Outline

- Introduction to water-level determination in Kansas
  - Annual Well Program
  - Factors affecting water levels
- The index (or calibration) well concept
  - Pressure transducer measurements
  - Index Well dataset
- Applications in 2010
  - Determination of equilibrium water levels
  - Thomas County expansion project update
- Summary
- Related research efforts by KGS
Annual Water Level Monitoring
Interpolated Change in Feet*, Cooperative Wells, 2010 to 2011

- Decline greater than -10
- -10 to -5
- -5 to -2.5
- -2.5 to 0
- 0 to 2.5
- 2.5 to 5
- Increase greater than 5
- Well Measured 2010 and 2011

* 2011 Measurements are considered provisional.
Interpolated Change in Feet*, Cooperative Wells, 2010 to 2011

- Decline greater than -10
- -10 to -5
- -5 to -2.5
- -2.5 to 0
- 0 to 2.5
- 2.5 to 5
- Increase greater than 5

* 2011 Measurements are considered provisional.
How Often?
How Often?
How Often?
How Often?

Thomas Co Index Well

- Diamond: E-Tape Measurements
- Circle: Annual Water Level Measurements

Water Level Elevation (ft ASL)

1-Aug-07 31-Oct-07 31-Jan-08 1-May-08 1-Aug-08 31-Oct-08 31-Jan-09 2-May-09 2-Aug-09 1-Nov-09 1-Feb-10 3-May-10 3-Aug-10 2-Nov-10 2-Feb-11
How Often?

- Relation to “equilibrium” water surface (recovery)
  - Frequency of observations
  - Timing of observations
“Index Well”

Typical Installation (Thomas County Site)

Solar panels
Telemetry system and batteries
Data available online for users and managers
Cable from pressure transducer in well to telemetry system

2.5” PVC well with steel wellhead protector
How Often?

- Relation to “equilibrium” water surface (recovery)
  - Frequency of observations
  - Timing of observations
How Often?

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How Often?

- Relation to “equilibrium” water surface (recovery)
  - Frequency of observations
  - Timing of observations

With ~5ft of annual water-level variation, ignoring barometric effect in annual measurements = error equivalent to ~20% of annual drawdown
KGS_BRF Excel Spreadsheet

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
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</table>
Barometric Pressure Correction

Thomas County Index Well

- WL_Elev (ft)
- Corrected WL_Elev (ft)
- Barometric Pressure (ft H2O)
Complex Geology – Haskell County
Similar Magnitude Responses

- Wells screened in same aquifer unit (confined)
Complex geology requires more control on well selection/construction.
Geological Complexity and Water Availability

Index Well: Unconfined
ST: 70.2’
PST: 49.9’
(2009 data)

Index Well: Unconfined
ST: 90.2’
PST: 54.8’
(2009 data)

Permeable (light) and impermeable (dark) zones

Index Well: Confined
ST: 175.4’
PST: 63’
(2009 data)
Geology and Barometric Pressure Response

Confined:

Unconfined:
Water Levels

- Measurements affected on different spatial and temporal scales by:
  - Timing, rate of, and distance to:
    - recharge/discharge
    - pumping
  - Hydrostratigraphy
Water Levels

- Measurements affected on different spatial and temporal scales by:
  - Timing, rate of, and distance to:
    - recharge/discharge
    - pumping
  - Hydrostratigraphy
Water Levels

- Measurements affected on different spatial and temporal scales by:
  - Timing, rate of, and distance to:
    - recharge/dischARGE
    - pumping
  - Hydrostratigraphy
  - Well construction
Water Levels

- Measurements affected on different spatial and temporal scales by:
  - Timing, rate of, and distance to:
    - recharge/discharge
    - pumping
  - Hydrostratigraphy
  - Well construction
  - Atmospheric pressure variation
  - Earth tides
  - Transient surface pressure loads (e.g. trains)
Index Well Hydrograph Updates
Hydrograph Update

- During observed recovery:
  - Haskell County – continued declines of 4-6’ /yr
  - Scott County – continued declines of 0.5-1’ /yr
  - Thomas County –
    - increased water level 09-10 (highest yet observed);
    - 10-11 same as 08-09

- Full recovery still not observed at any site, in any year, prior to resumption of pumping activities
What is Full Recovery?
Horner Recovery Method

- Developed by petroleum industry
- Based on Theis recovery method (similar assumptions)
  - Utilizes same truncation used in Theis and Cooper-Jacob
- Solve following equation for $h_o$ when the log ratio = 0

\[ h(r, t) \approx h_o - A \log \left( \frac{t_p + t'}{t'} \right) \]

Where:
- $[h(r, t)]$ = water level
- $t'$ = time since end of pumping period
- $t_p$ = total time of pumping period
- $A$ = constant coefficient
- $h_o$ = recovered water level
Example:

Six month ave: 2596.54’
Estimates:
Early time: 2596.53’

\[ y = -0.622 \ln(x) + 15.612 \]

\[ h(t' = 0) = 2580.92' \text{ AMSL} \]
Horner Recovery = +15.61
Recovered \( h = 2596.53' \text{ AMSL} \)
## Haskell Index Well Recovery

### $H_{\text{max}}$ Predicted ft AMSL

<table>
<thead>
<tr>
<th>Year</th>
<th>Recovery Period</th>
<th>Prediction</th>
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<tbody>
<tr>
<td>2008</td>
<td>(07-08 Recovery)</td>
<td>2587.03</td>
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<tr>
<td>2009</td>
<td>(08-09 Recovery)</td>
<td>2581.64</td>
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<tr>
<td>2010</td>
<td>(09-10 Recovery)</td>
<td>2576.71</td>
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</tbody>
</table>

The graph shows the recovery of water levels over time, with the Horner time ratio being used to normalize the data. The formula used to calculate the Horner time ratio is $\frac{(t_p + t')}{t'}$, where $t_p = 5$ days or 120 hours.
Thomas Co. Index Well

Elevation of Water Level (ft AMSL)

June 24
Early Recovery

Season Pumping (SP- t'=83d)

Recovery Level (ft)

(tp+t')/t'

28-Mar-09 27-Jun-09 26-Sep-09 26-Dec-09 28-Mar-10 27-Jun-10 26-Sep-10 29.5
Thomas Co. Index Well

Graph showing water level recovery over time with stages of early and late recovery. The graph includes a log-log plot with the equation $y = -0.151 \ln(x) + 1.9089$. The data includes timestamps for June 24, July 27, and late recovery stages.
# Thomas Co. Index Well

## Graphs and Tables

### Graph

- **Season Pumping (SP, t'=63d)**
- **Early recovery**
- **Late recovery**
- **Late recovery B1**
- **Late recovery B2**
- **Late recovery B3**

### Data Table

<table>
<thead>
<tr>
<th>Date</th>
<th>Recovery Phase</th>
<th>Water Level (ft AMSL)</th>
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</thead>
<tbody>
<tr>
<td>28-Mar-09</td>
<td>Early recovery</td>
<td>2975.5</td>
</tr>
<tr>
<td>27-Jun-09</td>
<td>Late recovery</td>
<td>2973.5</td>
</tr>
<tr>
<td>26-Sep-09</td>
<td>Late recovery</td>
<td>2971.5</td>
</tr>
<tr>
<td>28-Mar-10</td>
<td>Late recovery</td>
<td>2969.5</td>
</tr>
<tr>
<td>27-Jun-10</td>
<td>Late recovery</td>
<td>2967.5</td>
</tr>
<tr>
<td>26-Sep-10</td>
<td>Late recovery</td>
<td>2965.5</td>
</tr>
</tbody>
</table>

### Equations

- 5/1-6/4: $y = -13.89 \ln(x) + 7.7963$
- 4/1-6/4: $y = -10.62 \ln(x) + 7.1031$
- 3/1-6/4: $y = -9.419 \ln(x) + 6.8368$
- 2/12-6/4: $y = -8.851 \ln(x) + 6.7055$

### Additional Information

- **Elevation (ft H2O):**
  - 29.5
  - 30.5
  - 31.5
  - 32.5
  - 33.5
  - 34.5

- **BP (ft H2O):**
  - 29.5
  - 30.5
  - 31.5
  - 32.5
  - 33.5
  - 34.5

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### Notes

- **June 4:** Early recovery
- **July 27:** Late recovery B1
- **Aug. 27:** Late recovery B2
- **Aug. 27, 2011:** Late recovery B3

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### Footer

- **Graph:** Graph showing water level changes over time with recovery phases labeled.
Thomas Co. Index Well

Season Pumping (SP- t'=63d)
- SP, early recovery
- SP, late recovery
- SP, late recovery B1
- SP, late recovery B2
- SP, Late Recovery B3

Log. (SP, Early recovery)
Log. (SP, late recovery)
Log. (SP, late recovery B1)
Log. (SP, late recovery B2)
Log. (SP, Late Recovery B3)

Elevation of Water Level (ft AMSL)

y = -0.151ln(x) + 1.9083

BP (ft H2O)

June 4
J2 4
Early Recovery
Late Recovery B

April 27, 2971.11'

2976.5 2977.5
36.5 37.5
Transducer WL
Corrected WL
Site BP

2972.5 2973.5
2974.5 2975.5

2969.5 2970.5 2971.5
28-Mar-09
27-Jun-09
26-Sep-09
28-Mar-10
27-Jun-10
26-Sep-10
28-Mar-10

29.5 30.5 31.5 32.5 33.5 34.5
BPHO

Elev. of Water Level (ft AMSL)

(tp+t')/t'

Recovery Level (ft)
Recovery estimates continually increase – in this situation, Horner method only provides a minimum recovery estimate.
Comparing Annual Recoveries

- Similar every year
  - Unconfined storage?
  - Recharge boundary / regional flow?

<table>
<thead>
<tr>
<th>Year</th>
<th>Recovery (ft AMSL)</th>
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<tbody>
<tr>
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<td>2009 (08-09 Recovery)</td>
<td>2976.41</td>
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<td>2010 (09-10 Recovery)</td>
<td>2978.91</td>
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</table>
Thomas Co. Index Well

Thomas Co Index Well
09S 33W 33BBB

2578.91'

2976.53
2976.41'

2868.87 ac-ft
2825.21 ac-ft
1917.17 ac-ft
### Scott County Index Well

<table>
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<tr>
<th>Year</th>
<th>Recovery</th>
<th>$H_{\text{max}}$ Predicted</th>
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<td>(09-10 Recovery)</td>
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$H_{\text{max}}$ predicted in ft AMSL.
Thomas County Expansion
Thomas County Expansion

- Northwest ~5mi.
- Southwest ~2mi.
- Northeast ~1mi.
- East ~3mi.
Index Well
Expansion wells: similar BRF to index well
Index Well Summary

- In areas of high use, annual/semi-annual measurement not accurate at either township- or short-time scales
  - Local influences on water-levels
- Full recovery estimation
  - Possible in confined settings
  - Refinement needed for unconfined
  - Decline in ST less important than PST
- Relationship between water use and water-level decline?
- Thomas Expansion Well project:
  - Early results broadly confirm flow path set out in KGS Water Budget study
  - Similar BRF to index well
  - Need more consistent water level data
Related Research – Rawlins County

[Graphs showing WL elec (ft) versus Date for Rawlins County with associated barometric response functions for different observations.]
Similar to Thomas Index well, 30 mi. to South
Related Research – Stevens County

Stevens Co. 42421-42423-42523

Stevens Co. 40578-obs40578-44593
Related Research – Stevens County

- Similar to Haskell County index well to the northeast
- ~200’ annual drawdown
Other Related Research by the KGS

- Stratigraphic correlation, hydrostratigraphic characterization of fluid chemistry and age, Haskell and Stevens counties
  - NSF award to KGS
  - STATEMAP project
  - KWO-BOR support

- NMR testing, Haskell and Thomas Index Wells
  - Department of Energy
QUESTIONS?