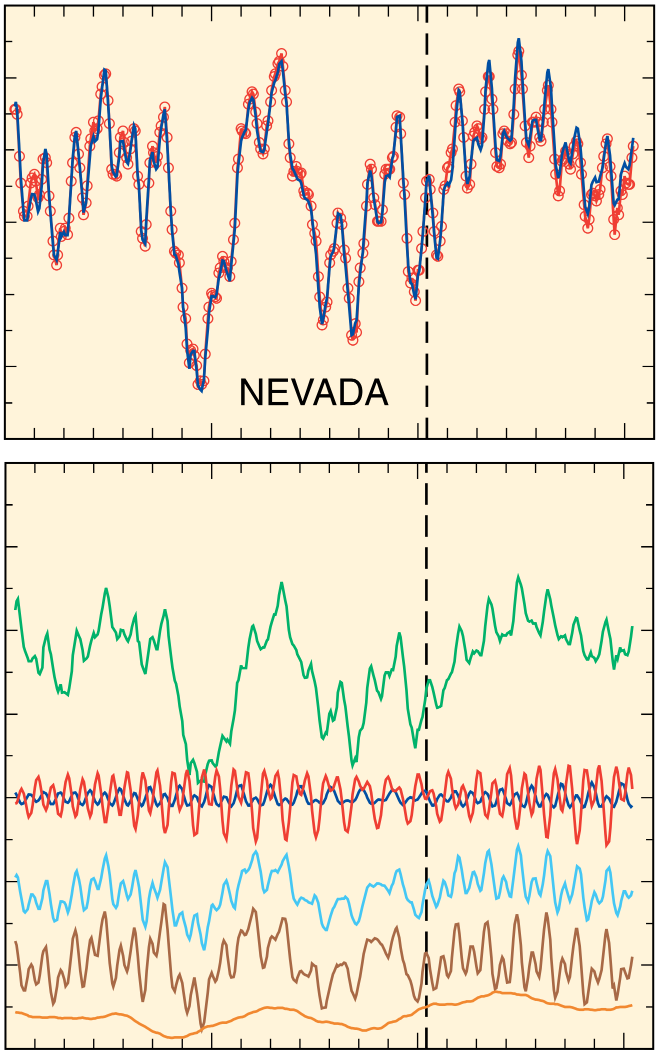
Documentation of a Spreadsheet for Time-Series Analysis and Drawdown Estimation



Prepared in cooperation with the
Southwest Florida Water Management District and
U.S. Air Force, Aeronautic Systems Command

Scientific Investigations Report 2006-5024

U.S. Department of the Interior
U.S. Geological Survey

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By Keith J. Halford

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U.S. Geological Survey

U.S. Department of the Interior
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Carson City, Nevada, 2006

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Conversion Factors and Datums

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day[1] (ft^2/d)	0.0929	meter squared per day (m^2/d)
gallon per minute (gal/min)	0.06308	liter per second (L/sec)
mile (mi)	1.609	kilometer (km)

[1]Expresses transmissivity. An alternative way of expressing transmissivity is cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)ft^2$] ft.

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27). Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Altitude, as used in this report, refers to distance above the vertical datum.

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Preface

This report documents a spreadsheet that has been developed for analyzing time series with an emphasis on estimating drawdowns during aquifer tests by removing extraneous water-level changes at observation wells resulting from barometric pressure changes, earth tides, or regional water-level trends. The spreadsheet was developed for Microsoft Excel version 9.0 or higher. Use of trade names does not constitute endorsement by the U.S. Geological Survey (USGS). The spreadsheet has been tested for accuracy using datasets from different aquifer tests and FORTRAN solutions of dry earth tide and gravity tide. If users find or suspect errors, please contact the USGS.

Every effort has been made by the USGS or the United States Government to ensure that the spreadsheet is error free. Despite our best efforts, the possibility exists that errors exist in the spreadsheet. The distribution of the spreadsheet does not constitute any warranty by the USGS, and no responsibility is assumed by the USGS in connection therewith.

Abstract

Drawdowns during aquifer tests can be obscured by barometric pressure changes, earth tides, regional pumping, and recharge events in the water-level record. These stresses can create water-level fluctuations that should be removed from observed water levels prior to estimating drawdowns. Simple models have been developed for estimating unpumped water levels during aquifer tests that are referred to as synthetic water levels. These models sum multiple time series such as barometric pressure, tidal potential, and background water levels to simulate non-pumping water levels. The amplitude and phase of each time series are adjusted so that synthetic water levels match measured water levels during periods unaffected by an aquifer test. Differences between synthetic and measured water levels are minimized with a sum-of-squares objective function. Root-mean-square errors during fitting and prediction periods were compared multiple times at four geographically diverse sites. Prediction error equaled fitting error when fitting periods were greater than or equal to four times prediction periods.

The proposed drawdown estimation approach has been implemented in a spreadsheet application. Measured time series are independent so that collection frequencies can differ and sampling times can be asynchronous. Time series can be viewed selectively and magnified easily. Fitting and prediction periods can be defined graphically or entered directly. Synthetic water levels for each observation well are created with earth tides, measured time series, moving averages of time series, and differences between measured and moving averages of time series. Selected series and fitting parameters for synthetic water levels are stored and drawdowns are estimated for prediction periods. Drawdowns can be viewed independently and adjusted visually if an anomaly skews initial drawdowns away from 0. The number of observations in a drawdown time series can be reduced by averaging across user-defined periods. Raw or reduced drawdown estimates can be copied from the spreadsheet application or written to tab-delimited ASCII files.

Introduction

Barometric pressure variations, earth tides, regional pumping, and recharge events commonly affect water levels in observation wells (Jacob, 1940; Ferris, 1951; Melchior, 1964; Gregg, 1966; Bredehoeft, 1967; Clark, 1967). Water levels typically fluctuate daily between 0.1 and 0.4 ft because of barometric pressure changes and tides (Merritt, 2004). Water levels can fluctuate more than a foot during a week due to large weather systems that change barometric pressure. Water levels fluctuate seasonally more than 30 ft where prevalent agricultural pumpage occurs, such as in central Florida. Individual recharge events have caused water levels in unconfined aquifers to rise more than 2 ft and decline at rates of 0.1 ft/d afterwards (O'Reilly, 1998).

Hydraulic properties of aquifer systems have been determined by analyzing periodic water-level fluctuations. Rock compressibility and porosity have been related to barometric loading (Jacob, 1940; Rojstaczer and Agnew, 1989). Specific storage has been estimated by analyzing water-level fluctuations that were induced by earth and ocean tides (Bredehoeft, 1967; Robinson and Bell, 1971; van der Kamp and Gale, 1983; Hsieh and others, 1988). Earth-tide, ocean-tide, and barometric fluctuations have been analyzed exhaustively to estimate lateral hydraulic diffusivity (Jacob, 1940; Ferris, 1951; van der Kamp, 1972; Jiao and Tang, 1999; Li and Jiao, 2001; Merritt, 2004). Pneumatic diffusivity has been estimated by exploiting transient, barometric pressure differences between a well in an unconfined aquifer and the surrounding unsaturated zone (Weeks, 1979; Rojstaczer, 1988; Rojstaczer and Riley, 1990).

Pumping-induced drawdowns are analyzed to estimate hydraulic properties and are the difference between observed water levels and what water levels would have been in the absence of pumping. Periodic water-level fluctuations and trends typically can be ignored where drawdowns are great and pumping periods are short. Daily fluctuations of 0.5 ft will not obscure drawdowns of more than 5 ft. Regional water-level declines of 0.05 ft/d typically will not alter hydraulic property estimates when pumping periods are less than a few days.

Periodic water-level fluctuations can obscure the measurement of interest during aquifer tests and in most other hydrologic applications. Water-level changes other than those from planned pumping are considered undesirable when analyzing an aquifer test and should be removed prior to analysis. These fluctuations substantially affect drawdown estimates where the extraneous water-level changes are of equal or greater magnitude. Tidal water-level fluctuations of several feet in coastal areas also complicate the construction of potentiometric surfaces (Gregg, 1966). Errors in water level of a foot can reverse apparent flow directions where the range of water levels is only a few feet (Erskine, 1991).

Barometric water-level fluctuations typically are removed by relating these periodic fluctuations to nearby air-pressure changes with a barometric efficiency (Jacob, 1940; Clark, 1967; Furbish, 1991). Barometric efficiency is the ratio of change in water level to change in barometric pressure (Ferris and others, 1962). Barometric effects are removed by subtracting air-pressure change times barometric efficiency from a measured water level. Tidal fluctuations also are described and removed with tidal efficiencies (Ferris and others, 1962; van der Kamp and Gale, 1983). A tidal efficiency is the ratio of change in water level to change in an ocean tide gage or theoretical earth tide (Bredehoeft, 1967; Erskine, 1991).

Regional water-level trends have been extrapolated from antecedent data to estimate drawdown during aquifer tests (Ferris and others, 1962). A linear trend can approximate regional water-level changes or recovery from previous pumping at an aquifer-test site but has limited utility after a couple of days. Regional pumping and a rainfall event during a 3-day aquifer test in Pennsylvania caused water-level changes to be poorly predicted by a linear trend that obscured drawdowns of less than 1 ft (Risser and Bird, 2003).

Water-level changes in the absence of pumping have been estimated with water levels from individual wells beyond the influence of an aquifer test (Kruseman and DeRidder, 1990). Water-level changes at an observation well and a background well in Volusia County, Florida, were related with double-mass curves (Rutledge, 1985). Drawdowns were less than 0.2 ft and were not successfully differentiated from natural water-level fluctuations in the surficial aquifer. Drawdowns also were estimated with linear regressions between water-level changes at observation wells and a background well (Halford, 1997). Drawdowns of 0.2 ft during a 2-day test in northeastern Florida were detected, but drawdown detection was limited to 0.1 ft.

Simple spreadsheet-based models are proposed for estimating water-levels unaffected by pumping during aquifer tests. The summation of multiple time series such as barometric pressure, tidal potential, and background water levels can simulate non-pumping water levels. These simulated water levels will be referred to as synthetic water levels. Synthetic water levels are needed because water levels unaffected by pumping cannot be measured during an aquifer test. The amplitude and phase of each time series component included in the summation are adjusted so that synthetic water levels match measured water levels during a non-pumping period. The synthetic water-level approach supplants barometric efficiency, tidal efficiency, linear trends, and other correction methods commonly applied.

Drawdowns of less than 0.1 ft can be detected with the synthetic water-level approach, which greatly expands the volume of aquifer investigated by an aquifer test. The radius of investigation in Theis-like aquifers with transmissivities greater than 10,000 ft^2/d will double at a minimum and can increase more than ten times by reducing drawdown detection limits from 0.5 to 0.05 ft. Vertical leakances of confining units can be estimated more reliably by reducing the limit of drawdown detection.

Purpose and Scope

The purpose of this report is to document an approach for estimating drawdowns with simple water-level models that sum multiple time series. A method for fitting these models to measured water-levels by adjusting the amplitude and phase of each series is reported. An approach for reducing drawdown measurements by averaging across user-specified intervals is reported. These approaches and methods are implemented in a spreadsheet application. This spreadsheet is compatible with Microsoft Excel versions 9.0 or higher and requires basic knowledge of Excel. Use and applicability of this software is documented in this report. The hydrologic concepts and methods used in the data processing also are described briefly.

Acknowledgments

This study was supported jointly by the Southwest Florida Water Management District and U.S. Air Force, Aeronautic Systems Command. Robert Peterson of the Southwest Florida Water Management District and the supportive personnel of the U.S. Air Force, Aeronautic Systems Command, provided valuable assistance. Data sets from Florida, Georgia, Louisiana, and Nevada were provided by Dann Yobbi, Gerard Gonthier, Chris Swarzenski, and Joe Fenelon, respectively, of the U.S. Geological Survey. Finally, the author is grateful to Paula Cutillo of the National Park Service and Randell Laczniak, Joe Fenelon, Eve Kuniansky, and Devin Galloway

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Water-Level Components

Barometric pressure, tidal potential, background water levels, stream stage, and any other time series are potential components in a water-level record. The relevant components can be selected where a relation in the water-level record is expected. For example, a relation between barometric pressure and water levels in well sct4 is not obvious (fig. 1), but a relation is expected. A barometric pressure component should be included to test if barometric pressure improves a synthetic water-level series of well sct4.

Barometric Effects

Barometric changes cause greater water-level fluctuations in deeper, confined aquifers where rock matrix absorbs more of the atmospheric load (Merritt, 2004). Fluctuations increase because pressure instantly affects water levels in wells while a stiffer rock matrix transfers little of the increased atmospheric load to the confined water column. Atmospherically induced water-level fluctuations typically are less than 0.2 ft during a day. Large barometric pressure changes from regional storms can cause water-level fluctuations of about 1 ft during a week.

Barometric changes also measurably affect water levels in unconfined aquifers (Weeks, 1979). Pressure changes do not propagate instantaneously through the unsaturated zone because air is highly compressible. The relatively low pneumatic diffusivity of the unsaturated zone creates substantial lags between atmospheric and water-level changes. Uncon-

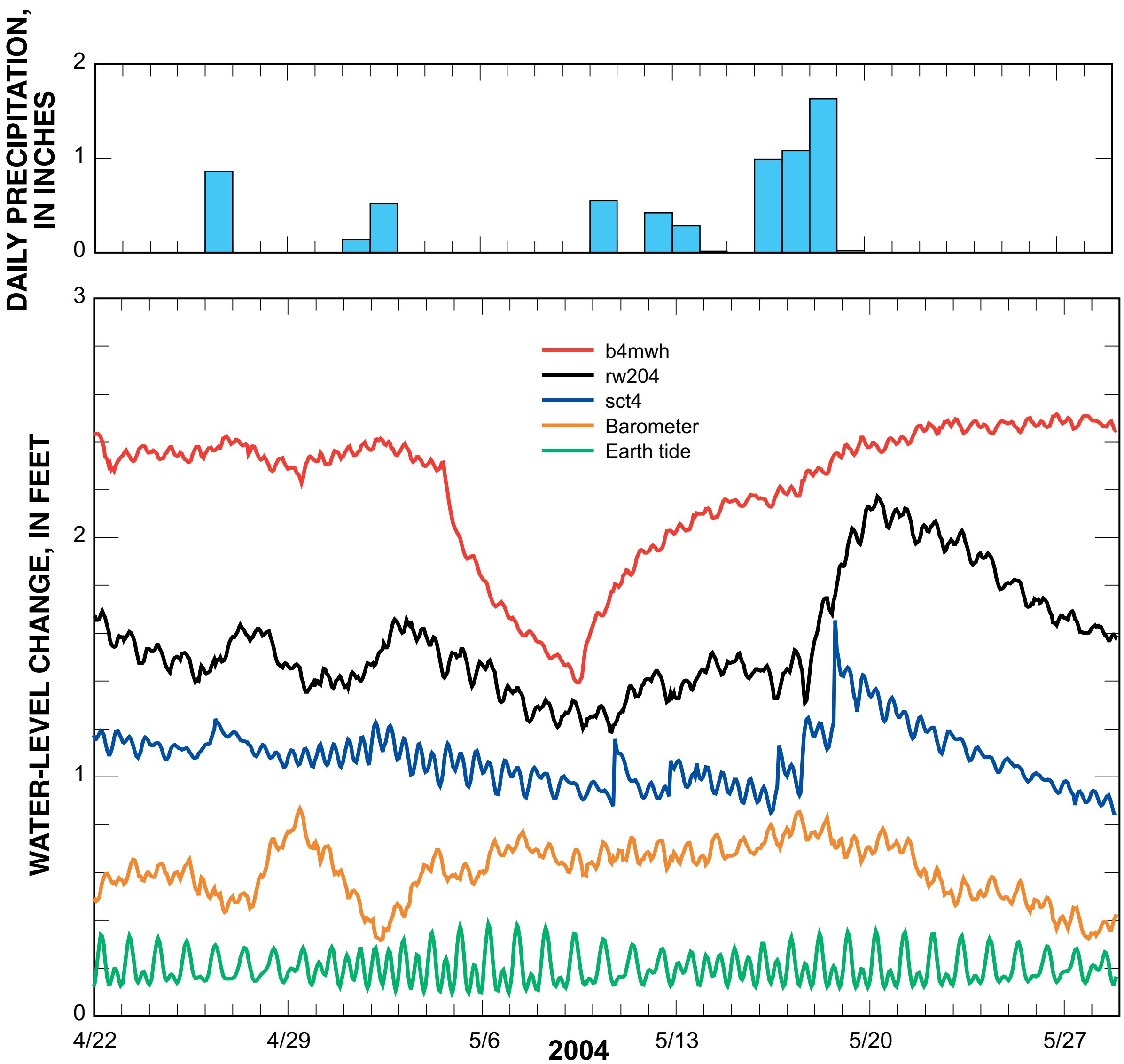


Figure 1. Daily precipitation, ground-water levels, barometric change, and earth tide at Air Force Plant 6, Marietta, Georgia, April 22 to May 28, 2004.

fined water-level fluctuations can approach the magnitude of confined water-level fluctuations as the depth to water exceeds 500 ft.

Tidal Effects

Tides result from changes in gravitational forces as the relative positions of sun, moon, and earth change. The diurnal rise and fall of ocean levels are the most common manifestation of varying gravitational forces and are referred to as ocean tides. Ocean tides affect ground-water levels through direct head changes in an aquifer or as loads applied through a confining unit (Merritt, 2004). Ocean tide effects are better approximated with a nearby tidal gage that also incorporates wind and coastal geometry effects in addition to direct gravitational forcing.

Tidal forces also distort the crust of the earth which creates water-level fluctuations in mid-continent wells (Bredehoeft, 1967; Marine, 1975; Hanson and Owen, 1982; Narasimhan and others, 1984). Earth tides periodically deform (dilate and compress) the skeleton of the aquifer system, changing the porosity and causing measurable water-level fluctuations of as much as 0.1 ft or more in wells penetrating aquifers with small storage coefficients (fig. 1). Coupling between the mechanical deformation and the fluid filling the secondary porosity amplifies water-level response in wells hydraulically connected to the secondary-porosity features. The presence of secondary porosity typically renders the formation more compliant to imposed stresses depending on orientation of the fractures or faults with respect to the principal component directions of the imposed stress. The theoretical crustal strain tensors resulting from the two principal lunar daily and semidiurnal tides (O_1 and M_2) are largely horizontal and orthogonal to one another. Subvertical fractures with azimuths oriented perpendicular to the strain tensor for a particular tide tend to amplify the strain and thereby the water-level response (Bower, 1983).

Two theoretical earth tides are included as internal functions in the drawdown estimation spreadsheet. The first earth tide function computes the areal strain tide in parts per billion (ppb), and the second function computes the gravity tide in microgals (μgal) downward normal to the Earth ellipsoid (Harrison, 1971).

Background Water Levels

Recharge events and regional pumping are identifiable stresses that typically affect large areas but are not predicted easily with independent time series such as barometric change and tidal potential. Recharge events and regional pumping stresses create similar water-level changes in multiple wells over areas of many square miles. Water levels in wells sufficiently removed from an aquifer test can simulate these regional stresses and any other unidentified stresses. Water levels in these remote wells will be referred to as background water levels.

Background water levels can be more effective correctors than independent barometric and tidal time series even where only barometric and tidal stresses are significant. Barometric forcing through the unsaturated zone lags behind because of the low permeability of unsaturated rock relative to an open well (Weeks, 1979). The complex relation between barometric pressure and water levels in a well are explained poorly with a barometric efficiency where the unsaturated zone is thick. Background water levels from another well of similar construction better approximate this relation. Likewise, rock properties and fracture orientation in an aquifer control tidal water-level fluctuations as much as dry earth tide. Water levels from background wells can better approximate the rock-tide interaction than just dry earth tide.

Moving Averages and Differences

Amplitudes of diurnal water-level fluctuations in wells frequently differ from lower frequency changes such as frontal barometric changes. Frequency dependent differences in water-level fluctuations exist between wells because of differences in well construction and aquifer properties. Diurnal water-level fluctuations will be less where communication between well and aquifer is impeded and wellbore storage is increased. Poorly developed wells with large casing diameters and short screens damp high frequency water-level fluctuations. Low transmissivity aquifers with large storage coefficients also will damp water-level fluctuations.

Low frequency signals are separated from diurnal water-level fluctuations with moving averages of the original time series in the spreadsheet. Water levels typically are averaged over 12-hour or 24-hour periods, but any averaging periods can be specified. High frequency signals are differences between the raw time series and the moving averages. Three time series: raw, moving average, and differences, are available for each water-level series.

Drawdown Estimation with Synthetic Water Levels

Drawdowns are differences between measured and synthetic water levels that are created for each observation well. Multiple time series such as barometric change, earth tide, and background water levels are specified as components of a synthetic water-level series. Synthetic water levels are modified by adjusting the amplitude and phase of each component. The synthetic water level at time, t, is

$$SWL(t) = C_0 + C_1(t - t_0) + \sum_{i=1}^{n} a_i V_i(t + \phi_i) \qquad (1)$$

where:

C_0 is an offset, L,
C_1 is the slope of water-level change, in LT^{-1},
n is the number of time-series components,
a_i is the amplitude multiplier of the i^{th} component, in L (units of i^{th} component)$^{-1}$,
ϕ_i is the phase-shift of the i^{th} component, T, and
$V_i(t+\phi_i)$ is the value of the i^{th} component at time $t+\phi_i$ in units of i^{th} component.

Each time series, V_i, is a smooth function because values are interpolated between consecutive data pairs. Interpolation allows data to be collected at variable intervals within a time series. This also means collection frequencies can differ between time series and do not need to be synchronized (fig. 2).

The amplitude and phase of each component are adjusted so synthetic water levels match measured water levels during periods unaffected by an aquifer test. These periods will be referred to as fitting periods. A sum-of-squares of differences between synthetic and measured water levels is minimized to estimate amplitudes and phases. Root-mean-square (RMS) error is reported instead of sum-of-squares so error and the range of fluctuation can be compared easily.

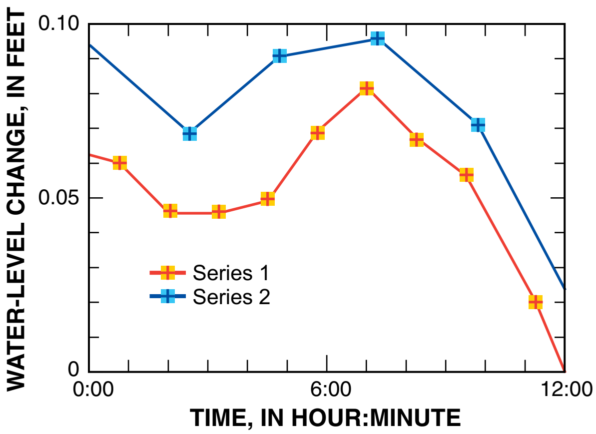


Figure 2. Two time series with different collection frequencies and sampling times.

Amplitude and phase estimates typically are non-unique, which is not important for drawdown estimation. Synthetic water levels are the important result, not parameter estimates. Amplitude estimates remain unique until two or more of the components are highly correlated. Phase estimates are non-unique regardless of the number of components because many local minima exist. Adjustment of the phase of each component is limited to a user-defined range. Sensitivity should be tested with multiple initial phase estimates because synthetic water-level estimates frequently can be improved.

Fitting periods should coincide with non-testing conditions where all stresses other than pumping for an aquifer test affect water levels. Ideally, a fitting period will be immediately antecedent to an aquifer test. Differences between an antecedent fitting period and an estimation period are compared easily because water-level changes are greatest at the beginning of an aquifer test (fig. 3). A fitting period can occur after an aquifer test, but synthetic water-level will not simulate measured water levels as well if water levels are still recovering or background conditions have changed.

Components of the synthetic water-level record are selected by trial-and-error. Time series that mimic the water-level record to be analyzed should be selected (fig. 4). Background water levels frequently best approximate the water levels to be analyzed. Irrelevant components make the fitting process take longer but do not degrade the predictive capacity of synthetic water levels. The amplitude of an irrelevant component will approach zero, which causes this component to negligibly affect the synthetic water levels.

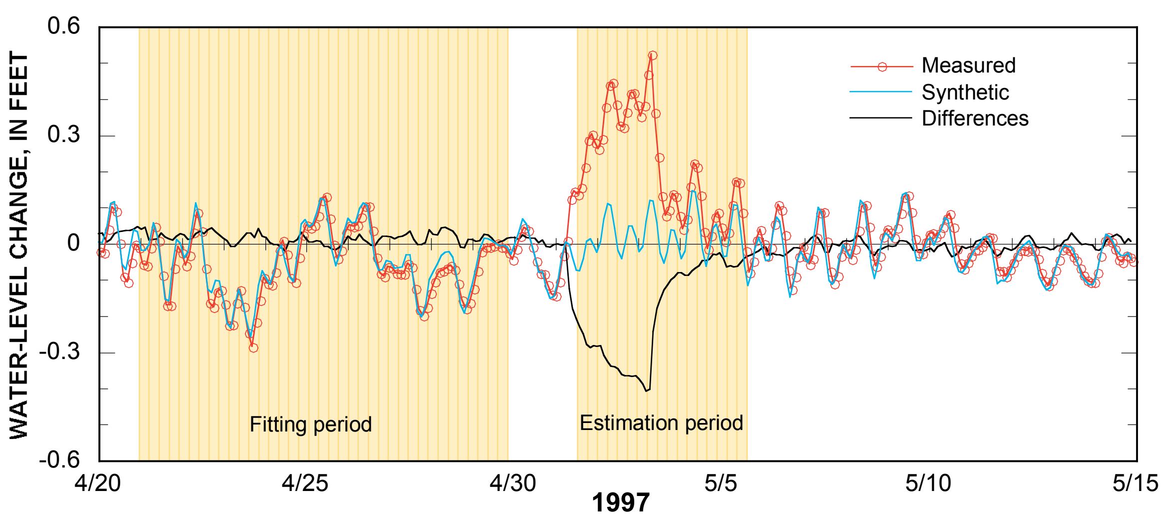


Figure 3. Example fitting period, April 17 to 30, 1997, and an estimation period, May 1 to 5, 1997.

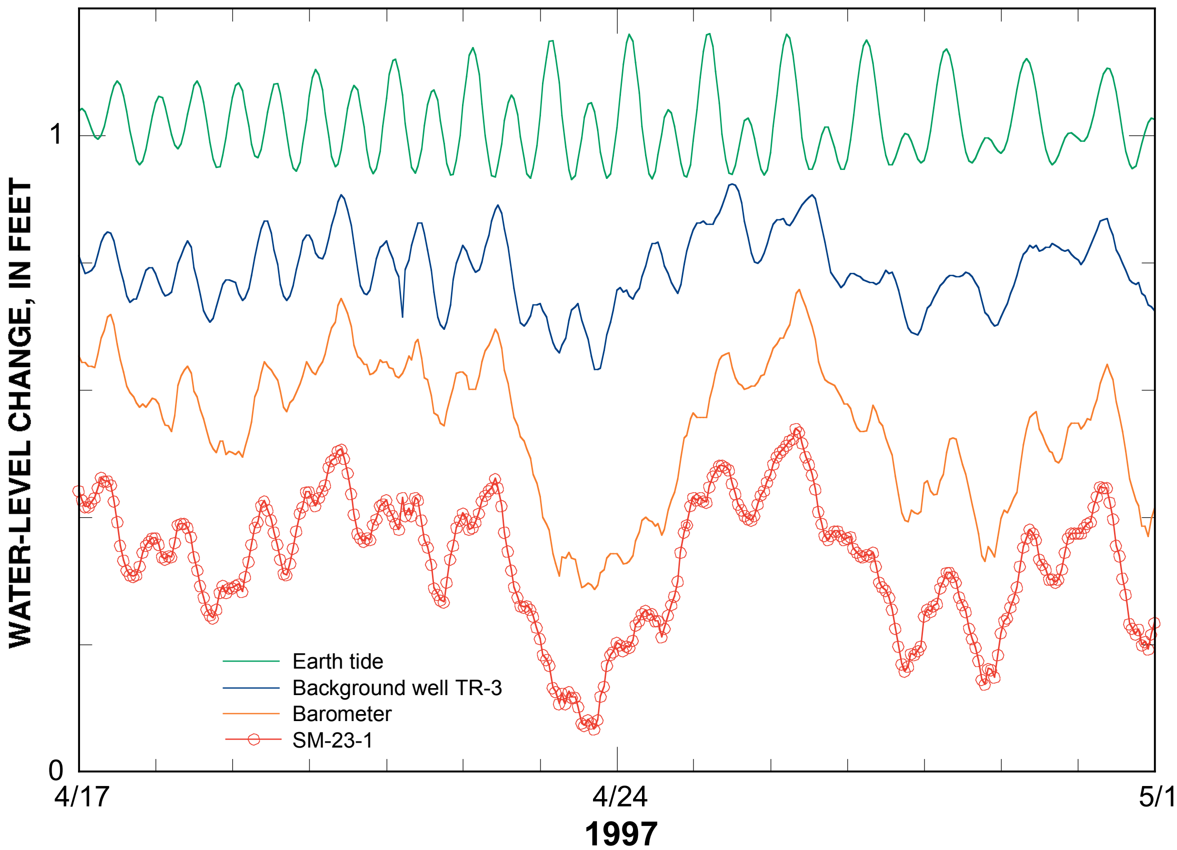


Figure 4. Barometric change, earth tide, and ground-water levels in wells TR-3 and SM-23-1 in the Amargosa Desert, Nevada, April 17 to May 1, 1997.

The significance of components can be tested by sequentially adding each component to the synthetic water-level series (fig. 5). For example, a synthetic water-level series for well SM-23-1 is simulated with barometric change, earth tide, and water levels in well TR-3 (table 1). Wells TR-3 and SM-23-1 are 15 mi apart and are both open to the same highly transmissive carbonate aquifer in southern Nevada. Barometric change approximates much of the observed water-level fluctuations in well SM-23-1 with an r^2 of 0.89 and a RMS error of 0.035 ft. Addition of an earth-tide series marginally improves the synthetic water-levels with an r^2 of 0.92. Addition of the background well TR-3 greatly improves the match between measured and synthetic water levels with an r^2 greater than 0.99 and a RMS error less than 0.01 ft (fig. 5).

Measured water levels are subtracted from synthetic water levels to estimate drawdowns in each observation well. The initial difference between measured and synthetic water levels at the beginning of an aquifer test is assumed to be zero. Drawdowns can be adjusted visually if discrete anomalies skew initial drawdowns away from 0. Adjustment of the minimum drawdown in a series to equal 0 is reasonable if water-level rises were caused by the "Noordbergum effect" (Verruijt, 1969; Wolff, 1970).

The number of observations in a drawdown time series can be reduced by averaging across user-defined periods (fig. 6). Drawdown and recovery in a well can be defined quite well with less than 100 observations. Large data sets should be reduced to ease aquifer-test analysis. Selective data reduction also controls the implicit weighting of solutions toward greater numbers of observations. Raw drawdowns are reduced by averaging to smooth high frequency water-level fluctuations (fig. 6).

Nevada Example

An example was created by adding drawdown and recovery from a hypothetical aquifer test in a confined aquifer to the time series from well TR-3. Pumping responses were simulated with a Theis (1935) solution with a transmissivity of 20,000 ft^2/d and a storage coefficient of 0.0005. Pumping started 5/1/1997 8:00 and a discharge of 100 gal/min was maintained over a 48-hour period. Pumping ceased 5/3/1997 8:00 and recovery was simulated until residual drawdown was less than 0.01 ft (fig. 7).

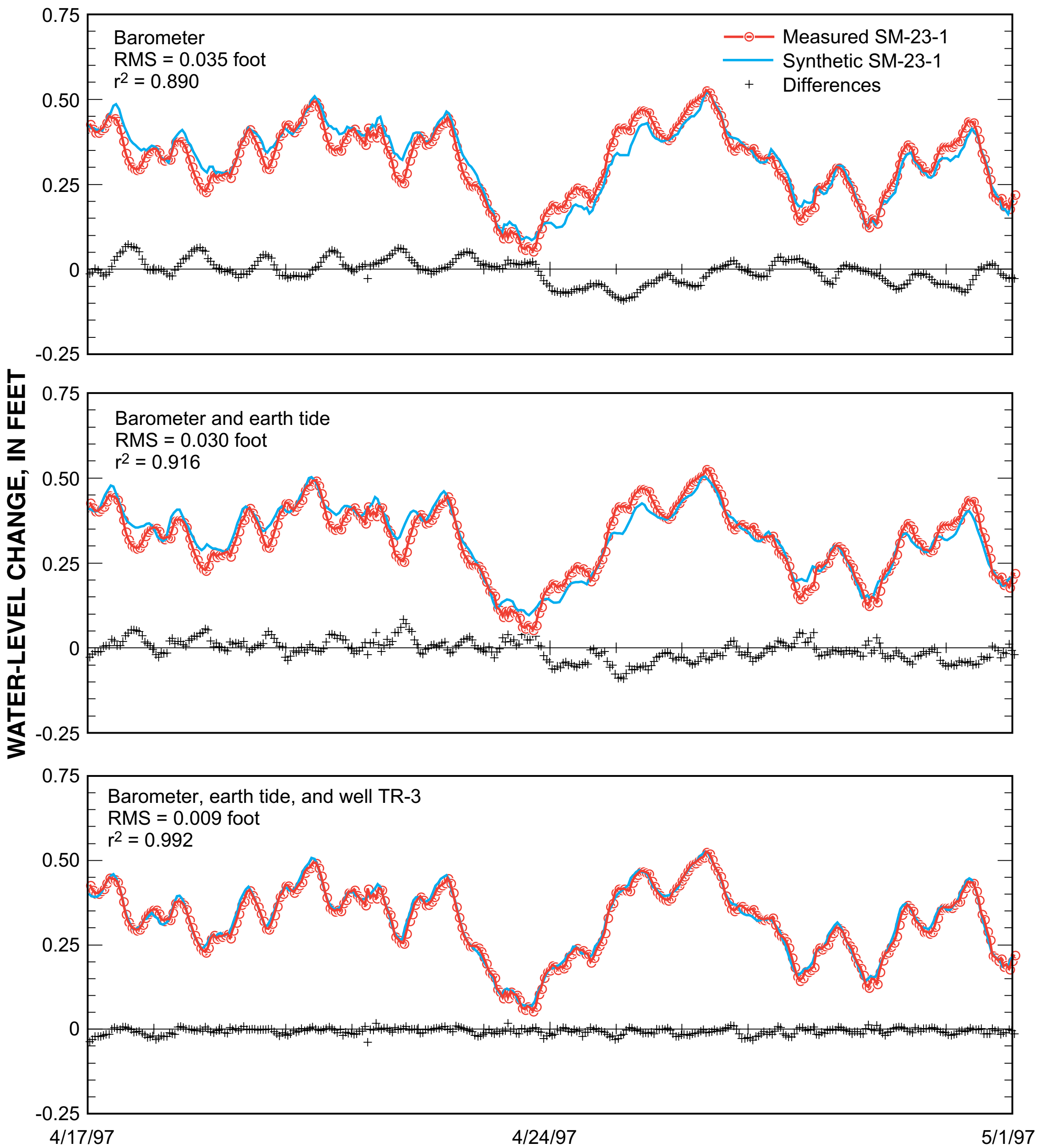


Figure 5. Improvement of synthetic water level for well SM-23-1, April 17 to May 1, 1997, by sequentially analyzing barometric change, earth tide, and water levels in well TR-3.

Table 1. Sites with water-level time series that were used to create synthetic water levels

State	USGS site identifier	Site name	Latitude	Longitude	Altitude (feet)	Well depth (feet)	Depth of top opening (feet)	Depth of bottom opening (feet)
Florida	272728081484701	R20AvPk	27°27'28"	81°47'47"	67	1,266	380	1,266
Florida	272714081545901	R31AvPk	27°27'14"	81°54'59"	78	1,152	460	1,152
Florida	271757081493002	R26AvPk	27°17'57"	81°40'39"	75	1,320	580	1,320
Florida	272012081482501	Marshall	27°20'12"	81°48"25"	63	178	137	478
Georgia	335557084312802	rw204	33°55'57"	84°31'29"	1,072	200	28	200
Georgia	335605084312101	Sct4	33°56'57"	84°31'20"	1,009	600	83	600
Georgia	335612084312901	Sct6	33°56'13"	84°31'31"	1,025	575	57	575
Louisiana	--	Lake Felicity	29°20'59"	90°24'48"	0	—	—	—
Louisiana	--	Oyster Bayou	29°15'42"	91°05'42"	0	—	—	—
Lousiana	--	Bay Junop	29°12'16"	91°03'56"	0	—	—	—
Louisiana	07381328	Houma Navigation Canal at Dulac	29°23'06"	90°43'47"	0	—	—	—
Nevada	363213116133800	TR-3	36°32'13"	116°13'38"	2,402	807	620	678
Nevada	363905116005801	SM-23-1	36°39'05"	116°00'58"	3,543	1,338	1,302	1,332

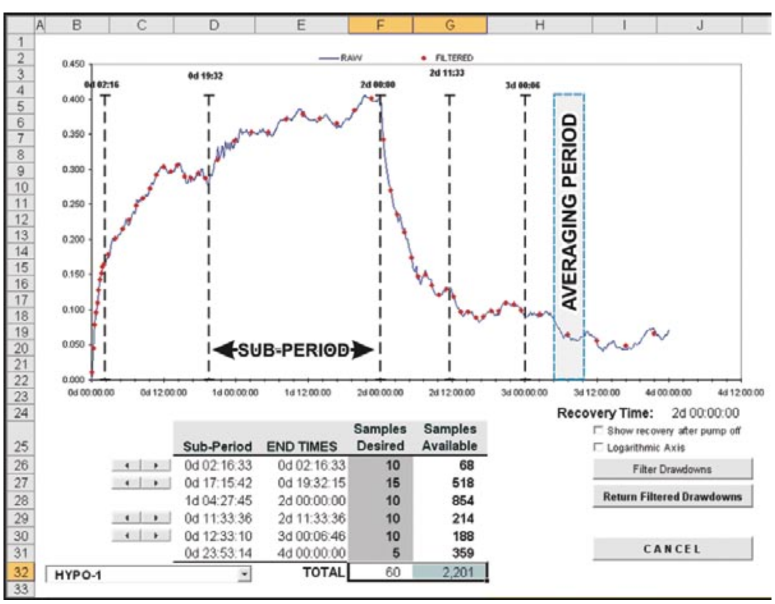


Figure 6. Example of drawdown filter, sub-periods, and averaging periods.

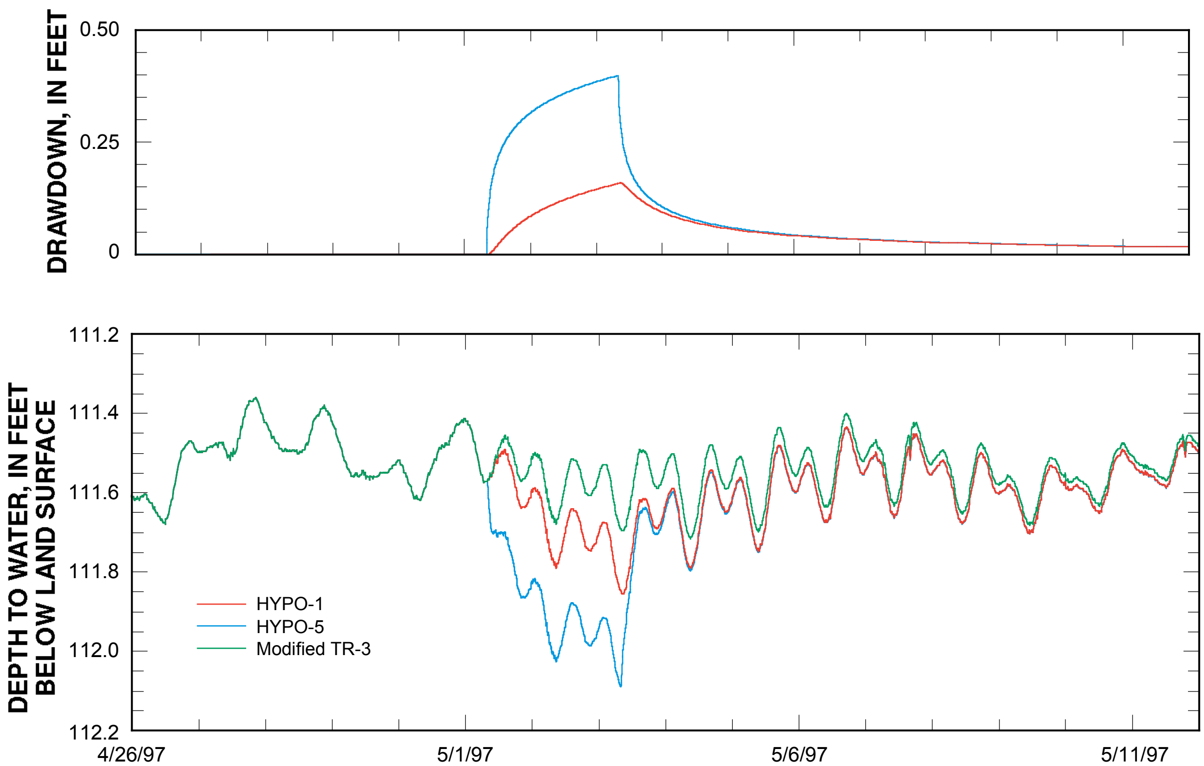


Figure 7. Water levels in wells HYPO-1, HYPO-5, and modified TR-3 and drawdowns in wells HYPO-1 and HYPO-5, April 26 to May 11, 1997.

Hypothetical water-level series HYPO-1 and HYPO-5 were created with the Theis model at radial distances of 1,000 and 5,000 ft, respectively, from the pumping well (fig 7). Unpumped water levels in wells HYPO-1 and HYPO-5 were the measured water levels from well TR-3 after multiplying by 1.4, adding 53.2 ft, and shifting forward 75 minutes. Pumping affected water levels were created at 2-minute intervals during the first 50 hours of the test and at 4-minute intervals during the remainder of the recovery period. Synthetic water levels that use well TR-3 will perfectly match measured water levels in either HYPO-1 or HYPO-5 because TR-3 is the underlying series in these hypothetical records.

Drawdown and recovery in well HYPO-5 were estimated between 5/1/1997 8:00 and 5/5/1997 8:00 (fig. 8). Synthetic water levels were created for HYPO-5 with barometric changes, dry earth tide, and water levels in well SM-23-1. The synthetic water levels matched measured water levels with a RMS error of 0.01 ft during the 2-week fitting period prior to the aquifer test. Drawdown and recovery were observed easily in the estimated time-series for HYPO-1, which was within 0.01 ft of the original Theis solution on average.

Eliminating more than 97 percent of the observations by averaging did not alter the interpretation or statistics of the estimated drawdown series (fig. 8). The raw drawdown series for HYPO-5 contained 2,203 observations during the 4-day period of analysis, which was reduced to 65 observations in the filtered drawdown series. Minimum, maximum, average, and standard deviation of the differences between a drawdown series and the original Theis solution were -0.05, 0.02, -0.01, and 0.01 ft, respectively, for both raw and filtered drawdowns.

The fitting and drawdown estimation processes would be repeated for HYPO-1 and any other observation well because the fitting coefficients differ between synthetic water-level series. Amplitude multipliers, phase shifts, and offsets are the fitting coefficients that are estimated for each synthetic water-level series. These fitting coefficients differ between water-level series to approximate each unique water-level series and should be unique even if the underlying time-series components are the same.

Drawdown Detection Limits

Drawdown detection limits affect hydraulic property estimates from aquifer tests. Hydraulic properties such as specific yield cannot be estimated when drawdowns are not detected in distant observation wells. The observations are still useful because a minimum specific yield can be determined by fitting a ground-water flow solution to the minimum detectable drawdown. Likewise, a maximum vertical hydraulic conductivity for a confining unit also can be determined. A drawdown detection limit typically is related to drawdown prediction error which is unknown during an aquifer test.

Prediction errors were computed and compared to fitting errors where local pumping was absent. RMS errors during

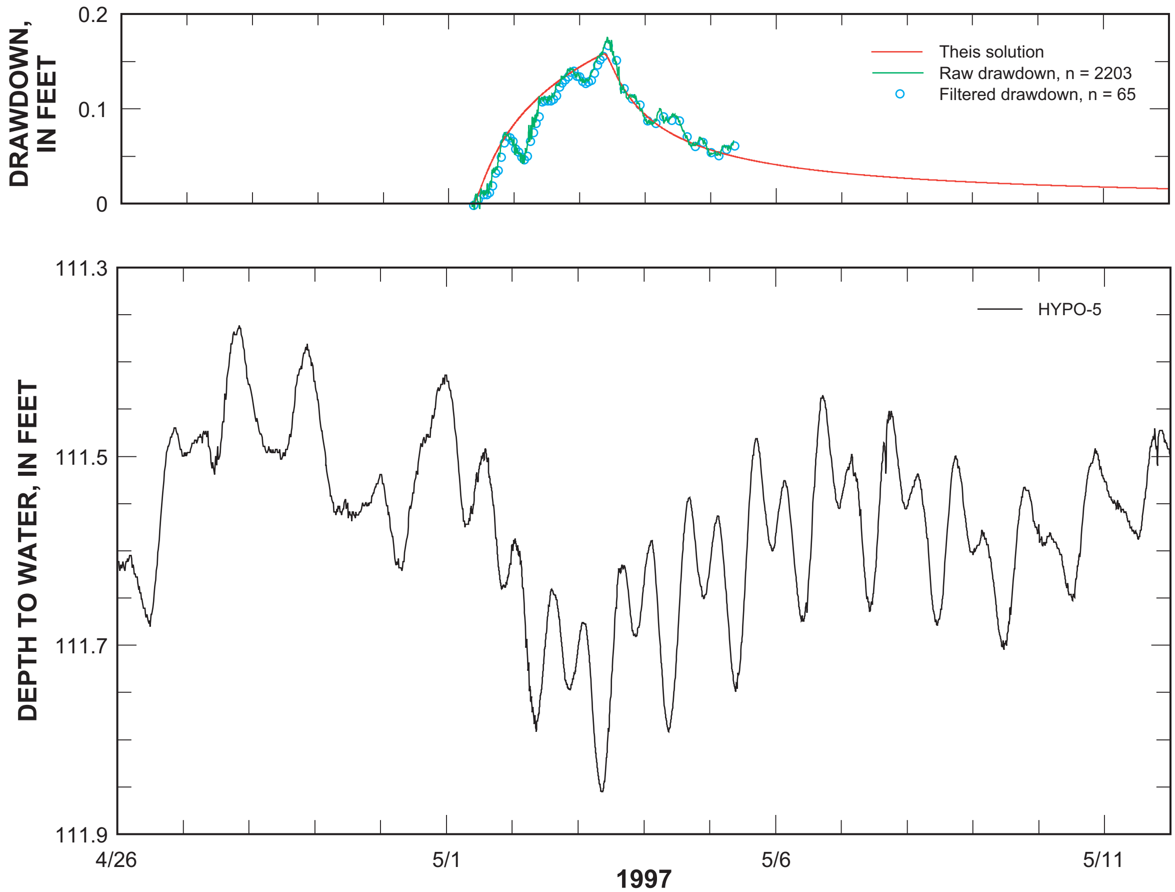


Figure 8. Water levels in well HYPO-5 and Theis, raw, and filtered drawdowns, April 26 to May 11, 1997.

Figure 9. Fitting and prediction error comparison sites.

fitting and prediction periods were compared at four geographically diverse sites in Florida, Georgia, Louisiana, and Nevada (fig. 9). Multiple synthetic water levels were created in a well at each site with fitting periods of 3, 7, 14, 28, and 56 days. RMS errors during fitting periods were compared to RMS errors during 7-day prediction periods. Two prediction periods were investigated at each site for eight prediction periods in total.

Synthetic water levels were created with six or more time-series components at each of the four sites (fig. 10). Many components created many degrees of freedom, which allowed for a better match to measured water levels. Several of the components likely were extraneous, but did not compromise the synthetic water-level results. For example, synthetic water levels were fit to measured water levels in well SM-23-1 between 4/17/1997 and 5/1/1997. RMS error was 0.0078 ft using barometer, earth tide, gravity tide, and background well TR-3 as synthetic water-level components. RMS error was reduced to 0.0071 ft by adding two components, a 24-hour moving average of water levels in well TR-3 and differences between water levels in well TR-3 and the moving averages. Results were functionally unchanged and the predictive power of the synthetic water levels was not degraded.

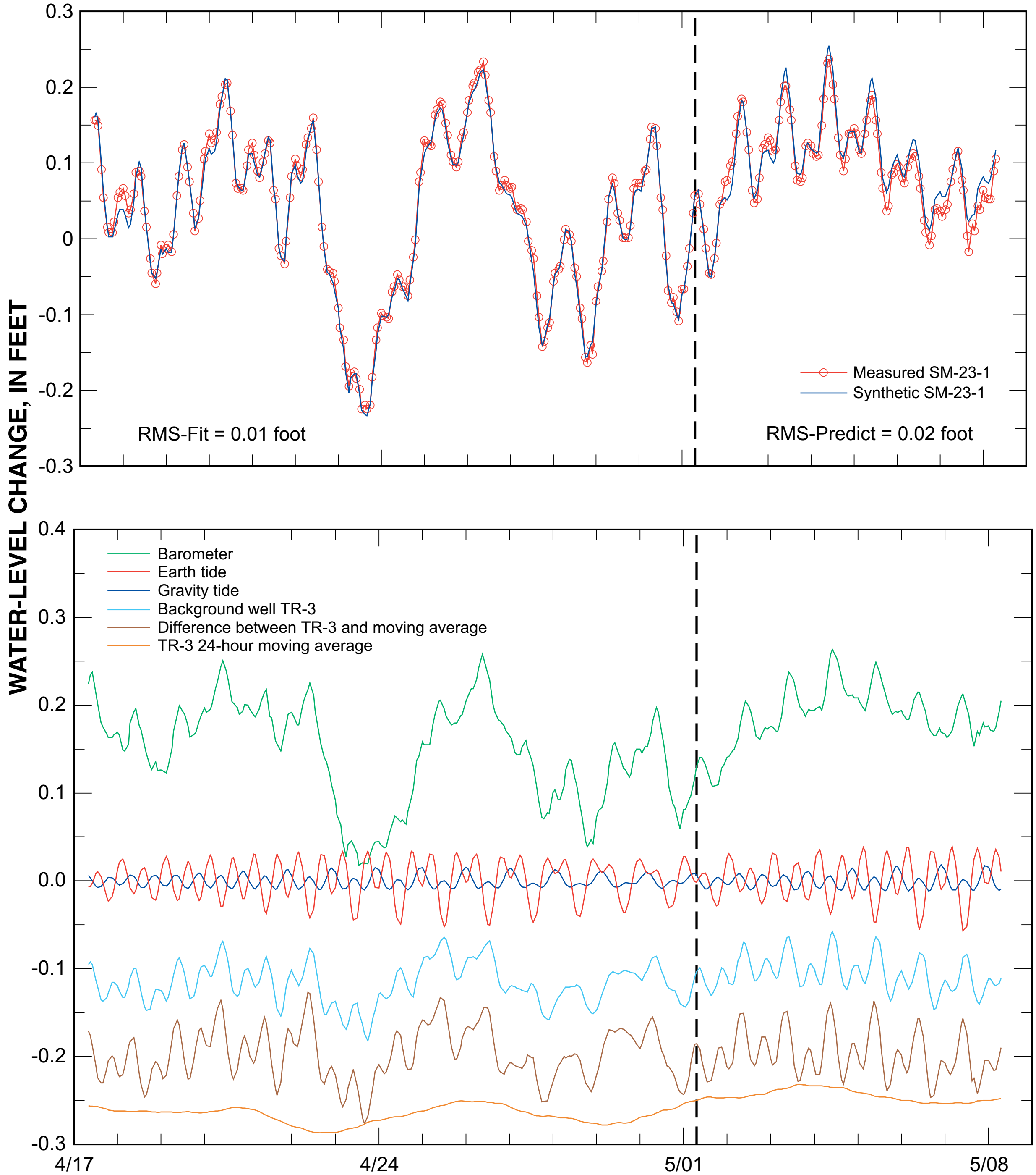


Figure 10. Measured water levels, synthetic water levels, and water-level components in well SM-23-1, Nevada, during a 14-day fitting period and a 7-day prediction period that began May 1, 1997.

Prediction error was assumed to be related to fitting error by a simple multiplier (table 2). Ratios of prediction-to-fitting error decreased to nearly 1 with fitting periods of more than two times the prediction periods. Large ratios of prediction-to-fitting error occurred when fitting periods were less than or equal to prediction periods. These large ratios resulted from small fitting errors and large prediction errors (fig. 11).

Water-level predictions from shorter fitting periods frequently were biased because a longer-term trend was not reproduced by the synthetic water levels (fig. 12). Synthetic and measured water levels differed by their respective RMS errors at the end of the prediction periods at the sites in Florida (fig. 12), Georgia (fig. 12), and Nevada (fig. 10). The magnitude of the errors ranged from 5 to 20 percent of the predicted change in water levels. The greatest relative error occurred at the Georgia site where the predicted change in water levels was only 0.2 ft.

Table 2. Ratios of prediction-to-fitting errors, prediction periods, water-level ranges, and prediction-error ranges at sites in Florida, Georgia, Louisiana, and Nevada

Site	Prediction error divided by fitting error					Start of 7-day prediction range	Water-level range, in feet	Prediction error, in feet	
	Fitting period								
	3-day	7-day	14-day	28-day	56-day			Minimum	Maximum
Florida	9.2	4.9	3.7	1.6	1.0	08/12/2004	1.86	0.08	0.16
Florida	56.8	4.5	1.7	1.0	1.1	11/12/2004	2.30	.28	.92
Georgia	11.3	6.5	1.8	.8	.4	04/24/2004	.21	.01	.03
Georgia	26.8	4.9	1.5	1.1	.9	05/17/2004	.30	.02	.08
Louisiana	5.4	2.2	1.9	1.6	1.3	05/16/2002	2.70	.09	.19
Louisiana	5.6	1.5	1.2	1.0	.9	06/02/2002	1.10	.05	.12
Nevada	2.5	3.9	1.9	1.0	1.0	05/10/1997	.28	.01	.02
Nevada	4.0	2.6	3.0	.9	.4	06/10/1997	.53	.01	.02

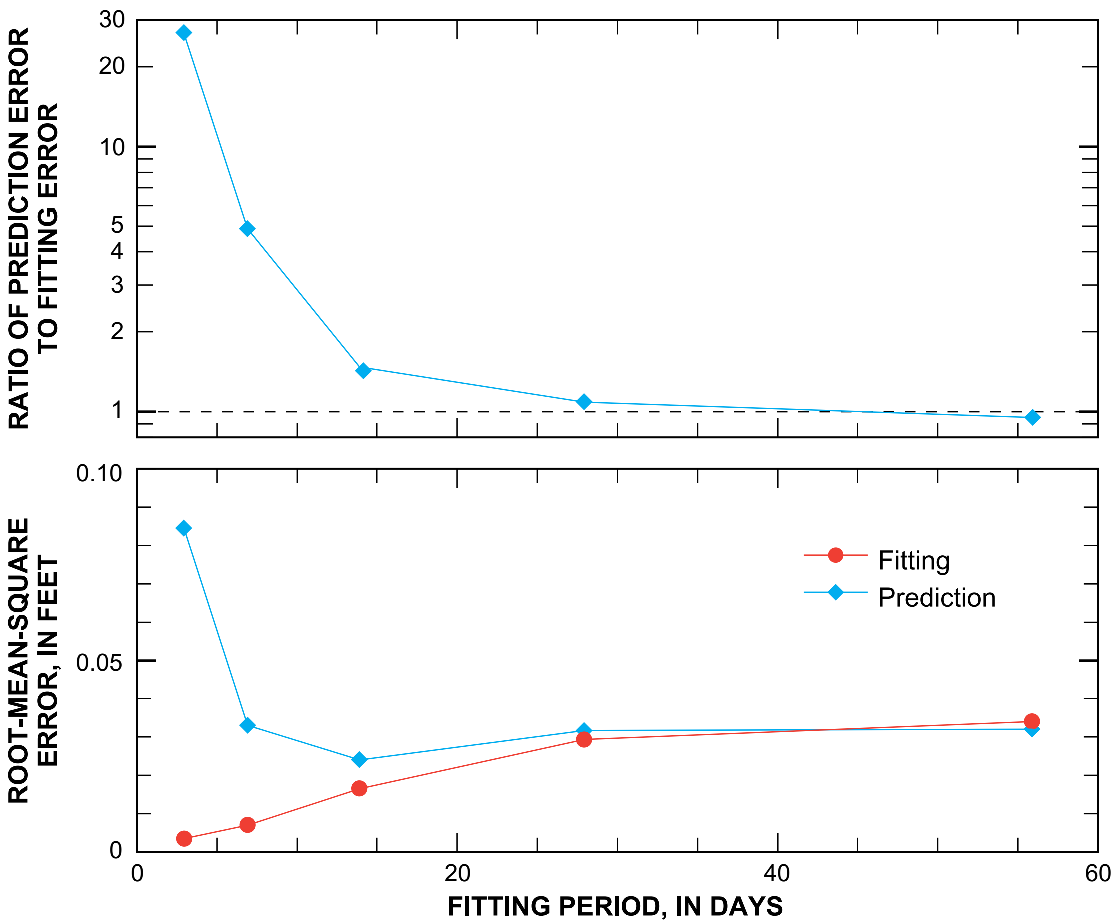


Figure 11. Fitting and prediction errors for five synthetic water levels in well sct4 in Georgia, with a 7-day prediction period that begins May 27, 2004.

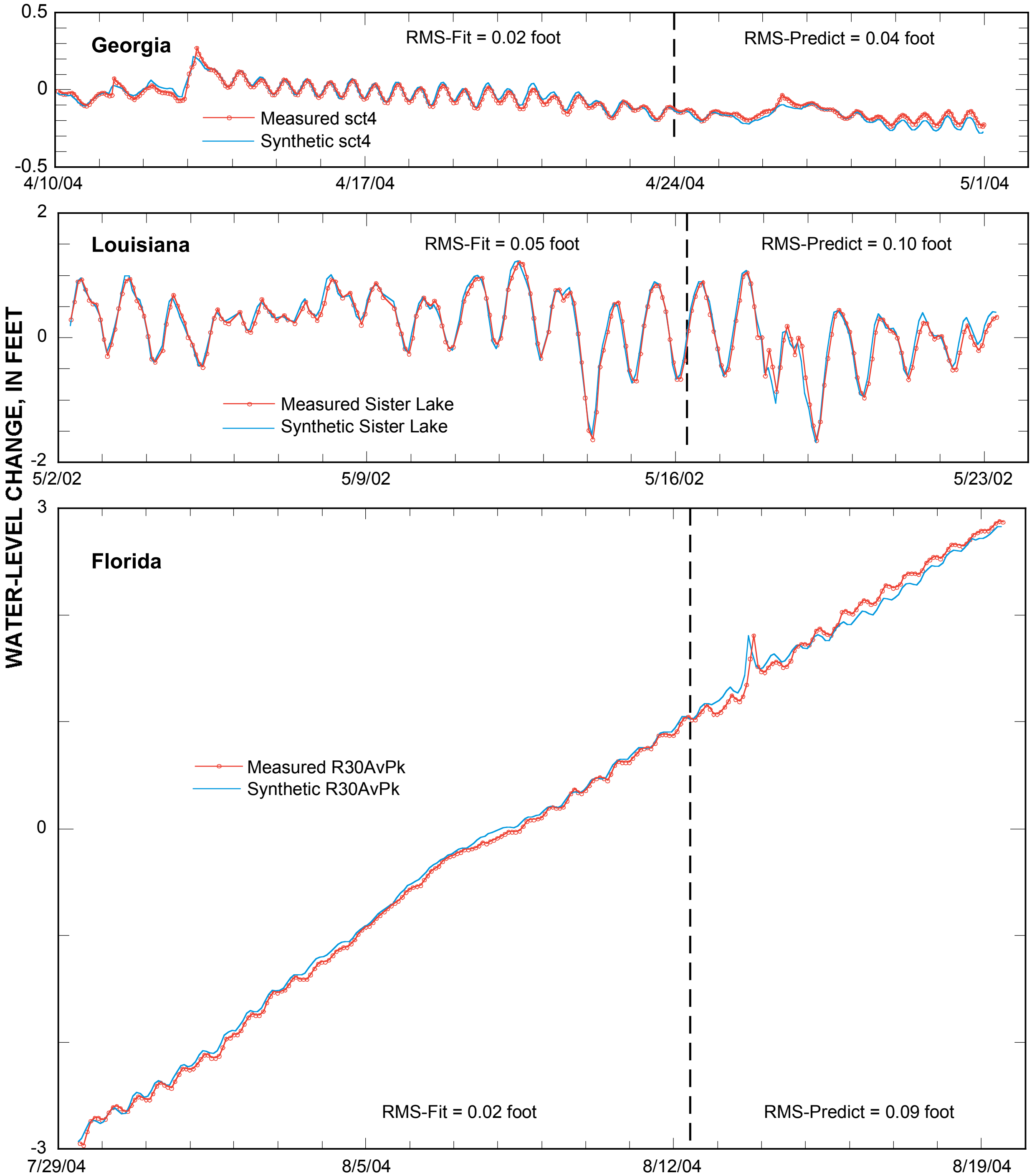


Figure 12. Measured and synthetic water levels at sites sct4 in Georgia, Sister Lake in Louisiana, and R30AvPk in Florida during 14-day fitting periods and 7-day prediction periods.

Instructions for Time-Series Analysis Workbook

Time-series analysis, data filtering, synthetic water-level simulation, and drawdown estimation are performed within an Excel workbook, *TimeSeries+Drawdown.RV1.0.xls*. Workbook pages are revealed sequentially as needed to analyze time series. All four workbook pages remain visible after being used unless the "RESET ALL" button on the **TimeSeries** page is pressed. Pressing the "RESET ALL" button eliminates all user-defined data, removes all series from charts, and hides all worksheets but the **TimeSeries** page.

The Time-Series Analysis workbook relies on inherent features of Excel 9.0+ and user-defined macros. The macro security level should be set to Medium (fig. 13) because the program will not function if the macro security level is set to High or Very high. The program will work with a macro security level of Low but this is ill advised. All macros, including malicious viruses, are activated without warning upon opening Excel. This program also needs access to VBA and the "Trust all installed add-ins and templates" option must be checked (fig. 13).

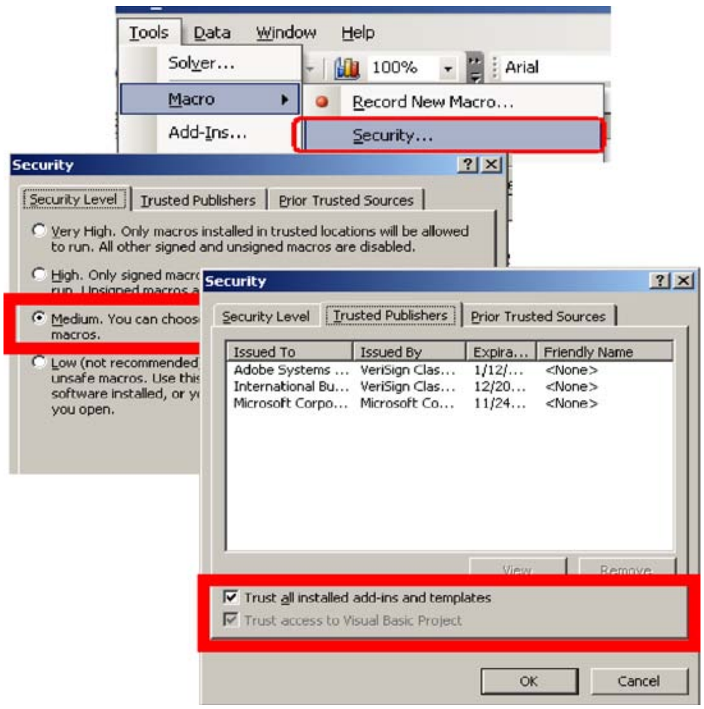
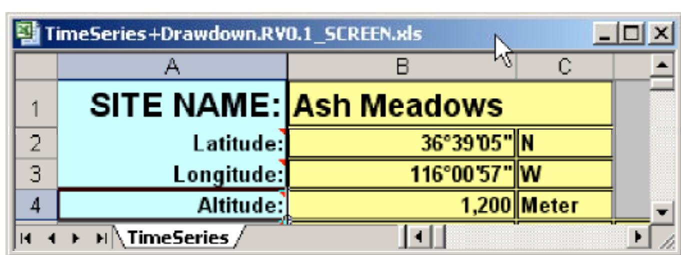
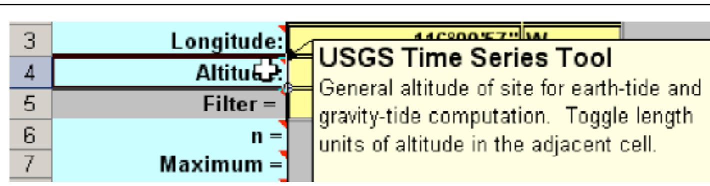


Figure 13. Example of Excel forms for changing security settings.

The Time-Series Analysis workbook fits synthetic water levels to measured water levels with the SOLVER add-in. The SOLVER is a general optimization routine that adjusts cell values to meet a user-specified objective. Adjusted cell values, parameters, can be constrained to user-defined ranges. Sum-of-squares differences are minimized in the Time-Series Analysis workbook. The SOLVER add-in is distributed with Excel and users must have this add-in installed. The path to the SOLVER library changes between versions of Excel; therefore, references to the SOLVER library are specified dynamically and trusted access to VBA is needed.

Input and heading cells have been identified with consistent formatting. Input cells are formatted with a pale yellow background and bounded by double lines. Data should be entered by either typing directly or pasting special as values. Help for data input is provided by the comments that are tagged in the associated heading cell.

Cell Formatting in the Time-Series Analysis Workbook

INPUT cells are formatted with a pale yellow background and bounded by double lines. Unused areas are shaded grey.	
HEADING cells are formatted with a light blue background. Embedded comments explain the related input.	

Step-by-Step Instructions

Step-by-step instructions for the TimeSeries+Drawdown spreadsheet also are provided in the appendix. The step-by-step instructions explicitly track each operation used to analyze the Nevada example. Users are referred specifically to a workbook, page, and cell for each operation. Limited descriptions of the actions are reported.

TimeSeries Page

All data are entered and stored on the **TimeSeries** page. Time-series are entered with multiple responses for a given time (fig. 14, columns B:D) or as independent time-response pairs. Columns of time entries are differentiated from columns of measured responses by the “DATE-TIME” label in row 12. Site name and location specified on the **TimeSeries** page. Latitude, longitude, and altitude are needed to compute the areal strain and gravity tides (Harrison, 1971).

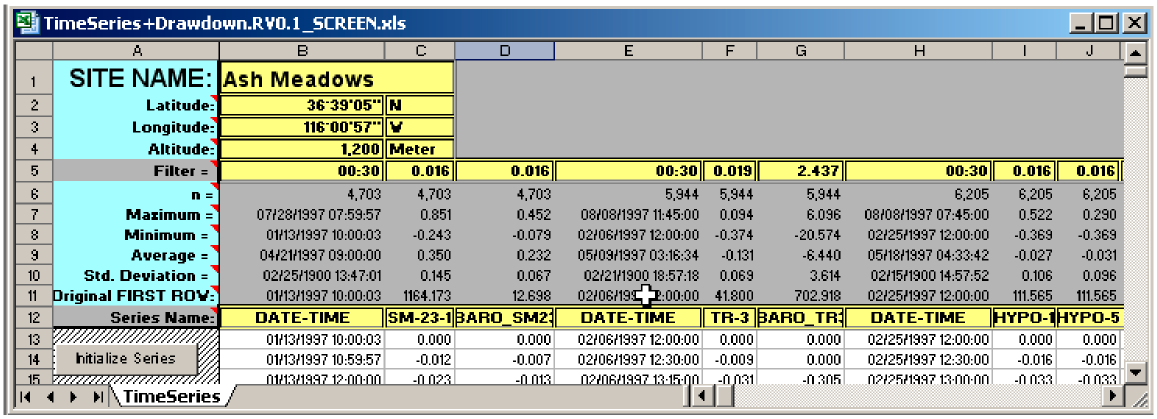
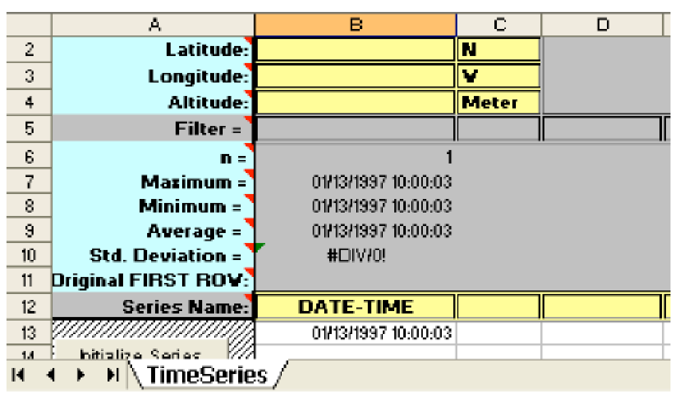


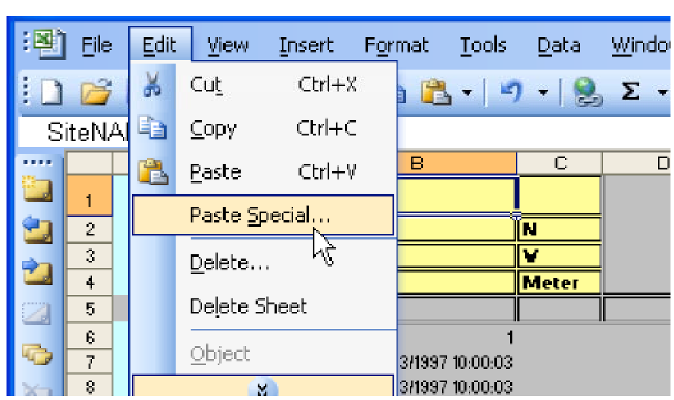
Figure 14. Example of TimeSeries page with data entered.

Pasting Data into the Time-Series Analysis Workbook

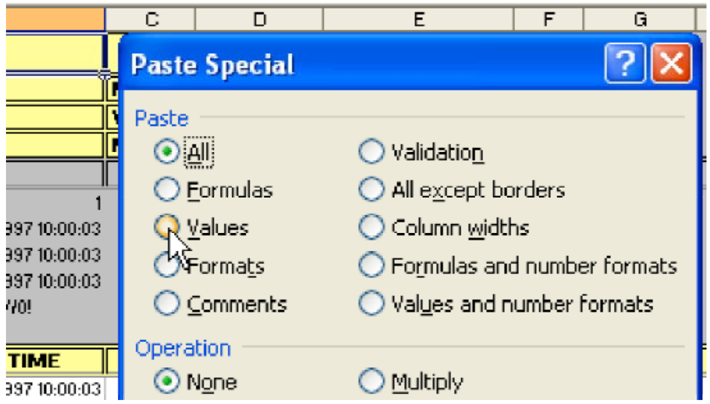
Analysis workbook is distributed with no data and only the **TimeSeries** page visible. Arrange input series in a data-source workbook as contiguous blocks of time and water level. *NV_WLsource.xls* is the data-source workbook that is distributed as an example.



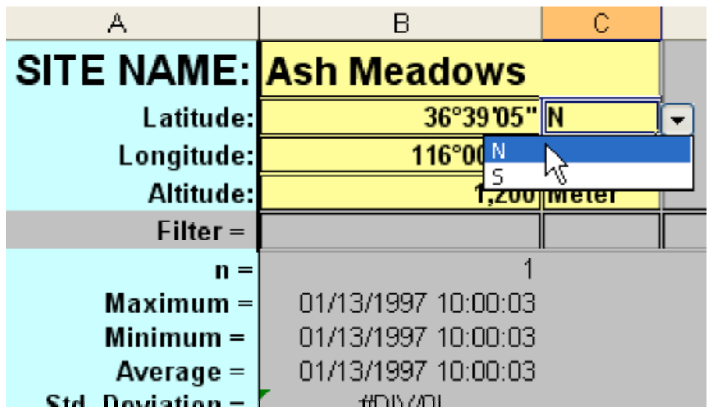
Copy data from the data-source workbook and Paste Special… to the analysis workbook.



Paste Special as values to preserve formatting in the analysis workbook and break links to the data-source workbook.

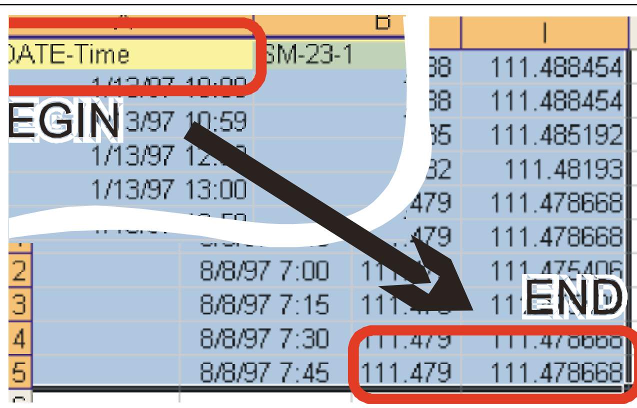


Use the pulldowns in cells C2:C3 to designate the correct hemispheres for latitude and longitude. Assign the correct altitude units in cell C4.

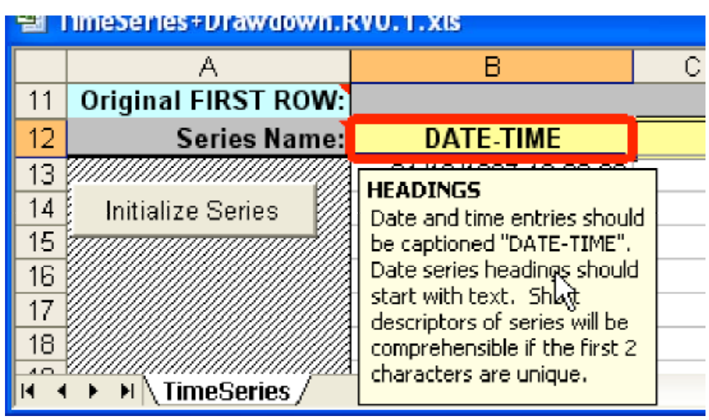


Copy the large data block from the data-source workbook by Selecting the upper-left cell, Holding the SHIFT key & Pressing <ctrl>+<end>. Copy region into memory.

Activate the analysis workbook. Paste Special as Values to cell B12.



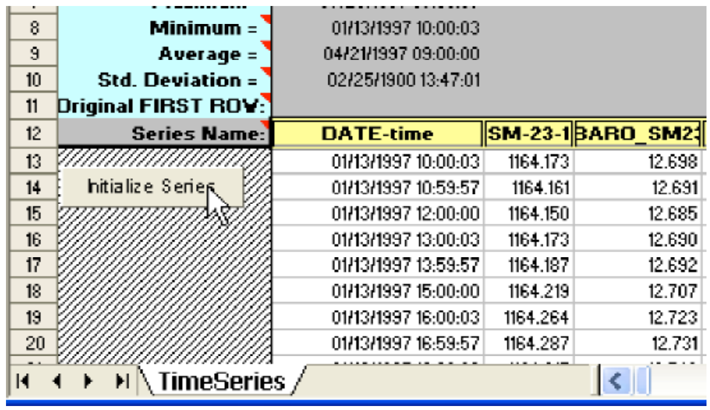
Date and time entries should be captioned "DATE-TIME". Date series headings should start with text. Short descriptors of time-series components will be comprehensible if the first 2 characters are unique.



Time series can be filtered to reduce dataset size by eliminating less significant data points. A measured response is judged necessary if the response changes more than a user-specified amount since the last stored response. Small changes are defined by the smallest non-zero change in each data series to avoid specifying units. A user-specified maximum time between measurements also constrains the amount of data to be eliminated. These specifications are defined through Filter-Explanation-&-Query wizard.

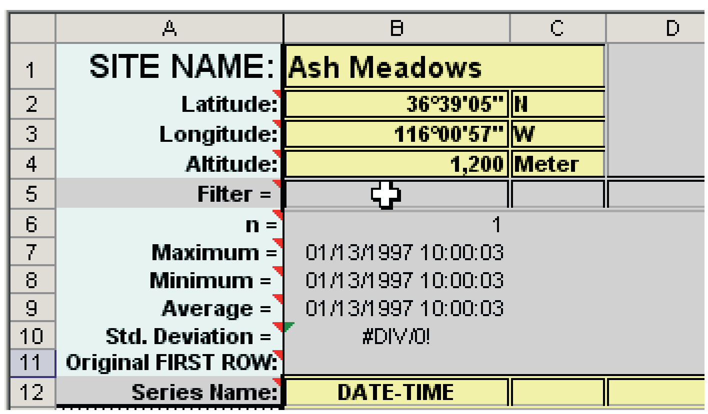
Initializing and Filtering Time Series

Press the “Initialize Series” button after inserting data.



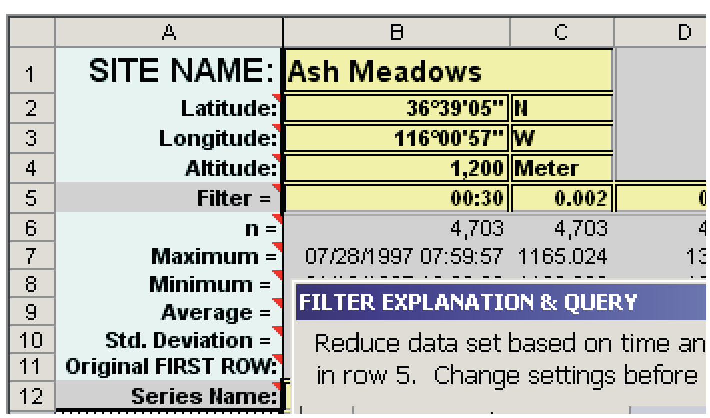
Row 5, the filter row, will change formatting from column B to the right.

Cells will change from gray to light yellow.

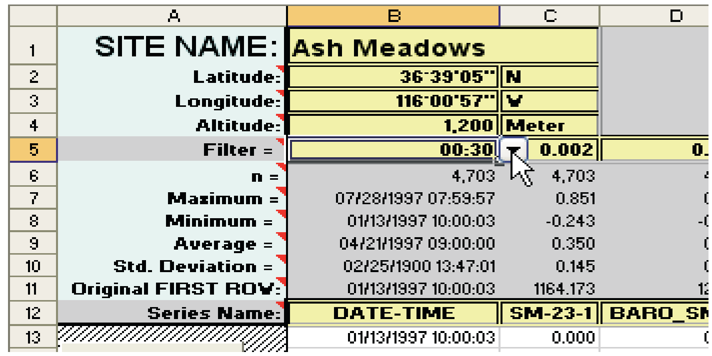


The Filter-Explanation-&-Query wizard will appear. Change filter criteria in row 5 of the **TimeSeries** worksheet.

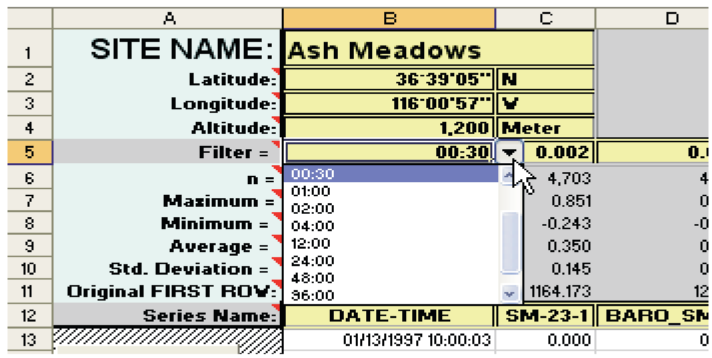
If desired, reduce data set based on time and measurement resolution. Change ***all*** settings before pressing the FILTER button.



Maximum time between filtered entries is assigned in DATE-TIME columns.

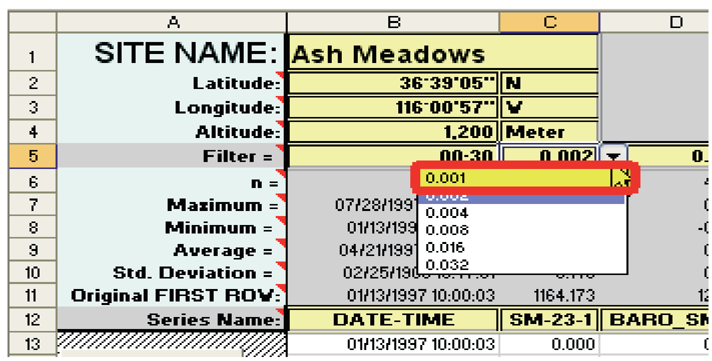


As much as a 30-minute gap can exist between filtered entries in this example.
Default is 30 minutes.



Data changes less than the filter value are considered insignificant and will be eliminated if the time between entries is less than the maximum time that was specified in the DATE-TIME column.

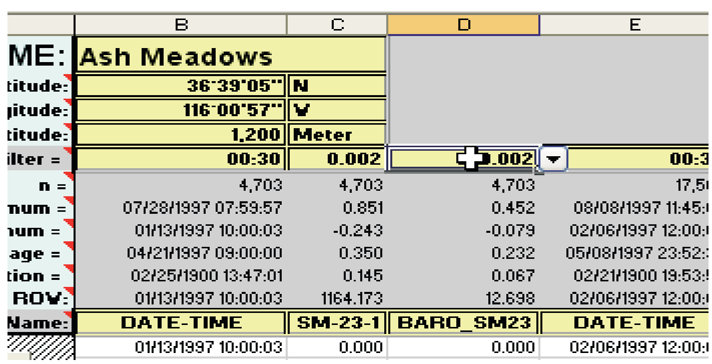
Choices are 1, 2, 4, 8, and 16 times the minimum, non-zero change between entries.

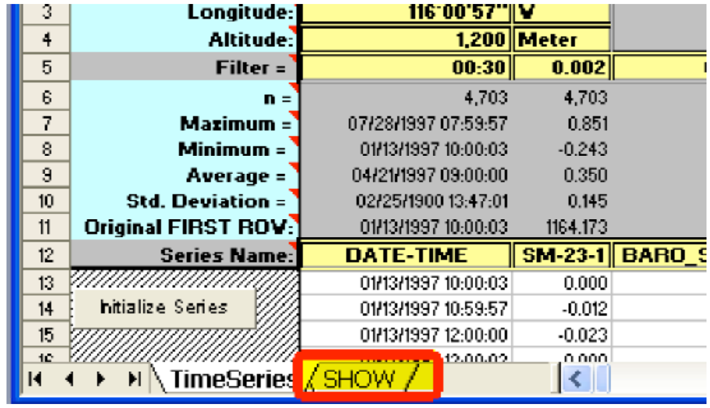


Revise all entries in row 5 before filtering the data set.

MAINTAIN BACK-UPS

Raw data are eliminated permanently and replaced by filtered data!!!

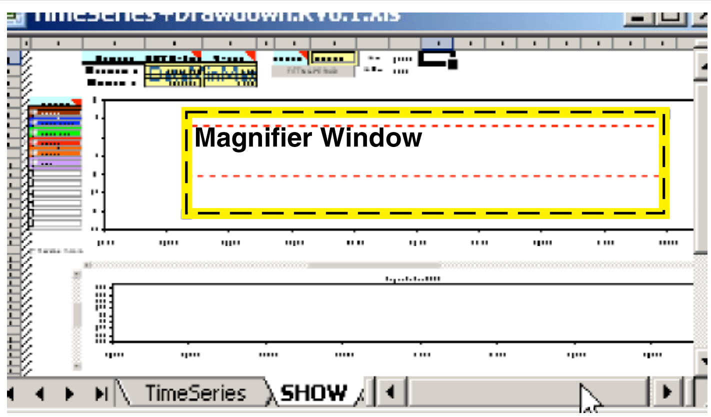


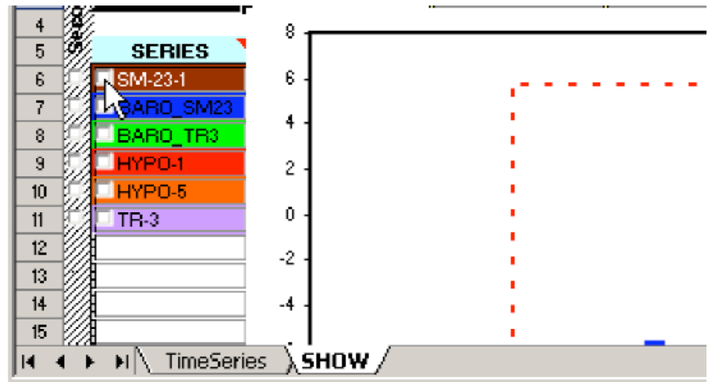
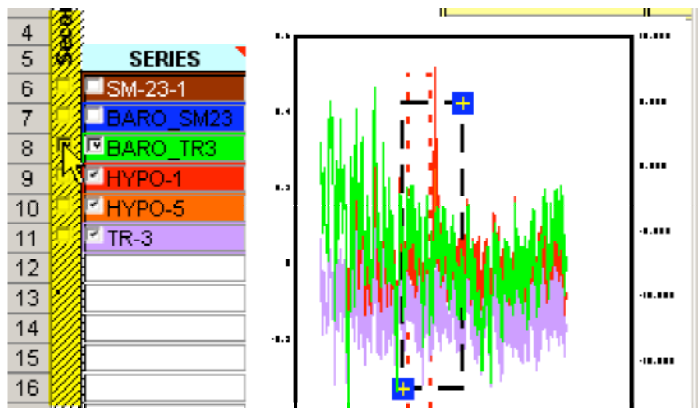
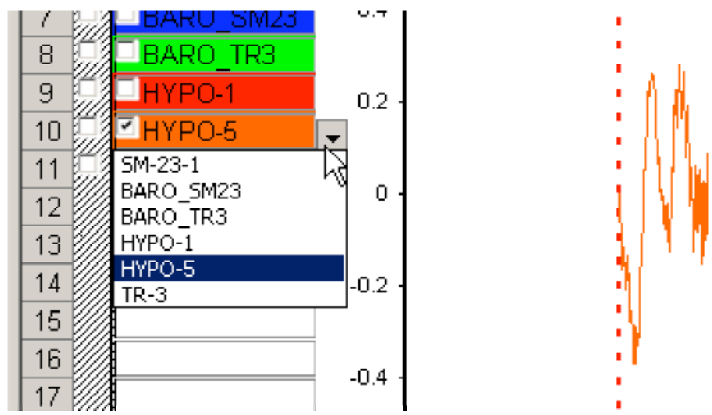
Pressing the “Initialize Series” button on the **TimeSeries** worksheet also causes the **SHOW** worksheet to be revealed.	

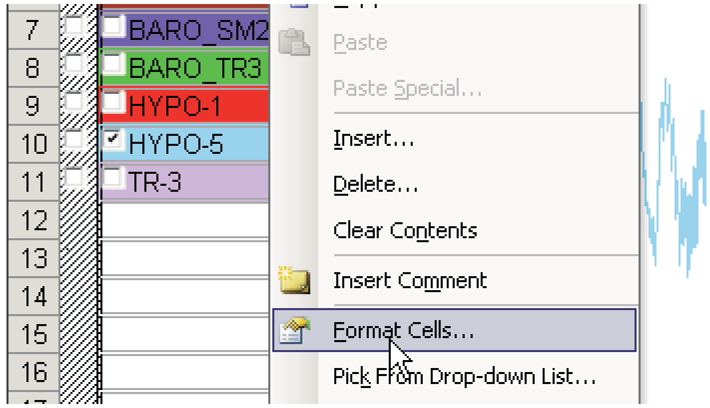
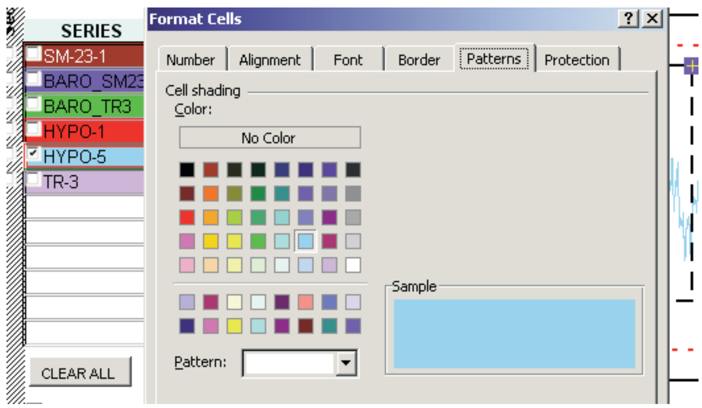
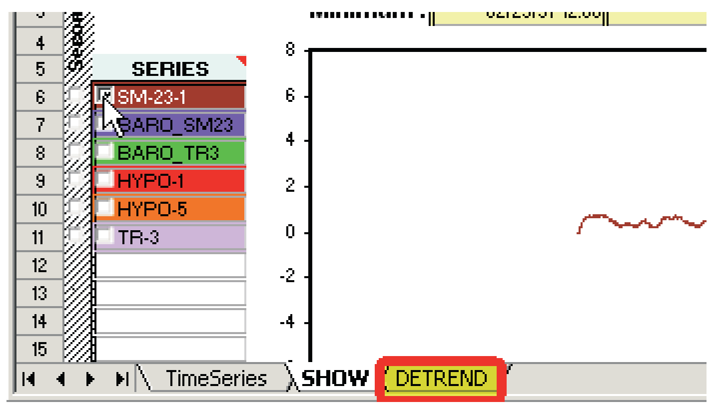
SHOW Page

Time-series data are viewed on the **SHOW** page, which was revealed after pressing the “Initialize Series” button on the **TimeSeries** page. Time-series data that could improve synthetic water-level simulation can be identified by inspecting hydrographs. Periods before an aquifer test are best for fitting synthetic water levels to measured water levels.

Viewing Time Series

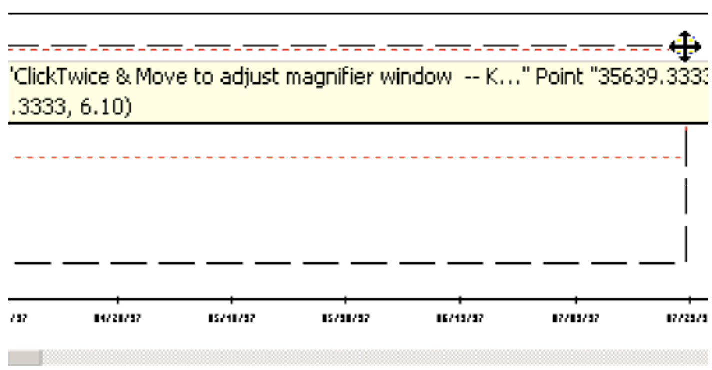
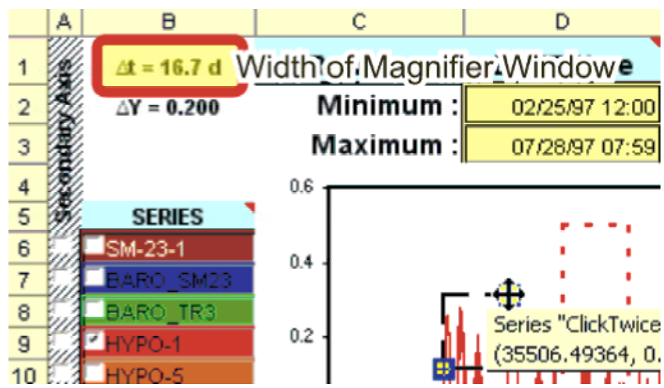
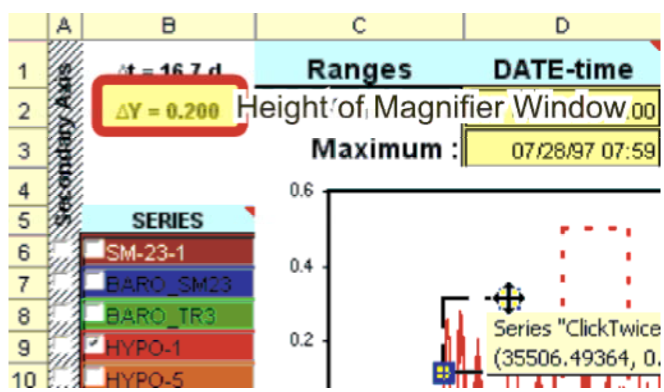
Time series are viewed on the **SHOW** worksheet. Periods of record can be magnified. FITTING, ESTIMATION, and FEEL GOOD periods can be defined graphically.	

Check box in column B to display a time series.	
Check box in column A to display on secondary axis.	
Different series names can be selected from a pull-down menu in cells B6:B17.	

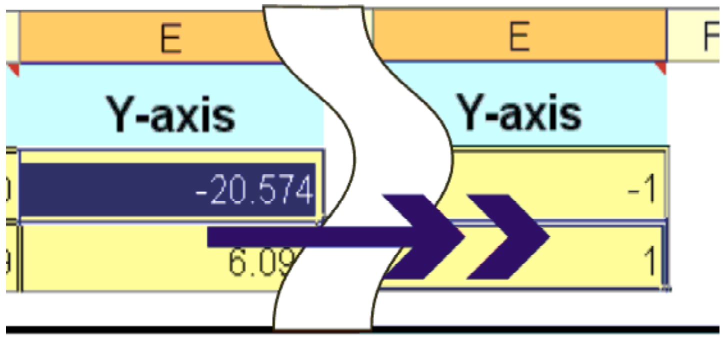
<table>
<tr>
<td>Series color will match the color of the cell background which can be changed by selecting a cell and changing the pattern color.</td>
<td>
</td>
</tr>
<tr>
<td>Activate the FORMAT CELLS panel with Format>Cells and select the PATTERNS tab.</td>
<td>
</td>
</tr>
<tr>
<td>Viewing any series on the SHOW worksheet also causes the DETREND worksheet to be revealed.</td>
<td>
</td>
</tr>
</table>

Time series are plotted on two charts so that selected records can be viewed at magnified scales. Height and width of magnifier window are adjusted graphically in the upper chart. Magnified area is viewed by sliding the vertical and horizontal scrollbars that bracket the lower window. Scrollbar sensitivity is controlled by minimum and maximum extents that are specified in cells D2:E3.

Magnifying Selected Periods of Time Series

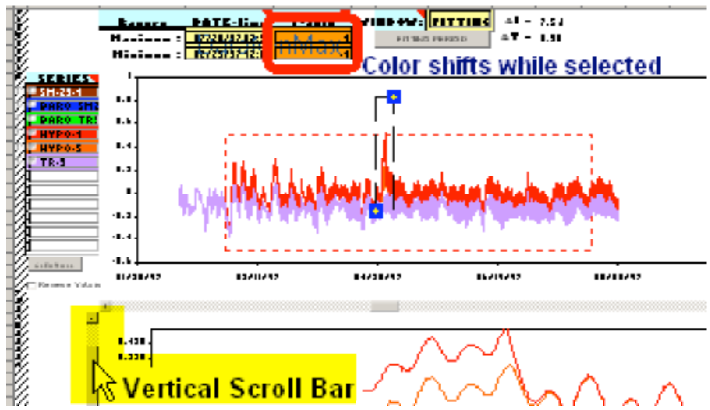
Adjust Magnifier Window A cross-arrow will appear with 2 clicks (not a double-click) on either the upper-right or lower-left handles.	
Move horizontally to change width of magnifier window which is reported in cell B1.	
Move vertically to change height of magnifier window which is reported in cell B2.	

Minimum (E2) and maximum (E3) values define the limits of the vertical scrollbar. Range frequently is not initialized well when amplitudes of series differ greatly.



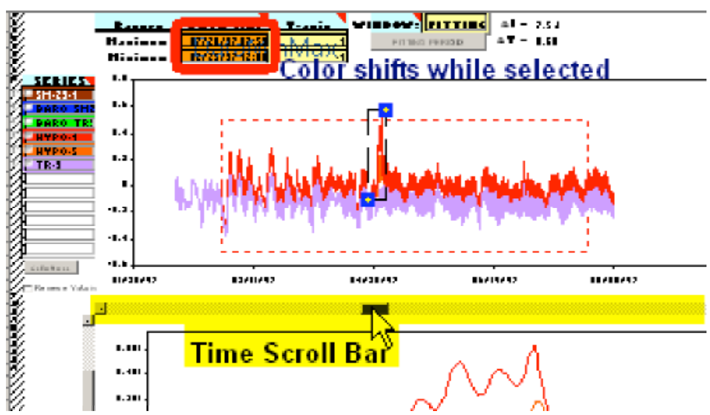
Enter reasonable minimum (E2) and maximum (E3) values of the Y-axis to reduce sensitivity of the vertical scrollbar.

Color of cells shifts from yellow to orange while scrollbar is selected.



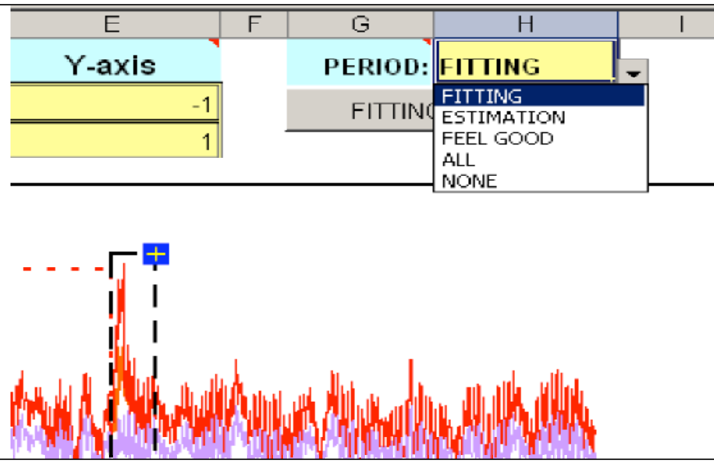
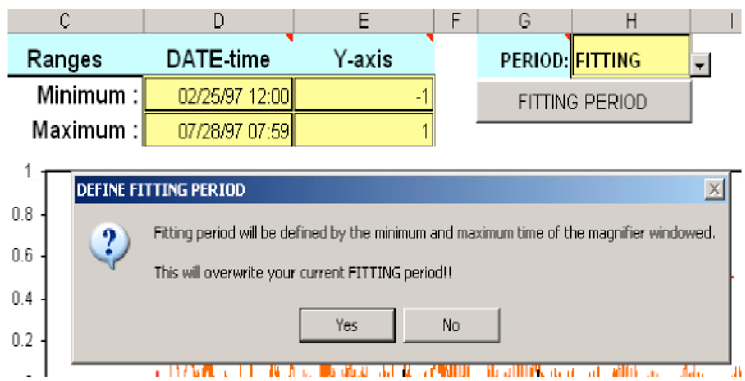
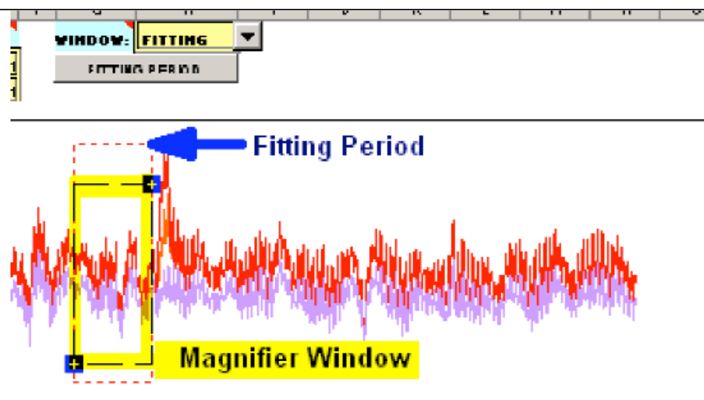
Minimum (D2) and maximum (D3) times define the limits of the horizontal scrollbar.

Color of cells shifts from yellow to orange while scrollbar is selected.

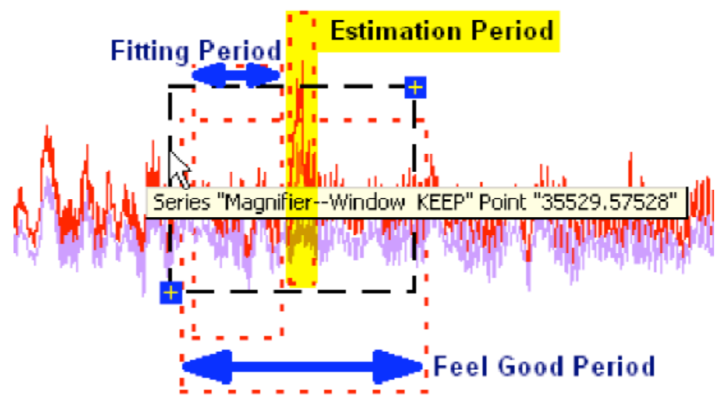


Fitting, estimation, and feel-good periods can be defined graphically from the SHOW page. Define the minimum and maximum times of a period with the magnifier window. Press the gray button in cell G2 to define the beginning and ending of a period. The fitting, estimation, and feel-good periods are defined in cells F27:F28, G27:G28, and H27:H28, respectively, on the DETREND page. Estimation periods for estimating drawdowns should be defined by typing directly into cells G27:G28 on the DETREND page.

Graphically Defining Fitting, Estimation, and Feel-Good Periods

<table>
<tr>
<td>Synthetic time series are simulated and matched to measured time series in the FITTING period.</td>
<td>
</td>
</tr>
<tr>
<td>The Command button will force minimum and maximum times of a selected period to the extents of the magnifier window.</td>
<td>
</td>
</tr>
<tr>
<td>The Fitting period and width of the magnifier window will coincide after pushing the command button and accepting the message choice.</td>
<td>
</td>
</tr>
</table>

Drawdowns or other anomalous responses are estimated by differencing synthetic and measured time series during the ESTIMATION period. Synthetic and measured time series are viewed for any arbitrary period in the FEEL GOOD period.



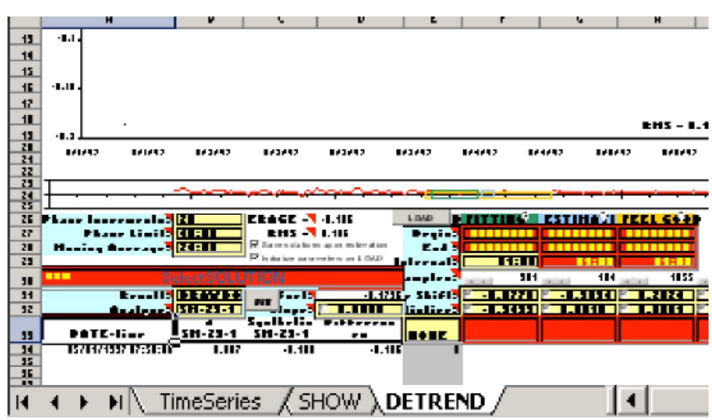
DETREND Page

Synthetic water levels are simulated and drawdowns are estimated from the **DETREND** page. Synthetic water levels can be simulated from a maximum of 24 time series, cells F33:AC33, plus a linear trend, cell D32. Raw, moving average, and differences between raw and moving averages of each user-defined series are available. Earth-tide and gravity-tide series are computed at 30-minute intervals from internal functions.

The estimation period in the Nevada example is from 5/1/1997 8:00 to 5/5/1997 8:00.

Major Features of the DETREND Page

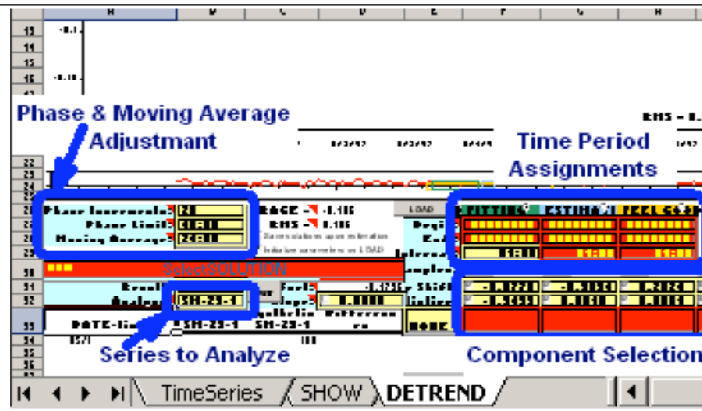
Synthetic time series are simulated and drawdowns are estimated from the **DETREND** worksheet.



<table>
<tr>
<td>

PRIMARY SELECTIONS
Assign phase-shift and moving average criteria, cells (B26:B28)
Refine time periods and sub-sampling, cells (F27:H29).
Select series to analyze, (B32).
Select components of synthetic time series, cells (F33:AC33).

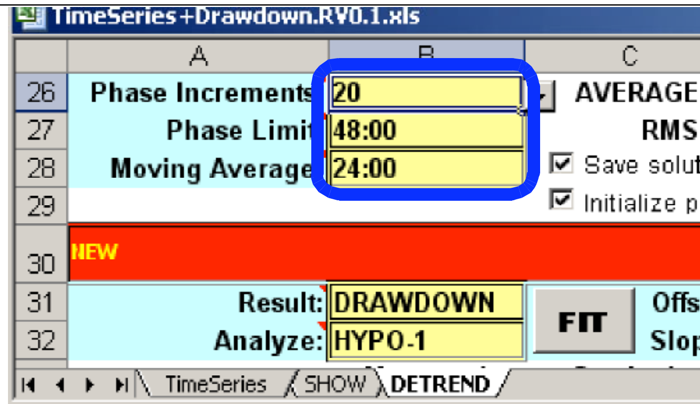
</td>
<td>



</td>
</tr>
<tr>
<td>

Phase increment is the number of subdivisions between the minimum and maximum phase-limit.
Moving averages of original series are averaged over the user-specified period.

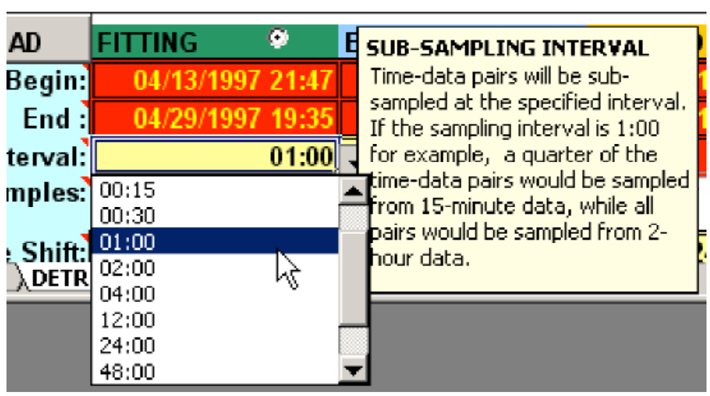
</td>
<td>



</td>
</tr>
<tr>
<td>

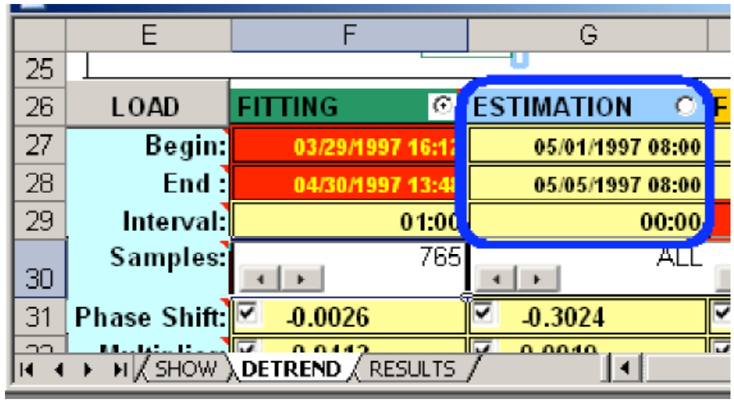
Begin is the first time sampled, row 27. End is the last time sampled, row 28. Interval defines the frequency of sub-sampling, row 29. All available data pairs will be sampled if an interval of 00:00 is specified.

</td>
<td>

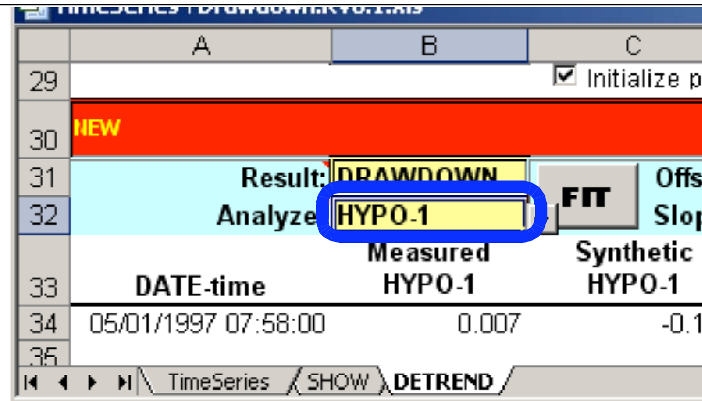


</td>
</tr>
</table>

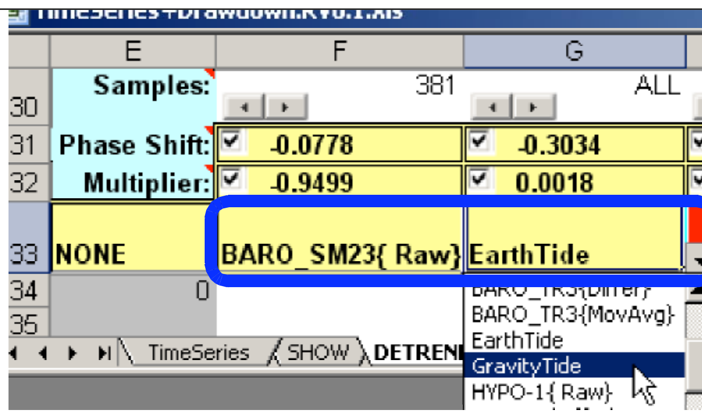
AQUIFER TESTS
Beginning of ESTIMATION, column G, are when pumping begins. End of ESTIMATION either is when pumping or recovery ceases.
Both values should be typed directly.
The estimation period in the Nevada example is from 5/1/1997 8:00 to 5/5/1997 8:00.



Time series to be analyzed, cell (B32), which is selected from a list.



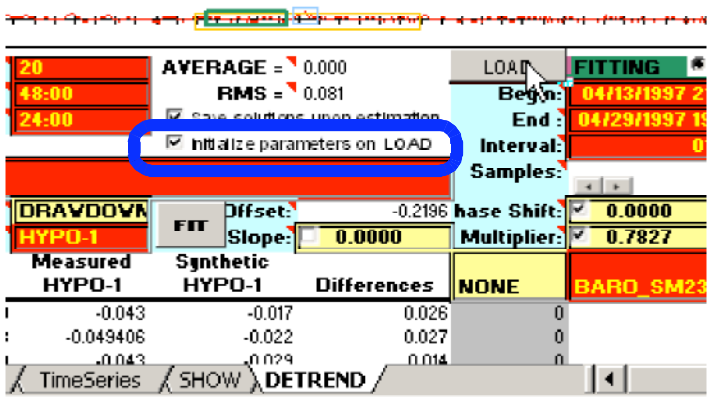
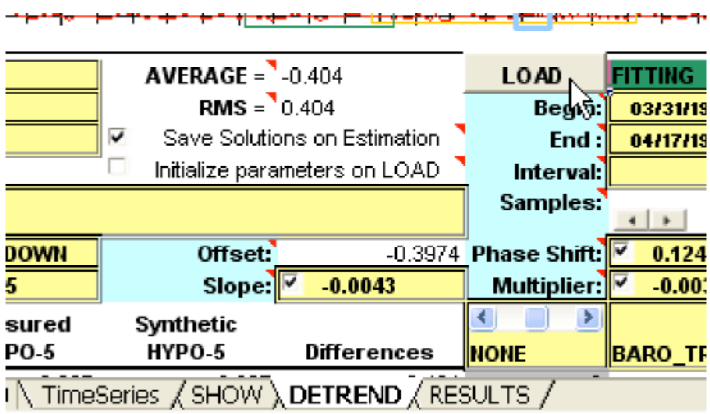
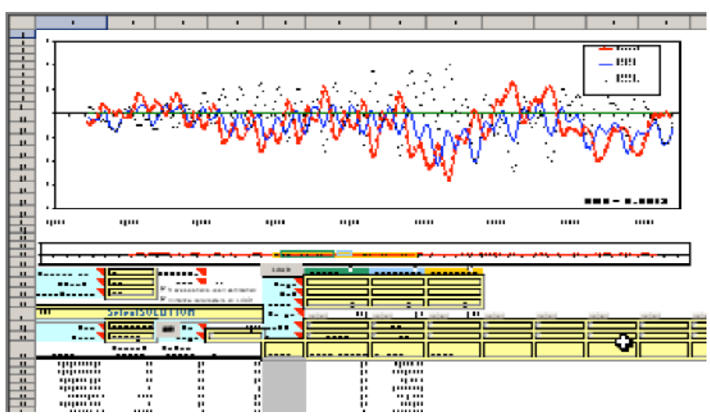
Select components of synthetic time series, cells (F33:AC33). Raw, moving average, and differences between raw and moving averages of each series are available in addition to earth-tide and gravity tide components. Checked cells are estimated.

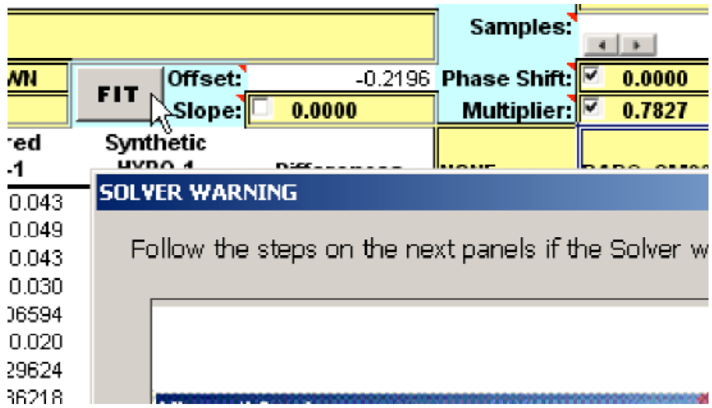
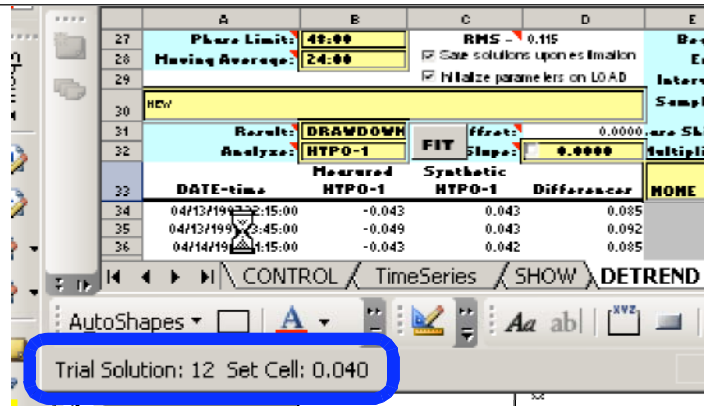


Synthetic time-series components are interpolated linearly from the user-supplied time series because fitting works when the functions are continuous. Subsets of the specified time series and their derivatives are copied to a hidden worksheet, TS3, when a new synthetic time series is loaded. Subsets are used because applying look-up functions to limited periods is faster.

Synthetic time series are estimated by fitting to measured values when an anomalous stress, such as pumping, is not present. Each component of a synthetic time series is modified with a multiplier that changes amplitude, row 32, and a constant that shifts phase, row 31. Amplitude and phase shift estimates typically are non-unique. This is not a limitation because synthetic time series are the result of interest, not the parameter estimates.

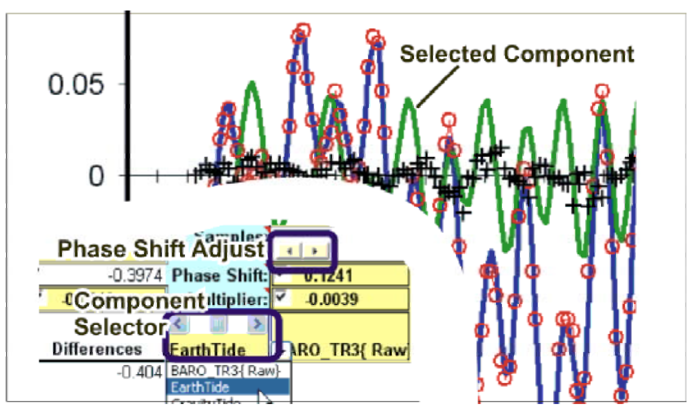
Loading and Fitting Synthetic Series

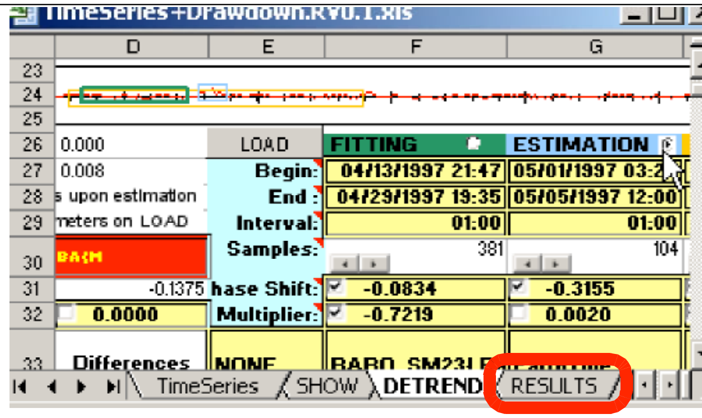
Phase shifts and multipliers will be initialized if option at cell C29 is checked. Cells that are not in agreement with the loaded time series and components are displayed with red backgrounds and bright yellow text.	
Cell content is forced into agreement after loading a time series and components. All input cells will revert to pale yellow backgrounds with black text.	
Synthetic, measured, and difference time series appear for the FITTING period after loading. Differences will be great if initialized at load.	

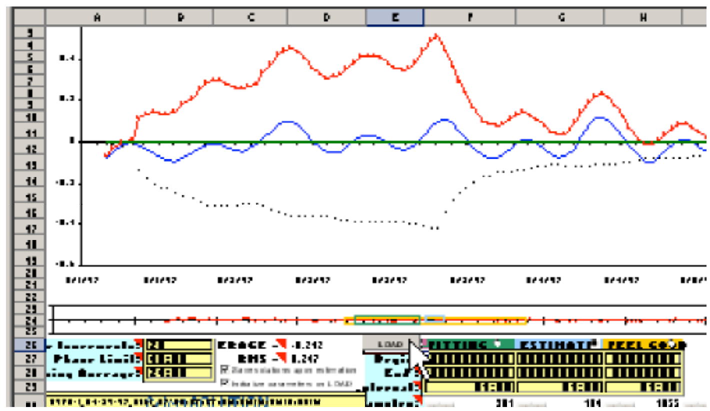
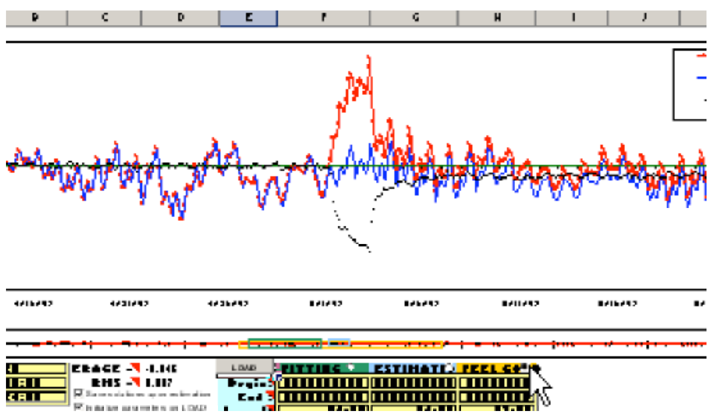
Press the FIT button to minimize the differences. Follow instructions in SOLVER WARNING for the first push of the FIT button. Solver panel must be activated and dismissed manually, once.	
Reduction of RMS error can be viewed in the lower left corner of the Excel window as the Solver minimizes the differences.	

Drawdown estimates are differences between measured and synthetic water levels. The initial difference between measured and synthetic water levels at the beginning of a test is eliminated by subtracting the initial difference from all synthetic water levels.

Viewing Components and Estimating Drawdowns

View individual components by changing selection in cell E33. Phase shift of selected component can be adjusted with slider in cell E33. Test effect of incremental phase change with the spin buttons in cells F30:AC30.	

<table>
<tr>
<td>Estimating any drawdown or detrended time-series on the DETREND worksheet also causes the RESULTS worksheet to be revealed.</td>
<td>


</td>
</tr>
<tr>
<td>Time series and components for the estimation period will be created after pressing the LOAD button.</td>
<td></td>
</tr>
<tr>
<td>Synthetic, measured, and difference time series are viewed for any arbitrary period when FEEL GOOD is selected and the series are LOADED.</td>
<td></td>
</tr>
</table>

RESULTS Page

Drawdown estimates are viewed and exported to ASCII files from the **RESULTS** page. Drawdowns in each well can be exported to individual, tab-delimited ASCII files, which can be used by software used to calculate hydraulic properties. A well name, starting date, and starting time are written to the header of each drawdown file. Measurement date and time are written with each elapsed time-drawdown pair to help trace spurious responses.

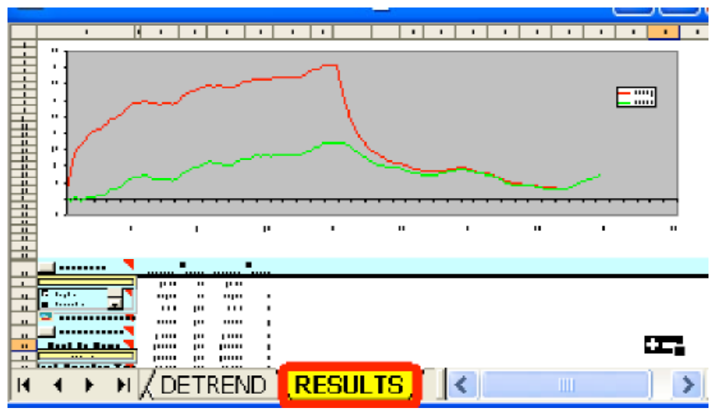
Drawdown responses can be reduced further by averaging during sub-periods with an auxiliary program that is called from the FILTER DRAWDOWN command in cell A33. This program replaces drawdown estimates with a reduced set of time-averaged values. Drawdown and recovery components are divided into three sub-periods each for a total of six sub-periods. Drawdowns are averaged over user-specified intervals for each sub-period.

Drawdown and recovery responses in a well should be defined with less than 100 observations. A drawdown response of 1,000 observations can be represented equally well with fewer than 100 observations. Solution time is directly proportional to the number of observations when using an analytical model. Furthermore, plotted results become unintelligible with too many observations, regardless of the solution technique.

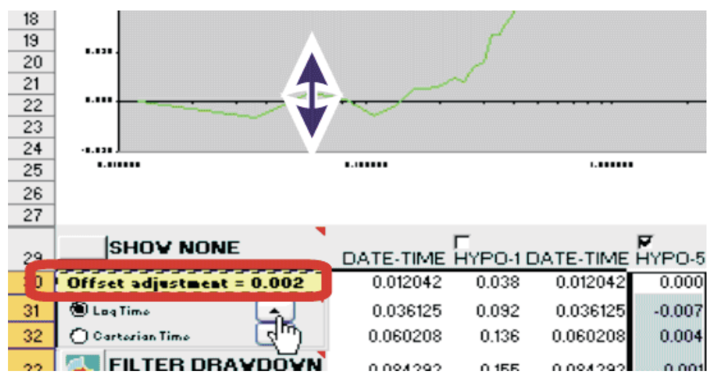
These drawdown estimates are analyzed by copying directly from the spreadsheet application or writing the results to tab-delimited ASCII files.

Viewing, Filtering, and Exporting Drawdowns

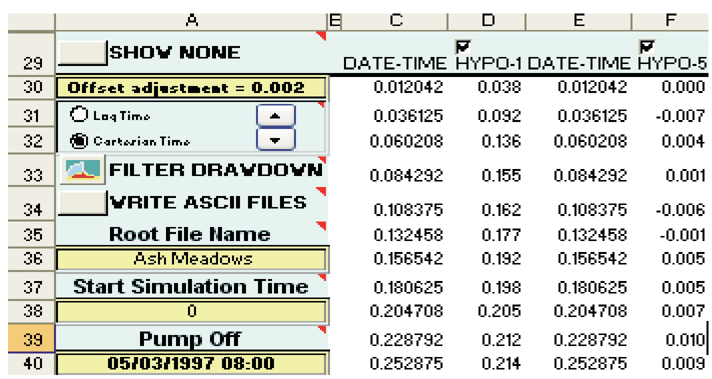
Drawdowns are viewed on the **RESULTS** worksheet.
Results can be written to tab-delimited, ASCII files or copied directly from the **RESULTS** worksheet.



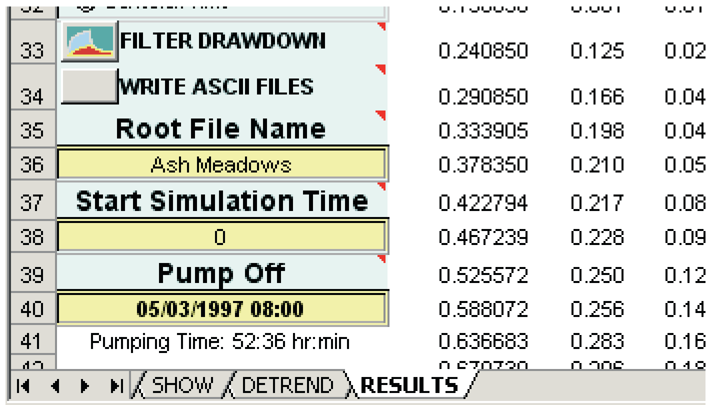
OFFSET ADJUSTMENT
Drawdowns can be adjusted with the spin button so the initial drawdowns are 0. Check the series to adjust before pressing the spin button. Slide a drawdown series up until the minimum drawdown in the series equals 0 if "Noordbergum effect" caused negative drawdowns.



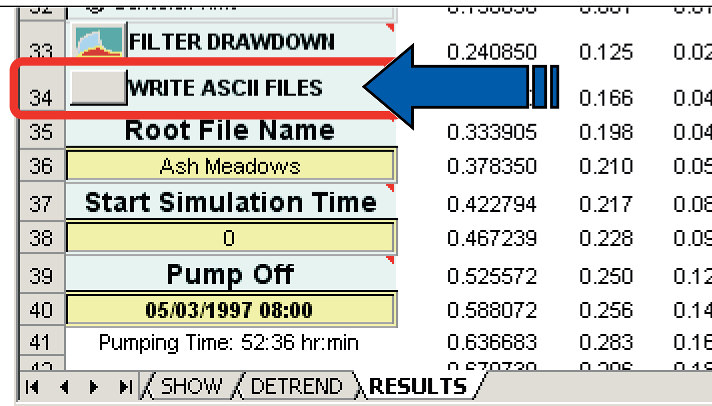
FILTER DRAWDOWN
Replaces drawdown estimates with a reduced set of time-averaged values. Drawdown and recovery components are divided into 3 sub-periods each for a total of 6 sub-periods. Drawdowns are averaged over user-specified intervals for each sub-period.



Pump Off time should be typed directly.
The pump-off time in the Nevada example is 5/3/1997 8:00.



Drawdown estimates are exported by copying directly from the spreadsheet or writing the results to tab-delimited, ASCII files.



Limitations

The TimeSeries+Drawdown spreadsheet was developed for Microsoft Excel which limits the program. Individual time series are limited to about 65,000 data pairs and should be reduced to less than 32,000 data pairs after filtering. Time series with more than 32,000 data pairs will be truncated in charts because Excel limits each series in a graph to 32,000 pairs.

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Appendix

Step-by-Step Instructions for Nevada Example

The spreadsheets TimeSeries+Drawdown.V1.0.xls, NV_WLsource.xls, and FilterTEMPLATE.AQUSGS are referred in the step-by-step instructions. TimeSeries+Drawdown.V1.0.xls and NV_WLsource.xls are opened directly as conventional Excel files. FilterTEMPLATE.AQUSGS is a specialized tool for filtering drawdown estimates that is called from the TimeSeries+Drawdown.V1.0.xls workbook. Users should not open FilterTEMPLATE.AQUSGS directly.

Instructions are provided in a five column table. The first three columns identify the workbook, page, and cell that should be selected for a specific step. User actions, such as copy, paste, slide, or press, are specified in the fourth column. Limited descriptions of spreadsheet responses to the user actions are reported in column 5. Row colors alternately are changed between white and yellow to indicate a change between pages or workbooks.

Step-by-Step Instructions for Nevada Example

WORKBOOK	Page	Cell	Action	Description
NV_WLsource.xls	NV	B1:B4	Edit > Copy Range	Define name and location of site
TimeSeries+Drawdown.V1.0.xls	TimeSeries	B1	Edit > Paste Special ... Values	
NV_WLsource.xls	NV	A6:I20015	Edit > Copy Range	Define time-series to be analyzed
TimeSeries+Drawdown.V1.0.xls	TimeSeries	B12	Edit > Paste Special ... Values	
TimeSeries+Drawdown.V1.0.xls	TimeSeries	A14	Press “Initialize Series” button	Catalog available time series, initialize time-series filtering process, and reveal the following page, SHOW
TimeSeries+Drawdown.V1.0.xls	TimeSeries	B5	Change settings in Row 5 of the sheet TimeSeries	Follow instructions in the wizard. Change settings on the sheet TimeSeries
TimeSeries+Drawdown.V1.0.xls	TimeSeries		Press “FILTER” button on the “FILTER EXPLANATION & QUERY” form	
TimeSeries+Drawdown.V1.0.xls	TimeSeries		Activate “SHOW” page	
TimeSeries+Drawdown.V1.0.xls	SHOW	B11	Check box and activate “TR-3” hydrograph	Plot hydrograph record
TimeSeries+Drawdown.V1.0.xls	SHOW	B9	Check box and activate “HYPO-1” hydrograph	Plot hydrograph record
TimeSeries+Drawdown.V1.0.xls	SHOW		Grab upper, right handle of magnifier window in the upper plot. Change from (7/28/97 07:59:57, 6.10) to ~(3/18/97, -19.4).	Adjust magnifier window to view water levels over a three week period.
TimeSeries+Drawdown.V1.0.xls	SHOW	B1	Magnifier window should be about 20 days wide	
TimeSeries+Drawdown.V1.0.xls	SHOW	B2	Magnifier window should be about 1 ft high	
TimeSeries+Drawdown.V1.0.xls	SHOW	E2	Change cell E2 to -1	
TimeSeries+Drawdown.V1.0.xls	SHOW	E3	Change cell E3 to +1	
TimeSeries+Drawdown.V1.0.xls	SHOW	B23	Move slider on vertical slide bar. Click again if cells E2:E3 remain orange.	Magnify periods of record graphically.

Step-by-Step Instructions for Nevada Example—Continued

WORKBOOK	Page	Cell	Action	Description
TimeSeries+Drawdown.V1.0.xls	SHOW	C22	Move slider on horizontal slide bar. Click again if cells D2:D3 remain orange.	
TimeSeries+Drawdown.V1.0.xls	SHOW	F22	Upper, right handle of magnifier window should be about 4/30/97 after adjusting the slider bar	
TimeSeries+Drawdown.V1.0.xls	SHOW	H1	Change to the FITTING selection	
TimeSeries+Drawdown.V1.0.xls	SHOW	G2	Press “FITTING PERIOD” button	Define a “FITTING PERIOD” graphically.
TimeSeries+Drawdown.V1.0.xls	SHOW	B1	Adjust magnifier window in upper plot to be about 4-d wide.	
TimeSeries+Drawdown.V1.0.xls	SHOW		Move slider on horizontal slide bar so left side of magnifier window is near 5/1/97 8:00 AM	
TimeSeries+Drawdown.V1.0.xls	SHOW	H1	Change to the ESTIMATION selection	
TimeSeries+Drawdown.V1.0.xls	SHOW	I1	Select an unused cell to force selection button to change	
TimeSeries+Drawdown.V1.0.xls	SHOW	G2	Press “ESTIMATION PERIOD” button	Define an “ESTIMATION PERIOD” graphically which is not a good idea for aquifer test analyses.
TimeSeries+Drawdown.V1.0.xls	SHOW	B1	Adjust magnifier window in upper plot to be about 40-d wide.	
TimeSeries+Drawdown.V1.0.xls	SHOW		Move slider on horizontal slide bar so left side of magnifier window is near 4/13/97	
TimeSeries+Drawdown.V1.0.xls	SHOW	H1	Change to the FEEL GOOD selection	
TimeSeries+Drawdown.V1.0.xls	SHOW	I1	Select an unused cell to force selection button to change	
TimeSeries+Drawdown.V1.0.xls	SHOW	G2	Press “FEEL GOOD” button	Graphically define a period for viewing both fitting and estimation periods simultaneously.
TimeSeries+Drawdown.V1.0.xls	SHOW		Activate “DETREND” page	
TimeSeries+Drawdown.V1.0.xls	DETREND	G27	Change cell G27 to 5/1/97 8:00	Specify beginning of aquifer test
TimeSeries+Drawdown.V1.0.xls	DETREND	G28	Change cell G28 to 5/5/97 8:00	Specify end of recovery period to be analyzed. End of aquifer test is specified in cell A40 on the RE-SULTS page.
TimeSeries+Drawdown.V1.0.xls	DETREND	F29	Change cell F29 to 2 hours	
TimeSeries+Drawdown.V1.0.xls	DETREND	G29	Change cell G29 to 0 hours	
TimeSeries+Drawdown.V1.0.xls	DETREND	H29	Change cell H29 to 4 hours	
TimeSeries+Drawdown.V1.0.xls	DETREND	F26	Select the “FITTING” radio button in cell F26	
TimeSeries+Drawdown.V1.0.xls	DETREND	B32	Select cell B32 and change to HYPO-1	Define components of the synthetic water levels.
TimeSeries+Drawdown.V1.0.xls	DETREND	F33	Select cell F33 and change to BARO_SM23{ Raw}	
TimeSeries+Drawdown.V1.0.xls	DETREND	G33	Select cell G33 and change to EarthTide	
TimeSeries+Drawdown.V1.0.xls	DETREND	H33	Select cell H33 and change to GravityTide	

Step-by-Step Instructions for Nevada Example—Continued

WORKBOOK	Page	Cell	Action	Description
TimeSeries+Drawdown.V1.0.xls	DETREND	I33	Select cell I33 and change to SM-23-1{ Raw}	
TimeSeries+Drawdown.V1.0.xls	DETREND	J33	Select cell J33 and change to SM-23-1{Differ}	
TimeSeries+Drawdown.V1.0.xls	DETREND	K33	Select cell K33 and change to SM-23-1{MovAvg}	
TimeSeries+Drawdown.V1.0.xls	DETREND	E26	Press "LOAD" button	Creates equations for each time-series component that was selected. These equations are limited to the fitting period plus the maximum phase shift.
TimeSeries+Drawdown.V1.0.xls	DETREND	C31	Press "FIT" button	Initiates SOLVER
TimeSeries+Drawdown.V1.0.xls	DETREND		Dismiss SOLVER warning. Call SOLVER and dismiss. SOLVER is called from Tools>Solver	
TimeSeries+Drawdown.V1.0.xls	DETREND	C31	Press "FIT" button	Initiates SOLVER
TimeSeries+Drawdown.V1.0.xls	DETREND	G26	Select the "ESTIMATION" radio button in cell G26	Creates equations for each time-series component that was selected. These equations are limited to the estimation period plus the maximum phase shift. Drawdowns also are estimated and written to the RESULTS page.
TimeSeries+Drawdown.V1.0.xls	DETREND	B32	Select cell B32 and change to HYPO-5	Changes site to analyze.
TimeSeries+Drawdown.V1.0.xls	DETREND	F26	Select the "FITTING" radio button in cell F26	
TimeSeries+Drawdown.V1.0.xls	DETREND	E26	Press "LOAD" button	Creates equations for each time-series component that was selected. These equations are limited to the fitting period plus the maximum phase shift.
TimeSeries+Drawdown.V1.0.xls	DETREND	C31	Press "FIT" button	Initiates SOLVER
TimeSeries+Drawdown.V1.0.xls	DETREND	G26	Select the "ESTIMATION" radio button in cell G26	Creates equations for each time-series component that was selected. These equations are limited to the estimation period plus the maximum phase shift. Drawdowns also are estimated and written to the RESULTS page.
TimeSeries+Drawdown.V1.0.xls	DETREND		Activate "RESULTS" page	
TimeSeries+Drawdown.V1.0.xls	RESULTS	A29	Press "SHOW ALL" to see drawdowns	
TimeSeries+Drawdown.V1.0.xls	RESULTS	A40	Change cell A40 to 5/3/97 8:00AM. Pumping time in cell A41 should read 48:00 hr:min	Specify when pumping ceased for the aquifer test.
TimeSeries+Drawdown.V1.0.xls	RESULTS	A31	Toggle radio button to Log time	
TimeSeries+Drawdown.V1.0.xls	RESULTS	A32	Toggle radio button to Cartesian time	
TimeSeries+Drawdown.V1.0.xls	RESULTS	A33	Press "FILTER DRAWDOWN" button.	Transfers drawdown estimates to another spreadsheet for reducing drawdowns by averaging over user-specified intervals.

Step-by-Step Instructions for Nevada Example—Continued

WORKBOOK	Page	Cell	Action	Description
FilterTEMPLATE.AQUSGS	SEE	F26	Change from 20 to 10	
FilterTEMPLATE.AQUSGS	SEE	F27	Change from 20 to 30	
FilterTEMPLATE.AQUSGS	SEE	F28	Change from 20 to 30	
FilterTEMPLATE.AQUSGS	SEE	F29	Change from 10 to 0	
FilterTEMPLATE.AQUSGS	SEE	F30	Change from 10 to 15	
FilterTEMPLATE.AQUSGS	SEE	I25	Check “Logarithmic Axis”	
FilterTEMPLATE.AQUSGS	SEE	C26	Adjust spin button until End Time in cell E26 is 0d 03:09:00	
FilterTEMPLATE.AQUSGS	SEE	C27	Adjust spin button until End Time in cell E27 is 0d 23:59:00	
FilterTEMPLATE.AQUSGS	SEE	I25	Check “Show recovery after pump off”	
FilterTEMPLATE.AQUSGS	SEE	C29	Adjust spin button until End Time in cell E29 is 2d 00:27:00	
FilterTEMPLATE.AQUSGS	SEE	C30	Adjust spin button until End Time in cell E30 is 2d 14:30:29	
FilterTEMPLATE.AQUSGS	SEE	I25	Uncheck “Show recovery after pump off”	
FilterTEMPLATE.AQUSGS	SEE	I25	Uncheck “Logarithmic Axis”	
FilterTEMPLATE.AQUSGS	SEE	I26	Press “Filter Drawdowns”	Drawdowns are averaged across equally spaced intervals in each sub-period.
FilterTEMPLATE.AQUSGS	SEE	I25	Check “Logarithmic Axis”	
FilterTEMPLATE.AQUSGS	SEE	I26	Press “Filter Drawdowns”	Drawdowns are averaged across log-equally spaced intervals in each sub-period.
FilterTEMPLATE.AQUSGS	SEE	I25	Uncheck “Logarithmic Axis”	
FilterTEMPLATE.AQUSGS	SEE	I26	Press “Filter Drawdowns”	Drawdowns are averaged across equally spaced intervals in each sub-period.
FilterTEMPLATE.AQUSGS	SEE	D32	Select “HYPO-5” from pulldown menu	View filtered and unfiltered drawdowns in well HYPO-5
FilterTEMPLATE.AQUSGS	SEE	D32	Select “HYPO-1” from pulldown menu	View filtered and unfiltered drawdowns in well HYPO-1
FilterTEMPLATE.AQUSGS	SEE	I28	Press “Return Filtered Drawdowns”	Unfiltered drawdowns on the RESULTS page in the TimeSeries+Drawdown.V1.0.xls workbook are cleared and replaced with the filtered drawdowns.
TimeSeries+Drawdown.V1.0.xls	RESULTS	A29	Press “SHOW ALL” 1-2 times until drawdowns are visible	
TimeSeries+Drawdown.V1.0.xls	RESULTS	A34	Press “WRITE ASCII FILES”	The files “Ash Meadows_HYPO-1.txt” and “Ash Meadows_HYPO-5.txt” will be created.

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