UTILIZING ANALOG GROUNDWATER FLOW MODELS TO ILLUSTRATE AND EXPERIMENT WITH PRINCIPLES OF GROUNDWATER

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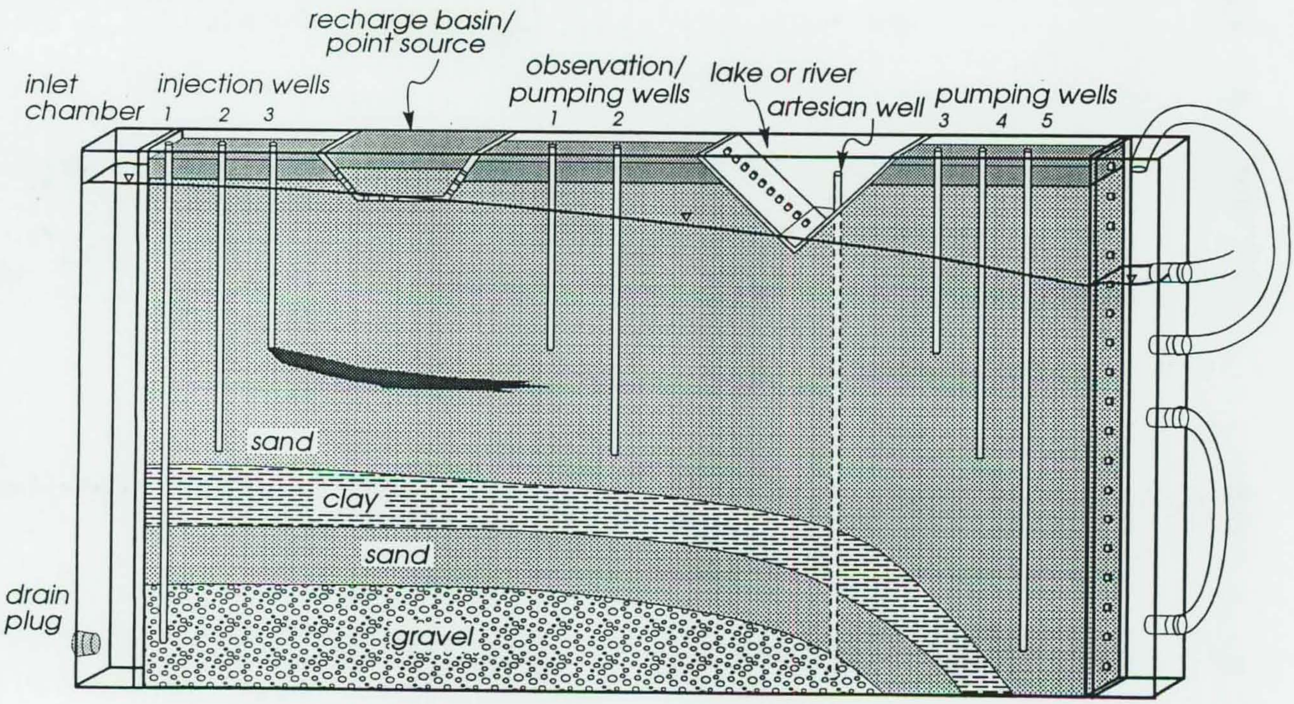
Physical groundwater flow models can be used to teach, demonstrate, and experiment with principles of aquifers. This paper deals with the construction of sand box models incorporating features that resemble the Long Island aquifer system. Similar models can be made in a school shop. The design of a realistic model of groundwater flow was the primary objective of my Brookhaven National Laboratory mentor, Dr. Jan Naidu. The second objective was to build the physical model, a sand/water tank, with an unconfined aquifer, confining layer and confined aquifer. Researchers at the department of Geology, University of Arizona, developed a hydraulic model analogous to the conditions found in subsurface groundwater flow. I have built a modified version. It is constructed of 3/8" thick Plexiglas and is 91 cm. long, 45.7 cm high and 3.9 cm deep (see Fig. 1). The model can be loaded with a variety of material including gravel, fine and coarse sand and clay. Colored dyes can be injected into the layers of material through wells while a constant flow of water is maintained through the model. Dye plumes with distinctly linear forms are observed. Depending on the water table level the triangular stream simulator is an influent or effluent stream. The rectangular point source simulator acts as a recharge basin, a pollutant point source, or as a pristine recharge area such as the Long Island Pine Barrens. This model has been extremely successful in demonstrating multiple parameters of groundwater flow in classes at the secondary and college level. The model can be emptied, cleaned and reloaded with layers of various materials at differing depths to simulate a variety of aquifers and soil profiles.



The features of the model can be seen in the figure. On the extreme left is an inlet chamber. Water is pumped into the square chamber that communicates with the central tank via holes drilled at one inch intervals and tapered at each end. At the bottom of the inlet chamber there is a drain plug. At the left end of the central tank are three injection wells made of Plexiglas tubing. Injection well 1 extends down into the confined layer at the bottom of the model. Injection well 2 extends approximately two-thirds of the depth of the tank to the right of well 1. Injection well 3 extends one-third of the depth of the tank. To the right of the injection wells is a small rectangular basin with sloping sides. This is a recharge basin or point source filled with coarse sand.

There are two observation/pumping wells in the middle of the tank. The first is at the same depth as injection well 3. The second is at the same depth as injection well 2. To the right is a triangular-shaped lake or river simulator. As the water table rises the lake or river becomes a groundwater fed lake or stream. If the head at the left end of the model is high enough, the river simulator will receive water from the artesian well. To the right of this at varying depths are pumping wells 3, 4 and 5.

The interior wall of the central tank has drainage holes at one inch intervals, leading to the draining chamber. This chamber allows water to drain from the model through a choice of four outlets of varying heights. These are fitted with brass plugs and tygon tubing. Water is set at a constant rate of flow through a tube inserted in the inlet chamber. The rate of flow is modified as necessary to maintain the water table desired. Layers in the soil profile tend to collapse under the influence of flow, and breakthroughs of the clay layer occur. A possible explanation is that as the model is loaded in a dry state, air pockets form and a certain amount of settling and shifting occurs.

Loading the gravel, sand and clay while the tank is filled with water was not successful. A technique for loading gravel, sand and clay sequentially in air was successful. The model is tilted to the left and held in place at approximately a 30 degree angle. Gravel is poured into the left side of the central chamber to a height of two inches using a Plexiglas tube, the gravel is spread evenly across the bottom of the tank until it reaches a point just past the artesian well. A piece of Plexiglas sidewall milled to exactly the depth of the tank is used as a temporary dam to hold back and define the layer of clay used as an aquaclude. A thin layer of coarse sand is poured on top of the gravel to gradually change the grain size. A thin layer of fine grained sand is added next to act as a more natural barrier and to simulate more closely the layering of grains in the soil profile of the model. Finely-sorted clay in dry powder form is added to the model at this point, with the Plexiglas dam delineating the edge. The clay is physically compacted using a square metal wand, and additional clay is layered in on top. Fine-grained sand is poured to hold the clay and underlying layers down, and the Plexiglas dam is withdrawn vertically. Sand is then added to the top of the model and the entire tank is rocked back and forth gently to aid in settling. After loading, water is pumped in from the inlet chamber slowly, to aid settling, and prevent disturbance of the layers. When settling or compression is complete, more sand can be added to the top. The final step in preparing the model for operation is to seal the top with tape or foam insulation.

Running the model starts with inserting a tygon tube as a water source into the inlet chamber until the end of the tube is resting just above the bottom of the tank. In situations where a sink or running water is not available, gallon containers can be used to both supply and collect water. The hydraulic head or water table level is adjusted by attaching the draining tube to one of the brass fittings on the right side of the model. After the central tank is saturated, the water flow is adjusted so that a constant height is maintained in the inlet chamber. Colored dyes can be inserted into any combination of the injection wells. The dyes are pumped into the injection wells with a syringe. Each well being used will fill with dye and begin to stream the dye into the sand layer. The dye begins as a circular stain. Shortly the dye forms a plume following the path of water flow. This plume shows the first concept of groundwater flow, that of linearity. The plume parallels the gradient of the water table. This is the second principle of groundwater flow that can be illustrated by the model.

As the water travels across the model, depending on the height of the water table, it will pass under the recharge basin and enter the river valley. The height of the stream should roughly match the water table in the model. The stream will then empty into the sand again before passing into the draining chamber. Parameters that can be adjusted for illustration involve attaching a pump to one of the pumping wells placed at various points in the model. The pumping wells, when activated, change the flow of water, and are capable of showing a marked curved pattern simulating a natural cone of depression in the water table. The dye follows the cone of depression and enters the well. If different dyes are used in each of the injection wells, the patterns can be followed and the change in sand layer aquifers can be easily distinguished. Experimentation with the model is highly recommended, as each usage yields slightly different results.

After completing an experiment or demonstration, the tank should be cleaned and all remnants of the dyes flushed from the system within 24 hours. This is accomplished by opening as many of the draining outlets as possible and running a continuous stream of water through the model until only the faintest traces of dye can be observed. The wells in the model can be flushed by pumping fresh water into them. Care must be taken to use an extremely low pressure or a drip syringe so that the earth materials at the bottom of the wells are not dislodged by the pressure of the rinsing action. If the model is to be left in one place for an extended period of time, water may be left in the tank to a height just above the clay layer to prevent the clay from drying out and cracking. If the clay dries out, add water slowly and allow the clay to saturate a few millimeters at a time. Bacterial or algal growth may appear after a period of time. This is indicated by a discoloration in the layers or may be observed along the walls. To prevent algal growth mix a dilute chlorine bleach solution (approximately one tablespoon per quart of water) in a clean gallon container and saturate the model for a period of more than one hour. Use a syringe to inject the cleaning solution into all the wells and ensure that the drain fittings are all sealed to raise the water table level as high as possible during cleaning. To flush the system after cleaning allow fresh water to run for one- half to one hour. Inject fresh water into the wells repeatedly, again taking care to keep the pressure to a minimum to avoid disturbance at the bottom of each well. Water may also be pumped from the wells as a rinsing measure.

If any leakage is observed along the Plexiglas joints, silicon sealer may be used. If the brass fittings begin to leak with time, unscrew them with a small wrench and reapply Teflon pipe tape before reinstalling. Do not leave the model out where it can be subjected to freezing temperatures. The exterior of the tank should only be cleaned with a plastic cleaner. Glass cleaners that contain acids, ammonia or vinegar will fog the plastic. The model should be placed securely during transport to ensure that it does not fall over and break the wells, which extend an inch above the tank.

The tank can be easily emptied and washed clean of all earth materials that have been previously loaded. This enables the researcher to change the soil profiles to fit the geographic area that is being investigated. My model as shown in the figure reflects most features of the Long Island substrata but could be modified to conform with most other aquifer situations.