HYDROLOGY ENGINEER

Quick Start Guide

Carlson
BREAK NEW GROUND

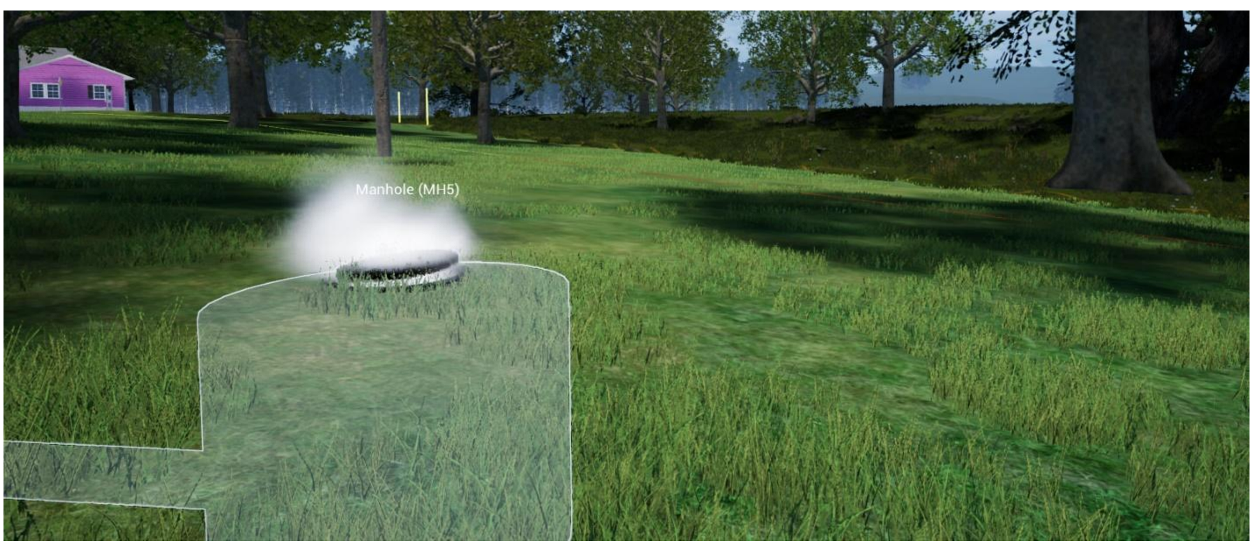
HYDROLOGY ENGINEER

Carlson Software's Hydrology Engineer STEM Video Game

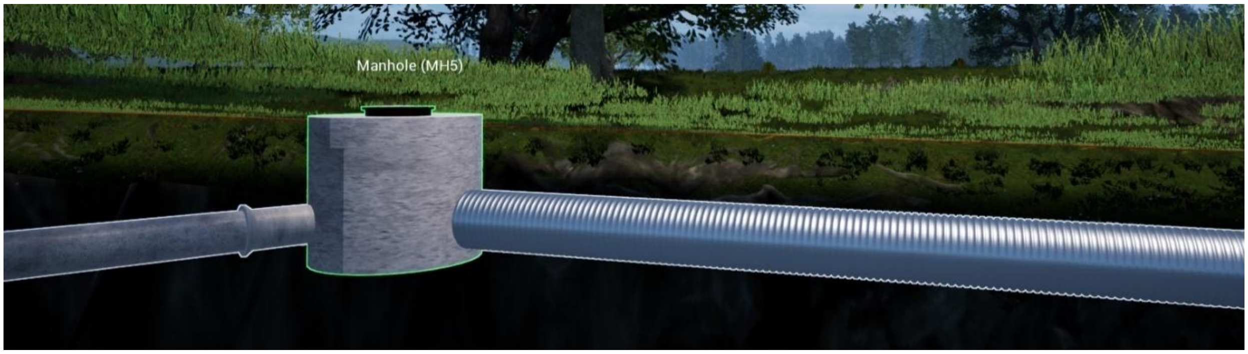
Executive Summary: Managing stormwater is one of the major civil engineering challenges of today. With more and more land being built over and paved over, more water is running off into streets and ultimately into creeks and rivers without feeding plant life and groundwater, without contributing to the transpiration water cycle, which can lead ultimately to drought. Ironically, drought conditions are occurring even while annual rainfall amounts are increasing. These problems are highlighted in a recent book by Tim Smedley called "The Last Drop" © 2023.

The Carlson Software's Hydrology Engineer STEM Video Game offers young, aspiring engineers (and "gamers" in general) the opportunity to learn about water flow in a typical built subdivision environment, where the goal is to feed the stormwater from drainage inlets placed in the curb line to an outlet headwall in a detention pond. This detention pond, although not the subject of the video game, represents the concept of water capture leading to greater groundwater infiltration and slower release to streams, mimicking the pre-development condition. This helps resist the advance of regional aridity.

The key challenge in the game is to deliver the stormwater to the detention pond at the lowest cost, while meeting the regulatory requirements of maximum 8-foot gutter spread in the road, as measured from the curb, and with large enough pipe sizes that there is no pressure, known as hydraulic grade line pressure, pressing on manholes or pushing water out of inlets. When that happens, you see visual effects such as shown below, which means design changes are required:



There are many other constraints on design that will lead to design rejection, the goal being to produce the lowest cost design that passes. For example, stormwater pipes cannot be over 300 feet in length between structures. Pipes must have a downhill or "negative" slope of at least 0.1%--they cannot be flat or uphill. Pipes cannot go under buildings, cannot intersect, cannot enter a rectangular catch basin on a corner—must enter on a wall side. All design constraints are discussed below. Some like the four mentioned here lead to rejection of the design. Others lead to added "penalty" costs, like passing within 10 feet of the outer edge of a building or going under a paved driveway. Every inlet with its catch basin, every manhole used to link inlets and headwalls together, every pipe, has a cost. Larger pipe diameters that flow more water, removing pressure on manholes as in the picture above, have more cost. Different pipe materials such as corrugated metal stormwater pipes can restrict water flow due to the roughness of the pipe, referred to as the "Manning's n" roughness coefficient. The higher the Manning's n, the less water can flow through the same diameter pipe, all things equal.



Because corrugated metal pipe (CMP) costs less than Reinforced Concrete Pipe (RCP) to buy and install, its selection is a trade-off on lower cost versus ability to flow water through the pipe. In some cases, you may find that an 18" RCP flows the water as effectively as a 24" CMP. This illustrates the essence of the design challenge: The Hydrology Engineer Video Game teaches players to "think like civil engineers," to try "what if" scenarios, to experiment. The STEM Video Game also closely duplicates the real-world experience of civil engineers—you must submit your designs for review, and you either are approved or rejected. In the world of engineering practice, you submit your designs to the regulatory agencies, such as a City Municipal Utility. In the game, you submit your design to the Carlson website, it is immediately analyzed and if it passes, you can choose to save your score (or project cost) for tabulation and comparison against all other players.

STEM stands for "Science, Technology, Engineering and Math." All four are taught and learned by playing the Hydrology Engineer Video Game. Hydrology is a Science, a subset of Civil Engineering and of growing importance. Formulas have been developed and empirically tested that have proven to closely predict peak flow runoff from watersheds. These formulas are pure math and are discussed at the end of the Quick Start Guide. But there are also deeply scientific topics within Hydrology dealing with the "hydraulics" of water flow in pipes. These include the "Manning's Equation" for water flow in open channels such as gutter lines and partially full pipes. Other more complex formulas apply to pipes flowing full and under pressure. The very act of playing the Hydrology Engineer Video Game teaches these STEM subjects almost by a process of osmosis—you learn and observe pipe and channel flow results and behaviors by playing, by experimenting with designs, and can gain half a semester of hydrology training through mastery of the game. You will find out, in short order, if you are cut out to be a Civil Engineer! But if you are, the world needs your talents and determination!

The 2023 Carlson STEM Scholarship is designed to encourage the purchase of the software in the last 6 weeks of 2023 as a Christmas present or program to be used by schools and colleges in the approaching Spring 2024 semester. The program costs $150, and a scholarship of $3,000 will be paid for the lowest cost approved Level1 solution (winning solution) submitted in each of the 50 United States by January 15, 2024. A prize of $10,000 will be awarded for the top 5 winning solutions on a worldwide basis. Players must be certified to be ages 13 to 19 by a parent, guardian or instructor. For states with no submitted designs, players with the next highest score who have not received an award will capture the $3,000 scholarship, so that a full 50 scholarships of $3000 each are awarded. All scholarships will be announced on January 20, 2024.

Playing the Hydrology Engineer Video Game: Getting Started

Show Low Points:
All low points on the site within the road network of 2 roads need to be drained by an inlet. Therefore, a good place to start is with the circled icon at right (below), which shows low points by placing a vertical yellow stick at all low points on the roads:

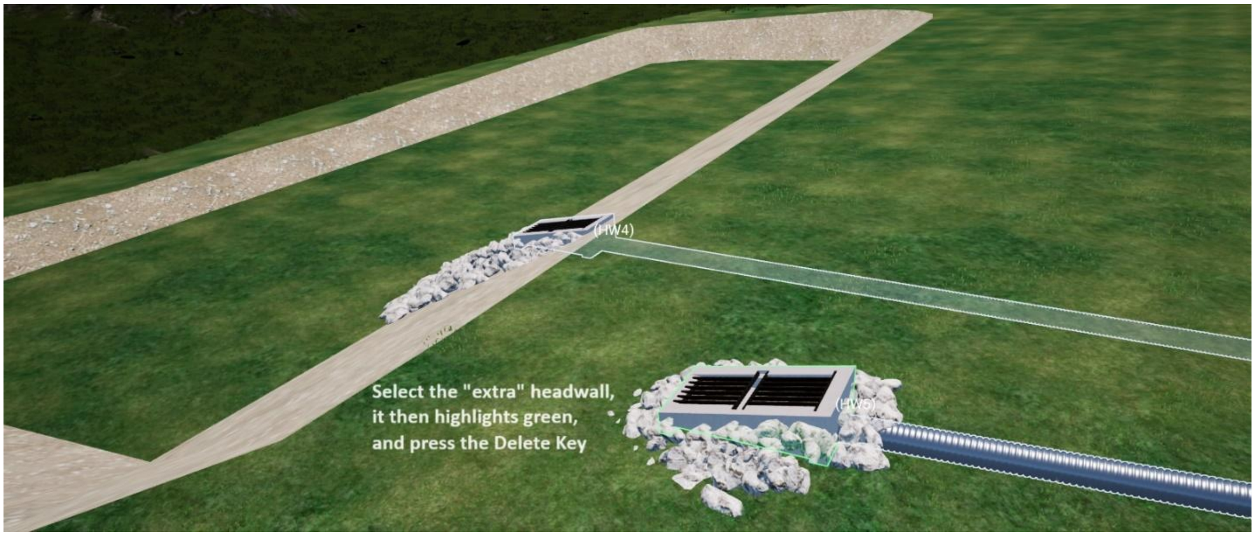
Place Inlets Auto-Connected by Pipes using the upper left icon circled below:

Note that you see the cost of the inlet type selected in the table at right and you see the cost of the pipe as it is placed. All pipes default to 12 inch diameter at first, and then must be increased in size if they create pressure in the pipe after a storm is calculated leading to overflow at the manhole or inlet. Inlets will "snap" to and follow the face of curb lines and gravitate even stronger to low points as you approach them.

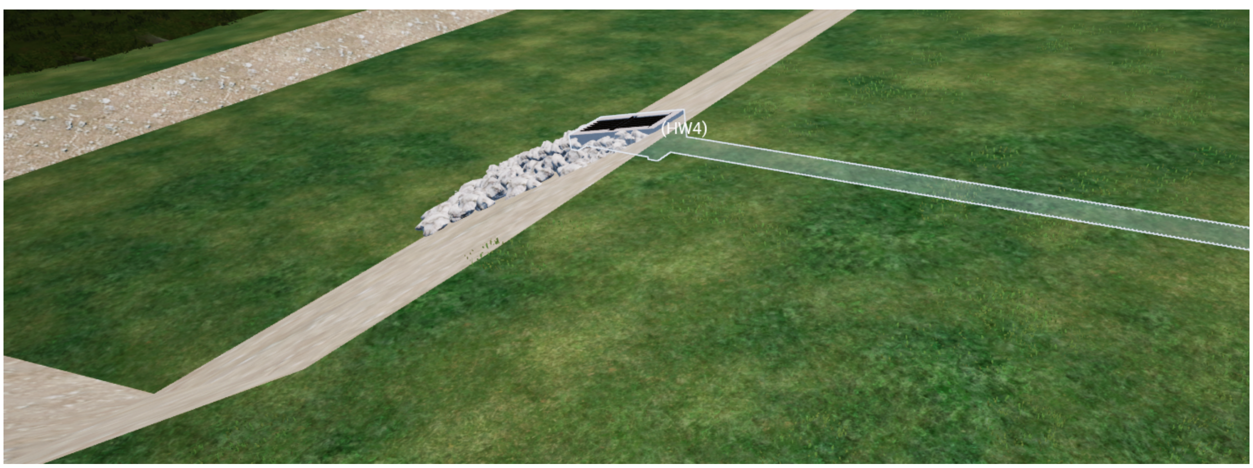
Manholes are Sometimes Useful to connect Structures:
For example, when two inlets are placed and you want to go cross-country to a point more than 300 feet away (which exceeds maximum pipe length allowed), you may need to add a manhole to reduce pipe length below 300 feet, as below. Note that the manhole option appears when you select the upper right icon shown above, and that a “diamond” snap option will allow you to pick on an existing structure without creating a new one. Pressing Enter exits the structure placement process. If the manhole below is placed, and you press Enter, you can click the upper left structure placement icon, select the manhole again, and the diamond snap ensures that you are starting a new pipe there and no new structure will be added.

Be sure that One Inlet or Manhole Drains the Site to a Headwall in the Detention Pond:
The design below is not likely to be part of a winning solution, but illustrates the need to drain stormwater to the detention pond by selection of the headwall icon (circled in red):

Select items to delete them. If you accidentally make more than one headwall or make ANY structure or pipe that you wish to delete, just exit any command you are in by pressing Enter, then select that structure or pipe with the left mouse button. The structure or pipe highlights with a green border when selected. Then press the Delete Key on your computer:

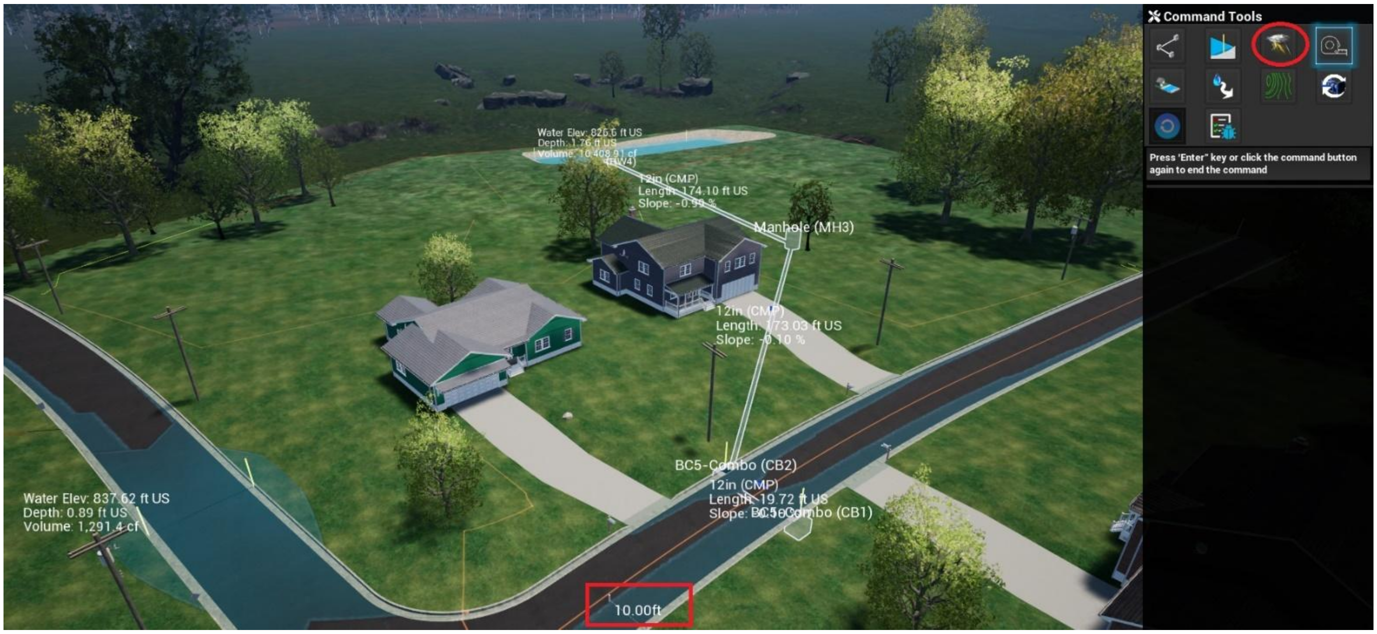


Pressing delete with the closer headwall selected leads to the following result. Even the connecting pipe is erased:



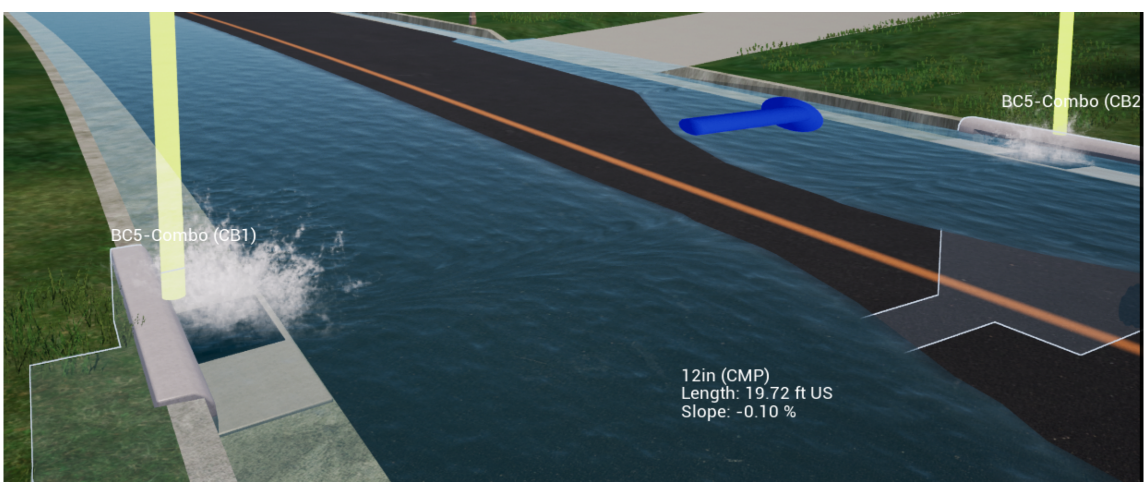
Run the Storm Event Icon to Test the Design and View Storm Results:
A 50-year storm is used by default. The “year” of the storm refers to how frequently the storm severity would recur. A 50-year storm would be expected to occur only once in 50 years. Many Civil Engineers design storm networks to handle 50-year and 100-year storm events without excessive “gutter spread” and pipe “hydraulic grade line” pressures on inlets and manhole lids.

The storm icon is circled in red below. After the storm is run (complete with thunder) and calculated, use the measuring tape icon in the upper right, also seen below highlighted by a blue square, to measure gutter spread. In the red square shown below, the gutter spread at that point is 10.00 feet.



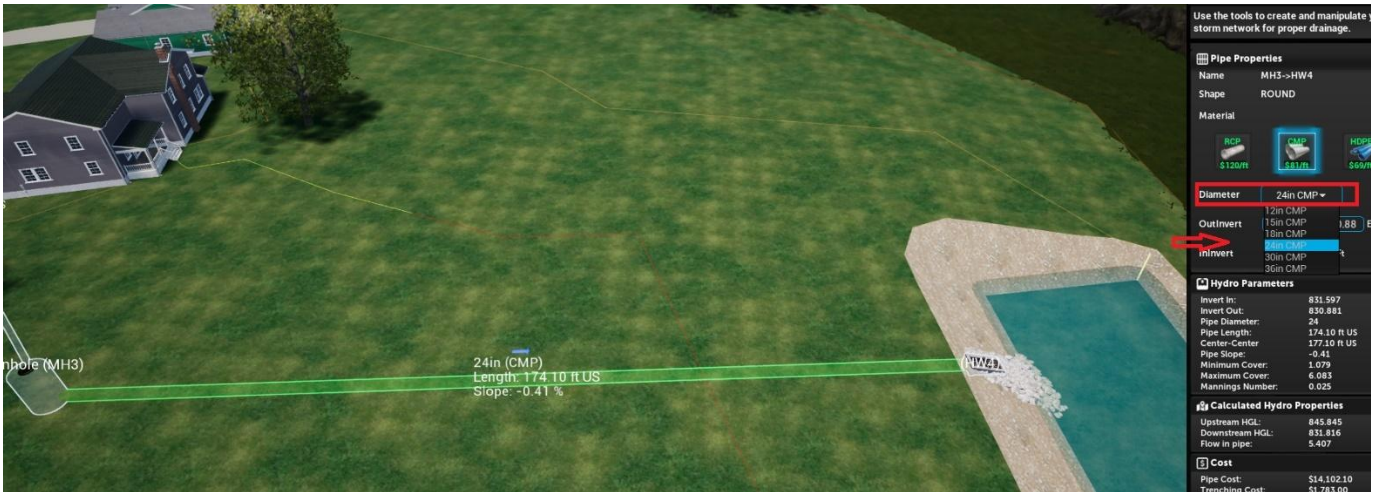
Gutter Spread of 10 feet is greater than the maximum gutter spread of 8 feet for a design to be approved. So additional inlets are necessary. Press Enter to exit the "Measuring Tape" mode on gutter spread. Note above that the water in the side road has not been drained and pools up completely across the road in the 50-year storm, forming a large pond. Even with this pond in place and visible, inlets can be added to drain the side road.

Demo Mode Allows only 2 Inlets: The Hydrology Engineer Video Game can be downloaded without purchase and studied. In this demo mode, only two curbside inlets are allowed, but any number of manholes and even headwalls can be added to study visual effects. The above design, also shown below, is a legitimate exercise in the demo mode, since only two inlets have been placed along with one manhole and one headwall.



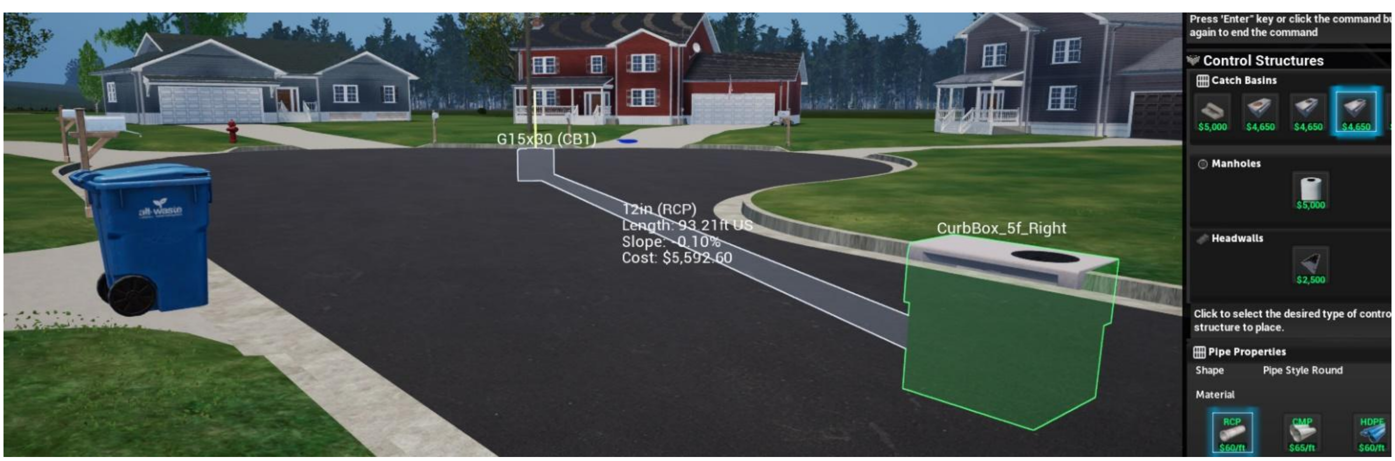
Visual Effects can be Enjoyed in Demo Mode: These effects include swaying trees, swaying grass at close zoom-in mode, gurgling sound in the inlets or manholes if you zoom in underground, motion in the water in the gutter lines, even falling leaves on certain trees! In the above graphic, we have an example where the pipes are not sized large enough, and the water pressure is such that water is gushing out of the inlets. The “geyser” of water coming from the inlets indicates downstream pipes below the inlets must be made larger.

To make Pipes Larger to Reduce Pressure on Manholes and Inlets, select the pipe and increase its size as shown in the graphic below:



By first selecting the pipe, then looking at the Diameter pulldown menu to the right, you can choose a larger diameter. Then you must rerun the Storm Event and observe the impacts on inlets and manholes to make sure no water is spewing from these structures. This is how you graphically, in a sense, design for sufficient pipe size. As pipe diameters are increased, project cost goes up.

The “Curb Snap” and “Low Point Snap” Make Inlet Placement Fast and Easy:
In Computer-Aided Drafting (CAD), the concept of the “snap” is well known. You can draw lines or place symbols by “snapping” to the end-point of lines, to the intersection of two lines, to the center of a circle or arc, etc. The Hydrology Engineer Video Game has a unique “curb snap” that tracks along the curb and zeroes in on the low points as you approach them. Yes, you can “force” an inlet in the middle of someone’s yard, but inlets are designed to be placed against the face of curb:



To Evaluate a Design and Determine if it is Rejected or Passes, click Check Design!

CHECK DESIGN

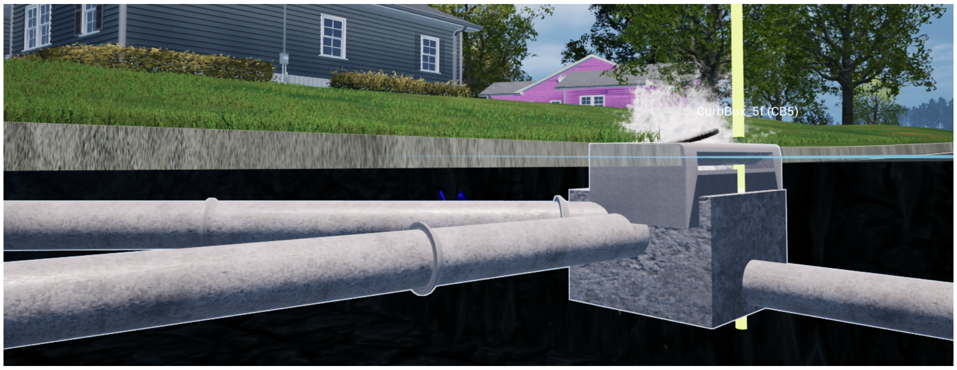
Before you select Check Design (button in lower right), first be sure to run the storm after any design changes.

If the design is incomplete or fails any number of evaluation requirements such as gutter spread less than 8 feet and no water pressure against manhole lids and inlet openings, then your design will be stamped "REJECTED"! Do not give up! If you add enough inlets, and increase pipe sizes sufficiently, and avoid other sources of design rejection, you can achieve a passing design. Then the question will be, at what cost! The lowest cost design that passes is the successful or "winning" design. No one at Carlson Software knows what the lowest cost design on this site actually is. That is the beauty and challenge of civil engineering: creative, trial-and-error design can lead to better and better designs at lower cost. As your designs get more and more affordable, you are learning to "think like an engineer".

Some Special Causes of Failed Design:

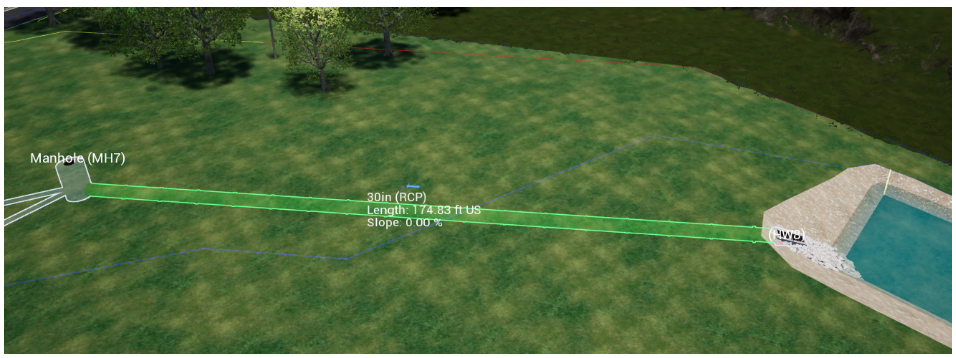
1. **The Storm Sewer Line goes beneath a house**, as shown below. You cannot "Cross under a Building!"

2. **Pipes Intersect,** for example, by Entering Catch Basin from Nearly Same Direction:



This example above also shows excessive pressure on the inlet (manhole lid being raised) which requires increasing pipe diameters downstream of the inlet.

3. **Pipe Flow is not at least -0.1% downhill** (downhill is indicated as a negative number):

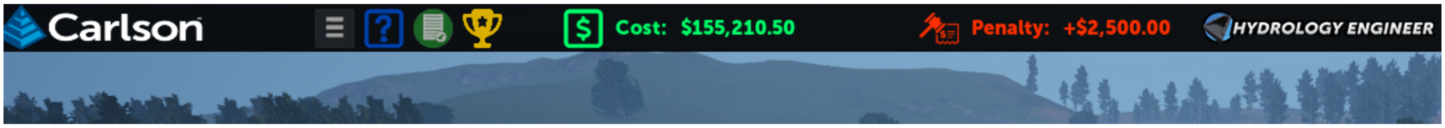


In the above example, the pipe slope is 0.0% (flat) and not at least -0.1% downhill. This can catch players of the Hydrology Engineer Video Game off-guard on the last pipe into the headwall in the detention pond. The reason is that the headwall elevation will not lower itself automatically when pipe sizes are increased. At the same time, the upstream elevation of the pipe (30 inches above) is lowered and the manhole shown is deepened when the pipe size is increased. This runs the risk of creating a flat or uphill slope in certain scenarios. Remedies include selecting the headwall and changing its elevation, or selecting the pipe itself and changing its slope.

Note that headwalls, manholes and inlets can be selected and moved. If MH7 (at left, above) is selected and moved, the two entering pipes move with it. But this can also impact pipe slope with the risk of slopes that may be less than -0.1%. The design process is very dynamic. It should be pointed out that pipes, when placed between inlets and manholes, default to -0.1%, the minimum slope.

The List of Failure Conditions for Stormwater System Design:
Along with the ongoing cost of the project in green, the complete list of rules and penalties can be seen by clicking the blue "?" symbol at the top of the Hydrology Engineer video game, in the "banner line" as it is sometimes called. Also click the Controls tab to review controls and methods for placing and moving objects.

For example, pipes can be gripped at the end entering catch basins (underneath inlets) and moved to a different catch basin wall to avoid design rejection due to intersecting pipes or pipes entering corners.



Rules: There is a Rules Tab that can be reviewed as well as a Penalties tab:

HELP MENU

SUMMARY | RULES | PENALTIES | CONTROLS

Jurisdictional Rules

Different Jurisdictions may have different requirements regarding storm sewer design. Below you will find a collection of rules regarding this site. While you ultimately want to have the cheapest design possible you need to get your design approved and that means playing by the rules.

Min Pipe Cover	1ft
Max Pipe Cover	15ft
Min Pipe Slope	-0.10%
Max Pipe Slope	-10.0%
Min Structure Depth	4ft
Max Structure Depth	9ft
Min Structure Distance	5ft
Max Pipe Length	300ft
Min Structure Setback	10ft
Max Gutterspread Allowed	8ft
Supply Water Clearance	1.5ft
Sanitary Sewer Clearance	-1.5ft
Roadside Ditch Pond	90%

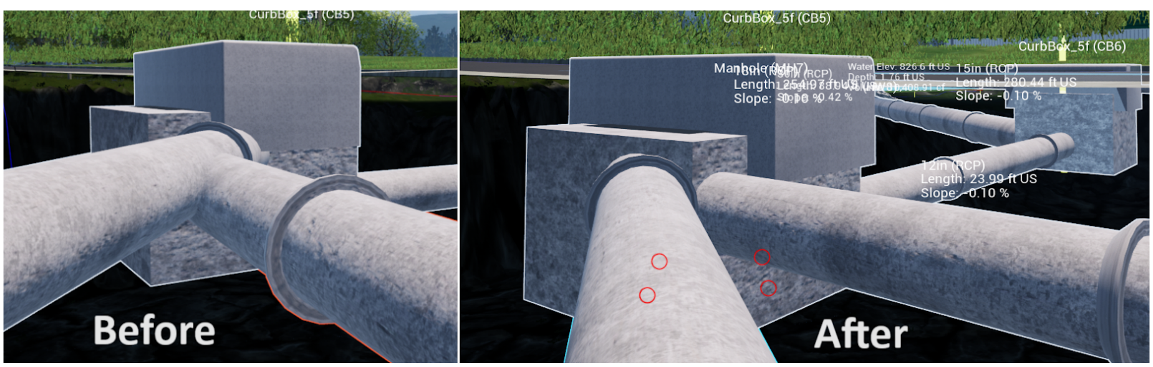
Penalties: Here is the list of Penalties as seen in the Penalties tab:

Penalties	
Pipe under driveway	$500
Building Encroachment (< 10ft)	$500
Building Encroachment (< 3ft)	$1000
Pipe over Max Pipe Length (300')	($100/lf) over max length
Max Structure Depth (> 9ft)	$500
Max Pipe Trenching Depth (> 8ft)	$2500
Incorrect Curb Box used	$500
Single user of structure type or pipe material/size	$500
Roadside ditch ponds not drained enough (90%)	$500

Design Failure Penalties	
Pipe under building	
Pipe exceeds absolute max depth	> 15ft
Pipe Exceeds Max Length	> 320ft
No headwall at outfall location	
Structure does not outflow to headwall	
HGL above rim elevation	
Pipe has invalid slope	> -0.10% or < -10.0%
Pipes Collide with each other	
> Max Gutterspread	8ft
> Max Inletspread	8ft
Pipe collides with structure	
Pipe collides with Utility Pipe	
Structure not found at low point (sag)	
Culvert Pipes much be below grade	
All roadside ditch ponds must be drained	
Headwall used for both Inflow and Outflow	

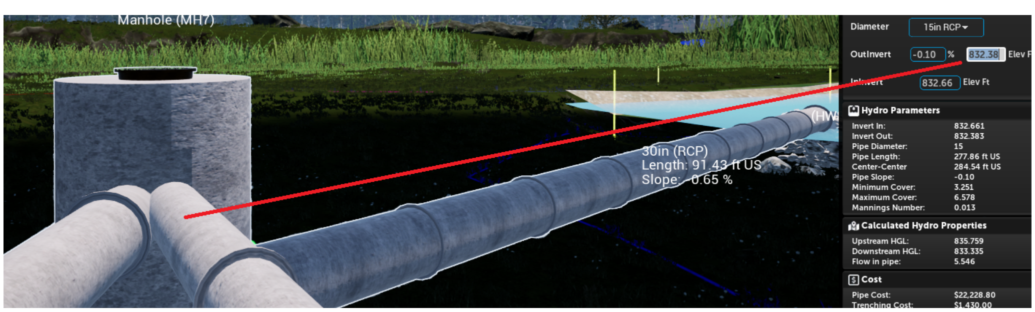
Design for Success—An Example of a Successful Design:
Although this document will not provide all the clues to a successful design, we will at least show one example and explain one aspect of this successful design. Let's assume we made the storm sewer pipes large enough to eliminate any geyser effect at inlets and manholes, meaning we are not applying undue pressure in the pipe system from small storm sewer pipes. Then by clicking Check Design, you might see a Failure summary such as below:

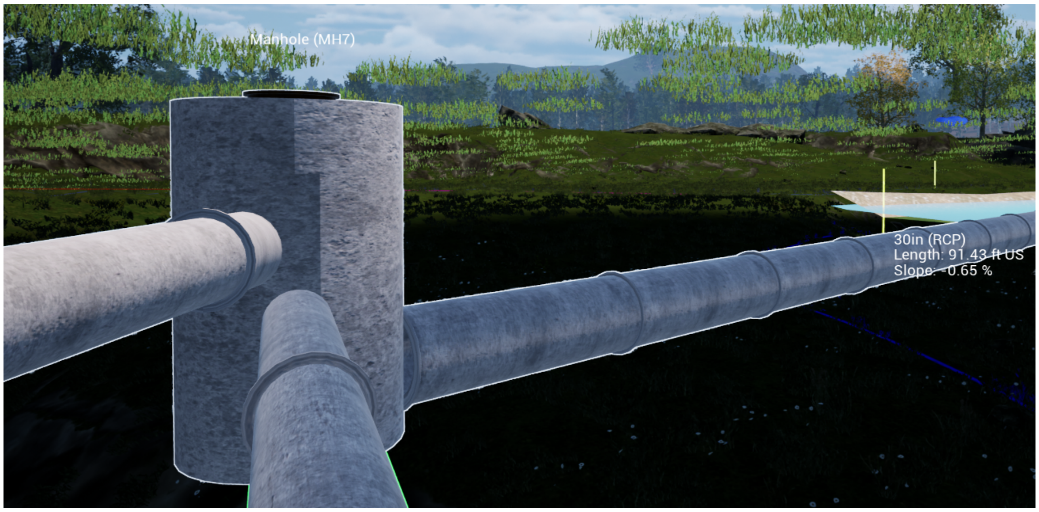
At this point, you would search for the colliding pipes and grip and move one of them to another wall or face of the catch basin. Shown below is the "Before" and "After" of this process. Note how during the move process, small red circles or "snaps" in the catch basin wall nearest to the mouse cursor are provided.



With this change, you may still find that you have 8 Failure Counts. All colliding pipes count as one failure!

There are several methods possible to avoid colliding pipes. One, shown below, is simply to lower the rightmost entry pipe by clicking that pipe and changing its "OutInvert" elevation in the dialog at right from 832.38 to 2.0 feet lower at 830.38. ("Invert" refers to the bottom pipe elevation—you are learning the lingo).





With this change, no pipe collisions occur and we are reduced to a Failure Count of 7:

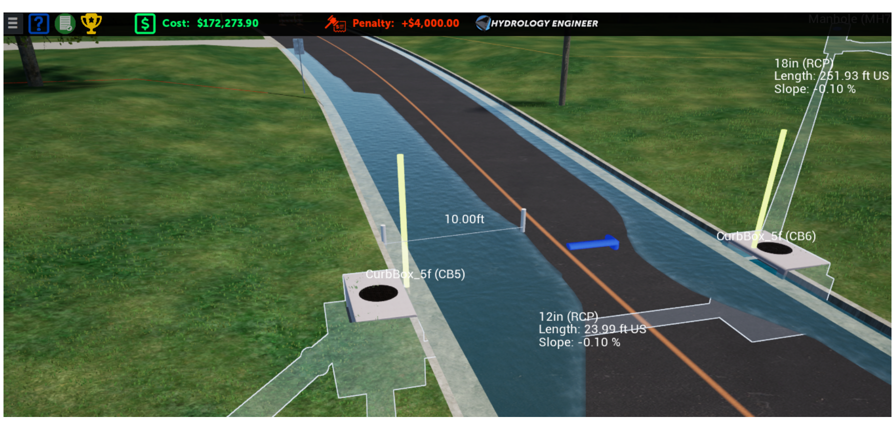
Failures

Failure Amount of Gutterspread Distance [Limit: 8 Feet]
Failure Amount of Gutterspread At Inlet [Limit: 8 Feet]
Failure Count: 7

There are many ways to overcome the design flaws as reported by the Hydrology Engineer Video Game. The method chosen above lowers one of the pipes entering the manhole that was placed just before the last pipe to the detention pond. This lowered pipe is deeper and will therefore have more trenching costs to place it in the ground. There are consequences to this decision. This illustrates why civil and hydrology engineering design are such dynamic and often iterative processes.

Solve the "Gutter Spread" Problem by Adding Inlets

Inlets can be added on either side of low points to reduce gutter spread. After calculating the Storm Event, by using the measuring tape icon, you can study all gutter spread dimensions that exceed 8 feet. For example, here on the side road, the gutter spread is 10 feet. Be sure to press Enter to exit the Tape Measure mode



Note in the distance on the left side of the road, the gutter spread sharply decreases. This is due to a “swale” or low depression in the “digital terrain model” or the surface ground, which enters the street at that point. More water pours into the street there, and if you zoom in closer using the mouse wheel, a special “waterfall” symbol indicates that flow has increased at that point. More inlets are needed to the left of that symbol.

Now without giving away too much in terms of methods and techniques for better designs, we will add lots of inlets to make sure our design passes.

Here’s an example design above, seen from a distance, with a reasonably good total cost of $232,232.30. Note that the gutter spread is pretty “dialed in.” The largest gutter spread is just under 8 feet!

Penalties

Gutterspread

Worst Distance: 7.947 FT

Penalties

Type	Penalty
10 FT Building Setback Encroachment [Limit: 10 Feet]	$ 500.00
Exceeds Maximum Structure Depth [Limit: 9 Feet]	$ 500.00
Incorrect Curb Box Used For Slope	$ 500.00
Single Use of a Different Pipe Type or Structure	$2,000.00

Penalty Count: 7

Penalties Cost: $3,500.00

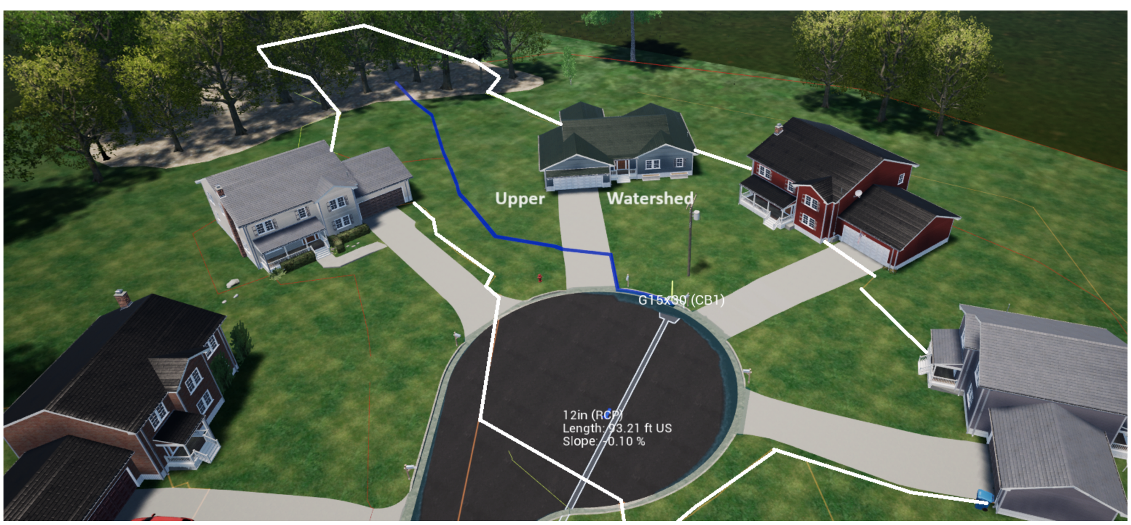
It should be pointed out that the total cost includes actual construction costs plus design penalties. Here we are penalized for using just one single corrugated metal pipe, with all other pipes being reinforced concrete. That one "special order" corrugated pipe comes with a penalty for loss of volume discounts, a typical consideration in engineering design.

We have a successful design and a cost target of $232,000 that will almost surely be improved on by the "winning" players!

Lesson in Hydrology: The Rational Method for Peak Flow, Q=CIA

The Hydrology Engineer Video Game calculates dynamically every watershed above any placed inlet, from the digital terrain model of the subdivision that is built into the game. A watershed is an area of land where all the water that falls or drains into it flows to a common outlet. It is the watershed area, slope and land cover types that help determine the peak flow in the 50-year storm that feeds into any placed inlet.

For example, consider the very first "upper" watershed on the site, that feeds into the cul-de-sac. When an inlet is placed at the low point in the cul-de-sac, the watershed that feeds to that inlet is automatically calculated. The perimeter of the watershed is shown approximately below as a white boundary line:



The Rational Method is a commonly used and nearly universal method for calculating peak flow in smaller watersheds. It has a simple, easy-to-remember formula, which is Q=CIA. The components of that formula are:

Q = Peak Flow in cubic feet per second (English units)
C = Average “composite” runoff coefficient for the site, with C=1 being 100% runoff
I = Rainfall amount in inches per hour—this increases typically the shorter the travel time (small watersheds)
A = Area in Acres

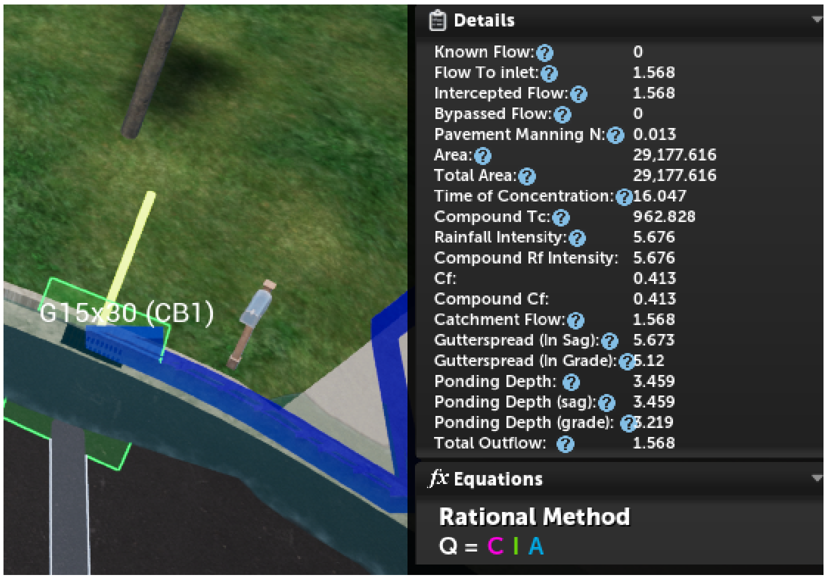
The easiest item for this STEM Video Game to compute is the A for Area. That would be the area of the white boundary shown for the approximate cul-de-sac watershed. The Video Game finds that watershed and calculates it precisely. The C factor or runoff coefficient is also relatively easy to calculate, since it is area-based. Within that white boundary, all roofs might have a runoff coefficient of 0.85. All concrete driveways and even the concrete curb and gutters might have a runoff coefficient of 0.95. Asphaltic areas might have a 0.9 C factor and the grassy areas could be 0.2. Forested areas like at the top of the watershed often have runoff coefficients as low as 0.12. The areas of these different land covers are auto-calculated by the video game which leads to a “composite” C factor used in the calculation of Q, the Peak Flow.

If you click on the inlet in the cul-de-sac (at the low point) and select it, you will see at right the full derivation of the Q or Peak Flow. Here Q = C * I * A, or 1.568 cfs = 0.413 * 5.676 * 0.67 Acres

The most complex aspect of Q=CIA is the I, or Rainfall Intensity. The program must first calculate the longest flow line, such as the blue flow line shown above, study its slope, figure its travel time to the inlet, and then consult a chart that interpolates the rainfall intensity in inches per hour from the travel time, often referred to as T_c or “Time of Concentration”. Travel time, T_c and Time of Concentration are used interchangeably and refer to the same thing. Blue flow lines can be placed on the surface for reference using the blue flow line icon.

If you expand out the Details for the selected inlet (CB1 or “Catch Basin 1”), you will see more information including the ponding depth in the “sag” inlet, which refers to an inlet at a low point. If an inlet is not placed at a low point but elsewhere along the road, it is referred to as an “on grade” inlet. In some cases, inlets catch all the water. In other cases, there is so much flow in the gutter that particularly an “on grade” inlet can have what is called “bypass flow”. Some of the flow is captured in the inlet, some runs around the inlet and continues down the gutter line.

There is an even more complex aspect to the gutter spread particularly in a “sag” or low point inlet like CB1. The gutter spread must be calculated by both “sag” and “on grade” methods, and the higher gutter spread is then used (to be conservative and prevent potential excessive gutter spread). Here the “sag” gutter spread of 5.673 feet was larger than the “on grade” gutter spread equivalent calculation, so the sag gutter spread governs. There are a lot of calcs going on in the background with each design decision exercised by the gamer!



Addendum: The Rules of the Scholarship Program

The $3,000 "Best in State" and $12,000 "Best in World" Grant and Scholarship Program Described: The scholarship program awards $3000 to the school where an enrolled student has the winning (lowest cost) score submitted in each of the 50 states in the U.S. by January 15, 2024. From the $3000 award, $2000 is designated for the student submitting the score, who can choose to be named or remain anonymous. Of the $3000 award, $1000 is a grant to the school for participation in the program. A $12,000 award will go to the school with a "top 5" best score (lowest score) anywhere in the world, of which $10,000 is a scholarship to the enrolled student submitting the score, with $2000 as a grant to the school. Schools will be paid the scholarship money and it is up to the schools to distribute the scholarship award to the students. It is possible that a "top 5" winner can also be a "best in state" winner, and in that case the school would receive $15,000 in grant and scholarship awards to distribute. A score wins by being the lowest cost solution that is "Approved" as shown below. When a design is Approved, it can be submitted to the in-game leader board in the name (or alias) of the player using the Hydrology Engineer Video Game, and lowest cost scores win per game rules and will be traced to the appropriate school and state.

Age Range: The scholarships will only be awarded to players or "gamers" of any age who are enrolled at a school, from Middle School through High School through college or university. Since the purpose of the scholarship is to provide funds for college education and to encourage the selection of civil engineering as a college major, awards are in the form of scholarships distributed by the school administration. Participants can submit multiple scores but only their lowest cost design will be considered for the school scholarship award. Carlson employees and their extended families are not eligible.

Winning Scores must be submitted from Copies of the Hydrology Engineer Video Game Purchased by Schools: If a student is playing the game on a personally purchased copy or purchased by a friend or parent and have a good "Approved" score that they would like to submit, they need to convince the school they attend to purchase the program and re-play the game and reproduce the same design to have the score considered for award. Only designs submitted on a school-purchased Hydrology Engineer Video Game are eligible for the award, and the award is distributed through the school itself as a school-based scholarship.

Middle Schools, High Schools, Vocational and Technical Schools, Colleges and Universities Retain a Portion of the Scholarship Award: For the "best in state" award, a school in a state with the winning lowest score for that state, as submitted by a student, obtains a $3000 scholarship award of which $2000 is designated for the student. A top 5 "best in world" winning submittal leads to a $12,000 scholarship award to the school of which $10,000 is designated for the student. Release of awards to the schools require agreement to these terms.

If No Submittals are Received from Schools in any of the 50 states in the United States, no Scholarship Award will be Provided in those States.

Designs Must be Different: All "top 5" winning submittals must contain the following differences: different number of inlet/manhole "nodes," or different connection geometry between nodes or if similar connection geometries, at least 4 pipes with lengths differing by over 10% or at least 10 different pipe material or inlet type selections. All winning designs will be published on the Carlson website with permission of schools.