WARD'S

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Groundwater Simulation System

User's Guide

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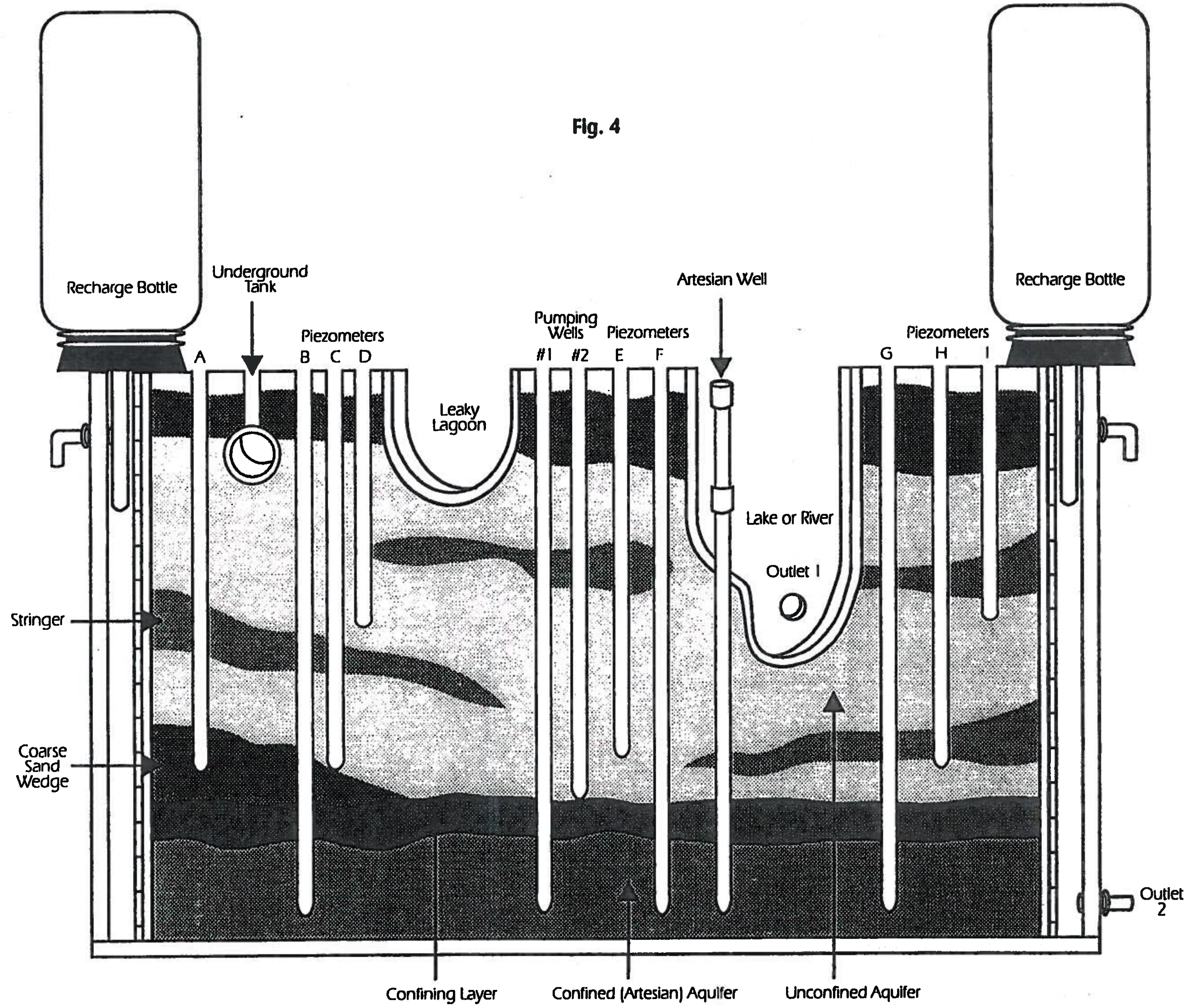
Fig. 4


Recharge Bottle
Underground Tank
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A
B C D
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Basic Assembly

After checking to make sure all components are accounted for, locate the main Groundwater Tank. Remove the bubble wrap packing material, and carefully peel back the protective paper coating from the acrylic sides and cover of the tank. Inspect the tank to make sure no obvious damage has occurred during shipment. Next, set the tank in its stand (locate two acrylic feet provided) so that it remains stable in an upright position. The two feet should generally be located about 2-3" from either end of the tank.

Now locate the three nylon elbow fittings, one straight fitting, and the roll of teflon tape. Carefully wrap a short length of the teflon tape around the threaded ends of each fitting about 2-3 turns, and press the tape tightly into the threads to hold. Install the nylon straight fitting in the hole located at the bottom right end of the tank, and hand tighten only.

In a similar manner, install two of the elbow fittings in the overflow holes located near the top at either end of the model. Position the elbows so that they are pointed downward when installation is complete. Finally, install the third elbow fitting in the hole located at the outflow of the lake on the front right panel of the tank. Once again, the elbow should be in a downward position when hand tightening is complete. Next, carefully connect one of the 5' lengths of plastic tubing provided to the elbow fitting on the lake outlet, and install the second length of tubing to the straight drainage fitting at the bottom right of the model. Locate the tubing closures on each piece, and familiarize yourself with their operation. The position of the closures on the tubing can be varied, but ideally should be kept within a few inches of the outlet fittings on the model in normal use.

Filling the Tank

Included with your system components is a set of four different sands and gravels which you will use to fill your tank to simulate subsurface groundwater conditions. Refer to Figure 4 to guide you in the placement of the various sands to ensure optimum performance of your model. A funnel and tubing are provided to help you direct the location and flow of the sands more precisely. Please note that quantities provided are more than sufficient to fill your tank, and that some sand will likely be left over in normal installation.

Proceed slowly and carefully with this filling process, and avoid unnecessary spilling of sands into the piezometers, pumping wells, recharge chambers, leaky lagoon, or lake area. To help prevent this from happening, we recommend covering the opening for each of these areas with masking tape before proceeding with the filling process. Should sand or gravel fall into these areas, try to remove these materials using compressed air or other suitable technique so they won't potentially clog critical drainage holes.

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Foreword

This user's guide was written to help you use your WARD'S Groundwater Simulation System. The guide first presents a brief introduction to groundwater and its importance, followed by instructions for setup and use of your working model. Finally, it lists concepts that the model can demonstrate, and the mechanics of the demonstration. Suggestions are also given for combining sets of concepts to make classroom presentations.

The level of information presented in the guide varies from basic to more technical. You may find it helpful to use the guide as a reference in which you look up topics of interest, rather than as a book to be read from cover to cover, until you become comfortable with the basic operations of the model.

The areas in the unconfined aquifer around the gravel wedge or stringers may build up concentrations of dye because of preferential movement through the coarser materials. You may be able to insert a thin strip of stiff plastic, such as a ruler, in the channel to temporarily close off flow to the gravel wedge and force more dye to go through that area of the sand aquifer.

Never allow the model to freeze. Store the model out of direct light to prevent algal growth, and use the clear acrylic cover provided to slow evaporation. The cover should also be used when transporting the model to prevent accidental spillage.

Troubleshooting and Repairs

Once installed, your WARD'S Groundwater Simulation System requires minimal care and maintenance. Most problems you may encounter during system operation are readily addressed with simple corrective measures. Listed below are possible solutions to several potential problems you might experience. Should you continue to have difficulty remedying your problem, please call WARD'S Customer Service Department (1-800-962-2660) for prompt technical assistance.

Problem: **The model has been spilled or needs refilling.**

Solution: You may attempt to sift the materials with suitable sieves to sort them by size for reuse, or contact WARD'S to purchase replacement sands.

Problem: **The model leaks water from seams.**

Solution: Locate and completely clean the bad spot and dry thoroughly. Apply a very thin layer of clear silicone caulk along the seam edge and allow to dry completely. Repeat if necessary, but do not exceed four applications.

Problem: **The model leaks water at outlet joints.**

Solution:

(1) With continuing use, the elbow joint threads may become smooth. A new elbow joint may be obtained at a local hardware store or ordered directly from WARD'S.

(2) Check to see that elbow joints are wrapped with teflon tape and are free of grit or particles.

(3) Try to avoid having to remove the elbows each time for transport or storage.

Problem: **Piezometer does not fill to correct water level.**

Solution:

(1) If model is clogged with bacterial or algal growth, see suggestions under **Long-Term Storage and Maintenance.**

(2) If the piezometer is clogged with sand or gravel, try:
   (a) Using the syringe as a vacuum and sucking it out;
   (b) Filling the syringe with clear water and gently but firmly pumping water through into the model. Be careful not to pump hard enough to create air pockets in the sand.

(3) If the screen has become dislodged at the base of the well casing, the model will need to be emptied and the screen repaired.

Problem: **Pumping wells pump sand.**

Solution: The screen at the base of the well casing is broken. The model will need to be emptied and the screen repaired.

Problem: **The artesian aquifer is not under artesian pressure.**

Solution:
(1) Be sure that the well cap tube is properly inserted into the artesian outlet in the lake, and that both recharge bottles are filled and maintaining inflow.

(2) If pressure is still not maintained, there is probably a break in the confining layer. The model should be emptied and refilled (see above).

(3) In the future, be sure to store the model with the confining layer kept moist.

III. GROUNDWATER CONCEPTS FOR MODEL DEMONSTRATION

The following are some examples of basic groundwater concepts you can demonstrate using your WARD'S Groundwater Simulation System. As you become more experienced with its operation, you will undoubtedly discover many others which may apply. We hope you will share your experiences with us so that we may continue to improve this system and provide these benefits and other helpful ideas to additional teachers and students.

1. **Concept:** **Groundwater often comes from nearby sources.**

   Action: Fill one plastic recharge bottle with water, insert stopper assembly, and invert it at the left end of groundwater tank.

   Discussion: People often erroneously believe that groundwater travels hundreds of miles underground. They may also believe that the water they drink has been underground for thousands of years. In fact, groundwater drawn from shallow wells in many areas usually enters the ground within a few miles of the well, and has been in the ground only a few years or decades.

2. **Concept:** **Groundwater is contained underground in the spaces between sand grains and other soil particles, or in cracks and fractures in rocks.**

   Action: Allow water to run through the model.

   Discussion: Underground lakes and rivers rarely exist. Notice that the water entering the model at the left side saturates the sand and gravel and exits at the right, but there are no observable rivers or channels through which it flows.

3. **Concept:** **Groundwater flows from upland areas to low areas, or from areas of high hydraulic head to areas of lower hydraulic head.**

   Action: Allow water to run through the model. Add dye to each of the piezometers (see Figure 4) until it moves out of the piezometers into the soil below.

   Discussion: Water enters the groundwater system in areas called recharge areas. It then flows "downhill" until it reaches an area where it can come to the surface of the ground, called a discharge area. When the outlets to the model are closed, there is no flow through it. When either of the outlets are open, water can move through the model, because the elevation of the outlet is lower than the inlet elevation. The dye that moves into the sand or gravel from the piezometers is carried along by the moving water, helping you to see the path and direction of flow.

4. **Concept:** **Groundwater is withdrawn from the ground through wells for use in our homes, farms, and industries.**

Action: Look at the two pumping wells (see Figure 4). Use a syringe to pump water from the wells.

Discussion: Wells are drilled or driven into water-bearing underground zones (aquifers). A screen is placed at the bottom of the well to keep soil from being pumped out along with the water. (Bedrock wells do not always have screens.) A pump is used to withdraw water from the well. Municipal water systems usually have one or more wells, a water tower or ground level reservoir for storage, and a distribution system of underground pipes which carries water to the individual homes.

5. **Concept:** **Groundwater is related to surface water and to all other forms of water found on earth through the hydrologic cycle.**

Action: Close the lake outlet so that the lake fills with water. Open the outlet on the bottom right side of the model.

Discussion: The hydrologic cycle describes the interrelationship of groundwater with surface water, such as lakes and streams, and the water found in the atmosphere, such as clouds, snow, and rain. Groundwater often feeds lakes and streams. The place where groundwater becomes surface water is a discharge area. When groundwater simply bubbles up at the surface of the ground, that discharge area is called a spring. The lake in the model is an example of the interrelationship of groundwater and surface water.

6. **Concept:** **The underground units of soil and rock which can yield water to wells are called aquifers. Aquifers are not always uniform either horizontally or vertically. Aquifers may be separated by layers which do not hold or transmit much water. These layers are called confining layers or aquitards.**

Action: Look at the sand and gravel layers in the model.

Discussion: The light-colored sand aquifer in the model has stringers of coarser gravel included within it. Below the light-colored sand layer is a darker layer of material containing clay. The layer allows very little water to pass through it, so it acts as a confining layer. Below the confining layer, there is a second aquifer of coarser sand. There is little interconnection between these two aquifers. If you pump the well in the upper aquifer, you will see that the piezometers in that aquifer show a drop in water levels, while those in the lower aquifer show little response. Similarly, pumping the well in the lower aquifer causes little response in the upper piezometers.

7. **Concept:** **The soil and rock below the earth's surface normally consist of both a saturated and an unsaturated zone. The top of the saturated zone is called the water table. A type of monitoring well, called a piezometer, can be used to define the top of the saturated zone.**

Action: Allow water to run through the model from both ends. Add dye to each of the piezometers.

Discussion: Notice that the end of the tube where water drips out of the recharge bottle (the inlet) is higher above the surface of the table than is the plastic elbow where the water flows out of the model at the lake (the outlet). As water flows from the inlet to the outlet, a slope is created on the water table.

Use a water soluble marker or grease pencil to connect the water levels in each of the piezometers in the upper aquifer. You have now drawn in the water table. Note that it slopes from both left and right inlets downward toward the outlet. Compare the slopes of both. Which appears greater?

If you wish, you may add a small block under the left end of the model. This will cause the difference in height between the inlet on the left and the lake outlet to increase, creating a larger and more obvious slope to the water table. Other methods of changing the slope of the water table include raising or lowering the inlet tube in the stopper, or changing the extent to which the outlet elbow is opened.

The level of the dye in the piezometers defines the hydraulic head in the aquifer that they penetrate. The piezometers in the sand aquifer nearest the water bottle on the left (C and D) have higher dye levels than piezometer E, located near the lake, because they are closer to the recharge area.

8. **Concept:** **Piezometers are a type of monitoring well. They differ from drinking water wells in their construction and use.**

Action: Look at the piezometers and drinking water (pumping) wells in the model.

Discussion: Piezometers are usually installed by researchers studying groundwater in an area. Since groundwater flows from high areas to low areas, knowing the height of water in a number of piezometers (relative to mean sea level) can allow you to map the direction of groundwater flow. Piezometers are designed to be open only at a single point in the aquifer. They usually can have water samples drawn from them. However, since they are not intended to be permanent sources of water, they are often not as large or as durably constructed as drinking water wells.

The construction of drinking water wells is normally regulated by state codes which specify the depth required and the materials used in construction. They must be carefully located away from sources of contamination, unlike piezometers, which are often intended to collect contaminated water. Existing drinking water wells can sometimes be used as monitoring wells by researchers if exact details of their construction and depth are known.

9. **Concept:** **Water in artesian aquifers is under pressure. This pressure causes the water level in wells penetrating the artesian aquifer to rise above the top of the aquifer.**

Action: At this time, be sure that the small well cap tube is inserted over the artesian well in the lake (see Figure 4). Look at the dye levels in piezometers B, F, and G. Notice that the water level is above the top of the coarse sand aquifer which they penetrate, and is also generally above the water levels in piezometers A, C, D, E, H, and I.

Discussion: The artesian aquifer in the model is under pressure because the confining layer of sandy clay above it significantly retards water movement upward. Also, this aquifer has a recharge area, but no obvious discharge area (with artesian well capped). If the confining layer was totally impermeable, there would be no flow in the artesian aquifer at this time. However, in the model and in nature, confining layers usually leak. The pressure in the aquifer allows water to move upward through the confining layer. If dye is injected into the artesian aquifer through piezometer B, this upward flow may be observed as dye moves upward through the bottom aquifer sand toward the confining layer after about 20 minutes.

10. Concept: **The potentiometric surface is the level to which water will rise in a well penetrating a confined aquifer.**

Action: Observe the water levels as defined by dye levels in each of the piezometers.

Discussion: The light-colored sand aquifer is an unconfined aquifer because it has no confining layer above it. The level to which water rises in a well in an unconfined aquifer is the water table. In the confined artesian aquifer, the potentiometric surface is above the top of the aquifer, and is actually above the water table in the overlying unconfined aquifer.

11. Concept: **When the potentiometric surface of an aquifer is above the surface of the ground, a flowing well or spring may result.**

Action: Look at the well cap tube covering the artesian outlet in the lake. Notice that the water level in the tube is above the lake level. (Adding dye to the tube may help you to see this more clearly.) Now remove the tube and close the lake outlet. Notice that water flows from this opening, and the lake level begins to rise. Also, observe that there is a slight lowering of the water level in piezometers F and G, since the opening of an outlet for the artesian aquifer reduces the hydraulic pressure caused by the inlet elevation.

Discussion: There are several types of springs that occur in nature, but the most common type of spring is a spot where the water table of an unconfined aquifer intersects the land surface. Such springs often occur in the bottoms and sides of lakes and rivers. Sometimes they appear at the surface of dry land and become the headwaters of a stream. The spring in the model is the result of penetration into and discharge from the artesian aquifer. It is more correctly thought of as a flowing well.

People sometimes believe that springs have mysterious health-giving properties, and that any water coming from a spring must be pure. However, since the water in springs is simply water that is moving through the hydrologic cycle, it can be affected by any groundwater pollution source that contaminates the aquifer supplying the spring.

12. Concept: **The texture of the materials in an aquifer affects the rate of flow through the aquifer.**

Action: Notice that the water feeding the model enters along the entire vertical channel at either end. Inject dye into piezometers A and C (see Figure 4). Notice that the dye injected into the coarse gravel wedge around piezometer A disperses much faster than the dye injected into the finer, light-colored sand surrounding piezometer C. The dye movement out of the gravel wedge will radiate out in all directions.

Discussion: Both the coarse gravel wedge and the light-colored sand aquifer are well-sorted, which means that the grains of gravel or sand are all roughly the same size within each unit. Water can move through well-sorted gravel faster than well-sorted sand because larger grain size leads to larger pore size, and larger pore size leads to less surface area in contact with the moving water. The smaller the surface area the water contacts, the less frictional resistance there will be in the moving water. The lower frictional resistance leads to a greater velocity of groundwater flow. The gravel can then be said to have a higher intrinsic permeability, and as a result, a higher hydraulic conductivity.

Water flowing through an aquifer will take the path of least resistance. Since the resistance to flow is lower, more of the water entering the model per unit area will enter into the gravel wedge than into the sand layer around it. However, all this water entering into the gravel must have a way to exit. A hydraulic pressure is created which allows the water to exit even in an upward direction into the sand above the gravel wedge. In other words, the unconfined sand aquifer becomes a confining layer for the gravel wedge, creating artesian conditions in the gravel. In this case, downgradient is actually upward.The dye movement should illustrate this.

13. Concept: **Water flows into rivers from many directions.**

Action: Use a second bottle and stopper unit to add water at the right end of the model. Open the discharge tube at the river (lake) outlet. Be sure the piezometers are still filled with dye.

Discussion: Rivers are natural discharge areas for groundwater. In the model, you will observe dye traces moving from all directions toward the river and then entering into the river when the river outlet is open.

14. Concept: **Pumping wells draw water toward them from all directions. The water table gradually becomes lower around a well in an unconfined aquifer as water is withdrawn from the ground. The unsaturated zone (the zone which has been dewatered) around the well is called the cone of depression or drawdown cone.**

Action: Use a syringe to withdraw water from well #2 (see Figure 4). Observe that the dye level in piezometer E, and to a lesser extent the dye levels in piezometers C and D, become lower as you pump well #2. Notice that dye traces from above, below, to the right, and to the left all move toward the bottom of the pumping well.

Discussion: Pumping the well causes a zone around it to become unsaturated.This unsaturated zone is called a cone of depression. The slope of the water table from the water level in the pumping well to surrounding areas is much greater than the normal slope of the water table, so water can move toward the well much faster than it normally would. The cone of depression is three-dimensional, so water can be drawn toward the well from any direction, even the direction that we would normally consider to be "downstream." If you vary the pumping rate on the syringe, you can observe changes in the size and shape of the cone of depression by observing the changes in the water level in surrounding piezometers and the change in the rate at which dye traces are drawn toward the well.

The source of water drawn from pumping well #2 is basically gravity drainage of water stored in the aquifer. However, the source of water drawn from pumping well #1 in the artesian aquifer is quite different. The artesian aquifer yields water mainly because reduction in pressure in the aquifer as water is withdrawn leads to expansion of the water in the aquifer and compaction and settling of the aquifer materials. Cones of depression in confined aquifers are usually not as deep, but are more areally extensive than those in unconfined aquifers.

15. Concept: **Drawing water from a well can interfere with the ability of neighboring wells to produce adequate water.**

Action: Pump well #2 with the syringe at a very rapid rate.

Discussion: If well #2 is pumped rapidly enough, the water level in the aquifer will drop below the level of piezometers D and E, so that these piezometers no longer contain any water. A high-capacity well may be able to lower the water table enough so that shallow wells nearby will fall within the cone of depression and will produce little or no water while the high-capacity well is being pumped. This is called well interference.

16. Concept: **Human activities at or near the land surface can contaminate groundwater.**

Action: Pour dye into the "leaky lagoon" (see Figure 4) to a level above the holes drilled in the sides of the lagoon. If the lagoon does not leak, help it by inserting the tip of the syringe into the holes in the lagoon wall and gently forcing air through the openings.

Discussion: Dye should quickly move out of the lagoon through the surface unsaturated zone to the water table.Observe that this "contamination" moves downward in the saturated zone and discharges either at the lake outlet or the outlet on the bottom right side of the model (if opened). The "leaky lagoon" can represent various sources of groundwater contamination, such as landfills, septic systems, or manure storage areas.

17. Concept: **Wells can be contaminated by human activities at or near the land surface.**

Action: Pump water from well #2 with a syringe after filling the leaky lagoon with dye. Notice that well #2 draws water toward it from all directions. It draws the dye traces from the leaky lagoon as well as those from the piezometers on either side. If you have added red dye to the lagoon, observe that the water being pumped from well #2 is now also red.

Discussion: Since wells create a cone of depression around them as they draw water, they can also draw contaminants toward them from any direction: above, below, or even the area that would normally be considered "downstream."

18. Concept: **Pollutants travel with the groundwater, but they may travel at different rates.**

Action: Observe that the plumes of green dye which you have injected at various points in the model have separated into blue and yellow areas.

Discussion: Groundwater can carry pollutants that it has picked up as it flows through the system. However, some chemicals move faster than others in groundwater. The soil particles that make up an aquifer may weakly adsorb some chemicals, slowing their flow rate. Others are more soluble and move through more rapidly. These soluble chemicals are good indicator chemicals to test for in drinking water. They can tell us that a pathway exists between a source of contamination and a drinking water well. Other chemicals associated with that source may also move down that pathway, although perhaps not as quickly or in as great a concentration.

19. Concept: **Contaminated groundwater may pollute surface water.**

Action: Notice that the water collecting in the lake is not clear. It has been affected by the dye that has been injected at various points.

Discussion: Surface water bodies such as lakes and rivers have two major sources of water: surface runoff from rainfall and snowmelt, and groundwater flow, called baseflow. Baseflow is the reason that streams flow even during dry spells. In addition, since the temperature of groundwater is about 50° Fahrenheit year-round, baseflow allows streams to flow in winter even when the ground is frozen. Any contaminants in groundwater can then be discharged into surface water. In many ways, surface water is better able to treat contaminants than groundwater. Natural processes such as sunlight, aeration, and turbulence break down some pollutants. However, other pollutants from groundwater, such as nutrients, can cause algae blooms, weed problems, and turbidity in surface waters.

20. Concept: **Contaminated surface water can pollute groundwater.**

Action: Pump well #2 steadily with a syringe until you see dye being drawn toward it from the river.

Discussion: If the cone of depression created by pumping well #2 extends all the way to the river, the river can actually recharge the groundwater. This occurs in some municipal wells and irrigation wells located in sandy aquifers near river systems. The filtering action of the sand removes most microorganisms, but chemical contamination can enter the aquifer in this way.

21. Concept: **Groundwater is recharged by precipitation and snowmelt.**

Action: Pour a small amount of dye at one or two points along the top gravel surface of the model. Use a sprinkling device or spray bottle to add water along this top surface.

Discussion: Recharge of the aquifer from above creates additional head that pushes dye plumes near the surface deeper into the aquifer. The dye plumes created by recharge of the model in this way are most representative of natural conditions. Groundwater contaminants normally enter the system from the surface, not at discrete points deep within the aquifer as the injection through piezometers might suggest.

22. Concept: **Capillary action can cause upward movement of water and contaminants above the surface of the water table.**

Action: Observe that most of the dye you have added to the leaky lagoon or underground tank has moved downward and to the right. However, some has moved upward into the gravel layer, above the potentiometric surface.

Discussion: Capillarity is a phenomenon that explains the upward movement of water above the surface of the water table. Water is attracted to and adheres to surfaces of solid materials. In addition, cohesive forces (also called hydrogen bonding) bind water molecules to each other. This allows water to move upward in small pores above a saturated layer. The pore spaces in the sandy and gravelly materials are small enough to act as capillary tubes. The smaller the size of the pores, the higher the water will rise in them. Because soil pores are not straight uniform openings, capillary rise in natural soils is less than in similarly sized glass tubes.

23. Concept: **Water quality can vary within an aquifer.**

Action: Observe that dye spots, when they first enter the aquifer, occur only in a narrow zone. As the dye plumes move downgradient, they become wider.

Discussion: Contaminants entering an aquifer often do so only at a point or in a narrow zone. The concentration of the contaminant may be quite high in that small volume of water. Often the contaminant is concentrated near the top of the water table. However, as groundwater continues to move, the zone of contamination widens out.

Contaminant transport, or the movement of contaminants in the groundwater system, is composed of a number of factors. **Advection** is the process by which contaminants are transported by the motion of flowing groundwater. **Dispersion** is the process by which contaminants follow a variety of distinct flow paths through the porous medium (the aquifer) and become more mixed. Reactions may occur which weakly adsorb contaminants, causing them to move at a slower rate than the water in the aquifer. The net effect of these processes is dilution. As the plume moves along and widens, a greater volume of water is mixed with the same quantity of contaminants.

It is also useful to note that if recharge were induced by sprinkling water over the top of the entire model, the dye traces would angle downward and widen as they moved across the model. This method of recharge would more closely simulate natural conditions.

24. Concept: **Confining layers that separate aquifers usually leak.**

Action: Pump water from well #1 using a syringe. Notice that the water levels in piezometers B, F, and G, which extend into the artesian layer, drop rapidly. The water levels in piezometers A, C, D, E, H, and I are relatively stable, since a confining layer separates the two aquifers. However, also notice that dye begins to move downward in the sand aquifer toward the confining layer.

Discussion: The artesian aquifer is able to yield large volumes of water and recharge itself quite rapidly from both sides of the model. However, when water is withdrawn from the artesian aquifer, a zone of lower pressure is created which induces water movement downward through the confining layer. Water moves through the confining layer very slowly, carrying dye with it and showing that the confining layer is not the totally impermeable barrier to flow that it might appear to be. In addition, most naturally occurring confining layers vary in thickness and may be fractured or discontinuous. The presence of a confining layer below is not always sufficient to protect a valuable aquifer below from contamination if a large waste source is placed above it.

25. Concept: **Wells can cause groundwater pollution.**

Action: Inject dye into each of the piezometers or into the two pumping wells using a syringe. Fill them until the solution reaches all the way to the bottom and begins to spill out below.

Discussion: Wells with defects, such as cracked or rusted casings, or wells not properly sealed at the surface, can serve as conduits for contaminated surface water to enter the groundwater. Wells should be protected from damage while they are being used, and should be properly sealed when they are to be permanently abandoned. Wells should never be used to dispose of unwanted materials. State and county governments have codes regulating the proper construction, maintenance, and abandonment of wells.

26. Concept: **Sources of groundwater contamination may be continuous or intermittent.**

Action: Observe that in operating the model, you need to add dye solutions to the piezometers periodically if you want a continuous dye trace. A single addition of dye at the beginning of the demonstration results in only a single spot of dye to follow.

Discussion: Some sources of contamination may occur as a single slug, such as a spill. These will eventually move through and be flushed out of the groundwater system.The time period required may be from days to years. Other contamination sources may input contaminants continuously, such as a wastewater treatment lagoon, septic system, or landfill. As these are flushed out of the groundwater system, additional contaminants from the source will move in to replace them.

27. Concept: **Once groundwater becomes contaminated, the contamination may persist for long periods of time and over long distances.**

Action: Observe that the dye is eventually flushed out of the model.

Discussion: Unlike our model, the environment is not easily able to eliminate pollutants. Contaminants in groundwater may move only a few feet each year, meaning that they will remain in groundwater for many years. Eventually, the contaminants that are not chemically or biologically modified will reach a discharge zone. The contaminated groundwater that discharges into rivers, if not removed by natural treatment processes, eventually makes its way to the ocean.

28. Concept: **Groundwater flow lines have curved paths.**

Action: Observe dye traces that extend from the recharge area to the discharge area. Notice that they travel in a nearly straight line across the model and then curve upward at the discharge area.

Discussion: Recall that the force potential, or the driving energy behind groundwater flow, is made up of two energy components: the pressure head and the elevation head. Recall also that groundwater moves from areas of high total head to areas of lower total head. At the recharge area of the model, the sum of the energy forces causes water and dye to move in a downward direction. At the discharge area, the pressure head and the total head become lower, since water is being removed from the system at that point. Although water is moving "uphill," it is actually moving from an area of higher total head to an area of lower total head.

V. GLOSSARY

Adhesion
The attraction of water molecules to solid sufaces.

Aquifer
An underground unit of saturated soil or rock that can transmit significant quantities of water to wells.

Artesian aquifer
See confined aquifer.

Baseflow
The component of flow in streams that comes from groundwater discharge.

Capillarity
The phenomenon by which water rises in small pores into the unsaturated zone above the water table, because of adhesive and cohesive forces.

Cohesion
The attraction of water molecules to each other because of hydrogen bonding. Also known as surface tension.

Cone of depression
The zone around a well in an unconfined aquifer that is normally saturated but becomes unsaturated when the well is pumped.

Confined aquifer
An aquifer that is bounded above and below by confining layers which transmit water significantly slower than the aquifer. The water level in a well tapping a confined aquifer will rise above the top of the aquifer because the confined aquifer is under pressure. Also called artesian aquifer.

Confining layer
A layer of lower permeability material that overlies an aquifer. Sometimes called an aquitard.

Dilution
A greater volume of groundwater being mixed with the same amount of contaminant.

Discharge
The removal of groundwater from an aquifer at lakes, streams, or wetlands, by pumping a well, or by leakage to another aquifer.

Dispersion
Water carrying a contaminant becoming more separated by following a variety of distinct flow paths through an aquifer. Dispersion has two components: mechanical mixing and diffusion.

Drawdown
A lowering of the water table in an unconfined aquifer or the potentiometric surface in a confined aquifer caused by pumping of a well.

Elevation head
The difference in elevation between the recharge area and the discharge area.

Evaporation
The process by which water is changed from a liquid or solid to a vapor at a temperature below the boiling point.

Evapotranspiration
Water returned to the atmosphere by evaporation from land and water, and by transpiration of living plants.

Groundwater
Water contained in saturated soil and rock materials below the surface of the ground.

Heat of fusion
The energy given off as water changes forms from a liquid to a solid.

Heat of vaporization
The energy consumed as water changes forms from a liquid to a gas.

Hydraulic conductivity
The rate of flow of groundwater in gallons per day through a cross-section of one square foot under a unit hydraulic gradient at the prevailing temperature. Hydraulic conductivity is related both to the type of earth materials and the water present in an aquifer.

Hydraulic head
The energy that causes groundwater to flow. It is the sum of the gravitational energy and the pressure energy.

Hydrogen bonding
The cohesive force caused by the polar nature of water, in which the oxygen atom in one water molecule is attracted to the hydrogen atom of another water molecule. This bonding causes water to have many of its unique properties.

Hydrologic cycle
The circulation of water from the land and bodies of water to the atmosphere and back again.

Indicator
A chemical or biological parameter that can be used to indicate the possible presence of other contaminants.

Permeability
The capacity of rock or unconsolidated material to transmit a liquid, which is primarily a function of the sizes of the interconnected pores and the shapes of the openings.

Piezometer
A well installed to monitor hydraulic head or to monitor groundwater quality.

Porosity
The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.

Potentiometric surface
The level to which water rises in a well drilled into a confined aquifer.

Pressure energy
The energy given to groundwater by the weight of overlying water and earth materials.

Recharge
The addition of water to the groundwater through the infiltration of precipitation through the unsaturated zone of the aquifer.

Saturated zone
The part of water-bearing formation in which all the void spaces are filled with water.

Specific heat
The number of calories required to raise the temperature of water 1° C.

Spring
A natural discharge of groundwater at the land surface.

Texture
The percentage of silt, sand, and clay materials making up a soil.

Unconfined aquifer
An aquifer which has no confining layers above it, so that the water table is exposed to atmospheric pressure and forms the upper boundary of the aquifer.

Unsaturated zone
The zone between the land surface and the water table, in which some of the pore spaces are filled with air and some are filled with water.

Water table
The level below which the soil or rock is saturated with water. The upper surface of the saturated zone in an unconfined aquifer.