



# HydroQuest

HydroQuest  
P.O. Box 387  
Stone Ridge,  
NY, 12484  
845-657-8111  
URL: [hydroquest.com](http://hydroquest.com)  
[hydroquest@yahoo.com](mailto:hydroquest@yahoo.com)

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Delaware Riverkeeper Network  
925 Canal Street  
7<sup>th</sup> Floor, Suite 3701  
Bristol, PA 19007

**RE: Review of EPA Investigation of Ground Water Contamination near Pavillion,  
Wyoming**

To whom it may concern,

The review comments provided herein relate to the draft EPA Investigation of Ground Water Contamination near Pavillion, Wyoming (the "EPA report"). The report provides much useful information, excellent analyses, and many credible lines of reasoning to support their conclusions. A few technical areas could be embellished before finalizing the report. Overall, the report provides all the needed documentation to support upward contaminant migration from poorly sealed gas wells into the overlying freshwater aquifer. The presence of synthetic non-naturally occurring gas field chemicals in deep EPA monitoring wells carefully constructed within the freshwater aquifer documents upward contaminant excursions. Once contaminants are in the freshwater aquifer, natural groundwater flow will transport them to private wells and Five-Mile Creek. The presence of some gas field contaminants in private wells documents that pollutants are already impacting the sodium-sulfate rich aquifer, although much of this may be derived from failed frack pits. Regardless of the fact that sodium and sulfate concentrations sometimes naturally exceed EPA guidance values, the important point here is that unnatural contamination of a surficial aquifer has and continues to occur. The same operating dynamics operate elsewhere in other gas fields. Herein lies the great importance of fully and further establishing the hydrogeologic situation underpinning the detailed chemistry provided in the EPA report.

Some portions of the EPA report would benefit from additional work, especially if additional sampling is considered. This includes greater accuracy relative to some groundwater samples that, when evaluated for ionic balances, failed to achieve sufficiently low cation-anion balances. After satisfactory laboratory accuracy has been achieved, interpretation and assessment of changes in groundwater chemistry over time can be made. This is important when monitoring advancing contaminant plumes.

## **Groundwater Chemistry**

The EPA study was sufficiently broad-based that baseline water chemistry of formation waters could be differentiated from adversely impacted groundwater situated near gas wells (i.e., the two deep EPA monitoring wells). Assessment of potential groundwater contamination must first be based on water chemistry data that exhibits excellent cation-anion balance accuracy, preferably less than five or, perhaps, ten percent balance error for the relatively highly concentrated sodium-sulfate waters of Pavillion, Wyoming. As part of the review process, a set

of water chemistry data was selected from Tables 11 and 12 of the Pavillion Area Groundwater Investigation ESI data. In addition, EPAMW 02 data was obtained from EPA report SI Table 2. Table 1 (below) reveals the results of this chemical calculation assessment in the Anion-Cation Balance Percent Difference column. Figures 1 to 5 are Stiff diagrams used in water quality assessments. Their characteristic water chemistry patterns provide ready visual assessment of water type and ionic balance. Anomalous water samples may be readily identified based on ionic concentrations and pattern (see, for example, samples PGMW01, PGMW01D, and EPAMW02). Of the 29 samples selected for review analysis 18 had calculated percent differences of greater than 5 percent and 10 had calculated differences of greater than 10 percent. Six of the samples had calculated percent differences in excess of 25 percent. Some possible reasons for elevated percent error values are discussed at the base of Table 1 and may account for why EPA had lower calculated cation/anion balances for some samples. After additional review of all ionic data for balance errors, consideration should be given to resampling groundwater where high percent differences were documented. In addition, other analyses not evaluated here should be evaluated for potential laboratory errors, being careful to include all cations and anions in the analyses.

Much of the shallow Pavillion area groundwater is a sodium-sulfate water. While the concentrations of sodium and sulfate commonly exceed current EPA guidance values of 20 mg/l and 250 mg/l, respectively the water is used and should not be subjected to contamination. Sodium-sulfate rich groundwaters have been documented in some closed basin settings. Sodium sulfate is highly soluble. Waters containing large amounts of these components with little calcium can attain sulfate concentrations in excess of 100,000 mg/l (Hem, 1970).

SI Table 2 (Geochemical results for Pavillion ground water) provides evidence for saline groundwater with elevated chloride in well EPAMW02 (Na: 420 ppm; Cl: 466 ppm). Similarly, its high pH of 12.01 is highly unusual. This EPAMW02 well water chemistry, used as an example here, indicates chemical alteration by unnatural synthetic chemicals. The EPA report should further address the conditions implied to account for this saline water. Other water samples with anomalous water chemistries, as compared to other Pavillion area samples also provide evidence for unnatural chemical alteration. The presence of numerous contaminants in some of these wells, as documented in the EPA report, supports contaminant migration to these wells.

<b>Table 1</b>	Calculated Dissolved Solids	Anion- Cation Balance	Mn	SO <sub>4</sub>	Na	Cl
<u>Well #</u>	<u>(mg/l)</u>	<u>% Diff.*</u>	<u>(ug/l)</u>	<u>(mg/l)</u>	<u>(mg/l)</u>	<u>(mg/l)</u>
PGDW03	886	5.2	1.7	570	251	20.7
PGDW04	876	0.8	2.8	532	265	23.3
PGDW05	595	1.1	2.2	287	189	16.5
PGDW05D	595	1.1	1.8	287	181	16.9
PGDW10	588	16.4	3.8	293	195	7.5
PGDW20	1971	1.5	31.3	1270	550	32.6
PGDW22	4499	7.8	3.0	2780	908	74.6
PGDW23	619	3.1	2.8	368	194	19.7
PGDW25	975	25.8	20.9	441	269	9.5
PGDW30	603	8.3	2.2	333	195	15.5
PGDW32	607	2.9	3.2	368	193	21.4
PGDW39	5426	1.6	174	3640	1,110	52.9
PGDW40	740	8.6	32.8	426	244	13.1
PGDW41	4127	5.5	222	2670	1,030	31.4
PGDW42	562	8.7	3.0	311	181	13.2
PGDW43	3708	1.3	84.4	2470	911	38.4
PGDW44	4262	2.2	213	2880	994	39.5
PGDW45	685	42.9	0.32J	213	59.4	14.5
PGDW46	524	53.2	0.31J	126	911	8.4
PGDW47	567	5.3	1.6	330	183	21.6
PGDW48	2792	0.4	85.7	1840	725	24.1
PGDW49	5234	14.0	158	3160	1,210	64.3
PGPW01	5383	7.9	7.1	300	173	15.3
PGPW02	1331	2.7	9.6	847	393	8.5
PGMW01	1806	13.3	3350	1010	128	3.5
PGMW01D	1843	12.7	3640	1040	133	3.9
PGMW02	3333	72.8	379	108	1,020	265
PGMW03	560	86.7	1170	28.4	26.9	6.4
EPAMW02	1211	28.5	-----	12.1	420	466

\*: When all major ions are considered, the accuracy of a complete chemical analysis of a water sample can be checked by calculating the cation-anion balance. Here, the ionic balances were calculated based on the reported presence of the major ions depicted in Figures 1 to 4. Ideally, depending on the total concentration of the water, the difference between the two sums should generally not exceed 1 or 2 percent of the total cations and anions in waters of moderate concentration (250-1,000 mg/l) [Hem, 1970]. Water with dissolved solids concentrations (calculated in second column above) much greater than 1,000 mg/l tends to have large amounts of a few constituents. In such cases, accuracy may be compromised by lesser constituents. A possible additional source of analytic error may lie in the calculated breakout of alkalinity into bicarbonate and carbonate. It would have been preferable to analyze carbonate and bicarbonate separately. In some Pavillion waters, the hydrogen ion may account for balance errors. Errors may also be due to laboratory issues or lack of consideration of additional ions that may be significant contributors to ionic balance (e.g., cations: hydrogen, iron; anions: carbonate, fluoride, nitrate). The ions used in the *HydroQuest* analyses are the typical, most commonly occurring ions present in groundwater and used in such calculations. Where laboratory reported ionic values were listed with a U (Non-Detect), a value of 0 was assumed. For purposes of this review, ionic balances of 10 percent or less are considered as reasonably representing the sample water chemistry.

J: Estimated as below Contract Required Quantification Limit but above Method Detection Limit.

## Hydrogeologic & Structural Factors

Transport of contaminants from deep gas wells into overlying aquifers and wells requires open hydraulic pathways and upward hydraulic gradients. Upward hydraulic gradients can be either naturally occurring or temporarily induced during hydrofracturing and well development episodes. Flowing artesian conditions in a number of stock wells document the presence of upward hydraulic gradients, at least in part of the Wind River Basin. The physical location of the basin, with relatively nearby mountains provides a setting where upward hydraulic gradients are likely to be present. Additional hydrogeologic assessment would benefit interpretation of potential contaminant migration vectors, thereby adding additional credence to conclusions reached. The EPA report provides detailed assessment and graphic illustration of potential and numerous pathways from gas wells to freshwater aquifers. As an example, Figure 3b, clearly shows open vectors from gas wells to elevations higher than the base of EPA wells MW01 and MW02 along well annuli with no or inadequate cement bonds (e.g., Pavillion Fee 41-11B, Tribal Pavillion 12-12, Pavillion Fee 33-12). Similarly, the EPA report well documents the risk to the surficial aquifer because only two of the many production wells have surface casing that extend below the maximum depth of domestic wells in the Pavillion area.

In some Pavillion locations there is an overlap of hydrofracked formation intervals with those of private wells. As stated in the EPA report: *“Hydraulic fracturing in gas production wells occurred as shallow as 372 m (1220 ft) below ground surface (bgs) with associated surface casing in production wells as shallow as 110 m (361 ft) bgs. ... Information obtained from the Wyoming State Engineer's Office and homeowners indicates that domestic wells (including stock wells) in the area of investigation are screened as deep as 244 m (800 ft) bgs.”* As discussed below, this extremely poor situation is further compounded by the presence of numerous joint sets and faults in the Wind River Basin.

The EPA report mentions that hydraulic gradients are currently undefined in the area of investigation. Importantly, it also mentions the presence of artesian flow conditions in a number of stock wells (e.g., PGDW44). These wells provide evidence of upward hydraulic gradients in the investigation area and, thus, a hydrologic mechanism capable of bringing deep contaminants upward into surficial aquifers. Thus open contaminant pathways from deep gas-bearing strata are available along failed cement sheaths and casing and along joint and fault planes. These groundwater vectors are illustrated in the diagram below, albeit the Marcellus and Utica shale used to illustrate flow paths do not apply to the Pavillion area. The Wind River Formation, like the geologic sequence illustrated, is comprised largely of interbedded sandstones and shales.

EPA's data supports the presence of an upward hydraulic gradient proximal to their two monitoring wells AND contaminant transport from gas wells to the deep monitoring wells. To assess deep groundwater chemistry within the ranges identified in the second paragraph above, EPA installed two deep wells: EPAMW 01 and EPAMW 02. These wells were screened at 233-239 m (765-785 ft) and 293-299 m (960-980 ft) bgs, respectively. Well construction schematics (EPA Figures 6a and 6b) indicate that these wells were grouted from the ground surface to the screened intervals. *“Both deep monitoring wells were located away from gas production wells, known locations of pits, and areas of domestic waste disposal (abandoned machinery)”* [page 5 EPA report]. The high static water levels in these wells in April 2011 (MW01: 61.2 m; 200.8 ft and MW02: 80.5 m; 264.2 ft), far above the screened intervals, documents the presence of a strong upward hydraulic gradient in this portion of the basin – to elevations well within that of domestic wells (see second paragraph above).

Thus, failed or missing cement/grout in gas well annuli result in boreholes providing an upward flow vector into overlying surficial aquifers. Non-naturally occurring synthetic contaminants were found in these wells (e.g., 2-butoxyethanol; glycols; isopropanol; Figure 17 EPA report), thereby documenting a hydraulic link between gas wells and the overlying aquifer. Once deep contaminants reach fractures and faults within the surficial aquifer (see discussion below documenting their presence), transport within the regional groundwater flow regime toward private wells and base level streams is assured. Logically, then, since the EPA monitoring wells were intentionally constructed away from gas wells or other sources of contamination, contaminants have both reached the surficial aquifer AND been transported within it to these wells. Hydrogeologically, once gas field contaminants are present anywhere within the surficial aquifer, they will move laterally toward domestic wells and upward toward base level streams (e.g., Five-Mile Creek). While EPA states that they have not yet established a definitive link between deep and shallow aquifer contamination, the hydrogeologic flow mechanism described here addresses the means by which domestic wells are likely to become contaminated, if some are not already contaminated. Slow groundwater flow toward base level discharge locations (e.g., Five-Mile Creek) may take years to reach assorted receptors, but in time it will. The attachment, authored by Dr. Arthur N. Palmer, details the hydrogeologic flow mechanics that apply to Pavillion and other similar worldwide settings, thereby further describing the hydrologic link between shallow and deep flow systems. This is why long-term groundwater monitoring should be mandated in gas field contamination situations, as in other chemical spill instances.

Figures 20 and 3b and the data used to support them paint a very disconcerting hydrogeologic picture that illustrates the groundwater flow routes through which contaminants move. It shows that cement failure is already occurring in Pavillion area gas wells. Clearly, contaminant vectors are open between gas-rich horizons and freshwater aquifers in some wells. The fact that some of the contaminants found in EPA wells MW01 and MW02 are not naturally occurring chemicals supports the link between gas wells and the overlying aquifer (see, for example, SI Table 3). As documented by the Delaware Riverkeeper Network in a number of *HydroQuest* reports and Fact Sheets, cement casings and steel casing will almost certainly fail in less than 100 years and 80 years, respectively. An opening of only 0.001 inch is sufficient to allow natural gas to rise up a well annulus into freshwater aquifers. This information and many of the related concerns are detailed in reports available, and hereby incorporated by reference, at the two following web sites:

<http://hydroquest.com/Hydrofracking/> and <http://hydroquest.com/Schoharie/>

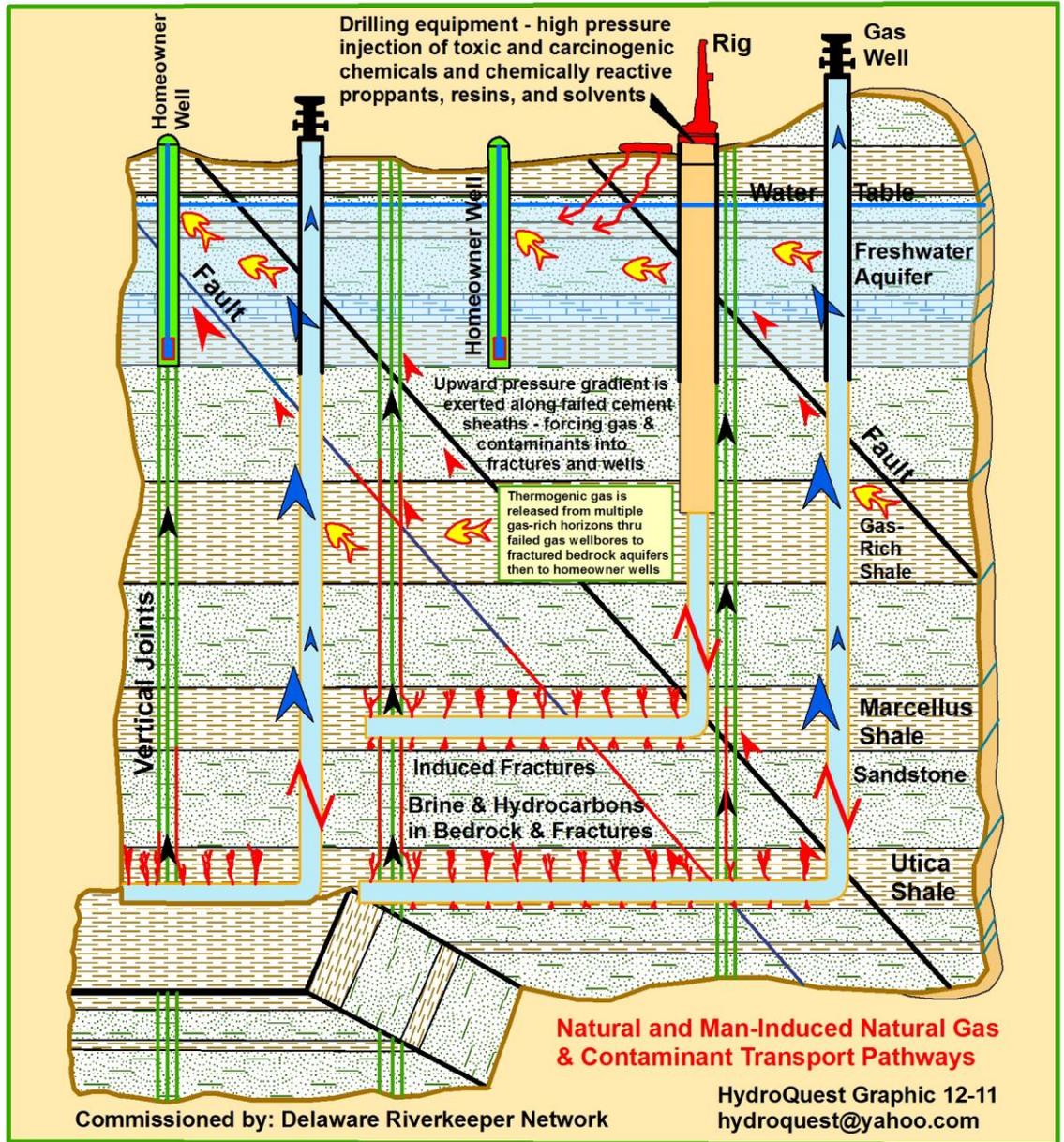
The role of systematic joints and faults present in the Wind River Basin has not been sufficiently addressed. The EPA report does not adequately identify important structural features present throughout much of the Wind River Basin area that almost certainly function as contaminant transport pathways. For example, Steidtmann and Middleton (1991 GSA Bulletin – Fault chronology and uplift history of the southern Wind River range, Wyoming: Implications for Laramide and post-Laramide deformation in the Rocky Mountain foreland) discuss nearby faulting events that almost certainly impacted the Wind River Basin area. Thompson (2010, MA Thesis: Two-stage development of the Wind River Basin, Wyoming: Laramide shortening followed by Post-Laramide regional extension, localized backsliding, and arch collapse) examined fracture development and deformation of the Wind River Basin. The datasets he used and discusses “... included 1447 fault strike segments digitized from geologic maps, 9107 subsurface fractures previously interpreted by log analysts from micro-resistivity image logs from 23 wells, and 1833 joints and minor faults measured at 42 stations in outcrops of Cambrian

*to Eocene units throughout the basin.*” Thompson further addresses hundreds of strike-slip, normal and thrust faults within the Wind River Basin, as well as a recent earthquake.

Other geologists have also documented fault presence in the Wind River Basin. Parker Gay (2002, Mapping geologic structure of basement and role of basements in hydrocarbon entrapment; Search and Discovery Article #40052) depicts a well known thrust-fold structure in the Wind River Basin as an example of asymmetric folds related to basement faults. These joints and faults (i.e., expansive planar features with high secondary permeability) provide extensive pathways for both upward migration of gas field contaminants and lateral, down gradient flow pathways in surficial aquifers (see figure below). The high density of fractures provides well interconnected groundwater flow pathways.

As discussed above, Thompson documented the hundreds of faults and joints in the Wind River Basin. Thus, all the key hydrogeologic factors needed to bring gas well contaminants upward into freshwater aquifers are in place and already functioning. Once deep-seated groundwater and contaminants in it reach overlying freshwater aquifers, it is just a matter of time for them to move with the operative groundwater flow regime. Initially, contaminants will slowly flow within regional aquifer systems, except when fractures are encountered - in which case contaminant migration may be quite rapid. Thus, gas field contaminants that reach the Pavillion freshwater aquifer will flow down gradient, adversely impacting private wells along the way.

Where no upward hydraulic gradients are present, contaminants will flow at depth along deep groundwater flow paths until they eventually move upward in valley bottom, regional aquifer, discharge areas (i.e., where our larger populations exist and use groundwater resources). While contaminant concentrations may become significantly diluted, they will concentrate and rise in valley bottom settings - providing a long-term supply of low level contaminants to our drinking water supplies. This, in turn, will expose large populations to low-level contaminants. Even the toxicologists are not in a position to fully understand the associated chronic health impacts from exposure to numerous, sometimes proprietary, contaminants.



## **Seismic**

While the thrust of the EPA investigation is that of assessing groundwater contamination, earthquakes have been documented in the area. Earth movement associated with seismic activity are a likely past, present, and future cause of cracking of cement in gas wells. This will almost certainly lead to contaminant migration into overlying aquifers. Thus, an evaluation of seismic risk with related loss of structural integrity of gas well cement sheaths and casing material should be evaluated as part of a broader, non snapshot in time, assessment of groundwater contamination. The seismic risk aspect might be patterned after that used to examine the Howes Cave area of Schoharie County, New York. Ten seismic risk/probability assessments and related discussion may be reviewed at: <http://hydroquest.com/Schoharie/>.

## **Recommendations**

Consider conducting a comprehensive evaluation to assess the cation-anion balance of groundwater samples used in the EPA report so that accurate data is present for future comparative purposes. Additional ionic balance assessment of cations and anions that are not normally major ions may decrease percent difference errors. Where necessary, resample and analyze well water samples.

Expand the current study to incorporate future seismic risk and potential past degradation of well sealant materials from earthquakes.

Thompson and others have documented hundreds of joints and faults in the Wind River Basin. All Thompson documented fractures, faults, and lineaments, plus any additional fractures not previously identified on aerial and satellite imagery should be plotted as an overlay on one of the gas and private well maps presented in the EPA study (e.g., Figure 5). Once plotted, relationships between contaminated wells and wells at future risk may become evident.

Consideration should be given to expanding the study to assess fracture interconnectivity between planned/upcoming gas well hydraulic fracturing events and nearby private wells. Should transducers placed in private wells record a surge or rise and subsequent fall in groundwater levels associated with fracking episodes, a fracture interconnection between deep and shallow horizons would be firmly established, as would the presence of open contaminant transport pathways.

Systematic measurement and survey of groundwater levels in private wells and other water bodies (e.g., streams, rivers, springs, lakes) should be conducted and used to produce a comprehensive groundwater flow map and to assess upward and downward hydraulic gradients between the EPA monitoring wells and private wells. This effort should also document all artesian wells, regardless of whether they are flowing or have potentiometric surfaces below the ground surface. The hydrogeologic information obtained will have great value in interpreting present and future contaminant migration.

If you have any questions regarding this assessment and recommendations, please feel free to contact me. Thank you.

Sincerely yours,

*Paul A. Rubin*

Paul A. Rubin  
*HydroQuest*  
Hydrogeologist