Q1. **To model a stationary, uniform river flow with equilibrium depth (normal depth) everywhere.**

With given initial condition U_0=1m/s, b=20000, normal water depth h_n=10m and slope i=10^{-4} (rectangular channel), we can evaluate discharge, Chezy's coefficient based on formulas below,

$$Q = CA\sqrt{Ri}$$

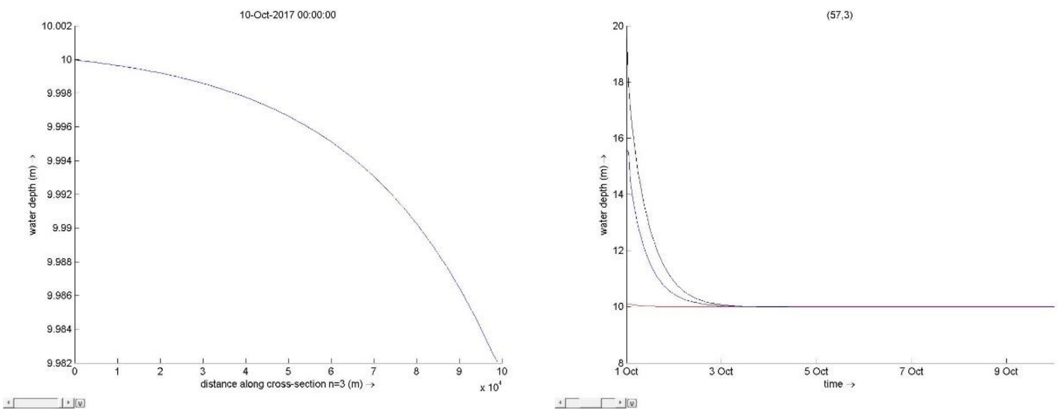
After calculation, we found discharge Q=200000m^3/s and Chezy's coefficient C=31.6. Substitute these values into Delft3D model.

What's more, we can calculate critical water depth by using the formula below,

$$h_c = \sqrt[3]{\frac{q^2}{g}} = 2.16\,m$$

Tab.1 setup 1

parameters	Setting	
Initial condition	Water level 0m	
Boundary condition	Upstream water level 0m	Downstream velocity 1m/s
Physical parameters	Roughness 31.6(H)	Roughness 31.6(V)
Time step	5 min	



(a) (b)

Fig1. Setup 1 (a) water depth along distance (b) water depth at different points

From fig.1 (a), water level drops a little while theoretically should stay stationary along distance. The total reason is that gravity force doesn't balance friction force while we're up to reduce the difference by two ways.

One way is that we can approximately achieve that by varying Chezy's coefficient to increase friction force.

Another way is to adjust boundary conditions in the left side. The reason behind this is due to the discretization of our model. It approaches our calculations as much while it can not be perfectly ideal. To reduce the difference, we can vary boundary condition h. in this case, driving force is h and curve drops, hence we decrease h to balance this.

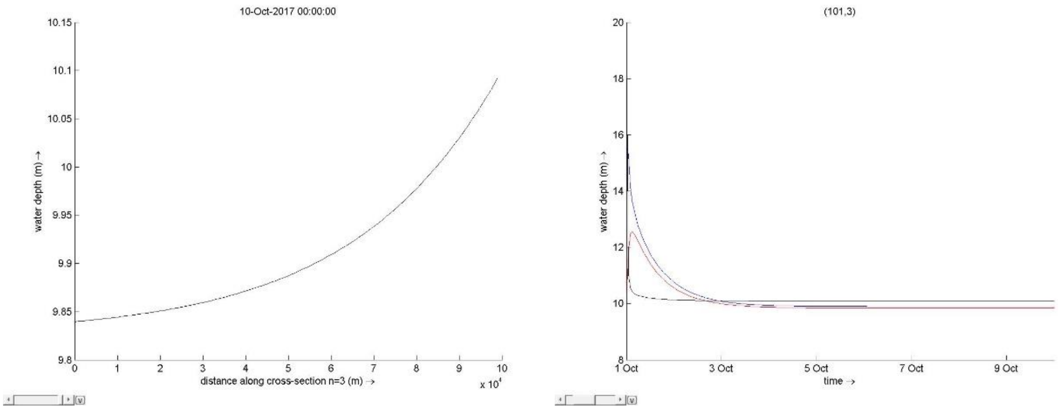
Form fig.1 (b), red line, blue line and black line are at observation point of (2,3), (52,3), (103,3) respectively in all cases. All curves converge to normal water depth eventually while still

observe some spin-up time at the beginning. Black line begins with around 20 meters because we set initial condition as 0 meter so that water depth is 20 meters by considering bathymetry at that point.
The reason about why the initial water depth is above normal water depth at the beginning and comes back to normal water depth eventually without following a “M1” profile is that it cannot get enough energy to generate “M1” profile because two boundaries are constrained.

Q2. **Impose different combination of boundary types (water levels, velocity, discharge) at both up and downstream boundaries and assess the effect on the final solution, and on the spin-up time required to get your solution.**

Tab.2 setup 2

parameters	Setting	
Initial condition	Water level 0m	
Boundary condition	Upstream velocity 1m/s	Downstream water level 0m
Physical parameters	Roughness 31.6(H)	Roughness 31.6(V)
Time step	5 min	



(a) (b)

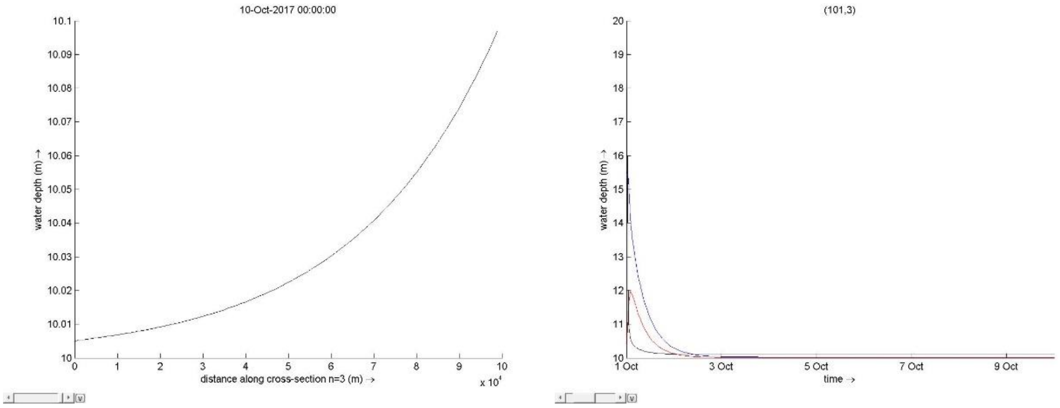
Fig.2 setup 2 (a) water depth along distance (b) water depth at different points

In fig2.(a) water depth starts with 9.85 while ideal condition should be 10 m. the reason about this is given above because of computational error. We can adjust roughness or boundary velocity to try to match.
Fig2.(b) shows us convergence of those water depth at different observation point. Spin-up time is around 3 days. All these results can be found in Tab.9.
As we compare fig2.(a) and fig1.(a) with inverse boundary conditions, the trends of the curves are conversed as well. That is because dominated driving force are different. The former one is water depth, gravity force dominates. Then the later one is velocity, friction force dominates.

Tab.3 setup 3

parameters	Setting	
Initial condition	Water level 0m	
Boundary condition	Upstream discharge	Downstream water level

	200000m^3/s	0m
Physical parameters	Roughness 31.6(H)	Roughness 31.6(V)
Time step	5 min	

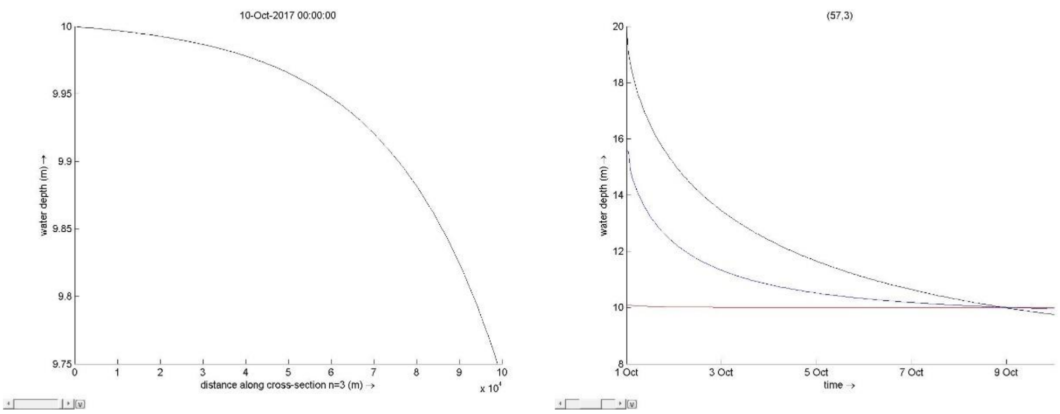


(a) (b)

Fig.3 setup3 (a) water depth along distance (b) water depth at different points

Tab.4 setup 4

parameters	Setting	
Initial condition	Water level 0m	
Boundary condition	Upstream water level 0m	Downstream discharge 200000 m^3/s
Physical parameters	Roughness 31.6(H)	Roughness 31.6(V)
Time step	5 min	



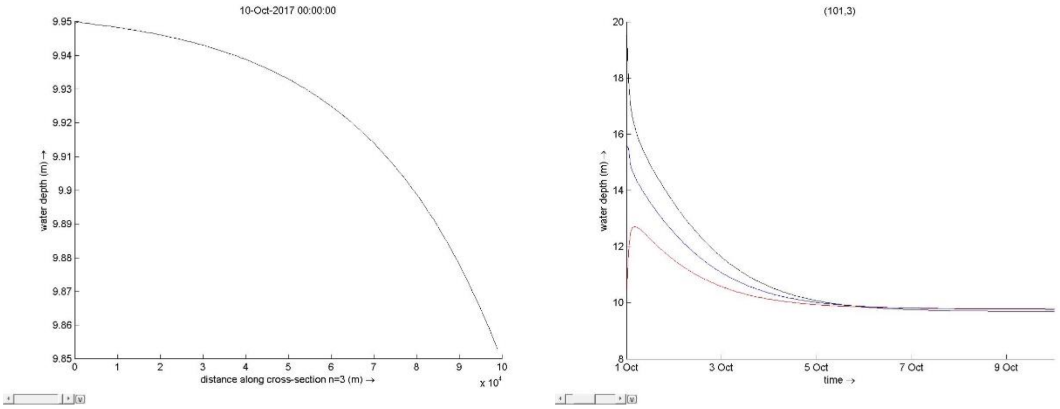
(a) (b)

Fig.4 setup 4 (a) water depth along distance (b) water depth at different points

Tab.5 setup 5

parameters	Setting	
Initial condition	Water level 0m	
Boundary condition	Upstream velocity 1m/s	Downstream velocity 1m/s

Physical parameters	Roughness 31.6(H)	Roughness 31.6(V)
Time step	5 min	



(a) (b)

Fig5. Setup 5 (a) water depth along distance (b) water depth at different points

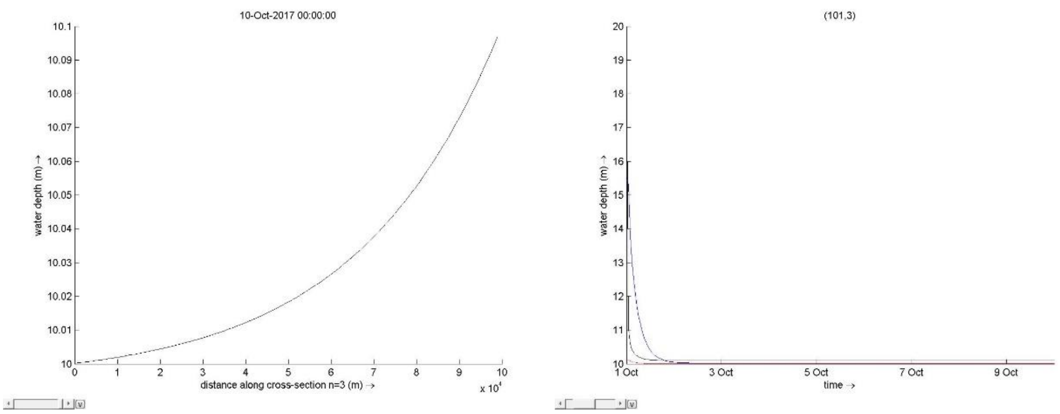
For this case, we understand that the final water depth begins at 9.95 based on boundary condition velocity. According to non-uniformed flow,

$$S_f = \frac{u^2}{C^2 R}$$

Our h is smaller than normal water depth, hence friction is greater than gravity force. The curve drops a little because of the other bounded boundary.

Tab.6 setup 6

parameters	Setting	
Initial condition	Water level 0m	
Boundary condition	Upstream Water level 0m	Downstream water level 0m
Physical parameters	Roughness 31.6(H)	Roughness 31.6(V)
Time step	5 min	

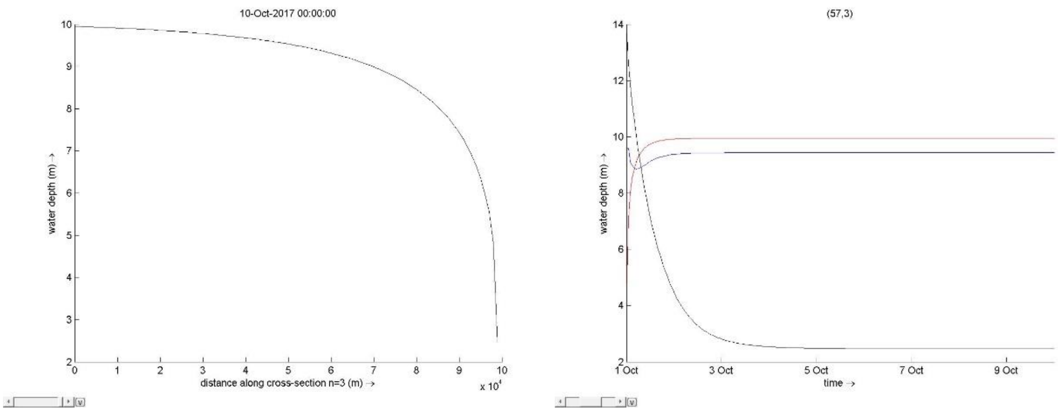


(a) (b)

Fig.6 setup 6 (a) water depth along distance (b) water depth at different points

Tab.7 setup 7

parameters	Setting	
Initial condition	Water level -6m	
Boundary condition	Upstream discharge 200000m^3/s	Downstream discharge 200000m
Physical parameters	Roughness 31.6(H)	Roughness 31.6(V)
Time step	5 min	



(a) (b)

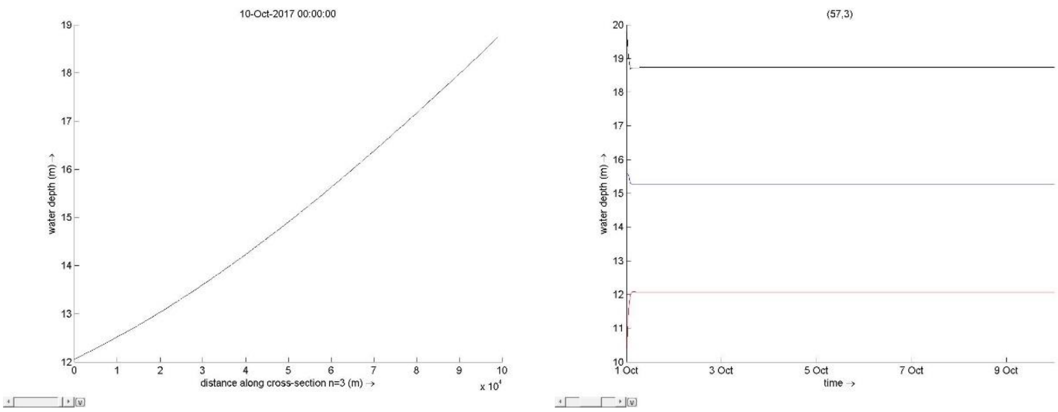
Fig.7 setup 7 (a) water depth along distance (b) water depth at different points

In this case, we see water depth drops a lot and is nearly perpendicular to x coordinate along distance. At point (2,3), red line water depth starts from initial condition and comes back to normal water depth at last, which satisfies boundary condition. While at point (52,3) and (103,3), water depth balance at different levels. This phenomenon can be explained by introducing non-uniformed open channel flow. This curve is called “M2” profile. It begins with normal water depth and is eventually perpendicular to critical water depth which is 2.16m.

The reason to form such a profile is because there are multiple solutions with given discharge. Different combination of velocity and water depth can satisfy that discharge. When water depth is below normal water depth, boundaries are not constrained and then it gets enough energy to hit a “M2” profile.

Tab.8 setup 8

Parameters	Setting	
Initial condition	Water level 2m	
Boundary condition	Upstream discharge 200000m^3/s	Downstream discharge 200000m
Physical parameters	Roughness 31.6(H)	Roughness 31.6(V)
Time step	5 min	



(a) (b)

Fig.8 setup 8 (a) water depth along distance (b) water depth at different points

Fig.8 (a) shows us a "M1" profile in open channel flow. It is like a "back-water" curve and occurs when a hydraulic structure eg. dam, sluice gate and so on lies in the downstream. Once water depth is above normal water depth, it starts increasing along distance with enough energy. In this case, it can get energy because "qq" boundaries have different combinations to aquire.

Fig.8 (b) shows us initial water depth transforms to final solution. Red line starts with 10m and ends up with 12m. That is possible because with "qq" boundaries, solution can be multiple and it also consists of conjugate water depth due to specific energy curve.

Tab.9 Results of all combination

Parameter	B.C		I.C	Results	Reason (gravity force vs. friction force)
	L	R			
Final solution	H=10m	V=1m/s	H=10m	10 to 9.982m	>
	V=1m/s	h=10m	H=10m	9.85 to 10.1m	<
	Q=200000	H=10m	H=10m	10 to 10.1m	<
	H=10m	Q=200000	H=10m	10 to 9.75m	>
	H=10m	H=10m	H=10m	10 to 10.1m	<
	V=1m/s	V=1m/s	H=10m	9.95 to 9.85m	>
	Q=200000	Q=200000	H=-6m	10 to 2m	Other
	Q=200000	Q=200000	H=2m	10 to 19m	Other
Spin-up time	H=10m	V=1m/s	H=10m	3 days	B.C. doesn't match I.C.
	V=1m/s	H=10m	H=10m	3 days	
	Q=200000	H=10m	H=10m	2 days	
	H=10m	Q=200000	H=10m	9 days	
	H=10m	H=10m	H=10m	2 days	
	V=1m/s	V=1m/s	H=10m	5 days	
	Q=200000	Q=200000	H=-6m	3 days	
	Q=200000	Q=200000	H=2m	1 day	