Report on Effects of Groundwater Withdrawal from the Doghouse Meadow, Yosemite National Park

William E. Sanford
Department of Geosciences
Colorado State University

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Purpose

The purpose of the work reported below was to study the effects of groundwater withdrawal from Doghouse Meadow. The approach taken was to use a numerical model (VisualMODFLOW) to estimate the effects of 20 years of pumping from the Doghouse Meadow Well (DHM) and to model the potential effects of various pumping scenarios for both wet and dry years. Due to the fact that the meadow is essentially re-filled with water from snow melt each year, it was not possible to model 20 years of withdrawals as during that period there were both wet and dry years.

Various water withdrawal scenarios were modeled for wet and dry years. Heavy pumping from DHM resulted in the water level in the meadow being significantly lowered during both dry and wet years. Scenarios where the pumping is less severe still show a drop in water levels but not significantly below what has been modeled as natural water levels decline during dry years.

Methods

The model used in this study was VisualMODFLOW version 4.1 from Waterloo Hydrogeologic. The first steps of the project were to define the model domain, input surface elevations, create subsurface layers to represent the hydrostratigraphy of the meadow, and to assign representative hydrologic parameters to each layer.

The model domain was selected using a topographic map of the site overlain on an air photo, each using UTM coordinates (Figure 1). The area shown in Figure 1 then imported into the modeling package and a grid system was created. The surface topography was created by estimating elevations from the topographic map and assigned to points on the grid. Elevations for the meadow itself were from information provided by the Park Service for each of the existing monitoring wells in the meadow. The point values of elevations were then kriged to produce the topography of the area used in the model (Figure 1). The next step was to create the area to use as the model domain. The area chosen started just to the south of Tioga Road and incorporated the springs to the west and continued south to near where the meadow as outlined on the topographic map ended (Figure 2).

Once the model domain was outlined, the next step was to create subsurface layers which represent the layers present in the meadow. It was decided to use 2 layers. The upper layer represents a combination of peat and soil and the lower layer represents the decomposed granite found in the upper part of the underlying bedrock (granite). Only the decomposed granite was used because it was determined by Todd Engineers from a packer pumping test that water removed from the 400-ft deep DHM was coming from above 91 ft depth (Todd Engineering Technical Memorandum dated September 28, 2005). Hydrologic parameters necessary to estimate the effects of pumping from the meadow were assigned to each layer. For the lower layer (decomposed granite) the hydraulic conductivities were based on existing aquifers tests: 10^{-4} m/s for horizontal hydraulic conductivity and 10^{-5} m/s for the vertical hydraulic conductivity. Estimates of storage parameters were assigned to the lower layer: specific storage of 10^{-5} m^{-1}, specific yield of 0.2, effective porosity of 0.25 and total porosity of 0.3. The lower layer was modeled as a semi-confined layer. For the upper layer (peat/soil) all hydrologic parameters were estimated based on the author's professional judgment: horizontal hydraulic conductivity of 10^{-6} m/s, vertical hydraulic conductivity of 10^{-7} m/s, specific storage of 0.001 m^{-1}, specific yield of 0.05, effective porosity of 0.20 and a total porosity of 0.3. The values chosen were calibrated to the results of water level responses in wells measured during the existing pumping regime.

It was necessary to assign layer thicknesses to determine the subsurface topography. Limited data is available so values were assigned to the upper layer based on data for the monitoring wells provided by Dr. David Cooper and Evan Wolf. The bottom topography of the lower layer was estimated from a driller's log for DHM included in the Todd Engineering report mentioned above. This was only one point so the author estimated elevations elsewhere by assuming that the meadow is located in a bath-tub-like configuration with the deepest portions below the meadow and the layer thinning away from the meadow as a subdued replica of the surface topography.

To run the model boundary conditions must be assigned all around the model domain. Several attempts were made to assign recharge values to the northern portion of the model to represent inflow from the area of Crane Flat located north of Tioga Road and to estimate recharge from the springs located along the western edge limb of the domain. This was unsuccessful as there is limited information on these values. Data was provided by the Park Service on seasonal water level fluctuations in monitoring wells 42 and 47 located at the northern and southern ends of the domain, respectively for both dry and wet years (2004 and 2005, respectively). The boundaries at the northern and southern ends were modeled as time varying water levels for dry and wet years; these values will be discussed below. To represent the springs located at the western limb, a constant hydraulic head was assigned to a line located several meters to the springs for wet years and the levels varied for the dry years. This was decided upon based on the information that the springs flow at a relatively constant value. All other boundaries of the domain were treated as no flow boundaries.

Estimates of the Effects of Pumping

To estimate the effects of water withdrawals from DHM on water levels in the meadow, various pumping scenarios were created for models using boundary conditions representing wet and dry years. For both wet and dry years, the water levels at the northern and southern boundaries started at a high level representing the conditions of the site being saturated due to snow melt. The water levels then decline over a 90-day period (termed growing season form here on), then increase back to the higher levels to represent the increased input from snow melt. For the wet years, the water levels at the northern boundary fluctuate 1 m over the growing season and 0.5 meters at the southern boundary. For the dry years, the northern water levels fluctuate 1.5 meters and the southern levels also fluctuate 1.5 meters. Along the western limb, a single value of hydraulic head was used for the wet years; for the dry years, the water levels fluctuated 2 meters. These head values were used in the model to generate water levels for the meadow, which show a very low hydraulic gradient from the north to the south, as is necessary for a wetland which has formed peat.

Pumping Scenarios

Several pumping scenarios were tested to estimate the effects on water levels within the meadow for the wet and dry year models. The various scenarios are listed in Table 1.

Table 1. Various Pumping Scenarios Tested in the Model

Scenario	Description
1	8 hrs pumping at 125 m^3/day (25 gpm) for 5 days followed by 2 weeks of recovery, then repeated for the 90-day growing season.
2	24 hrs of pumping at 50 m^3/day (10 gpm) for 5 days followed by 2 weeks of recovery, then repeated for the 90-day growing season.
3	8 hrs pumping at 125 m^3/day (25 gpm) for 3 days followed by 2 weeks of recovery, then repeated for the 90-day growing season.
4	24 hrs of pumping at 50 m^3/day (10 gpm) for 3 days followed by 2 weeks of recovery, then repeated for the 90-day growing season.
5	8 hrs pumping at 75 m^3/day (15 gpm) for 3 days followed by 2 weeks of recovery, then repeated for the 90-day growing season.

For each scenario, Doghouse Meadow well was used as the pumping well. In the model, the open section of DHM was placed within the lower layer (decomposed granite). Modeled water level changes were monitored in wells corresponding to the following monitoring wells which exist in the meadow: 42 – this is a piezometer located within the upper part of the lower layer and is used to calibrate the response of the model at the northern end; 46 – this is a well located in the upper portion of the lower layer and is used to calibrate the model response at the southern end; 49 – a piezometer located in the lower layer which is located near DMH and is used to calibrate the response of the model in the lower layer and to confirm that the hydraulic parameters assigned to each layer are representative of the actual system; 3 – a well located at the same location as 49 and is used to monitor the overall water level decline in the meadow (see Figure 2 for well locations). Model well 3 is used as the main location to discuss the overall effects of water withdrawals since it is located near the middle of the meadow.

The modeling was done as if there were two conditions – an extreme wet year and an extreme dry year. Each model run for the scenarios included several years before pumping in order to estimate the effects of the wet and dry years on water levels in the meadow. Although no data were available for these conditions, increased water level declines for the pumping regimes were compared to what is termed in the following as “natural” water level fluctuations. As mentioned above, the modeled growing season was 90 days but the pumping scenarios started at the peak water levels which can be considered to be late June or early July; therefore, the relative water level changes are a valid estimate of the pumping situation at the site.

Assuming that more water is available during the wet years, scenarios 1 and 2 were used. Assuming less water available during dry years, scenarios 3 and 4 were used. After the water level responses for these model runs were compared, scenarios 3 and 5 were used with the wet year conditions and scenario 5 was used with dry year conditions.

Note: For this modeling, surface water was not included. It is relative changes in water levels that are examined. Actual water levels measured at locations were made relative to ground surface. I looked at level changes as a whole so, for example, water levels that changed from 0.1 m above ground surface to 0.9 m below ground surface are compared to a 1.0-m water level drop in the model results.

Results

I was given periodic water level measurements for monitoring wells 42 and 46 and well nest A-2 taken during dry (2004) and wet (2005) conditions. I used these responses to compare those that were generated by the modeling. For these 3 locations, the measured water levels cannot be considered the natural response to the different amounts of water but include the effects of water withdrawals. The model well 3 represents well nest A-2.

In the section below, I will first present the modeling results for one pumping cycle at well 49 and compare those to the measured response at well 49 to pumping. Following this, I will present the modeling results for all scenarios for model wells in the following order: 42, 46, and 3. In this discussion I will also include measured responses for the corresponding real wells.

Well 49

Well 49 is a piezometer screened within the decomposed granite near DHM. The water level responses (Figure 3) are indicative of a confined aquifer in that the hydraulic heads drop very soon after pumping starts and recover quickly once the pumps are turned off. Measured water levels for the dry year (2004) are in Figure 4 and for the wet year (2005) are in Figure 5. Note how the quick response seen in the modeled water levels are also seen in both measured years. The water level declines for each individual 8-hr pumping cycle for each of the pumping rates used in scenarios 1 and 3 are similar to those seen for the actually pumping regime used at the site (Figure 3 compared to Figures 4 and 5). There is a better correspondence to those seen in 2004 since there was no surface water present and the model does not incorporate surface water. The close match of modeled and measured responses to pumping indicates that the hydrologic parameters assigned to the two layers are representative of the system. Note the much greater seasonal water level decline in the dry year (Figure 4) then in the wet year (Figure 5).

Well 42

The modeled water level responses at well 42 for the various scenarios are plotted in Figure 6. Both axes on this and all the following water level graphs are relative – it is the variations in levels with time that are important. The pumping scenarios start at the peak water levels on model day 1440 , which can be thought of as the first day that pumping from DHM occurs (late June – early July). Plotted on the graph are vertical lines marking the relative elapsed time since pumping started – the first line on the left denotes when the pumping starts and each line is separated by 30 days. At this time I will not discuss the results of the individual pumping scenarios for well 42 except to note that the effects of the individual pumping cycles are minimal.

The measured water level responses for well 42 for both the dry (2004) and wet (2005) years are presented in Figure 7. A comparison of the modeled water declines to those measured are a check on the relative accuracy of the boundary conditions. For the dry years, the modeled water levels match those measured quite well (compare Figure 6 to Figure 7a) in that there are similar water level declines at 60 days (~60 cm) and 90 days (~80 cm). For the wet year, the modeled water levels decline more over the first 60 days after the start of pumping than for scenarios wet-1 and wet-2 (compare Figure 6 to Figure 7b). This is a result of the model not accounting for surface water. Notice that when the water levels in well 42 reach the ground surface, they decline at a similar rate as that modeled.

Well 46

The water level responses modeled for well 46 are presented in Figure 8 and the measured responses are presented in Figure 9. For the dry years (Dry-4 and Dry-5) the modeled and measured water levels dropped 20 cm after 30 days, 50 cm after 60 days and 75 cm after 90 days (compare Figure 8 to Figure 9a). The modeled water level responses for the wet years again decline faster than those measured (compare Figure 8 to 9b) but as for well 42, once the water level reaches the ground surface, the rates of decline are similar.

The close match of the modeled water level responses to those measured in wells 42, 46, and 49 indicate that the hydrologic parameters and the boundary conditions are representative of the meadow.

Well 3

Well 3 is located near well 49 and is in the middle of the meadow. The response of the water levels in this well are considered to be the most important as it is located in the thickest development of peat. Well 3 is a fully screened well, which is the reason that the individual short-period pumping cycles seen in well 49 are not seen here (Figure 10). The National Park Service supplied water level measurements at a location in the meadow – Well Nest A-2 – which is at the location of well 3 (Figure 11). The modeled water levels responses at well 3 are in good agreement with those measured in Well Nest A-2 (compare Figure 10 to Figure 11). For the dry year (2004), when the May snowpack was only 34% of average, the modeled water levels declined 25 cm, 55 cm and 80 cm after 30, 60, and 90 days, respectively. For the same period, the measured water levels declined 40 cm, 80 cm and 100 cm. For the wet year (2005), when the May snowpack was 230% of average, the modeled water levels at 30 and 60 days fell 20 cm and 30 cm, respectively, and the measured levels fell the same.

Modeled Water Levels with no Pumping

There is no data available on how the water levels in Doghouse Meadow fluctuate during dry and wet years when there is no pumping from DHM. I estimated the response by running the model for several years with the same conditions as the dry and wet years but with no pumping. The results are seen in Figure 12. For the dry years there is a water level drop of over 60 cm, while for the wet year, the water levels dropped less than 10 cm over the growing season. This confirms what is expected in the annual variations water input into the meadow controls water levels. The large drop seen for the dry year is not unexpected and the peat can withstand this as long as the drops of this magnitude happen only once or twice a decade (Dr. David Cooper, personal communication). I modeled extreme dry and wet years so a normal year with average May snowpack will produce water level fluctuations in the meadow that will be between those seen in Figure 12.

Discussion

In this section I will compare water level responses at well 3 for the various pumping scenarios to the modeled response when there is no pumping. To do this, I created Table 2 which is a comparison of the timing and magnitude of modeled water levels changes between the various pumping scenarios and the no-pumping "normal" years.

Table 2. Comparison of the modeled water level declines versus time for the various pumping scenarios. 0.1 m = 10 cm = 4 inches

Elapsed Time from start of water level declines (days)	Wet Year no pumping (meters)	Wet Year Scenario 1 (meters)	Wet Year Scenario 2 (meters)	Wet Year Scenario 3 (meters)	Wet Year Scenario 5 (meters)
30	0	0.17	0.19	0.11	0.06
60	0.03	0.30	0.32	0.22	0.14
90	0.05	0.38	0.43	0.33	0.25
	Dry Year no pumping (meters)	**Dry Year Scenario 3 (meters)**	**Dry Year Scenario 4 (meters)**	**Dry Year Scenario 5 (meters)**	
30	0.17	0.22	0.24	0.19	
60	0.40	0.58	0.54	0.52	
90	0.58	0.84	0.81	0.75	

Scenarios wet-1 and wet-2 produce water level changes that are similar. These changes are significant when compared to those modeled with no pumping. After 90 days, the “natural” water level fell by only 5 cm while for both wet-1 and wet-2, they fell by over 15 cm in just the first 30 days, and nearly 40 cm after 90 days. For the dry year, scenarios dry-3 and dry-4 both increase the magnitude and rate of the water level decline compared to the “normal” year (Table 2). However, for no pumping and for dry-3 and dry-4 scenarios (pumping and no pumping) the water levels fell by ~20 cm after 30 days. It is not until after 60 days of pumping that the difference is significant.

For scenarios dry-3 and dry-4, water was removed from the meadow at rates of about 225 m^3 and 300 m^3 per month, respectively (60,000 and 80,000 gallons). **Note: I am considering 1 month to consist of two pumping cycles and two 2-week recovery periods.** I created a fifth scenario (Table 1) to model the effects of a lower extraction rate during the dry year. Scenario 5 is similar to scenario 3 in that the pumping is for 8-hrs a day for 3 days followed by 2 weeks of recovery. The difference is that for scenario 5 the pumping rate was lowered from 125 m^3/day to 75 m^3/day (25 gpm down to 15 gpm). The monthly extraction rate for scenario 5 is ~135 m^3 per month (36,000 gallons). Using scenario 5 for the dry year did not improve the situation (Figure 10 and Table 2) and the water level declines are similar to the other scenarios. The “natural” rate of water level decline is so great during the dry year that the extraction of water at any rate will increase the magnitude of the decline.

The large water level decreases during the dry years are unavoidable, even without pumping. It is the potential level drops during wet year pumping that can be modified. During a dry year (not as extreme as modeled) water levels in the meadow probably drop about 30 cm below ground surface. Since a dry year may happen twice a decade, this is most likely not harmful to a peat body (David Cooper, personal communication). However, if extracting water from Doghouse Meadow can lower water levels at the thickest portion of the peat during wet years by nearly 30 cm after 60 days (wet-1 and wet-2; Figure 10 and Table 2) as modeled, it is similar to having several dry years in a row. For scenarios wet-1 and wet-2 water was removed at around 425 m^3 and 500 m^3 per month, respectively (110,000 and 130,000 gallons), which are conditions similar to those currently in use. To model the effects of a reducing the rate of water extraction, I used scenarios 3 and 5 with the wet year conditions (wet-3 and wet-5; Figure 10 and Table 2). Scenario wet-3 (225 m^3 or 60,000 gallons per month) resulted in water levels that were about 30% higher after 30 days of pumping than those modeled in wet-1 and wet-2. For scenario 5 (135 m^3 or 36,000 gallons per month) water levels dropped only one-third as much as for wet-1 and wet-2 after 30 days and one-half as much after 60 days.

Summary

For the modeling of the extreme wet year conditions, the effects of surface water are not incorporated. The measured water levels for the wet year (2005) clearly show that the was up to 10 cm of surface water on a significant portion of the meadow until the end of July and beginning of August. The model results are a more accurate representation of the system starting at the time the water levels are at the ground surface. After this time, it would take over 30 days of pumping at the rates of scenarios 1 and 2 to lower the water level 20 cm. This all suggests that for the wet, even average, years, the higher pumping rates can be used earlier in the season when surface water is present, and then the rates should be decreased towards those of scenarios 3 or 5 as the water levels drop below ground surface. Continued pumping at the higher rates after this time could potentially produce a drop in water levels in the peat body that would be similar to those of a dry year.

For the dry year, measured water levels were seen to decline very early in the season and were nearly 50 cm below the ground surface at the beginning of July. The modeling suggests that there is really no water extraction rate that will not exacerbate the situation. However, because the water levels will be dropping naturally, pumping rates lower than those of scenario 5 could be used with out significantly worsening what would happen naturally. It will be important to pay attention to pumping rates during wet years so that dry-year conditions are not reproduced several years in a row, then having an extreme dry year such as 2004 resulting in permanent peat loss.

<u>Suggested Pumping Schedules to Minimize Peat Exposure</u>

Modeling of water availability in Dog House Meadow was conducted on the basis of data collected during 2004 and 2005, extremely dry and wet years respectively. The following is a summary of water withdrawal that could occur under these conditions without having an adverse impact on the meadow and associated wetland. It should be noted that the volumes stated below are approximate values and any pumping regime that is adopted must be accompanied by monitoring of water levels in the wetland to allow adjustment of the pumping schedule.

During a year such as 2005, an extremely wet year with high April and May snowpack, scenario 3 provides adequate protection to the wetland. This scenario allows for the production of ~70000 gallons per 28 day period. During such years, higher production rates may be feasible while there is surface water present in the wetland. Once surface water is no longer present, however, pumping rates would have to be reduced to the level stated above.

During a year such as 2004, an extremely dry year with very low April and May snowpack, scenario 5 provides adequate protection to the wetland. This scenario allows for the production of ~40000 gallons per 28 day period. Once surface water is no longer present, pumping at this rate for more than 60 days would likely have an adverse effect on the wetland. Close monitoring of water levels in the wetland would be required to inform acceptable pumping rates.

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Recommendations

To protect Doghouse Meadow from the effects of over pumping, planning of the pumping schedule early in the season needs to be undertaken. It is clearly seen in the inter-annual water level comparisons (Figure 11) that the percent of average snow pack is a possible metric to determine whether there will be a wet, dry, or normal year for water input into the meadow. Caution is needed in that there may be increased early season runoff which will result in what may appear as a possible wet year turning into a dry year. To develop this metric, it is recommended that a data base be developed and updated annually which relates the May snowpack to the magnitude and timing of water level changes in the meadow. This is much like what water districts do to predict how much water will be available to the users downstream.

Another management step would be to periodically monitor water levels in Well Nest A-2. The modeling suggests that water levels start to decline relatively quickly even during wet years once the water levels drop below ground surface and the pumping rates need to be adjusted.

There are several pieces of information needed to improve the modeling of the impacts of water withdrawal from the Doghouse Meadow well on the peat body in the meadow. These include: 1) a better determination of the thickness of the decomposed granite, which is the major aquifer in the system; 2) seasonal changes in the inflow of water from the springs located in the western limb of the meadow should be measured; 3) a better estimate of water inflow from the portion of Crane Flat located north of Tioga Road; and 4) measurements of surface water flow at the southern end of the meadow should be made.

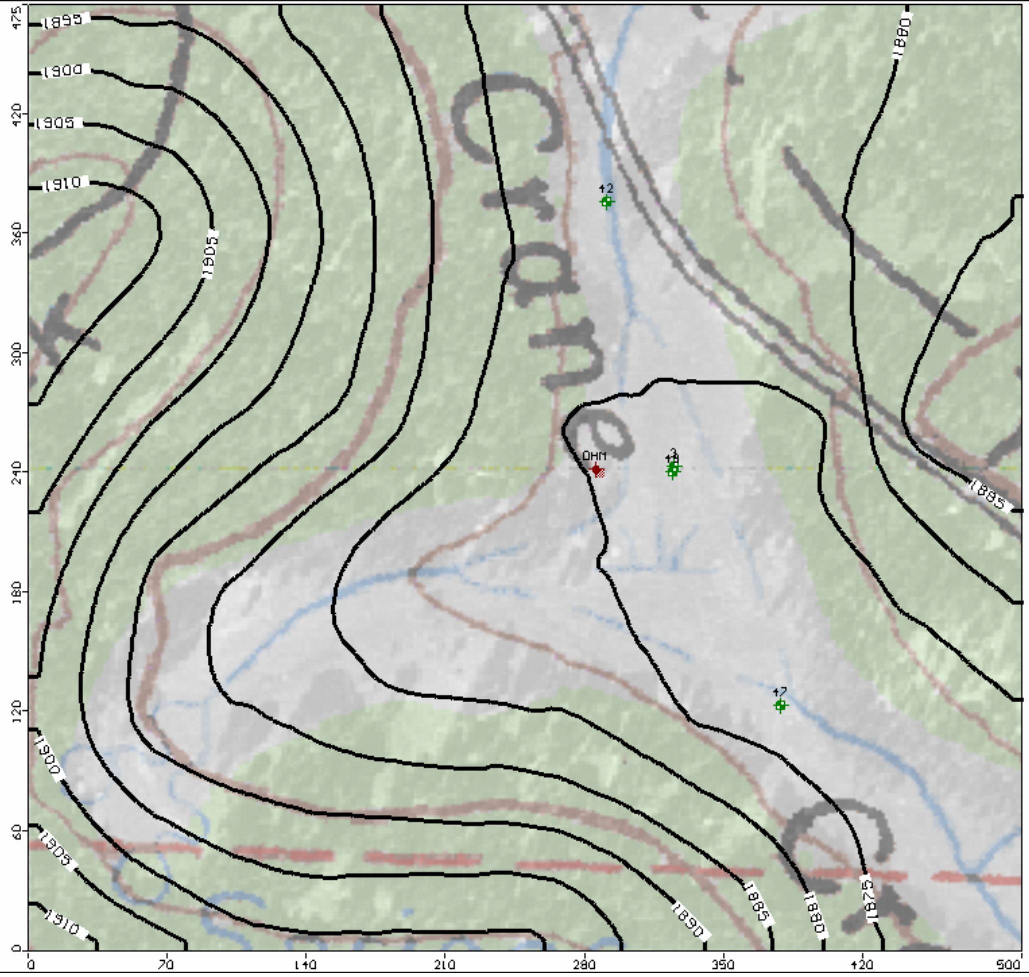

Figure 1. Base map of Doghouse Meadow showing surface contours and well locations. Contour interval is 5 meters.

Figure 2. Modeling Domain.

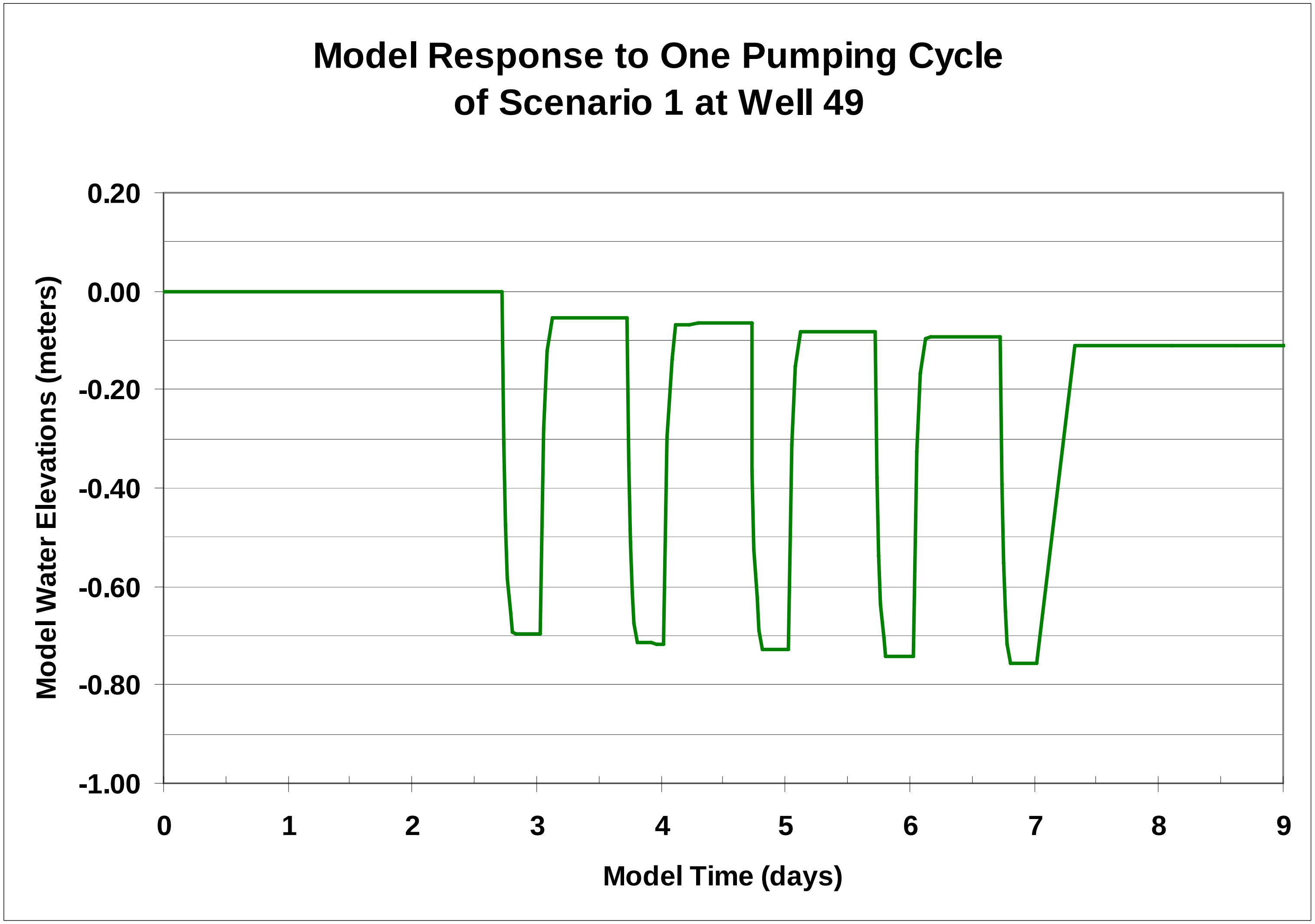

Figure 3. The modeled water level response at Well 49 for one pumping cycle.

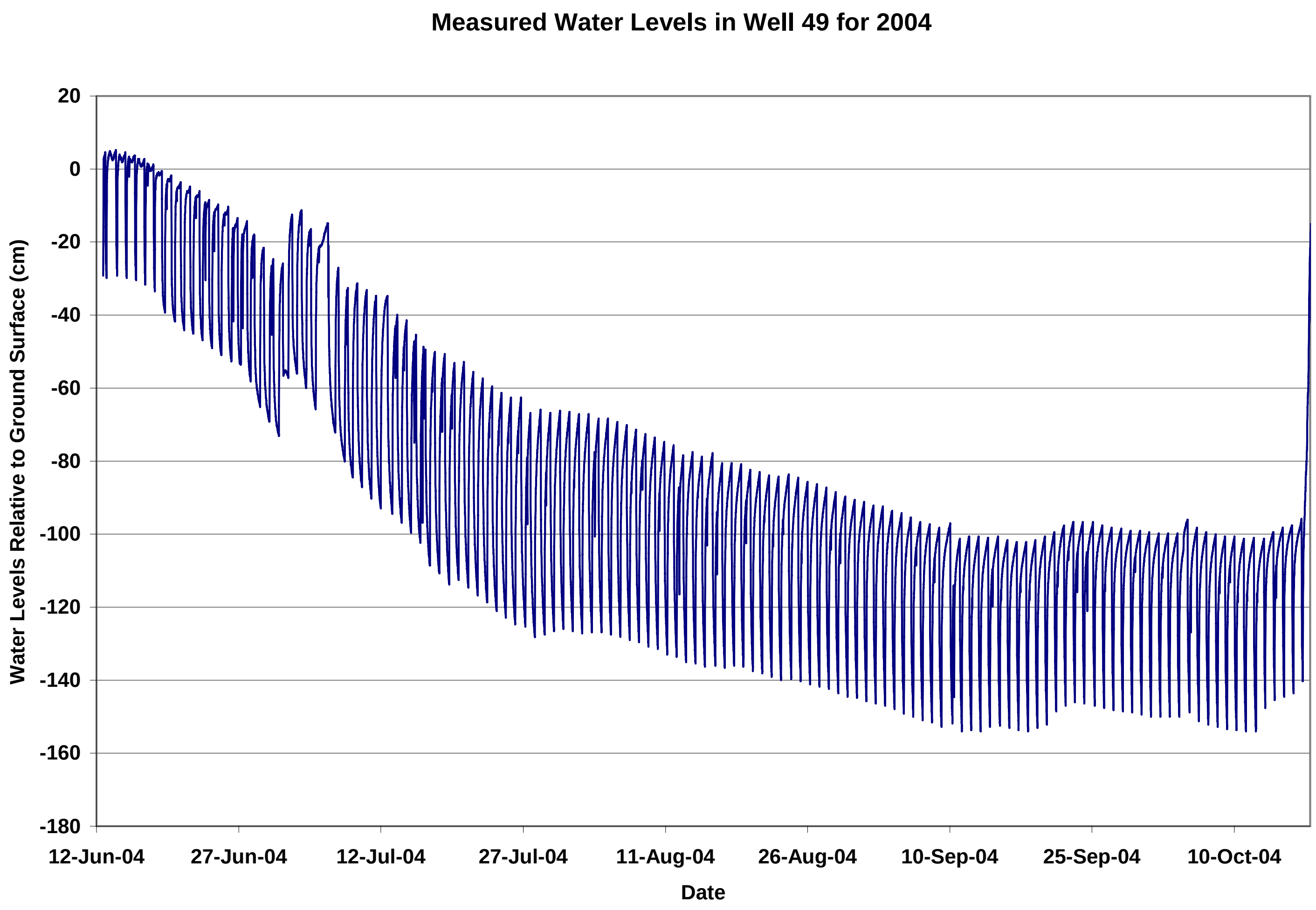

Figure 4. Water levels in Well 49 for dry year 2004. Levels measured with a pressure transducer. Data provided by NPS.

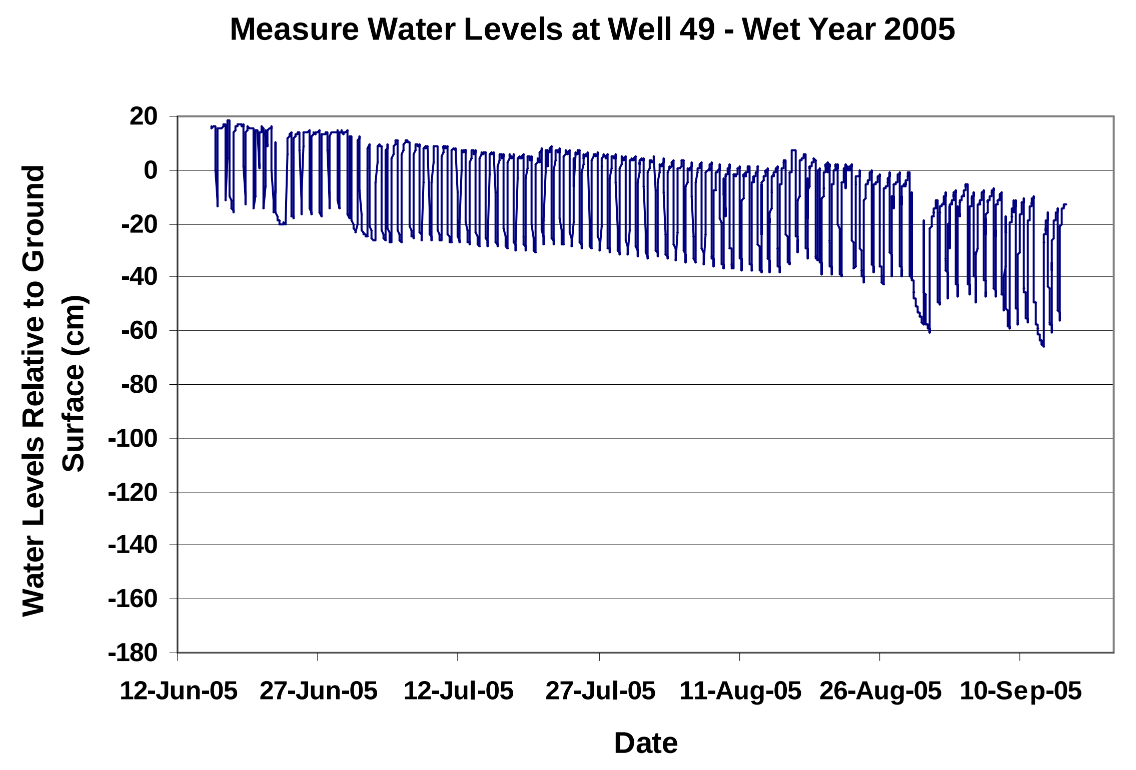

Figure 5. Water levels in Well 49 for wet year 2005. Levels measured with a pressure transducer. Data provided by NPS.

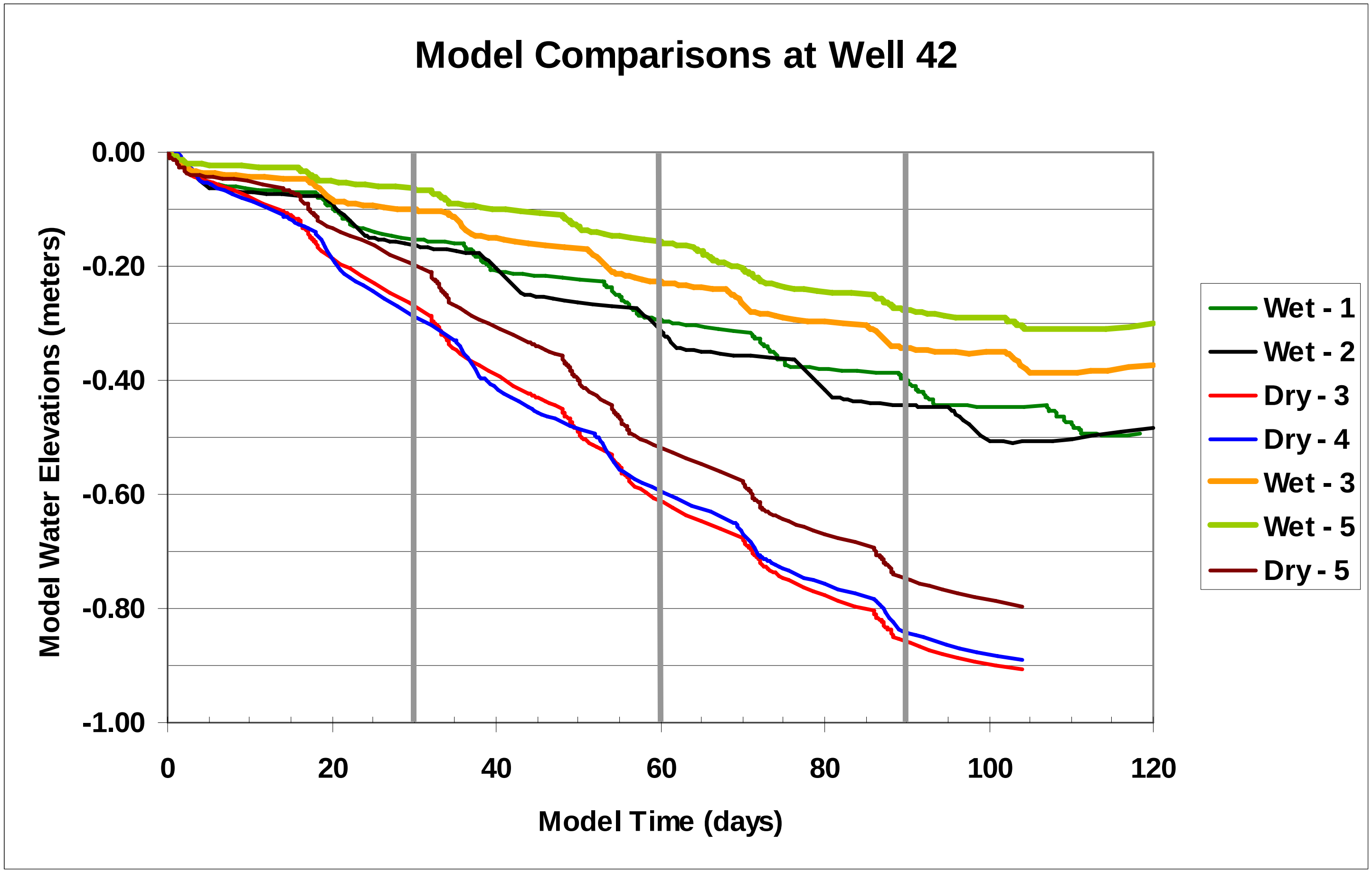

Figure 6. The modeled water level responses at well 42 for the various pumping scenarios.

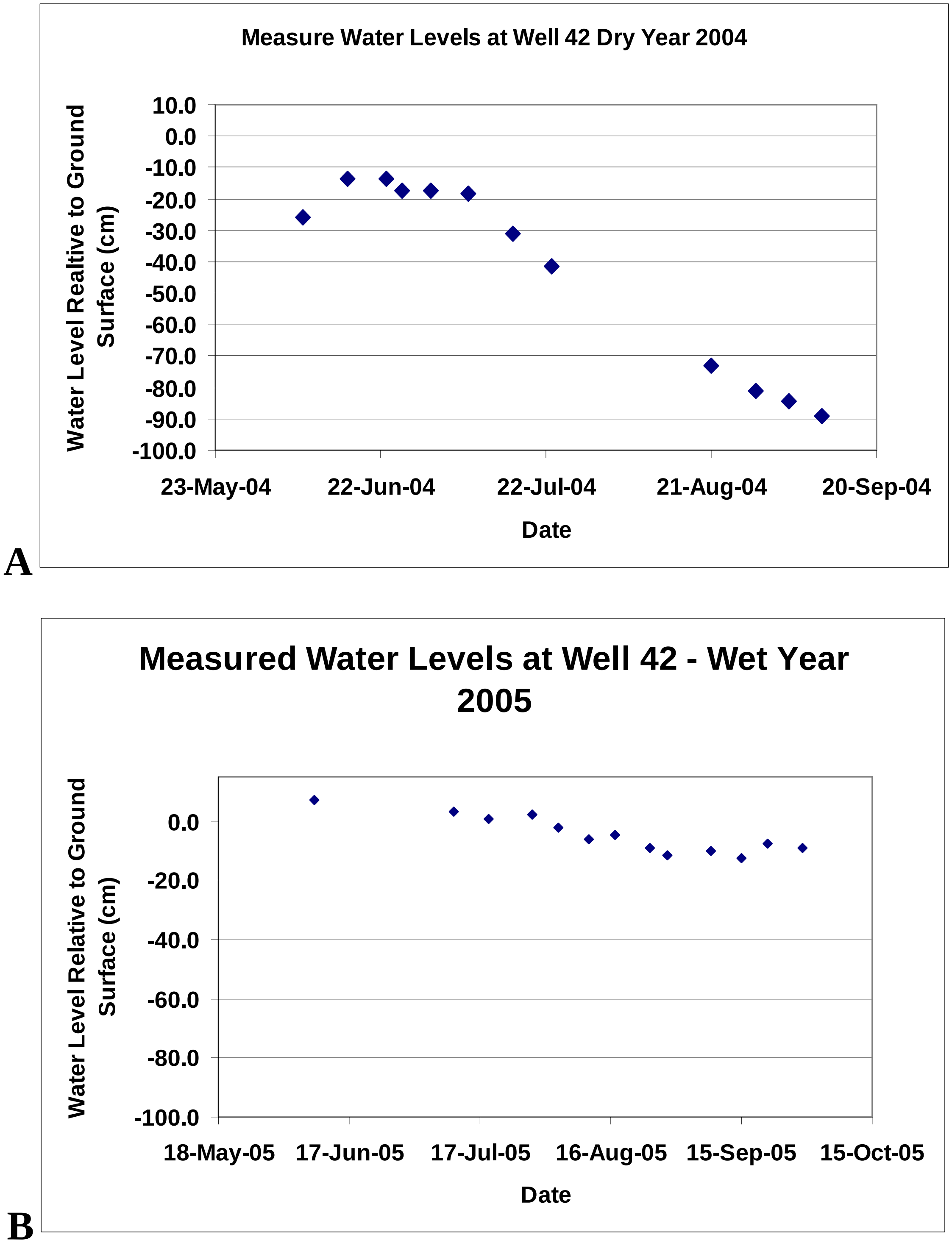

Figure 7. Measured water levels at Well 42. A) Dry year 2004. B) Wet year 2005. Data provided by the NPS.

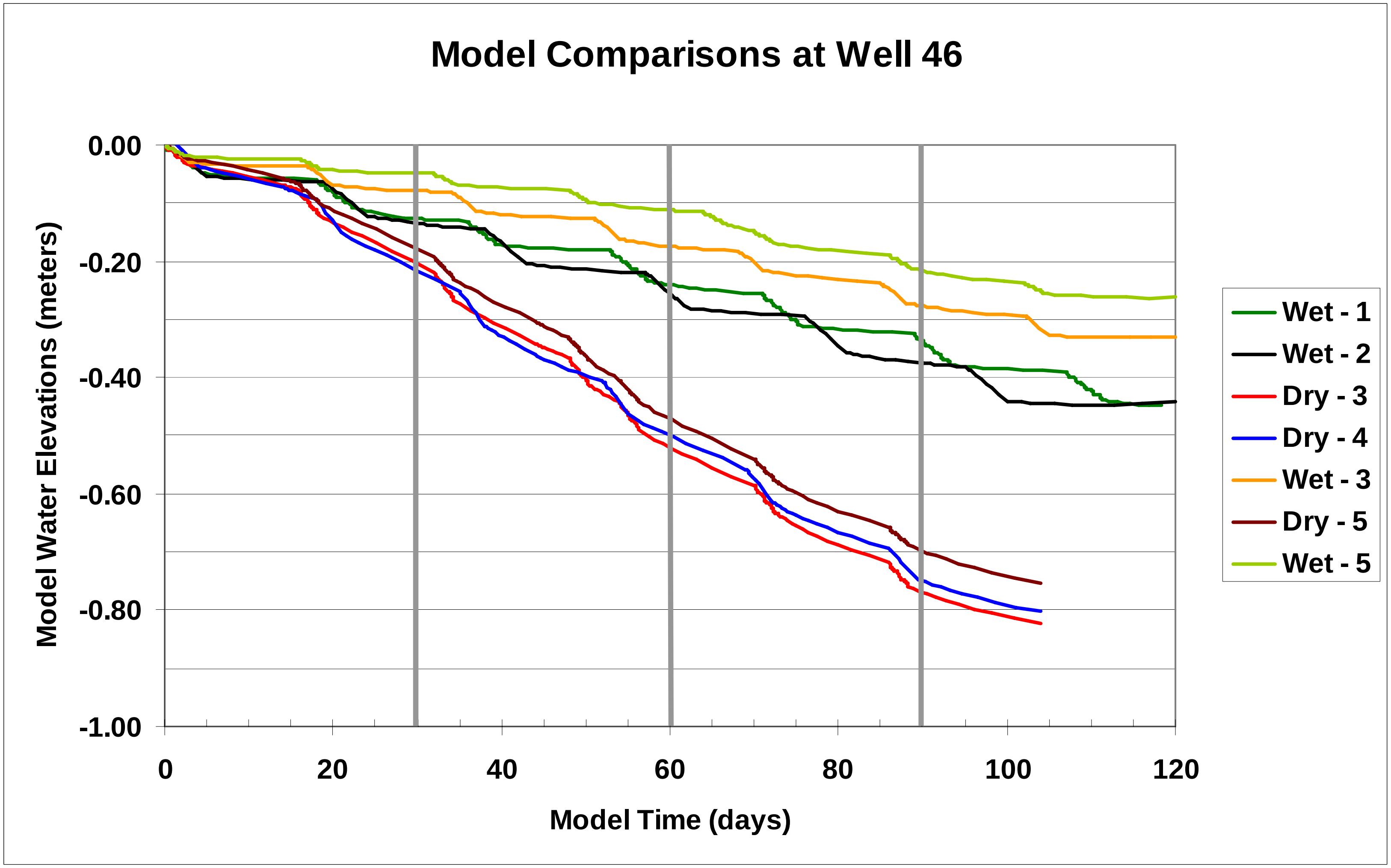

Figure 8. The modeled water level responses at well 46 for the various pumping scenarios.

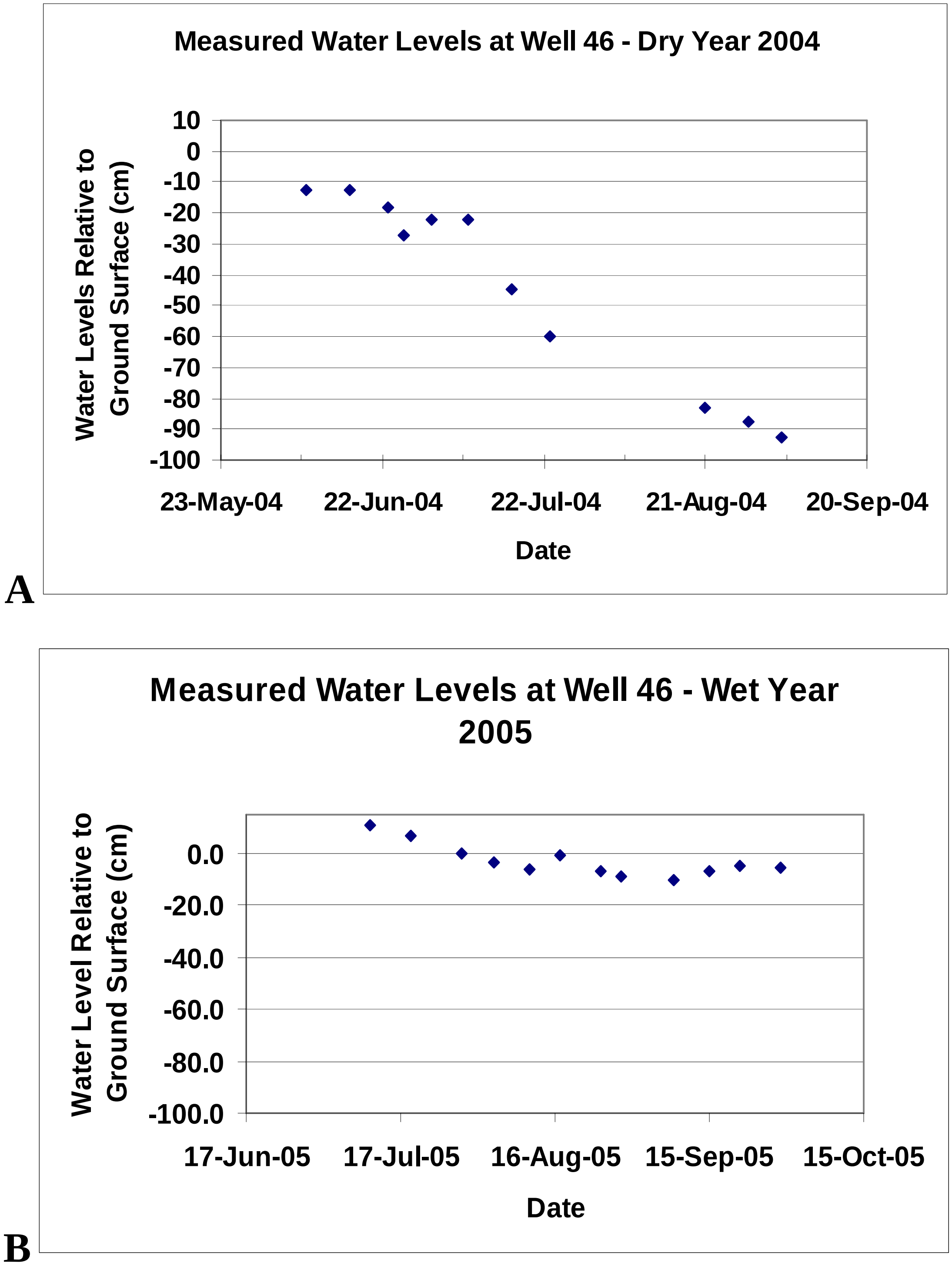

Figure 9. Measured water levels at Well 46. A) Dry year 2004. B) Wet year 2005. Data provided by the NPS.

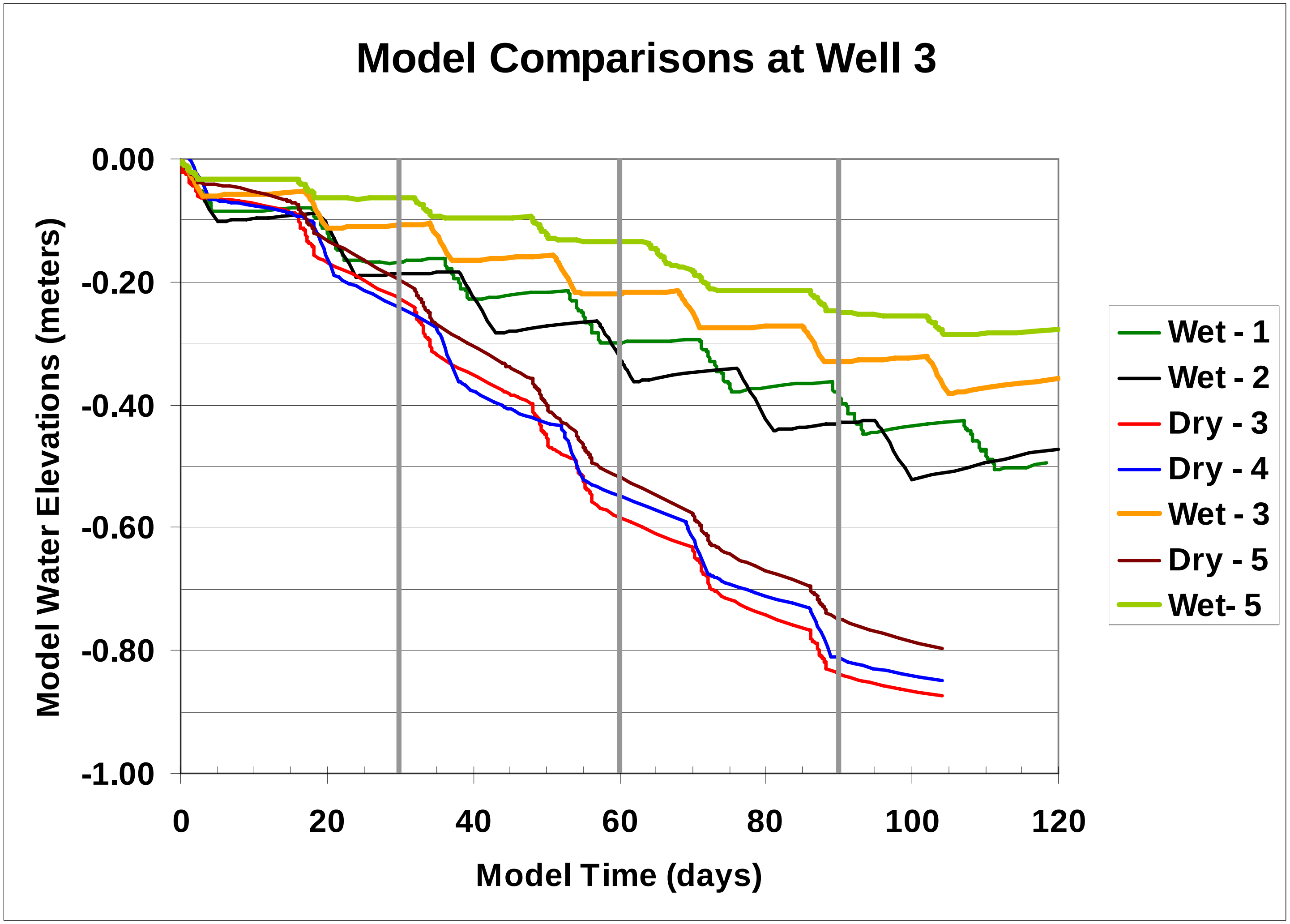

Figure 10. Modeled water level responses at Well 3 for the various pumping scenarios.

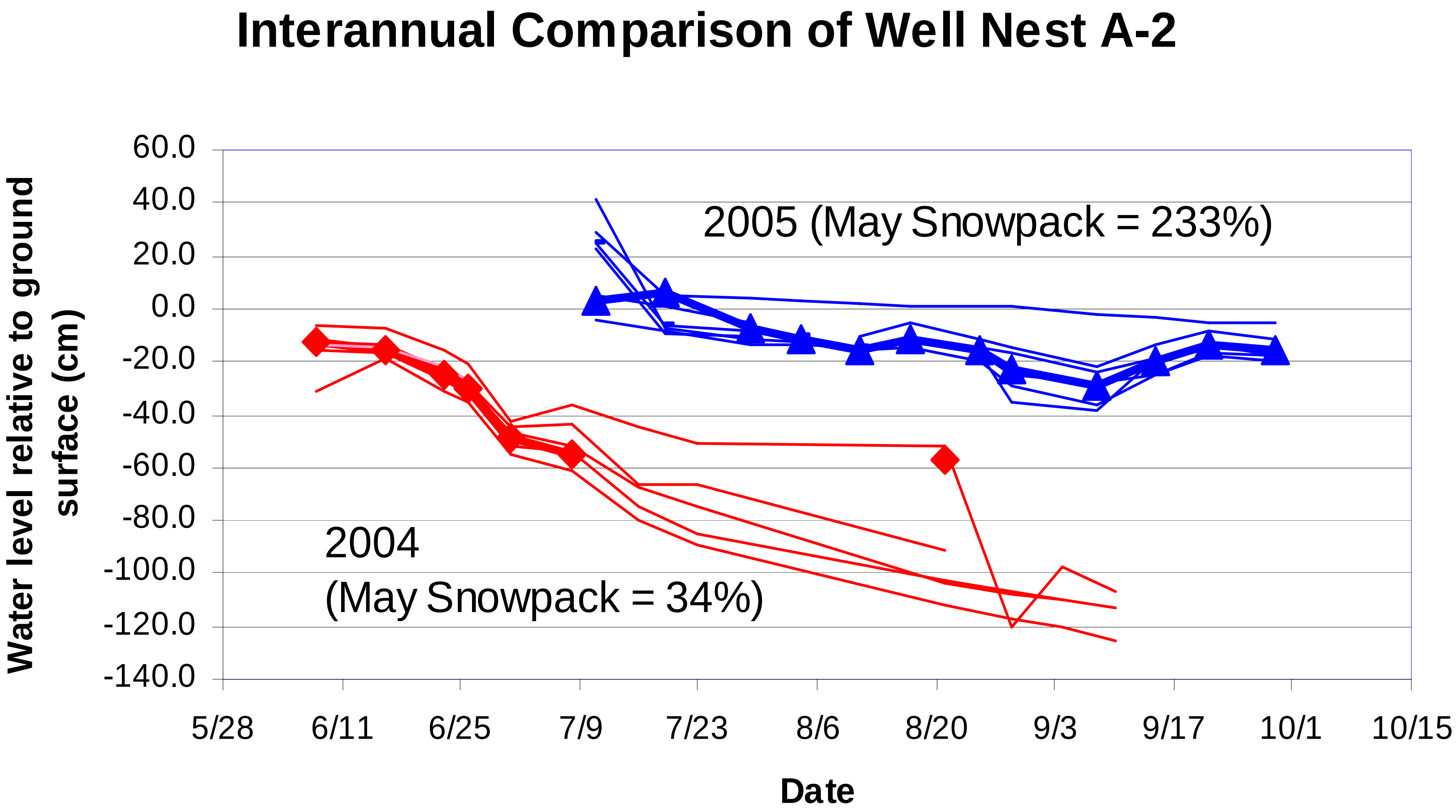

Figure 11. Inter-annual comparison of water levels at Well Nest A-2. Location is near Well 3. Data provide by the NPS.

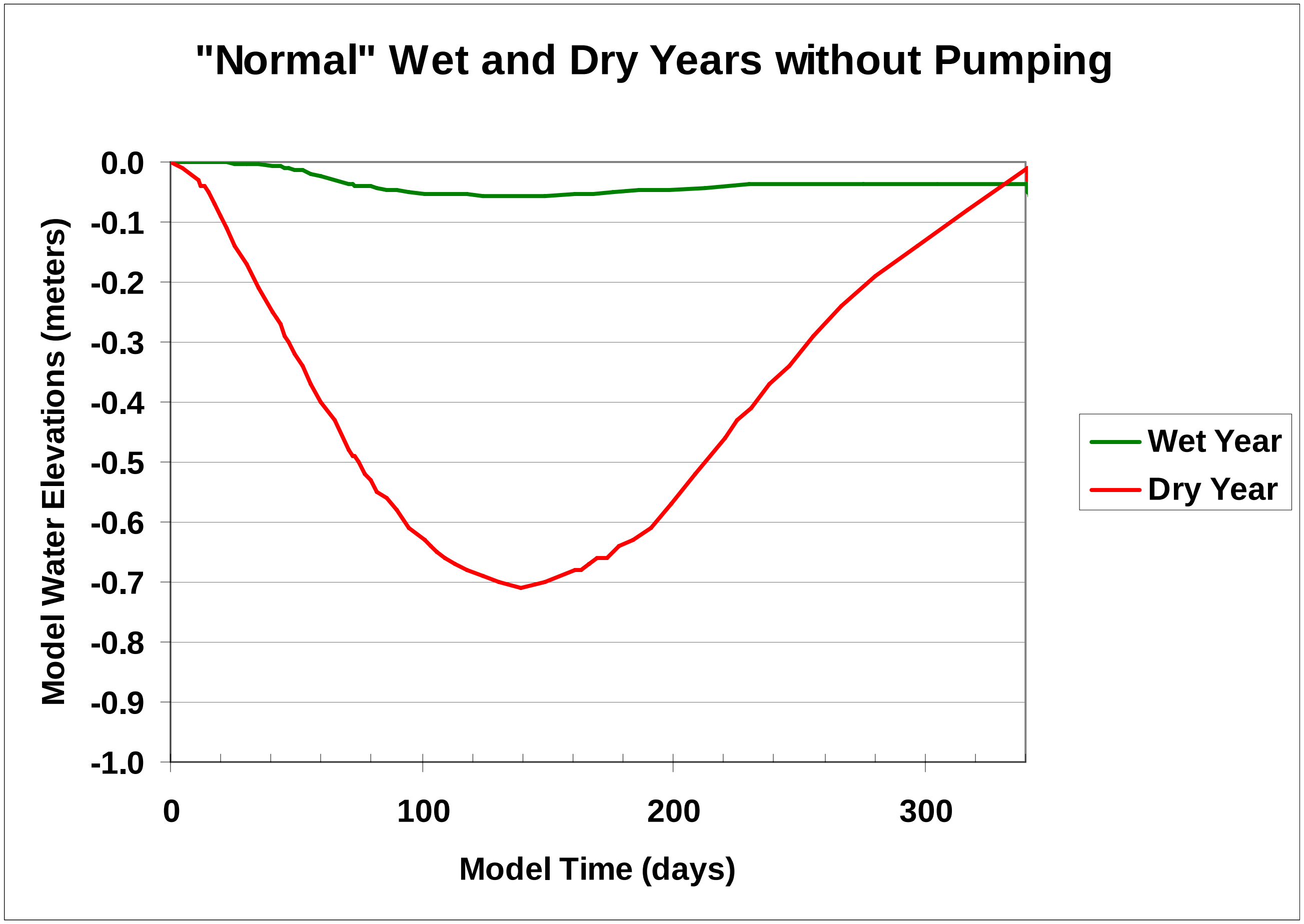

Figure 12. Modeled water level response for wet and dry years with no pumping.