Springs in time:
Comparison of present and historical flows
(Part 1)

Annual Report Submitted to:

OKLAHOMA WATER RESOURCES RESEARCH INSTITUTE

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Start Date: March 1, 2004

End Date: August 31, 2005

Congressional District: 4th District

Date: June 20, 2005

Project Synopsis

This project began on March 1, 2004 and was scheduled to end on March 28, 2005. However, in November 2004, the PIs requested, and received a six-month, no-cost extension to August 31, 2005. The project built upon an earlier OWRRI funded study by Dr. Elizabeth Bergey (Co-PI on this proposal) titled: *Springs in Peril: Have changes in groundwater input affected Oklahoma Springs?* (Bergey, 2002). In that project, anecdotal evidence emerged mostly from land owners that suggested many springs in Oklahoma had either gone dry or were experiencing significantly diminished flow rates. Such outcome implied major changes in the groundwater aquifers that fed the springs. The present study was therefore developed to investigate those claims because groundwater is important to Oklahoma's economy, tourism, agriculture, and ecosystem health. The study had two main goals:

(1) To determine whether spring discharge in each of five identified aquifers was being adversely impacted by groundwater abstraction, and

(2) To further document faunal biodiversity of Oklahoma spring-fed streams and habitats.

This portion of the report, titled Part I, pertains to objective (1) above. Part two of the report will address the second objective.

Original Project Design

The study aquifers were those identified from Dr. Bergey's research as experiencing declining flow rates. These included the Ogallala Formation, Trinity Group, Vamoosa Formation, and the Garber Sandstone/Wellington Formation. Additionally, it was also decided to add the Simpson-Arbuckle aquifer, where a large-scale water sales plan has been proposed, to the list of study aquifers. The study approach was to re-measure the discharge of 50-100 springs in the study aquifers and compare our discharge values to historical flow values.

Statement of Benefits and Outputs

The project anticipated the following benefits and outcomes, which are used in this report as benchmarks for evaluating success. This study will assess temporal patterns of discharge in the springs of five aquifers, in order to gauge the long-term sustainability of current groundwater use. For aquifers associated with proposed water sales (i.e., the Simpson-Arbuckle aquifer and the Trinity Group), this information will be helpful in indicating whether local springs may be impacted by future water sales. (2) Faunal surveys will increase our knowledge of this under-studied group and may indicate susceptible species. (3) The two P.I.'s will form an instructive and potentially fruitful hydrology-biology collaboration that will extend beyond the term of this project. (4) One graduate student and at least two undergraduate students will receive field and laboratory training in hydrology and biology. (5) Discharge records obtained from this study will be added to the USGS database; faunal records will be added to the Oklahoma Biological Survey database. (6) Results will be presented at one or more meetings, appear in at least one peer-reviewed manuscript, and be added to the project's website.

Approach

To compile the historical spring flow data, we recruited a M.Sc. graduate student in the Department of Geography, Mr. Mark Faulkner. Criteria were developed to guide the selection of springs, including length and completeness of records, as well as the number of flow measurements per year. Mark searched primarily the archives of the USGS and the OWRB. He uncovered data for spring measurements going back to the 1930s that had not yet been digitized and digitized them. Even so, the records proved to be temporally more spotty than anticipated and it was virtually impossible to definitively establish trends over time. Given this situation, it was clear that the addition of one or a few more flow measurements (as originally proposed) would not resolve the flow trends. Although discharge records of various lengths and completeness were found for nearly 60 springs, only three springs had historical flow measurements sufficiently long and continuous to justify statistically rigorous trend analysis. These were Antelope Spring, Buffalo Spring, and Byrdsmill Spring. As an alternative, it was decided to analyze trends in well level fluctuations in the aquifers feeding the streams. The following section describes the rationale for this approach.

Theoretical Consideration

Springs, by definition, are points where groundwater flows to the surface. In Oklahoma, the two major types of springs are contact springs – where the water table intersects the surface, and artesian springs - where the water reaches the surface under pressure from a confined aquifer. If the water table in an aquifer falls due either to climatic or anthropogenic factors, then the flow of water from the discharging springs would also fall. Moreover, contact springs discharging near the top of the aquifer may dry up completely. While springs discharging near the bottom of the aquifer may not dry up, their flow rates or volumes will decline as the water pressure in the aquifer falls. Thus, the head in the aquifer - reflected in water level elevations - could be used in conjunction with data on spring elevations to determine springs at risk of drying out. In addition, because historical well water levels measurements are generally more abundant and longer, analysis of their temporal variability is a suitable proxy for spring some flows. Figure 1 illustrates the concept.

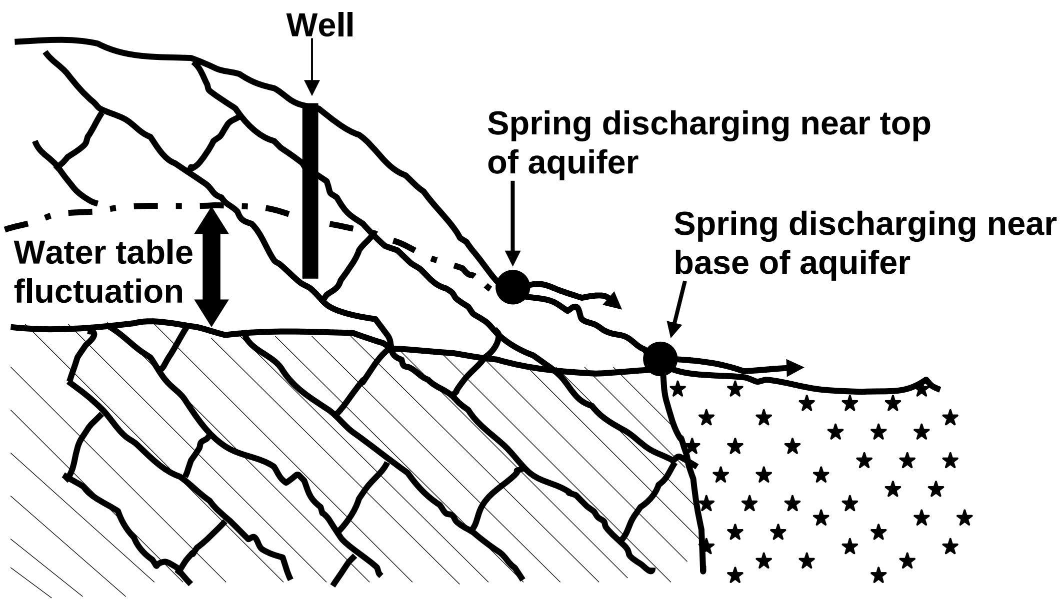

Fig. 1 Conceptual illustration of aquifer water table fluctuations and changes in spring

Data and Methods

Guided by the above consideration, we obtained data for selected wells from the USGS database. The selection criterion was that the wells should have continuous water level measurements for at least 25 years with no more than 10% consecutive missing years. We are cognizant of the fact that well level elevations are discrete point measurements that may reflect local water withdrawal patterns (or local cones of depression) and therefore may not be representative of the aquifer-wide water table. To address this problem, wells in the vicinity of springs were accorded higher priority and as many wells as possible were selected within the same aquifer. A total of 437 wells satisfied this criterion and were selected. Figure 2 shows the location of these wells. The selected study wells were analyzed for trends using both parametric and non-parametric methods and the results visualized using GIS to reveal spatial patterns. The base period for analyzing the trends was 1970-2000, except for wells where the data began after 1970 (in which case the starting point of the data is used). The reason for using 1970 as the base period is that evidence in the literature (e.g. Karl et al., 1998; Groisman et al., 2001; Chen et al., 2004) indicates statistically significant positive increases in precipitation throughout the interior of continental North America. Thus, using this period allows us to evaluate the relative contributions of both climatic and anthropogenic effects on any observed patterns in the well level fluctuations. Details of the analytical procedures will be described in the technical report.

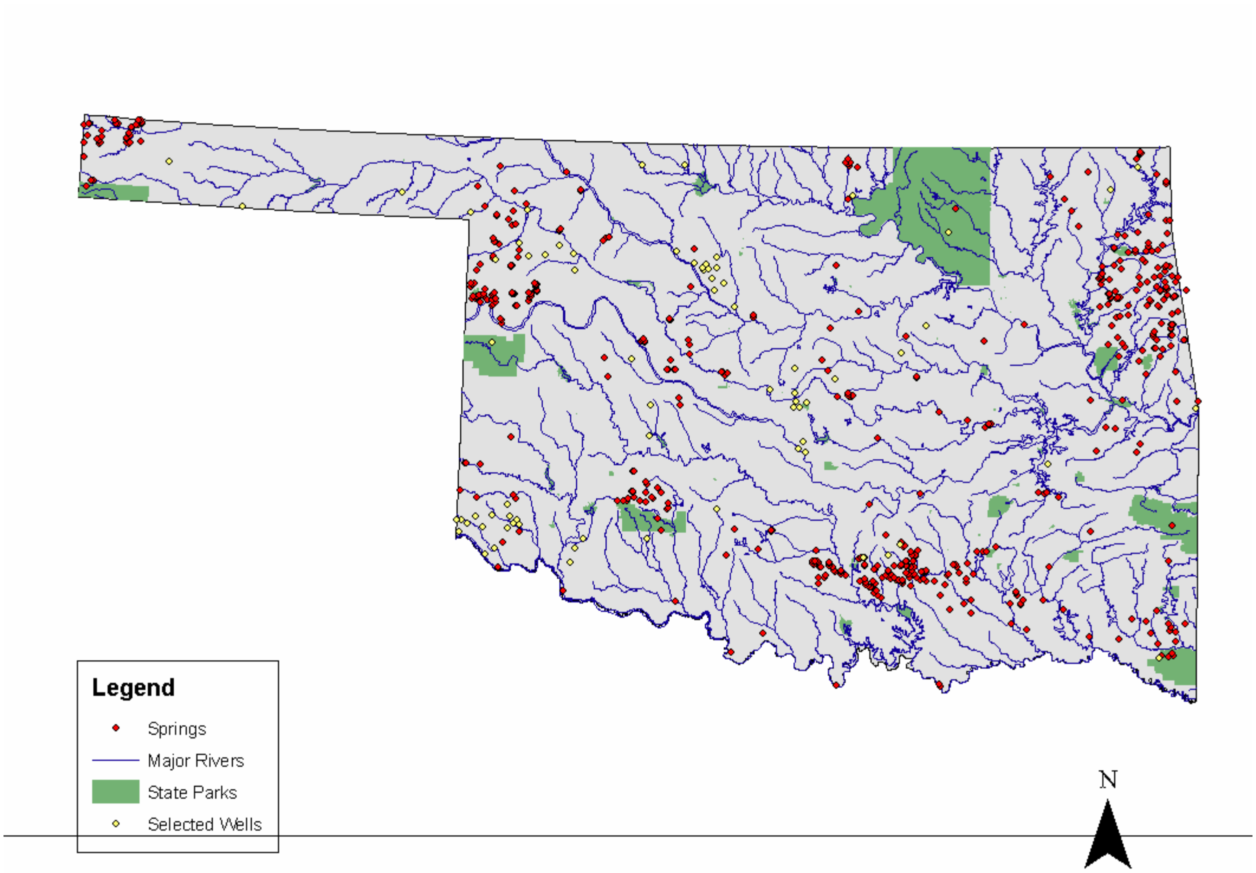

Fig. 2 Location of springs and study wells in Oklahoma

Preliminary Results

Fig. 3 summarizes the record length and data characteristics of the selected wells. Of the 437 wells analyzed, 226 (≈ 52%) showed statistically significant ($P<0.05$) upward trends, 112 (≈26%) of the wells showed statistically significant decreases, and 99 wells (22%) showed no change.

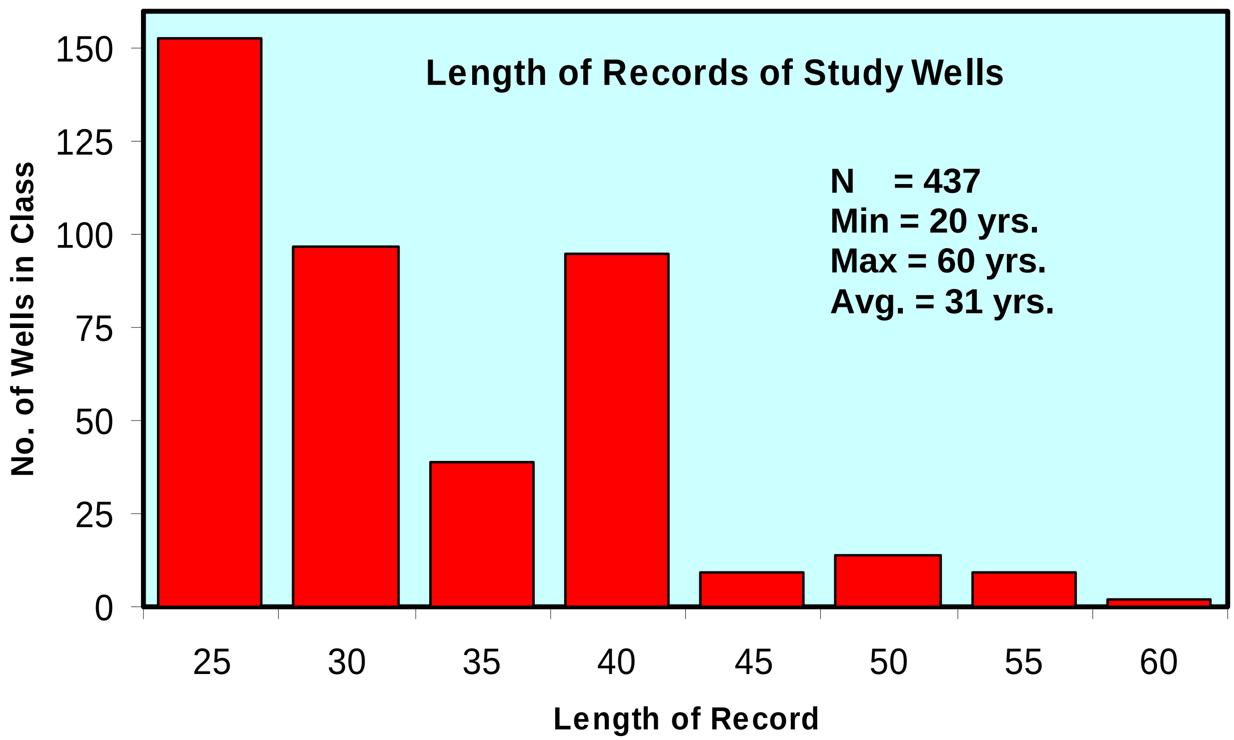

Fig. 3 The length of water elevation records at the selected study wells

Figure 4 shows the spatial distribution of these wells. It is immediately obvious that the vast majority of wells showing decreases are in the Oklahoma Panhandle (Ogallala Formation). Elsewhere, a few isolated wells also show decreases but the lack of a coherent spatial pattern to these wells suggests these are probably due to random and or localized effects.

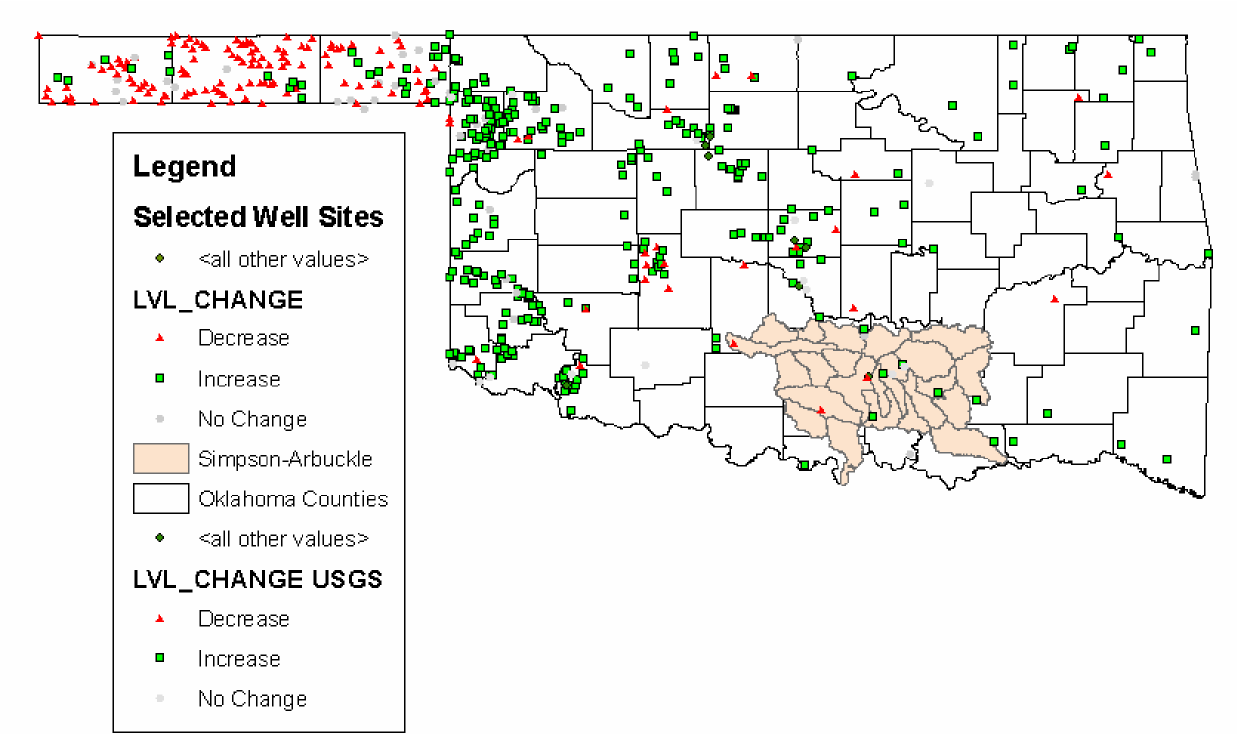

Fig. 4 Location of wells showing significant increases (P<0.05), decreases or no change

Otherwise, the general pattern outside of the panhandle is for well level rises. This result as well as precipitation trend analysis (not shown) is consistent with the findings reported in the literature (e.g. Groisman et al., 2001; Chen et al., 2004), which suggest that groundwater level rises in the continental North America are probably related to precipitation increases. Further analysis is contained in the technical report to follow. Our preliminary conclusion is that spring flows are unlikely to be declining in those parts of Oklahoma experiencing groundwater level rises. This conclusion does not preclude the fact that site specific geology and water use patterns may influence some springs even in areas of general water level rises. The Panhandle region is, of course, a different matter. Here, aquifer wide water level declines suggest that the some springs may be drying out or experiencing severe flow declines. The technical report discusses the implications of these finding as well as the magnitudes of well level rises and declines around the state.

Major Accomplishments

To date the projects has accomplished the following targets set out in the original proposal

1. Compiled a comprehensive database of spring flows throughout Oklahoma and analyzed trends for springs with long continuous records.
2. Extracted and analyzed trends in well level fluctuations to provide insights into the likely temporal patterns of spring flows.
3. A significant part of the above data compilation and analysis was carried out by Mark Faulkner. This one of our objective to “train one graduate student in spring hydrology and biology, and to expose two or more undergraduate students to laboratory and fieldwork” (the two undergraduate students are working on the fauna inventory component of the study). Mark searched the archives.
4. These results were presented at the November 2004 regional meeting of the Southwestern Association of American Geographers (SWAAG) in Nacogdoches, Texas. We have also submitted an abstract for the forthcoming 2005 Oklahoma Water Resources conference. These efforts disseminate the findings to the wider research community.

Outstanding Tasks

While the results above are strongly indicative, they do not explain the causes of the above groundwater level trends. We have therefore selected five drainage basins with high density well points. We plan to carry out first, trend analysis between precipitation and groundwater to compare the magnitudes of rises or declines in both variables. Then we will carry out cross correlation analysis between the two variables to establish the extent to which precipitation could be said to be the cause of groundwater level changes. Using this approach, the residual or unexplained variance between precipitation and groundwater level will be attributed to anthropogenic withdrawals. In addition, we plan to employ spatial statistical methods such as Principal Components Analysis, to define the spatial zones of patterns of different water level changes. Finally, we will again use GIS to display the results and to investigate its association with other factors, such as agricultural water use intensity, that may have impact on groundwater levels. Towards this goal, we have recruited another graduate student for two months (July-August, 2005) to do the cross correlation analysis.

It is also necessary to revisit the original the anecdotal evidence that prompted this study in the first place. Why did some landowners believe their springs are going dry when the evidence points to the contrary? Is the problem perceptual or were the landowners concerns/observations based on time frames that over weighted the effects of inter annual variability as opposed to long term patterns? The information learned will be important in facilitating communication between water researchers and stakeholders.

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