# WinTR-55
## Small Watershed Hydrology

### Intermediate WinTR-55 Training
*Modeling Watersheds with Structures*

**SEE NOTES AT CLASS EXERCISE #4.**

# Course Outline

- Overview
- Review of Hydrology Terms
- Modeling Single Sub-area Watersheds
- Modeling Single Sub-area Watersheds
- Multiple Sub-area Watersheds
- Modeling Structures

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WinTR-55 Structures

This portion of the WinTR-55 Training covers modeling of Structures. We'll look at how data is entered for structures and how to interpret the output data for structures and watersheds with structures. Be aware that there are a number of things you have to be careful of and watch out for when modeling structures.

# Lesson Objectives

Upon completion of this lesson, you will be able to:

- Describe the relationship between structures, stream reaches and sub-areas in the modeling process
- Develop input data for watersheds with structures
- Input structure data into WinTR-55
- Run WinTR-55
- Interpret Output

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*WinTR-55 Structures*

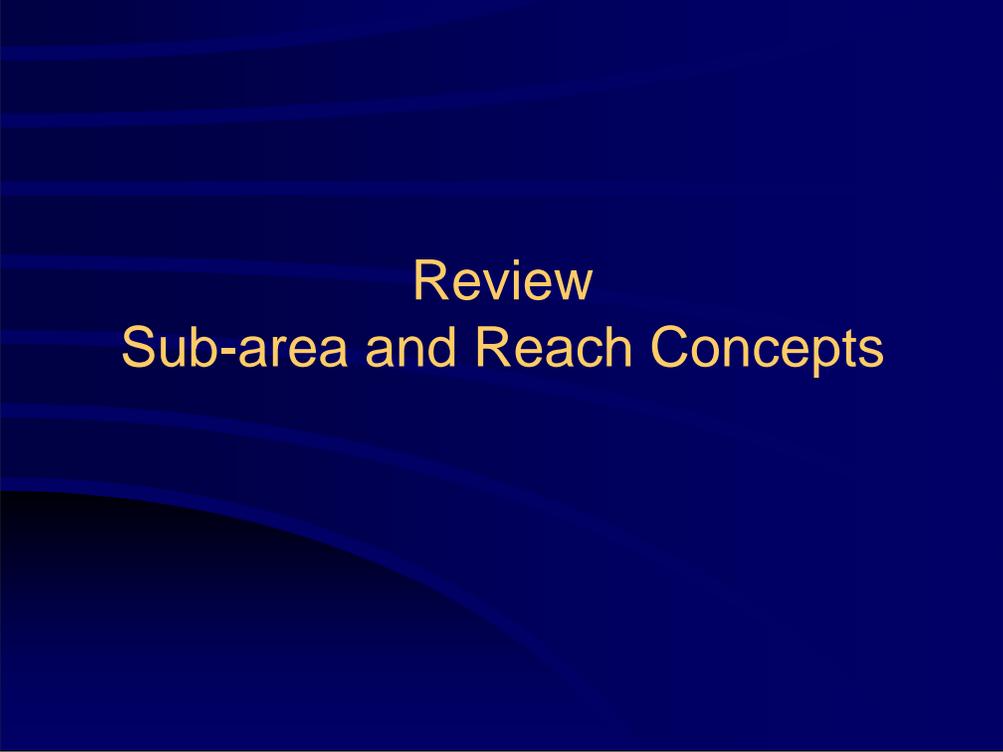The objectives for this lesson are for you to be able to:

Describe the relationship between structures, stream reaches and sub-areas in the modeling process;

Develop input data for watersheds with structures;

Input structure data into WinTR-55;

Run the program; and

Interpret the output.

# Review
# Sub-area and Reach Concepts

Because the sub-area and reach concepts are so important to the modeling process, we'll take just a few moments to review them again. If there's anything you didn't get the first time or you're still not clear on it, please ask questions.

Sub-area / Reach Concepts

- **Watershed** - system of sub-areas and reaches
- **Sub-areas** - watersheds that generate runoff
- **Reaches** - represent watershed flow paths (stream channels) or structures
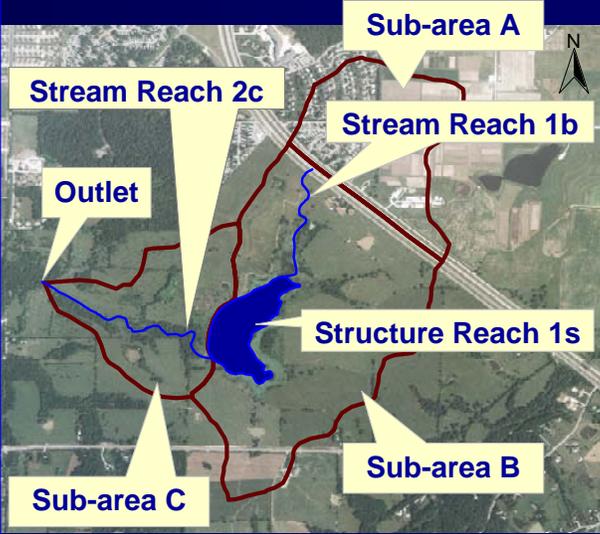
WinTR-55 Structures

A watershed can be split up into multiple sub-areas and reaches. Look closely at our watershed map and notice how the parts of the watershed are identified. Sub-areas are those land areas that can be thought of as generating runoff. Reaches are watershed flow paths through which runoff is conveyed in a concentrated manner. Stream reaches are the most easily identifiable of reaches, however, within WinTR-55, one may also have structure reaches. If we are modeling runoff that is conveyed through a structure, we identify a Structure Reach, labeled 1s for this example. We looked at stream reaches in the last lesson, so now we'll focus on the structure reaches.

Another important consideration is how runoff from sub-areas and water conveyed through reaches are combined to produce hydrographs. In other words, how do reaches and sub-areas relate to one another.

From the figure shown here imagine rain falling over the entire watershed. At some point enough rain falls and runoff starts to occur. If we look at each sub-area and treat it individually it is easier to analyze what is happening over the watershed. First start with Sub-area A. The water hits the ground, a portion of it runs off the ground surface and ultimately ends up at a point in which we are interested, for example at the highway culvert at the outlet of Sub-area A.

All that water is then conveyed through Reach 1b. While all that is going on, the rain falling on Sub-area 2 is also running off and collecting, probably in the lake shown here. We need to combine the runoff from Sub-area B with the water coming down through the stream channel (Reach 1b) from Sub-area A. We do that, and then route the water through the structure reach, 1s, to get a total outflow hydrograph from the structure. Once routed through the structure, the water is conveyed through Reach 2c to the watershed outlet where it is combined with the runoff from Sub-area C to get a total runoff hydrograph for the entire watershed area at the watershed outlet.

# Sub-area/Reach Concepts

- **Watershed** - system of sub-areas and reaches
- **Sub-areas** - generate runoff
        - feed into the upstream end of reaches
- **Reaches** or Routing Elements- represent watershed stream flow paths or structures
    - *Channel* Routing elements - Stream Reaches
    - *Structure* Routing elements - Reservoir/Structure Reaches
- Watershed **Outlet** - downstream end of the watershed (required for all watersheds)

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You saw this slide in the previous lesson, but for review and to re-emphasize the important points.

🖱 A watershed can be thought of as a system of sub-areas and reaches.

🖱 Sub-areas are those smaller subwatersheds that generate runoff and feed into the upstream end of reaches.

🖱 Reaches are routing elements through which water is conveyed.  There are two types of reaches.

🖱 Channel routing elements or Stream reaches, and 🖱 Structure routing elements or structure reaches.

🖱 All watersheds are required to have an identified Watershed Outlet.  Do not confuse the Watershed Outlet with outlets for individual sub-areas.

In the last lesson we looked at stream reaches, so now we'll focus on structure reaches.
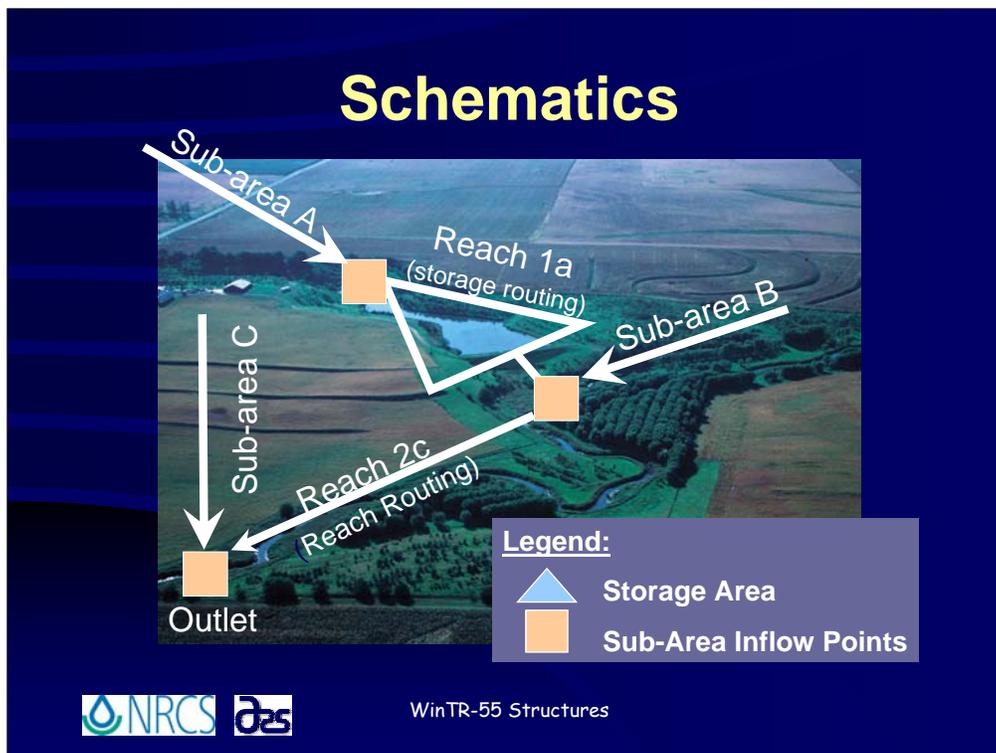
A quick review of Schematics:
Schematics are simply line drawing representing the elements of a watershed model. Remember we said that watersheds consist of a series of sub-areas and reaches. The idea behind building a schematic is to show how these elements are combined to represent our watershed as we build our computer model for that watershed. Taking the time to make a quick sketch of a schematic for a watershed model will really help clarify how all those parts fit together when it comes to the time of entering your data. I can't emphasize enough the importance.

You've seen this slide before, so we'll go through it a bit more quickly than earlier, but again, the sub-area/reach concepts utilized in this model are one of the most important things you need to have a clear idea of in order to build good models.

As I mentioned, t the schematic is a simple line drawing representing the elements of a watershed model. 🖱 In this schematic blue triangles represent storage areas (or STRUCTURE reaches) and orange squares represent sub-area inflow points. Other lines represent either sub-areas or stream reaches as labeled.

🖱 Starting with Sub-area A we have a line representing the Sub-area. We develop a runoff hydrograph for that sub-area. The orange square show us that this is where the inflow (runoff hydrograph) from Sub-area A enters the watershed system. 🖱 We route the runoff from Sub-area A through the structure (blue triangle) at the outlet of Sub-area A and label it a structure reach. In this case, REACH 1a.

🖱 Next we develop a runoff hydrograph for Sub-area 2 which is represented by a line and show the point at which this runoff enters the watershed system (orange square). The water from REACH 1a (the structure) and Sub-area B are combined then at the TOP of REACH 2c (which is the stream reach running through the middle of Sub-area C). 🖱 This entire hydrograph is then routed through the stream reach, REACH 2c towards the watershed outlet.

🖱 We next develop a runoff hydrograph for Sub-area C, showing the location at which that runoff enters the watershed system as an orange triangle. 🖱 The water from REACH 2c and Sub-area C are then combined into one total hydrograph at the WATERSHED OUTLET.

# Adding Structure Reaches
## and
## Developing Structure Data

Just as with modeling multiple sub-area watersheds, when modeling structures there are a number of steps you have to go through to make certain the model reflects the structures so that you are properly modeling the effects of structures.
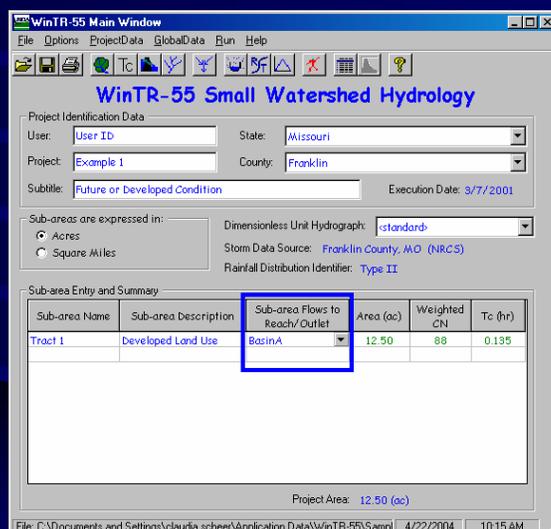
# Adding Structure Reaches

1. **WinTR-55 Main Window**
2. Reach Data Window
3. Structure Data Window
4. Reach Flow Path Window

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WinTR-55 Structures

To add structures to a file, there are four steps to follow. Starting with the *WinTR-55 Main Window*, then proceeding to the *Reach Data Window* and the *Structure Data Window*. You will finally want to check the *Reach Flow Path Window* to make certain everything is properly entered into WinTR-55.

# WinTR-55 Main Window



**On the** *WinTR-55 Main Window* **you will specify that runoff from the particular sub-areas flows into STRUCTURE REACHES under the** *Sub-area Flows to Reach/Outlet* **column.**

**The name of the reach will be the name of the structure reach if the runoff from that sub-area is routed through a structure before proceeding further downstream through the watershed to the outlet.**
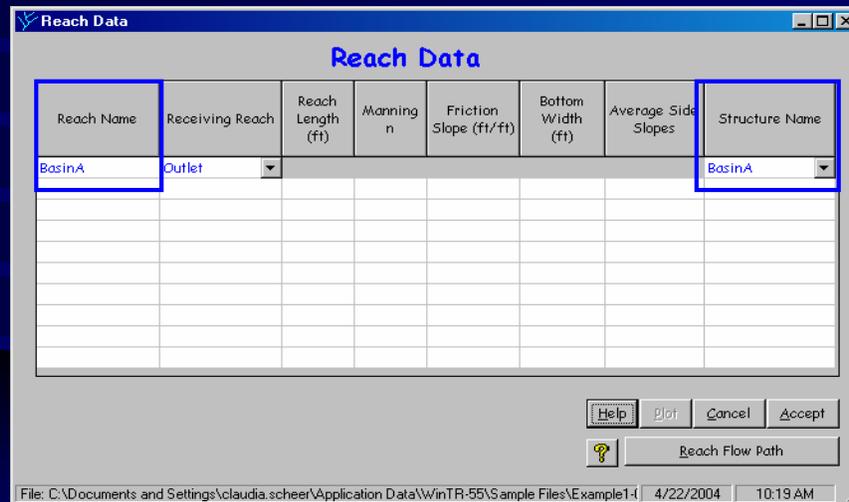
# Adding Structure Reaches

1. WinTR-55 Main Window
2. **Reach Data Window**
3. Structure Data Window
4. Reach Flow Path Window

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WinTR-55 Structures

**Next, proceed to the** *Reach Data Window* **where you will specify the name of the structure reach and the name of the structure itself.**

You noticed on the previous slide that it is necessary to specify both a *Reach Name* and a *Structure Name*.

Generally it is recommended that you use the same name for both as this is less confusing. However, since the same structure configuration as specified on the *Structure Data Window* can be used for more than one structure reach, it is not a necessity. In other words, the names CAN be different. However, if you use different names for the Reach and Structure, make certain you are careful when specifying the combinations of Reach and Structure data that you want to use.

Again, it's generally just easier and causes less confusion if you give them the same name.

Structure names may be up to 10 alphanumeric characters in length, but the program only recognizes the first 8 characters, so those first 8 characters must be unique. Don't forget that the reach name must contain at least one alphabetic character.

**Adding Structure Reaches**

1. WinTR-55 Main Window
2. Reach Data Window
3. **Structure Data Window**
4. Reach Flow Path Window

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Once you've completed inputting the information on the *WinTR-55 Main Window* **and specified the Reach and Structure Names on the** *Reach Data Window*, **you should proceed to the** *Structure Data Window* **where you will define the physical parameters of the structure.**

The *Structure Data Window* **allows you to define the physical features of the structure so far as the hydrologic analysis of that structure is concerned.**

🖱 **You will first need to either enter the** *Structure Name***, or if you've specified it on the** *Reach Data Window***, use the** *dropdown list* **and select the appropriate structure.**

🖱 **Next you will enter the** *Pond Surface Area* **information. The first entry is for the surface area of the pond at the principal spillway crest elevation. The area will be in appropriate units for whichever system of units in which you've chosen to work, in this case acres.**

🖱 **There is an optional entry for second surface area at some stage above the principal spillway.** <u>If you do not enter anything here, the program will assume the detention basin has vertical sides and will use the same surface area at each stage when computing structure storage volume. If you do enter a value here, the program assumes a trapezoidal shape to the basin and will adjust the storage volume computations accordingly.</u>

🖱 **The** *Discharge Description* **portion of the** *Structure Data Window* **will differ for the** *Spillway Type* **you select.** 🖱 **You may specify a** *Pipe* **or a** *Weir***. We'll take a look at each of those in detail shortly.**

**As with all the WinTR-55 windows, there is a** *Help Button* **and a** *Quick Help Button***. And as a reminder, when you have finished data entry on this window, you must click the** *Accept button* **to save the data. Clicking** *Cancel* **or the** *X* **at the upper right of the box will cause you to lose your data.**

**You will notice on this window that some buttons are grayed out. Once you've entered sufficient data for the structure, the program will compute a structure rating curve and those buttons will go live. You'll see that as we look more in detail at pipe and weir spillways.**

## Spillway Types

- **Pipe**
- Weir

Now let's take a look at the spillway types, starting with Pipe Spillways.

# Pipe Spillway

WinTR-55 Structures
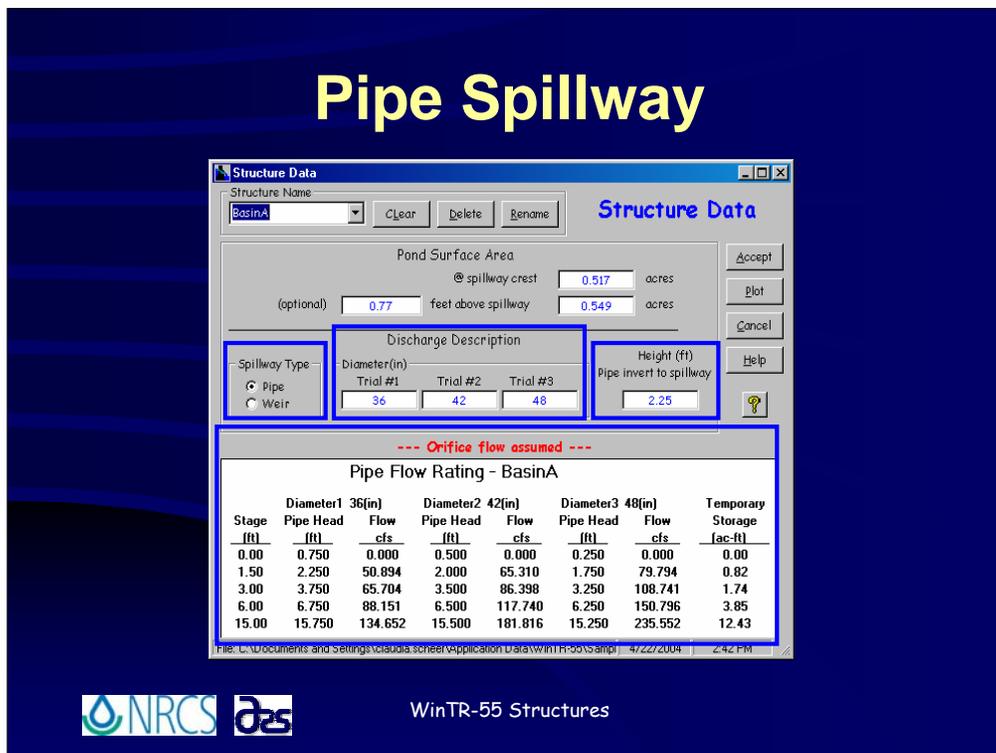
To specify a pipe spillway, click the radio button 🖱 **for** *Pipe* **under** *Spillway Type*.

**The pipe spillway is the default, so when you open the** *Structure Data Window* **it will open to a pipe spillway configuration.**
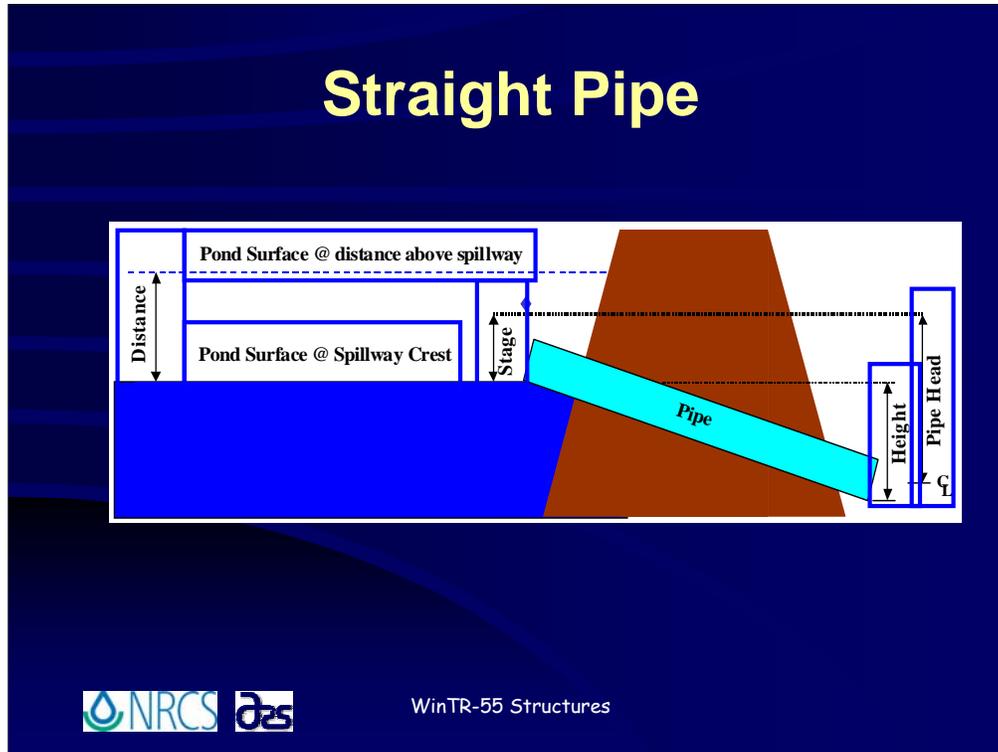
🖱 **When specifying a pipe spillway, you may enter up to three different pipe diameters to test. The program will make as many runs through the data as pipe trial sizes are indicated. If you enter three pipe diameters the program will use the Trial #1 pipe diameter for the first run through, the Trial #2 pipe diameter for the second run, and the Trial #3 pipe diameter for the third run. This will be done for each storm event indicated, however the program will make no more than 3 runs for each storm even if multiple structures are included. In the event there are 2 or more structures in the watershed, all the Trial #1's are run together, then all the Trial #2's and then all the Trial #3's.**

🖱 **You must also specify a Height from the pipe invert at the outlet end of the pipe to the spillway. You'll see more clearly in the next illustrations how that is defined. One thing to keep in mind though is that this height must be at least ½ times the pipe diameter or greater. So, in the example of a 48" pipe diameter, a height from pipe invert at outlet to spillway crest elevation of no less than 2 feet could be specified. This is because of the way the program does the pipe flow computations we'll look at in a moment.**

One thing to notice here is that the pipe diameter is specified in inches, while the height from the pipe invert at outlet to the principal spillway crest is in feet. In the case of SI units, the values are in units of millimeters and meters, respectively.

🖱 **Once sufficient data is entered for the pipe diameter and height from the pipe invert at outlet to the spillway crest, WinTR-55 automatically computes a pipe flow rating for the structure.**

Pay attention to the note in red that says "Orifice Flow Assumed." We'll talk about that in just a moment.

# Straight Pipe

Pond Surface @ distance above spillway

Distance

Pond Surface @ Spillway Crest

Stage

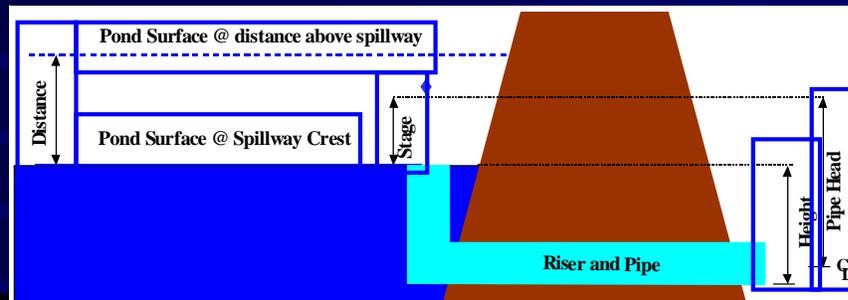Pipe

Height

Pipe Head

C_L

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This slide and the next show the types of pipe configurations for which WinTR-55 can be used. The first, shown her is a straight pipe through a fill.

This illustration shows how the variables used in the pipe computations are defined.

🖱 First, the pond surface area at the spillway crest.

🖱 Next, the pond surface area at some distance above the spillway crest. Remember if you don't enter a value for this, the program assumes the pond has vertical sides.

🖱 I also want to point out the Height from the pipe invert at the outlet to the spillway crest elevation, illustrated here.

🖱 In the computations for pipe flow, pipe head is computed from the centerline of the pipe at the outlet at stage, measured above the spillway crest.

This slide shows the drop inlet type spillway, and again, this illustration shows how the variables used in the pipe computations are defined.

🖱 **Pond surface area at the spillway crest.**

🖱 **Pond surface area at some distance above the spillway crest.**

🖱 **Height from the pipe invert at the outlet to the spillway crest elevation, illustrated here.**

🖱 **Pipe head, computed from the centerline of the pipe at the outlet at stage, measured above the spillway crest.**

# Pipe Flow Equations

where:
g = gravity
$c_d = 0.6$
Height, feet
$Head_{pipe}$, feet
Stage, feet
$D_{pipe}$, inches
$A_{pipe}$, square feet
$Flow_{pipe}$, cfs

$$Head_{pipe} = Height + Stage - \frac{D_{pipe}}{24}$$

$$A_{pipe} = \pi(\frac{D_{pipe}}{24})^2$$

$$Flow_{pipe} = A_{pipe}c_d\sqrt{2gHead_{pipe}} = 4.8A_{pipe}\sqrt{Head_{pipe}}$$

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**WinTR-55 uses an orifice flow equation to develop the rating curve for pipe flow.**

# Pipe Flow Assumptions

- Short-tube approximation – assumes orifice flow through the pipe at all stages
  - *Reasonable for drop inlet configuration*
  - *May be unreasonable for large straight pipes*
- If not appropriate, use other routing models
  - *SITES*
  - *WinTR-20*

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At any given stage, WinTR-55 assumes orifice controlled flow for the computed pipe head based upon pipe diameter. This is a reasonable assumption for the riser and pipe configuration. However, this assumption may be unreasonable for large, straight pipes.

In this case, the orifice flow assumption has not been satisfied. Other routing software, such as SITES, is necessary to analyze these cases. Another option is to develop your own rating curve for the pipe and use WinTR-20.
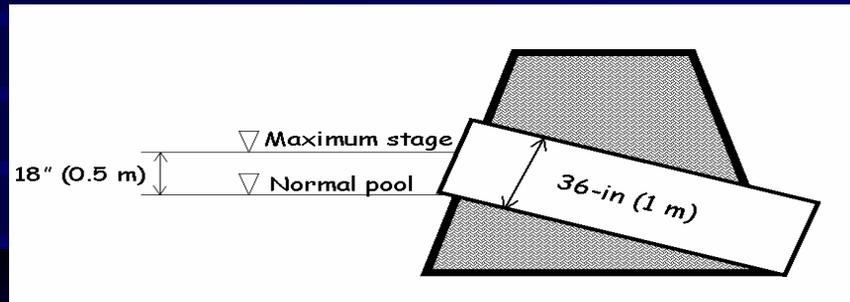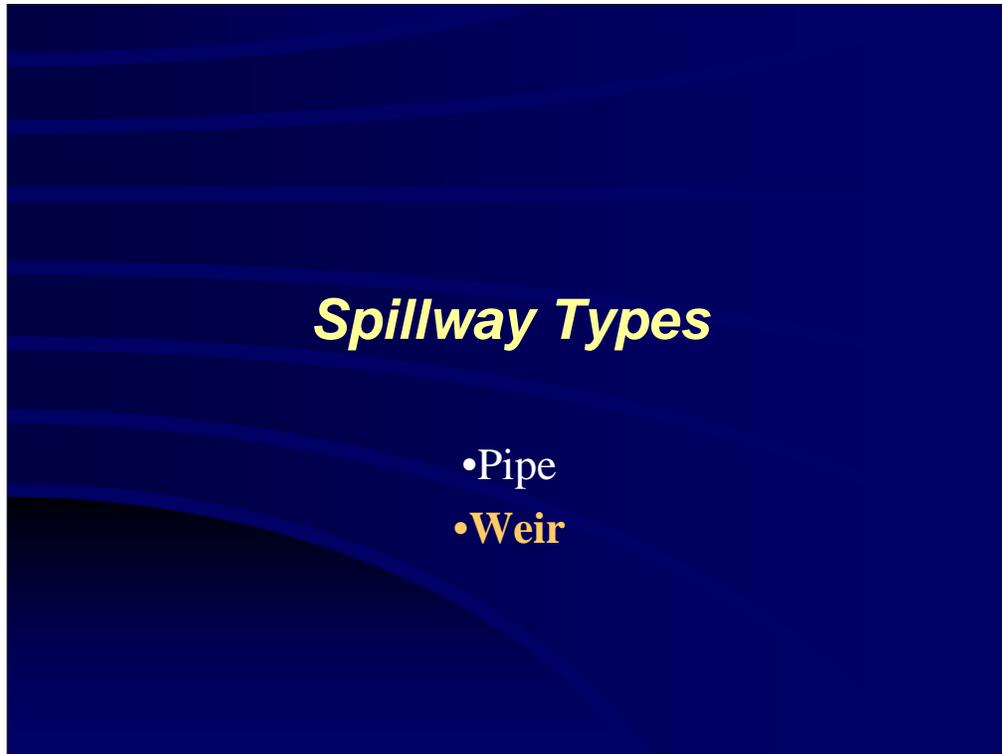
This is an illustration of when the full pipe flow assumption would not be valid.

In this example, if the structure outlet is a 36-inch (1-m) diameter pipe culvert and the maximum computed stage is 1.5 feet (0.5 m). If maximum stage is 1.5 feet, the pipe will never flow more than half-full.

If WinTR-55 is used and orifice flow is assumed at all stages, the program will give artificially high structure discharges and may not be a method you wish to use in this situation.

# Spillway Types

- Pipe
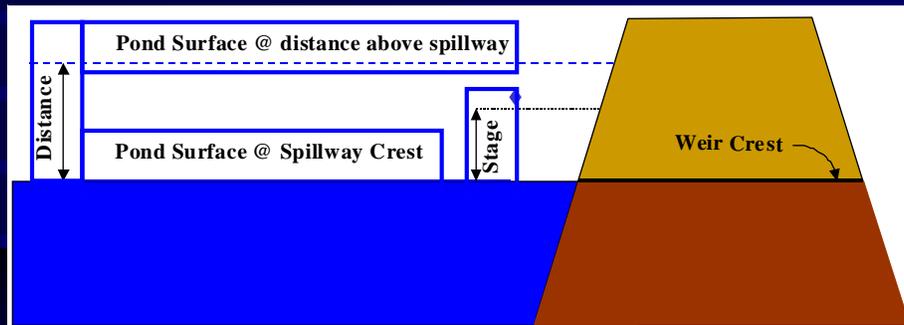- **Weir**

The second option is to model a weir spillway.

**To specify a weir spillway, click the radio button 🖱 for** *Pipe* **under** *Spillway Type***.**

**🖱 When specifying a weir spillway, you may enter up to three weir lengths to test. Just like with the pipe spillway, the program will make as many runs through the data as trial sizes are indicated.**

**🖱 Once sufficient data is entered for the weir, WinTR-55 automatically computes a weir flow rating for the structure.**

**Weir Configuration**

Pond Surface @ distance above spillway

Distance

Pond Surface @ Spillway Crest

Stage

Weir Crest

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This illustration shows the assumed weir configuration.

The information necessary to model a weir spillway are:

🖰 **Pond surface area at the spillway crest.**

🖰 **Pond surface area at some distance above the spillway crest.**

🖰 **And the weir length perpendicular to the flow (in other words, the length INTO the picture as shown here).**

WinTR-55 uses the surface area information to compute the stage-storage relationship and will use the weir length to compute flow rates over the top of the weir for various stages.

# Weir Flow Equations

$$Flow_{broad-crested-weir} = 2.8 L_{weir} Stage^{1.5}$$

$$Flow_{v-notch-weir} = 2.5 Stage^{2.5}$$

*where:  $L_{weir}$ = weir length, feet*

*Stage, feet*

*$Flow_{weir}$, cfs*

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Using WinTR-55, you can model either a broad crested weir or a v-notch weir. Shown here are the equations WinTR-55 uses to compute flow rates through the structure for those weir configurations.

# Weir Flow Assumptions

- Entry of a zero weir length indicates a 90° v-notch weir

- Other entry for weir length indicates a rectangular – *having vertical sides* - broad-crested weir

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The assumptions in developing weir ratings are:

The entry of zero for a weir length indicates a 90-degree v-notch weir.

Any other entry for length indicates a rectangular broad-crested-weir, or one having vertical sides.

If you wish to model a different configuration, it will be necessary for you to develop your own rating curve and utilize WinTR-20 as there is no provision for using anything other than these weir configurations at present.

# Plotting Structure Ratings
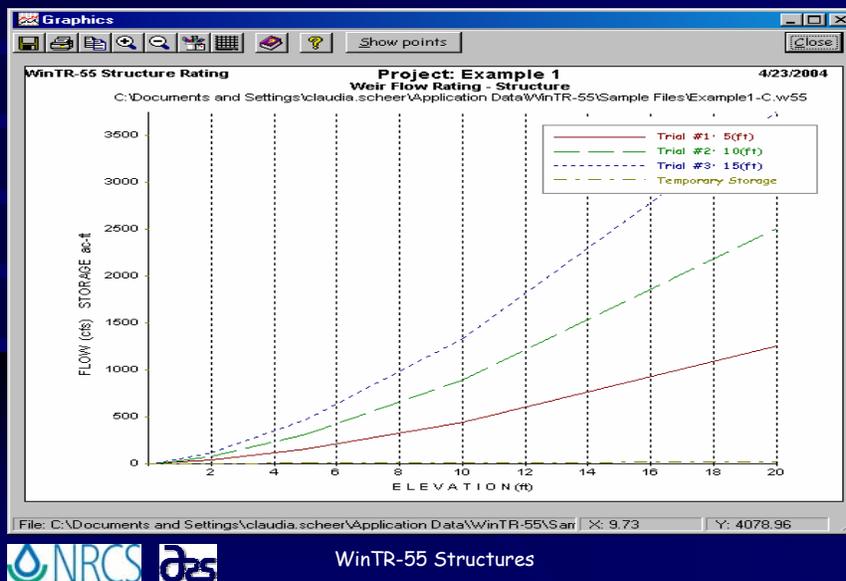
Once you've developed the rating curve for the structure, it is possible to plot and view using the *Graphics Window.* **Shown here are the ratings for the three weir widths you saw in the previous slide.**

Questions?

**Note to Instructor:**

**Take time here to answer any questions that may have arisen and then move on to the next section.**

# *Structure Reach Routing*

Once the structure rating information (stage-discharge-storage volume) information is developed WinTR-55 will use that to perform the structure routing.

# Storage-Indication Routing Method

- Estimates how the hydrograph changes as it flows through a structure

- $\Delta$Storage = (inflow - outflow) * $\Delta$t

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**WinTR-55/WinTR-20 utilize the storage-indication method to perform structure routings. Routing is performed to determine how the hydrograph changes as it flows through the structure and is based on the simple premise that the volume of storage behind the structure is the difference between the rate of inflow and the rate of outflow over a specified time period.**

# Structure Routing Plot
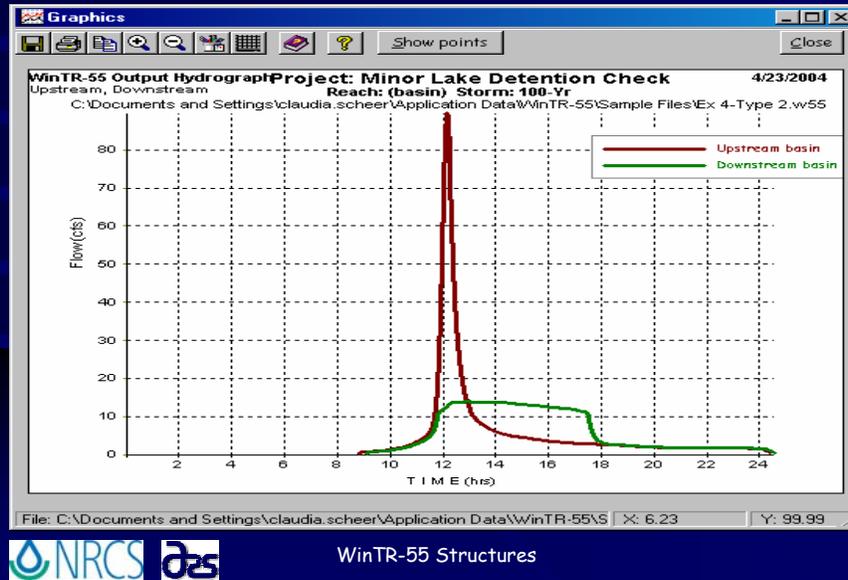
The effects of structure routing are dramatically illustrated here where the brown line represents the inflow to the structure and the green represents the water leaving the structure. This example happened to be for a pipe structure.

# Adding Structure Reaches

1. WinTR-55 Main Window
2. Reach Data Window
3. Structure Data Window
4. **Reach Flow Path Window**

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Now that you've entered all appropriate data on the *WinTR-55 Main Window*, **specified that this is a structure reach on the** *Reach Window*, **and developed the structure rating through the** *Structure Data Window* **there is only one step left before you can attempt to execute a run. That is, the double check that you have everything going where you want it on the** *Reach Flow Path Window*.
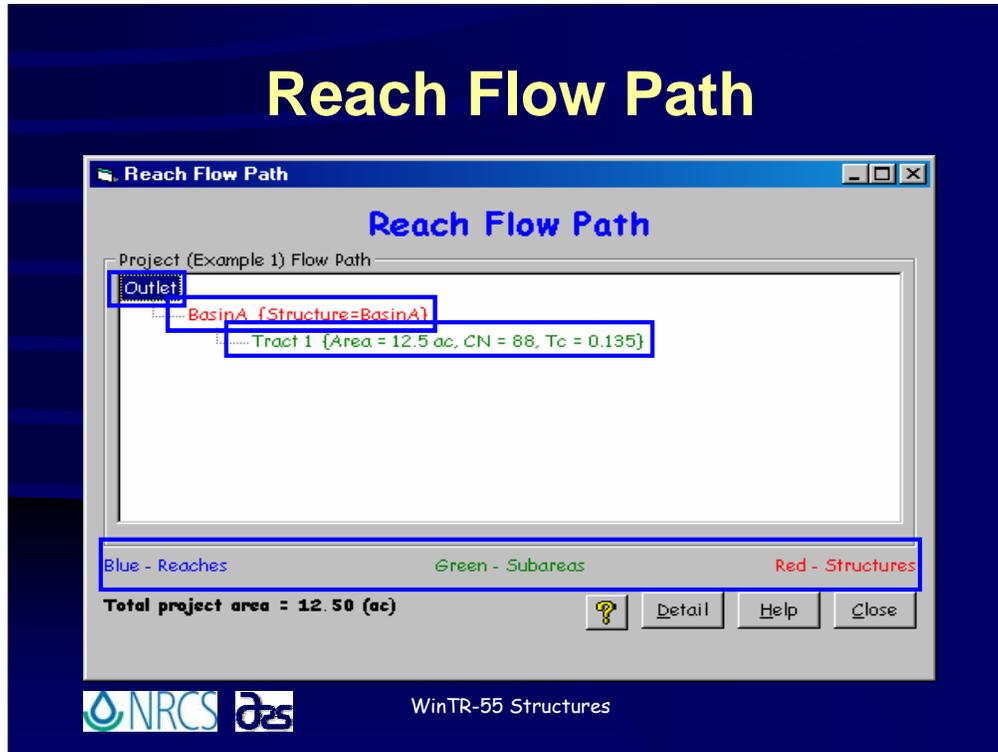
One thing that hasn't been pointed out before is that the watershed elements are color coded on the Reach Flow Path Window. You'll notice here that a Blue color indicates reaches, in this case meaning stream channel reaches; green indicates sub-areas; and red indicates structures.

For the watershed illustrated here, 🖱 the sub-area named Tract 1 flows into 🖱 the structure named BasinA and the flow from BasinA 🖱 flows directly to the outlet. In other words, this structure is located at the watershed outlet.

🖱 Notice that the structure reach name and the structure name are the same for this example. Both are named BasinA. Remember that it is not necessary that they have the same name, but it makes keeping track of things a little easier.
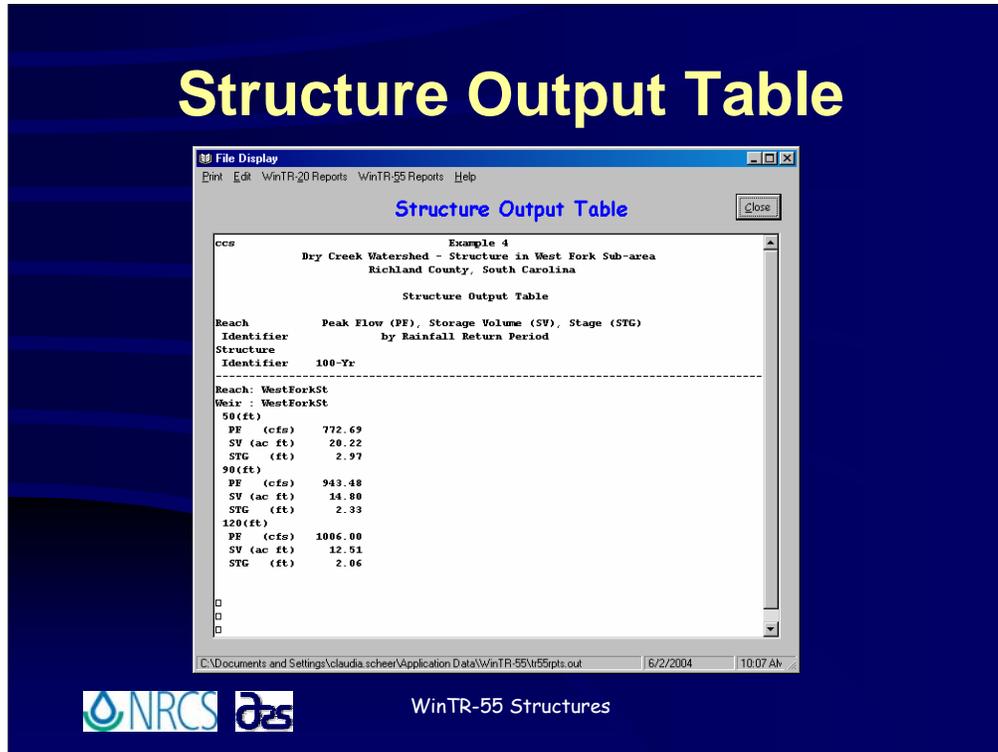
**What weir sizes did you all come up with?** (Allow students to offer input and discussion.)

You'll note here that 3 different outlet weir sizes, 50 ft, 90 ft and 120 ft, were evaluated.

Based on the criteria that the 100-year post development discharge at the watershed outlet not increase, it is necessary to select a weir configuration that produces approximately the same discharge as occurred under existing conditions at the outlet of the WestFork sub-area. From Example Problem #3, the 100-year peak discharge, pre-development, was 940 cfs. So, the weir discharge should be that or less in order that the peak at the watershed outlet isn't increased. Correct?

As shown here, the 90 ft weir throttles the peak from the proposed development in the West Fork sub-area down to a little more than the pre-development peak of 940 cfs.

To see if this will satisfy the requirement that the total watershed peak discharge not increase from pre-development conditions, let's look at the watershed peak table.

**Note to Instructor:**

**Take time here to answer any questions that may have arisen and then move on to the next section.**