**UOG water use model**

There seem to be two comparisons of water use that the data make possible. One is a time comparison between years either during or not during oil and gas production for counties within the Bakken Play. The other is a space comparison between counties either within or not within the Bakken Play for years during oil and gas production.

Taking the difference between times and spaces may also show the effect of oil and gas production on use type and source type of water permits. In addition, if population can be used to model water use by use type of water permits, it may be possible to show the effect on use types that are seemingly unrelated to oil and gas production.

To normalize the model it will be necessary to get the IHS data on oil and gas production by year at 1-mile resolution from Seth Haines, similar to the IHS data on well treatments.

*Data*

Following is a presentation and discussion of the possible data in the model.

IHS well production data

We hopefully will get IHS well production data for years 1980-2015 from Seth Haines.

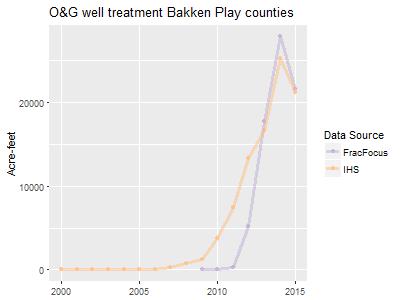
U.S. Census Bureau (USCB) population data

We have data by county for years 1980-2015. Not much more needs discussion as these data are necessary to normalize the response variable as county-level per capita water use estimates for each year modeled. In the table below are summary statistics of these data for 1980 and 2015 for counties within or not within the Bakken Play.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Year | Counties | Min. | Median | Mean | Max. | Sum |
| 1980 | Bakken Play | 1138 | 5879.5 | 10375.67 | 58392 | 186762 |
| 2015 | Bakken Play | 764 | 5269.5 | 11924.67 | 71379 | 214644 |
| 1980 | Non-Bakken | 2495 | 6585.5 | 31074.22 | 652717 | 1118672 |
| 2015 | Non-Bakken | 1302 | 4230.5 | 36084.06 | 756835 | 1299026 |

IHS and FracFocus well treatment data

We have data by county for years 2000-2015 for IHS and for years 2009-2015 for FracFocus. We hopefully will get IHS well treatment data for years 1980-2000 from Seth Haines. These data have some uncertainty as the figure below shows a difference between the two data sources for some years. It may be justifiable just to use the maximum value from either data source for each year, except that the uncertainties of each source are not necessarily similar.



North Dakota State Water Commission (NDSWC) standard water permit data

We have data by county for years 1980-2015 by surface or ground water source type and by twelve use types. In the table below are summary statistics of these data by source type and use type for 1980 and 2015 for counties within or not within the Bakken Play (not all source or use types had reported use for each year-by-county combination). These data have some uncertainty as reporting of use might be only partial for some permits. Some use types will not be that important in the model because they have relatively negligible water use, including domestic, fish and wildlife, flood control, recreation, and stock.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Counties | UseType | Min. | Median | Mean | Max. | Sum |
| 1980 | Bakken Play | Ground Water | 0 | 185.1 | 478.2326 | 4898 | 21998.7 |
| 2015 | Bakken Play | Ground Water | 0 | 92.233 | 641.285 | 7993.276 | 46813.8 |
| 1980 | Non-Bakken | Ground Water | 0 | 212.4 | 757.1402 | 9420.8 | 65871.2 |
| 2015 | Non-Bakken | Ground Water | 0 | 264.65 | 1155.09 | 17049.03 | 120129.4 |
| 1980 | Bakken Play | Surface Water | 0 | 170.9 | 1995.991 | 48010.6 | 91815.6 |
| 2015 | Bakken Play | Surface Water | 0 | 192.9 | 1984.04 | 15960.37 | 105154.1 |
| 1980 | Non-Bakken | Surface Water | 0 | 93.45 | 1150.21 | 11613 | 80514.7 |
| 2015 | Non-Bakken | Surface Water | 0 | 41.2305 | 943.0239 | 12002.5 | 66011.67 |
| 1980 | Bakken Play | Domestic | 2.9 | 7.1 | 7.1 | 11.3 | 14.2 |
| 2015 | Bakken Play | Domestic | 0.01 | 1.3 | 1.503333 | 3.2 | 4.51 |
| 1980 | Non-Bakken | Domestic | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| 2015 | Non-Bakken | Domestic | 0.9 | 32.7 | 32.7 | 64.5 | 65.4 |
| 1980 | Non-Bakken | Fish and Wildlife | 0 | 460 | 3573.333 | 10260 | 10720 |
| 1980 | Bakken Play | Flood Control | 50 | 50 | 50 | 50 | 50 |
| 1980 | Bakken Play | Industrial | 0 | 82.8 | 98.31333 | 317.5 | 1474.7 |
| 2015 | Bakken Play | Industrial | 0 | 88 | 682.0714 | 7858.36 | 17051.79 |
| 1980 | Non-Bakken | Industrial | 0 | 9.2 | 380.2235 | 3115.8 | 6463.8 |
| 2015 | Non-Bakken | Industrial | 0 | 0.9 | 215.9807 | 2792.07 | 7559.326 |
| 1980 | Bakken Play | Irrigation | 0 | 568.5 | 3153.226 | 48010.6 | 85137.1 |
| 2015 | Bakken Play | Irrigation | 0.43 | 537.737 | 2323.099 | 14160.67 | 67369.88 |
| 1980 | Non-Bakken | Irrigation | 0 | 177.95 | 1175.473 | 11294.2 | 72879.3 |
| 2015 | Non-Bakken | Irrigation | 0 | 335.988 | 1760.619 | 17049.03 | 112679.6 |
| 1980 | Bakken Play | Multiple Use | 0 | 1411.65 | 1411.65 | 2823.3 | 2823.3 |
| 2015 | Bakken Play | Multiple Use | 0 | 164.9 | 690.7 | 2433 | 2762.8 |
| 1980 | Non-Bakken | Multiple Use | 220.3 | 305.15 | 305.15 | 390 | 610.3 |
| 2015 | Non-Bakken | Multiple Use | 0 | 0 | 26.22857 | 138.3 | 183.6 |
| 1980 | Bakken Play | Municipal | 0 | 231 | 557.8385 | 4898 | 14503.8 |
| 2015 | Bakken Play | Municipal | 0 | 29.7 | 835.3449 | 7036.8 | 22554.31 |
| 1980 | Non-Bakken | Municipal | 0 | 218 | 909.2426 | 11613 | 42734.4 |
| 2015 | Non-Bakken | Municipal | 0 | 166.65 | 1119.73 | 12002.5 | 51507.57 |
| 1980 | Bakken Play | Power Generation | 182.1 | 1388.6 | 2249.325 | 6038 | 8997.3 |
| 2015 | Bakken Play | Power Generation | 12778.65 | 14369.51 | 14369.51 | 15960.37 | 28739.02 |
| 1980 | Non-Bakken | Power Generation | 0.1 | 172.4 | 1652.475 | 6265 | 6609.9 |
| 2015 | Non-Bakken | Power Generation | 82.7 | 1393.35 | 1393.35 | 2704 | 2786.7 |
| 1980 | Bakken Play | Recreation | 0 | 0 | 41.95 | 167.8 | 167.8 |
| 1980 | Non-Bakken | Recreation | 0 | 236 | 680.5 | 2250 | 2722 |
| 1980 | Bakken Play | Rural Water | 0 | 41.8 | 78.1375 | 214.9 | 625.1 |
| 2015 | Bakken Play | Rural Water | 0 | 50.25 | 225.7594 | 822 | 3612.151 |
| 1980 | Non-Bakken | Rural Water | 0 | 232.55 | 260.2429 | 1055.5 | 3643.4 |
| 2015 | Non-Bakken | Rural Water | 0 | 433.3 | 597.8332 | 1733.8 | 11358.83 |
| 1980 | Bakken Play | Stock | 0 | 0 | 7 | 21 | 21 |
| 2015 | Bakken Play | Water Depot | 0 | 49.96 | 519.6546 | 3456.2 | 9873.438 |

North Dakota State Water Commission (NDSWC) temporary water permit data

We have data by county for years 1989-2015 by surface or ground water source type and by thirteen use types. In the table below are summary statistics of these data by source type and use type for 1989 and 2015 for counties within or not within the Bakken Play (not all source or use types were allocated for each year-by-county combination). These data are greatly uncertain as they represent allocation, not reported use. Some use types will not be that important in the model because they have relatively negligible water use, including archaeology, domestic, fire protection, fish and wildlife, flood control, livestock, and resource planning. However, the industrial and water depot use types are almost equal and much greater, respectively, than those use types for the standard water permits.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Counties | Source/Use Type | Min. | Median | Mean | Max. | Sum |
| 2015 | Bakken Play | Ground Water | 0.8 | 69.9 | 493.1 | 4125.3 | 8382.9 |
| 2015 | Non-Bakken | Ground Water | 2 | 165 | 371.6 | 1782 | 4459.5 |
| 1989 | Bakken Play | Surface Water | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 2015 | Bakken Play | Surface Water | 0 | 82.8 | 3648 | 60144.3 | 149568.7 |
| 1989 | Non-Bakken | Surface Water | 1 | 510.9 | 510.9 | 1020.8 | 1021.9 |
| 2015 | Non-Bakken | Surface Water | 0 | 4.9 | 238.7 | 4391.6 | 7878.2 |
| 2015 | Bakken Play | Construction | 1 | 28.4 | 116.2 | 401 | 1975.5 |
| 2015 | Non-Bakken | Construction | 0.6 | 4.9 | 26.9 | 280 | 617.8 |
| 2015 | Non-Bakken | Fire Protection | 0 | 0.1 | 0.1 | 0.2 | 0.2 |
| 1989 | Bakken Play | Industrial | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 2015 | Bakken Play | Industrial | 0 | 15 | 537.9 | 4301.7 | 5917.1 |
| 1989 | Non-Bakken | Industrial | 1 | 1 | 1 | 1 | 1 |
| 2015 | Non-Bakken | Industrial | 10 | 542 | 512.7 | 986 | 1538 |
| 2015 | Bakken Play | Irrigation | 25 | 200 | 387.6 | 1363.1 | 1937.9 |
| 2015 | Non-Bakken | Irrigation | 24.6 | 300 | 637.3 | 2285 | 5736 |
| 2015 | Bakken Play | Livestock | 4 | 12.8 | 12.8 | 21.5 | 25.5 |
| 2015 | Non-Bakken | Livestock | 50 | 50 | 50 | 50 | 50 |
| 1989 | Non-Bakken | Municipal | 1020.8 | 1020.8 | 1020.8 | 1020.8 | 1020.8 |
| 2015 | Bakken Play | Resource Planning | 0 | 0.8 | 0.9 | 2.9 | 6 |
| 2015 | Non-Bakken | Resource Planning | 0 | 0 | 0.7 | 4.2 | 4.2 |
| 2015 | Bakken Play | Rural Water | 500 | 500 | 500 | 500 | 500 |
| 2015 | Bakken Play | Water Depot | 64.2 | 1240.9 | 9839.3 | 60144.3 | 147589.4 |
| 2015 | Non-Bakken | Water Depot | 4391.6 | 4391.6 | 4391.6 | 4391.6 | 4391.6 |

*Model*

Following is a discussion of the potential structure of the model.

Left-hand side of the equation

The response variable is total water use related to oil and gas production. The direct use has already been estimated by Bridget Scanlon and Seth Haines. The IHS data on direct use from Seth Haines can be included in our model and subtracted from the total water use, resulting in the indirect use.

The response variable will be normalized by the oil and gas production data, so the units will be, for example, gallons of total water used per gallon of oil and gas produced for each year modeled. The total water use will be divided between direct and indirect use. The indirect use is simply the difference between total water use and direct use; and direct use is available from the IHS data from Seth Haines and/or from the FracFocus data on well treatments.

The indirect use can be further discretized into water use types (per those used in the USGS national water use estimates) based on the use types of the water permit data from NDSWC. Many of those USGS use types may not be applicable to our model, but it may be possible to estimate indirect use from those water permit use types that are seemingly unrelated to oil and gas production (e.g. irrigation). However, that is a highly uncertain possibility that may be beyond the means of the data and/or our purpose and scope.

Right-hand side of the equation

The explanatory variables will be derived from the population data from UCSB, the direct water use data from IHS and/or FracFocus, and the direct and indirect water use data from NDSWC.

The population data will also be used to normalize the response variable as county-level per capita water use estimates for each year modeled.

The potential formula for the model

We can probably assume the population data have no measurement error (data from USCB seems reasonably reliable). However, none of the other data are likely as certain. The temporary water permit data from NDSWC probably have the most uncertainty, and the NDSWC standard water permit data are perhaps the least uncertain. The IHS and FracFocus well treatment data have intermediate uncertainty, although the FracFocus data are probably more uncertain than the IHS data and are not available for as many years. It seems that we will need some latent variables related to the potential measurement error in those data (i.e. incorrect recording of data or partial reporting of use).

The potential model in its simplest formulation is:

where

is the total water use (as gallons of total water used per gallon of oil and gas produced for each year modeled );

is the USCB population data;

is the IHS well treatment data (and/or FracFocus well treatment data; however, these data may be treated as a latent variable related to uncertainty in the IHS data);

is the NDSWC standard water permit data, which will be disaggregated into additional Xs (1-14) depending on use type and source type;

is the NDSWC temporary water permit data, which will be disaggregated into additional Xs (1-15) depending on use type and source type (however, these data may be treated as latent variables related to uncertainty in the NDSWC standard water permit data);

is the residual error.

Summary of potential variables in the model

Some variables have more uncertainty, some have either upper or lower boundedness, some are less important, and some relate to direct and/or indirect water use or are unrelated to oil and gas production as the table below summarizes.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | Confidence in variable veracity | Likelihood of variable boundedness | Variable importance to model | Type of water use involved |
| UCSB population | High | Unlikely upper- or lower-bounded | Very high |  |
|  |  |  |  |  |
| IHS well treatment | Medium-high | Probably lower-bounded | Very high | Direct |
| FracFocus well fluid | Medium | Very likely lower-bounded | High | Direct |
|  |  |  |  |  |
| Standard water permit reported use | Medium-high | All probably lower-bounded |  |  |
| Ground Water |  |  | Medium | All |
| Surface Water |  |  | Medium | All |
| Domestic |  |  | Low | Most unrelated; maybe some indirect |
| Fish and Wildlife |  |  | Very low | Unrelated |
| Flood Control |  |  | Very low | Unrelated |
| Industrial |  |  | Very high | Some direct; some indirect; some unrelated |
| Irrigation |  |  | High | Most unrelated; maybe some indirect |
| Multiple Use |  |  | Medium | Some direct; some indirect; some unrelated |
| Municipal |  |  | Medium | Most unrelated; maybe some indirect |
| Power Generation |  |  | Medium | Most unrelated; maybe some indirect |
| Recreation |  |  | Very low | Unrelated |
| Rural Water |  |  | Medium | Most unrelated; maybe some indirect; maybe some direct |
| Stock |  |  | Low | Most unrelated; maybe some indirect |
| Water Depot |  |  | Very high | Most direct; some indirect |
|  |  |  |  |  |
| Temporary water permit allocation | Medium-low | All almost certainly upper-bounded |  |  |
| Ground Water |  |  | Medium | All |
| Surface Water |  |  | Medium | All |
| Archaeology |  |  | Very low | Unrelated |
| Construction |  |  | Medium | Most unrelated; maybe some indirect |
| Domestic |  |  | Low | Most unrelated; maybe some indirect |
| Fire Protection |  |  | Low | Most unrelated; maybe some indirect |
| Fish and Wildlife |  |  | Very low | Unrelated |
| Flood Control |  |  | Very low | Unrelated |
| Industrial |  |  | Very high | Some direct; some indirect; some unrelated |
| Irrigation |  |  | High | Most unrelated; maybe some indirect |
| Livestock |  |  | Low | Most unrelated; maybe some indirect |
| Municipal |  |  | Medium | Most unrelated; maybe some indirect |
| Resource Planning |  |  | Very low | Unrelated |
| Rural Water |  |  | Medium | Most unrelated; maybe some indirect; maybe some direct |
| Water Depot |  |  | Very high | Most direct; some indirect |