Development and Demonstration of a Method for Assessment and Mapping of Ground-Water Level Changes

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Abstract

As ground water is increasingly developed in the Lower Colorado River Basin in Arizona, information on the effects of ground-water withdrawals is needed for assessment of water availability. Individual basin studies have mapped declines for some aquifers and some time periods, but a consistent regional depiction of the declines and associated storage changes has not been done in recent years. An effort to depict ground-water conditions such as long-term and recent water-level changes involves basic hydrologic analyses such as comparison of historical and recent water levels and intervening trends. Data screening and analysis procedures, however, can be developed to assist in the synthesis of information required for such studies. This project is developing such procedures from analyses of alluvial aquifers in the Lower Colorado River Basin, utilizing information available from the U.S. Geological Survey's (USGS) National Water Information System (NWIS) and the Arizona Department of Water Resources' Groundwater Site Inventory (GWSI) databases. An algorithm has been developed that “mines” NWIS and GWSI database files by user-specified selection criteria including date range, season of observation, minimum number of observations, and time span between first and last observation. The algorithm performs a linear regression on the resulting selected water-level observations and an output file is created containing water-level change per year for wells with a user-specified minimum linear coefficient of determination (R^2). A second algorithm uses this

summary data to produce an areal representation of the change in ground-water levels with time based on Voronoi (Thiessen) polygons and a user-specified region of influence for each well.

Method of Analysis of Trends in Ground-water Levels

To facilitate the determination of trends in ground-water levels, a FORTRAN program was written that performs a linear regression on a subset of water-level data chosen interactively from user-specified criteria. A data set containing at a minimum a unique well identifier, well-location coordinates, water-level observations, and dates is required; although additional well information such as well depth and altitude of land surface are useful in constructing informative hydrographs. The user is prompted for the start and end dates of the time period under investigation, and the number of wells with ≥ 2 water-level observations in the specified time period is reported. Once the subset of observations in the requested time period has been determined, the user is prompted to select the data in the subset to be used for trend analysis. Options for this selection are to: use all the water-level observation in the date range, use only seasonal data based on user-specified months of the year, or use only observations that occur at the maximum or minimum amplitude of cyclical data (fig. 1). Multiple subsets can be created by choosing more than one option. The purpose of providing multiple options for subsets of data is to compute an acceptable linear regression that accurately describes the trend of water levels for as many wells as possible. For infrequently measured water levels, as is the case with many wells in Arizona, using all data in the date range provides the most information and the best possibility of identifying a trend in water-level observations. However, data that are collected more frequently, such as is done in Idaho, may benefit from analyses of seasonal (specified months) or cyclical (maximum and minimum) subsets of data.

After choosing the type of data to be used for trend analysis, the user is prompted for the minimum number of water-level observations required for a well to be used in the analysis. Rejecting wells with less than a minimum number of valid measurements allows the user to maximize confidence in the resulting trend information while providing information on tradeoffs between minimum observations and number of selected wells. Following this step the user is provided the option to "bracket" the start and/or end dates. Bracketing requires that at least 1 water-level observation be within a user-specified number of months after the start date and/or before the end date for the well to be given further consideration in the trend analysis. The use of bracketing assures that trends are computed from wells with water-level observations that span the time period under investigation and are not simply grouped together around a single point in time. At this point in the algorithm, subset(s) of water-level data have been produced by choices in date range, type of data (i.e., all, seasonal, maximum amplitude and/or minimum amplitude), minimum number of observations, and possibly start and/or end bracketing.

Linear trends of water level versus time are computed on all remaining subsets of data. Users are prompted for a minimum R^2 value for the well to be included in the output file. The user also chooses the subset of data to be output from all options previously selected (i.e., all, seasonal, maximum amplitude and/or minimum amplitude) as well as any combination of these subsets. The program will output all water-level information and well data for wells obtaining the minimum goodness of linear fit for each of the subsets chosen. If a well appears in more than one subset of data, the subset producing the highest R^2 value is written to the output file. Two files are produced in this final step of the first program: an input file used by the program described in the next section for spatial analysis of ground-water conditions, and an output file containing trend information for each well along with water-level observations and dates used in determining the trend. This second file is used to construct well hydrographs that indicate which water-level observations were used in calculating the trend.

To present regional trends in ground-water conditions computed for selected wells, spatial extrapolation of the well information is desired. For this study, spatial extrapolation of the trend information was performed using the concept of Thiessen (or Voronoi) polygons. Thiessen polygons have been used to analyze spatially distributed data in ecology (individual space per plant or animal), meteorology (areal rainfall estimations from rain gauges) and business (delineation of the marketshed of retail or service nodes), as well as other fields. In this approach, a region of influence for a well is computed by constructing perpendicular bisectors between the well and all other wells in the dataset. The intersections of these bisectors form potential vertices of the Thiessen polygons. Final vertices are chosen as the intersections closest to the well that form a closed loop. Thiessen polygons are constructed so that any location within a polygon is nearer to that polygon's well than to any other well.

A second program was written in FORTRAN to construct modified Thiessen polygons for spatial representation of ground-water trends. The user is first prompted for a maximum distance of influence for a well in the current domain under consideration. The maximum distance creates boundaries at locations where no other wells exist and, therefore, limits the distance to which the recent trend information will be applied. The program computes Thiessen polygon vertices by selecting the nearest intersections of all perpendicular bisectors between a well and all other wells in the domain. Additional points are added between each computed vertex to smooth polygon edges during application of the maximum distance of influence. The user-defined maximum radius of influence is then applied to each vertex of each polygon. If a vertex lies further from a well than the maximum distance of influence, then the vertex is brought to the maximum distance along the line between the well and the original vertex, creating a modified

Thiessen polygon. Vertices are sorted in a clockwise direction, formatted for use with the ArcGIS® tool “text to features” that creates polygon shapefiles, and saved to a polygon coordinates file. An additional file is written that contains trend information, well information, and the file path to the hydrograph with data for each well used to create each polygon. This file is joined with the polygon shapefile in ArcGIS® as an attribute table. This permits display options in ArcGIS® such as shading by trend value as well as hyperlinking between trend polygons and well hydrographs, allowing end users to see further details of water-level observations.

Demonstration of Recent Trend Analyses

Trends in recent water-level observations were computed for wells in the Phoenix, Pinal and Tucson Active Management Areas (AMAs). For these analyses, the time period of interest was from January 1, 1997 to December 31, 2006 (the most-recent 10-year period), no bracketing of start or end times was used, a minimum of 3 observations during the period of interest was required, and a goodness of linear fit (R^2) of at least 0.75 was required for use in trend analysis. As there were not enough data available for satisfactory regression on any subset of the data, no periodic or seasonal screening was performed and all available data meeting the R^2 criteria were used in the analyses. Modified Thiessen polygons were constructed for the resulting 807 wells using a maximum distance of influence for any well of 5 km. Three trend categories were chosen for presentation: areas with water levels declining at a rate of more than 0.3048 m (1 ft) per year were labeled “falling”; wells with water-level trends between -0.3048 m and +0.3048 m (±1 ft) per year were labeled “nearly stable”; and wells with water levels rising at a rate of more than 0.3048 m (1 ft) per year were labeled “rising”. Areas of falling or rising water levels tend to be grouped together (fig. 2). Areas of rising water levels of particular note include the western

Tucson AMA associated with a large aquifer recharge project from the Colorado River and in the southeastern Phoenix AMA. Areas of falling water levels are seen within the city of Tucson, where a majority of municipal water comes from ground water, and in agricultural areas of the Pinal AMA, among other places. Hydrographs were created for each of the wells used in the trend analysis and hyperlinked to the polygon shapefile in an online interactive mapping system (fig. 3). This capability allows interested parties to inspect the data used to categorize recent trends as well as to view water-level observations over the well's entire period of record.

Conclusions

A method of determining recent trends in ground-water conditions and displaying these trends spatially was described and demonstrated. The trend analysis program is able to look for trends in all water-level data in a specified time period, in user-specified months in the time period, or in the maximum and minimum amplitude of periodic data. A program was also described that presents trends spatially using modified Thiessen polygons and a user-specified maximum distance of influence for a well. Example data from Phoenix, Pinal and Tucson Active Management Areas (AMAs) were analyzed and trends presented to identify areas of falling, nearly stable, or rising water levels in the most-recent 10 year period. Visual presentation and limited categorization of trends (such as rising, stable or falling) in ground-water levels provides an easy-to-understand overview of regional trends in ground-water conditions for the general public, while links to well hydrographs allow access to further details. Application of this method on a national scale would provide a consistent portrayal of US ground-water conditions that is currently lacking.

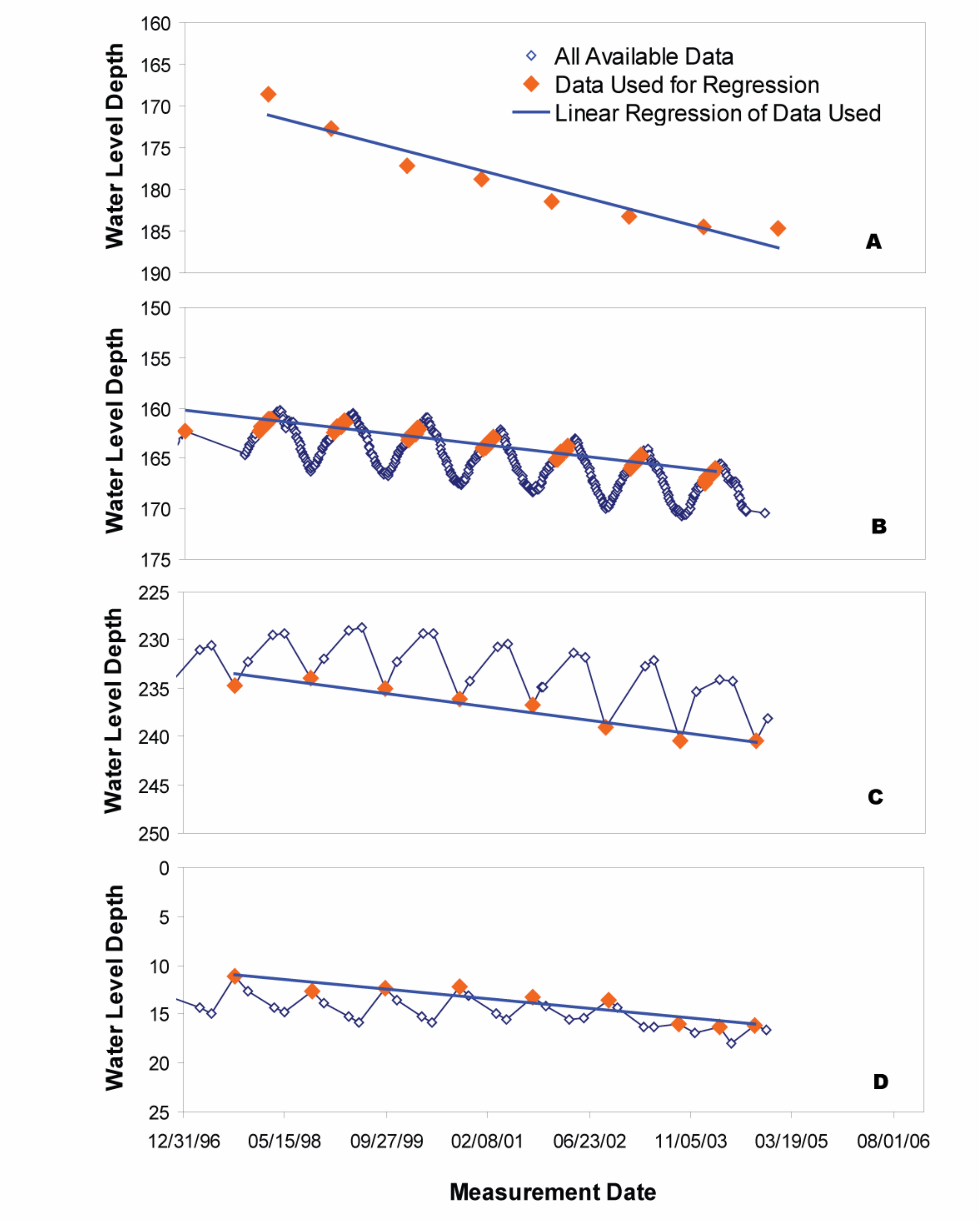

Figure 1. Examples of different subsets of water-level data in a given time period used for trend analyses including A) all data, B) seasonal data (here January and February), C) minimum amplitude data and D) maximum amplitude data.

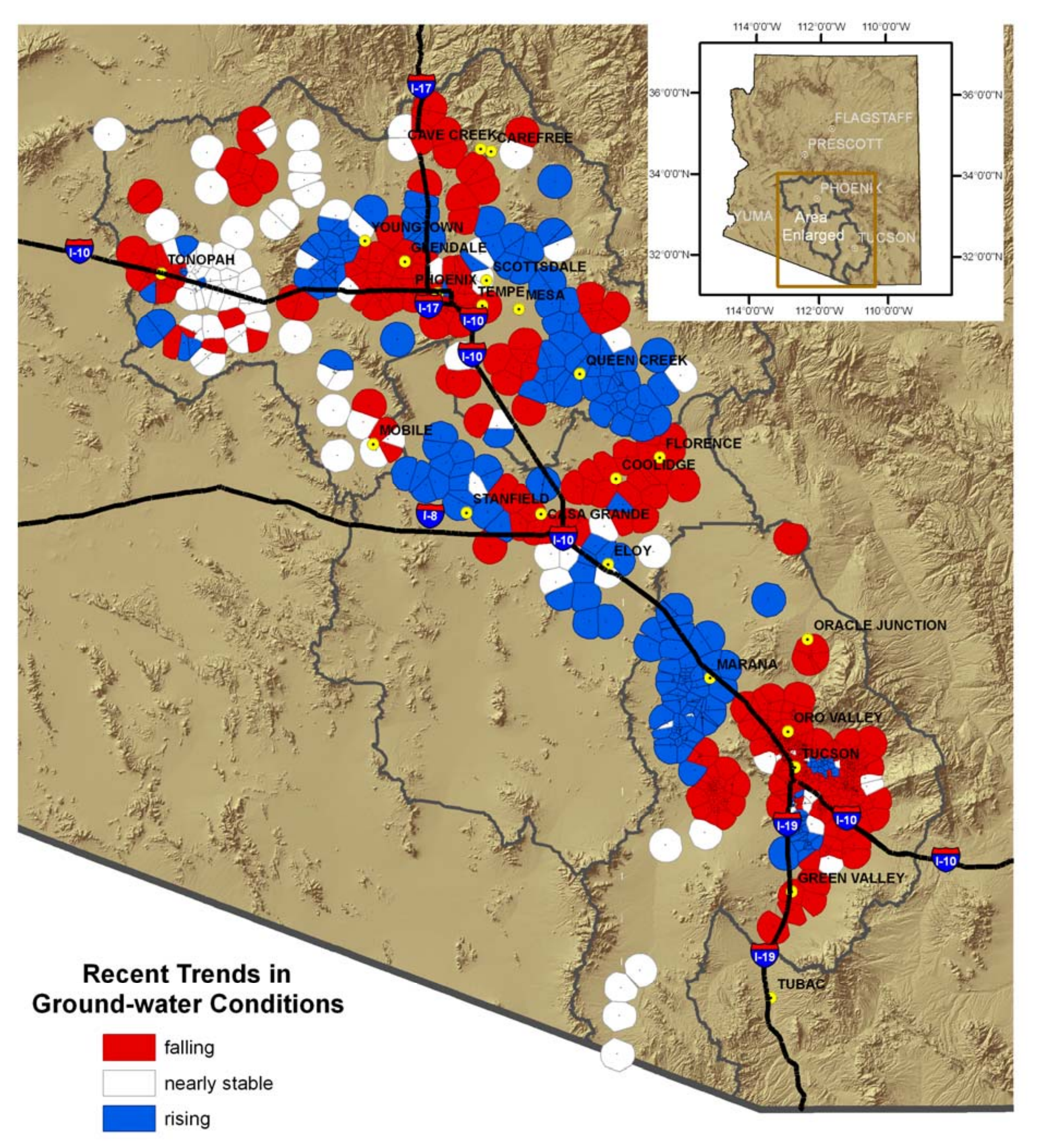

Figure 2. Demonstration of application of recent trend analysis for Phoenix, Pinal and Tucson Active Management Areas (AMAs). Areal representation is for linear trend of water level observations between 1/1/1997 and 12/31/2006 for goodness of fit of ≥0.75 with at least 3 measurements in the time period.

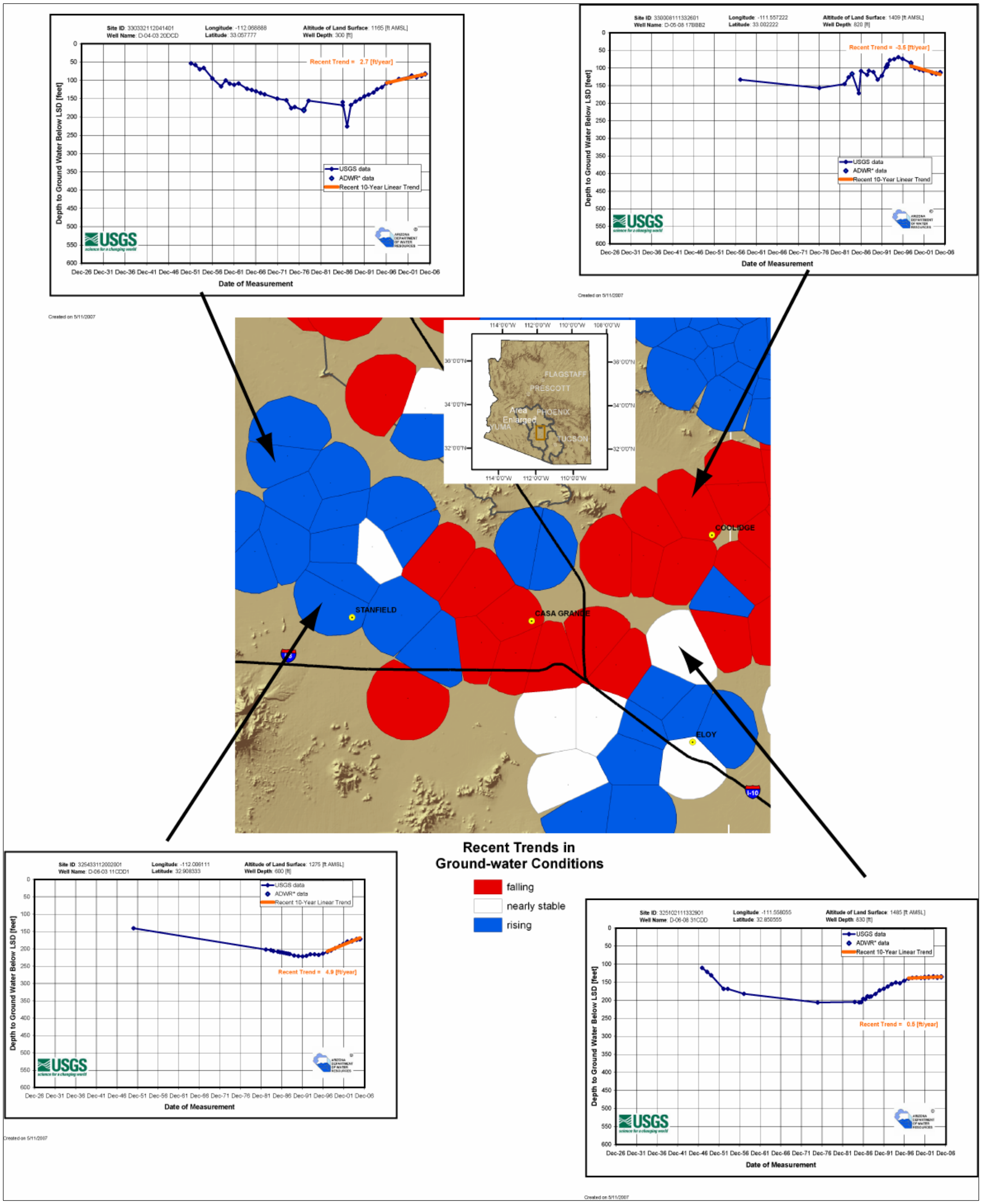

Figure 3. Detail of recent trends in ground-water levels in the Pinal Active Management Area with examples of hydrographs linked to trend areas in on-line mapping system.