SE MAPS PROJECT

Nuclear Science Activity #3

(Valley and Ridge Region)

Water as a Cooling Agent

The SE MAPS Project is a NSF-funded project that evolved from a South Carolina model for inquiry-based classroom instructional modules proposed by South Carolina K-12 teachers participating in a series of Professional Development Courses designed to help educators better understand and appreciate the natural environment of their state. Each activity was reviewed by content specialists at Clemson University before final publication. Funding support for the 'Nuclear Science' series of activities was provided by the NEESRWM Center at Clemson University (The Center for Nuclear Environmental Engineering Sciences and Radioactive Waste Management).

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Use of Water as a Cooling Agent

Steven Pruitt and John Wagner [based on an activity written by Sarah Disario, Nick Hill, and Alexandra McIntyre]

INSTRUCTIONAL FOCUS: Students will understand that nuclear reactions generate heat and that cooling systems are required for safe and efficient operation of nuclear power plants. They will analyze the role that water plays in the cooling process and recognize the importance of constructing reservoirs as an effective source of water storage for use in a typical cooling system.

SUGGESTED TARGET AUDIENCE: high school chemistry and earth science classes

PRIMARY CORRELATION TO S.C. ACADEMIC SCIENCE STANDARDS (2014):

CHEMISTRY - ATOMIC STRUCTURE AND NUCLEAR PROCESSES

Standard H.C.2: The student will demonstrate an understanding of atomic structure and nuclear processes.

H.C.2B.3 Obtain and communicate information to compare and contrast nuclear fission and nuclear fusion . . . .

EARTH SCIENCE - EARTH'S HYDROSPHERE

Standard H.E.6: The student will demonstrate an understanding of Earth's freshwater and ocean systems.

H.E.6A.2 Obtain and communicate information to explain how location, movement, and energy transfers are involved in making water available for use on earth's surface (including lakes . . .).

Other Curriculum Connections [middle-school earth, environmental, and physical science]

"SE MAPS (SouthEast Maps and Aerial Photographic Systems) – Study Site #5A"
"SC MAPS (South Carolina Maps and Aerial Photographic Systems) – Study Site #3A"

PRIOR SKILLS REQUIRED: Students should be able to read and interpret topographic maps (scale/legend/symbols). They should also understand basic concepts of nuclear fission and radioactivity and be familiar with accessing websites and programs such as Google Earth™.

LOGISTICS: The basic activity could fit within a 50-minute class, but more time is recommended, especially if supplemental materials or optional activities are used – a flat work area is needed so students can draw on large maps – work in cooperative groups. Internet access is required.

KEY VOCABULARY AND CONCEPTS:

- condenser
- containment structure
- reactor vessel
- reservoir
- steam generator
- thermal pollution
- turbine

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CONTENT OVERVIEW: [more detail is provided in the "Teacher Answer Key."]

1. The process of nuclear fission produces large amounts of heat.
   - *Most nuclear processes are 'exothermic' reactions, releasing heat as a by-product when atoms are split.*
   - *The heat that is generated by nuclear reactions can be used to turn water into steam, which then can be used to turn turbines to generate electricity.*
   - *After the steam has passed through the turbine, it must be cooled and condensed back into liquid water before it can be recycled back to the reactor core to be heated again.*
2. Most US nuclear power plants use external water sources to provide the cooling for the condenser.
   - *A large quantity of cool water is required to enable efficient, continuous operation of the condenser.*
   - *The external water supply never comes in contact with the reactor vessel or any other radioactive structure.*
   - *When reservoirs are used, cooler water is drawn from near the bottom of the reservoir and, after passing through the condenser, the resulting warmer water is released near the surface of the reservoir.*
3. Nuclear power plants typically are located in areas topographically suited for reservoir construction.
   - *A topographic constriction around a river or stream is the best place to construct a dam to make a reservoir.*
   - *Canyons or other features of high relief produce the deepest reservoirs for the minimum surface area.*
   - *The height of the dam determines the depth of the reservoir and the amount of surface area to be flooded.*

MATERIALS: internet access (including Google Earth™); 6 SE MAPS laminated lithographs ["Map #4A - "Cumberland Plateau/Sequatchie Valley" and "Map #5A - "Little River Canyon, Alabama"]; 6 SC MAPS Map #3A (Forty-Acre Rock) [optional]; 6 'wet-erase' marker pens; 6 calculators; 6 rulers; 6 'red/cyan 3-D' glasses; 6 pieces of string (~18" long).

PROCEDURES:

1. Either ask students to access the website <*http://www.whatisnuclear.com/articles/nucreactor.html*> themselves and/or project this website on a screen for the entire class to see. Scroll down to the 'Animated Reactor System' graphic. Point out the various components of the typical nuclear reactor facility and discuss what part each of these components plays in the safe and successful operation of a nuclear power plant.
2. Point out the various ways that water is used in a nuclear power plant (refer to the 'Animated Reactor System' graphic) and ask student groups to describe and characterize the three separate water circulation systems and answer the questions about these systems on the Student Work Sheet Part I.
3. Make sure students understand that the water that cools the condenser is the only circulation system open to the environment. Ask students to speculate about ways that the local area around a nuclear power plant could provide enough water to provide adequate cooling.
4. Direct student groups to locate the Sequoyah Nuclear Power Plant near Chattanooga, Tennessee using Google Earth™ [coordinates of nuclear plant: 35º 13' 36.70" N; 85º 05' 32.65" W]; and the Chicamauga Dam [coordinates of dam: 35º 06' 15.14" N; 85º 13' 44.81" W] and work the activities and answer the questions listed on Student Work Sheet Part II. Also hand out lithograph Map #4A.
5. Hand out the lithograph Map #5A and other listed materials to each group and direct them to follow the instructions and answer the questions listed on the Student Work Sheet Part III.
6. [optional] Have students locate the nuclear power plant closest to their school and research how that plant obtains enough water for effective cooling. Use Google Earth™ and/or local topographic maps to investigate the topography and land use of the area.
7. [optional] Use SC MAPS Map #3A (Forty-Acre Rock) to construct a hypothetical dam and reservoir along Flat Creek (SC MAPS Activity #3A-2, questions #1, 2 on page 3A-7 of SC MAPS Teaching Manual [available online at <http://www.clemson.edu/ces/geolk12/scmaps/Manual/chap3.pdf>].

SAMPLE CULMINATING ASSESSMENT:

- Ask students to describe (in approximately 50 words) the specific topographic requirements necessary to build a reservoir capable of cooling a nuclear power plant.
- Ask students to diagram and describe the three 'water circulation systems' that are in use in the typical nuclear power plant.

Use of Water as a Cooling Agent

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STUDENT WORK SHEET – Part I

Part I – Water Circulation Systems in a Typical Nuclear Reactor Facility

A. Access the following website <*http://www.whatisnuclear.com/articles/nucreactor.html*> and scroll down to the 'Animated Reactor System' graphic. Pay particular attention to the three separate water circulation systems. Fill in the following chart based on your observations.

WATER CIRCULATION SYSTEM	RECIRCULATED [yes or no]	UNDER PRESSURE [higher, lower, or no]	RADIOACTIVE [yes or no]
within reactor vessel			
steam generator/turbine/condenser			
external - pass through condenser			

B. Knowing that the condenser requires a large volume of water to pass through it continuously, where, geographically (in general terms), would you recommend building a nuclear power plant to accommodate this large demand for water?

C. Why would it NOT work well to recycle the same water through the condenser over and over again?

STUDENT WORK SHEET – Part II

Part II – Study of a reservoir/dam system in Tennessee

A. Access Google Earth™ and locate the following two sites north of Chattanooga, Tennessee:
- Sequoyah Nuclear Power Plant [latitude = 35° 13' 36.70" N; longitude = 85° 05' 32.65" W]
- Chicamauga Dam [latitude = 35° 06' 15.14" N; longitude = 85° 13' 44.81" W]

B. Based on your observations, answer these questions about operations at the Sequoyah Nuclear Plant:

1. Where do you think the Sequoyah Nuclear Power Plant gets the water to cool the condenser?

2. Do you think the plant draws water from the bottom of the reservoir or the surface? Explain your reasoning for your answer.

3. Do you think the used water is returned to the bottom of the reservoir or the surface? Explain your reasoning for your answer.

4. What ecological changes or environmental consequences might result from the addition of warmer water to the reservoir? Explain your reasoning for your answer.

C. Based on your observations in Google Earth™, answer these questions about the Chicamauga Dam:

1. What is the elevation difference between the water surface above (upstream) of the dam and the water surface below (downstream) from the dam? [note: Google Earth™ shows elevations]

2. Why do you think the dam was built at this particular geographic location? Explain your reasoning for your answer.

3. Locate the Chicamauga Dam on MAP #4A (Cumberland Plateau/Sequatchie Valley) [note that this is a 3-D topographic map and must be viewed through special red/cyan glasses with the red filter over the left eye]. Use the latitude/longitude numbers along the map margins to help you locate the dam site. Survey the map area surrounding the dam and look for any topographic landform features that might explain why this location was chosen for the dam. List any features that you find. Explain your reasoning why those features might have provided ideal conditions to construct the dam.

STUDENT WORK SHEET – Part III

Part III – Constructing a hypothetical reservoir to service a nuclear power plant

A. Locate the Little River and the Little River Canyon on MAP #5A, 'Lookout Mountain'. Focus on the 'mouth' of the canyon (where the Little River exits Lookout Mountain). Locate the 'gaging station' where the railroad crosses the river (approximately .5 miles upstream from the town of Little River). You will construct a dam (and create a reservoir) at a spot one mile upstream from the 'gaging station', where the canyon is very narrow. Use the following guidelines:

1. Locate the 900-foot contour line on both the north and south sides of the river. Use a wet-erase marker to draw a line (across the river) connecting the two 900-foot contour lines. [note that the contour interval on this map is 20 feet and that the 900-foot contour line is an index contour (index contour lines are darker than other lines and are numbered). Answer these questions:

    a. How high will the top of the dam be above the river bed? ______________________

    b. How wide will the top of the dam be from side to side? _______________________

    c. Will the dam have to be built thicker at the top or the bottom, or will it be the same thickness throughout? Explain your answer.

2. Use wet-erase markers to trace the 900-foot contour lines up the canyon on <u>both sides</u> of the river. Continue tracing on both sides until the lines finally meet. [even though the contour lines are very close together, the 900-foot contour line will be labeled periodically so you should be able to find it again, even if you lose it]. You have now outlined the shoreline of the reservoir. Use a piece of string to measure the length of the reservoir from the dam to its farthest point. Use the map scale to convert this measurement to real distance.

    a. String length from dam to farthest point? MAP DISTANCE IN INCHES = ______

    REAL DISTANCE IN FEET = ______ REAL DISTANCE IN MILES = _________

    b. Which part of the reservoir will be the deepest? _____________________________

    c. Are there any islands in this reservoir? Explain why or why not.

B. Examine the features of the reservoir you have created and recommend a specific site for constructing a nuclear power plant. List reasons for your selection and be prepared to defend your reasoning.

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TEACHER ANSWER KEY

KEY VOCABULARY AND CONCEPTS:

- **condenser** = the container through which external cooling water is circulated around pipes transporting steam from the turbine, converting that steam back into liquid water.
- **containment structure** = structure that separates the nuclear reactor vessel from the environment. These structures are usually dome-shaped and are made of high-density, steel-reinforced concrete.
- **reactor vessel** = a storage unit that contains the nuclear fuel rods where nuclear fission occurs.
- **reservoir** = a large body of surface water, usually held back by a dam, constructed to provide a sufficient quantity of water to cool the coolant (turn steam to water) passing through the condenser.
- **steam generator** = the location where heat from the reactor vessel is transferred to the coolant. When the coolant is water, the heat turns the water to steam which then is piped to the turbine.
- **thermal pollution** = discharge of heated air or water into the environment, creating disequilibrium.
- **turbine** = the mechanism that is turned by the heated coolant (usually steam) to generate electricity.

PROCEDURES:

1. Access website <http://www.whatisnuclear.com/articles/nucreactor.html> and discuss role that various components play in operation of a nuclear power plant.

At most nuclear power plants, the reactor containment building holds the reactor vessel which is where the nuclear fuel is placed and where nuclear fission occurs. The heat that is generated in the reactor vessel is transferred to a steam generator in which the coolant (usually water) is heated, turning it to steam. The steam turns the turbine which is connected to the generator that actually produces the electricity. The condenser turns the coolant steam back into liquid water so it can be recirculated back to the steam generator, over and over again.

2. Point out the various ways water is used in a nuclear power plant, specifically the three separate water circulation systems, and instruct students to complete Student Work Sheet - Part I.

The answers to the questions on the Work Sheet can be deduced from the 'Animated Reactor System' graphic.

A. Fill in the following chart based on your observations.

WATER CIRCULATION SYSTEM	RECIRCULATED [yes or no]	UNDER PRESSURE [higher, lower, or no]	RADIOACTIVE [yes or no]
within reactor vessel	***yes***	***higher***	***yes***
steam generator/turbine/condenser	***yes***	***lower***	***no ****
pass through condenser	***no***	***no***	***no***

*note – there may be traces of radiation in this system, but no direct contact with radioactivity

Point out that when liquid water turns to steam (in the steam generator), the volume increases significantly, generating pressure that not only turns the turbines, but drives the circulation of the coolant through the system. Stress that the 'open' circulation system of the cooling water is never exposed to radiation from the reactor.

3. Make sure students understand that the water that cools the condenser is the only circulation system open to the environment and how to insure an adequate water supply for cooling.

B. . . . . where, geographically (in general terms), would you recommend building a nuclear power plant to accommodate this large demand for water? *Either a very large river or a large reservoir is needed.*

C. Why would it NOT work well to recycle the same water through the condenser? *Each time the water would circulate through the condenser, it would pick up more heat; eventually the 'cooling' water would become so hot that it would be unable to cool the condenser. If there was no way to cool the coolant (in the condenser), the coolant would get hotter and hotter until it would all turn to steam and circulation would end.*

4. Direct student groups to locate the Sequoyah Nuclear Plant and the Chicamauga Dam using the coordinates provided and fill out answers on the Student Work Sheet - Part II.

Answers will vary. What follows are some typical answers to these questions. Other answers may be possible.

A. Access Google Earth™ to locate sites. *The position of the cursor on the screen determines the precise latitude/longitude coordinates that display in the data line at the bottom of the screen. The elevation of the site is also displayed along the bottom of the screen. The Google Earth™ application is available for free download.*

B. Based on observations, answer questions about operations at the Sequoyah Nuclear Plant:

1. Where do you think the Sequoyah Nuclear Power Plant gets the water to cool the condenser? *The location of the plant next to the reservoir should make it obvious that cooling water comes from that source.*
2. Do you think the plant draws water from the bottom of the reservoir or the surface? Explain your reasoning for your answer. *In most lakes and reservoirs, the coldest water is found at the bottom, in the deepest places (cold water is denser than warm water and therefore sinks). Even for large flowing rivers, the coldest water is still near the bottom. Colder water provides more efficient cooling for the plant.*
3. Do you think the used water is returned to the bottom of the reservoir or the surface? Explain your reasoning for your answer. *The warmed water is returned to the surface (where the water is warmer anyway) to minimize thermal impacts on plants and animals that live in or near the water.*
4. What ecological changes or environmental consequences might result from the addition of warmer water to the reservoir? Explain your reasoning for your answer. Explain your reasoning for your answer. *Plants and animals living in and around this reservoir are adapted to conditions that have existed since the reservoir was built. Adding warmed water could affect oxygen levels in the water, alter the metabolism of organisms, affect reproduction cycles, or disrupt the food chain.*

C. Based on your observations in Google Earth™, answer questions about the Chicamauga Dam:

1. What is the elevation difference between the water surface above (upstream) of the dam and the water surface below (downstream) from the dam? [note: Google Earth™ shows elevations] *Answers may vary, as Google Earth™ does not always give identical answers for water surfaces (even though it should). The average water surface elevation above the dam is 655 feet. The average water surface elevation below the dam is 615 feet. Therefore the dam would be at least 40 feet high (actually a little higher because there is a highway crossing the dam and the road would have to be several feet above the water level).*

2. Why do you think the dam was built at this geographic location? Explain your reasoning for your answer. *Answers may vary because the Google Earth™ view does not provide any clear rationale. Some possible answers could include: "recreation opportunities for residents of City of Chattanooga"; "that is where a major highway crossed the river"; "the land to be flooded by the reservoir was cheaper to buy in this area". The intent is to get students to think about why certain structures are placed where they are.*

3. Locate the Chicamauga Dam on MAP #4A. Look for topographic features that might explain why this location was chosen. List features and explain your reasoning. *The most obvious reason is that there is a noticeable long ridge (rising to over 100 feet high in places) running approximately north-to-south through the area where the dam is located (runs from 'East Lake' at the bottom of the map to 'Ridge Bay', about halfway up the right margin of the map). The '3-D' glasses are required to see this feature. The ridge is composed of more resistant rock, which provides a better foundation on which to construct a dam; plus the river (before reservoir construction) was likely very shallow in this area. There may have been other socio-economic reasons the dam was built here, but the landscape feature is the most likely answer.*

5. Hand out lithograph MAP #5A and direct students to work on Student Work Sheet – Part III.

Answers will vary. What follows are some typical answers to these questions. Other answers may be possible.

A. Locate the Little River and the Little River Canyon on MAP #5A, 'Lookout Mountain'. You will construct a dam (and create a reservoir) at a spot one mile upstream from the 'gaging station', where the canyon is very narrow. *The exact location of the dam is not critical as long as the dam is drawn somewhere within the first northwest-southeast trending portion of the canyon.*

1. Locate the 900-foot contour line on both the north and south sides of the river. Use a wet-erase marker to draw a line (across the river) connecting the two 900-foot contour lines. *The contour lines are very close together here, but the '900-foot' contour line is labeled on the south side of the canyon and the '800-foot' contour line is labeled on the north side of the canyon. Because the contour interval of the map is 20 feet, the '900-foot' contour line is the fifth line above the '800-foot' line (going away from the river).*

   a. How high will the top of the dam be above the river bed? *Any number between 280 and 300 feet is acceptable: the top of the dam is exactly 900 feet. The river bed is somewhere between 600 and 620 feet in elevation (based on contour line information).*

   b. How wide will the top of the dam be from side to side? *The exact distance will depend on exactly where the line representing the dam is drawn on the map (the two 900-foot contour lines are not everywhere the same distance apart. Answers should range from 1,200 to 1,600 feet.*

   c. Will the dam have to be built thicker at the top or the bottom, or will it be the same thickness throughout? Explain your answer. *Dams are always constructed to be thicker at the bottom because the water pressure on the dam increases with depth and near the bottom of the dam, the structure has to be very thick to withstand those high pressures. There is not nearly as much water pressure on the top of the dam, so the structure can be built thinner there.*

2. Use wet-erase markers to trace the 900-foot contour lines up the canyon on <u>both sides</u> of the river. Continue tracing on both sides until the lines finally meet. You have now outlined the shoreline of the reservoir. *View the map on the page 9 to see how the reservoir and dam should look.*

   a. String length from dam to farthest point? MAP DISTANCE IN INCHES ~ _*map on*_

   REAL DISTANCE IN FEET ~ _*map on*_ REAL DISTANCE IN MILES ~ _*6.5*_
   Any number between 6 and 7 miles is acceptable (based on map scale).

   b. Which part of the reservoir will be the deepest? *The deepest part of the reservoir will be just upstream of the dam; approximately the same depth as the height of the dam.*

   c. Are there any islands in this reservoir? Explain why or why not. *Many reservoirs have islands, but this one does not. A narrow canyon is highly erosional, and any higher areas along the river bank (which might have created islands after flooding) would have been washed away a long time ago by the force of the water.*

B. Examine the features of the reservoir and recommend a specific site for constructing a nuclear power plant. List reasons for your selection; be prepared to defend your reasoning. *Answers may vary. Two critical issues to consider are water depth (to get coldest cooling water) and 'flatness' of the land along the canyon to make construction easier. The best location is probably close to the dam on the north side of the reservoir (fairly flat topography close to the shoreline and access to deepest, coldest water).*

6. [optional] Have students locate the nuclear power plant closest to their school and research how that plant obtains enough water for effective cooling. Use Google Earth™ and/or local topographic maps to investigate the topography and land use of the area.

The United States Nuclear Regulatory Commission has a map on its website <http://www.NRC.gov>, more specifically <http://www.nrc.gov/info-finder/reactors/> of all nuclear power reactors in the country. Visitors can select a specific power reactor from the map to find out more information about it. The page also includes an alphabetical listing of the reactors . Topographic maps can be accessed at the website of the United States Geological Survey <http://www.usgs.gov> for general information, or more specifically at <http://store.usgs.gov/b2c_usgs/usgs/maplocator/%28xcm=r3standardpitrex_prd&layout=6_1_61_48&uiarea=2&ctype=areaDetails&carea=%24ROOT%29/.do>.

7. [optional] Use SC MAPS Map #3A (Forty-Acre Rock) to construct a dam and reservoir along Flat Creek (SC MAPS Activity #3A-2, questions #1, 2 on page 3A-7 of SC MAPS Teaching Manual [online at <http://www.clemson.edu/ces/geolk12/scmaps/Manual/chap3.pdf>]

This activity does not specifically deal with nuclear power plant siting, but once the reservoir is constructed (in a similar fashion to the instructions used in Procedure #5 above), you can ask the question "where would you located a nuclear power plant to best advantage along this reservoir". The reservoir constructed on this topographic map does have three islands. Be sure to use the PDF file to insure page numbers match.

SAMPLE CULMINATING ASSESSMENT:

- Ask the students to describe (in approximately 50 words) the specific topographic requirements necessary to build a reservoir capable of cooling a nuclear power plant.

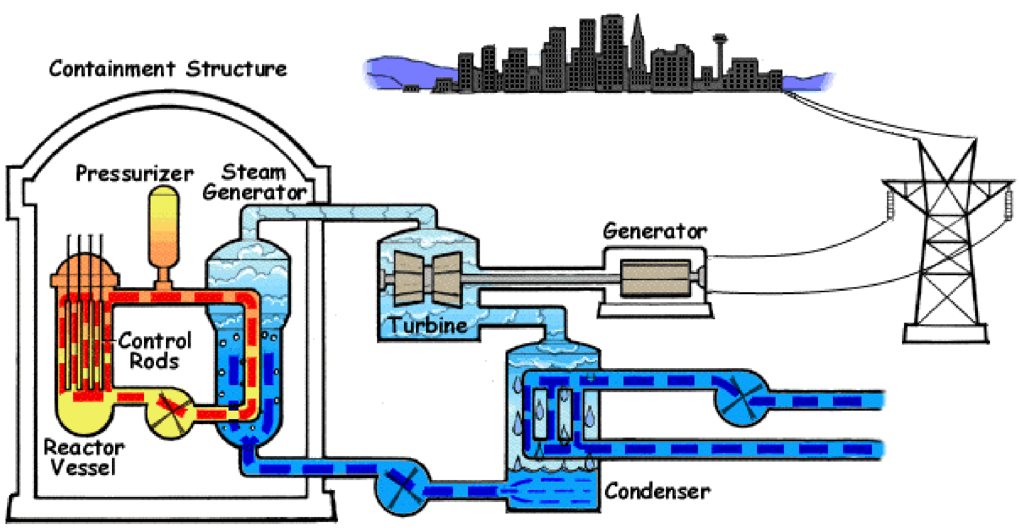
The most important topographic requirement is to have some landform constriction that forces a river to go through a narrow opening with higher land close in on each side. A linear ridge composed of resistant rock, through which the water flows in a canyon or 'water gap', is an ideal situation. Other requirements include making the dam tall enough so that a sufficient body of water is dammed up behind to supply the power plant with cold water, and having a large enough surface area to the reservoir so that the water doesn't dry up during drought seasons.

A typical good answer to this question might read like this:

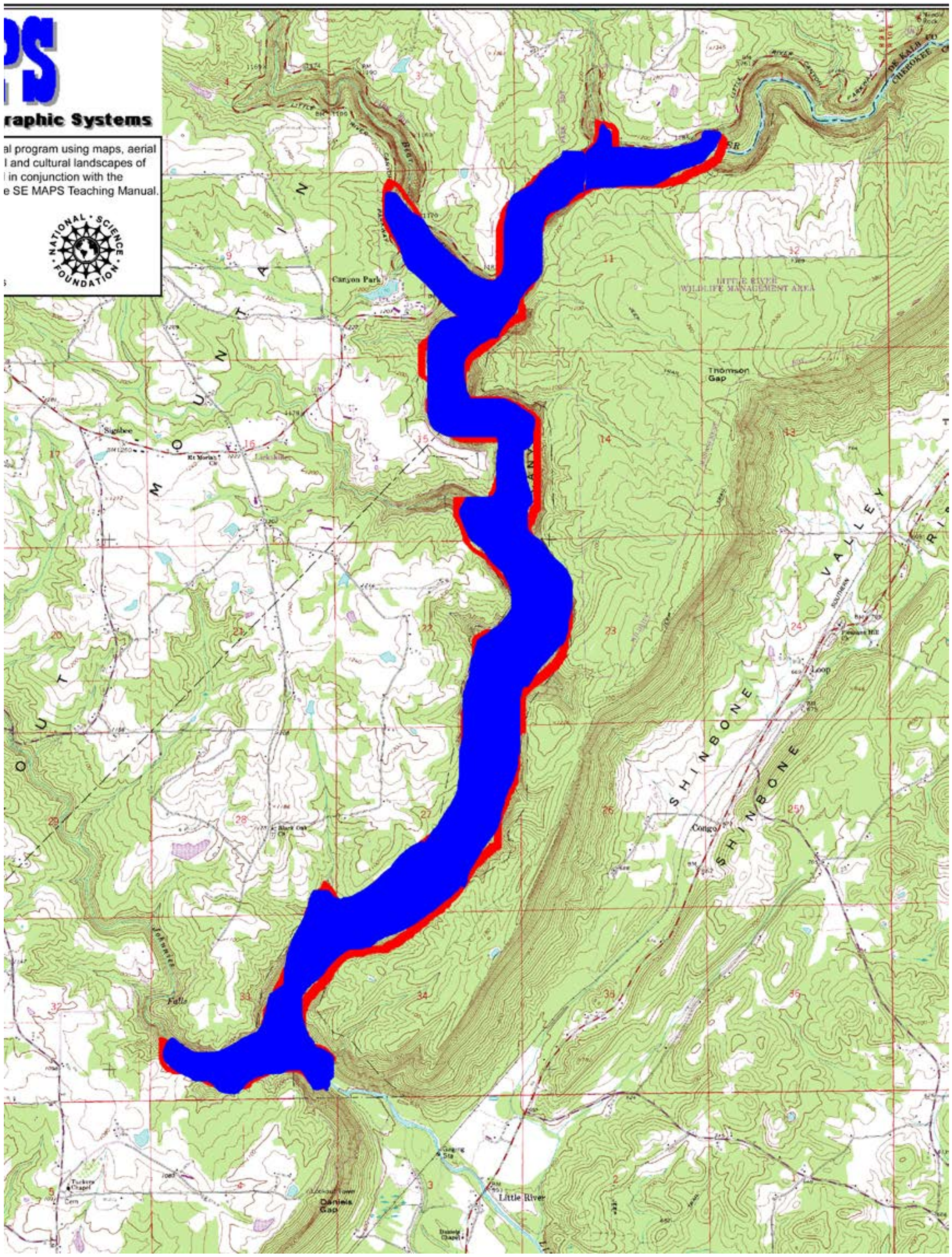
The best spot to build a reservoir for a nuclear power plant is where a stream cuts through a mountain range. You would build the dam across the river so it blocks the water and backs it up to form a reservoir. The reservoir has to be big enough and deep enough to provide a lot of cold water for the power plant.

- Ask the students to diagram and describe the three 'water circulation systems' that are in use in the typical nuclear power plant.

Students should draw something that looks like the "Animated Reactor System' graphic used at the beginning of this lesson. They should describe the 'reactor' water system as hot, pressurized, and radioactive; the 'steam generator' system as heated to steam by the 'reactor water' to turn the turbines; and the 'cooling water' as non-radioactive water brought in from a reservoir of some type to condense the 'steam generator' water back into liquid form.



<u>**MAP OF RESERVOIR CONSTRUCTED IN LITTLE RIVER CANYON**</u>



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Websites Used – Water as Cooling Agent Activity

1. **General Information about Nuclear Energy and Nuclear Power Plants**

   <http://www.NRC.gov>
   - everything you would want to know about nuclear energy and nuclear power plants

   <http://www.nrc.gov/info-finder/reactors/>
   - locates specific nuclear power plants anywhere in the USA and provides info on each

   <http://www.whatisnuclear.com/articles/nucreactor.html>
   - provides good graphics and explanations about how nuclear power plants operate

2. **Sources for Topographic Maps**

   <http://www.usgs.gov>
   - everything you wanted to know about maps and map-making

   <http://store.usgs.gov/b2c_usgs/usgs/maplocator/%28xcm=r3standardpitrex_prd&layout=6_1_61_48&uiarea=2&ctype=areaDetails&carea=%24ROOT%29/.do>
   - locates specific topographic maps anywhere in the USA for viewing/downloading

3. **Optional SC MAPS Activity**

   <http://www.clemson.edu/ces/geolk12/scmaps/Manual/chap3.pdf>
   - Teaching Manual. Contains optional activity #3A-2 on page 3A-7.

