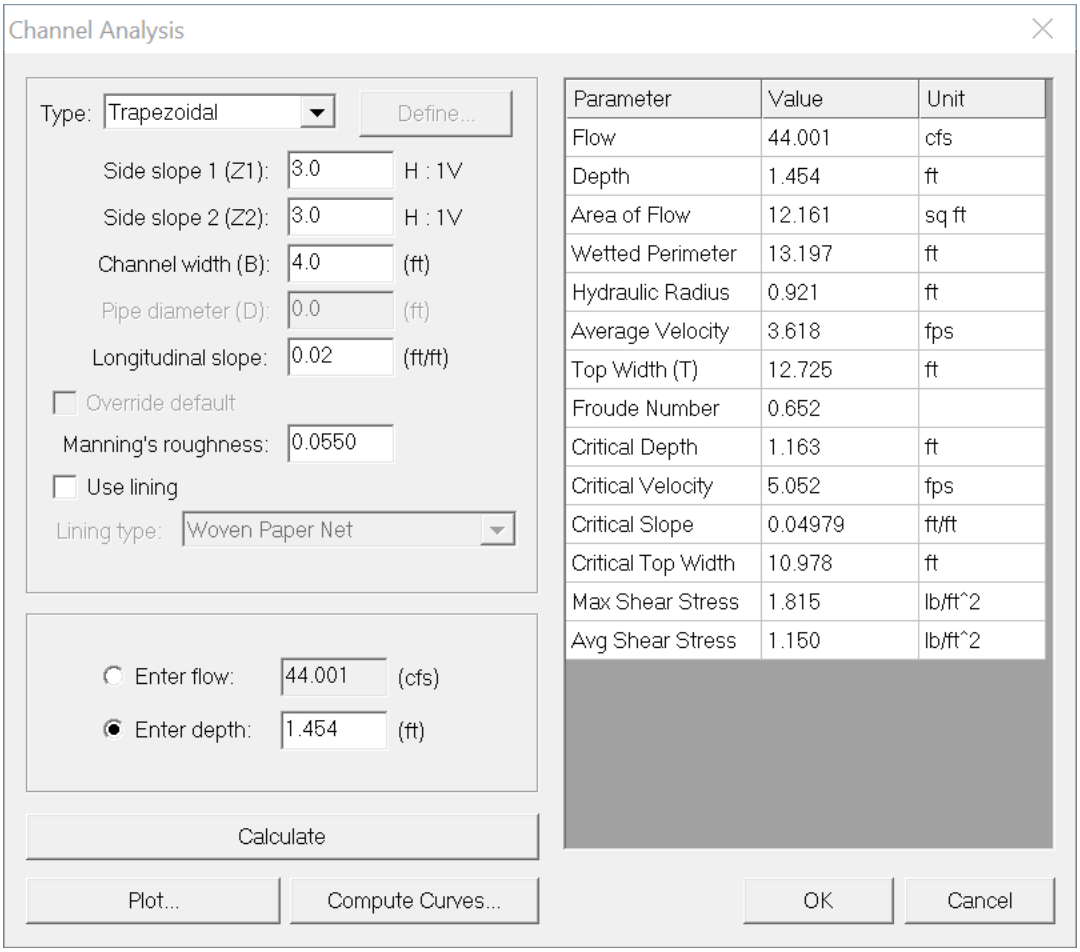
> "When F (Froude number) is equal to unity, … the flow is said to be in a *critical* state. If F is less than unity, … the flow is *subcritical*. If F is greater than unity, … the flow is *supercritical*.
>
> "… the critical state of flow through a channel section is characterized by several important conditions. Recapitulating, they are (1) the specific energy is a minimum for a given discharge; (2) the discharge is a maximum for a given specific energy; (3) the specific force is a minimum for a given discharge; (4) the velocity head is equal to half the hydraulic depth in a channel of small slope; (5) the Froude number is equal to unity; and (6) the velocity of flow in a channel of small slope with uniform velocity distribution is equal to the celerity of small gravity waves in shallow water caused by local disturbances.
>
> "Discussions on critical state of flow have referred mainly to a particular section of a channel, known as the *critical section*. If the critical state of exists throughout the entire length of the channel or over a reach of the channel, the flow in the channel is a *critical flow*."

–Ven Te Chow, Ph.D., *Open-Channel Hydraulics*, McGraw-Hill Classic Textbook Reissue, New York City, New York: McGraw-Hill Book Company, 1988, pages 13, 63.

Example 1

Given a trapezoidal channel with 3 ft symmetric side slopes, a channel width of 4 ft, a longitudinal slope of 0.02 ft/ft, Manning's roughness coefficient of 0.0550, and a depth of 1.454 ft, calculate the missing parameters for a critical state.

FHWA Hydraulic Toolbox Example 1 (Image)



FHWA Hydraulic Toolbox Example 1 (Text Table)

```
fhwa_ex1 <- data.table(Parameter = c("Flow", "Depth", "Area of Flow", "Wetted Perimeter",
    "Hydraulic Radius", "Average Velocity", "Top Width (T)", "Side slope 1 (Z1)",
    "Side slope 2 (Z2)", "Channel width (B)", "Longitudinal slope", "Manning's roughness",
    "Froude Number", "Critical Depth", "Critical Velocity", "Critical Slope", "Critical Top Width",
    "Max Shear Stress", "Avg. Shear Stress"), Value = c(44.001, 1.454, 12.161, 13.197,
    0.921, 3.618, 12.725, 3, 3, 4, 0.02, 0.055, 0.652, 1.163, 5.052, 0.04979, 10.978,
    1.815, 1.15), Unit = c("cfs", "ft", "sq ft", "ft", "ft", "fps", "ft", "", "",
    "ft", "ft/ft", "", "", "ft", "fps", "ft/ft", "ft", "lb/ft^2", "lb/ft^2"))
```

```
pander(fhwa_ex1, missing = "")
```

Parameter	Value	Unit
Flow	44	cfs
Depth	1.454	ft
Area of Flow	12.16	sq ft
Wetted Perimeter	13.2	ft
Hydraulic Radius	0.921	ft
Average Velocity	3.618	fps
Top Width (T)	12.72	ft
Side slope 1 (Z1)	3	
Side slope 2 (Z2)	3	
Channel width (B)	4	ft
Longitudinal slope	0.02	ft/ft
Manning's roughness	0.055	
Froude Number	0.652	
Critical Depth	1.163	ft
Critical Velocity	5.052	fps
Critical Slope	0.04979	ft/ft
Critical Top Width	10.98	ft
Max Shear Stress	1.815	lb/ft^2
Avg. Shear Stress	1.15	lb/ft^2

Dr. Xing Fang's Open Channel Flow Calculator's Solution of Example 1 (Image)

Dr. Xing Fang's Open Channel Flow Calculator's Solution of Example 1 (Text Table)

```
fang_ex1 <- data.table(Parameter = c("Flow", "Depth", "Area of Flow", "Wetted Perimeter",
    "Hydraulic Radius", "Average Velocity", "Top Width (T)", "Side slope 1 (Z1)",
    "Side slope 2 (Z2)", "Channel width (B)", "Longitudinal slope", "Manning's roughness",
    "Froude Number", "Critical Depth", "Critical Velocity", "Critical Slope", "Critical Top Width",
    "Max Shear Stress", "Avg. Shear Stress"), Value = c(43.9882, 1.454, 12.16, 13.2,
    "", 3.6179, 12.72, 3, 3, 4, 0.02, 0.055, 0.65, 1.17, "", 0.0492, "", "", ""),
    Unit = c("cfs", "ft", "sq ft", "ft", "ft", "fps", "ft", "", "", "ft", "ft/ft",
        "", "", "ft", "fps", "ft/ft", "ft", "lb/ft^2", "lb/ft^2"))
```

```
pander(fang_ex1, missing = "")
```

Parameter	Value	Unit
Flow	43.9882	cfs
Depth	1.454	ft
Area of Flow	12.16	sq ft
Wetted Perimeter	13.2	ft
Hydraulic Radius		ft
Average Velocity	3.6179	fps
Top Width (T)	12.72	ft
Side slope 1 (Z1)	3	
Side slope 2 (Z2)	3	
Channel width (B)	4	ft
Longitudinal slope	0.02	ft/ft
Manning's roughness	0.055	
Froude Number	0.65	
Critical Depth	1.17	ft
Critical Velocity		fps
Critical Slope	0.0492	ft/ft
Critical Top Width		ft
Max Shear Stress		lb/ft^2
Avg. Shear Stress		lb/ft^2

iemisc's Manningtrap Solution of Example 1

```
uuc1 <- Manningtrap_critical(y = 1.454, b = 4, m = 3, Sf = 0.02, n = 0.055, units = "Eng",
    type = "symmetrical", critical = "accurate", output = "data.table")
```

```
##
## Flow IS in the rough turbulent zone so the Gauckler-Manning-Strickler equation
##  is acceptable to use.
##
##
## This is subcritical flow.
```

```r
pander(uuc1, missing = "")
```

Parameters	Normal Value	Critical Value
Flow depth (y)	1.454	1.551
Flow area (A)	12.158	13.417
Wetted Perimeters (P)	13.196	13.808
Top Width (B)	12.724	13.304
Bottom width (b)	4	
Hydraulic Radius (R)	0.921	0.972
Hydraulic Depth (D)	0.956	1.008
Flow Mean Velocity (V)	3.618	7.064
Flow Discharge (Q)	43.986	67.414
Manning's roughness coefficient (n)	0.055	
Slope (Sf)	0.02	0.015
Temperature	68	
Absolute Temperature	293.15	
Saturated Liquid Density	1.937	
Absolute or Dynamic Viscosity	2.092885e-05	
Kinematic Viscosity	1.080619e-05	
Froude number (Fr)	0.652	1
Reynolds number (Re)	308461	
symmetric side slope (m)	3	
non-symmetric side slope (m1)		
non-symmetric side slope (m2)		
Wetted Length (w)	4.598	
Wetted Length for a non-symmetric trapezoid (w1)		
Wetted Length for a non-symmetric trapezoid (w2)		
Section Factor (Z)	11.512	11.885
conveyance (K)	311.026	
Specific Energy (E)	1.657	1.718
Velocity Head (Vel_Head)	0.203	
Maximum Shear Stress (taud)	1.812	
Average Shear Stress (tau0)	1.148	

Units
ft
ft^2
ft
ft
ft
ft
ft
ft/sec (fps)
ft^3/sec (cfs)
dimensionless
ft/ft
degrees Fahrenheit
Kelvin
slug/ft^3

Units
slug/ft*s
ft^2/s
dimensionless
dimensionless
ft/ft
ft/ft
ft/ft
ft
ft
ft
ft
ft^3/sec (cfs)
ft
ft
lb/ft^2
lb/ft^2

```
uuc1a <- Manningtrap_critical(y = 1.454, b = 4, m = 3, Sf = 0.02, n = 0.055, units = "Eng",
    type = "symmetrical", critical = "accurate", output = "list")
```

```
##
## Flow IS in the rough turbulent zone so the Gauckler-Manning-Strickler equation
##  is acceptable to use.
##
##
## This is subcritical flow.
```

```
uuc1b <- Manningtrap_critical(y = 1.454, b = 4, m = 3, Sf = 0.02, n = 0.055, units = "Eng",
    type = "symmetrical", critical = "approximate", output = "list")
```

```
##
## Flow IS in the rough turbulent zone so the Gauckler-Manning-Strickler equation
##  is acceptable to use.
##
##
## This is subcritical flow.
```

Comparing All 3 Solutions for Example 1

```
compare_ex1 <- data.table(Parameter = c("Flow", "Depth", "Area of Flow", "Wetted Perimeter",
    "Hydraulic Radius", "Average Velocity", "Top Width (T)", "Side slope 1 (Z1)",
    "Side slope 2 (Z2)", "Channel width (B)", "Longitudinal slope", "Manning's roughness",
    "Normal Froude Number", "Critical Froude Number", "Critical Depth", "Critical Velocity",
    "Critical Slope", "Critical Top Width", "Max Shear Stress", "Avg. Shear Stress"),
    `FHWA Value` = c(44.001, 1.454, 12.161, 13.197, 0.921, 3.618, 12.725, 3, 3, 4,
        0.02, 0.055, 0.652, "", 1.163, 5.052, 0.04979, 10.978, 1.815, 1.15), `Wang Value` = c(43.9882,
        1.454, 12.16, 13.2, "", 3.6179, 12.72, 3, 3, 4, 0.02, 0.055, 0.65, "", 1.17,
        "", 0.0492, "", "", ""), `iemisc Value (Accurate Critical Froude)` = c(uuc1a$Q,
```

```r
uuc1a$y, uuc1a$A, uuc1a$P, uuc1a$R, uuc1a$V, uuc1a$B, uuc1a$m, uuc1a$m, uuc1a$b,
uuc1a$Sf, uuc1a$n, uuc1a$Fr, uuc1a$Frc, uuc1a$yc, uuc1a$Vc, uuc1a$Sfc, uuc1a$Bc,
uuc1a$taud, uuc1a$tau0), `iemisc Value (Approximate Critical Froude)` = c(uuc1b$Q,
uuc1b$y, uuc1b$A, uuc1b$P, uuc1b$R, uuc1b$V, uuc1b$B, uuc1b$m, uuc1b$m, uuc1b$b,
uuc1b$Sf, uuc1b$n, uuc1b$Fr, uuc1b$Frc, uuc1b$yc, uuc1b$Vc, uuc1b$Sfc, uuc1b$Bc,
uuc1b$taud, uuc1b$tau0), Unit = c("cfs", "ft", "sq ft", "ft", "ft", "fps",
"ft", "", "", "ft", "ft/ft", "", "", "", "ft", "fps", "ft/ft", "ft", "lb/ft^2",
"lb/ft^2"))
```

```r
pander(compare_ex1, missing = "")
```

Parameter	FHWA Value	Wang Value	iemisc Value (Accurate Critical Froude)
Flow	44.001	43.9882	43.99
Depth	1.454	1.454	1.454
Area of Flow	12.161	12.16	12.16
Wetted Perimeter	13.197	13.2	13.2
Hydraulic Radius	0.921		0.921
Average Velocity	3.618	3.6179	3.618
Top Width (T)	12.725	12.72	12.72
Side slope 1 (Z1)	3	3	3
Side slope 2 (Z2)	3	3	3
Channel width (B)	4	4	4
Longitudinal slope	0.02	0.02	0.02
Manning's roughness	0.055	0.055	0.055
Normal Froude Number	0.652	0.65	0.652
Critical Froude Number			1
Critical Depth	1.163	1.17	1.551
Critical Velocity	5.052		7.064
Critical Slope	0.04979	0.0492	0.0153
Critical Top Width	10.978		13.3
Max Shear Stress	1.815		1.812
Avg. Shear Stress	1.15		1.148

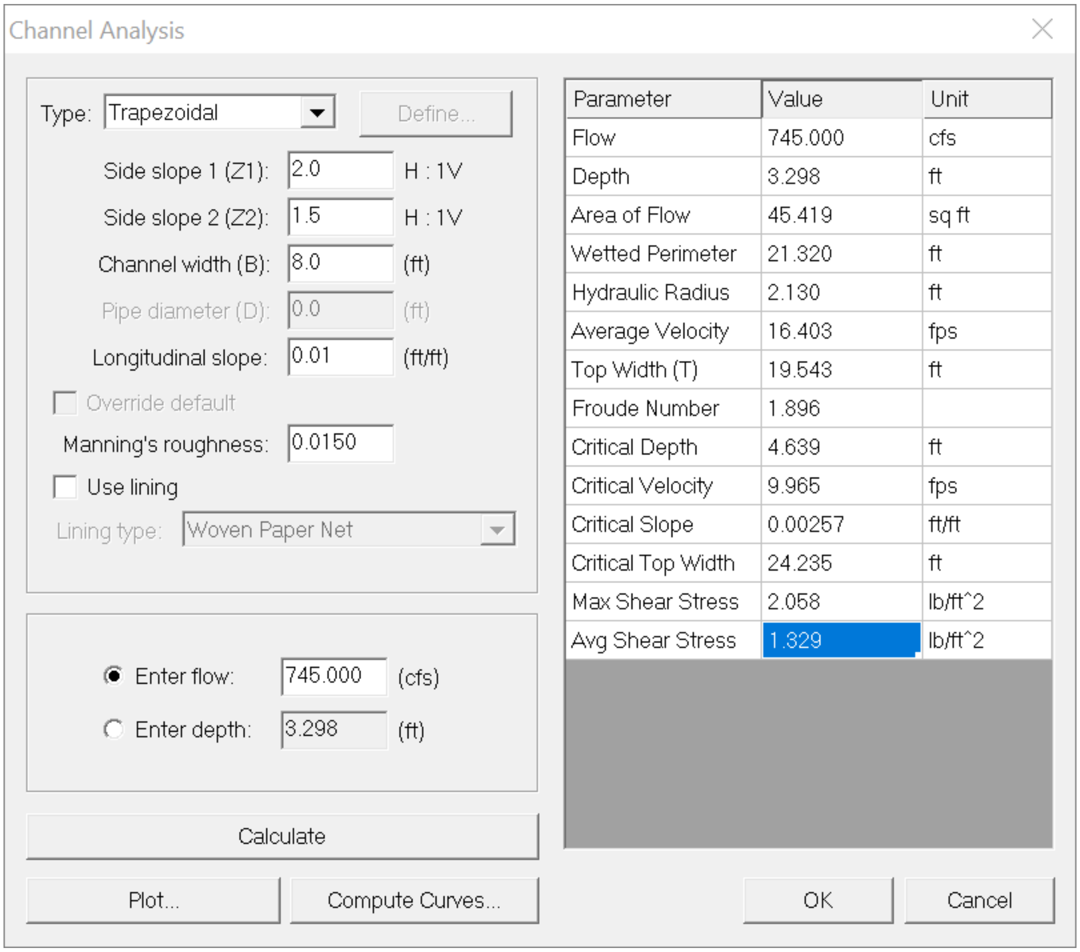
iemisc Value (Approximate Critical Froude)	Unit
43.99	cfs
1.454	ft
12.16	sq ft
13.2	ft
0.921	ft
3.618	fps
12.72	ft
3	
3	
4	ft
0.02	ft/ft
0.055	
0.652	
0.826	

iemisc Value (Approximate Critical Froude)	Unit
1.163	ft
5.052	fps
0.04981	ft/ft
10.98	ft
1.812	lb/ft^2
1.148	lb/ft^2

Example 2

Given a trapezoidal channel with 2 ft and 1.5 ft non-symmetric side slopes, a channel width of 8 ft, a longitudinal slope of 0.01 ft/ft, Manning's roughness coefficient of 0.0150, and a flow of 745 cfs, calculate the missing parameters for a critical state.

FHWA Hydraulic Toolbox Example 2



FHWA Hydraulic Toolbox Example 2 (Text Table)

```r
fhwa_ex2 <- data.table(Parameter = c("Flow", "Depth", "Area of Flow", "Wetted Perimeter",
    "Hydraulic Radius", "Average Velocity", "Top Width (T)", "Side slope 1 (Z1)",
    "Side slope 2 (Z2)", "Channel width (B)", "Longitudinal slope", "Manning's roughness",
    "Froude Number", "Critical Depth", "Critical Velocity", "Critical Slope", "Critical Top Width",
    "Max Shear Stress", "Avg. Shear Stress"), Value = c(745, 3.298, 45.419, 21.32,
    2.13, 16.408, 19.543, 2, 1.5, 8, 0.01, 0.015, 1.896, 4.639, 9.965, 0.0257, 24.235,
    2.058, 1.329), Unit = c("cfs", "ft", "sq ft", "ft", "ft", "fps", "ft", "", "",
    "ft", "ft/ft", "", "", "ft", "fps", "ft/ft", "ft", "lb/ft^2", "lb/ft^2"))
```

```r
pander(fhwa_ex2, missing = "")
```

Parameter	Value	Unit
Flow	745	cfs

Parameter	Value	Unit
Depth	3.298	ft
Area of Flow	45.42	sq ft
Wetted Perimeter	21.32	ft
Hydraulic Radius	2.13	ft
Average Velocity	16.41	fps
Top Width (T)	19.54	ft
Side slope 1 (Z1)	2	
Side slope 2 (Z2)	1.5	
Channel width (B)	8	ft
Longitudinal slope	0.01	ft/ft
Manning's roughness	0.015	
Froude Number	1.896	
Critical Depth	4.639	ft
Critical Velocity	9.965	fps
Critical Slope	0.0257	ft/ft
Critical Top Width	24.23	ft
Max Shear Stress	2.058	lb/ft^2
Avg. Shear Stress	1.329	lb/ft^2

Dr. Xing Fang's Open Channel Flow Calculator's Solution of Example 2

Dr. Xing Fang's Open Channel Flow Calculator's Solution of Example 2 (Text Table)

```
fang_ex2 <- data.table(Parameter = c("Flow", "Depth", "Area of Flow", "Wetted Perimeter",
    "Hydraulic Radius", "Average Velocity", "Top Width (T)", "Side slope 1 (Z1)",
    "Side slope 2 (Z2)", "Channel width (B)", "Longitudinal slope", "Manning's roughness",
    "Froude Number", "Critical Depth", "Critical Velocity", "Critical Slope", "Critical Top Width",
    "Max Shear Stress", "Avg. Shear Stress"), Value = c(745, 3.3, 45.51, 21.34, "",
    16.371, 19.56, 2, 1.5, 8, 0.01, 0.015, 1.89, 4.64, "", 0.0026, "", "", ""), Unit = c("cfs",
    "ft", "sq ft", "ft", "ft", "fps", "ft", "", "", "ft", "ft/ft", "", "", "", "ft",
    "fps", "ft/ft", "ft", "lb/ft^2", "lb/ft^2"))
```

```
pander(fang_ex1, missing = "")
```

Parameter	Value	Unit
Flow	43.9882	cfs
Depth	1.454	ft
Area of Flow	12.16	sq ft
Wetted Perimeter	13.2	ft
Hydraulic Radius		ft
Average Velocity	3.6179	fps
Top Width (T)	12.72	ft
Side slope 1 (Z1)	3	
Side slope 2 (Z2)	3	
Channel width (B)	4	ft
Longitudinal slope	0.02	ft/ft
Manning's roughness	0.055	
Froude Number	0.65	
Critical Depth	1.17	ft
Critical Velocity		fps
Critical Slope	0.0492	ft/ft
Critical Top Width		ft
Max Shear Stress		lb/ft^2
Avg. Shear Stress		lb/ft^2

iemisc's Manningtrap Solution of Example 2

```
uuc2 <- Manningtrap_critical(Q = 745, b = 8, m1 = 2, m2 = 1.5, Sf = 0.01, n = 0.015,
    units = "Eng", type = "non-symmetrical", critical = "accurate", output = "data.table")
```

```
##
## Flow IS in the rough turbulent zone so the Gauckler-Manning-Strickler equation
##  is acceptable to use.
##
##
## This is supercritical flow.
```

```r
pander(uuc2, missing = "")
```

Parameters	Normal Value	Critical Value
Flow depth (y)	3.298	6.442
Flow area (A)	45.423	74.086
Wetted Perimeters (P)	21.321	34.019
Top Width (B)	19.544	30.548
Bottom width (b)	8	
Hydraulic Radius (R)	2.13	2.178
Hydraulic Depth (D)	2.324	2.425
Flow Mean Velocity (V)	16.401	14.397
Flow Discharge (Q)	745	392.789
Manning's roughness coefficient (n)	0.015	
Slope (Sf)	0.01	0.004
Temperature	68	
Absolute Temperature	293.15	
Saturated Liquid Density	1.937	
Absolute or Dynamic Viscosity	2.092885e-05	
Kinematic Viscosity	1.080619e-05	
Froude number (Fr)	1.897	1
Reynolds number (Re)	3233520	
symmetric side slope (m)		
non-symmetric side slope (m1)	2	
non-symmetric side slope (m2)	1.5	
Wetted Length (w)		
Wetted Length for a non-symmetric trapezoid (w1)	7.375	
Wetted Length for a non-symmetric trapezoid (w2)	5.946	
Section Factor (Z)	58.585	69.248
conveyance (K)	7449.995	
Specific Energy (E)	7.479	8.014
Velocity Head (Vel_Head)	4.181	
Maximum Shear Stress (taud)	2.055	
Average Shear Stress (tau0)	1.328	

Units
ft
ft^2
ft
ft
ft
ft
ft
ft/sec (fps)
ft^3/sec (cfs)
dimensionless
ft/ft
degrees Fahrenheit
Kelvin
slug/ft^3

Units
slug/ft*s
ft^2/s
dimensionless
dimensionless
ft/ft
ft/ft
ft/ft
ft
ft
ft
ft
ft^3/sec (cfs)
ft
ft
lb/ft^2
lb/ft^2

```
uuc2a <- Manningtrap_critical(Q = 745, b = 8, m1 = 2, m2 = 1.5, Sf = 0.01, n = 0.015,
    units = "Eng", type = "non-symmetrical", critical = "accurate", output = "list")

##
## Flow IS in the rough turbulent zone so the Gauckler-Manning-Strickler equation
##  is acceptable to use.
##
##
## This is supercritical flow.
```

```
uuc2b <- Manningtrap_critical(Q = 745, b = 8, m1 = 2, m2 = 1.5, Sf = 0.01, n = 0.015,
    units = "Eng", type = "non-symmetrical", critical = "approximate", output = "list")

##
## Flow IS in the rough turbulent zone so the Gauckler-Manning-Strickler equation
##  is acceptable to use.
##
##
## This is supercritical flow.
```

Comparing All 3 Solutions for Example 2

```
compare_ex2 <- data.table(Parameter = c("Flow", "Depth", "Area of Flow", "Wetted Perimeter",
    "Hydraulic Radius", "Average Velocity", "Top Width (T)", "Side slope 1 (Z1)",
    "Side slope 2 (Z2)", "Channel width (B)", "Longitudinal slope", "Manning's roughness",
    "Normal Froude Number", "Critical Froude Number", "Critical Depth", "Critical Velocity",
    "Critical Slope", "Critical Top Width", "Max Shear Stress", "Avg. Shear Stress"),
    `FHWA Value` = c(745, 3.298, 45.419, 21.32, 2.13, 16.408, 19.543, 2, 1.5, 8,
        0.01, 0.015, 1.896, "", 4.639, 9.965, 0.0257, 24.235, 2.058, 1.329), `Wang Value` = c(745,
        3.3, 45.51, 21.34, "", 16.371, 19.56, 2, 1.5, 8, 0.01, 0.015, 1.89, "", 4.64,
        "", 0.0026, "", "", ""), `iemisc Value (Accurate Critical Froude)` = c(uuc2a$Q,
```

```r
uuc2a$y, uuc2a$A, uuc2a$P, uuc2a$R, uuc2a$V, uuc2a$B, uuc2a$m1, uuc2a$m2,
uuc2a$b, uuc2a$Sf, uuc2a$n, uuc2a$Fr, uuc2a$Frc, uuc2a$yc, uuc2a$Vc, uuc2a$Sfc,
uuc2a$Bc, uuc2a$taud, uuc2a$tau0), `iemisc Value (Approximate Critical Froude)` = c(uuc2b$Q,
uuc2b$y, uuc2b$A, uuc2b$P, uuc2b$R, uuc2b$V, uuc2b$B, uuc2b$m1, uuc2b$m2,
uuc2b$b, uuc2b$Sf, uuc2b$n, uuc2b$Fr, uuc2b$Frc, uuc2b$yc, uuc2b$Vc, uuc2b$Sfc,
uuc2b$Bc, uuc2b$taud, uuc2b$tau0), Unit = c("cfs", "ft", "sq ft", "ft", "ft",
"fps", "ft", "", "", "ft", "ft/ft", "", "", "", "ft", "fps", "ft/ft", "ft",
"lb/ft^2", "lb/ft^2"))
```

```r
pander(compare_ex2, missing = "")
```

Parameter	FHWA Value	Wang Value	iemisc Value (Accurate Critical Froude)
Flow	745	745	745
Depth	3.298	3.3	3.298
Area of Flow	45.419	45.51	45.42
Wetted Perimeter	21.32	21.34	21.32
Hydraulic Radius	2.13		2.13
Average Velocity	16.408	16.371	16.4
Top Width (T)	19.543	19.56	19.54
Side slope 1 (Z1)	2	2	2
Side slope 2 (Z2)	1.5	1.5	1.5
Channel width (B)	8	8	8
Longitudinal slope	0.01	0.01	0.01
Manning's roughness	0.015	0.015	0.015
Normal Froude Number	1.896	1.89	1.897
Critical Froude Number			1
Critical Depth	4.639	4.64	6.442
Critical Velocity	9.965		14.4
Critical Slope	0.0257	0.0026	0.00366
Critical Top Width	24.235		30.55
Max Shear Stress	2.058		2.055
Avg. Shear Stress	1.329		1.328

iemisc Value (Approximate Critical Froude)	Unit
745	cfs
3.298	ft
45.42	sq ft
21.32	ft
2.13	ft
16.4	fps
19.54	ft
2	
1.5	
8	ft
0.01	ft/ft
0.015	
1.897	

iemisc Value (Approximate Critical Froude)	Unit
0.588	
7.229	ft
8.962	fps
0.00281	ft/ft
33.3	ft
2.055	lb/ft^2
1.328	lb/ft^2

Works Cited

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