Culvert Design Process:

The following is a step-by-step culvert design procedure for a standard culvert configuration—straight in profile and if multiple barrels are used, with barrels that are parallel and of equal size. Any of the configurations considered in the iterative process of design influences a unique flow type. Each new iteration requires a determination of whether there is inlet or outlet control.

1. Establish an initial trial size. You can pick the trial size at random or judiciously, based on experience. However, one expedient is to assume inlet control as follows: Determine the maximum practical rise of culvert (Dmax) and the maximum allowable headwater depth (HWmax). Determine a trial head using the head equation below. Next use the area equation below (a form of the orifice equation) to determine the required area, A, for the design discharge, Q. This assumes an orifice coefficient of 0.5, which is reasonable for initial estimates only.

   h = HWmax –Dmax/2

   Where:
   h = allowable effective head (ft. or m)
   *HW*max = allowable headwater depth (ft. or m)
   *D*max = maximum conduit rise (ft. or m).

   A = 0.45(Q/(h^0.5))

   Where:
   A = approximate cross-sectional area required (sq.ft. or m2)
   Q = design discharge (cfs or m3/s).
   Decide on the culvert shape:

   - For a box culvert, determine the required width, W, as A/Dmax. Round W to the nearest value that yields a whole multiple of standard box widths. Divide W by the largest standard span S for which W is a multiple. This yields the number of barrels, N. At this point, the determination has been made that the initial trial configuration will be N - S Dmax L.

   - For a circular pipe culvert, determine the ratio of area required to maximum barrel area according to the equation below. Round this value to the nearest whole number to get the required number of barrels, N. At this point, the determination has been made that the initial trial size culvert will be N - D L circular pipe.

     4A/(3.14Dmax^2)<=N

- For other shapes, provide an appropriate size such that the cross section area is approximately equal to A.

2. Determine the design discharge per barrel as Q/N. This assumes that all barrels are of equal size and parallel profiles with the same invert elevations. The computations progress using one barrel with the appropriate apportionment of flow.

3. Perform a hydraulic analysis of the trial configuration. Generally, employ a computer program or spreadsheet, (nomographs and simplified hand methods should be used only for preliminary estimates). For the trial configuration determine the inlet control headwater (HWic), the outlet control headwater (HWoc) and outlet velocity (vo).

4. Evaluate trial design. At this step in the design process, you have calculated a headwater and outlet velocity for the design discharge passage through a trial culvert configuration.

    - If the calculated headwater is equal to or is not appreciably lower than the allowable headwater, (an indication of culvert efficiency), the design is complete. A good measure of efficiency is to compare the calculated headwater with the culvert depth D. If the headwater is less than the depth, the configuration may not be efficient.

    - If the calculated headwater is considerably lower than the allowable headwater or lower than the culvert depth D, a more economical configuration may be possible. Choose the trial culvert configuration by reducing the number of barrels, span widths, diameter, or other geometric or material changes. Repeat the calculations; go back to step 2.

    - If the calculated headwater is equal to or is not appreciably lower than the allowed headwater and the culvert is operating as inlet control, an improved inlet may be in order.

    - If the calculated headwater is greater than the allowable headwater, change the trial culvert configuration to increase capacity by adding barrels, widening spans, and increasing diameter. Regardless of the changes made here, repeat the calculations and go back to step 2.

    - If the operation is not inlet control, then the culvert geometry design is complete.

    - If the culvert is operating with inlet control, the possibility exists for improving the entrance conditions with the aim of reducing the overall cost of the structure. Investigate the design of a flared (or tapered) inlet and associated structure.

- Because of the cost of the improved inlet, make a careful economic comparison between the design with a normal entrance and the design with an improved inlet.

- The culvert for which the calculated headwater is satisfactory may have an excessive outlet velocity. The definition of an "excessive" outlet velocity is normally an engineering judgment based on local conditions.

- In comparison to adjusting the culvert barrel configuration, it is usually more economical to provide riprap, sills, or a stilling basin at the outlet end to control any excessive velocity.

- Consider any required outlet control or protection device as part of the hydraulic design. It is normal for a properly designed culvert to have an outlet velocity that is greater than the natural stream velocity.

5. Develop a hydraulic performance curve using the procedures outlined in the Hydraulic Operation of Culverts section. An overall hydraulic performance curve for the designed culvert indicates headwater and outlet velocity characteristics for a wide range of discharges. Use the performance curve to check other stormwater discharges.

    - For any culvert design, the minimum additional analysis required is typically the application of the 100-year discharge to the culvert. Consider the design complete if the results of the headwater and outlet velocity represent an acceptable risk and conform to the requirements of local authorities.

    - However, if any of the hydraulic characteristics are unacceptable, some adjustment to the facility design may be in order. This is an analysis technique to define risks of greater floods to help judge whether or not to accept the risks involved. Evaluate other culvert performance risks. Identify and evaluate the potential for increased impact associated with different flood conditions.