CHAPTER 4

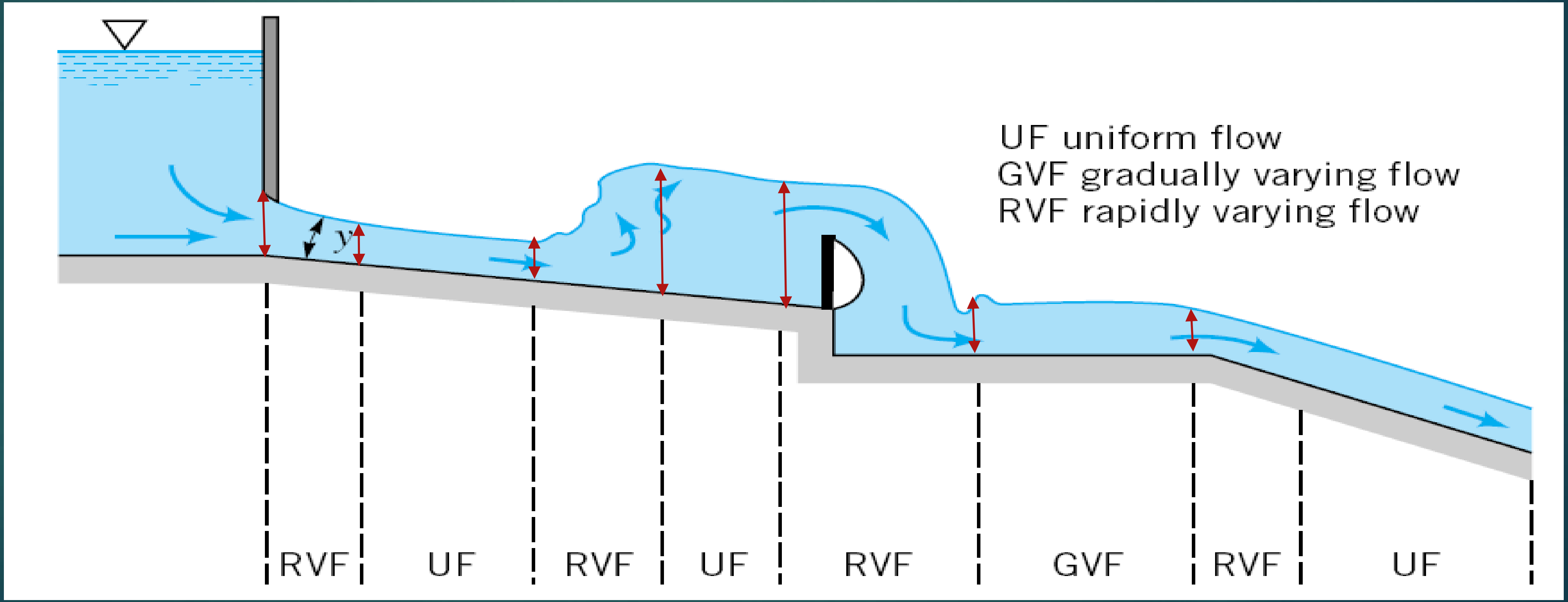
GRADUALLY VARIED FLOW

Gradually Varied Flow In Open Channels

- Flow control is any feature that imposes a relationship between the flow depth
- and discharge in a channel.
- A critical flow section, for instance, is a flow control, since at this section Fr=1.0.
- Likewise, various hydraulic structures such as weirs and gates will control the flow.
- Normal flow may be viewed as a flow control also because a normal flow equation, like Manning Equation, describes a depth-discharge relationship.
- However, sometimes the other controls will pull the flow away from the normal flow conditions.

Gradually Varied Flow In Open Channels

- The flow depth varies between two flow controls.
- Such a non-uniform flow is called gradually-varied flow if the changes in the flow depth are gradual.



Gradually Varied Flow In Open Channels

- To obtain an expression for gradually-varied flow, recall energy equation:

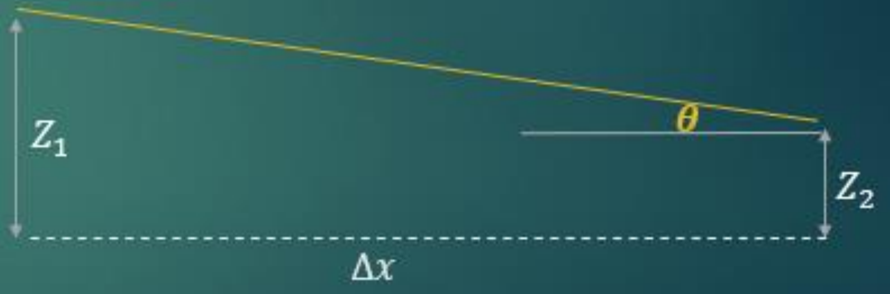
$$\frac{V_1^2}{2g}+y_1+Z_1=\frac{V_2^2}{2g}+y_2+Z_2$$

$$y_1+\frac{V_1^2}{2g}+S_0\Delta x=y_2+\frac{V_2^2}{2g}+S_f\Delta x$$

Proof is required

$$\frac{dy}{dx}=\frac{S_0-S_f}{1-Fr^2}$$

$$S_f=Tan\theta=\frac{h_L}{\Delta x}\rightarrow \boldsymbol{h_L=S_f\Delta x}$$



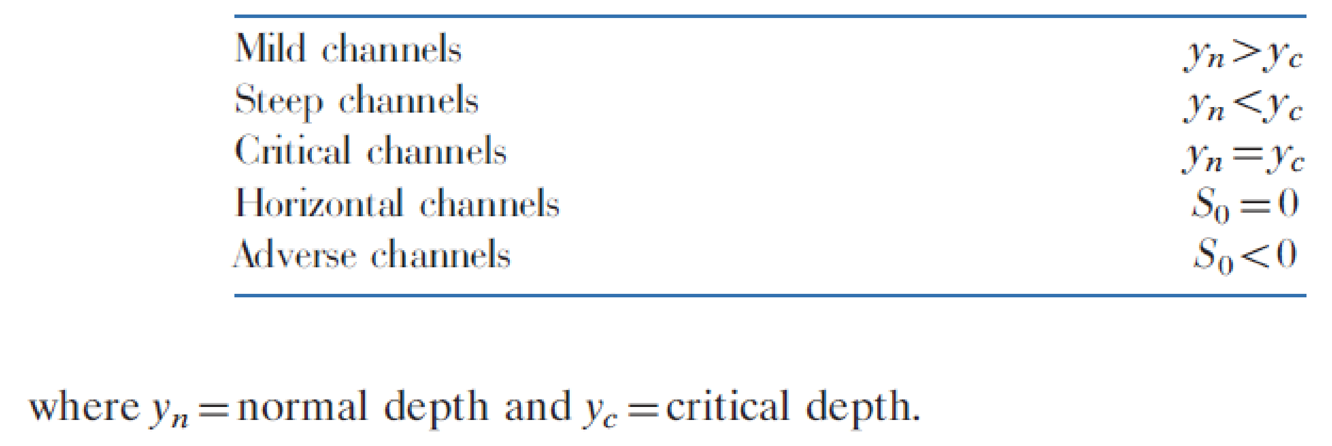
$$Tan\theta=\frac{Z_1-Z_2}{\Delta x}=S_0\rightarrow \boldsymbol{Z_1-Z_2=S_0\Delta x}$$

Gradually Varied Flow In Open Channels

- Open channels are classified as being mild, steep, critical, horizontal, and adverse in gradually-varied flow studies. If for a given discharge:
  - If the normal depth of a channel is greater than the critical depth, the channel is said to be **mild**.
  - If the normal depth is less than the critical depth, the channel is called **steep**.
  - For a **critical** channel, the normal depth and the critical depth are equal.
  - If the bottom slope of a channel is zero, the channel is called **horizontal**.
  - A channel is said to have an adverse slope if the channel bottom rises in the flow direction.

Gradually Varied Flow In Open Channels

- A gradually-varied flow profile or gradually-varied water surface profile is a line indicating the position of the water surface.



Mild channels	$y_n > y_c$
Steep channels	$y_n < y_c$
Critical channels	$y_n = y_c$
Horizontal channels	$S_0 = 0$
Adverse channels	$S_0 < 0$

where y_n = normal depth and y_c = critical depth.

- It is a plot of the flow depth as a function of distance along the flow direction.
- A sound understanding of possible profiles under different flow situations is essential before we can obtain numerical solutions to gradually-varied flow problems.

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$$

Classification of Surface Profiles

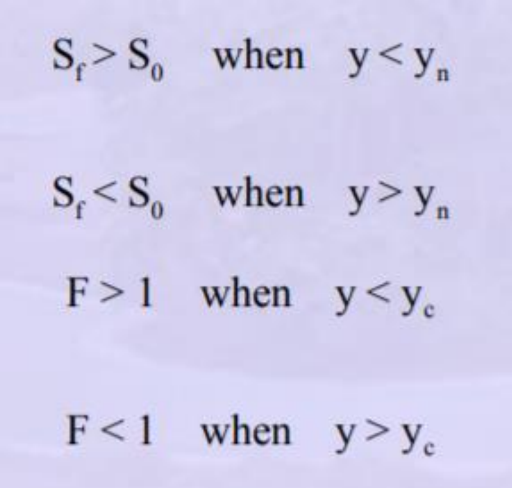
We have three depths here:

Actual depth of flow (y)   Normal depth of flow (y_n)   Critical depth of flow (y_c)

For a given discharge:

1. If the actual flow depth is greater than both normal and critical depths = Zone 1
2. Between the normal and critical depths = Zone 2
3. Less than both normal and critical depths = Zone 3

Note: Both Fr and S_f are functions of the depth, y. In fact, both Fr and S_f will decrease as y increases.



$S_f > S_0$ when $y < y_n$

$S_f < S_0$ when $y > y_n$

$F > 1$ when $y < y_c$

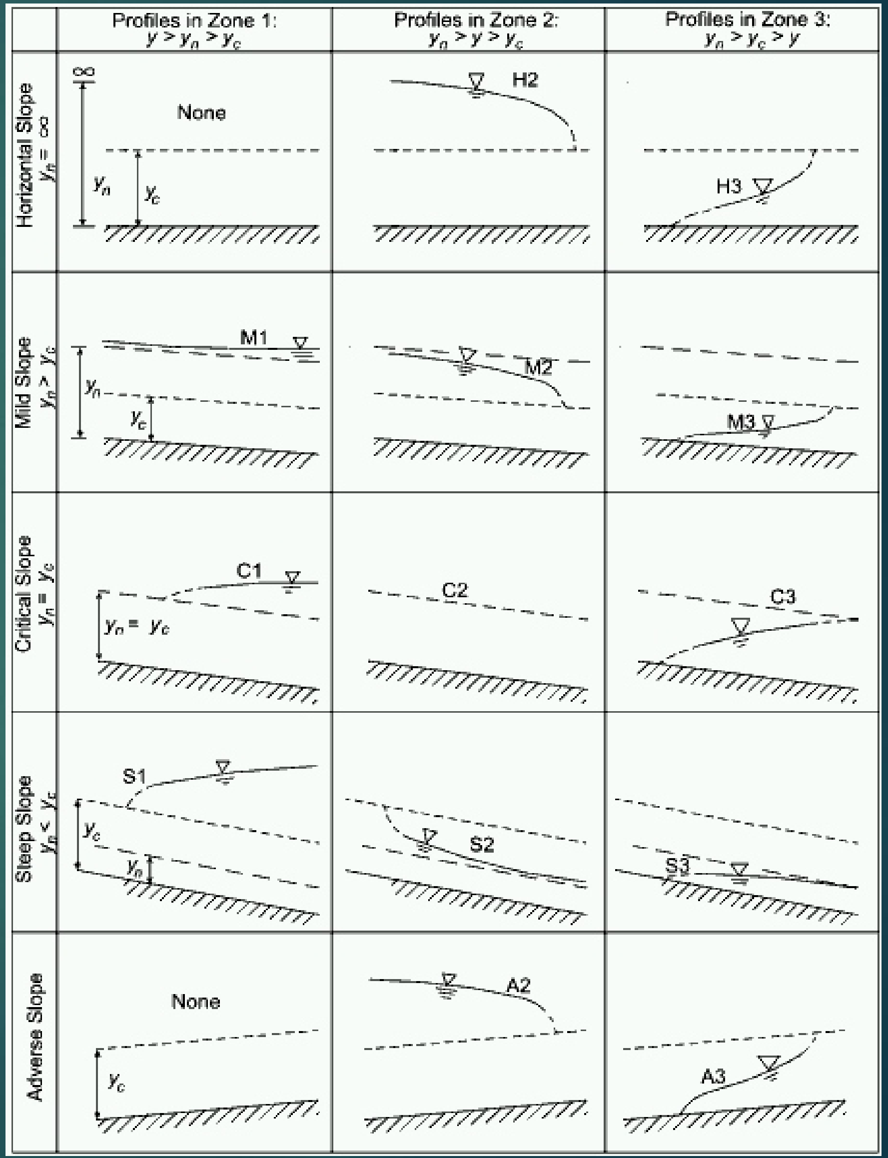
$F < 1$ when $y > y_c$

Classification of Surface Profiles

So, water surface profiles classified into two different ways:

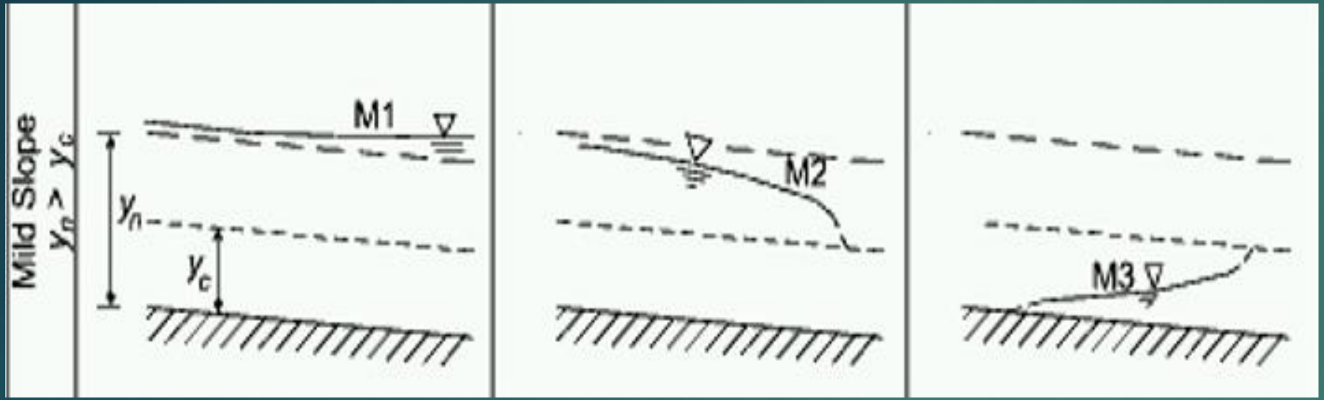
1. According to the slope of channel (**M**ild, **S**teep, **C**ritical, **H**orizontal, or **A**dverse)
2. According to the actual depth of flow in relation to the critical and normal depth (zone 1,2 and 3)

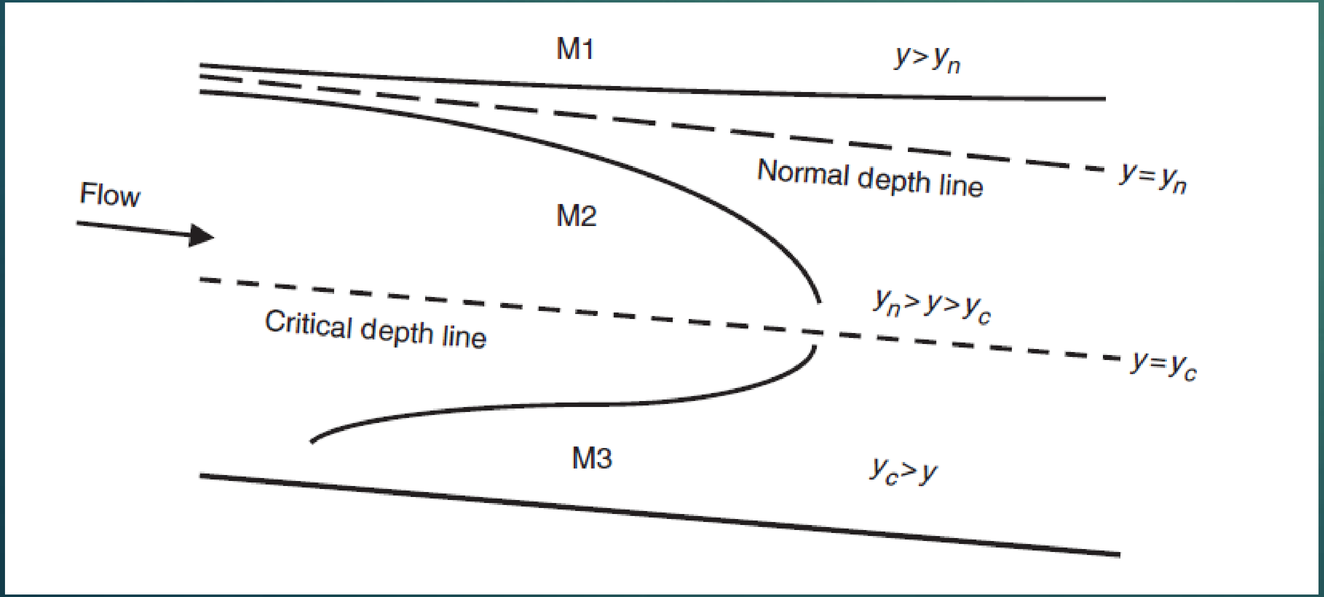
The first letter of slope (M, S, C, H, or A) in combination with 1, 2, or 3 defines the type of surface profile.



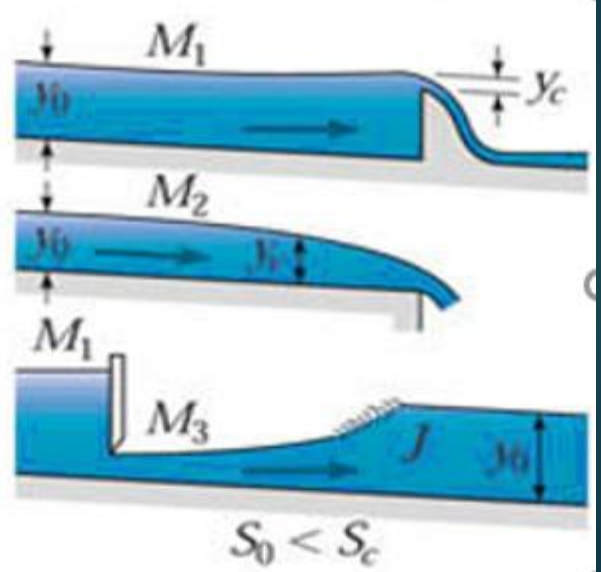
Classification of Surface Profiles

Mild (**M**): The normal depth is **greater** than critical depth





$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$$

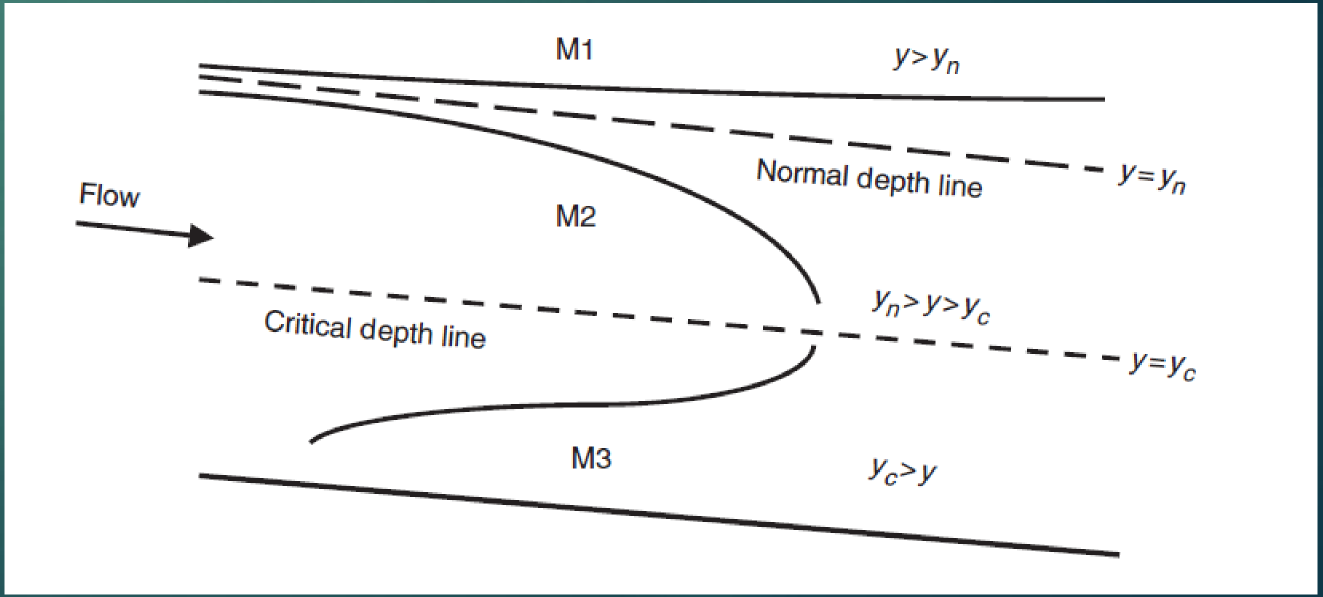


Classification of Surface Profiles

The channel bottom, the critical depth line, and the normal depth line divide the channel into three zones in the vertical dimension, namely M1, M2, and M3.

The solid lines in the figure represent the shapes of the possible flow profiles in these three zones.

Obviously, the normal depth line itself would represent the water surface if the flow in the channel were normal.



Classification of Surface Profiles

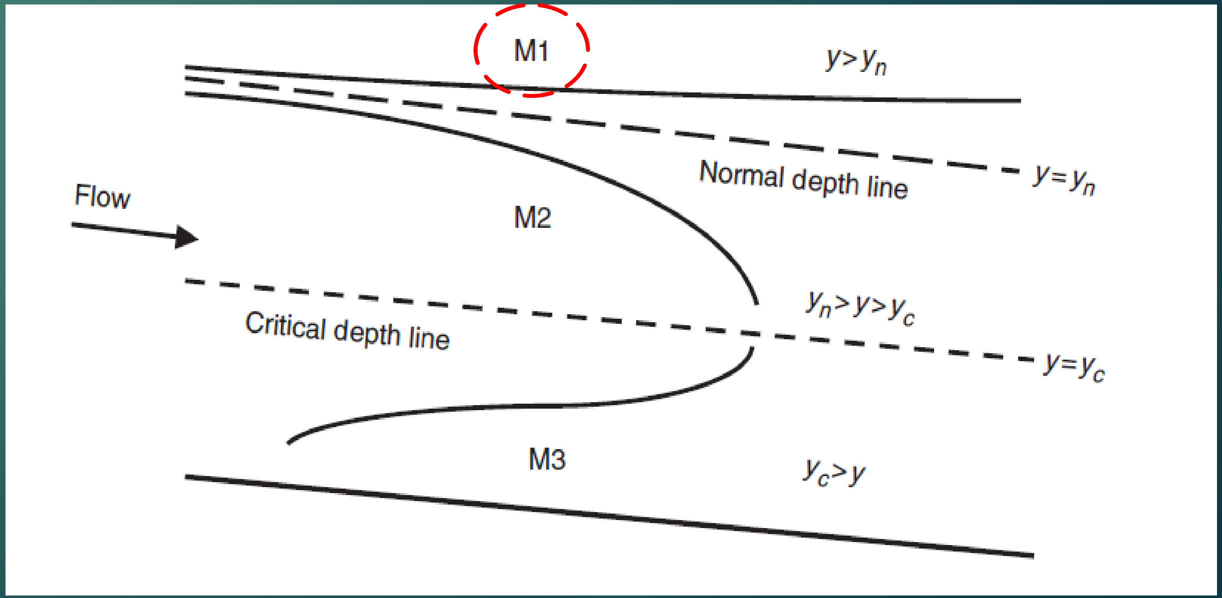
In zone M1, the water surface is above the normal depth line. Therefore, in this zone $y > y_n$ and consequently $S_f < S_0$.

Also, $y > y_C$ and thus $Fr < 1.0$ in zone M1.

Therefore, both the numerator and the denominator are positive quantities, and $dy/dx > 0$.

In other words, the flow depth must increase in the flow direction in zone M1.

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$$



Classification of Surface Profiles

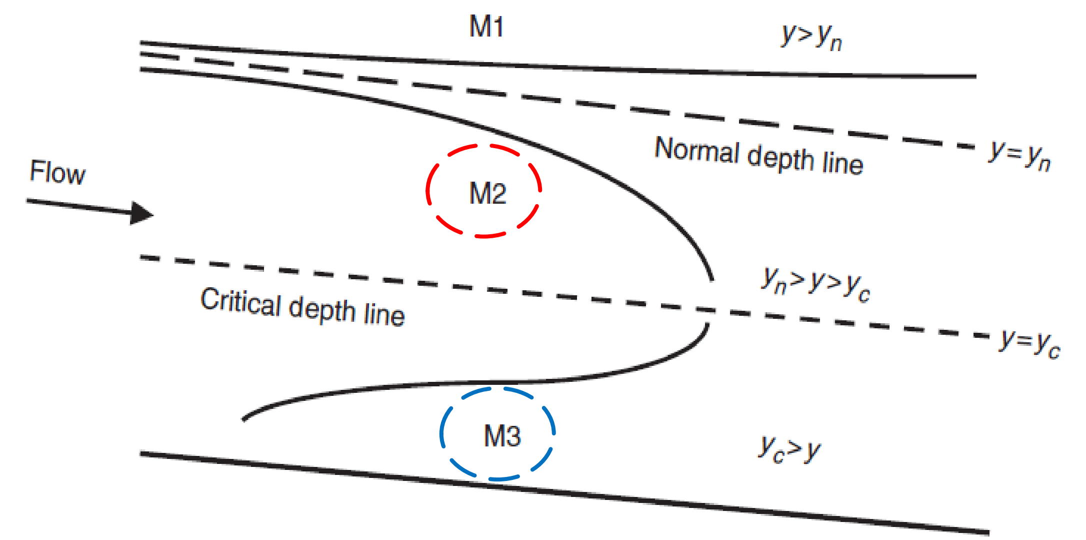
In the zones M2:

$y < y_n$ and consequently $S_f > S_0$

$y > y_c$ and thus $Fr < 1.0$

−

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$$



In zone M3:

$y < y_n$ and consequently $S_f > S_0$

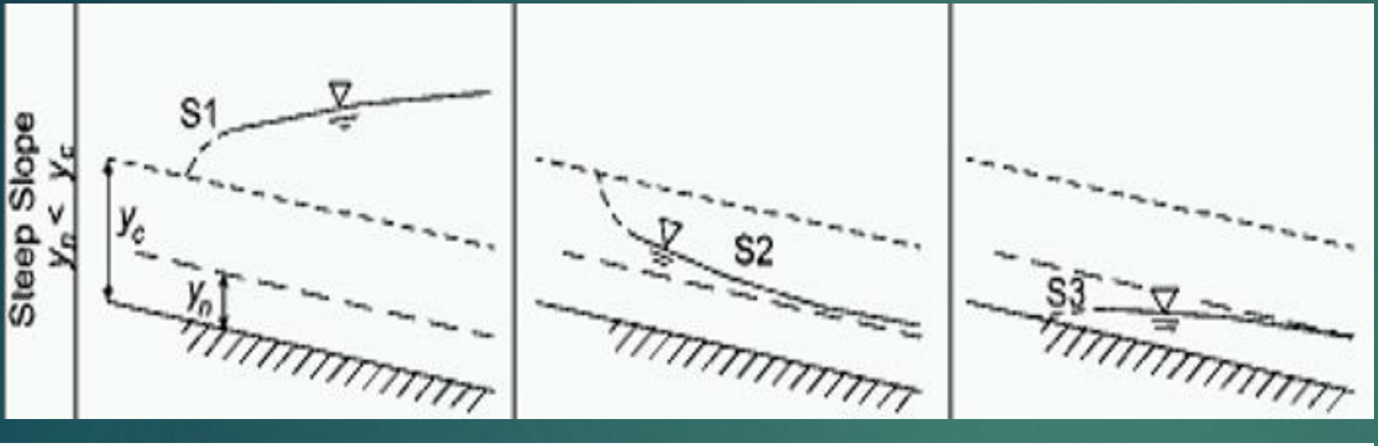
$y < y_c$ and thus $Fr > 1.0$

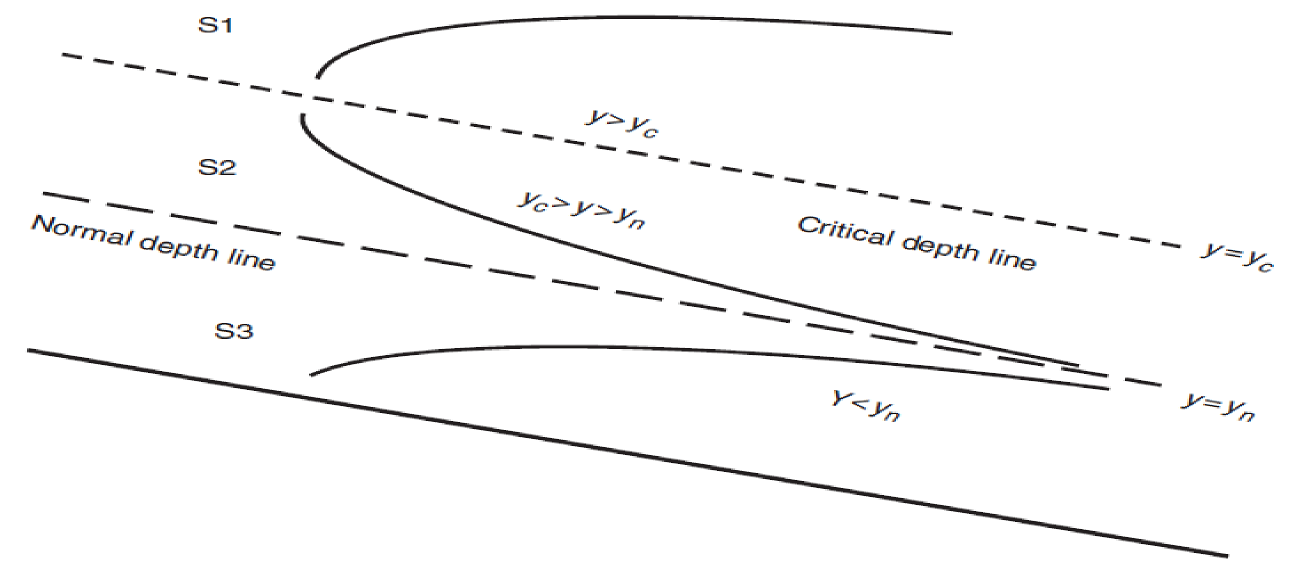
+

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$$

Classification of Surface Profiles

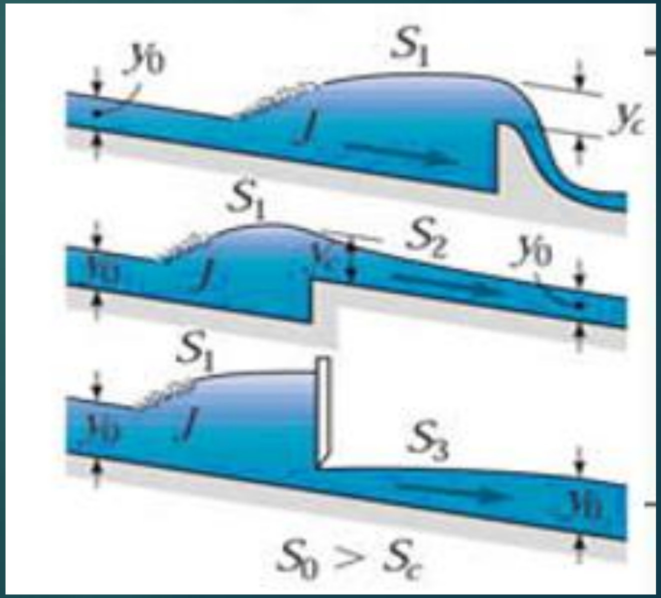
Steep (**S**): The normal depth is **less** than critical depth





$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$$

±



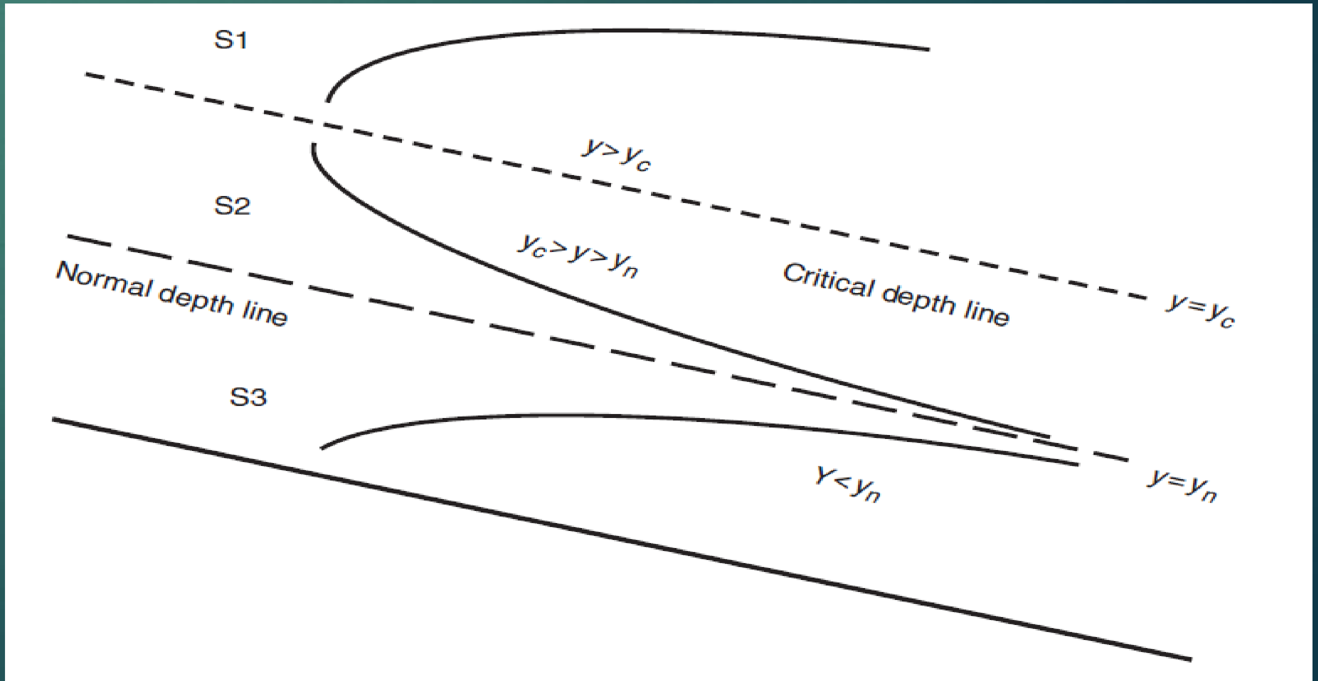
Classification of Surface Profiles

For a steep channel, $y_n > y_C$ by definition.

The channel bottom, the normal depth line, and the critical depth line divide the channel into three zones in the vertical dimension, namely S1, S2, and S3.

As before, the solid lines in the figure represent the shapes of the possible flow profiles in these three zones.

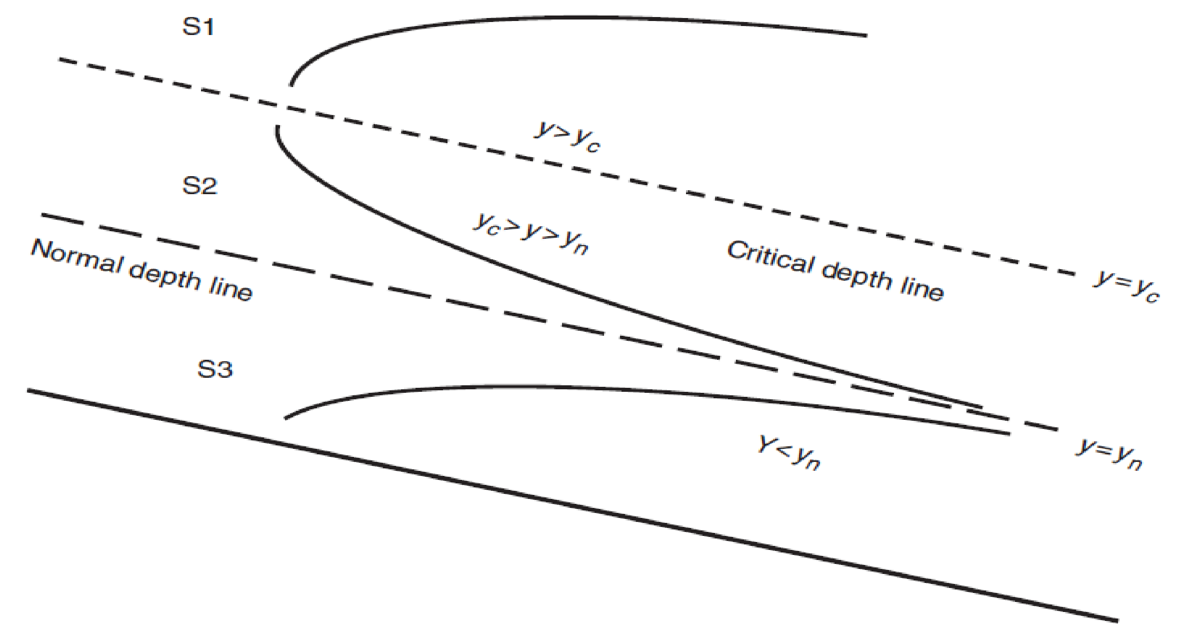
If the flow were normal in this channel, the normal depth line itself would represent the water surface.



Classification of Surface Profiles

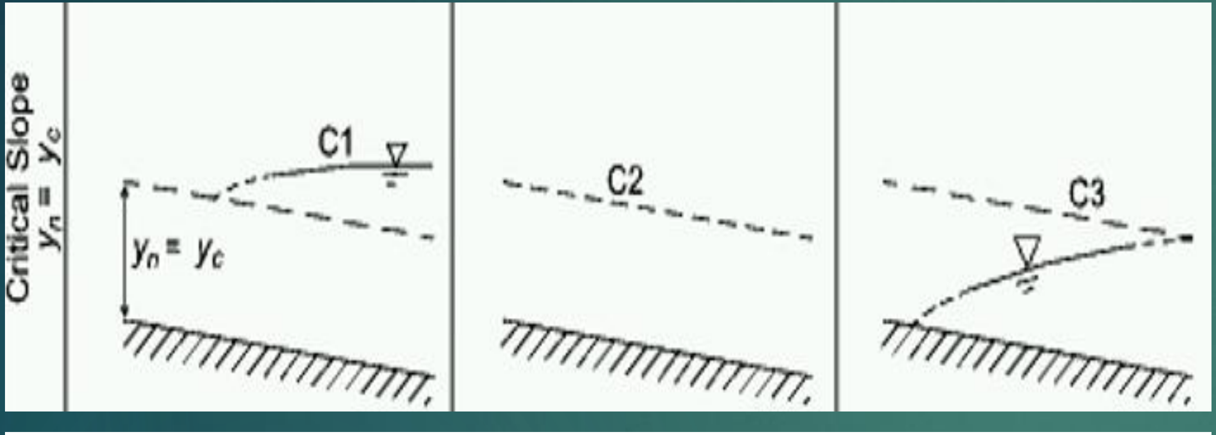
- In zone S1 the water surface is above the critical depth line, therefore in this zone $y > y_C$ and thus $Fr < 1$. Also, $y > y_C > y_n$, and consequently $S_f < S_o$.
- Therefore, both the numerator and the denominator of equation are positive quantities, and in zone S1 $\left(\frac{dy}{dx}\right) > 0$. In other words, the flow depth must increase in the flow direction.

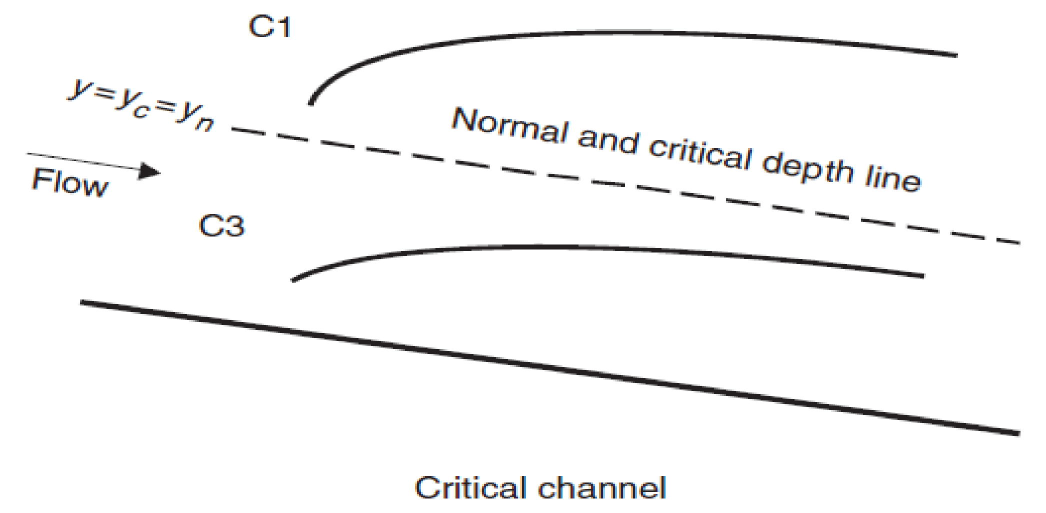
- We can examine the zones S2 and S3 in a similar manner, and conclude that $\left(\frac{dy}{dx}\right) < 0$ in zone S2 and $\left(\frac{dy}{dx}\right) > 0$ in zone S3.



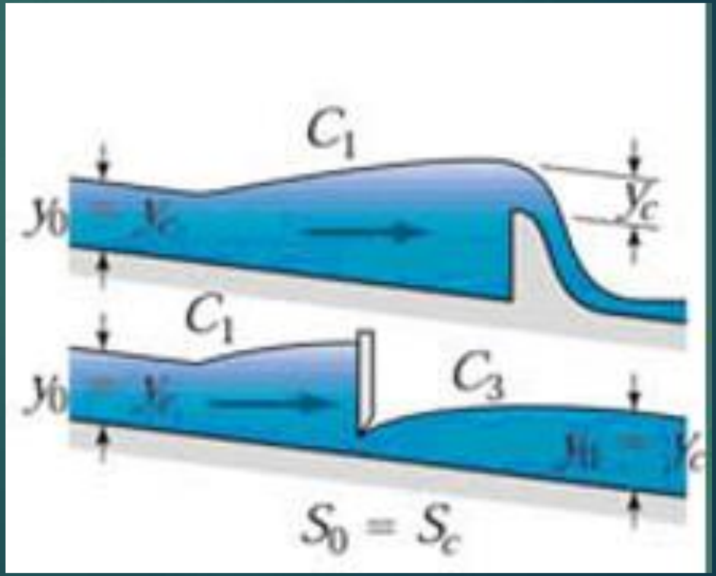
Classification of Surface Profiles

Critical (**C**): The normal depth equals critical depth



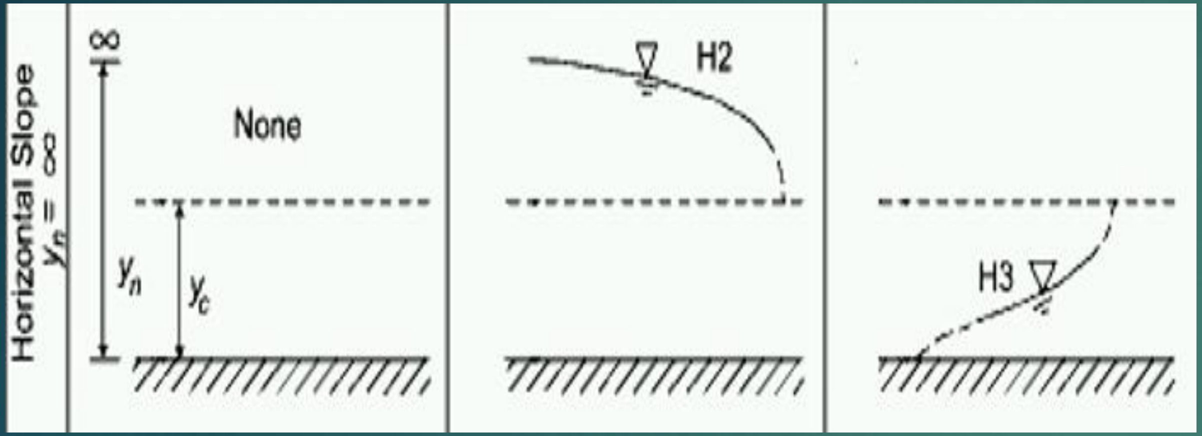


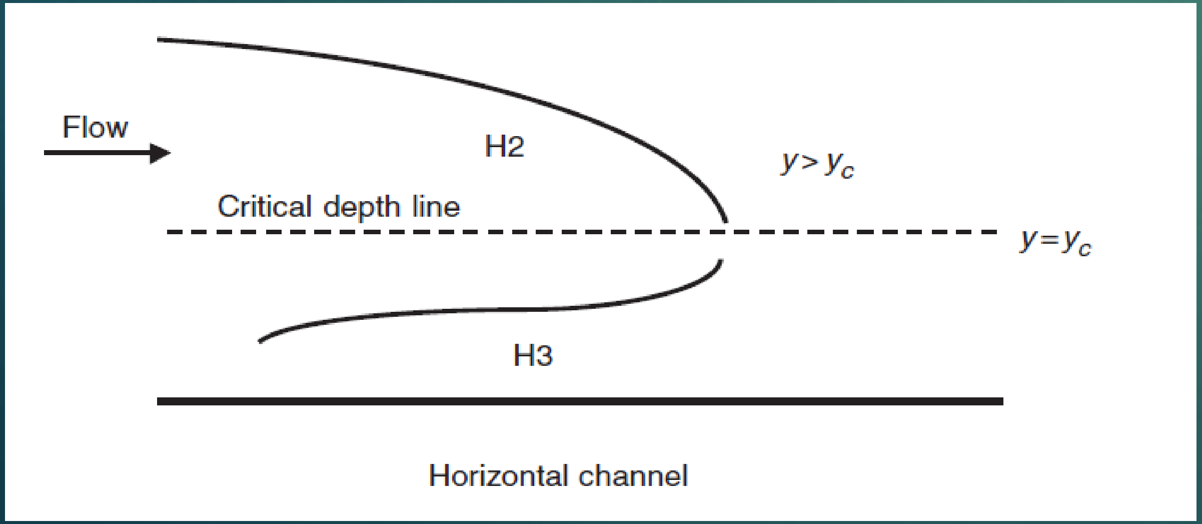
$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$$



Classification of Surface Profiles

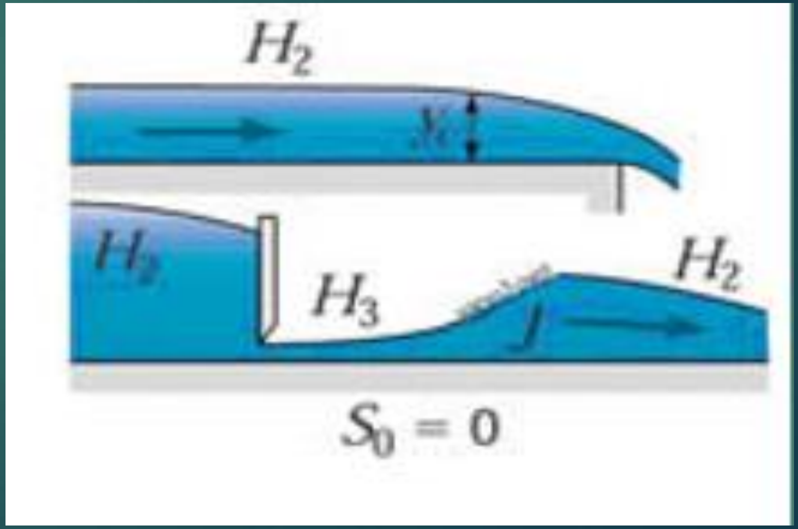
Horizontal (**H**): There is no normal depth.





±

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$$

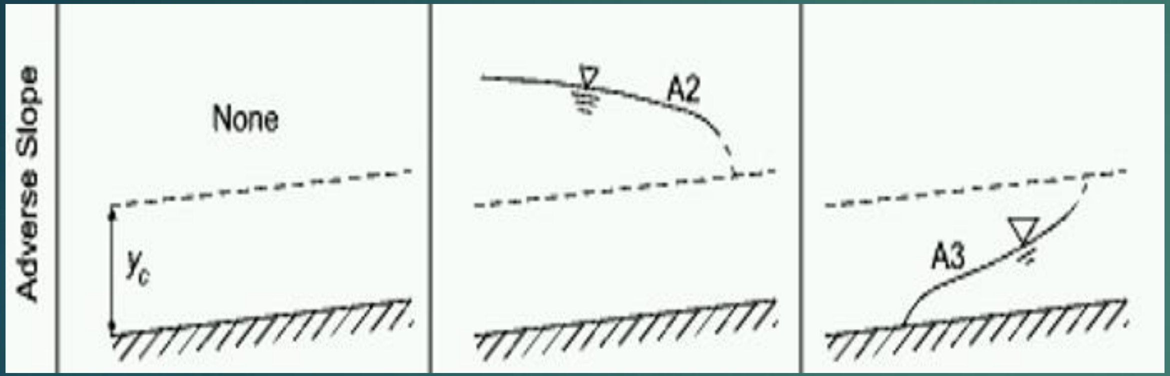


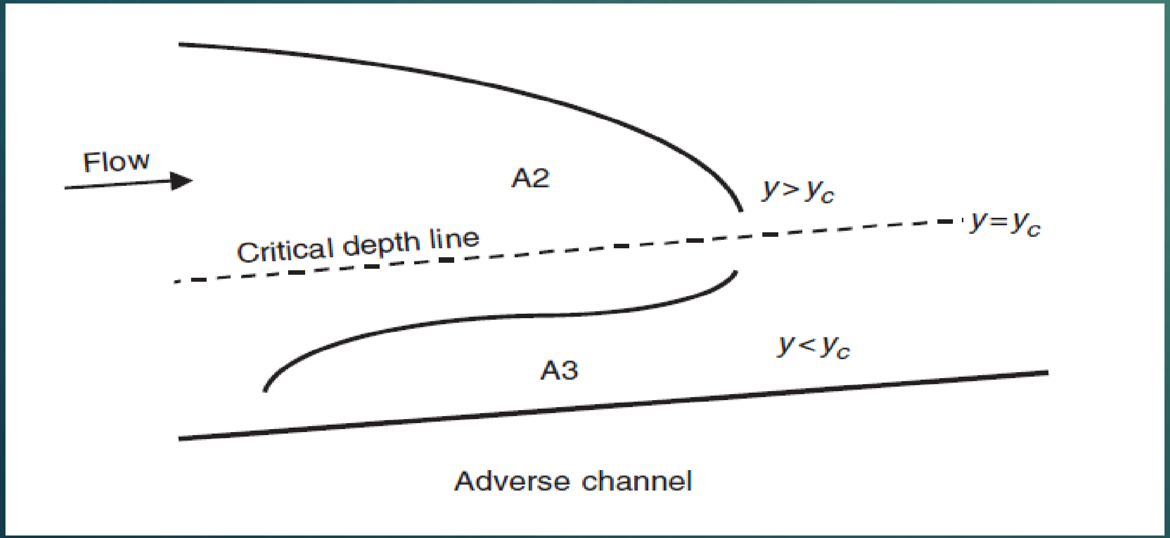
Classification of Surface Profiles

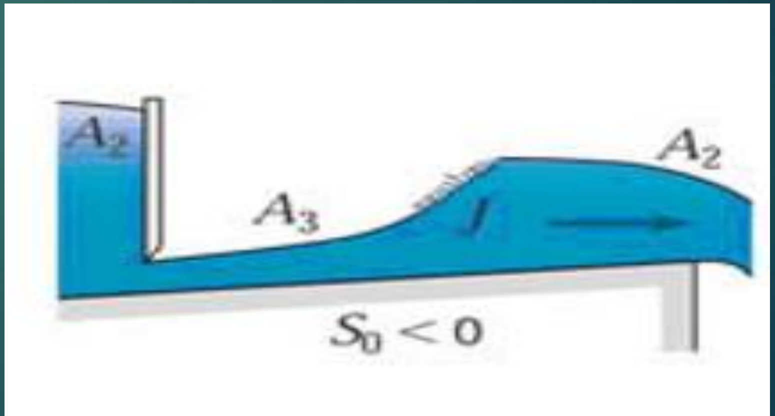
Adverse (**A**): There is no normal depth.

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - Fr^2}$$

±





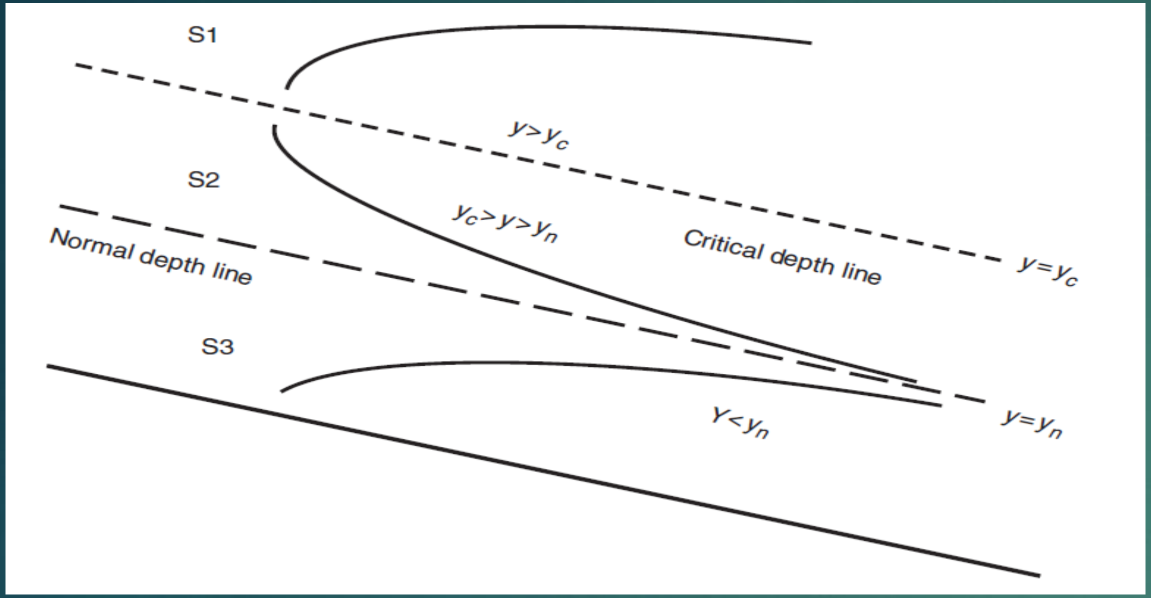


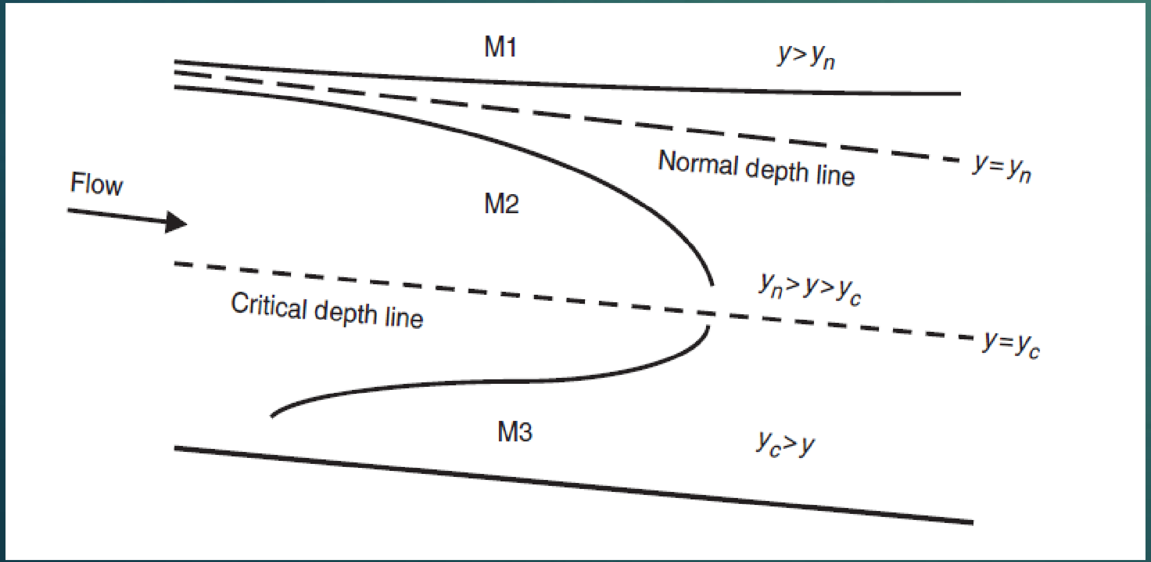
Classification of Surface Profiles

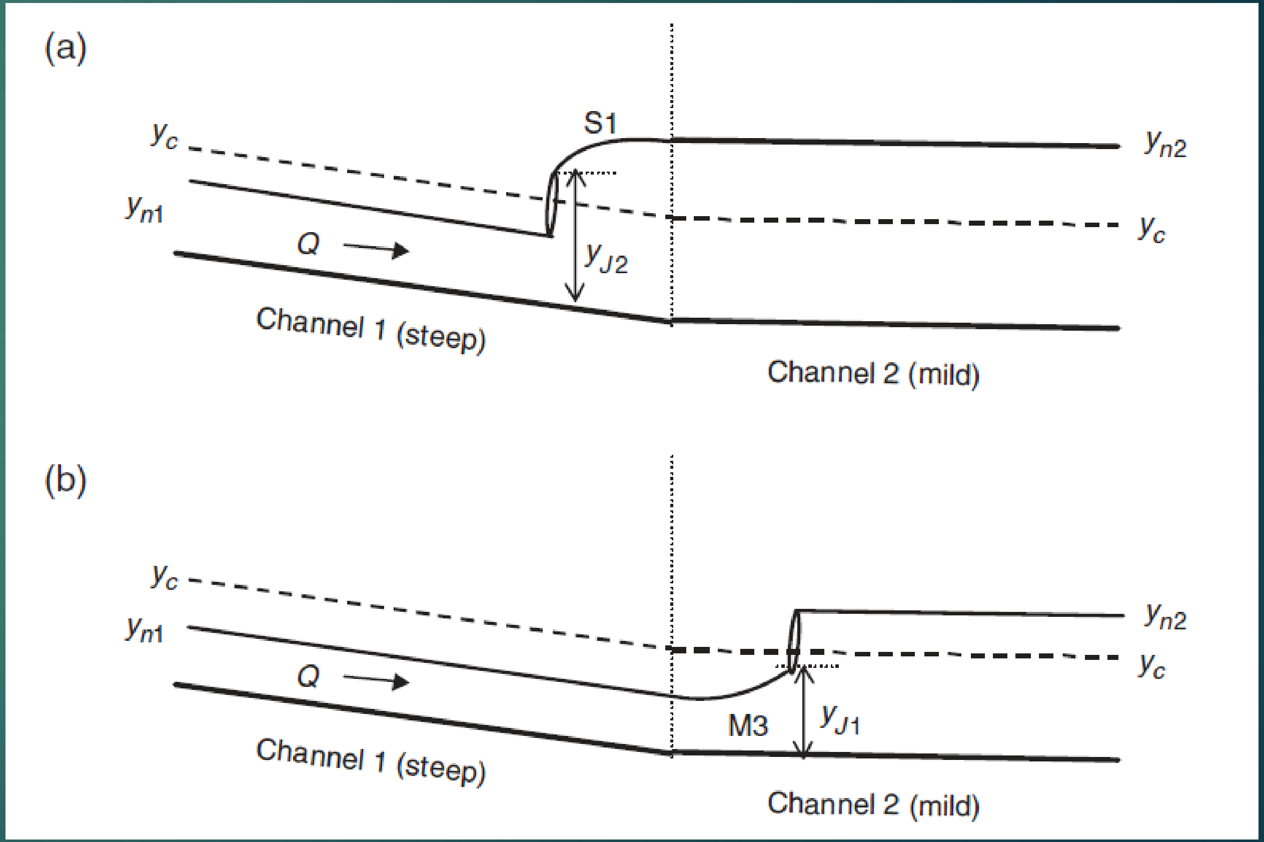
Example 4-1

A very long rectangular channel (channel 1) has a width of $b = 10ft$, Manning roughness factor of $n = 0.020$, and a bottom slope of $S_0 = 0.02$. It carries a discharge of $Q = 300\, cfs$. This channel joins another channel (channel 2) downstream, that has identical properties except for a slope of $S_0 = 0.005$. Determine the type of water surface profile occurring in these two channels.

Classification of Surface Profiles







Classification of Surface Profiles

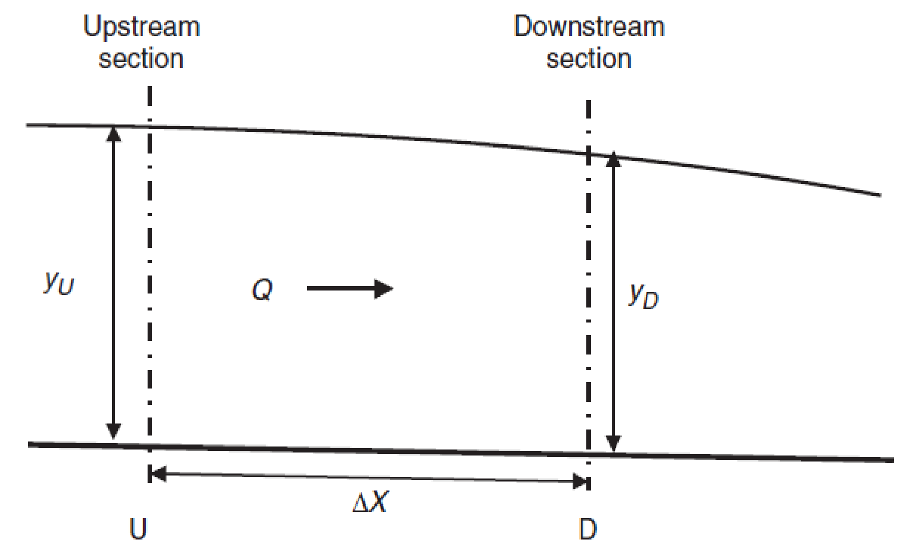
Example 4-2

Suppose in Example 4.1 the slope of channel 2 were $S_0 = 0.001$. Determine whether the hydraulic jump would occur in channel 1 or channel 2.

Quantitative Evaluation of Surface Profile

In practice, most surface profiles are generated by numerical integration, which is, by dividing the channel into reaches and carrying the computation of water surface evaluation from one end of reach to the other.

- Consider the channel reach shown in having a length of Δx.
- Sections U and D denote the flow sections at the upstream and downstream ends of the reach, respectively.
- Using the subscripts U and D to denote the upstream and downstream sections, we can write energy equation as:



Quantitative Evaluation of Surface Profile

The applicable equation is:

$$\frac{V_{\mathrm{U}}^2}{2g} + y_U + Z_{\mathrm{U}} = \frac{V_{\mathrm{D}}^2}{2g} + y_{\mathrm{D}} + Z_{\mathrm{D}}$$

$$\frac{V_{\mathrm{U}}^2}{2g} + y_U = \frac{V_{\mathrm{D}}^2}{2g} + y_{\mathrm{D}} + (S_f - S_0)\Delta x$$

$$\underbrace{E_U}_{\frac{V_{\mathrm{U}}^2}{2g}+y_{\mathrm{U}}} = \underbrace{E_D}_{\frac{V_{\mathrm{D}}^2}{2g}+y_{\mathrm{D}}} + (S_f - S_0)\Delta x$$

$$\Delta x = \frac{E_U - E_D}{S_f - S_0}$$

$$\Delta x = \frac{E_D - E_U}{S_0 - S_{fm}}$$

Quantitative Evaluation of Surface Profile

Where S_{fm} is:

$$S_{fm} = \frac{1}{2}\left(S_{fu} + S_{fD}\right)$$

By rearranging the Manning formula, the friction slopes at sections U and D are obtained as:

$$S_{fU} = \frac{n^2}{K_n^2}\frac{V_U^2}{R_U^{4/3}}$$

$$S_{fD} = \frac{n^2}{K_n^2}\frac{V_D^2}{R_D^{4/3}}$$

Quantitative Evaluation of Surface Profile

The two most common methods used to perform the gradually-varied flow calculations are the direct step method and the standard step method.

Direct Step Method

In this method, the depth and velocity are known at a given section of the channel (one end of the reach), and one arbitrarily chooses the depth at the other end of the reach. Then the length of the reach is solved for.

$$\Delta x = \frac{E_D - E_U}{S_0 - S_{fm}} = \frac{(y_D + V_D^2/2g) - (y_U + V_U^2/2g)}{S_0 - S_{fm}}$$

This method is called the direct step method, since the reach length is obtained directly from the Equation without any trial and error.

Quantitative Evaluation of Surface Profile

- For subcritical flow calculations, we start from the downstream end of a channel and proceed in the upstream direction.
- At downstream, y_D is known.
- Using the known discharge and the cross-sectional properties, we first calculate V_D, and S_{fD}.
- Next we pick a value for y_U and calculate the corresponding V_U, S_{fU}.
- Then, from Equation, we determine the channel reach Δx.

$$\Delta x = \frac{E_D - E_U}{S_0 - S_{fm}} = \frac{(y_D + V_D^2/2g) - (y_U + V_U^2/2g)}{S_0 - S_{fm}}$$

Quantitative Evaluation of Surface Profile

- This process is repeated for further upstream reaches until the entire length of the channel is covered.
- Note that y_U of any reach becomes y_D for the reach considered next.
- Also, we must be careful in picking the values for y_U. These values depend on the type of the profile that will occur in the channel.
- For example, if an M2 profile is being calculated, y_U must satisfy the inequalities $y_U > y_D$ and $y_n > y_U > y_C$.
- Likewise, for an S1 profile, $y_U < y_D$ and $y_U > y_C > y_n$.

Quantitative Evaluation of Surface Profile

- For supercritical profiles, we start at the upstream end and proceed in the downstream direction.

- For the first reach, y_U is known from the upstream boundary condition.

- We choose a value for y_D and calculate the reach length, Δx.

- This process is repeated for further downstream reaches until the length of the channel is covered. The y_D of any reach becomes y_U of the subsequent reach.

- The values of y_D must be chosen carefully in the process. For instance, for M3 profiles, $y_D > y_U$ and $y_D < y_C < y_n$.

- Likewise, for S2 profiles, $y_D > y_U$ and $y_n < y_D < y_C$.

Quantitative Evaluation of Surface Profile

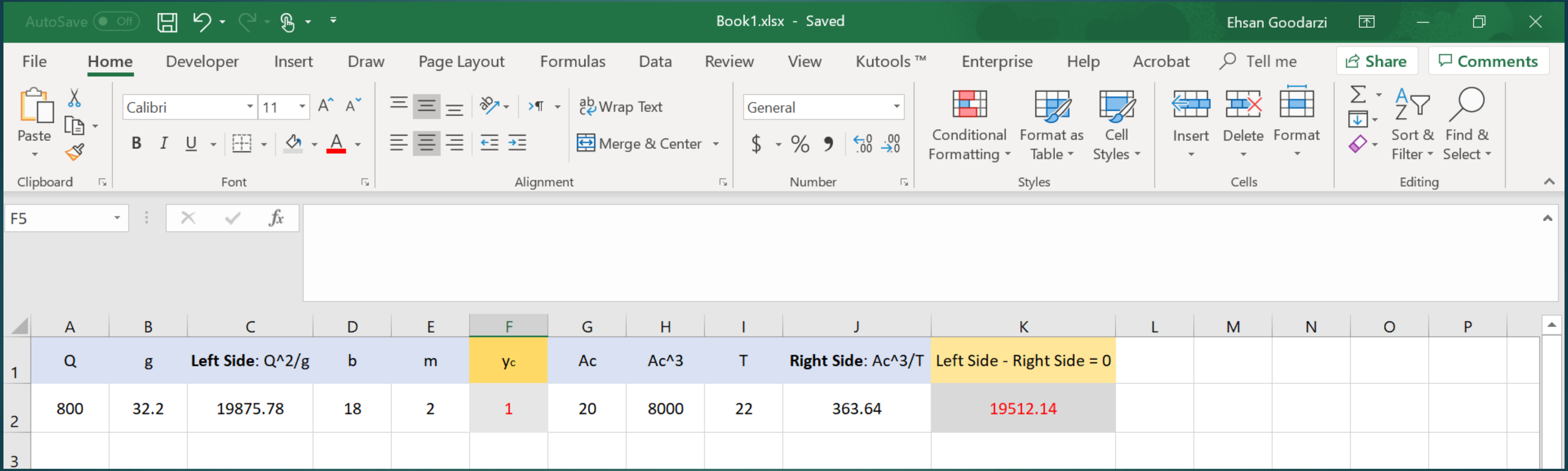
- In certain situations, the flow depths at both ends of a surface profile will be known and we can perform the calculations to determine the total length of the profile.
- In such a case we can start from either the upstream end or the downstream end, regardless of whether the flow is subcritical or supercritical.
- However, a downstream boundary condition is always known for subcritical flow, and an upstream boundary condition is always known for supercritical flow.
- Therefore, it is reasonable to adopt the general rule that subcritical flow calculations start at the downstream end, and supercritical flow calculations start at the upstream end.

Quantitative Evaluation of Surface Profile

Example 4-3

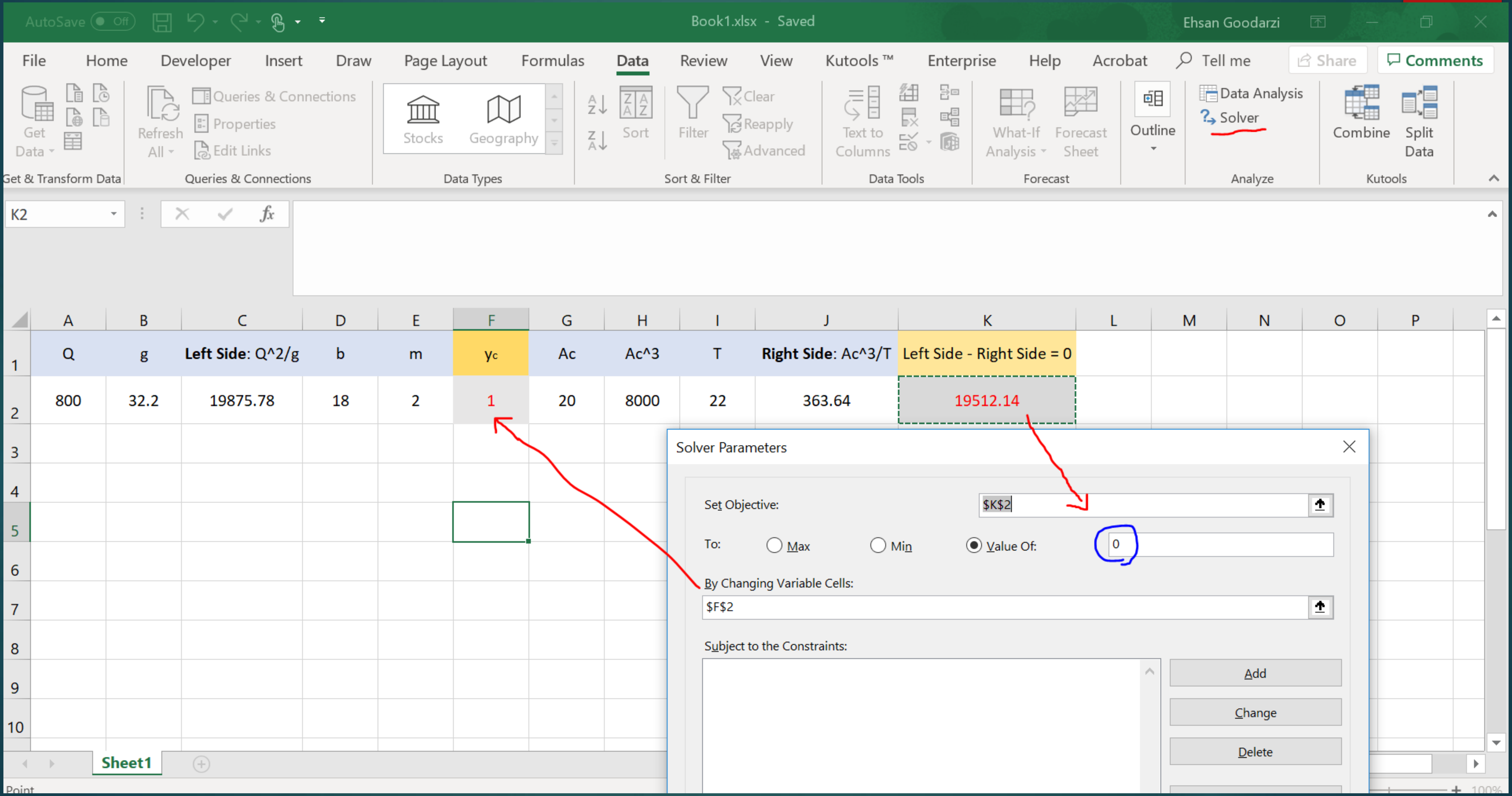
A very long trapezoidal canal has $b = 18\ ft$, $m = 2.0$, $S_0 = 0.001$, and $n = 0.020$, and it carries $Q = 800\ cfs$. The canal terminates at a <u>free fall</u>. Calculate the water surface profile.

Quantitative Evaluation of Surface Profile



	A	B	C	D	E	F	G	H	I	J	K
1	Q	g	**Left Side**: Q^2/g	b	m	y_c	Ac	Ac^3	T	**Right Side**: Ac^3/T	Left Side - Right Side = 0
2	800	32.2	19875.78	18	2	1	20	8000	22	363.64	19512.14
3											

Quantitative Evaluation of Surface Profile



	A	B	C	D	E	F	G	H	I	J	K
1	Q	g	**Left Side**: Q^2/g	b	m	yc	Ac	Ac^3	T	**Right Side**: Ac^3/T	Left Side - Right Side = 0
2	800	32.2	19875.78	18	2	1	20	8000	22	363.64	19512.14

Solver Parameters

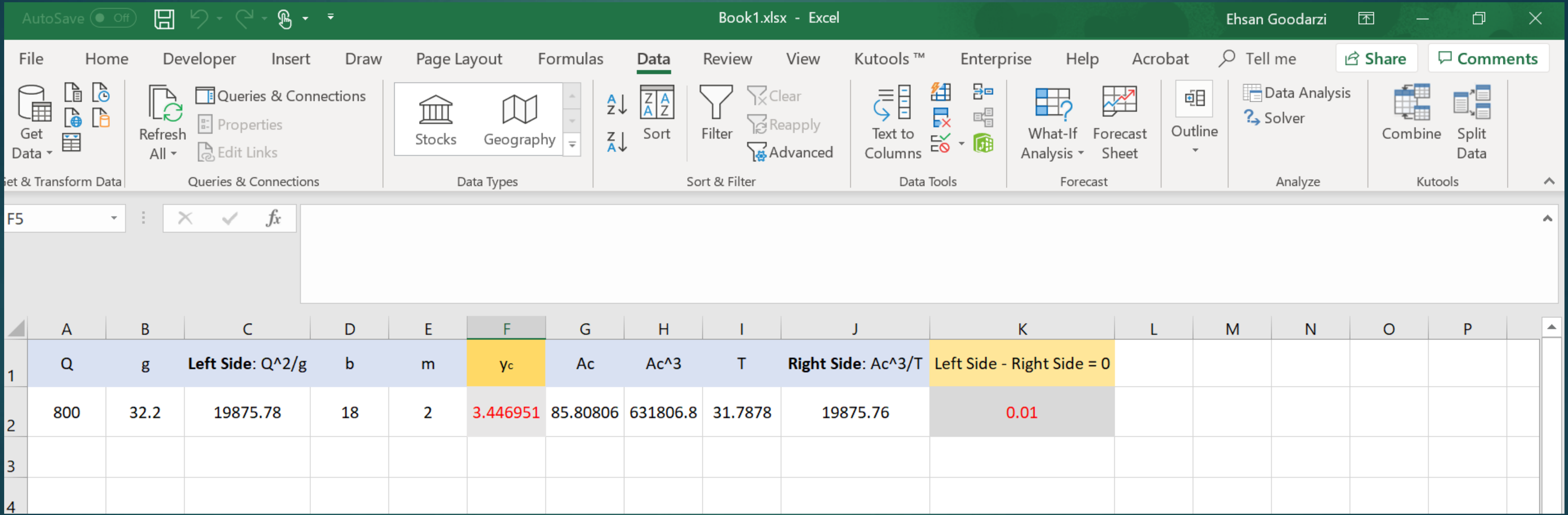
Set Objective: K2

To: ○ Max ○ Min ● Value Of: 0

By Changing Variable Cells:
F2

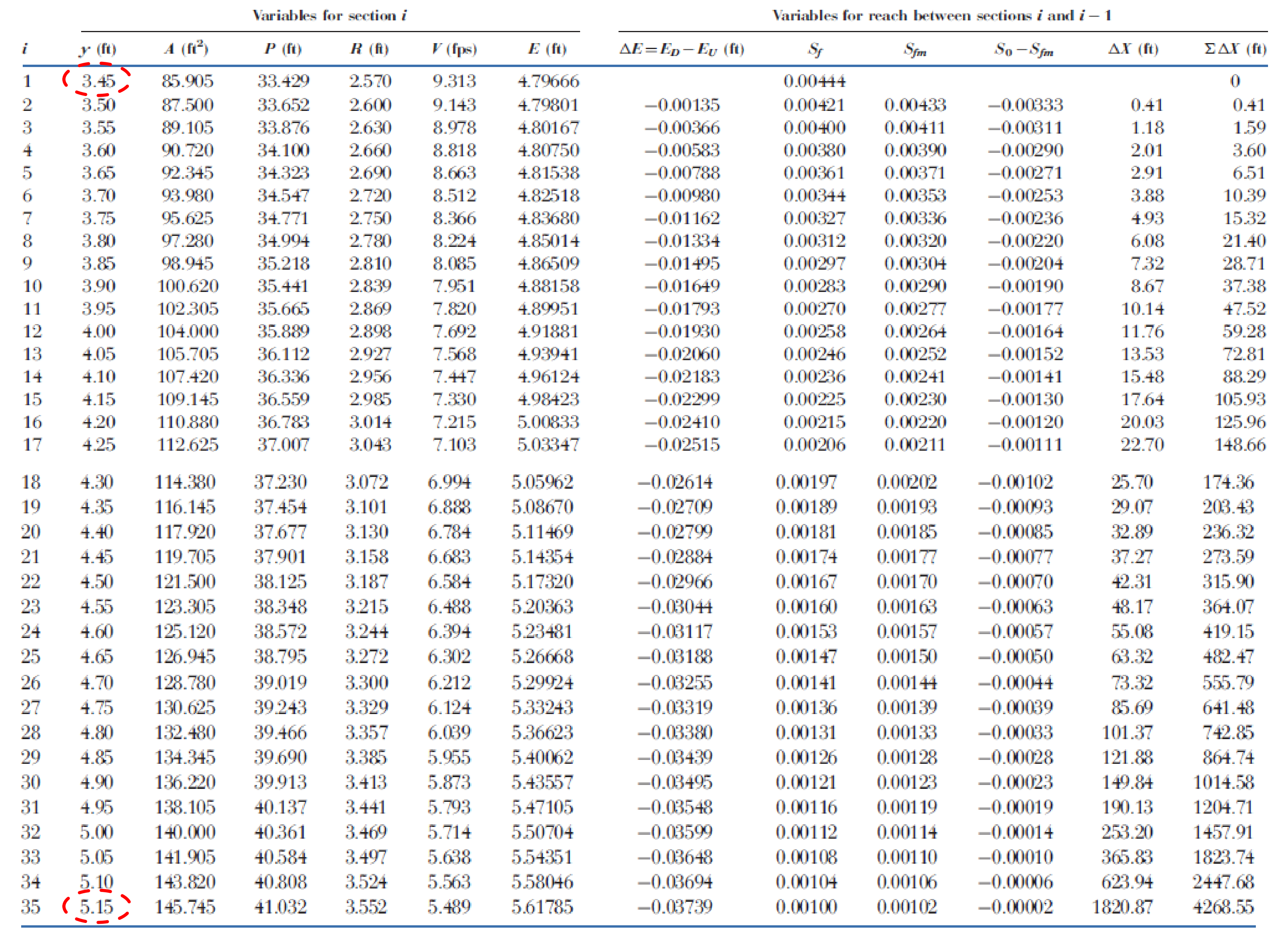
Subject to the Constraints:

Quantitative Evaluation of Surface Profile



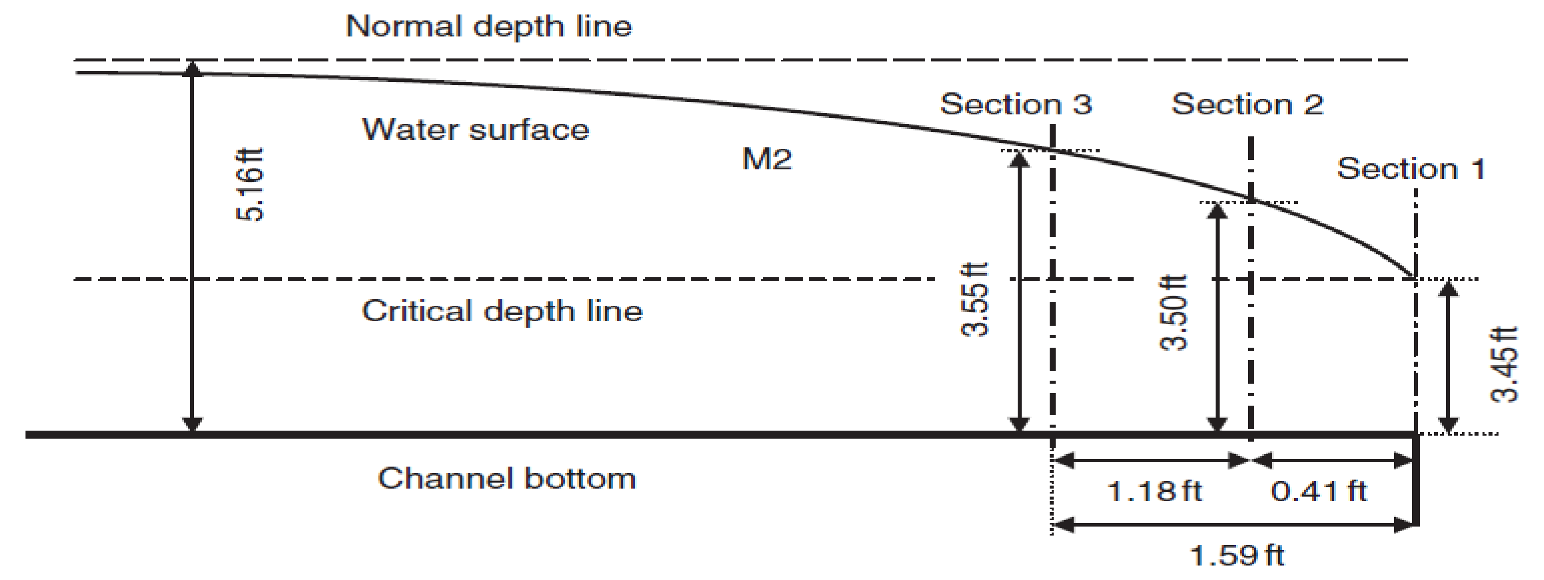
Q	g	**Left Side**: Q^2/g	b	m	y_c	Ac	Ac^3	T	**Right Side**: Ac^3/T	Left Side - Right Side = 0
800	32.2	19875.78	18	2	3.446951	85.80806	631806.8	31.7878	19875.76	0.01

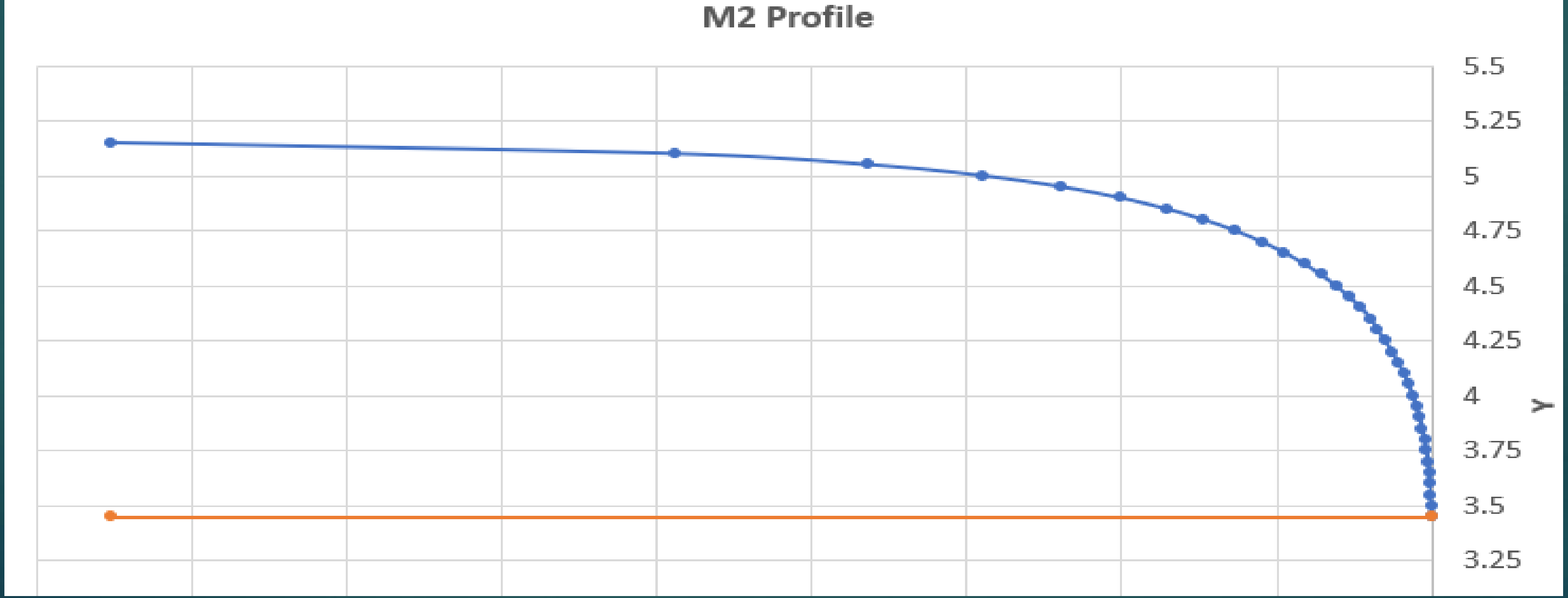
Quantitative Evaluation of Surface Profile



	Variables for section i						Variables for reach between sections i and $i-1$					
i	y (ft)	A (ft^2)	P (ft)	R (ft)	V (fps)	E (ft)	$\Delta E = E_D - E_U$ (ft)	S_f	S_{fm}	$S_0 - S_{fm}$	ΔX (ft)	$\Sigma \Delta X$ (ft)
1	3.45	85.905	33.429	2.570	9.313	4.79666		0.00444				0
2	3.50	87.500	33.652	2.600	9.143	4.79801	−0.00135	0.00421	0.00433	−0.00333	0.41	0.41
3	3.55	89.105	33.876	2.630	8.978	4.80167	−0.00366	0.00400	0.00411	−0.00311	1.18	1.59
4	3.60	90.720	34.100	2.660	8.818	4.80750	−0.00583	0.00380	0.00390	−0.00290	2.01	3.60
5	3.65	92.345	34.323	2.690	8.663	4.81538	−0.00788	0.00361	0.00371	−0.00271	2.91	6.51
6	3.70	93.980	34.547	2.720	8.512	4.82518	−0.00980	0.00344	0.00353	−0.00253	3.88	10.39
7	3.75	95.625	34.771	2.750	8.366	4.83680	−0.01162	0.00327	0.00336	−0.00236	4.93	15.32
8	3.80	97.280	34.994	2.780	8.224	4.85014	−0.01334	0.00312	0.00320	−0.00220	6.08	21.40
9	3.85	98.945	35.218	2.810	8.085	4.86509	−0.01495	0.00297	0.00304	−0.00204	7.32	28.71
10	3.90	100.620	35.441	2.839	7.951	4.88158	−0.01649	0.00283	0.00290	−0.00190	8.67	37.38
11	3.95	102.305	35.665	2.869	7.820	4.89951	−0.01793	0.00270	0.00277	−0.00177	10.14	47.52
12	4.00	104.000	35.889	2.898	7.692	4.91881	−0.01930	0.00258	0.00264	−0.00164	11.76	59.28
13	4.05	105.705	36.112	2.927	7.568	4.93941	−0.02060	0.00246	0.00252	−0.00152	13.53	72.81
14	4.10	107.420	36.336	2.956	7.447	4.96124	−0.02183	0.00236	0.00241	−0.00141	15.48	88.29
15	4.15	109.145	36.559	2.985	7.330	4.98423	−0.02299	0.00225	0.00230	−0.00130	17.64	105.93
16	4.20	110.880	36.783	3.014	7.215	5.00833	−0.02410	0.00215	0.00220	−0.00120	20.03	125.96
17	4.25	112.625	37.007	3.043	7.103	5.03347	−0.02515	0.00206	0.00211	−0.00111	22.70	148.66
18	4.30	114.380	37.230	3.072	6.994	5.05962	−0.02614	0.00197	0.00202	−0.00102	25.70	174.36
19	4.35	116.145	37.454	3.101	6.888	5.08670	−0.02709	0.00189	0.00193	−0.00093	29.07	203.43
20	4.40	117.920	37.677	3.130	6.784	5.11469	−0.02799	0.00181	0.00185	−0.00085	32.89	236.32
21	4.45	119.705	37.901	3.158	6.683	5.14354	−0.02884	0.00174	0.00177	−0.00077	37.27	273.59
22	4.50	121.500	38.125	3.187	6.584	5.17320	−0.02966	0.00167	0.00170	−0.00070	42.31	315.90
23	4.55	123.305	38.348	3.215	6.488	5.20363	−0.03044	0.00160	0.00163	−0.00063	48.17	364.07
24	4.60	125.120	38.572	3.244	6.394	5.23481	−0.03117	0.00153	0.00157	−0.00057	55.08	419.15
25	4.65	126.945	38.795	3.272	6.302	5.26668	−0.03188	0.00147	0.00150	−0.00050	63.32	482.47
26	4.70	128.780	39.019	3.300	6.212	5.29924	−0.03255	0.00141	0.00144	−0.00044	73.32	555.79
27	4.75	130.625	39.243	3.329	6.124	5.33243	−0.03319	0.00136	0.00139	−0.00039	85.69	641.48
28	4.80	132.480	39.466	3.357	6.039	5.36623	−0.03380	0.00131	0.00133	−0.00033	101.37	742.85
29	4.85	134.345	39.690	3.385	5.955	5.40062	−0.03439	0.00126	0.00128	−0.00028	121.88	864.74
30	4.90	136.220	39.913	3.413	5.873	5.43557	−0.03495	0.00121	0.00123	−0.00023	149.84	1014.58
31	4.95	138.105	40.137	3.441	5.793	5.47105	−0.03548	0.00116	0.00119	−0.00019	190.13	1204.71
32	5.00	140.000	40.361	3.469	5.714	5.50704	−0.03599	0.00112	0.00114	−0.00014	253.20	1457.91
33	5.05	141.905	40.584	3.497	5.638	5.54351	−0.03648	0.00108	0.00110	−0.00010	365.83	1823.74
34	5.10	143.820	40.808	3.524	5.563	5.58046	−0.03694	0.00104	0.00106	−0.00006	623.94	2447.68
35	5.15	145.745	41.032	3.552	5.489	5.61785	−0.03739	0.00100	0.00102	−0.00002	1820.87	4268.55

Quantitative Evaluation of Surface Profile





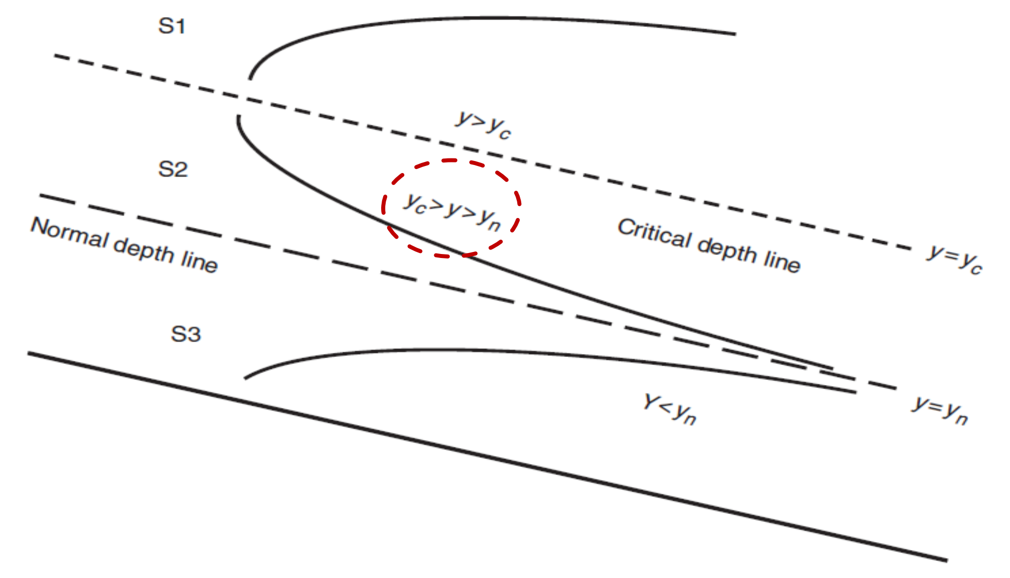
Quantitative Evaluation of Surface Profile

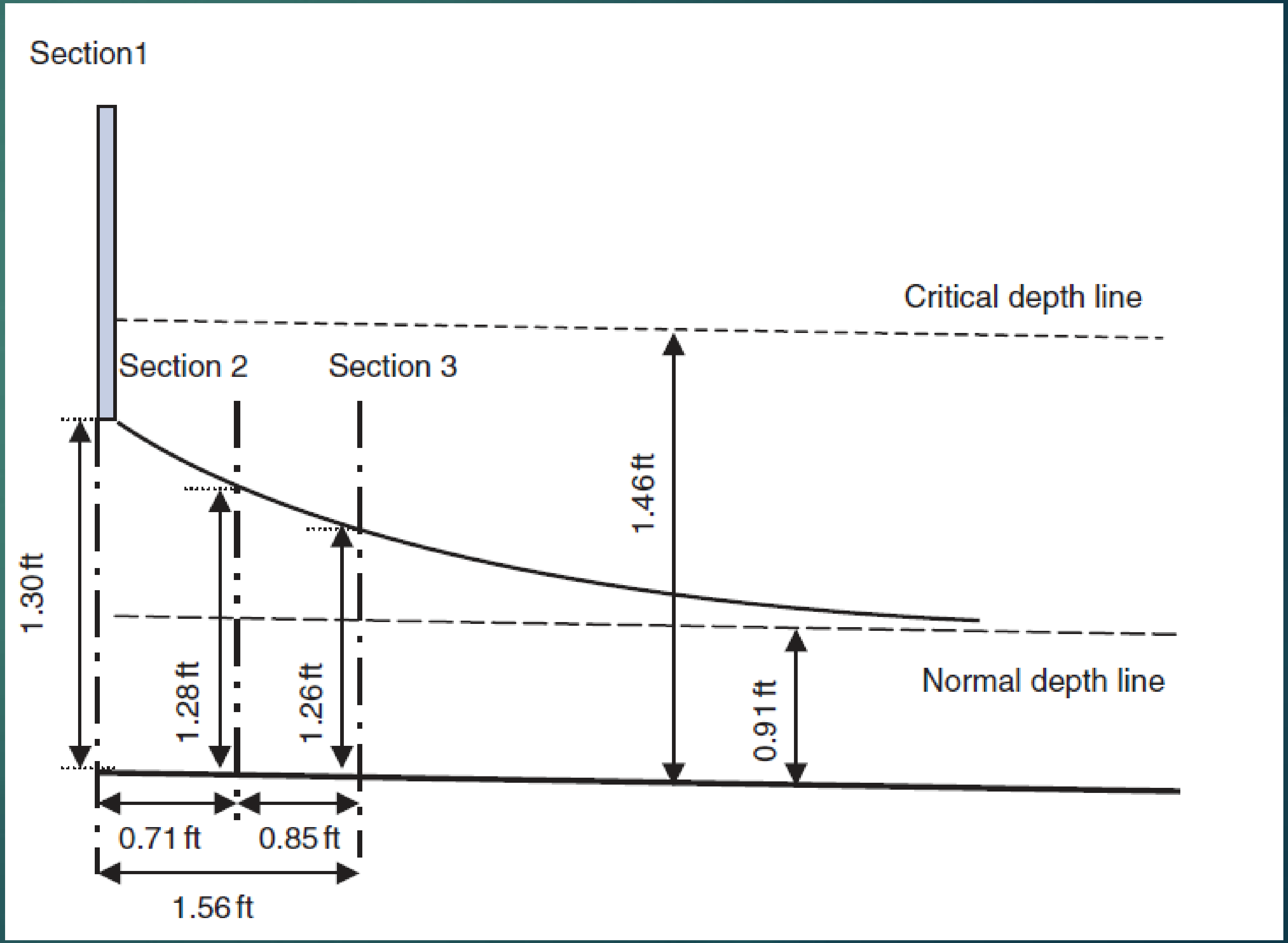
Example 4-4

Flow enters a long, rectangular flume at its upstream end from under a sluice gate. The flume has $b = 3\ ft$, $n = 0.013$, and $S_0 = 0.02$. The flow depth at the entrance is $1.30\ ft$ and the discharge is $30\ cfs$. Determine the water surface profile.

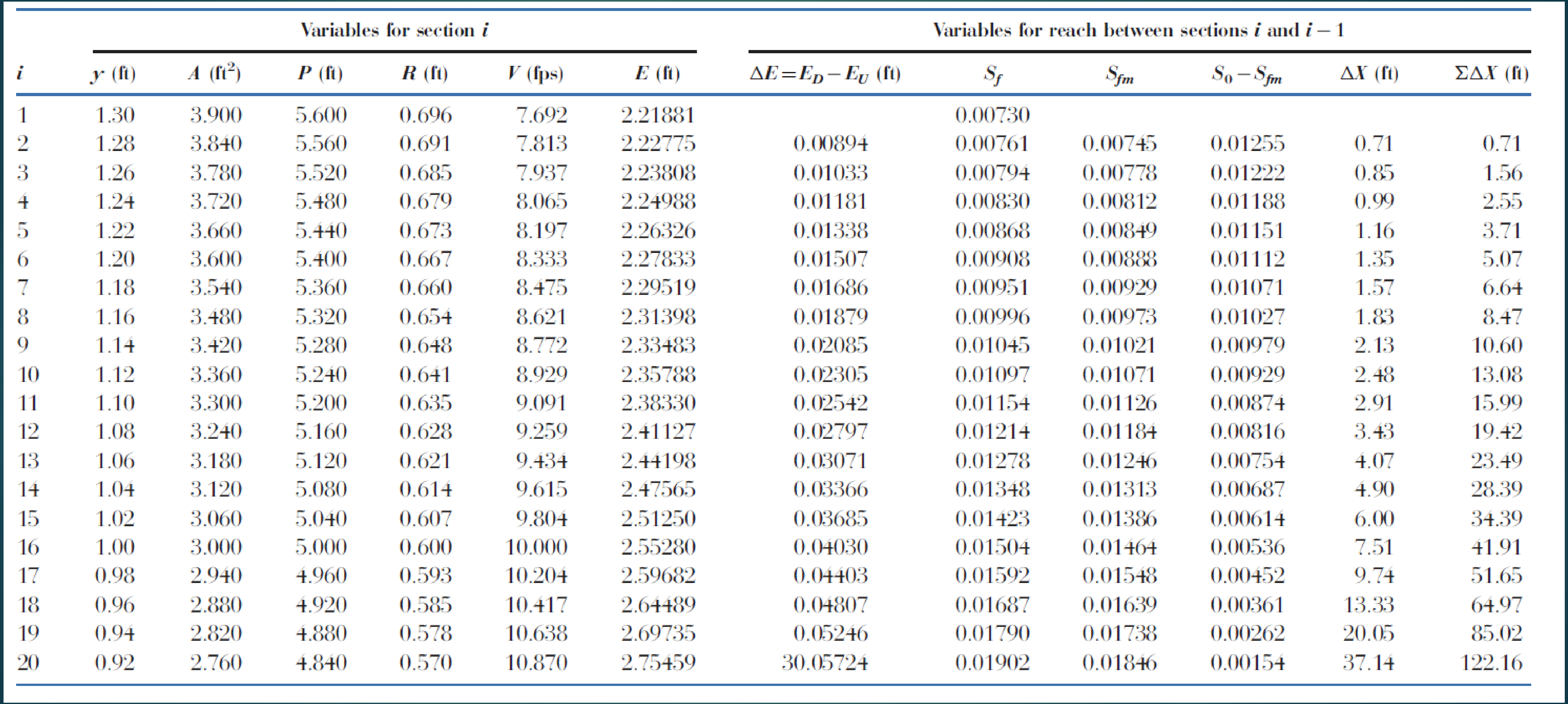
Quantitative Evaluation of Surface Profile

S2 Profile





Quantitative Evaluation of Surface Profile



	Variables for section i						Variables for reach between sections i and $i-1$					
i	y (ft)	A (ft^2)	P (ft)	R (ft)	V (fps)	E (ft)	$\Delta E = E_D - E_U$ (ft)	S_f	S_{fm}	$S_0 - S_{fm}$	ΔX (ft)	$\Sigma\Delta X$ (ft)
1	1.30	3.900	5.600	0.696	7.692	2.21881		0.00730				
2	1.28	3.840	5.560	0.691	7.813	2.22775	0.00894	0.00761	0.00745	0.01255	0.71	0.71
3	1.26	3.780	5.520	0.685	7.937	2.23808	0.01033	0.00794	0.00778	0.01222	0.85	1.56
4	1.24	3.720	5.480	0.679	8.065	2.24988	0.01181	0.00830	0.00812	0.01188	0.99	2.55
5	1.22	3.660	5.440	0.673	8.197	2.26326	0.01338	0.00868	0.00849	0.01151	1.16	3.71
6	1.20	3.600	5.400	0.667	8.333	2.27833	0.01507	0.00908	0.00888	0.01112	1.35	5.07
7	1.18	3.540	5.360	0.660	8.475	2.29519	0.01686	0.00951	0.00929	0.01071	1.57	6.64
8	1.16	3.480	5.320	0.654	8.621	2.31398	0.01879	0.00996	0.00973	0.01027	1.83	8.47
9	1.14	3.420	5.280	0.648	8.772	2.33483	0.02085	0.01045	0.01021	0.00979	2.13	10.60
10	1.12	3.360	5.240	0.641	8.929	2.35788	0.02305	0.01097	0.01071	0.00929	2.48	13.08
11	1.10	3.300	5.200	0.635	9.091	2.38330	0.02542	0.01154	0.01126	0.00874	2.91	15.99
12	1.08	3.240	5.160	0.628	9.259	2.41127	0.02797	0.01214	0.01184	0.00816	3.43	19.42
13	1.06	3.180	5.120	0.621	9.434	2.44198	0.03071	0.01278	0.01246	0.00754	4.07	23.49
14	1.04	3.120	5.080	0.614	9.615	2.47565	0.03366	0.01348	0.01313	0.00687	4.90	28.39
15	1.02	3.060	5.040	0.607	9.804	2.51250	0.03685	0.01423	0.01386	0.00614	6.00	34.39
16	1.00	3.000	5.000	0.600	10.000	2.55280	0.04030	0.01504	0.01464	0.00536	7.51	41.91
17	0.98	2.940	4.960	0.593	10.204	2.59682	0.04403	0.01592	0.01548	0.00452	9.74	51.65
18	0.96	2.880	4.920	0.585	10.417	2.64489	0.04807	0.01687	0.01639	0.00361	13.33	64.97
19	0.94	2.820	4.880	0.578	10.638	2.69735	0.05246	0.01790	0.01738	0.00262	20.05	85.02
20	0.92	2.760	4.840	0.570	10.870	2.75459	30.05724	0.01902	0.01846	0.00154	37.14	122.16

APPLICATIONS OF GRADUALLY-VARIED FLOW

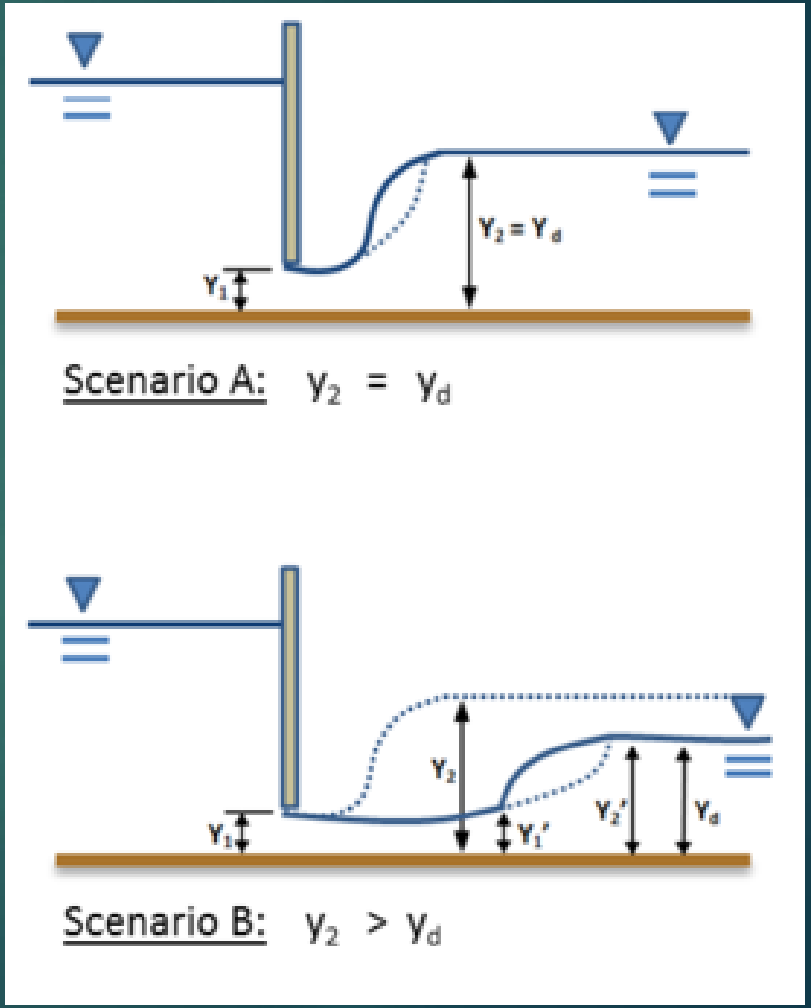
LOCATING HYDRAULIC JUMPS

- To determine the jump location in a channel, we need to use the jump equation along with the gradually-varied flow calculations.
- The jump length is usually negligible compared to the length of a channel. Therefore, we often perform these calculations assuming that the jump occurs vertically.
- The flow depths, y_{J1} and y_{J2}, just upstream and downstream of the jump should satisfy the jump equation.

APPLICATIONS OF GRADUALLY-VARIED FLOW

- If there is gradually-varied flow upstream of the jump, y_{J1} should also satisfy the gradually varied equations upstream.

- Likewise, if there is gradually varied flow downstream, then y_{J2} should also satisfy the downstream gradually-varied flow equations.

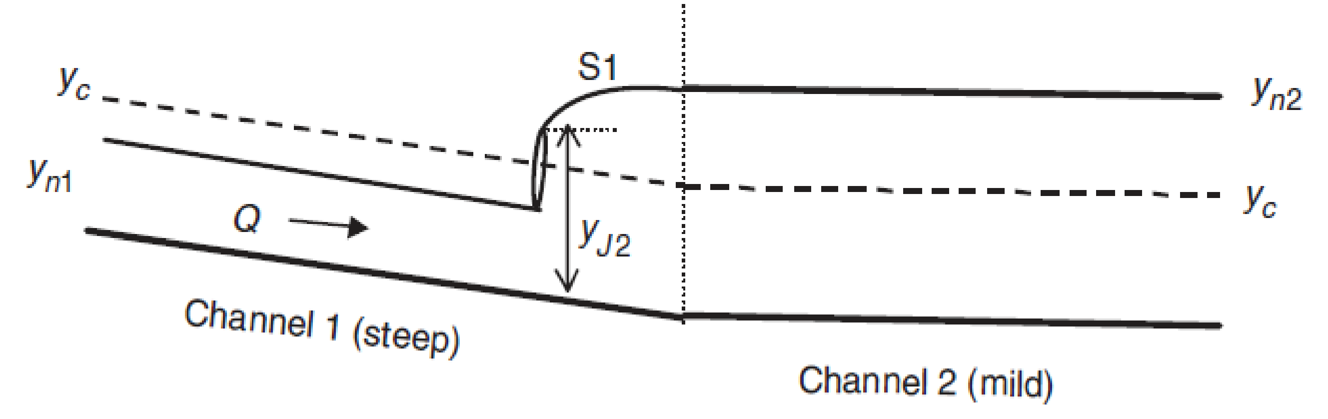


APPLICATIONS OF GRADUALLY-VARIED FLOW

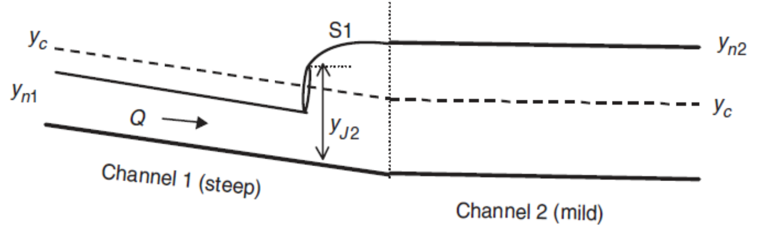
Example 4-5

In Example 4.2, Determine the distance between the hydraulic jump and the downstream end of channel.

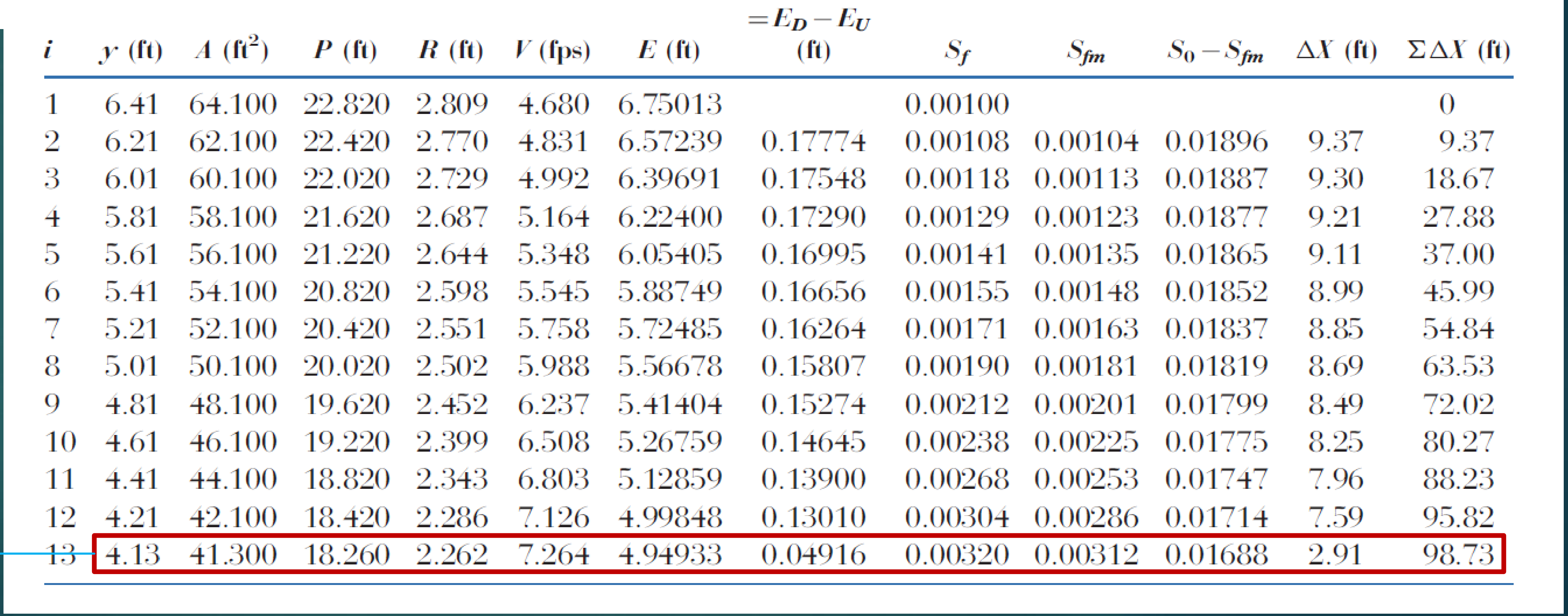
Example 4:2 A very long rectangular channel (channel 1) has a width of $b = 10ft$, Manning roughness factor of $n = 0.020$, and a bottom slope of $S_0 = 0.02$. It carries a discharge of $Q = 300\ cfs$. This channel joins another channel (channel 2) downstream, that has identical properties except for a slope of $S_0 = 0.001$. Determine the type of water surface profile occurring in these two channels.



APPLICATIONS OF GRADUALLY-VARIED FLOW



Depth after jump



	Variables for section i						Variables for reach between sections i and $i-1$					
i	y (ft)	A (ft^2)	P (ft)	R (ft)	V (fps)	E (ft)	$\Delta E = E_D - E_U$ (ft)	S_f	S_{fm}	$S_0 - S_{fm}$	ΔX (ft)	$\Sigma \Delta X$ (ft)
1	6.41	64.100	22.820	2.809	4.680	6.75013		0.00100				0
2	6.21	62.100	22.420	2.770	4.831	6.57239	0.17774	0.00108	0.00104	0.01896	9.37	9.37
3	6.01	60.100	22.020	2.729	4.992	6.39691	0.17548	0.00118	0.00113	0.01887	9.30	18.67
4	5.81	58.100	21.620	2.687	5.164	6.22400	0.17290	0.00129	0.00123	0.01877	9.21	27.88
5	5.61	56.100	21.220	2.644	5.348	6.05405	0.16995	0.00141	0.00135	0.01865	9.11	37.00
6	5.41	54.100	20.820	2.598	5.545	5.88749	0.16656	0.00155	0.00148	0.01852	8.99	45.99
7	5.21	52.100	20.420	2.551	5.758	5.72485	0.16264	0.00171	0.00163	0.01837	8.85	54.84
8	5.01	50.100	20.020	2.502	5.988	5.56678	0.15807	0.00190	0.00181	0.01819	8.69	63.53
9	4.81	48.100	19.620	2.452	6.237	5.41404	0.15274	0.00212	0.00201	0.01799	8.49	72.02
10	4.61	46.100	19.220	2.399	6.508	5.26759	0.14645	0.00238	0.00225	0.01775	8.25	80.27
11	4.41	44.100	18.820	2.343	6.803	5.12859	0.13900	0.00268	0.00253	0.01747	7.96	88.23
12	4.21	42.100	18.420	2.286	7.126	4.99848	0.13010	0.00304	0.00286	0.01714	7.59	95.82
13	4.13	41.300	18.260	2.262	7.264	4.94933	0.04916	0.00320	0.00312	0.01688	2.91	98.73

Homework 4

Q4-1 Determine the critical depth, normal depth and water surface profile in a rectangular channel with the width of 10ft, n=0.015 and S_0=0.001, and Q=300 cfs, if:

a. y = 2ft

b. y= 4ft

c. y=6ft.

Homework 4

Q4-2 The flow enters a rectangular channel from under a sluice gate, as shown in Figure, at a depth of $1.75\,ft$. The channel has a width of $b = 4\,ft$, a Manning roughness factor of $n = 0.013$, and a bottom slope of $S0 = 0.001$. The discharge is $Q = 133\,cfs$. The channel is $200\,ft$ long, and it terminates at free fall. Calculate the free surface profile.