

Name _____

32 Points

2. The Reynolds Number: A Measure of Stream Turbulence

The Reynolds number assesses the degree of turbulence in stream flow. Non-turbulent flow, also called **laminar flow**, has water molecules moving along parallel paths in a downstream direction at a constant velocity. **Turbulent flow** has water molecules moving along different paths in different directions and at different velocities. Turbulence is generated by obstructions to forward flow, such as irregularities along the channel boundary (e.g. cobbles, boulders, bars and ripples). The Reynolds number estimates the degree of turbulence by calculating the ratio of inertial resistance to viscous resistance:

$$Re = \frac{\textit{inertial resistance}}{\textit{viscous resistance}}$$

Inertial resistance is the resistance of a fluid to a change in the speed and/or direction of flow and results from the forces driving the fluid forward. In the case of flowing fluids, velocity and mass determine the ease with which changes in the direction and/or speed of flow can occur. **Viscous resistance** is the resistance of a fluid to a change in shape (forward motion) due to friction between molecules (**molecular viscosity**). As a result, the Reynolds number can be thought of as the ratio of driving forces to resisting forces:

$$Re = \frac{\textit{driving forces}}{\textit{resisting forces}} = \frac{\bar{v} \times r}{\nu}$$

where \bar{v} is the average flow velocity, r is the hydraulic radius, and ν (theta) is the kinematic viscosity of water. The Reynolds number is dimensionless; there are no units associated with Re .

Because water has a very low viscosity compared to most other fluids, the denominator in the Reynolds number equation for water is very small and the Reynolds number itself is quite large. The low viscosity of water means that disturbances due to irregularities along the channel boundary are readily transmitted throughout the fluid and it is easy for water flow to become turbulent. More viscous fluids, such as honey, for example, are less likely to become turbulent. Disturbances along the channel boundary are quickly dampened by a viscous fluid and are not readily transmitted throughout the fluid. Because of the high viscosity of honey, the denominator for the Reynolds number for honey is large and the Reynolds number itself is small. More viscous fluids are less likely to experience turbulent flow than less viscous fluids.

Reynolds numbers less than 500 refer to laminar flow, which is steady and smooth. Under conditions of laminar flow, flow behavior is determined primarily by the fluid viscosity. Reynolds numbers greater than 2000 (or 2500 depending on the reference source) refer to turbulent flow, which is unsteady and churning or roiling. Under conditions of turbulent flow, flow behavior is determined more by the momentum of the fluid than by its viscosity. An intermediate condition that is partly laminar and partly turbulent is called transitional flow and has Reynolds numbers between 500 and 2000 (or 2500).

All flowing fluids experience **molecular viscosity**, friction generated by molecular interactions. In addition to molecular viscosity, however, turbulent flow (but not laminar flow) also experiences **eddy viscosity**, frictional resistance generated along eddy boundaries. This additional source of frictions causes turbulent flow to be more viscous than laminar flow. The viscosity term in the Reynolds equation, however, is a just function of the fluid viscosity (molecular viscosity), not the flow conditions. Eddy viscosity, in comparison, is a function of the flow conditions, not the fluid. Ultimately, the combined effects of molecular viscosity (viscosity due to the fluid) and eddy viscosity (viscosity due to flow conditions) impact the ability of rivers to do work.

The objective of this assignment is to gain an understanding of the Reynolds number and the factors affecting turbulent flow in rivers.

LEARNING OUTCOMES

By the end of this assignment you should be able to:

- Calculate the degree of turbulence of a stream; and,
- Explain how and why different combinations of flow velocity, stream discharge, and channel geometric characteristics such as depth, hydraulic radius, wetted perimeter, and cross-sectional area affect the degree of turbulence.

SYMBOLS

Re = Reynolds number

\bar{v} = average velocity (ft/s)

r = hydraulic radius (ft)

ν = kinematic viscosity of water = 0.00001076 ft²/s

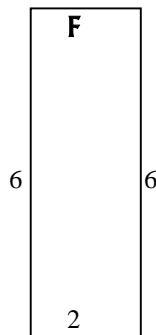
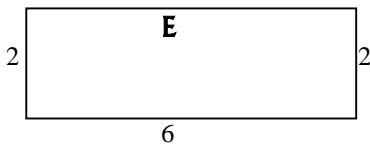
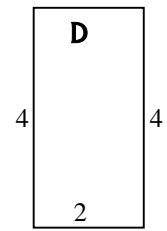
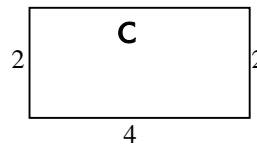
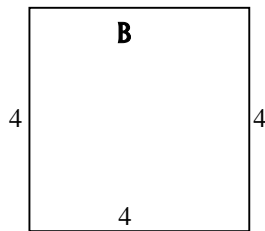
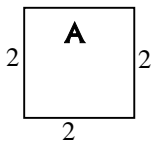
EQUATIONS

Q = discharge = A × \bar{v}

Re = $\bar{v} \times r / \nu$

INFORMATION

	A	B	C	D	E	F
Average depth, \bar{d}	2	4	2	4	2	6
Channel width, w	2	4	4	2	6	2
Cross-sectional area, A	4	16	8	8	12	12
Wetted perimeter, P _w	6	12	8	10	10	14
Hydraulic radius, r	0.7	1.3	1	0.8	1.2	0.9



QUESTIONS

1. a. Calculate the Reynolds number for each channel assuming $\bar{v} = 3.2$ ft/s. [6]

Channel A _____

Channel D _____

Channel B _____

Channel E _____

Channel C _____

Channel F _____

- b. How does the hydraulic radius of a channel affect the degree of turbulence *at a given flow velocity*? Why? [2]

- c. If two channels have the *same cross-sectional area* (compare channel C to D, and channel E to F) *and the same flow velocity* but a different shape, is flow more turbulent in the wide shallow channel or the narrow deep channel? Why? [2]

- d. Channels A, C and E have the *same shape and flow velocity* but *different cross-sectional areas*, while channels A, D and F have the *same shape and flow velocity* but *different cross-sectional areas*. How does cross-sectional area affect the degree of turbulence *provided the channel shape and the flow velocity are the same*? Why? [2]

- e. How would the degree of turbulence change (i.e. how would the Reynolds number change) for each of these channels if flow velocity increased to 4.8 ft/s? Why? [2]

2. a. Calculate Re for each channel assuming $Q = 25 \text{ ft}^3/\text{s}$. [9]

Channel A _____

Channel D _____

Channel B _____

Channel E _____

Channel C _____

Channel F _____

- b. Channels A, C and E have the *same shape and discharge* but *different hydraulic radii*, while channels A, D and F have the *same shape and discharge* but *different hydraulic radii*. How does an increase in hydraulic radius affect the degree of turbulence *for a given shape and discharge*? Why? [2]

- c. *At a given discharge*, is flow more turbulent in wide shallow channels or narrow deep channels? [1]

- d. Channels A, C and E have the *same shape and discharge* but *different cross-sectional areas*, while channels A, D and F have the *same shape and discharge* but *different cross-sectional areas*. How does cross-sectional area affect the degree of turbulence *for a given shape and discharge*? Why? [2]

3. Turbulence impacts the ability of a stream to do work. As turbulence increases, the viscosity of water increases, the likelihood of water currents moving upward away from the stream bed increases, and the velocity gradient upward away from the bed increases. The increase in these three factors increases the ability of flowing water to entrain (“pick up”) particles from the bed of the river (i.e. to erode material from the stream bed). Knowing this, what would be the ideal conditions for maximum turbulence and sediment entrainment if: [4]

a. there are no constraints on velocity, discharge or channel geometry?

b. velocity is held constant but everything else can change?

c. discharge is held constant but everything else can change?

d. cross-sectional area is held constant but everything else can change?