Lecture 15
Canal Design Basics

I. Canal Design Factors

- There are a number of criteria to consider when designing canals
- Below is a list of main criteria, not necessarily in order of importance:

    1. Flow rate capacity requirements (demand)
    2. Expected flow rate entering the canal (supply)
    3. Construction cost
    4. Safety considerations
    5. Hydraulic operational characteristics
    6. Water management needs
    7. Maintenance requirements
    8. Environmental conservation
    9. Need for emergency spill structures
    10. Cross-channel surface drainage needs
    11. Need for drainage directed *into* the canal
    12. Right-of-way (easements) along the canal path
    13. Secondary uses (clothes washing, swimming, others)
    14. Aesthetics

- Historically, flow rate capacity and construction cost have been the dominant design criteria, but it is better to take into account all of the above factors before finalizing a design
- This is not to say that you necessarily have to dwell on an issue like aesthetics, for example

- However, issues such as dynamic operation, maintenance requirements and need for spillways have often been given only cursory attention during the design phase, requiring subsequent post-construction modifications to the infrastructure
- Water management and operational needs are very similar
- Secondary uses can include things like navigation (large canals), clothes washing, other domestic uses, aquatic production, bathing, and many others
- Remember that every design has both common and unique *(site-specific)* features, compared to other canals

II. Capacity-Based Design

- This is an important consideration because a canal must have sufficient capacity, but not "too much"
- Construction and maintenance costs increase significantly with larger canals
- Actual required delivery system capacity depends on:

    1. size of the irrigated area
    2. cropping patterns (crop types, planting & rotation schedules)
    3. climatological conditions
    4. conveyance efficiencies
    5. on-farm efficiencies
    6. availability & exploitation of other water sources (conjunctive use)
    7. type of delivery schedule (continuous, rotation, on-demand)
    8. non-agricultural water needs

- It is often recommendable to allow for a safety factor by increasing capacities by 10% to 20% in case crops change, an expansion in irrigated area occurs, conveyance losses increase, and other possible factors
- The magnitude of design safety factors is very subjective and debatable
- Capacity requirements can change with different crop types, different total area, different planting schedules, and different efficiencies due to maintenance and rehabilitation (or lack thereof)
- On-demand delivery schedules require higher capacities because the combined requirements will tend to peak higher at some point during each growing season (on-demand delivery schemes can fail when there is not enough water or not enough conveyance capacity)
- Administrative losses can be significant, especially if the delivery schedule is very flexible (need extra water running through the system to buffer sudden turnout deliveries, else spill the excess)

- The required design flow rate capacity is usually known from independent calculations
- For example, irrigation project canal capacities are based on peak crop evapotranspiration requirements and net irrigated area
- A typical main canal capacity is approximately 1 lps per irrigated hectare
- Irrigation canal capacity may also be partially based on non-irrigation requirements, such as municipal supply, industry, fishery & wildlife conservation, and others
- Of course, the capacity of the canals will depend on location, whereby the capacity requirements tend to decrease in the downstream direction due to deliveries in upstream reaches
- But, if the capacity for each reach is known based on crop water and other requirements, and one or more canal layouts have been identified, the design problem becomes one of cross-sectional shape and size, and longitudinal bed slope

- An important point in capacity-based designs is that most canal designs are "static", based only on the hydraulic ability to carry up to a specified maximum flow rate
- The problem with this is that many designs did not consider the "dynamics" of canal operation, nor the type of delivery schedules envisioned
- This oversight has caused many operational difficulties and has limited the operational flexibility of many systems, sometimes severely
- The dynamics of canal operation can be taken into account through design-phase modeling, either with physical models or mathematical models

- In earthen canals, and for canals in general, the most efficient cross section is a secondary consideration to erodibility, maintenance, safety, and convenience
- The ratio of flow depth, h, to canal bottom width, b, usually varies from 1:2 to 1:4 for small canals, and from 1:4 to 1:8 in large canals
- Freeboard can be designed into the canal size at ¼ of the maximum water depth plus one foot (maximum of 6 ft)
- Less freeboard is required if the canal is carefully controlled during operation
- Top width of the bank should allow for a vehicle to pass on one side; the other side can be more narrow

III. System Layout Considerations

- A primary concern in the layout of the system is that it serves the purpose of conveying and distributing water to key locations in the area of service
- Another concern is that the excavation and earthen fill volumes not be excessive
- When large volumes of excavation and or fill are required, the construction costs can increase tremendously
- In fill areas, compaction of the soil material is very important, to avoid settlement problems and possible structural failure

- In reaches constructed over fill, the seepage losses tend to be high, even if the canal is lined
- For these reasons, canals are often designed to follow the existing topography for the design bed slope, which often means routing the canals indirectly so that earth moving work can be minimized, or at least held to an acceptable level
- The selection of longitudinal bed slope should also take into account the existing slopes of the terrain, so as to minimize deviations in canal routing
- Curves in canals should not be too sharp; following are some recommended limits:

Central Arizona Project canal (USBR)

Channel Capacity (m^3/s)	Minimum Curve Radius (m)
< 15	300
15-30	600
30 -90	1,000
> 90	1,500

- In bends, the radius of curvature should usually be between 3 and 7 times the top width of flow at maximum design discharge (larger radius for larger canals)

IV. Designing for Maximum Discharge and Uniform Flow

- For a known design discharge, known longitudinal bed slope, and selected cross-sectional shape, the Manning or Chezy equation can be solved for the required depth
- Or, for a known design discharge, known longitudinal bed slope, and specified maximum depth, the Manning equation can be solved for the required base width of a rectangular section
- In general, the equation can be solved for any "unknown", where all other parameters are specified
- You can also go to the field and measure everything but roughness under steady, uniform flow conditions, then calculate the value of n
- Avoid critical flow at or near design discharge (unstable water surface)

V. Manning Equation

- The Manning equation has been used to size canals all over the world
- It is an empirical equation for approximating uniform flow conditions in open channels
- A roughness factor, n, is used in the equation

- This factor is dependent on the type and condition of the canal lining
- But in reality, the factor also depends on the Reynold's number, N_R (that is, the size and shape of the cross section, not just the roughness of the lining material)
- In practice, it is often erroneously assumed that n is independent of N_R

- In **Metric units**:

$$Q = \frac{1}{n} AR^{2/3} \sqrt{S_o} \tag{1}$$

where Q is in m^3/s; A is cross-section flow area (m^2); R is hydraulic radius (m), equal to A divided by wetted perimeter; and S_o is the longitudinal bed slope (dimensionless)

- In English units, a coefficient must be added to the equation:

$$\frac{1}{(0.3048 \ m/ft)^{1/3}} \approx 1.49 \tag{2}$$

- In **English units**:

$$Q = \frac{1.49}{n} AR^{2/3} \sqrt{S_o} \tag{3}$$

where Q is in cfs; A is in ft^2; and R is in (ft)

- An alternative to the Manning equation is the Chezy equation

VI. Chezy Equation

- The Chezy equation is an alternative to the Manning equation, and can be applied as described above
- It is also an empirical equation for approximating uniform flow conditions in open channels, but it has more of a theoretical basis
- The Chezy equation has a diagram analogous to the Moody diagram for the Darcy-Weisbach equation (pipe flow head loss) that takes the Reynold's number into account, which makes it technically more attractive than the Manning equation
- Another advantage is that the Chezy equation can be applied successfully on steeper slopes than the Manning equation

$$Q = CA\sqrt{RS_o} \tag{4}$$

where Q is in m^3/s; A is cross-section flow area (m^2); R is hydraulic radius (m), equal to A divided by wetted perimeter; and S_o is the longitudinal bed slope (dimensionless)

VII. Chezy C Value

- The units of C are $m^{1/2}$/s
- Note that the numerical value of C increases for smoother surfaces, which is opposite to the behavior of Manning's n
- The relationship between C and Manning's n is (for m and m^3/s):

$$C = \frac{R^{1/6}}{n} \tag{5}$$

- The relationship between C and the Darcy-Weisbach f is:

$$C \approx \sqrt{\frac{8g}{f}} \tag{6}$$

- Thus, C can be defined as a function of relative roughness (ε/R) and Reynold's number, and the resulting graph looks much like the Moody diagram, vertically inverted
- Reynold's number can be defined like this:

$$N_R = \frac{4RV}{\nu} \tag{7}$$

where R is the hydraulic radius (m), A/W_p; V is the mean flow velocity in a cross section (m/s); and ν is the kinematic viscosity of water (m^2/s)
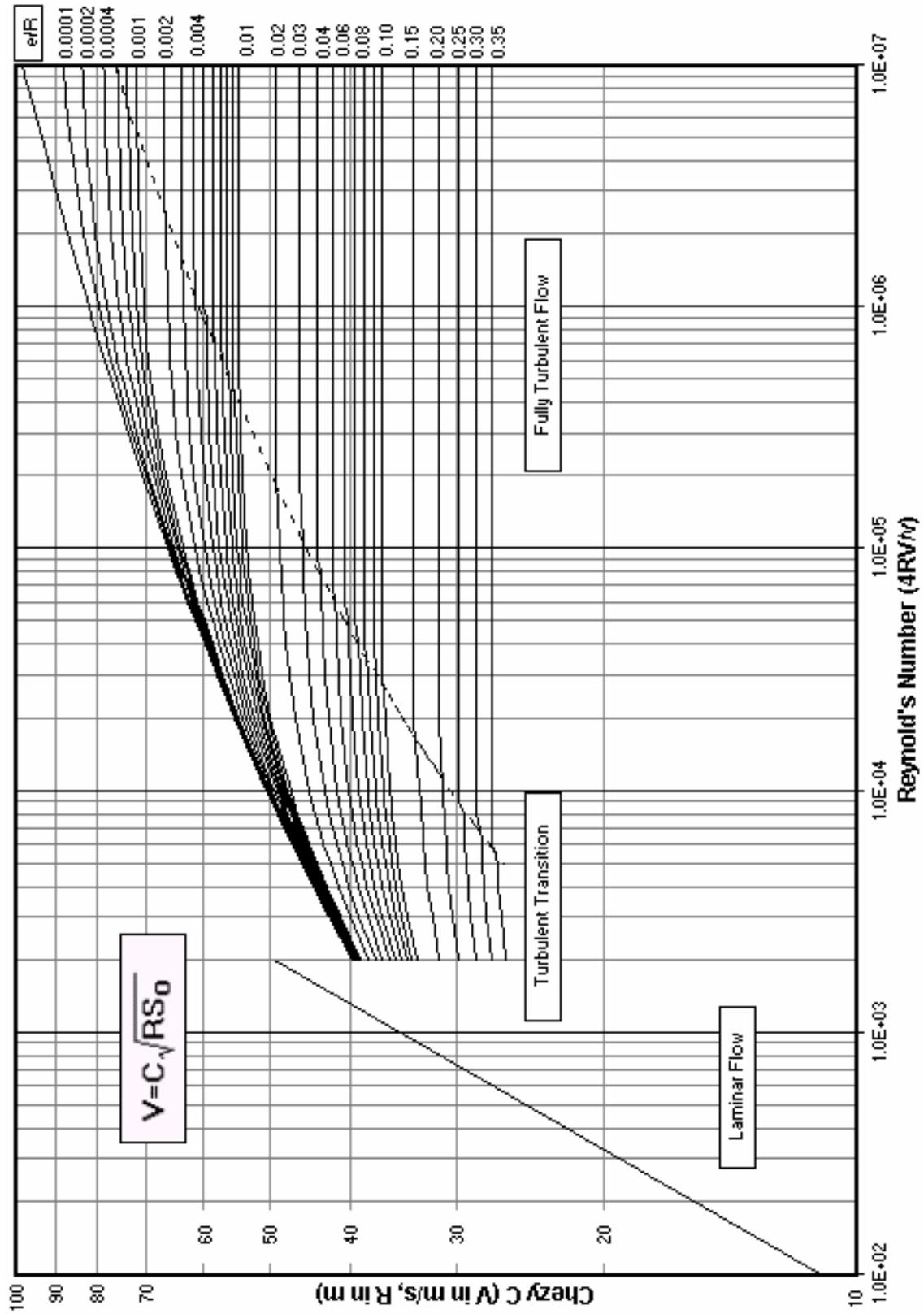
- For a full circle:

$$R = \frac{A}{W_p} = \frac{\pi r^2}{2\pi r} = \frac{r}{2} \tag{8}$$

whereby 4R = D (diameter), so use 4R in general for non-circular sections

- Kinematic viscosity is a function of water temperature

Water Temperature (°C)	Kinematic Viscosity (m^2/s)
0	0.000001785
5	0.000001519
10	0.000001306
15	0.000001139
20	0.000001003
25	0.000000893
30	0.000000800
40	0.000000658
50	0.000000553
60	0.000000474

The graph shows Chezy C (V in m/s, R in m) on the vertical axis versus Reynold's Number (4RV/ν) on the horizontal axis, with the equation $V = C\sqrt{RS_0}$. The relative roughness values (e/R) shown are: 0.0001, 0.0002, 0.0004, 0.001, 0.002, 0.004, 0.01, 0.02, 0.03, 0.04, 0.06, 0.08, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35. Flow regions labeled: Laminar Flow, Turbulent Transition, Fully Turbulent Flow.

- For laminar flow ($N_R < 2000$) and units of m and m³/s:

$$C = 1.107\sqrt{N_R} \qquad (9)$$

which is analogous to the Blasius equation (Darcy-Weisbach f)

- For turbulent smooth flow ($N_R > 2000$ & $\varepsilon \approx 0$) and units of m and m³/s:

$$C = -17.7\ \log_{10}\left(\frac{0.28\,C}{N_R}\right) \qquad (10)$$

- For turbulent transitional flow ($N_R > 2000$ & $\varepsilon > 0$) and units of m and m³/s:

$$C = -17.7\ \log_{10}\left(\frac{\varepsilon/R}{12} + \frac{0.28\,C}{N_R}\right) \qquad (11)$$

- For turbulent rough flow ($N_R > 20{,}000$ & $\varepsilon > 0$), where C is no longer a function of N_R, and units of m and m³/s:

$$C = 17.7\ \log_{10}\left(\frac{12}{\varepsilon/R}\right) \qquad (12)$$

which gives the flat (horizontal) lines for fully turbulent flow

- To determine the threshold between turbulent transition and turbulent rough flow for a given ε/R ratio, first determine C from Eq. 11, then calculate N_R as:

$$N_R = \frac{75\,C}{\varepsilon/R} \qquad (13)$$

- Other equations exist to define the C value as a function of N_R and relative roughness, and these can be found in hydraulics textbooks & handbooks
- For R in ft, A in ft², and Q in cfs, multiply C by:

$$\frac{\sqrt{0.3048}}{0.3048} = 2.006 \qquad (14)$$

- That is, in English units:

$$Q = 2.006\,C\,A\sqrt{RS_o} \qquad (15)$$

where Q is in cfs; A is in ft^2; and R is in ft

- Note that for all but laminar flow, you must iterate to solve for C
- This can be done quickly and easily in a computer program, and the results can be presented as in the graph above

VIII. Chezy Epsilon Values

- Epsilon (roughness height) values depend on channel lining material type & condition:

Material & Condition	ε (m)
Very smooth and essentially seamless concrete	0.0003
Smooth concrete with joints between panels	0.0005
Rough concrete surfaces	0.0012
Very rough concrete surfaces	0.004 to 0.005
Gunite with a smooth finish	0.0005 to 0.0015
Untreated gunite	0.003 to 0.010

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