[PS]Revising the Fresh-Saline Water Interface in Eastern Kentucky*

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Abstract

Shallow drilling depths in the Devonian Berea Sandstone oil and gas play and potential high-volume hydraulic fracturing in the budding Cambrian Rogersville Shale play have generated a renewed interest in protecting groundwater quality in eastern Kentucky. The depth to the base of potable water was mapped by H.T. Hopkins in 1966 in his "Fresh-Saline Water Interface Map of Kentucky." The map remains an important guidance document for well operators and the Kentucky Division of Oil and Gas when evaluating surface casing depth. To create the map, Hopkins assumed that the total depth of domestic water wells equaled the base of fresh groundwater (total dissolved solids equal less than 1,000 ppm) or the fresh-saline water interface. However, it is likely that most water wells did not penetrate the base of the deepest fresh water. As a result, Hopkins' map likely underestimates the depth of the fresh-saline water interface.

To increase the accuracy of the map, post-1966 domestic water-well data were added to the Hopkins data in a 14-county area covering the Berea and Rogersville plays in eastern Kentucky. The number of wells increased from 50 used by Hopkins to 4,824 in this study. The elevation range for the interface increased from 300 ft to 1,020 ft in the Hopkins map to 75 ft to 2,198 ft in our analysis.

Despite the increased robustness, the data from shallow wells continued to underestimate the fresh-saline water interface in regions of the map. Groundwater depth is influenced by topography and surface water, and to ameliorate underestimation, the added wells were examined in relation to their respective watershed elevations defined by hydrologic unit codes (HUC). Specifically, wells with total depths deeper than the minimum stream elevation in a HUC (pour point) were used to map the fresh-saline water interface. Excluding wells with total depth elevations above their HUC pour points resulted in reducing the maximum fresh-saline water interface elevation by 1,173 ft. Despite the improvement, the true depth of the interface in any given area remains uncertain, and we suggest the alternative term, "deepest observed fresh water."

Revising the Fresh-Saline Water Interface in Eastern Kentucky

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Kentucky Geological Survey

BACKGROUND

- A revitalized oil and gas play in Devonian Berea Sandstone in northeastern Kentucky has been developed using hydraulic fracturing and horizontal drilling at shallow depths, with many completions within 1,600 feet of the surface (Figure 1).
- Eastern Kentucky is also home to a nascent gas play in the Cambrian Rogersville Shale. Although the potential of the Rogersville play is being evaluated, early tests show that development of the Rogersville will involve high-volume hydraulic fracturing at depths on the order of 6,500 to 13,500 feet.
- The shallow depth of development in the Berea and the potential for large-scale hydraulic fracturing in the Rogersville play have generated a renewed awareness in protecting groundwater quality in eastern Kentucky.

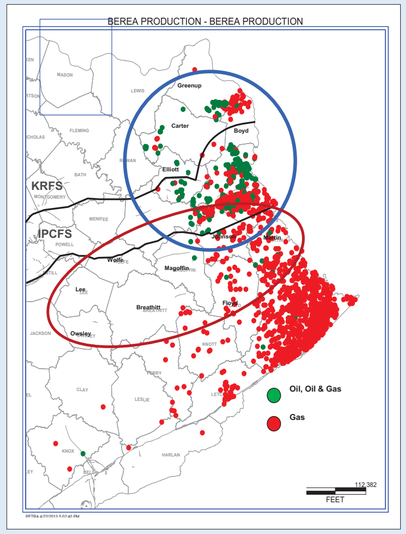


Figure 1 — Oil and gas completions in the Berea Sandstone. Area of recent Berea oil play is circled in blue while prospective area for the Rogersville Shale is circled in red.

- Protection of groundwater requires an accurate understanding of its distribution

PREVIOUS WORK

- Only published analysis of fresh and saline water distribution is by Hopkins (1966) in his "Fresh-Saline Water Interface Map of Kentucky" (Figure 2).
- Map remains an important guidance document for well operators and the Kentucky Division of Oil and Gas when evaluating surface casing depth.

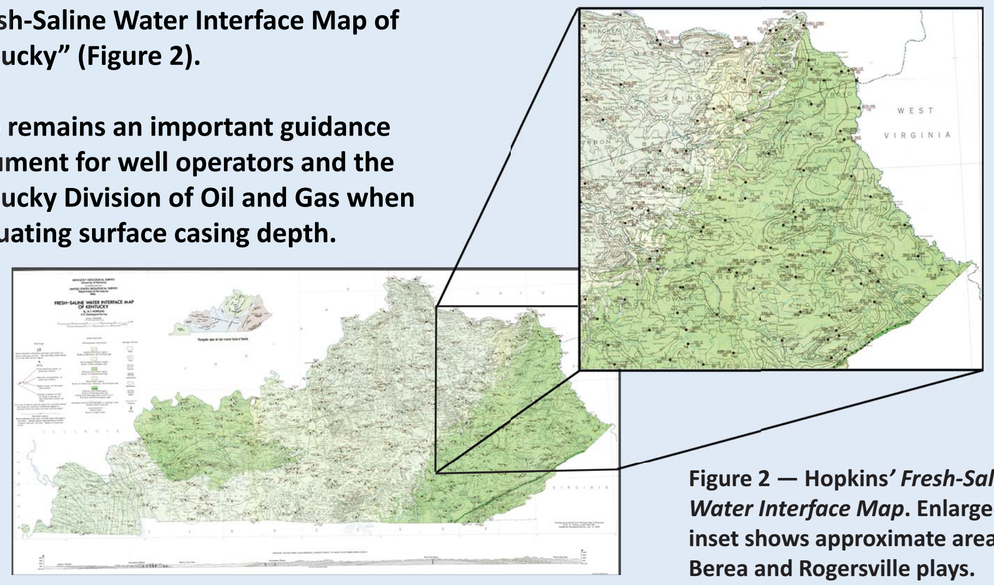
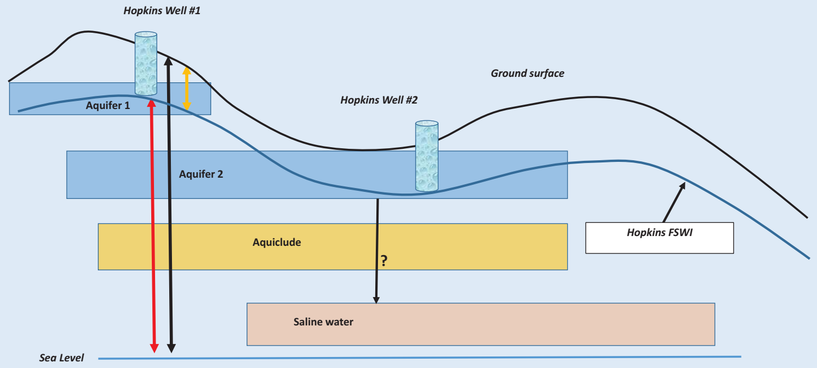


Figure 2 — Hopkins' *Fresh-Saline Water Interface Map*. Enlarged inset shows approximate area of Berea and Rogersville plays.

PREVIOUS WORK

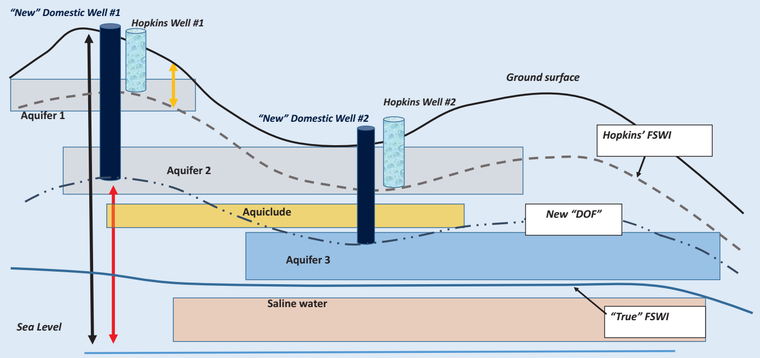
- Hopkins used domestic water wells having aqueous chemistry data and defined the fresh-saline water interface (FSWI) as the boundary that separated water with total dissolved solids (TDS) less than 1,000 ppm versus water with higher TDS values.
- Hopkins assumed that total depth of domestic wells with TDS less than 1,000 ppm equaled the base of fresh groundwater or the FSWI (Figure 3).

Figure 3 — Schematic cross-section showing method Hopkins used to create his FSWI map.



- However, due to financial and technical (avoiding saline water) reasons it is likely that most domestic wells do not reach the base of the deepest fresh groundwater.
- Consequently, the elevation of Hopkins' FSWI is in most, if not all, cases shallower than the true FSWI. Recognizing this limitation, Grider and Parris (2014) proposed the term *Deepest Observed Freshwater (DOF)* to more accurately describe the uncertainty mapping the FSWI.
- Adding data from post-1966 domestic water wells with chloride concentrations less than 500 mg/L (Kentucky Groundwater Data Repository), Grider and Parris (2014) produced a DOF map in the area of the Berea play (5 counties) that yielded 120 wells as data points, as compared to 28 used by Hopkins.
- Addition of the post-1996 wells increased the depth range over which freshwater was observed by 228 ft as compared to Hopkins.

Figure 4 — Schematic cross-section illustrating the impact of adding post-1966 wells to estimate the DOF and the relation to the FSWI.



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METHODS – THIS STUDY

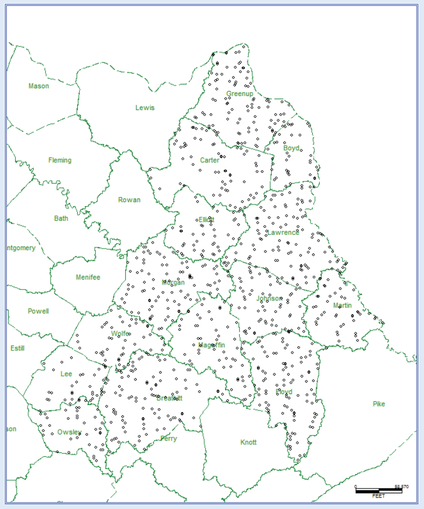

Figure 5 — Distribution of domestic water wells in the expanded analysis area that includes the Berea and Rogersville plays.

- In this study we have expanded the analysis beyond the Berea play to include the Rogersville play area (14 counties) (Figure 5).
- This expanded query of the Kentucky Groundwater Data Repository extracted all active domestic water wells with total depths of 1,000 ft or less below ground surface. Moreover, we assumed that all domestic water wells produce freshwater.
- The search yielded 4,824 wells, whereas Hopkins used data from 50 water wells in the same area. Addition of new wells showed a range of TDs, and hence DOF values, of 75 to 2198 ft, whereas Hopkins shows a range of 290 to 1020 ft.

- In addition to expanding the study area, this study made a strategic shift to analyze the data using the framework of drainage basins as defined by Hydrologic Unit Codes (HUCs) (Figure 6).
- HUCs or watershed boundaries in the U.S. have been defined and mapped by the U.S. Geological Survey and are catalogued numerically in Hydrologic Unit Codes.
- This shift was made for two reasons.
  - County boundaries are strictly administrative and have no relevance on the distribution of groundwater.
  - HUCs provide a hydrogeological framework for assessing the depth of domestic water wells above and below drainage elevation.

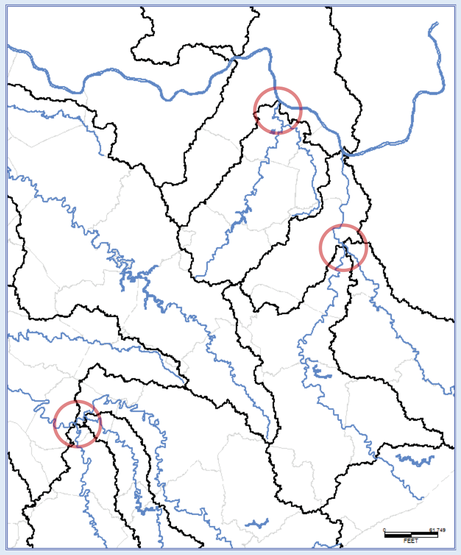

Figure 6 — HUCs (heavy black lines) define watershed boundaries where tributaries converge with a master stream (blue lines) that acts as the main surface flow path out of the drainage basin. Examples of pour points are circled in red.

METHODS – THIS STUDY

- Larger drainage basins or HUCs are represented with smaller numbers (e.g. Kentucky River basin equals a 6-digit HUC, 051002) and they include multiple smaller HUCs (represented by larger numbers) within their borders.
- In Kentucky, 14-digit HUCs are defined by 1st order streams and 11-digit HUCs generally correspond to 3rd and 4th order streams.
- A significant feature of a HUC is the pour point, which is the intersection of a drainage basin's stream outlet and the HUC boundary (Figures 6, 7). The pour point thus marks the minimum stream elevation within a HUC.

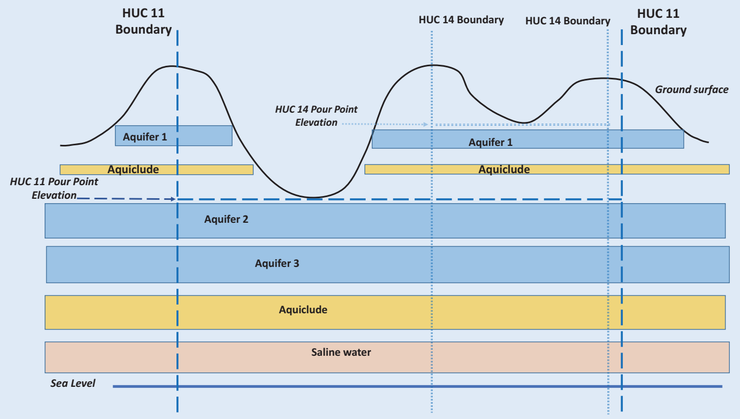

Figure 7 — Schematic cross-section illustrating HUCs and their pour point elevations. Typically 14-digit HUCs are defined by smaller-order streams, and as a result, their pour points sit at higher elevations than adjacent 11-digit HUCs.

- Accordingly, domestic water wells with TDs above the pour point cannot represent the deepest freshwater in a drainage basin. We therefore restricted our analysis to wells having TDs below the pour point elevation.
- Using the above depth restriction, DOF maps were constructed for 14- and 11-digit HUCs for two scenarios: (1) using all wells with TDs below the pour point, and (2) using the single deepest well in each HUC. Maps were constructed with Petra mapping software.

RESULTS

- The 14-digit HUC map using all wells yielded 3,122 wells as data points (Figure 8). The range of DOF values for these wells is 75 to 1300 ft above sea level.
- The 11-digit HUC map using all wells yielded 1,981 wells as data points (Figure 9). The range of DOF values for these wells is 75 to 1,025 ft.

Davis and Parris — Panel 3

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RESULTS

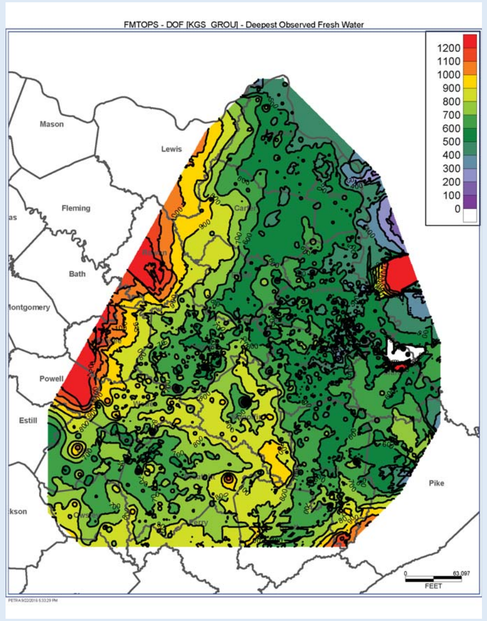


Figure 8 — DOF contour map for wells with TDs below 14-digit HUC pour points.

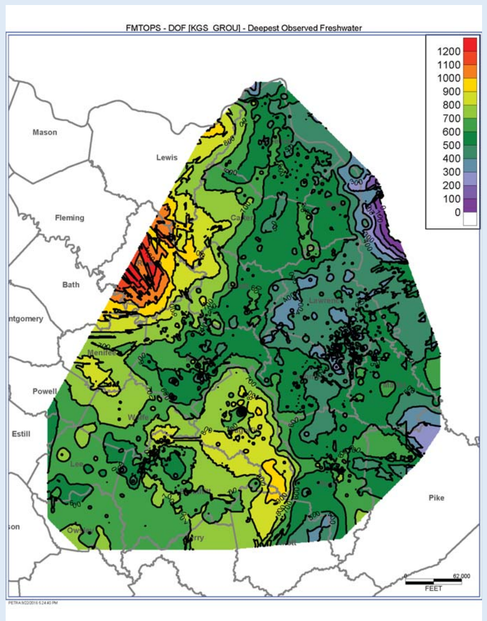


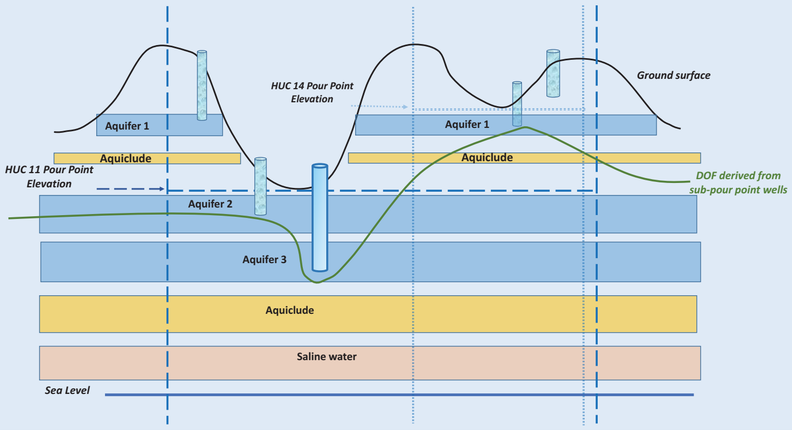
Figure 9 — DOF contour map for wells with TDs below 11-digit HUC pour points.

- The DOF maps for the 14- and 11-digit HUCs show a similar broad distribution of the DOF (Figures 8, 9). Both maps—especially the 14-digit HUC with more data points—frequently show "bullseye" contours that are likely spurious.

- The "bullseye" contours represent, in many cases, the juxtaposition of wells with TDs in aquifers of different depths (Figure 10). As such, the wells reflect the depth distribution of target aquifers rather than the DOF.

- Though we limited data to wells with TDs below the pour point, wells completed in shallow aquifers continue to obscure our ability to more accurately resolve the DOF (Figure 10).

Figure 10 — Schematic cross-section showing method used to contour DOF maps with wells having TDs below the pour point. The DOF surface (green line) traces the depths of wells below the pour point. Note how the inclusion of all wells below the pour point result in an exaggerated DOF surface that is not representative of the deepest freshwater aquifer.



RESULTS

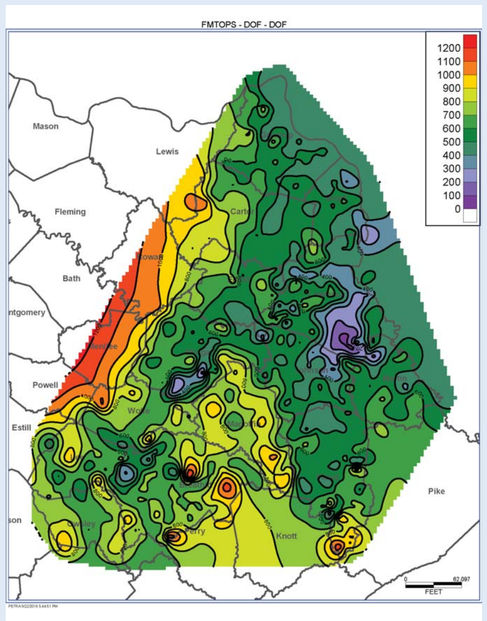


Figure 11 — DOF contour map using the single deepest well in each 14-digit HUC.

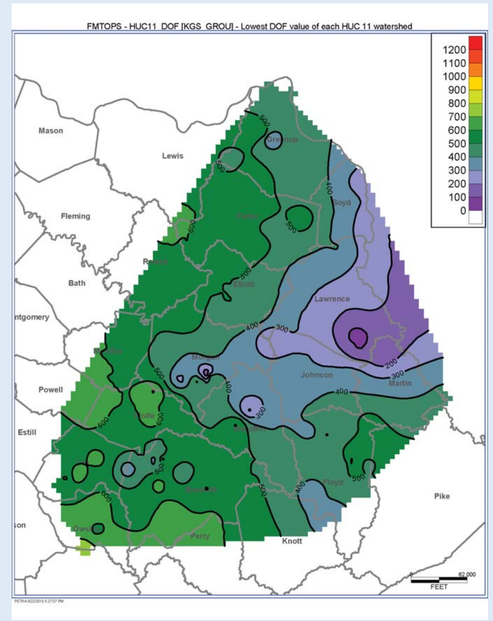


Figure 12 —DOF contour map using the single deepest domestic well in each 11-digit HUC.

- The map using the single deepest well in each 14-digit HUC yielded 854 wells as data points (Figure 11). The DOF values for the 14-digit HUC range from 75 to 1,237 ft. The map using the single deepest well in each 11-digit HUC (Figure 12) yielded 81 wells as data points. The DOF values for the 11-digit HUC range from 75 to 770 ft.

- The 14-digit HUC continues to show a bulls-eye pattern, but for reasons different than previously observed. In this example, the pattern results from using smaller size HUCs, many of which occur at higher elevations and therefore have shallow well TDs (Figure 11).

- The 11-digit HUC is noticeably free of bulls-eye patterns (Figure 12). This suggests that the contours are less influenced by shallow wells, and therefore, represent a more accurate spatial distribution of the DOF. One potential source of uncertainty, however, is the determination of how far a DOF value be spatially extended beyond the well control point.

SUMMARY

- Use of HUCs has provided a method for filtering out the effects of domestic water wells completed at shallow TDs. The results have produced an estimate of the base of freshwater that is more accurate than previously available. This improved understanding will enhance the protection of groundwater quality. Given the type of data used, however, the work described here remains an estimate prompting our use of the term, "deepest observed freshwater."