Models and Real Watersheds

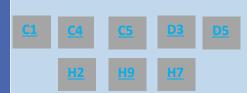
Lesson Summary

Students use Netlogo and a physical model to explore and quantify the processes that determine stream flow after a rainfall event. Students calculate runoff ratios from surfaces with different properties and then look at runoff data from an actual precipitation event across two very different watersheds.

Purpose/Objectives

- To understand how computer models represent real-world systems.
- To learn basics of agent based modeling to visualize a phenomenon (topography driven runoff).
- Become familiar with the limitations of modeling.
- To use the conservation of mass of water to construct total budgets.
- To see and interpret differences in real world runoff ratios and hydrographs, and relate these to controlling factors.
- To learn about the significance of infiltration and storage for reducing runoff and runoff ratios.

Comp Hydro Learning Goals



Next Generation Science Standards



Materials Needed

Activity 1: Netlogo model

- Computers with NetLogo installed
- O Folder of HerringRun files including
 "Netlogo WB of Herring Run Lesson 4.nlogo"
 Downloaded to student computers
- <u>Introduction to</u>NetLogo Powerpoint

Activity 2: For each small research group

- O Paint tray
- Spray bottle
- Sponges or other absorbent material
- Graduated cylinder
- Funnel
- Water
- O Paper towels
- Activity 2 Student Pages
- Activity 2 Excel Data Sheet

Activity 3: Data Investigation

- Activity 3 Rain and Runoff Excel file
- Activity 3 Student
 Pages short version
- Activity 3 StudentPages long version
- O Two Watersheds
 Powerpoint for
 Handouts
- Two WatershedsPowerpoint

<u>Agenda:</u>

Activity #	Activity Label	Timing	Activity Description			
1	NetLogo Surface Runoff Model	25 min	Students use a NetLogo model that includes slope to simulate runoff and a hydrograph from a real storm in the West Branch of Herring Run			
2	Physical Model	30 min	Students use a physical model of a land surface to examine runoff and retention under difference scenarios of infiltration and storage			
3	Data Investigation (comparing two	30 min	Students compare precipitation and hydrograph data from the same storm in two different watersheds			

Safety Concerns:

Students will be using spray bottles with water. Ensure students use spray bottles properly and avoid spraying peers and classroom materials. Floors may become slippery.







Activity One: Simulating Surface Water Runoff

Activity Summary

Students will use a NetLogo model to simulate a rainfall event in the West Branch of Herring Run watershed.
Students will learn about computer models and discuss their accuracy and limitations.

Key Vocabulary

Topography Elevation Aerial Image Infiltration Hydrograph

Advanced Preparation

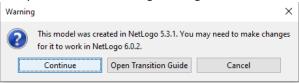
You will need to download and install NetLogo on all the student computers before you begin this lesson. Netlogo is free and downloading is easy, but does take time and effort. You should also have all the Netlogo files for lesson four on a flash drive. The files can be downloaded from the shared Google Folder. Do not try to run the model from Google Drive directly. Use the flash drive to place the folder with the files onto each student computer for ease of access. Download Netlogo at https://ccl.northwestern.edu/n etlogo/

Materials Needed

- Computers with NetLogo installed https://ccl.northwestern.edu/netlogo/
- Folder of HerringRun files including "Netlogo WB of Herring Run Lesson 4.nlogo" Downloaded to student computers

Activity Sequence

- 1. Open the <u>Introduction to NetLogo Powerpoint</u> presentation and go through the slides with your students. While they will have used NetLogo to run the Floorlandia simulation, this will be the first time they will hear about the different components of NetLogo and how the computer program works.
- 2. Navigate to the folder of Netlogo files you downloaded and installed on the student computers. Open "Netlogo WB of Herring Run Lesson 4.nlogo" by double clicking the file. If you see the following message, click "continue."



- 3. When the model opens, click 'Setup' and be patient until the setup button returns to gray.
- 4. Look through each of the data layers by selecting a 'Later to View' and clicking the 'Refresh' button. Discuss the apparent meaning of each layer: <u>Elevation</u>: A Digital Elevation Model of the Herring Run watershed <u>Topography</u>: Satellite imagery of elevation note building shapes <u>Aerial Image</u>: Picture of the watershed taken from an air photo <u>Marked Image</u>: Composite image with aerial image, region boundary, stream beds, partial contours of storm rainfall, location of a rain gauge (JF14 green) and a USGS stream gauge (red)

Rainfall Aug 24, 2015: A raster interpolation of rainfall for a major storm Infiltration: A model output showing the number of times drops have infiltrated into each landscape patch







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Continued: Simulating Surface Water Runoff

- 5. Select the Digital Elevation Model and Refresh. Now click 'Go'. Observe the progression of the storm. Discuss what is happening?
 - a. 'Raindrops' (volumes of water) are appearing at regular times in random locations
 - b. Raindrops are flowing downhill
 - c. Some raindrops get 'stuck'
 - i. Why?
 - i. "Local minimum points" are places in the data where all the neighboring points are higher. The simplest rule for raindrops is to "go downhill" to a lower neighboring point, but sometimes there may not be a lower point in the data! In the real system, water might flow along ditches or sidewalk cracks that are "in between" the data points and find other lower places. Or it might accumulate (think of a puddle) in the low area and then flow out once it got high enough. Or it might infiltrate and flow away as groundwater.
 - ii. How do they get out?
 - i. The basic model does not take the accumulation of water into account, so if we just use the simple rule of checking the nearest neighbors, the model raindrops in a "local minimum" will collect indefinitely and never find their way out of the watershed, which we know is not realistic. One way to handle this algorithmically is to have the raindrops that are 'stuck' (haven't moved from their current area) expand their boundary of search and look for nearby areas that are past the nearest neighbors in order to find a downhill direction. This algorithmically represents the water 'finding a way' out of the puddle via overflow, groundwater or in between low areas. This method is often used to explore mathematical spaces for *lowest* points in a large region (called "global minimum points"). Do you think it is a good method? Could it be improved?
 - d. Two hydrographs are produced by the model. One hydrograph is the "observed" hydrograph from an actual rain event in August of 2015. The other hydrograph is the "simulated" hydrograph generated by the model using the same rainfall data from the August 2015 storm.
 - i. Why are the hydrographs different?
 - ii. Can the computer model generate the exact same hydrograph as what was observed during the real storm?
 - iii. Why or why not?
- 6. Start the model again by clicking "Refresh." Apply the same runoff rules as we did for Floorlandia (make sure the infiltration slider is set to zero). In Floorlandia we simulated a runoff only storm event. In Netlogo, we are simulating a runoff only rain event in the West Branch of Herring Run. When you compare the hydrograph from the runoff only simulation to the "observed" hydrograph, there are noticeable differences:





Activity Two: Physical Runoff Model and Runoff Ratios

Activity Summary

Students will be revisiting the key findings in Activity one. They then explore how to explain and quantify the processes of runoff and infiltration to determine streamflow after a rainfall event. A physical model of a land surface will be used to look at runoff and runoff ratios from surfaces with different properties.

Key Vocabulary

Watershed Surface runoff Precipitation Stream gauge

Advanced Preparations

Gather all the materials you will need to run this activity. Have a source of towels to wipe up any water that may end up on the tabletop or floor. Extra buckets on-hand, or another location for students to dump their measured water, will make the activity run more smoothly.

Materials Needed for each small group

\Diamond	Paint tray	\Diamond	Paper towels
\Diamond	Spray bottle	\Diamond	Water
\Diamond	Sponges or other absorbent	\Diamond	Activity 2 Student Pages
	material	\Diamond	Activity 2 Excel Data Sheet
\Diamond	Graduated cylinder (various sizes)		
\Diamond	Funnel		

Activity Sequence

- 1. Introduce Activity 2 by revisiting the key findings from using the NetLogo model of streamflow in the West Herring Branch Run Watershed:
 - a. When setting the model to assume 100% topography-driven surface runoff (similar to the Floorlandia model), simulated streamflow both:
 - Starts sooner than was observed at the actual stream gauge and
 - Reaches a much higher peak flow than was observed at the stream gauge.
 - b. Therefore,
 - Actual runoff is slower than in the 100% runoff model
 - A significant amount of the precipitation water is staying in the watershed
 - c. The main purpose of this lesson is explore how to explain and quantify the processes that determine streamflow after a rainfall event in addition to surface runoff. We will use a physical model of a land surface to look at runoff and runoff ratios from surfaces with different properties.
- 2. Introduce the physical model for Activity 2
 - a. We will be using paint trays, which have edges, a sloping area and a flat lower area, as a physical model of a watershed.
 - b. We will be using spray bottles to simulate rainfall onto the watersheds.
 - c. We will be carefully measuring the amount of water we spray onto the watersheds as simulated rainfall and measuring the amount of water that runs off and collects in the low part of the model. We need to be careful not to spray outside the model, and not to spill when we're measuring the runoff.
 - d. We will be calculating runoff ratios the percentage of the precipitation added that runs off for different scenarios (that is, runoff / precipitation added).
 - e. We will be creating different scenarios by using different materials to test hypotheses about the number and nature of absorbing surfaces in watersheds and their effects on runoff and runoff ratios.
 - f. We have a number of materials available sponges, felt, etc. to test these hypotheses.
 - g. Enter your hypotheses, methods and results on the <u>Activity 2 Student Pages</u>, and then answer the discussion questions there.





Continued: Physical Runoff Model and Runoff Ratios

- 3. Instructions for each "run" using the physical model
 - a. Start with a dry paint tray; dry with paper towels if necessary.
 - b. Decide how much simulated rain to use and/or how many sprays you will use.
 - c. Fill the water bottle to a point where it is easy to read the volume.
 - d. Set up whatever materials in the paint tray you want to use to test specific hypotheses.
 - e. Spray the intended amount of water, carefully making sure that all your spray goes into the tray.
 - f. Determine the volume of simulated rain by subtracting the volume in the bottle at the end from the volume at the beginning. Record this amount.
 - g. Carefully pour the water that has accumulated in the trough of the paint tray into a graduated cylinder using a funnel.

 Record this amount.
 - h. Calculate the runoff ratio by dividing the runoff amount by the precipitation amount.
 - i. NOTE: if you use the <u>Activity 2 Excel Data Sheet</u>, it will calculate volume added and runoff ratios from the data you enter for starting and ending volume and runoff.
- 4. Here are some hypotheses your students can test:
 - a. In a paint tray watershed with no other materials present, all the water added as precipitation runs off. Therefore, we predict that measured runoff ratios with the empty trays will be 1.
 - b. In a paint tray watershed with absorbing materials (sponges, etc.), runoff is reduced. Therefore, we predict that runoff ratios will be less than 1.
 - c. As the amount of absorbing materials increase, runoff is reduced.
 - d. The reduction of runoff by absorbing materials is larger with materials that are dry compared to materials that already are wet or saturated with water.
- 5. Discussion questions (these appear on the Activity 2 Student Pages):
 - a. Did you have any scenarios that had a runoff ratio of 1? If not, why not?
 - b. Under what conditions did you find the largest runoff ratio, and under what conditions did you find the smallest runoff ratio? Why do you think the results turned out the way they did?
 - c. In what ways do you think this activity and the paint tray physical models represent real-world runoff processes and principles? In what ways are these models different from the real world?
 - d. What are the problems with this method? Are there ways you could improve this method for future students and classes?
 - e. How do your results help you think about and explain the difference we observed between the actual streamflow in West Branch Herring Run after the rain event and what we modeled assuming 100% surface runoff?







Activity Three: Comparing runoff from the same storm in two watersheds

Activity Summary

Students will analyze real runoff data from a single rainfall event passing over two very different watersheds to apply their knowledge of runoff and infiltration to a real-world scenario.

Key Vocabulary

Watershed Surface runoff Precipitation Stream gauge Hydrograph

Advanced Preparations

Spend some time looking at the data before teaching this lesson.

Materials Needed

- Activity 3 Rain and Runoff Excel file with data sets from the August 25, 2015 storm for Baismans Run and West Branch of Herring Run.
- Two Watersheds Powerpoint for Handouts
- Two Watersheds Powerpoint with air photos of two watersheds, data, charts and calculations if needed.
- **Activity 3 Student Pages short version**
- Activity 3 Student Pages long version

Activity Sequence

- 1. Introduce this activity:
 - a. Now we are going to look at real data from a single rainfall event and two watersheds to apply what we've learned from the physical paint tray models to the real world.
 - b. How can comparing streamflow in two watersheds that differ in land cover help us learn about the factors that control runoff?
- 2. Get to know the two watersheds by looking at the powerpoint with an aerial image of the Baisman Run (slide 1) watershed and an aerial image of the West Branch of Herring Run watershed (slide 2). Discussion questions:
 - a. What differences can you see in the two watersheds?
 - b. How might those differences influence how quickly water gets to the outlet (bottom of stream) of the watershed?

Short Version – examining graphs and runoff ratio calculations

- 3. Open the Two Watersheds Powerpoint, or use printed Two Watersheds Powerpoint for Handouts. You will need to have the Activity 3 Student Pages short version available for your answers to the questions in the lesson.
- 4. Explore precipitation data.
 - a. Look at slide 3, the graph of rain intensity over time (slide 3). Precipitation is collected by a device that records the amount of rain that accumulates for each five minute period. The rainfall intensity is the rate for each 5 minute period expressed as inches/hour. Considering that a rainfall of 1 inch is considered "large," rainfall intensities over 1 or 2 inches are considered very high.
 - b. Compare and contrast the rain event and rainfall intensities in each location. How long did each last? Were the patterns similar?
 - c. What reasons could explain the differences in rain amounts between the two watersheds, even though it was the same storm?







Continued: Comparing runoff from the same storm in two watersheds

- 5. Explore stream flow rate data (hydrograph).
 - a. Look at the graph in slide 4. It shows the stream flow rate every 5 minutes (for WBHR) or 15 minutes (for BR) versus time, divided by the area of the watershed (units are cu ft/sq mile). Stream flow data are collected by a sampler that takes a measurement in cubic feet per second (cfs) every 5 minutes (for the WBHR gauge) or 15 minutes (for the BR gauge). You can learn more about the gauges and the watersheds of the streams they are on at the USGS website for each location:
 - i. Baisman Run: http://waterdata.usgs.gov/nwis/inventory/?site_no=01583580&agency_cd=USGS
 - ii. W Branch Herring Run: http://waterdata.usgs.gov/usa/nwis/uv?01585200
 - b. Data for both watersheds were adjusted so the time of the beginning of the rain event was the same for each. This kind of graph of stream flow versus time is called a hydrograph.
 - c. The stream flow rate that is not influenced by rain is called the baseflow. What was the baseflow rate in the streams before the rain started?
 - d. What are the main differences you notice in stream flow or hydrographs of the two watersheds over the course of and after the rain event?
- 6. Explore stream discharge data.
 - a. Which watershed do you think had more total discharge, and why do you think that was the case?
- 7. Explore runoff ratios.
 - a. Look at Slide 5. Here are the steps taken to calculate runoff ratios for each watershed
 - i. Convert watershed area from sq miles to sq ft by multiplying lines A and B and enter in line C.
 - ii. Enter the total amount (depth, in inches) of rainfall measured at each watershed in line D. This comes from data in Slide 4.
 - iii. Convert this amount to feet by dividing line D by 12.
 - iv. The total volume of water that entered the watershed in the rain event can be estimated using the equation: Volume = depth of rain * area of watershed. Make this calculation by multiplying line C and line E and enter in line F.
 - v. Enter the volume of water that left the watershed via the stream from slide 6 on line G.
 - vi. The runoff ratio is the percentage of water entering as precipitation in a rain event that leaves the watershed via the stream. Calculate the runoff ratio by dividing line G by line F and record as a % in line H.
 - b. Compare the runoff ratios. What does the runoff ratio tell us about what happened to the water that entered each watershed during the rain event? How might you explain differences in runoff ratios between the two watersheds?
 - c. OPTIONAL look at hydrographs and runoff ratios for other storms.







Continued: Comparing runoff from the same storm in two watersheds

Long Version – examining datasets, calculating precipitation total, discharge total, runoff ratios

- 3. Open the Activity 3 Rain and Runoff Excel file. There are 7 worksheets in the file: two for precipitation, two for hydrographs (stream flow), one for discharge, and two for calculating runoff ratios. You will need the Activity 3 Student Pages long version to record answers to the questions in the lesson.
- 4. Explore precipitation data.
 - a. Look at the worksheet, Data for Precip at 2 sites. Precipitation is collected by a device that records the amount of rain that accumulates for each five minute period. In the spreadsheet. These data are in column B (for the gauge near Baisman's Run (BR) and column F for the gauge near West Branch Herring Run (WBHR)). Time periods when rain was collected are highlighted in blue. The rainfall intensity is the rate for each 5 minute period expressed as inches/hour. This is calculated in columns C and G. The cumulative precipitation from the start of the rain event is calculated in columns D and H.
 - b. Compare and contrast the rain event in each location. How long did each last? Were the patterns similar? How about the total amount of precipitation?
 - c. Look at the graph of rain intensity in the worksheet, Chart of Precip at 2 sites. Why is it interesting to look at rain intensity? What do you notice about the rain intensity over time and across the two watersheds?
- 5. Explore stream flow rate data (hydrograph).
 - a. Look at the worksheet, Data for 2 Hydrographs. Stream flow data are collected by a sampler that takes a measurement in cubic feet per second (cfs) every 5 minutes (for the WBHR gauge) or 15 minutes (for the BR gauge). These data are shown in column D for BR and E for WBHR. You can learn more about the gauges and the watersheds of the streams they are on at the USGS website for each location:

<u>Baisman Run:</u> http://waterdata.usgs.gov/nwis/inventory/?site_no=01583580&agency_cd=USGS W Branch Herring Run: http://waterdata.usgs.gov/nwis/inventory/?site_no=01583580&agency_cd=USGS W Branch Herring Run: http://waterdata.usgs.gov/usa/nwis/uv?01585200

- b. The stream flow rate that is not influenced by rain is called the baseflow. Look at lines 3-21; what were the baseflow rates in each stream? What might explain the difference in baseflow?
- c. Look at the numbers once rain started falling in the watersheds (starting on line 22). [NOTE: the rain actually started 25 minutes later in WBHR than in BR, but the data in the worksheet for WBHR were adjusted so that the beginning of rainfall corresponds to line 21 in both cases.] What do you notice about stream flow rates after the rain started?
- d. Look at lines 99-105. How does flow the next day compare to flow before the storm? What might explain the differences in flow?
- e. Now look at the graph in worksheet, Chart of 2 Hydrographs. These graphs show the flow rate every 5 minutes (for WBHR) or 15 minutes (for BR) versus time. Data for both watersheds were adjusted so the time of the beginning of the rain event was the same for each. This kind of graph of stream flow versus time is called a hydrograph.

[NOTE: the stream flow rates in this graph are on a "per sq. mile" basis so that rates can be compared in the two watersheds despite their difference in size.] What are the main differences you notice in stream flow or hydrograph of the two watersheds over the course of and after the rain event?

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Continued: Comparing runoff from the same storm in two watersheds

- 6. Explore stream discharge data.
 - a. Look at the data in the worksheet, Discharge 2 sites. This shows the stream flow data again for BR in column C and WBHR in column F. It also calculates an estimate of the discharge for each 15 or 5 minute period, shown in columns D and G. Discharge is the total amount of water passing the gauge for each time period, measured in cubic feet (cu ft).
 - b. The total discharge that left each watershed via stream flow can be calculated by adding the amount of water for each time period starting with the beginning of the rain event and ending in this case 24 hours later. Look at the values for total discharge on line 296. Which watershed had more total discharge, and why do you think that was the case?
- 7. Calculate and explore runoff ratios.
 - a. Go to the worksheet, Calculations Blank. Column D is for Oregon Ridge/Baisman's Run and column for WBHR. Follow these steps to calculate runoff ratios for each watershed, using equations in excel. Instructions refer to lines A-H (see column A).
 - b. Convert watershed area from sq miles to sq ft by multiplying lines A and B and enter in line C.
 - c. Enter the total amount (depth, in inches) of rainfall measured at each watershed in line D. This comes from the worksheet, Data for Precip at 2 sites.
 - d. Convert this amount to feet by dividing line D by 12.
 - e. The total volume of water that entered the watershed in the rain event can be estimated using the equation:

 Volume = depth of rain * area of watershed. Make this calculation by multiplying line C and line E and enter in line

 F
 - f. Enter the volume of water that left the watershed via the stream on line G.
 - g. The runoff ratio is the percentage of water entering as precipitation in a rain event that leaves the watershed via the stream. Calculate the runoff ratio by dividing line G by line F and record as a % in line H.
 - h. First, compare the total amount of precipitation that entered each watershed during the storm. Why were they different?
 - i. Second, compare total amount of water leaving as stream discharge. Why were they different?
 - j. Finally, compare the runoff ratios. What does the runoff ratio tell us about what happened to the water that entered each watershed in the rain event? How might you explain differences in runoff ratios between the two watersheds?
 - k. OPTIONAL look at hydrographs and runoff ratios for other storms.







Simulating Surface Water Runoff Worksheet

NAME:	DATE:
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Discussion questions:

- 1. List the layers of the NetLogo model and a one-sentence description of each:
- a.
- b.
- c.
- d.
- e.
- 2. What happens when you click 'Go' on the model? Describe the process in multiple steps here:
- 3. There are two graphs. What does each represent?
- 4. How does the hydrograph the model generates with zero infiltration, differ from the "observed" hydrograph generated from the actual storm in 2015?

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VOCABULARY - Define each in your own words:

- (recall) Rain Gauge
- (recall) Hydrograph
- (recall) Stream Gauge
- (recall) Watershed
- (recall) Elevation
- (recall) Topography







Runoff Ratios Testing Different Hypotheses

<u>Part 1</u> - Data Sheet. Fill in your hypothesis and describe the scenario for each trial you run. Record the volume of water in the bottle before and after the trial, calculate the amount of water added, record the amount of water collected in the tray, and calculate the runoff ratio.

Trial	Llypothesis	Cooresia	Values of	Volume of	Volume of	Volument	Dunoff Datia
iriai	Hypothesis	Scenario	Volume of			Volume of	Runoff Ratio
			Water in	Water in	Water	Runoff	(runoff/added)
			Bottle-	Bottle-	Added	(collected in	
			start	finish	(start-end)	tray)	
1	In a dry paint tray watershed, all the water added as precipitation runs off.	Dry tray, no materials present.					
2							
3							
4							
5							







Trial	Hypothesis	Scenario	Volume of	Volume of	Volume of	Volume of	Runoff Ratio
			Water in	Water in	Water	Runoff	(runoff/added)
			Bottle-	Bottle-	Added	(collected in	
			start	finish	(start-end)	tray)	
6							
6							
7							
8							
9							
10							
10							



Runoff Ratios Testing Different Hypotheses

Part 2. Answer these questions about your hypotheses and results.

1. Did you have any scenarios that had a runoff ratio of 1? If not, why not?

2. Under what conditions did you find the largest runoff ratio, and under what conditions did you find the smallest runoff ratio? Why do you think the results turned out the way they did?

3. In what ways do you think this activity and the paint tray physical models represent real-world runoff processes and principles? In what ways are these models different from the real world?

4. What are the problems with this method? Are there ways you could improve this method for future students and classes?

5. How do your results help you think about and explain the difference we observed between the actual streamflow in West Branch Herring Run after the rain event and what we modelled assuming 100% surface runoff?







Teacher Resources

- 1. Additional Coding Extension:
 - a. Examine NetLogo code for the West Branch of Herring Run simulation and discuss important components
- 2. Additional Math/data Extension:
 - a. Examine raw data from WBHR rainstorm
- 3. Modeling Background:
 - a. Randall Boone's 1/28/2017 Why We Model presentation to Comp Hydro Teachers (video)



- b. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/hydrological-modeling
- 4. Hydro modeling/motivation for further study:
 - a. Andy Miller's 11/5/2016 presentation to Comp Hydro teachers
- 5. Additional PowerPoint that goes with this lesson:
 - a. Step-by-step walkthrough, with screenshots showing layers and steps, and discussion questions for the class to reflect upon
 - i. Runoff ratio lecture
- 6. Predicting Floods:
 - a. https://science.nasa.gov/science-news/science-at-nasa/2015/22jul floods
 - b. https://www.usgs.gov/special-topic/water-science-school/science/how-much-water-flows-during-a-storm?qt-science center objects=0#qt-science cent
 - c. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=37886.wba



