WHY GROUNDWATER LEVELS CHANGE

Groundwater levels change for many reasons. Some changes are due to natural phenomena, and others are caused by man's activities. Missouri has many different aquifers. Some are relatively shallow unconfined aquifers that are affected by surface activities. Others are much deeper confined aquifers that are well isolated from surface or shallow subsurface influences. Some aquifers consist of competent bedrock units; others are composed of unconsolidated sediments. Some aquifers are heavily used for water supply while others receive very little use. All of these factors can influence how water levels in the aquifers change over time.

All of the observation wells record a water level every 30 minutes. The data graphs show depth to water below land surface plotted on the Y or vertical axis, and time plotted on the X or horizontal axis. The "real time" data category will automatically display the last 7 days of 30-minute data. At a maximum, the 30-minute water-level data can be viewed for only the preceding 30 days. Daily data can be viewed for longer periods of time. The daily data consists of one value per day; it being the average water level calculated from the 30-minute data values. Some of the types of water-level fluctuations described below can only be recognized using the detailed 30-minute data. Other types of fluctuations are best seen using the daily data. Long-term changes that predate 2000 can only be identified using the long-term hydrographs.

Water-level changes can be divided into several categories. There are short-term changes that can only be seen when water-level measurements are made many times a day. There are long-term changes that can only be seen after data are collected for many years. There are minor changes of only a few hundredths of a foot, and changes that are hundreds of feet. Fluctuations are generally due to one of three major factors: 1) change in the volume of water stored in the aquifer, 2) changes in atmospheric pressure, and 3) changes caused by aquifer deformation. Many of the causes of water-level changes can be easily recognized simply by the shape of the groundwater-level hydrograph. Other changes are more subtle, and their causes are not immediately recognizable.

Fluctuations due to Aquifer Storage Changes

Groundwater is not static. It is part of a dynamic flow system. It moves into and through aquifers from areas of high water-level elevation to areas of low water-level elevation. Groundwater-level fluctuations due to aquifer storage changes involve either the addition or extraction of water from the aquifer, both through natural means and human involvement.

Groundwater recharge occurs naturally where the earth materials are sufficiently permeable to allow water to move downward through them. It occurs most easily in unconfined aquifers where water provided by precipitation moves downward from land surface until the water reaches the water table. The water table is the boundary between the unsaturated zone above it where the pore spaces are not filled with water and the saturated zone below it where essentially all of the interconnected pore spaces are filled with water. When recharge occurs in an unconfined aquifer, the water table rises to a higher elevation, much like water level in a bucket will rise as water is added to it. One inch of precipitation moving underground to the water table will cause the groundwater level to rise considerably more than an inch. This is because unlike a bucket, most of the volume of an aquifer is occupied by rock, sand or other solid geologic material. The water can only occupy the void or pore spaces. For example, an aquifer with a porosity of 5 percent will, theoretically, experience a water-level rise of 20 inches due to one inch of recharge.

The most significant water-level changes due to recharge generally occur during springtime of the year when precipitation is generally greatest and evaporation and plant usage rates are low. There are several wells in the observation well network that show water-level increases due to rapid groundwater recharge following significant precipitation events. These include Halfway, Akers, Fairview, and Big Spring observation wells. All of these are relatively shallow wells with modest lengths of casing. All are drilled into unconfined aquifers. Figure 1 shows the hydrograph of the Akers Observation well for one year. The vertical rises in early December 2006, and January and April 2007 is recharge from rainfall events at those times. Figure 2 is the hydrograph from the Big Spring observation well during the same period of time. It shows the same basic trends that appear on the Akers observation well, except the response to local precipitation is even more pronounced.

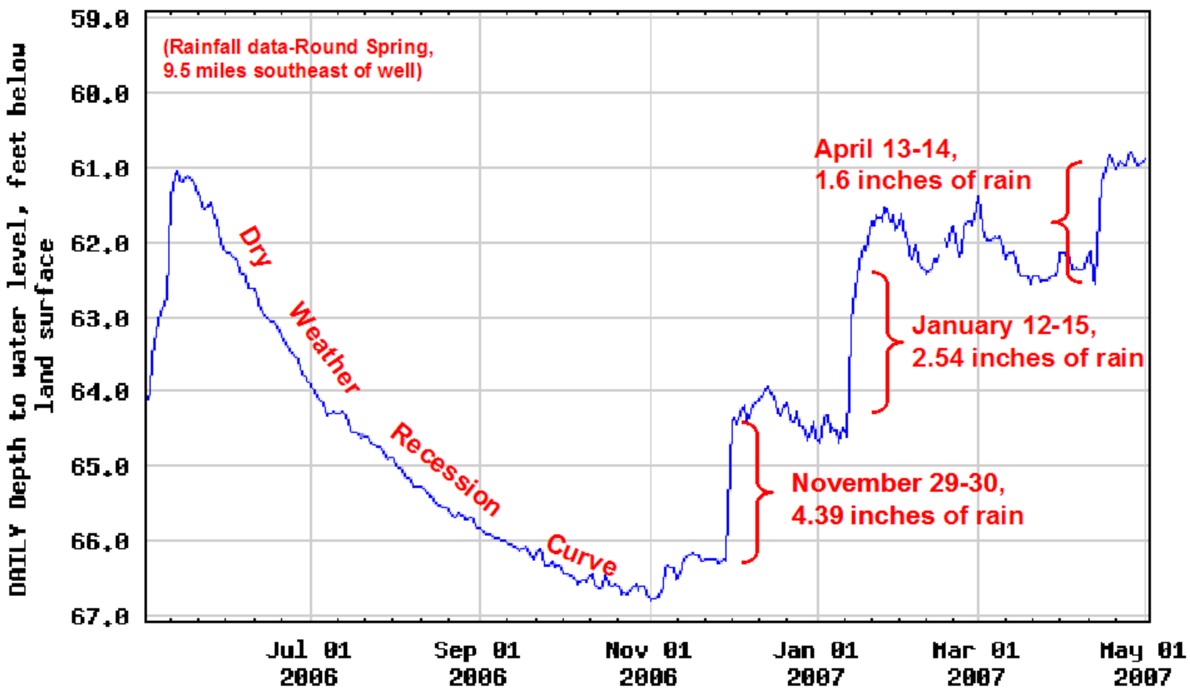


Figure 1. Groundwater recharge and discharge, Akers observation well, Shannon County

Groundwater levels in many of these same wells will show a steady decline between spring and fall, especially during dry years. This is because there is little recharge to the aquifers during those months. However, groundwater continues to move through the aquifers to supply springs and streams in the area. The water lost from storage to the springs and streams provides stream flow even during the driest of years, but also causes a decline in groundwater level. The water-level declines are usually greatest in the upland recharge areas where groundwater levels are typically at a higher elevation. Groundwater-levels at lower elevations near valley bottoms, which are groundwater discharge areas, generally show much less change. The Akers observation well hydrograph in figure 1 also shows the effects of groundwater discharging from the Ozark aquifer in that area during dry weather. The steady drop in water level from early May to November of 2006 is the result of water discharging from the aquifer to feed local streams and springs but not being replaced by recharge. Big Spring observation well during that same period showed much the same pattern.

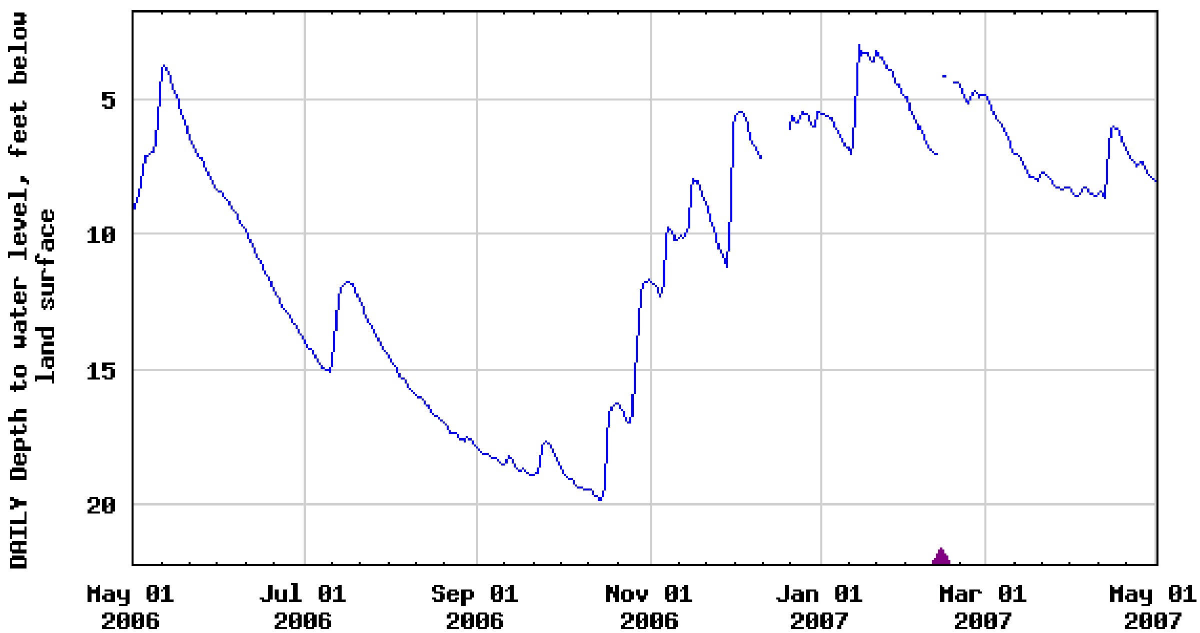
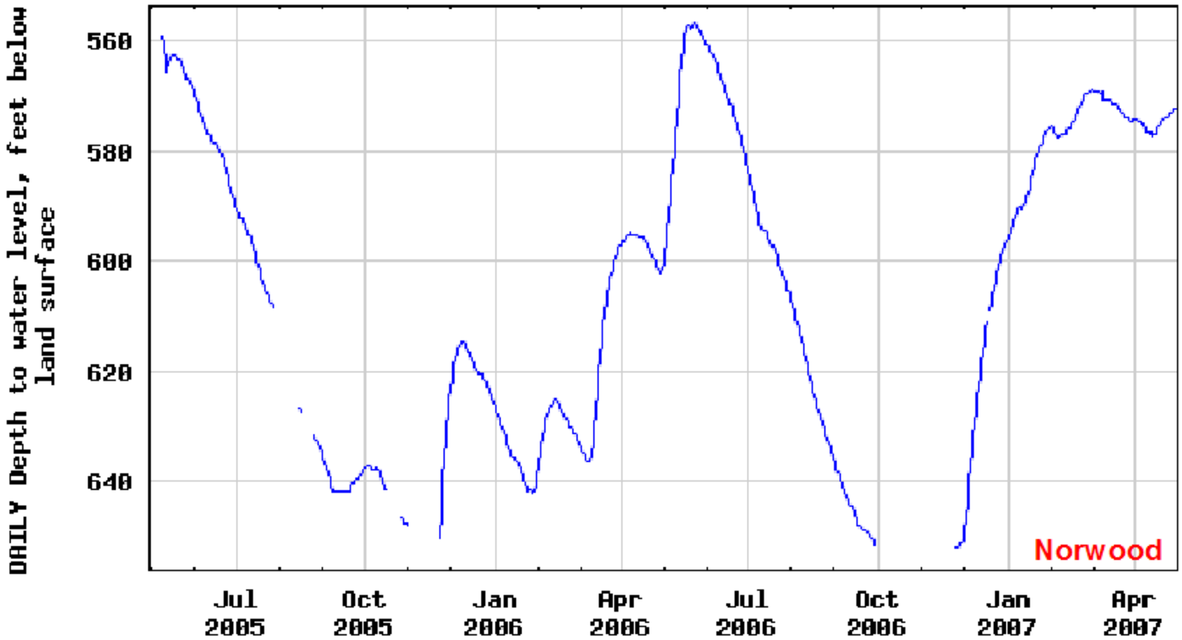


Figure 2. Daily hydrograph of Big Spring observation well showing recharge and discharge.

There are two other wells that also show water-level rises following precipitation that are much deeper and are cased very deeply, Norwood and West Plains (figure 3). Both of these wells are in an area of south-central Missouri where the soluble dolomite bedrock has been extensively dissolved, creating numerous karst features such as sinkholes, losing streams, springs, and caves. Recharge through sinkholes, losing streams and the deeply weathered bedrock allows water from the surface to rapidly move downward into the aquifer and circulate to substantial depths. At West Plains, rainfall events of several inches can cause groundwater levels to rise more than 150 feet within a few days.

Several of the observation wells show the effects of recharge in a much more subtle manner. Both the Shelbina and Vandike Farms observation wells measure water-level changes in the shallow glacial drift aquifer in northeast Missouri. There is very little groundwater use in the vicinity of these two wells, so changes in water levels in them are almost entirely due to natural phenomena. In most years, water levels in the two wells rise during the late winter and spring months, then decline through the summer and fall. The seasonal cycles are clearly due to recharge and discharge of the aquifer, but because the movement of groundwater in these areas is much slower than that in the Ozarks region, the water level changes are correspondingly slow.

Rainfall is not the only source of groundwater recharge. The alluvial aquifers that underlie river floodplains are partly recharged by the rivers during high-flow stages. When the water level of the river is at an elevation higher than the groundwater level, then water will move from the river into the alluvial aquifer. When the river level is lower than that of the groundwater, water flows from the aquifer back into the stream. Wells near the river will show the response more quickly than wells farther away. Figure 4 shows the stage of the Missouri River at St. Joseph during 2001 and groundwater levels at the St. Joseph observation well, which is completed into the Missouri River alluvial aquifer, during the same period of time. The well is about 4,000 feet from the Missouri River. Note how prolonged rises in river stage cause water level in the alluvial aquifer to also rise



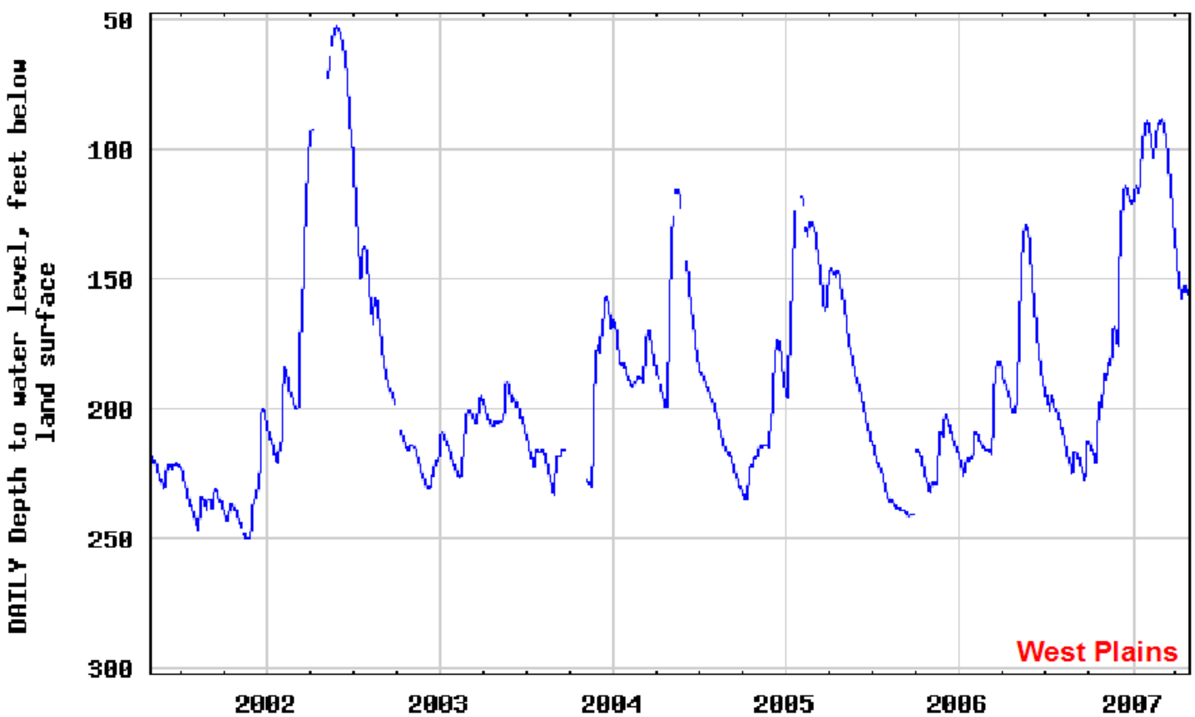
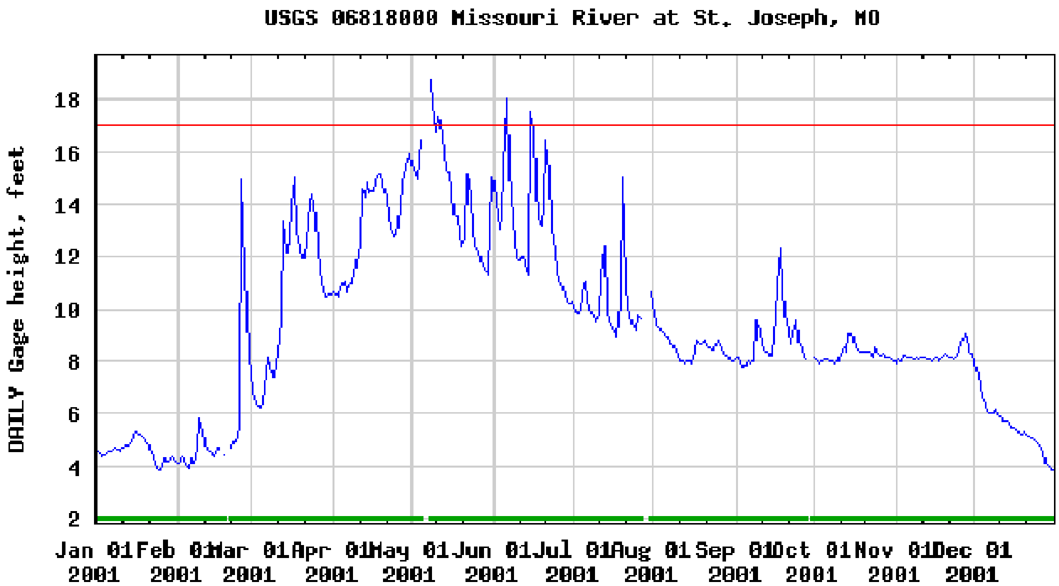
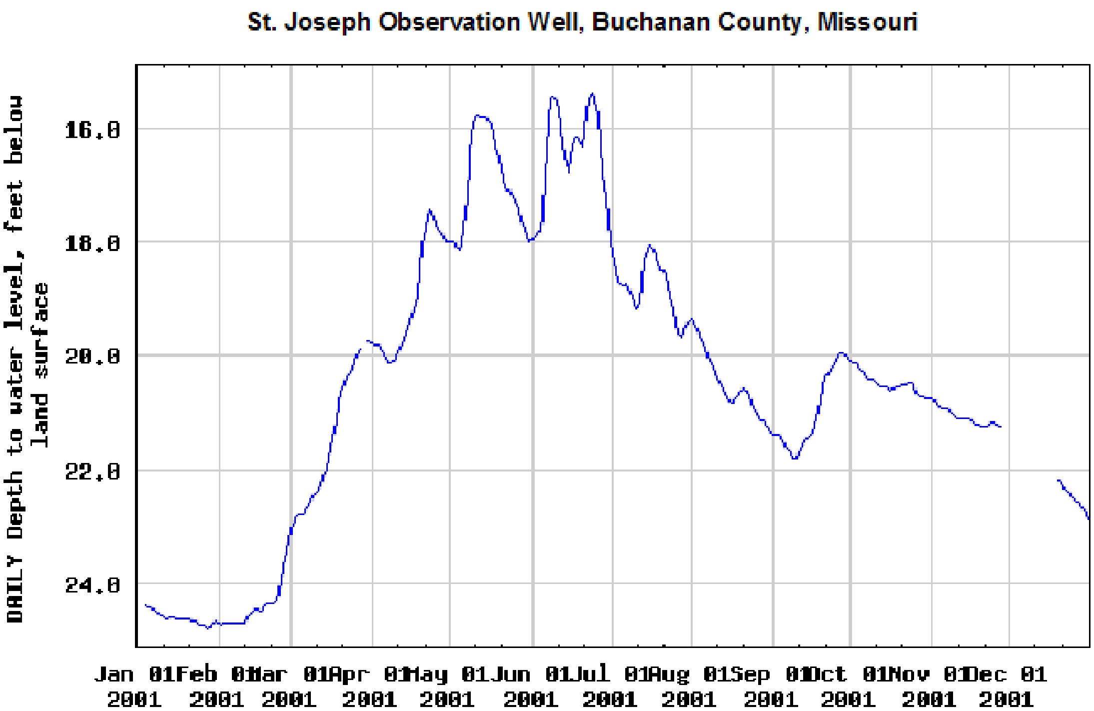


Figure 3. Recharge effects recorded at the Norwood (top) and West Plains (bottom) observation wells





.

Figure 4. Hydrographs of the St. Joseph observation well (bottom) and Missouri River at St. Joseph (top) showing how prolonged high river stages on affect alluvial groundwater level.

Water level rises and falls can also be caused by water wells producing groundwater in the vicinity of the observation wells. Many of the observation wells, especially those that were originally municipal water supply wells, show water-level changes that reflect municipal water use. Most cities and towns use considerably more water during the summer months than other times of the year, so it is normal to see groundwater-levels drop during the summer months and recover during the off-peak times of the year. Several of the observation wells are very near active producing wells. The Eureka and Cole Camp observation wells were both drilled as municipal water-supply wells and much later configured to collect water-level information. Both are very close to operating municipal wells. The rapid water-level fluctuations they record are due to the pumps cycling on and off at the nearby producing wells (figure 5). The Rolla Ramada Inn observation well also shows a pronounced drawdown-recovery cycle pattern (figure 6). The hydrograph show how a nearby Rolla municipal well affects water level in the observation well. When the data were collected, the municipal well, one of 17 wells serving Rolla, had a 6-day cycle with about one-day of pumping followed by 5 days of recovery.

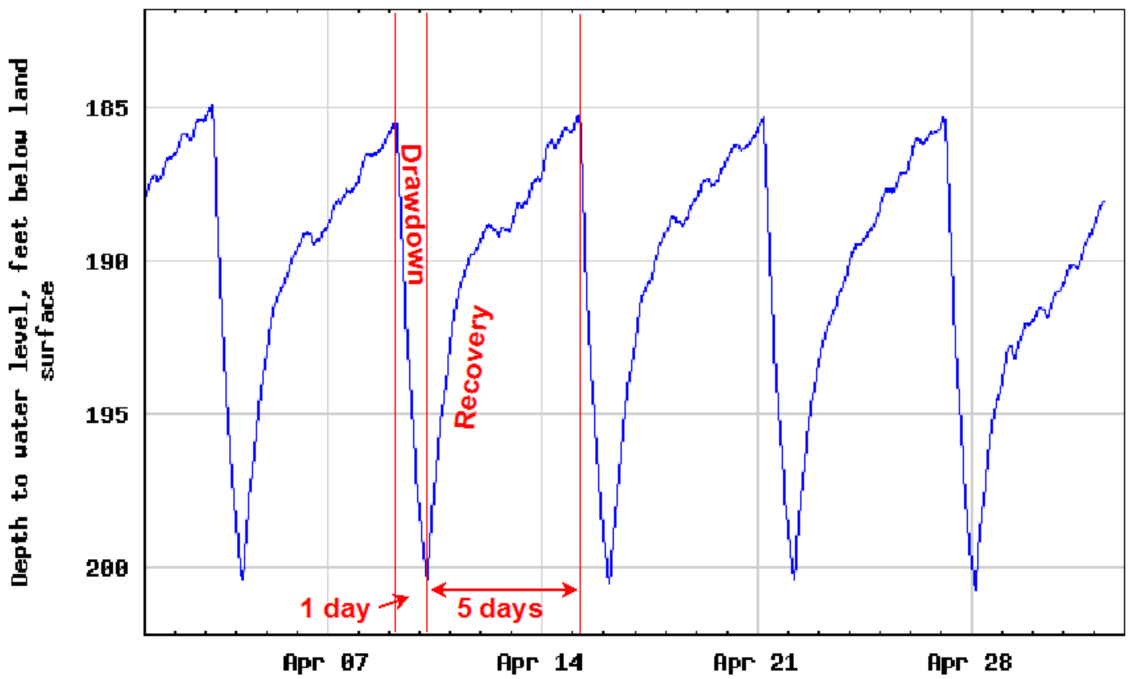


Figure 5. Water-level changes due to a nearby pumping well, Ramada Inn (Rolla) observation well

Several wells are strongly influenced by nearby industrial pumping. Industrial water usage is often closely tied to the workweek. The Dresden School observation well and the Noel observation well (figure 6) are both near major industrial water users. Water levels in both wells typically are highest on Mondays and lowest early Saturday. Water use during the weekends is much less than during the week, allowing water levels to recover somewhat, until the following Monday morning when the pumping cycle starts again.

Longer-term pumping cycles affect several observation wells. Water levels in the Lamar and Golden City observation wells are mostly affected by agricultural irrigation. The irrigation season in southwestern Missouri typically begins in early July and ends in mid-September. Between late

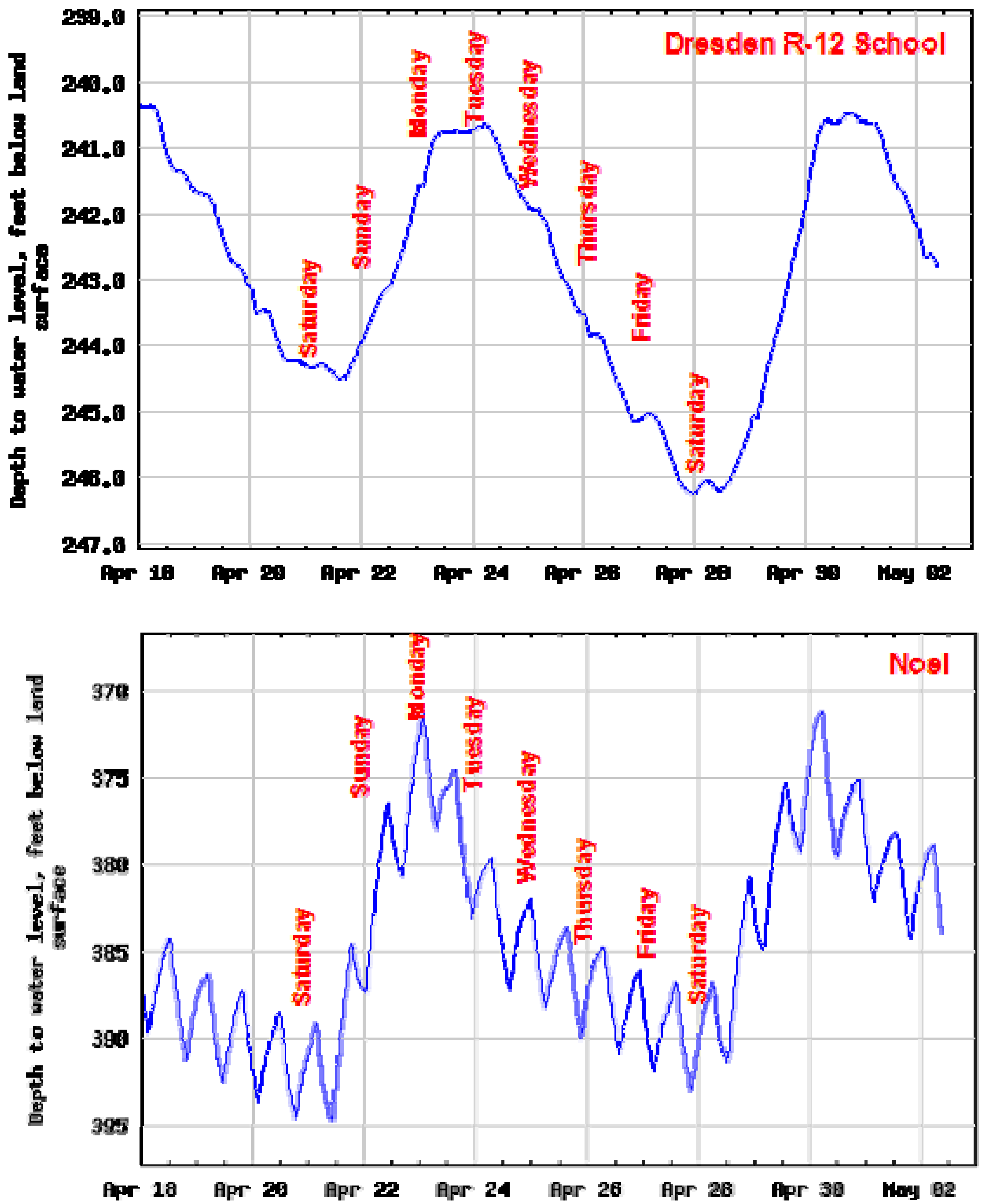


Figure 6. Weekly cycle of drawdown and recover, Dresden R-12 School (top) and Noel (bottom) observation wells.

September and early July, the Golden City observation well shows about six to eight feet of fluctuation due to pumping at the city's other wells. However, groundwater levels in the Ozark aquifer in that area drops sharply during the irrigation season, then slowly recovers the remainder of the year (figure 7). The McDaniel Lake observation well is about a mile from a high-yield well

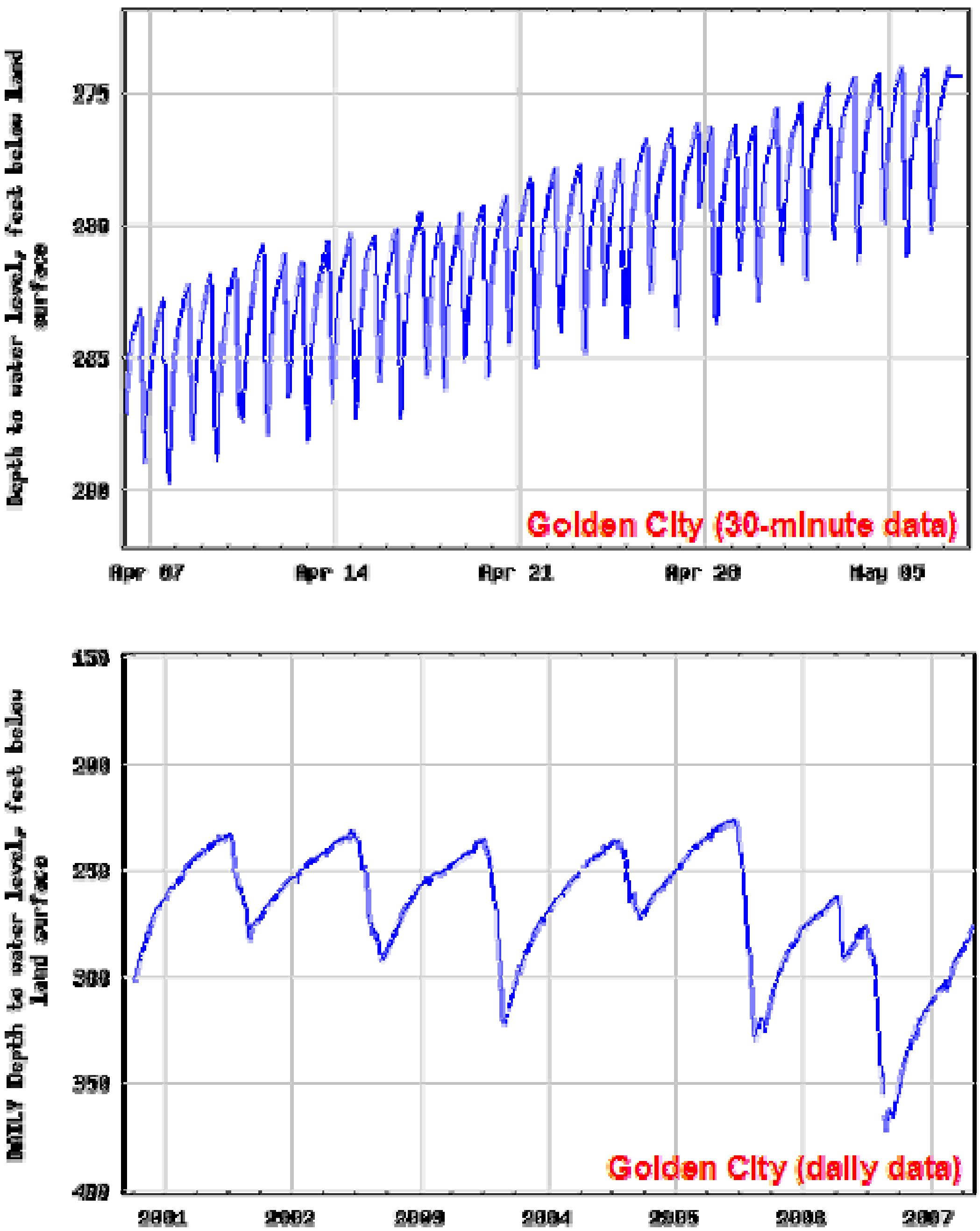


Figure 7. Daily water-level fluctuations due to nearby municipal pumping (top) and seasonal drawdown and recovery patterns resulting from extensive local irrigation (bottom) at Golden City

that helps supply the city of Springfield. Fulbright well #1, which was drilled in the early 1900s, produces about 2,100 gallons of water per minute. It is often pumped continuously several months or more. It was operated nearly continuously from May 2006 through December 2006. The McDaniel lake observation well recorded a water-level drop of more than 80 feet before pumping ended in early 2007. By May 1, 2007, water level had recovered 50 feet (figure 8).

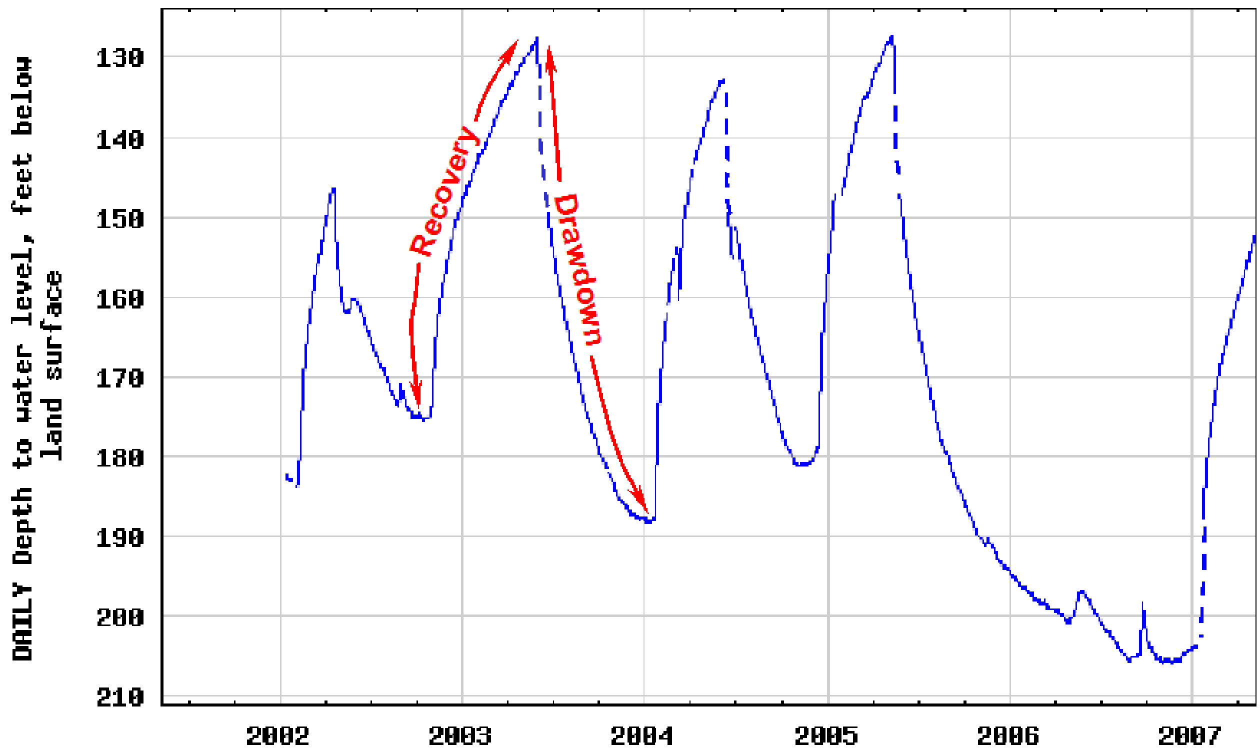


Figure 8. Hydrograph of the McDaniel Lake observation well showing the effects of nearby pumping.

A few of the observation wells have recorded long-term water-level declines that are due to groundwater use. The long-term hydrographs at Noel, Golden City, Dresden, Lamar, New Florence, Sedalia, Rolla (Ramada Inn), Bixby show long-term declines of from less than 50 feet to as much as 400 feet. The Festus observation well, however, shows just the opposite. Depth-to-water there was about 275 feet in 2000 when the well was equipped with recording equipment. Presently, groundwater-level in the observation well averages about 75 feet below land surface. The recovery in groundwater level in that area is due to a change in water supply sources. Much of the water formerly supplied by numerous deep wells producing from the Ozark aquifer is now supplied by surface water piped south out of St. Louis County into northern Jefferson County, and installation of a high capacity collector well in the Mississippi River alluvium at Festus.

Fluctuations Due to Atmospheric Pressure Changes

Rainfall is not the only weather factor that can affect groundwater levels. Changes in atmospheric pressure can also cause groundwater levels to fluctuate. Atmospheric pressure is caused by the Earth's gravitational attraction of air in the atmosphere. At sea level, the weight of the atmosphere exerts a pressure of about 14.7 pounds per square inch on the Earth's surface. This is equivalent to the pressure exerted by a column of mercury that is 29.92 inches high. Most weather forecasters report barometric pressure using the units "inches of mercury", but there are several other units that can also be including "feet of water". The weight of the atmosphere at sea level exerts the same pressure as a column of water 34 feet high. When discussing the effects of atmospheric pressure change on groundwater levels it is convenient to use feet of water as the units. To convert atmospheric pressure measured in "inches of mercury" to "feet of water", simply multiply it by 1.133. Atmospheric pressure decreases with altitude, so for weather reporting purposes it is corrected to what it would be at sea level, regardless of the elevation of the reporting station.

According to the National Weather Service office in Springfield, barometric pressure in that area is typically between 29.6 and 30.2 inches of mercury, but can be higher or lower during unusual weather conditions. Between November 2003 and May 2007 barometric pressure measured at Sanborn Field, University of Missouri- Columbia, reportedly varied between 29.21 inches of mercury and of 30.86 inches of mercury. However, most of the readings fell between 29.4 and 30.4 inches.

Changes in barometric pressure will cause water levels in some wells penetrating confined or semi-confined aquifers to change. The relationship is inverse. An increase in air pressure will cause water level in the well to fall, and a decrease in air pressure will cause water-level in the well to rise.

The air pressure applies a force to the entire land surface, including the water in the open well bore. An unconfined aquifer where the water table is essentially open to changes in air pressure will typically show little or no water-level change because the air pressure is the same on the water table as it is in the well bore. Air pressure above confined aquifers, especially confined bedrock aquifers that are very rigid, will not be transmitted through the confining unit, but it will exert a force on the water in the open bore of the well. The barometric efficiency of the aquifer is basically the ratio of the water level change in the well to the change in air pressure. For example, if the barometric pressure drops 0.4 inches of mercury (which is equivalent to a pressure change of 0.45 feet of water), and as a result the water level in a well rises 0.3 feet, the barometric efficiency of the well would be 0.67 or 67 percent. Barometric efficiencies generally are less than 80 percent.

More than one-third of the wells in the observation well network clearly show barometric tendencies. Passage of a strong high or low pressure system will generally generate water-level changes of from 0.2 to more than 0.5 feet in the wells. Figure 9 shows hydrographs of three widely separated observation wells, Jameson in Daviess County, Arrow Rock in Cooper County and Shelbina, in Shelby County. The three wells are about 100 miles apart, yet their short-term hydrographs are usually very similar. Also shown on both graphs is the barometric pressure measured at Sanborn Field, on University of Missouri-Columbia campus. The inverse relationship between barometric pressure changes and water-level changes is quite clear.   Other observation wells known to show barometric effects include Sedalia, Department of Conservation-Rolla, Wentzville, Ozark Fisheries, Coffey, Longview, New Florence, Osceola, Arrow Rock, Troy (1), Warrensburg, Desoto, Akers, Pomme de Terre State Park, Linn, South Jefferson County, Urich, Sullivan, St. Clair, Mexico, Lebanon, and Fredericktown.

Fluctuations Due to Aquifer Deformation

Water-level changes due to aquifer deformation are commonly due to either Earth tides, or earthquakes. Other external stresses caused by heavy trucks and trains can also cause groundwater fluctuations in some aquifers.

When most people think of tides, they immediately think of the change in sea level caused by gravitational attraction of the Sun and Moon along with other factors. The tidal effects on groundwater, commonly called Earth tides, have nothing to do with the oceans, but are related to

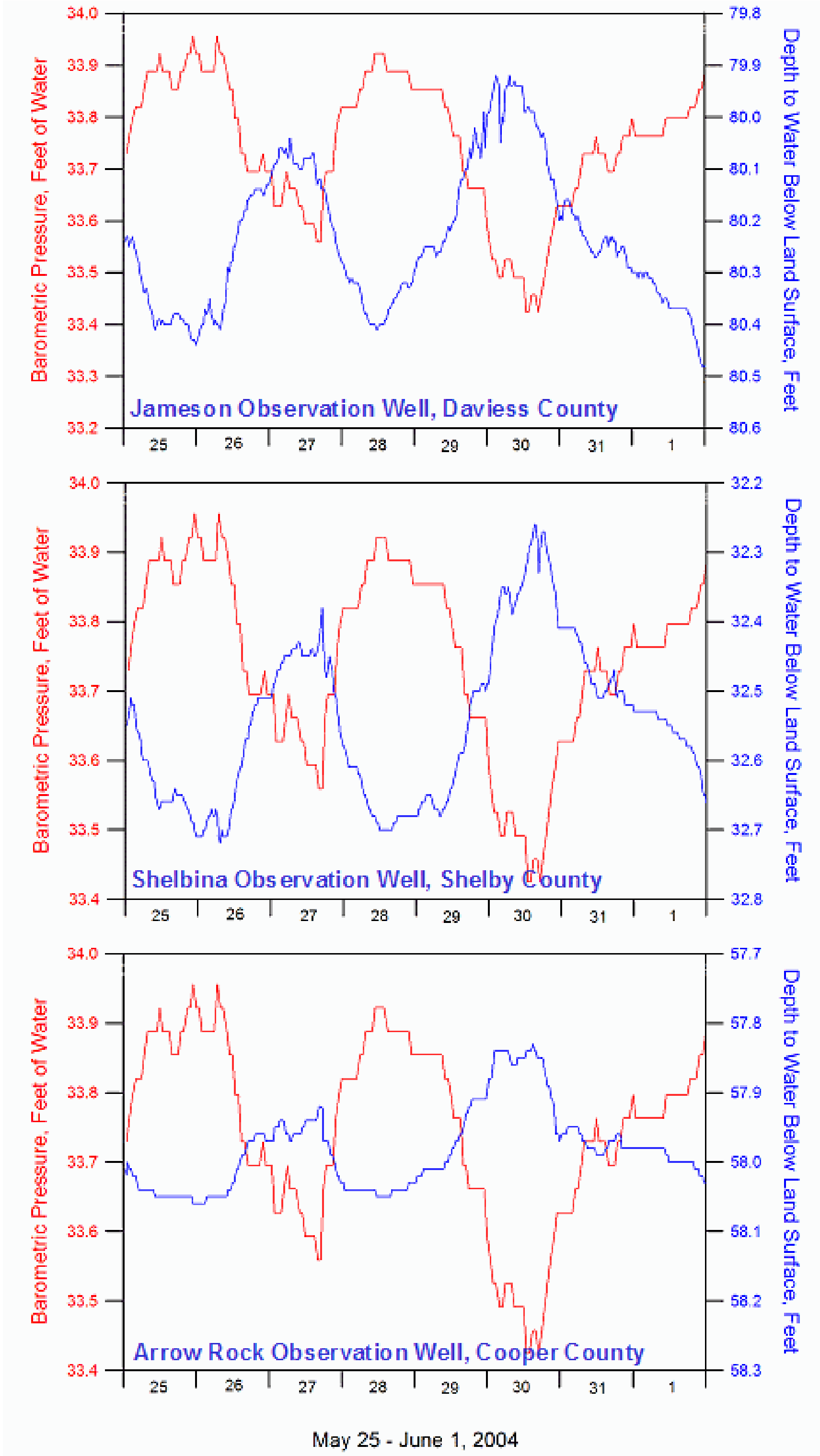


Figure 9. Hydrographs of Jameson, Shelbina, and Arrow Rock observation wells (blue) and barometric pressure at Sanborn Field, University of Missouri-Columbia (red) showing the effects of barometric pressure changes on groundwater levels.

the gravitational effects of the Moon and Sun. Changes in gravitational attraction causes a slight dilation of some aquifers, which in turn temporarily changes the aquifer porosity a slight amount. Wells showing tidal effects show two maximum and two minimum water levels each day, each of which are about 6 hours apart. The minimum measurements occur when the Moon is either directly overhead, or on the opposite side of the planet. The strongest effects are seen at New Moon, when the Moon is directly between the Earth and Sun, and at Full Moon when the Earth is between the Sun and Moon. At First Quarter and Third Quarter phases, when the Moon is at a right angle with respect to the Earth and Sun, the cycles become very poorly defined.

Water-level fluctuations due to tidal effects are generally small, in the range of 0.2 to 0.4 ft. Figure 10 is hydrograph of the Aurora Observation well showing water-level changes for a month. The phases of the Moon are also indicated on the graph. Many of the observation wells show at least some effects of Earth tides. They are generally wells that are not significantly influenced by more major factors such as nearby pumping. Observation wells that commonly show tidal effects include Mexico, Lamar, Columbia, McDaniel Lake, Ozark Fisheries, Springfield-Valley Park, Urich, Akers, Fairview, West Plains, Pomme de Terre, Warrensburg, Aurora, Troy (1), Fredericktown, New Florence, Linn, National Lead, Sedalia, Wentzville, Cooper Creek, St. Clair, Drake, South Jefferson County, Department of Conversation-Rolla, and Marshfield. The graphs showing tidal effects the best are generally from wells that are not being influenced in other ways. Wells that ordinarily display tidal effects, but whose water levels are changing much more than a few tenths of a foot per day because of nearby pumping, groundwater recharge, etc., lose the smooth sine-wave curve characteristic of tidal effects.

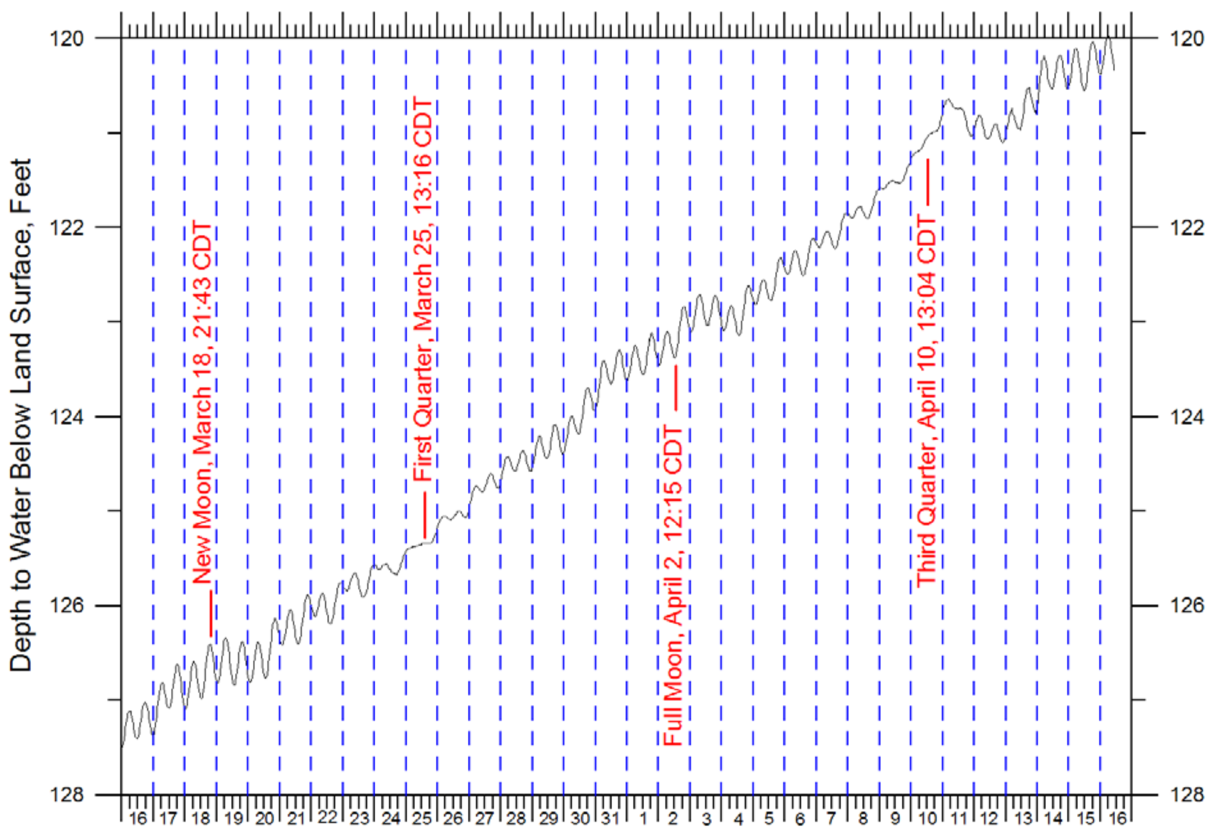


Figure 10. Tidal effects, Aurora observation well, March 16 to April 16, 2007.

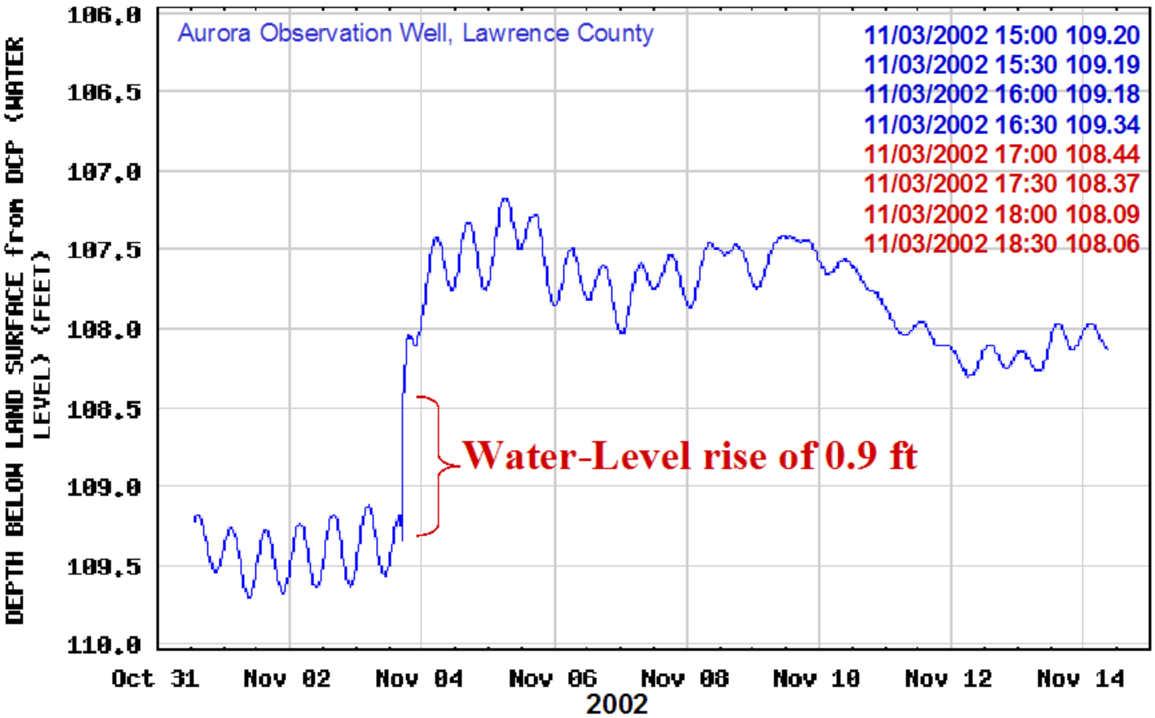
Groundwater levels can be affected to a small degree (a few hundredths of a foot) by the weight of passing trucks or trains, provided they are close enough to the well. Many years ago the observation wells were equipped with graphic recorders that used paper, pen, and ink to record the water-level hydrograph. Any change in water level more that a few thousandths of a foot was instantly recorded on the paper chart. The chart paper advanced through the recorder at the rate of 1.2 inches each 24 hours. Events like passing trains and heavy trucks were so short that the hydrograph change appeared as small vertical lines just above the normal water-level line. Data are collected today each 30 minutes, so even if a passing heavy truck or train affects water level in the well the chances of recording that change are slight. At one time, a rail line passed within 100 feet of the Delta observation well. The Malden observation well, which is actually a few miles south of Malden, is at the edge of a highway right-of-way. When a heavy vehicle passes water level in the well will rise a few hundredths of a foot as the truck passes, then return to its previous level.

Earthquakes cause some of the most dramatic stress-related groundwater-level fluctuations that are observed. Seismically induced water-level fluctuations, also called hydroseisms, are commonly observed following major earthquakes. Energy released by earthquakes travels great distances in the form of several different types of waves. Wells relatively close to a major earthquake may experience permanent water level changes but typically the earthquake causes water level in a well to fluctuate for perhaps a few minutes then return to normal level.

The pen and ink chart recorders discussed above were able to measure the water-level fluctuations caused by earthquake much more completely than the digital equipment used today. When the Good Friday Earthquake occurred in Alaska in 1964, its effects on groundwater were felt essentially world-wide. At that time, the observation well network in Missouri consisted of 38 observation well, 28 of which recorded at least some water-level oscillation following the earthquake. Some of the fluctuations were only a few hundredths of a foot, but the Lamar observation well fluctuated about 10 feet and a now-discontinued observation well at Springfield saw more than 20 feet of water-level changes.

Even though the equipment currently in use records water levels every 30 minutes, the effects of earthquakes are still seen. A November 3, 2003 earthquake in Alaska was detected at several observation wells, but most notably at Aurora and National Lead. Aurora observation well in Lawrence County saw a water-level rise of about 0.9 foot, while water level at National Lead in Perry County dropped 1.95 feet (figure 10). The December 26 Earthquake (6:58 PM December 25 central standard time) off of the northern coast of Sumatra caused groundwater level fluctuations in eight of 73 observation wells. Aurora observation well recorded the maximum change, about 0.71 feet (figure 11).

The groundwater-level hydrograph patterns described above will help those using this information to recognize basic hydrograph shapes and to understand the factors that cause them. Many wells can show multiple patterns. For example, it is not uncommon to see the tidal effects in wells that also show barometric tendencies. In figures 10 and 11, the earthquake effects are visible at wells also showing tidal effects. Small-scale changes caused by tidal effects, earthquakes and barometric pressure changes are discernible in the real-time (30 minute collection interval) data. Daily data best shows other effects such as nearby water use.



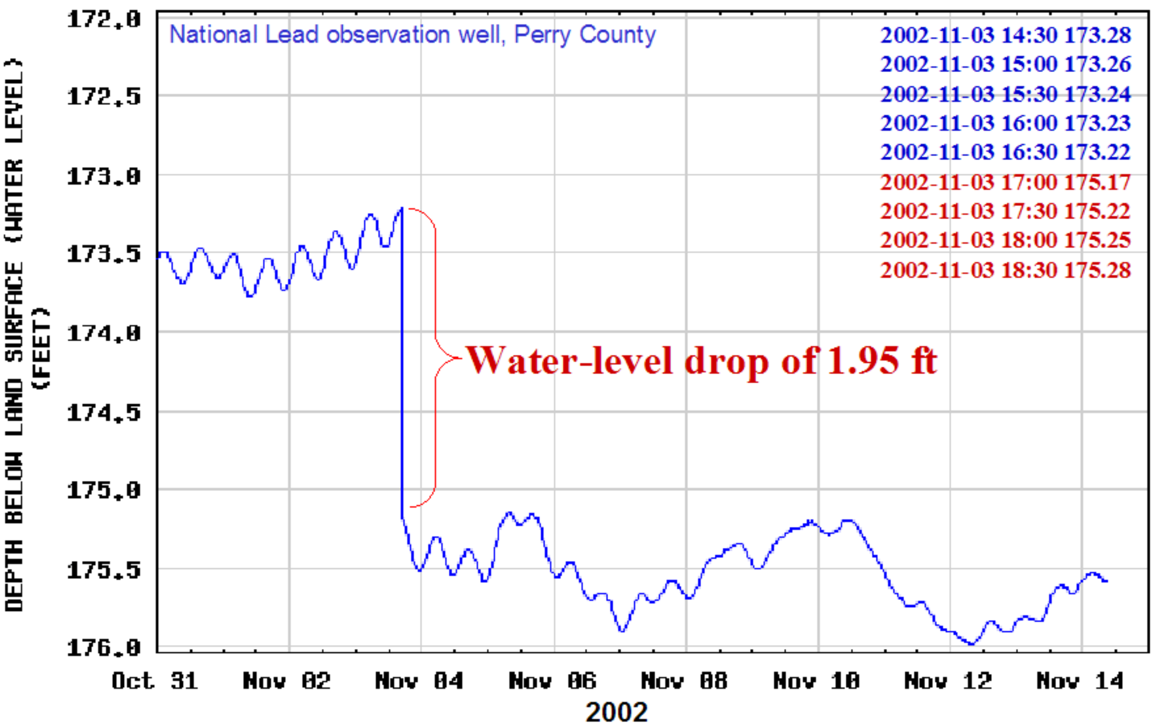


Figure 10. The effects of the November 3, 2002 Alaskan earthquake on water levels at Aurora observation well (top) and National Lead observation well (bottom).

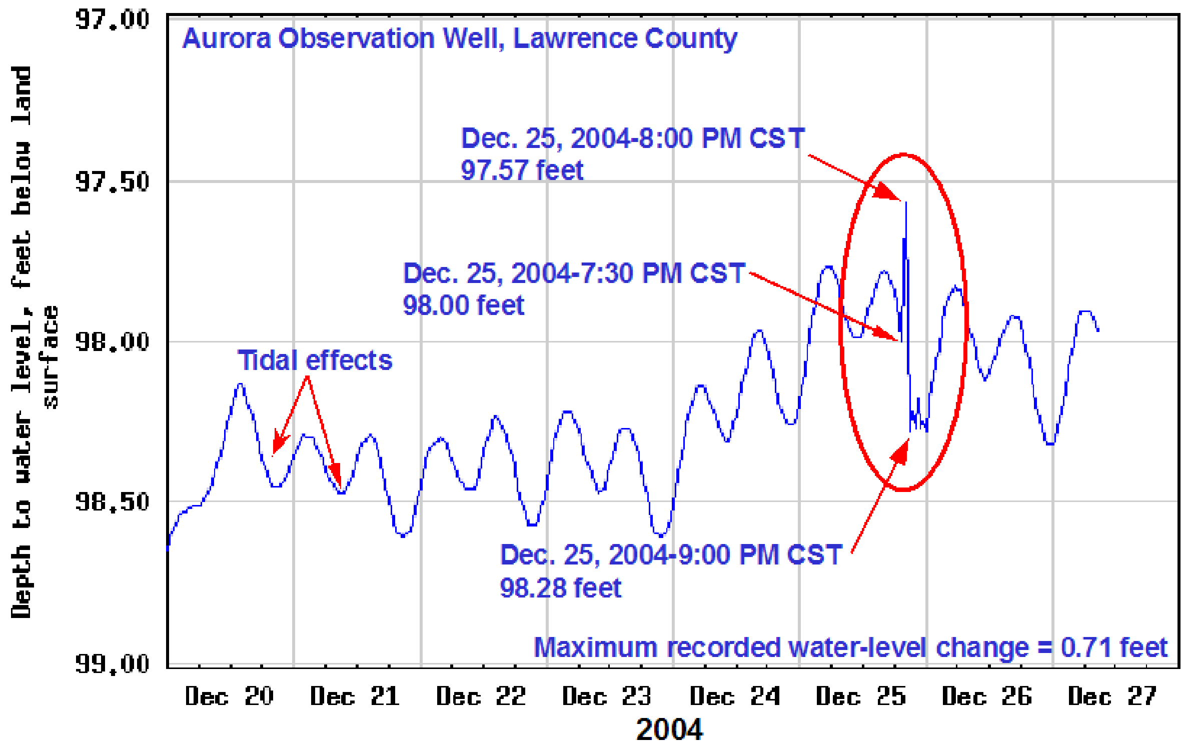


Figure 11. The effects of the December 2004 Sumatra earthquake on water level at the Aurora observation well.