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NORTHROP GRUMMAN
Mission Systems

Produced Water in the Rocky Mountain Region – Quantity and Quality

White Paper – Phase 2

By:
Don J. Remson

November, 2005

FOR

U. S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Work Performed Under Contract No. DE-AD26-01NT00249

Northrop Grumman Mission Systems
Information & Technical Services Division
Tulsa, Oklahoma

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Northrop Grumman Mission Systems
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Produced Water in the Rocky Mountain Region – Quantity and Quality

This report represents the second phase of a two phase study of produced water from oil and gas operations in the lower 48 states. Unlike the phase 1 report[1] which discussed produced water in general from lower 48 onshore oil and gas operations, the purpose of this second phase is to tie water quality and quantity data in much greater detail for the Rocky Mountain Region where greatest demand for produced water is most likely to occur.

1 Introduction

The Rocky Mountain region has been singled out for this second phase study due to the fact that it is an arid region with few competing water resources and has a large potential for production of water due to relatively high water oil ratios as well as water gas ratios in its producing basins. There is a large amount of unconventional gas development ongoing which relies on significant de-watering of coal resulting in production of large volumes of sometimes relatively good quality water. In order to assess the potential for beneficial uses of produced water from oil and gas development, it is first necessary to determine the location of the water being produced, forecast its future production potential, and determine the quality of the water.

This report will focus entirely on historical produced water production, forecast produced water production, and produced water quality samples for ten significant oil and gas producing basins located within 5 states in the Rocky Mountain region. The following is a list of the basins studied and their locations.

Basin	Location
Powder River	N.E. Wyoming, S.E. Montana
Big Horn	N.W. Wyoming and S. Montana
Piceance	N.W. Colorado

[1] "Produced Water from Oil and Gas Operations in the Onshore Lower 48 States", by Robert A. Welch and Dwight F. Rychel, December, 2004

Denver	N.E. Colorado
Wind River	Central Wyoming
Raton	S.E. Colorado, N.E. New Mexico
Paradox	S.W. Colorado, S.E. Utah
Uinta	N.E. Utah
San Juan	N.W. New Mexico, S.W. Colorado
Greater Green River	S.W. Wyoming

The produced water from these 10 basins represents over 73% of the produced water from these 5 states[2]. Almost all of the remaining 27% is produced in the Permian Basin in New Mexico which is not considered part of the Rocky Mountain region.

This report consists of 4 major sections. The first section will forecast the quantity of produced water expected from each of the 10 highlighted oil and gas producing basins over the next 20 years as well as discuss the historical water production over the previous 5 years. The methodology used to generate the forecast will be discussed.

The next section of the report will discuss efforts to acquire produced water quality sample data. A multitude of water quality samples have been acquired from these 10 basins. The elements of the data as well as a discussion of their sources are provided.

Finally, a summary of each producing basin is provided. Each summary will provide a basin produced water history and forecast covering the years 2000 – 2025 as well as statistical data generated from the produced water quality data. For this report the statistical analysis will be primarily limited to Total Dissolved Solids (TDS) as this can be considered a general indicator of water quality.

The final section of the report will discuss the possible beneficial use of produced water for use in existing and planned CO2 sources.

[2] Year 2000 statistics compiled from "Produced Water Management Handbook" , Deidre Boysen, John Boysen, Jessica Boysen, and Tim Larson

2 Rocky Mountain Region Basin Level Produced Water Forecast

2.1 Forecasting Methodology

The method used to forecast produced water at the basin level relies on historical oil, gas, and water production collected on an annual basis at the county level as well as play and region level oil and gas forecasts provided by the U.S. Department of Energy, Energy Information Agency's Annual Energy Outlook 2005[3]. These forecasts will be referred to throughout this document as AEO 2005. The AEO production forecasts cover years 2004 through 2025. The approach used to create the produced water forecasts is described as follows.

Annual oil and gas production data was collected by county for years 2000-2004 from the various state agencies[4]. This county level data was then aggregated into the 10 oil and gas producing basins. Next, the play level unconventional gas forecasts from AEO 2005 were aggregated into their respective basins. The conventional non-associated gas as well as the associated/dissolved gas forecasts from AEO 2005 are reported only at the region level and had to be disaggregated into the respective basins. This was performed by assuming that any year 2004 historical gas production in a basin not accounted for by the AEO unconventional gas forecast for that basin could be attributed to a combination of conventional AD and NA gas. The relative proportions of conventional AD and NA gas which make up the shortfall are assumed to be the same as the relative volume of gas produced from counties in the basin with GOR > 5000 scf/bbl and the volume of gas produced from counties which are primarily oil producing. After the relative proportions are known, calculations are made to determine what fraction of the region level NA and AD gas volumes are needed by the basin to makeup the production shortfall. The year 2004 was used to perform this reconciliation of numbers since there are both historical and AEO forecast production numbers for this year.

Based on Gas/Oil ratios, all of the basins were considered to be primarily gas producing with the exception of the Big Horn Basin which is primarily oil producing. The method of forecasting for the Big Horn Basin was to decline the historical oil production into the future. This future prediction of oil production was multiplied by an estimate of WOR. The WOR was estimated by taking the most recent value of WOR (2004) and increasing it 2.2% per year. This was the rate of increase in WOR observed in the historical production.

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[3] Energy Information Administration, 2005 Annual Energy Outlook 2005 – With Projections to 2025, DOE/EIA-0383(2005)

[4] Colorado Oil and Gas Conservation Commission (COGCC); Wyoming Oil and Gas Conservation Commission (WOGCC); Utah Department of Natural Resources, Division of Oil, Gas, and Mining; Montana Board of Oil and Gas Conservation; New Mexico Energy, Minerals, and Natural Resources Department, Oil Conservation Division

The approach used to estimate water production for the 9 primarily gas producing basins was to add the basin level unconventional gas production predictions to fractions of Rocky Mountain regional AD and NA gas production forecasts. The fractions used for each basin are the same as the fractions calculated for the year 2004 reconciliation described earlier. These gas predictions are then multiplied by the basin level WGR to determine annual produced water. The 2004 value of WGR was used throughout the 20 year prediction as the future behavior of this value was uncertain.

2.2 Historical Production Data

As mentioned, historical oil, gas, and water production was gathered at the county level from the various state agencies. Data was gathered for years 2000 – 2004. The reason for gathering data for these five years is that the water production data could be cross-checked with data collected for year 2000 published in the GRI atlas[5]. Year 2004 data could be used for reconciliation with the 2005 AEO forecast. Tables 2-1, 2-2, and 2-3 display basin level oil, gas, and water production respectively.

Historical Oil Production (barrels)					
Basin	**2000**	**2001**	**2002**	**2003**	**2004**
Powder River	13,487,329	11,837,316	10,805,022	10,304,074	9,476,103
Greater Green River Basin	9,361,314	9,927,304	10,539,480	10,578,243	11,001,891
Big horn Basin	17,392,237	16,596,890	15,764,776	15,525,879	15,340,480
Wind River Basin	3,282,857	3,308,545	3,137,384	3,025,557	3,065,681
Piceance Basin	6,665,309	6,469,635	6,208,402	6,134,809	6,282,734
Paradox Basin	6,944,143	6,230,988	5,861,207	5,264,836	4,754,145
San Juan Basin	3,335,870	3,202,773	3,005,314	2,872,085	2,729,601
Raton Basin	0	0	0	0	0
Denver Basin	9,106,260	9,703,843	10,698,258	11,877,678	12,944,529
Uinta Basin	7,592,264	8,176,681	7,310,002	7,409,541	9,617,641
10 Basin Total	77,167,583	75,453,975	73,329,845	72,992,702	75,212,805

Table 2-1 Historical Oil Production

[5] Year 2000 statistics compiled from "Produced Water Management Handbook" , Deidre Boysen, John Boysen, Jessica Boysen, and Tim Larson

Historical Gas Production (Mcf)					
Basin	**2000**	**2001**	**2002**	**2003**	**2004**
Powder River	248,511,545	334,239,406	399,005,706	411,152,733	405,581,952
Greater Green River Basin	738,527,478	813,659,513	896,467,233	984,153,756	1,056,250,158
Big horn Basin	23,595,463	24,400,059	25,237,167	24,799,233	25,037,147
Wind River Basin	133,651,909	141,845,894	153,639,702	155,414,973	196,006,151
Piceance Basin	106,846,803	124,580,708	159,859,305	192,721,541	249,979,121
Paradox Basin	311,958,829	316,881,988	322,985,281	350,664,278	386,827,356
San Juan Basin	1,550,335,081	1,505,280,075	1,483,618,796	1,480,600,362	1,492,343,322
Raton Basin	75,844,131	76,803,834	92,771,633	98,248,304	101,697,994
Denver Basin	174,061,885	193,549,867	217,617,085	233,253,519	232,006,659
Uinta Basin	169,516,655	195,727,812	207,452,473	208,371,434	225,340,518
10 Basin Total	3,532,849,779	3,726,969,156	3,958,654,381	4,139,380,133	4,371,070,378

Table 2-2 Historical Gas Production

Historical Water Production (barrels)					
Basin	**2000**	**2001**	**2002**	**2003**	**2004**
Powder River	842,242,616	963,486,125	1,017,839,960	1,003,035,750	951,343,011
Greater Green River Basin	92,754,523	90,194,954	108,075,305	116,528,828	120,896,290
Big horn Basin	817,188,460	817,314,736	819,296,369	816,819,223	824,881,447
Wind River Basin	124,300,993	139,727,196	148,701,999	148,138,273	153,501,466
Piceance Basin	97,043,305	96,615,657	91,767,026	88,028,559	103,968,912
Paradox Basin	64,450,577	54,867,130	63,167,208	58,714,110	53,484,368
San Juan Basin	48,930,461	48,219,732	47,355,962	50,930,140	50,776,753
Raton Basin	55,614,167	69,011,981	93,804,088	108,314,052	87,833,517
Denver Basin	44,361,347	42,608,394	40,241,790	44,569,123	42,756,342
Uinta Basin	75,018,770	77,611,084	67,265,461	67,491,300	71,612,907
10 Basin Total	2,261,905,219	2,399,656,989	2,497,515,168	2,502,569,358	2,461,055,013

Table 2-3 Historical Water Production

Using the historical production data presented, additional calculations were made to acquire WOR, WGR, and GOR. These ratios were used in predicting future water production from the individual basins. Calculated values of WOR are presented in Table 2-4, WGR is shown in Table 2-5, and calculated GOR is shown in Table 2-6.

Historical Water Oil Ratio (WOR) (BBL/BBL)					
Basin	**2000**	**2001**	**2002**	**2003**	**2004**
Powder River	44.83	56.36	64.49	67.38	67.58
Greater Green River Basin	9.91	9.09	10.25	11.02	10.99
Big horn Basin	46.99	49.25	51.97	52.61	53.77
Wind River Basin	37.86	42.23	47.40	48.96	50.07
Piceance Basin	14.56	14.93	14.78	14.35	16.55
Paradox Basin	9.28	8.81	10.78	11.15	11.25
San Juan Basin	14.67	15.06	15.76	17.73	18.60
Raton Basin	0.00	0.00	0.00	0.00	0.00
Denver Basin	4.87	4.39	3.76	3.75	3.30
Uinta Basin	9.88	9.49	9.20	9.11	7.45

Table 2-4 Historical Water Oil Ratio

Historical Water Gas Ratio (WGR) (BBL/Mcf)					
Basin	**2000**	**2001**	**2002**	**2003**	**2004**
Powder River	3.39	2.88	2.55	2.44	2.35
Greater Green River Basin	0.13	0.11	0.12	0.12	0.11
Big horn Basin	34.63	33.50	32.46	32.94	32.95
Wind River Basin	0.93	0.99	0.97	0.95	0.78
Piceance Basin	0.91	0.78	0.57	0.46	0.42
Paradox Basin	0.21	0.17	0.20	0.17	0.14
San Juan Basin	0.03	0.03	0.03	0.03	0.03
Raton Basin	0.73	0.90	1.01	1.10	0.86
Denver Basin	0.25	0.22	0.18	0.19	0.18
Uinta Basin	0.44	0.40	0.32	0.32	0.32

Table 2-5 Historical Water Gas Ratio

Basin	2000	2001	2002	2003	2004
Powder River	13.23	19.55	25.28	27.62	28.81
Greater Green River Basin	78.89	81.96	85.06	93.04	96.01
Big horn Basin	1.36	1.47	1.60	1.60	1.63
Wind River Basin	40.71	42.87	48.97	51.37	63.94
Piceance Basin	16.03	19.26	25.75	31.41	39.79
Paradox Basin	44.92	50.86	55.11	66.60	81.37
San Juan Basin	464.75	469.99	493.67	515.51	546.73
Raton Basin	No Oil	No Oil	No Oil	No Oil	No Oil
Denver Basin	19.11	19.95	20.34	19.64	17.92

Table 2-6 Historical Gas Oil Ratio

This data clearly shows that the Big Horn Basin is primarily oil producing while the other nine are gas producing. This is why water predictions for the Big Horn basin were generated using WOR while WGR was used for the remaining basins.

2.3 Basin Level Annual Produced Water Forecast

Using the methodology described in section 2.1, projections of future water production[6] were developed for the 10 basins of this study. Figure 2-1 graphically displays the results of this analysis. This figure displays annual water production for each of the 10 basins. The five years of historical water production data along with 21 years of projected water production are displayed. The same data is displayed in a slightly different format as Figure 2-2. In this presentation the data is plotted as a stacked area chart. This allows one to easily see the relative contribution of each of the basins to the regional total.

It is readily apparent that two of the basins, Powder River and Big Horn, currently produce and are projected to produce most of the water associated with oil and gas production in the Rocky Mountain region. They each produce on the order of a billion barrels of water per year. This is far more than the remaining 8 basins combined. The next most important basin as far as produced water is concerned is likely to be the Piceance Basin. The AEO projections have this basin increasing gas production by more than 400% in the next 20 years. That is why water production in this basin is projected to go from around 100 million barrels/year to over 400 million barrels.

[6] complete annual basin projections and all data used to make them is available in excel spreadsheet basin_production.xls

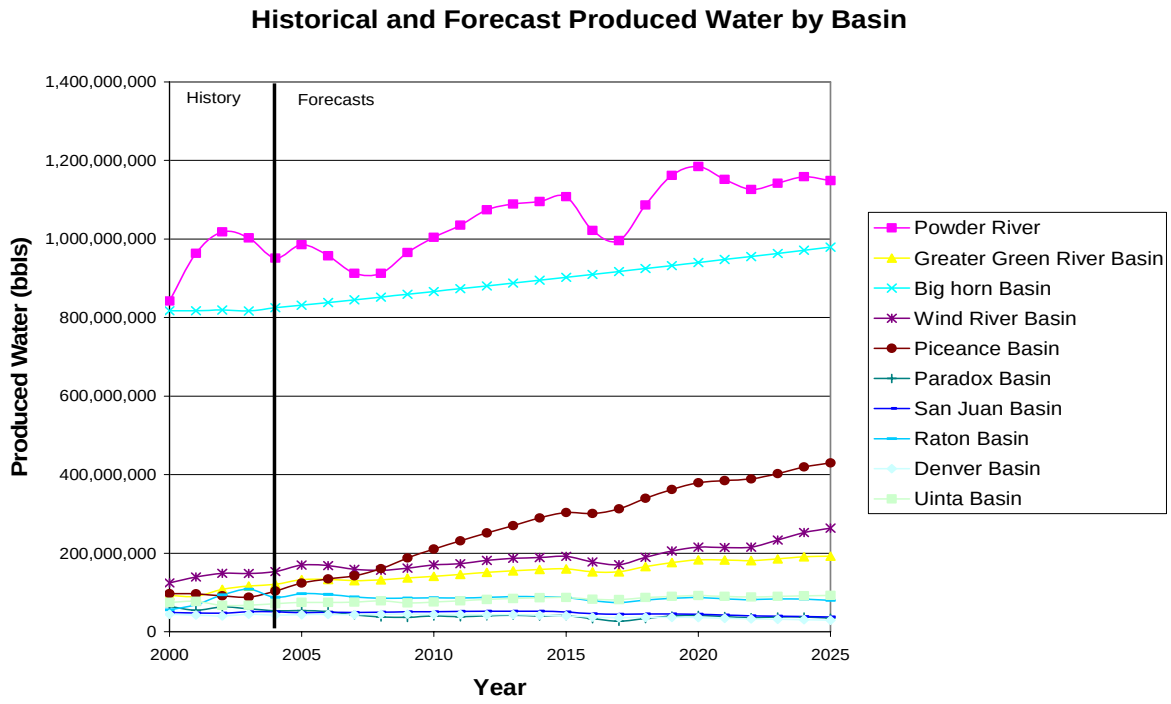


Figure 2-1 Annual Basin Water Production (history + forecast)

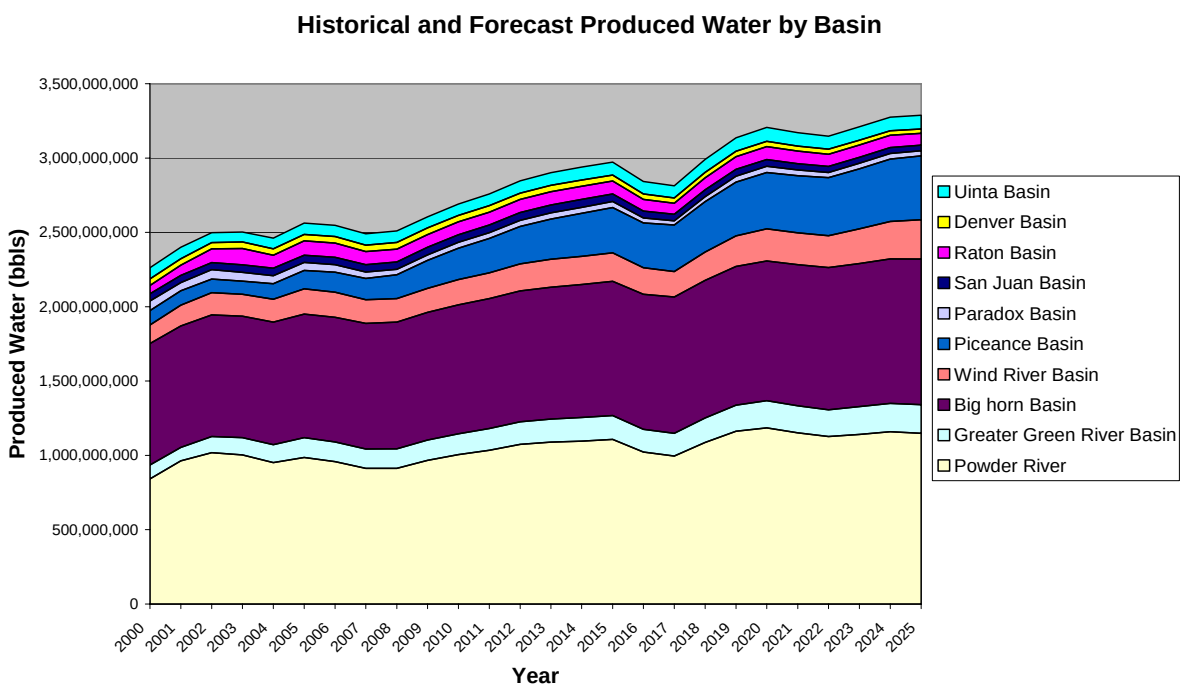


Figure 2-2 Stacked Area Chart of Basin Water Production (history + forecast)

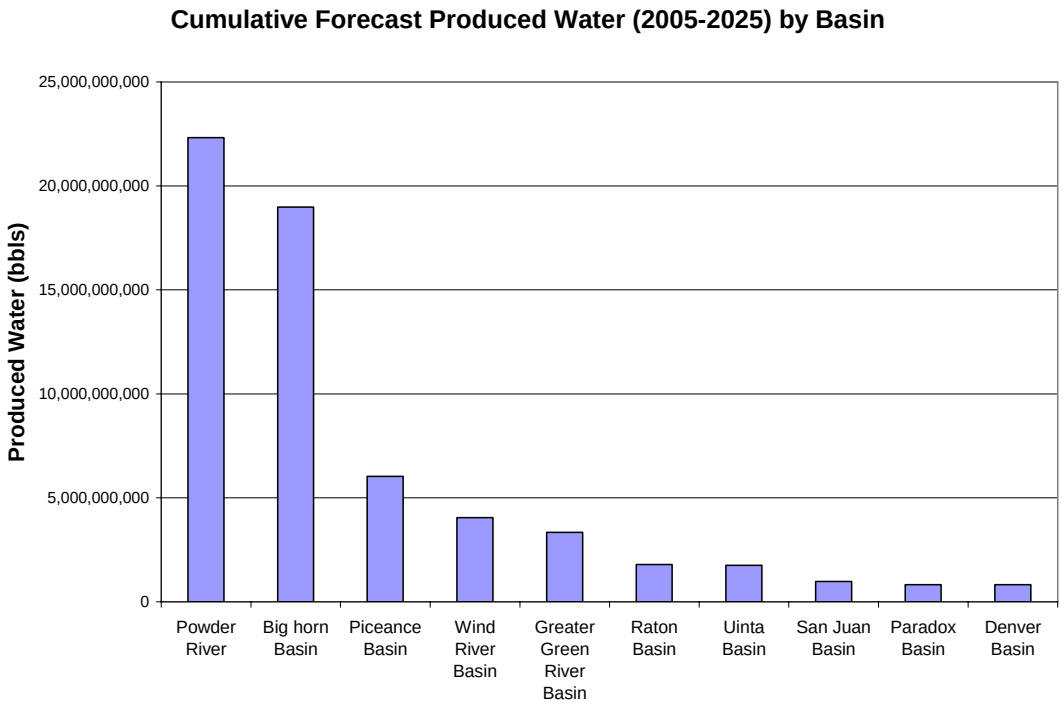


Figure 2-3 Cumulative Produced Water Forecast by Basin (2005-2025)

Figure 2-3 is a bar chart reporting cumulative water produced as part of oil and gas operations during the 21 year forecast period (2005-2025). During this time the Powder River Basin is projected to produce slightly more than 20 billion barrels of water while the Big Horn basin is expected to produce slightly less than 20 billion barrels. The Piceance basin will produce slightly over 5 billion while the remaining basins will produce much less.

3 Sources of RMR Produced Water Sample Data

After collection of historical water production data and forecasting future water production, the next task on the agenda was to gather as much publicly available water quality data as possible for the 10 Rocky Mountain oil and gas producing basins which make up this study. Although it is not clear at this point how to best use this data, the current objective is to collect data from as many samples as possible and store it in a manner that it would be readily available for any future analysis.

The initial focus of this effort was going to be to poll individual operators within each basin for water quality data. It was quickly discovered that this very time consuming effort had already been taken on by various state agencies and geologic societies. These groups had already collected thousands of samples directly from labs hired by operators to evaluate samples as well as the operators themselves. These data were subject to varying degrees of scrutiny and then placed in databases. At this time I have identified and collected data from 7 major data sources. Here is a brief description of these sources of water quality samples. Some statistics generated by these samples will be displayed in the basin summaries presented later in this report.

3.1 USGS Produced Waters Database

This database was briefly described and some of its data statistically described in the phase 1 report. To recap, it is a revision of a database originally compiled at the DOE Fossil Energy Research Center that was located in Bartlesville, Oklahoma. It contains 50,605 entries from all regions in the U.S. Although the information is fairly dated, pre-1980 data, it is very useful in that its coverage is very good. The database contains a substantial number of samples for each of the 10 basins in this report. It is easily downloaded from the web[7] in Microsoft access format.

Each sample contains test location information (State, county, basin, province, region, field name, section, township, range, latitude), well information (API number, well name, completion date, depth), and finally test results (Ph, TDS, and concentration of Bicarbonate, Calcium, Chloride, Magnesium, Potassium, Pot-Sodium, Sodium, and Sulfate).

3.2 47 Powder River Samples (Rice, USGS)

This data source consists of an Open-File Report[8] published in 2000 by USGS. It contains a very high quality analysis of 47 samples obtained from various coals in the Tongue River Member of the Fort Union Formation. These coals are representative of the current coalbed methane activity in the Powder River basin. These samples are fairly current having been collected in late 1999 and early 2000. In a telephone discussion with

[7] http://energy.cr.usgs.gov/prov/prodwat/intro.htm

[8] "Water co-produced with coalbed methane in the Powder River Basin, Wyoming: preliminary compositional data" by Rice, C.A., Ellis, M.S. , and Bullock, J.H. Jr. Open-File Report 00-372

the author, Cynthia Rice, it was learned that another 202 samples have been collected and recently analyzed and will be published in the very near future.

The data samples from this report are contained in an excel spreadsheet[9]. The data contains 2 parts, well information and test results. The well information provided contains things such as sample number, sampling date, API number, well name, Township, Range, and section information, GIS coordinates, total depth, producing interval, and producing coal. Test data includes measured parameters (pH, Temperature, Conductivity, TDS, SAR), major and minor element concentrations (i.e. F, CL, SO_4, Br, NH_4, Ca, K, Mg, Na, Ba, Fe, Si, Sr) and finally, a slew of trace element concentrations (Ag, Al, As, B, Be, Bi, Cd, Ce, Co, Cr, Cs, Cu, Hg, La, Li, Mn, Ni).

3.3 Interactive Geologic, Hydrologic, and Water Quality Database and Model for the Northern Powder River Basin, Wyoming

This unique data source was a cooperative effort of the Wyoming State Geological Survey, the Wyoming Water Resource Data System (WRDS), the Wyoming Oil and Gas Conservation Commission (WOGCC), the Wyoming State Engineer's Office, the Wyoming Geographic Information Science Center, the Wyoming Department of Environmental Quality (DEQ), and the United States Geological Survey – Water Resources Division. It was funded through the Wyoming Water Development Commission in response to requests for information from coalbed methane producers in the Powder River basin.

The data found in this interactive database system was generated using approximately 3,700 water samples contributed by at least 14 different operators in the basin. This interactive data model has been posted on the internet and can be found at the following URL[10]. Unfortunately, the actual water sample data which went into creating the model was considered proprietary by the companies who provided it and could not be released when I requested it from the Wyoming State Geological Survey. What is provided is summary statistics generated from the 3,700 samples reported at the individual Coal level of detail.

The study area of this model encompasses the majority of Campbell, Sheridan, and Johnson counties in Wyoming. A similar model is being planned for the southern Powder River basin. The model allows the user to generate a geologic column at any desired point in the study area. A cross section can be generated between any set of points in the study area. The geologic columns allow the user to determine which coals will be accessed by a well drilled at a given location. While actual water quality samples are not given to the public, summary level statistics are provided for 16 different coal groupings.

[9] powder_river_rice.xls
[10] http://ims.wrds.uwyo.edu/prb/index.html

The total number of samples, minimum value, maximum value, and median values are provided for a list of constituents. The constituents reported for each coal are TDS, Conductance, Calcium, Potassium, Magnesium, Sodium, Chloride, Fluoride, Bicarbonate, Sulfate, and Sodium Adsorption Ratio (SAR).

3.4 New Mexico Water and Infrastructure Data System (NM WAIDS)

This web site[11] provides several tools and data sets to help New Mexico oil and gas producers find information about both produced and ground water issues in New Mexico. The web site consists of four sections: data, maps, scale information, and corrosion information. This site is managed by the Petroleum Recovery Research Center (PRRC) through the Gas and Oil Technology Exchange and Communications Highway (GO-TECH). The data section includes two searchable databases; one for groundwater in southeast New Mexico, and one for produced water analyses throughout the state. The maps section of the website provides on on-line map based interface to these two databases. Of interest to this analysis are the produced water samples contained in the produced water analyses database. Of the approximately 7,500 produced water samples found in the database, roughly 3,200 are from the San Juan Basin in the counties of San Juan, Rio Arriba, Sandoval, and McKinley.

These samples may be accessed individually using the on-line GIS map feature. They may also be accessed by API number, Section, Township, and Range information, county, formation, or field name. The easiest way to obtain the data was to purchase a copy of the entire GIS system from PRRC. The CD is available at a very modest fee to simply cover the cost of handling/shipping etc. The CD includes several shape files, one of which contained the produced water data which was easily converted to Microsoft Access and then to an Excel spreadsheet[12].

Each sample contains both location/well information as well as test data. The well information provides state, county, field, formation, well name, well ID, API number, Township, Range, and section information, GIS coordinates, depth, and operator. Test data includes collection data (lab, sample date, analysis date, sample number) and results and concentrations (Ph, specific gravity, resistivity, conductivity, TDS, Na, Ca, Fe, Ba, Mg, K, Sr, Mn, Cl, carbonate, bicarbonate, sulfate, hydroxide and also concentrations of gas such as H_2S, CO_2, and O_2).

3.5 Rocky Mountain Basins Produced Water Database (NETL)

[11] http://octane.nmt.edu/waterquality/
[12] NMWAIDS.xls

This recently created database is distributed free of charge over the internet through the Department of Energy's National Energy Technology Laboratory (NETL) website[13]. It contains almost 8,000 produced water samples from 3,200 wells located in the Greater Green River and Wind River Basins. This database is a by-product of a NETL sponsored research effort[14]. The data was collected for the purpose of deducing depositional environments and diagenetic alterations to the formation waters and to help construct models describing the distribution and movements of waters in the subsurface. These models are to be used to devise strategies for the avoidance or remediation of movable waters in the subsurface. A future deliverable of this project will feature an "atlas" of Rocky Mountain produced water compositions.

The produced water data were collected from multiple sources, including Amoco, British Petroleum, Anadarko Petroleum Corporation, United States Geological Survey (USGS), Wyoming Oil and Gas Commission (WOGC), Denver Earth Resources Library (DERL), Bill Barrett Corporation, Stone Energy, and other operators. In addition, 86 new samples were collected during the summers of 2003 and 2004 from the following areas: Waltman/Cave Gulch in the Wind River Basin and Pinedale, Tablerock and Wild Rose in the Greater Green River Basin. Samples were subjected to a high degree of QA/QC before publication.

Each sample contains both well identification information as well as the actual test results. The well identification information provides formation interval, well name, well ID, API number, Township, Range, and section information, GIS coordinates, upper and lower depth intervals of sample. Test data include lab that ran sample, sample date, analysis date, and sampling method. Results and concentrations provided for the overwhelming majority of samples include Ph, resistivity, TDS, Sodium, Potassium, Calcium, Magnesium, Iron, Sulfate, Chloride, and Bicarbonate. Concentrations of additional minor ions and trace elements are provided for a very small fraction of samples.

3.6 Colorado Oil and Gas Conservation Commission (COGCC)

This Colorado Oil and Gas Conservation Commission provide a large online GIS system[15] from which it provides data to the general public. Aside from the online GIS system there an online query system known as the Colorado Oil and Gas Information System (COGIS) where users may perform live queries on production and facilities information. The COGIS system does not contain any water quality data. The online GIS

[13] http://www.netl.doe.gov/scngo/index.html
[14] "Identifying and Remediating High Water Production Problems in Basin Centered Formations" contract number DE-FC26_02NT41437. Performers: Advanced Resources International, Inc. (ARI), Schlumberger, Inc. , and BP America
[15] http://www.oil-gas.state.co.us/

system does have water quality sample locations spotted on the internet site, however, the user is asked to contact COGCC for data.

When contacted, COGCC generously agreed to help by providing data from their system. They ran a query on all produced water quality samples and generated an excel file[16] containing all of the water samples for which data was available. They informed me that the data was compiled from a wide variety of sources, and that in many cases they did not know any details about how the sample was collected or analyzed. For this reason, these analyses must be used cautiously. This data was very helpful in that it provided water quality samples for the Denver, Piceance, Paradox, Raton, and San Juan Basins. A total of 4952 water quality samples were provided.

Well and sample identification data is limited and consists basically of well name, API number, and township, range, and section information, and the date in which the sample was collected. There are over potentially over 140 test results published for each data sample. In reality, however, this information is relatively sparse. The following data elements and concentrations are fairly well populated among the samples: Ph, TDS, Ca, Cl, Fe, K, Mg, Na, and SO_4.

3.7 Wyoming Oil and Gas Conservation Commission (WOGCC)

This data source is very analogous to the one just described for the state of Colorado. There is both an online data query system as well as an online GIS system for obtaining oil and gas data free of charge from the state. There are over 3,000 produced water quality samples currently entered into the system with the addition of many more planned for the near future. The produced water quality data can be accessed through both the query system and the GIS system. The problem is that both methods must be queried one sample at a time. The sample data is reported in the form of a report which is not in a form suitable for collecting and analyzing large numbers of samples.

The solution to this dilemma will be to have the WOGCC online system operators perform an internal query within their system which will gather this information and provide it in the form of a Microsoft Access database or as records of an Excel spreadsheet. In talking to WOGCC I was told that this will be possible to do in the future depending on the workload of the WOGCC employees. Many of the samples included on the WOGCC site are already reported in the USGS database as well as the NETL database. For now selected information will be gathered one sample at a time from this site, time allowing, filling gaps in basin coverage left by the other data sources.

The well/location information provided for each sample includes well name, township, range and section information, API number, field name, formation name, and date sampled. In addition to Ph and TDS information, the following cation and anion

[16] COGCC.xls

concentrations are included: Sodium, Potassium, Lithium, Calcium, Magnesium, Iron, Sulfate, Chloride, Carbonate, Bicarbonate, Hydroxide, and Hydrogen Sulfide.

3.8 Coverage Statistics for Water Quality Data Sources

The seven sources for produced water quality samples described in this section will suffice for now due to time constraints. Statistics will be generated for data in each of the 10 basins. Again, due to lack of time, there will not be a high level of QA/QC applied to the available data. There is potential for data duplication between sources and also for data with incorrect ion balance problems or resistivity and TDS relationships which do not make sense. These problems should be cleaned up by development of a data screening model. For this current analysis, statistics will be run on the data on an "as is" basis. This should be sufficient for providing a general sense of the type of water which has been and is being produced in each of the basins. Table 3-1 displays the number of water samples acquired for each of the 10 basins from the 7 data sources used in this analysis.

Number of Water Samples by Data Source

	Usgs Database	Rice 47 Samples	NETL / ARI	New Mexico WAIDS	COGCC	WOGCC	WGS Interactive Model
Big Horn	2285					56	
Powder River	3158	47				57	Averaged data for 12 Coal Groupings
Piceance	444				262		
Denver	1148				703		
Wind River	2492		2372				
Raton	20				2158		
Paradox	518				9		

Uinta	625						
San Juan	349			3081	1625		
Greater Green River	2721		5537			TBD	

Table 3-1 Distribution of Water Samples Collected for Study

4 Rocky Mountain Region Basin Summaries

4.1 Big Horn Basin

4.1.1 Produced Water Forecast

Figure 4-1 shows both historical and forecast water production in the Big Horn basin for years 2000 – 2025. In this basin, most of the water production is associated with high water cut oil wells. The forecast is for production to increase from the current rate of about 825 million barrels per year to about 975 million barrels per year. The reason for this projection is that currently the water oil ratio is increasing about twice as fast as the oil rate is declining.

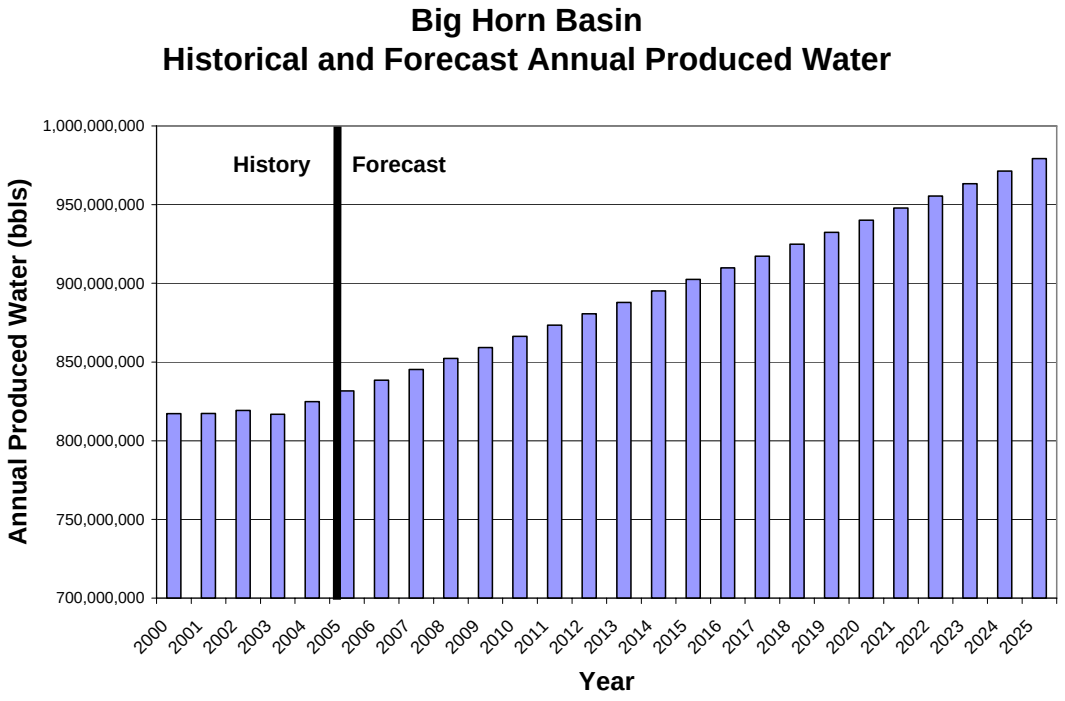


Figure 4-1 Big Horn Basin Produced Water History + Forecast

4.1.2 Produced Water Quality Statistics

Water Quality data for the Big Horn basin is derived from two sources. The USGS database contains about 2285 samples. An additional 56 samples were collected from the WOGCC website. Of these samples, only 13 were classified as “New Data” meaning they were collected in the last 10 years. Figure 4-2 and Table 4-1 present statistics regarding the Total Dissolved Solids concentrations of the Big Horn basin water samples.

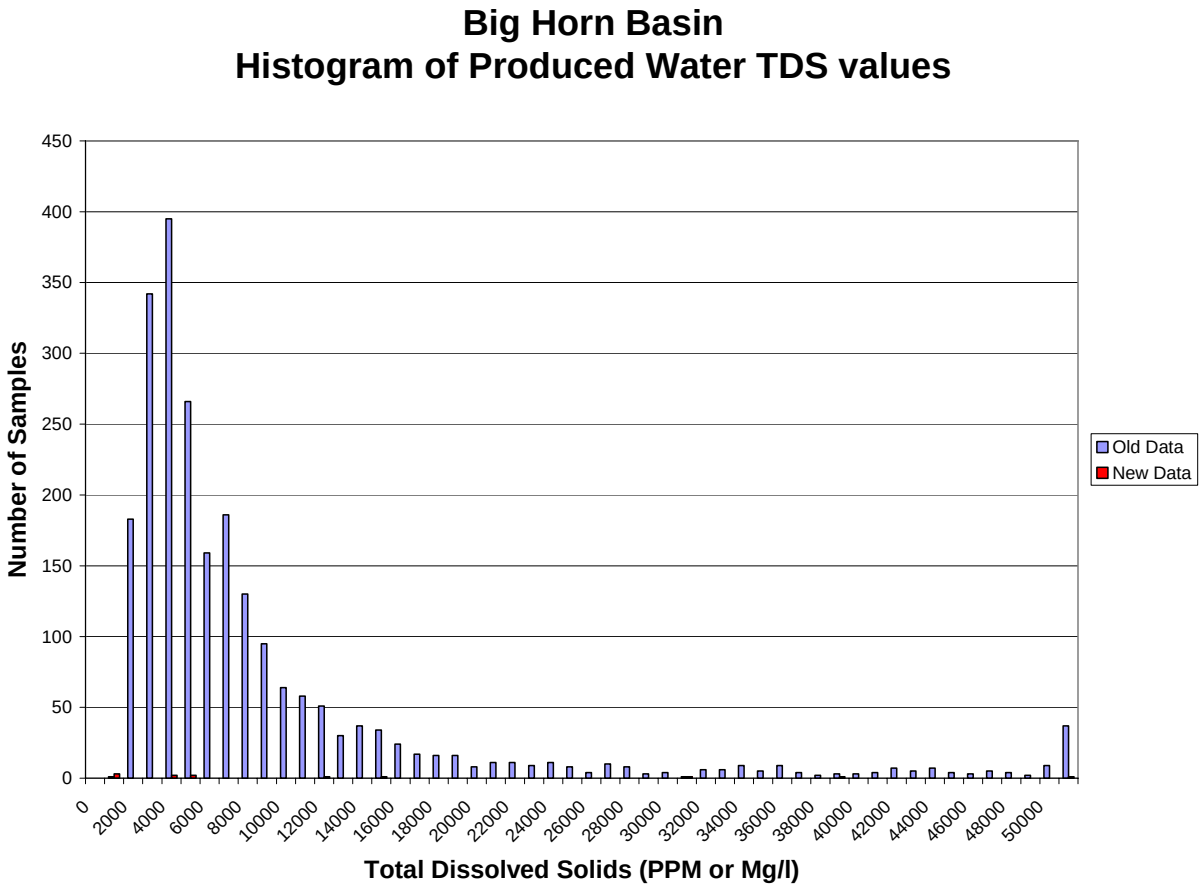


Figure 4-2 Big Horn Basin Histogram of TDS values

	Old Data (Pre 1995)	New Data (1995 - 2005)
Number of Samples	2326	12
Average TDS Value	8,930	13,545
Median TDS Value	4,891	4,216

Table 4-1 Big Horn Basin Water Sample TDS Statistics

4.2 Powder River Basin

4.2.1 Produced Water Forecast

Figure 4-1 shows both historical and forecast water production in the Big Horn basin for years 2000 – 2025. The basin is projected to continue producing on the order of 1,000,000 barrels of water per year well into the future as the drilling for coalbed methane wells is expected to continue at a pace of at least 1,500 wells per year throughout the forecast period.

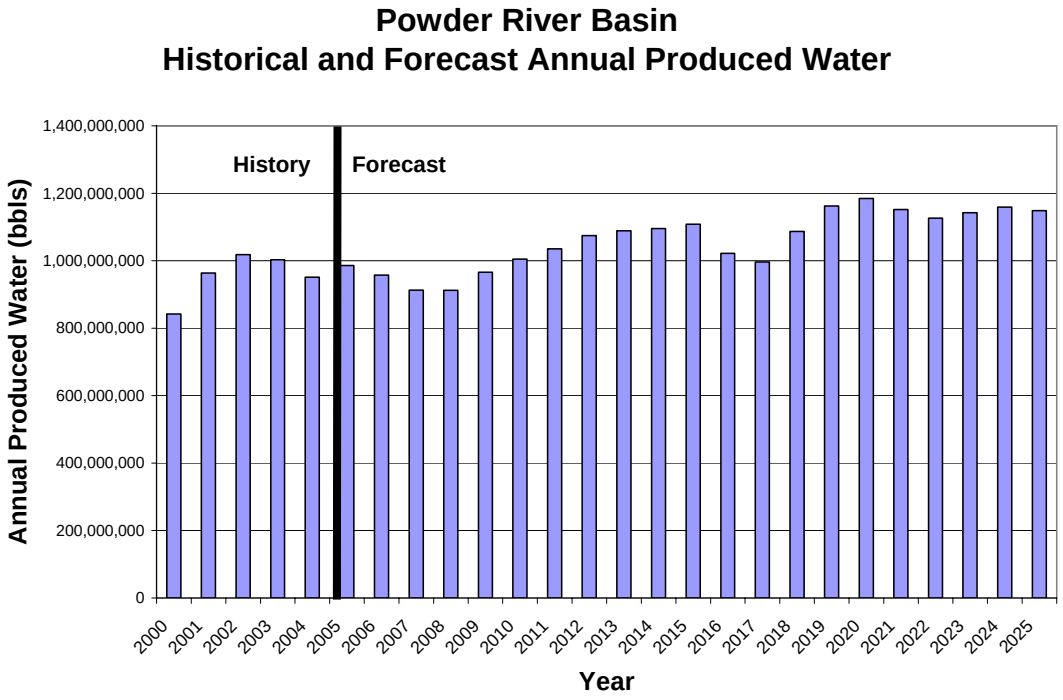


Figure 4-3 Powder River Basin Produced Water History + Forecast

4.2.2 Produced Water Quality Statistics

The water produced by recent oil and gas operations in the Powder River Basin can be divided into two groupings, that which is produced by coalbed methane operations and that which is not. Figure 4-4 shows the historical breakdown of this water production. Over the last 4 years slightly greater than half of the produced water from the Powder River basin has been from coalbed methane operations. Most of the older water quality analyses collected are for non coal formations, most of the more recent data has been

sampled from coal de-watering operations. A total of 3,158 samples were reported in the USGS database. These were from non-coal formations. An additional 57 non coal samples were selected from the WOGCC website of which 18 were from the last 10 years.

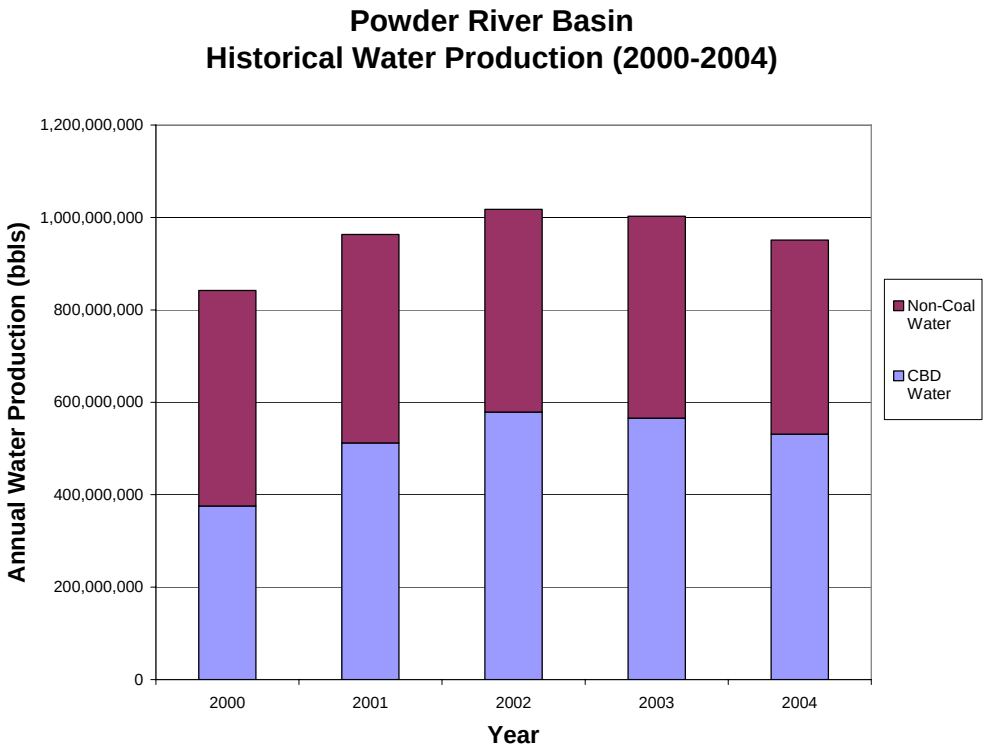


Figure 4-4 Historical Breakdown of Powder River Produced Water

Figure 4-5 and Table 4-2 present the distribution of non coal water samples for both old and recent data collected. The TDS data for coalbed methane water production comes from two sources. A collection of 47 samples from the literature[17] and averaged water samples from the hydrologic model and water quality database of the northern Powder River basin maintained by the Wyoming State Geologic Survey. Figure 4-6 presents TDS statistics for the water being produced by coalbed methane operations in the Powder River Basin. Comparison with the histogram of Figure 4-5 shows the much higher quality of the water produced from coal than that of the water produced from the other formations.

[17] "Water co-produced with coalbed methane in the Powder River Basin, Wyoming: preliminary compositional data" by Rice, C.A., Ellis, M.S. , and Bullock, J.H. Jr. Open-File Report 00-372

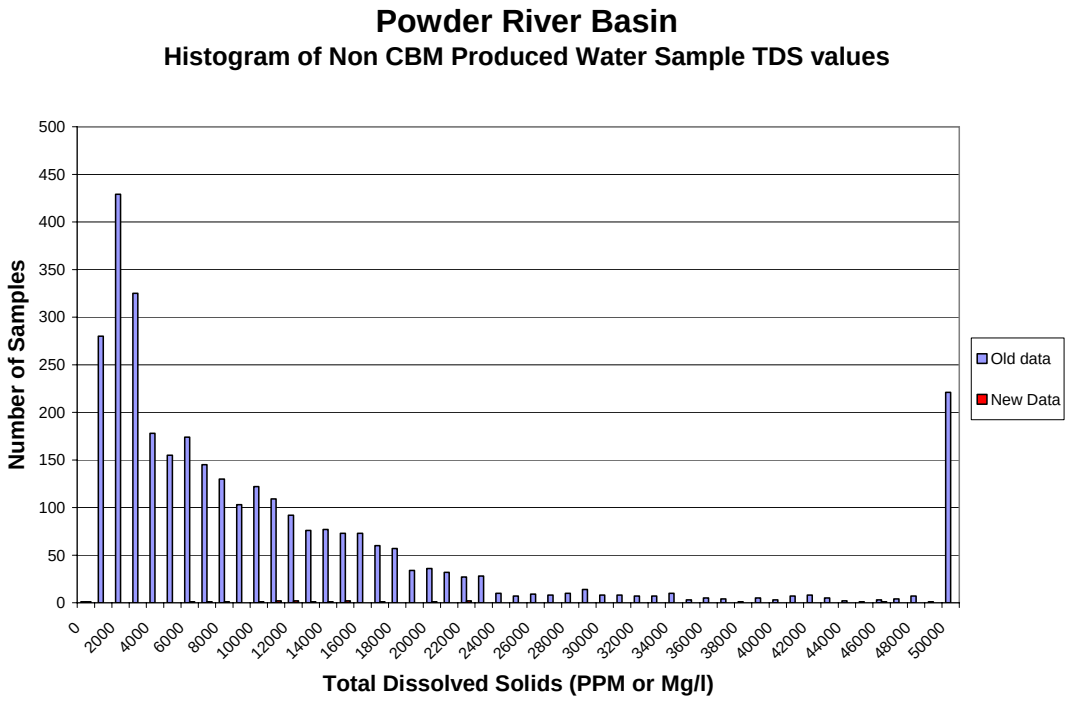
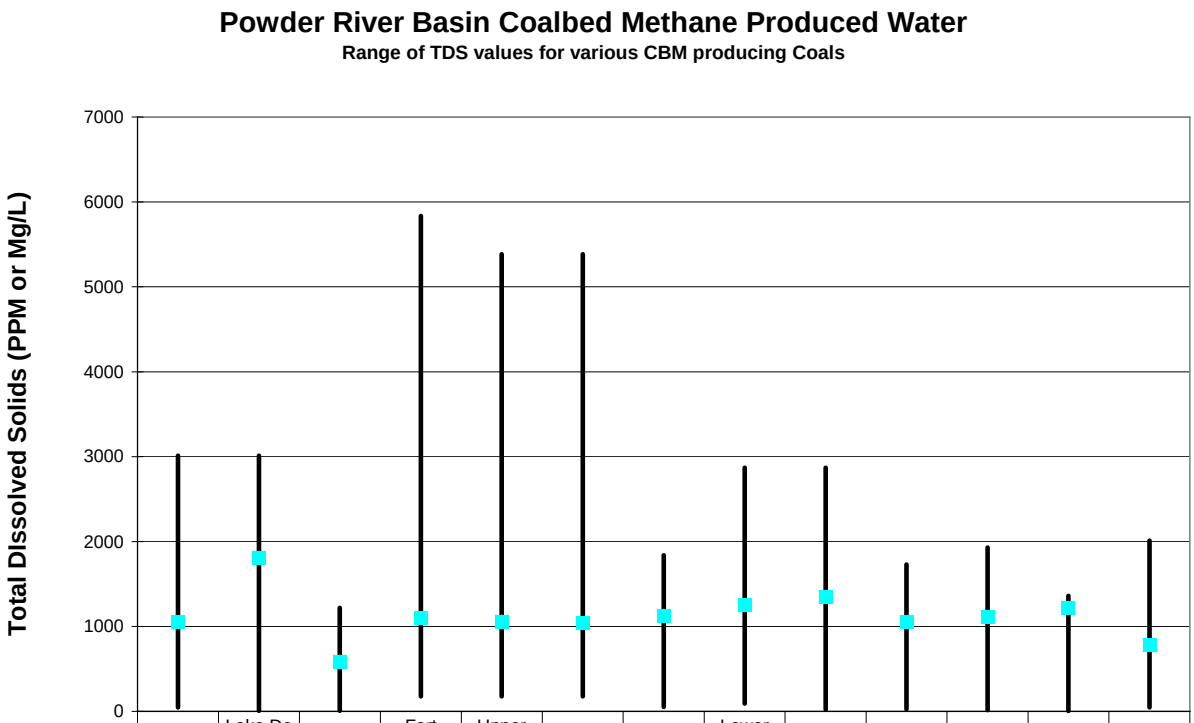


Figure 4-5 Powder River Histogram of non coal TDS values

	Old Data (Pre 1995)	New Data (1995 - 2005)
Number of Samples	3,194	18
Average TDS Value	17,219	15,011
Median TDS Value	7,364	13,183

Table 4-2 Powder River Non Coal Water Sample TDS Statistics



	Wasatch Coal	Lake De Smet Coal	Felix Coal	Fort Union Coal	Upper Wyodak Coal	Anderso n Coal	Canyon Coal	Lower Wyodak Coal	Monarch Coal	Cook Coal	Wall Coal	Carney Coal	Rice (47 samples)
Max	3011	3011	1220	5834	5384	5384	1840	2870	2870	1730	1930	1360	2010
Min	535	550	535	180	180	180	660	528	1012	591	537	910	270
Median	1050	1812	588	1100	1060	1040	1127	1250	1349	1055	1110	1220	780
Samples	47	9	8	434	319	242	54	92	22	28	16	7	47

Figure 4-6 Powder River Histogram of TDS values from Coalbed Methane Samples

4.3 Piceance Basin

4.3.1 Produced Water Forecast

Figure 4-7 shows both historical and forecast water production in the Piceance basin for years 2000 – 2025. Of all of the projections in this report, it is felt that this water production forecast is definitely optimistic. The reason is that the methodology being used is to apply the current WGR to future gas projections. The problem is that a lot of the current water production is related to oil production, especially in Rio Blanco county. The huge increase in gas production forecast for this basin by the AEO is tight gas which will have a lower WGR than that currently calculated for the entire basin. To determine a more accurate projection of produced water, one would have to do a more detailed

analysis in which projections are made for the individual types of petroleum resource being produced in the basin.

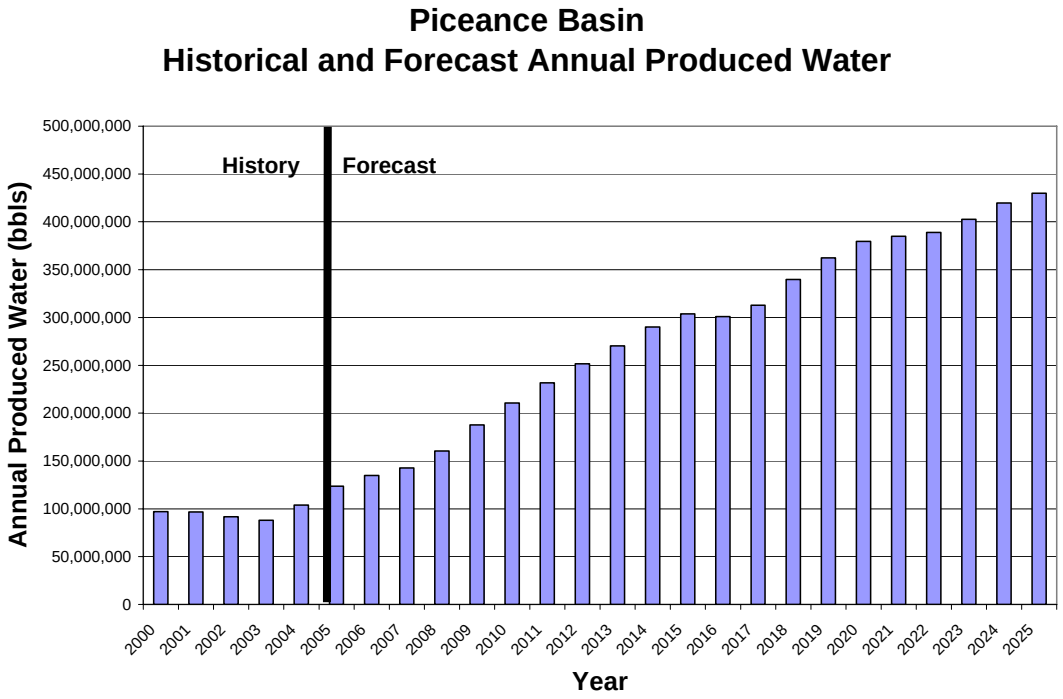


Figure 4-7 Piceance Basin Produced Water History + Forecast

4.3.2 Produced Water Quality Statistics

Water Quality data for the Piceance basin is derived from two sources. The USGS database contains about 444 usable samples. An additional 199 samples were collected from data supplied by the COGCC. Of these samples, a total of 68 were classified as "New Data" meaning they were collected in the last 10 years. Figure 4-8 and Table 4-3 present statistics regarding the Total Dissolved Solids concentrations of the Piceance basin water samples

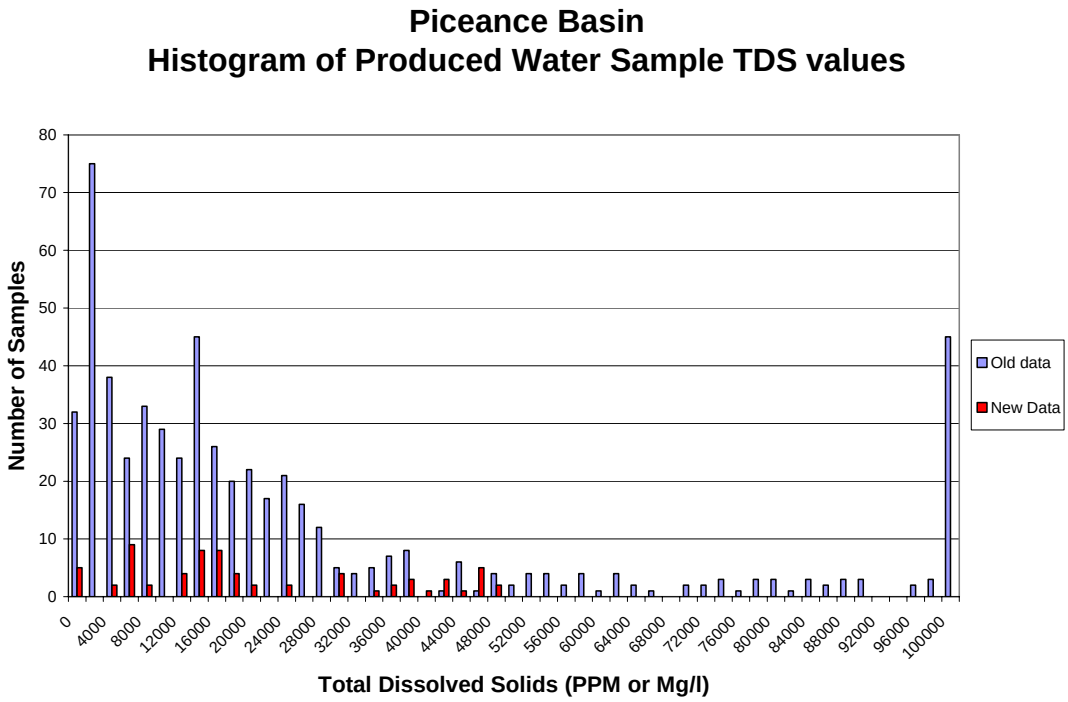


Figure 4-8 Piceance Basin Histogram of TDS values

	Old Data (Pre 1995)	New Data (1995 - 2005)
Number of Samples	575	68
Average TDS Value	27,693	21,760
Median TDS Value	15,407	16,400

Table 4-3 Piceance Basin Water Sample TDS Statistics

4.4 Denver Basin

4.4.1 Produced Water Forecast

Figure 4- 9 shows both historical and forecast water production in the Denver basin for years 2000 – 2025. The produced water projections show a decline from the current range of about 43 million barrels per year to around 30 million barrels per year. This decline reflects the decline in gas production forecast by the 2005 AEO for this basin.

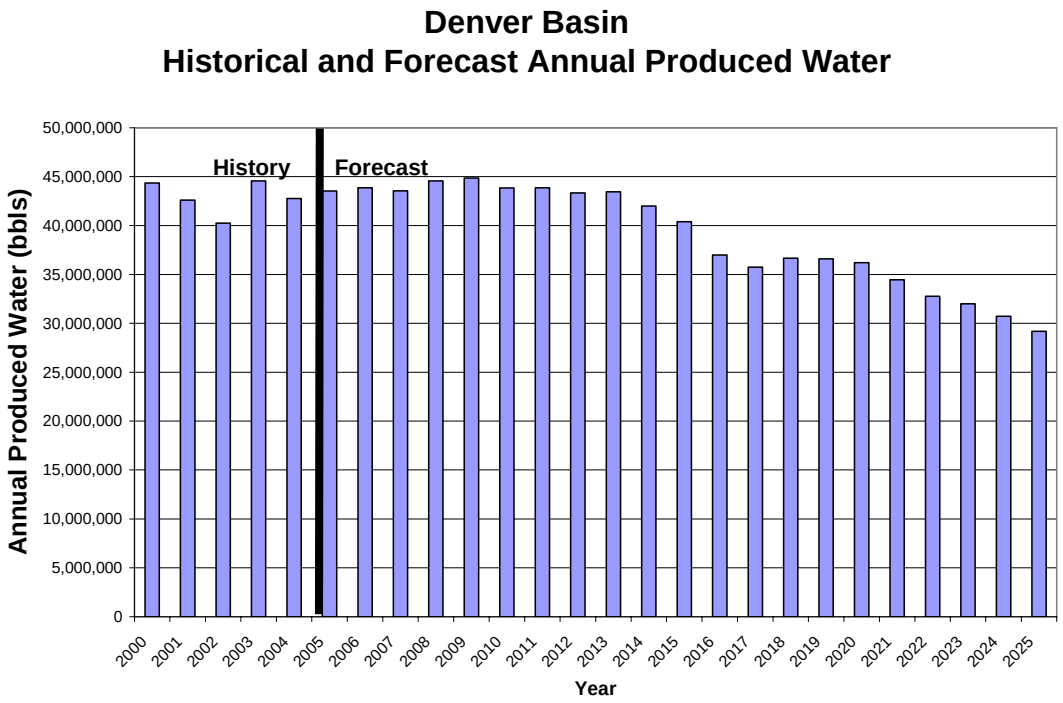


Figure 4-9 Denver Basin Produced Water History + Forecast

4.4.2 Produced Water Quality Statistics

Water Quality data for the Denver basin is derived from two sources. The USGS database contains about 1,148 usable samples all of which are at least 25 years old. An additional 605 samples were provided by the COGCC. Of these samples, a total of 38 were classified as “New Data” meaning they were collected in the last 10 years. Figure 4-10 and Table 4-4 present statistics regarding the Total Dissolved Solids concentrations of the Denver basin water samples.

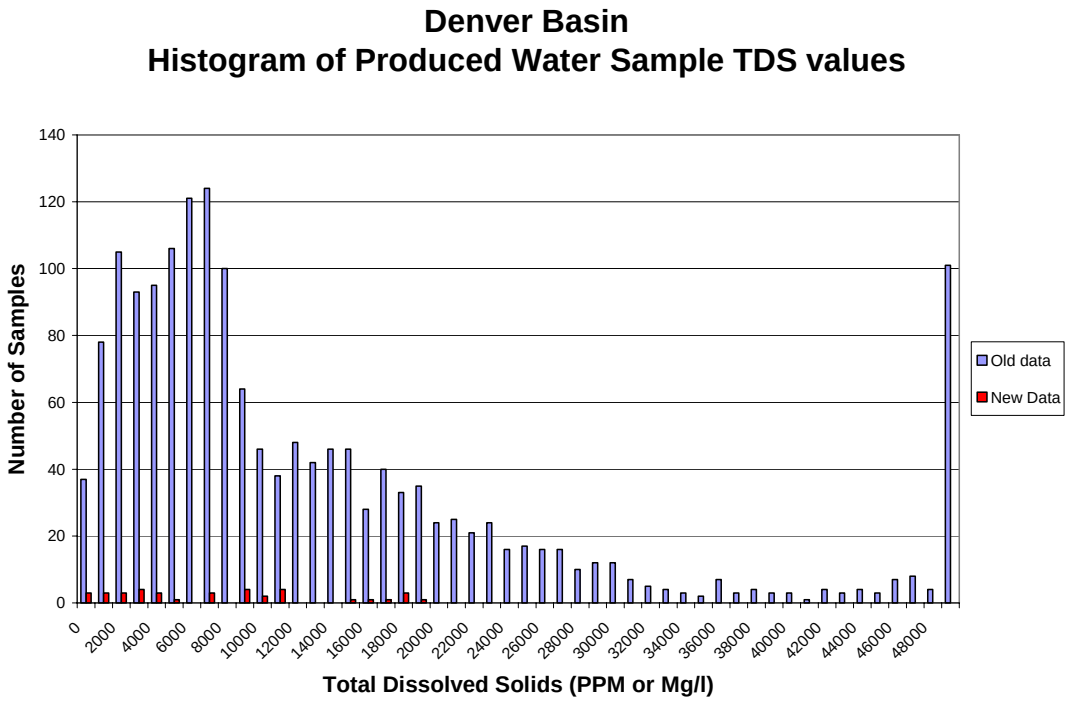


Figure 4-10 Denver Basin Histogram of TDS values

	Old Data (Pre 1995)	New Data (1995 - 2005)
Number of Samples	1,715	38
Average TDS Value	16,890	8,860
Median TDS Value	9,710	8,450

Table 4-4 Denver Basin Water Sample TDS Statistics

4.5 Wind River Basin

4.5.1 Produced Water Forecast

Figure 4- 11 shows both historical and forecast water production in the Wind River Basin of Wyoming for years 2000 – 2025. The produced water projections show a gradual increase in produced water from a current rate of about 150 million barrels per day to about 250 million barrels by 2025. These projections assume a constant WOR which has been fairly consistent over the history period.

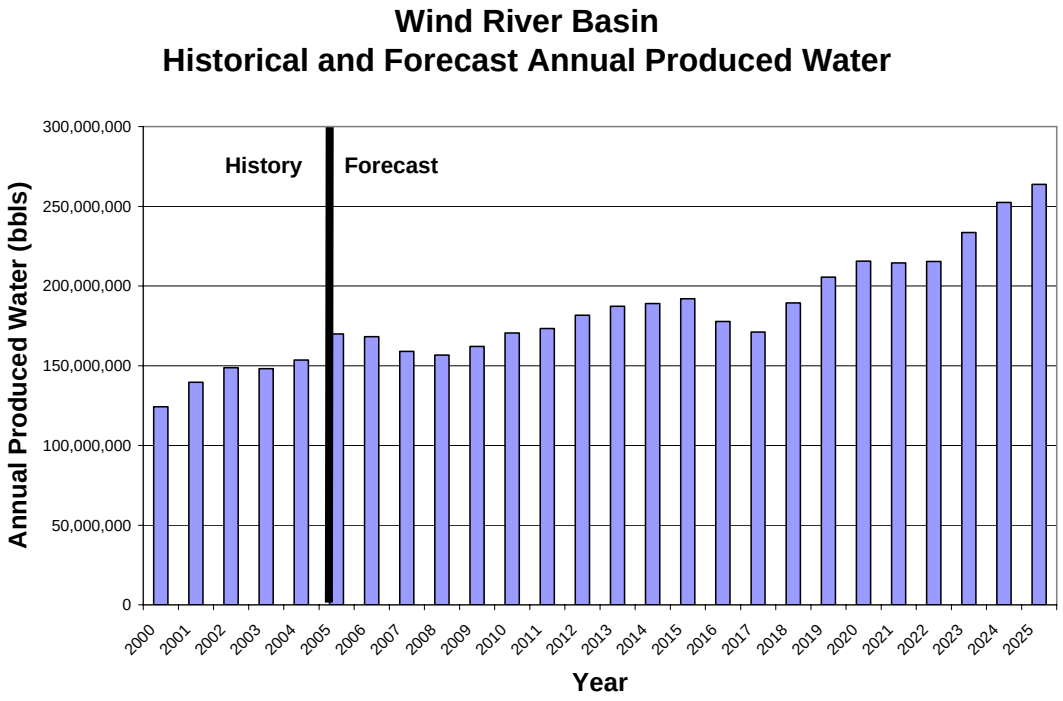


Figure 4-11 Wind River Basin Produced Water History + Forecast

4.5.2 Produced Water Quality Statistics

Water Quality data for the Wind River basin is derived from two sources. The USGS database contains about 2,490 usable samples. An additional 2,280 samples were obtained from NETL[18]. Of these samples, a total of 93 were classified as "New Data" meaning they were sampled in the last 10 years. A majority of the older samples were duplicates from the USGS database. These duplicates were removed giving a total of 2,617 unique samples for analysis. Figure 4-12 and Table 4-5 present statistics regarding the Total Dissolved Solids concentrations of the Wind River basin water samples.

[18] http://www.netl.doe.gov/scngo/index.html

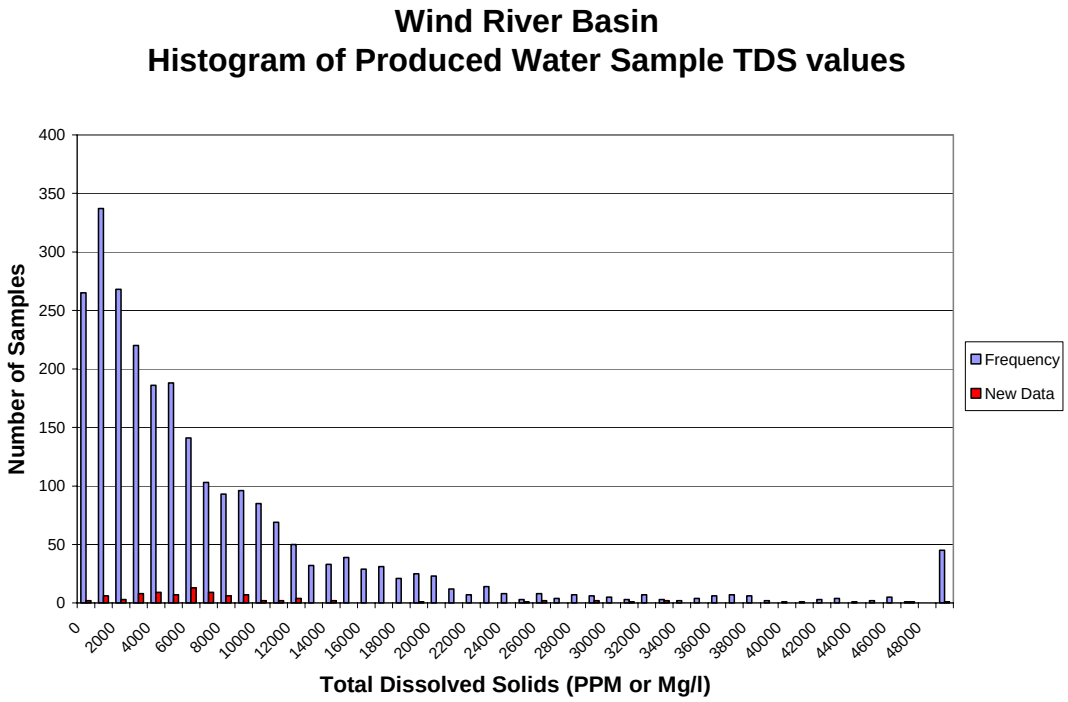


Figure 4-12 Wind River Basin Histogram of TDS values

	Old Data (Pre 1995)	New Data (1995 - 2005)
Number of Samples	2,524	93
Average TDS Value	9,738	10,393
Median TDS Value	5,874	7,938

Table 4-5 Wind River Basin Water Sample TDS Statistics

4.6 Raton Basin

4.6.1 Produced Water Forecast

Figure 4- 13 shows both historical and forecast water production in the Raton basin for years 2000 – 2025. The produced water projections hold steady at just over 80 million barrels per year. This relatively constant forecast is a result of applying a stable WOR to a relatively constant gas production forecast for this basin from the AEO report. There is no oil production in this basin.

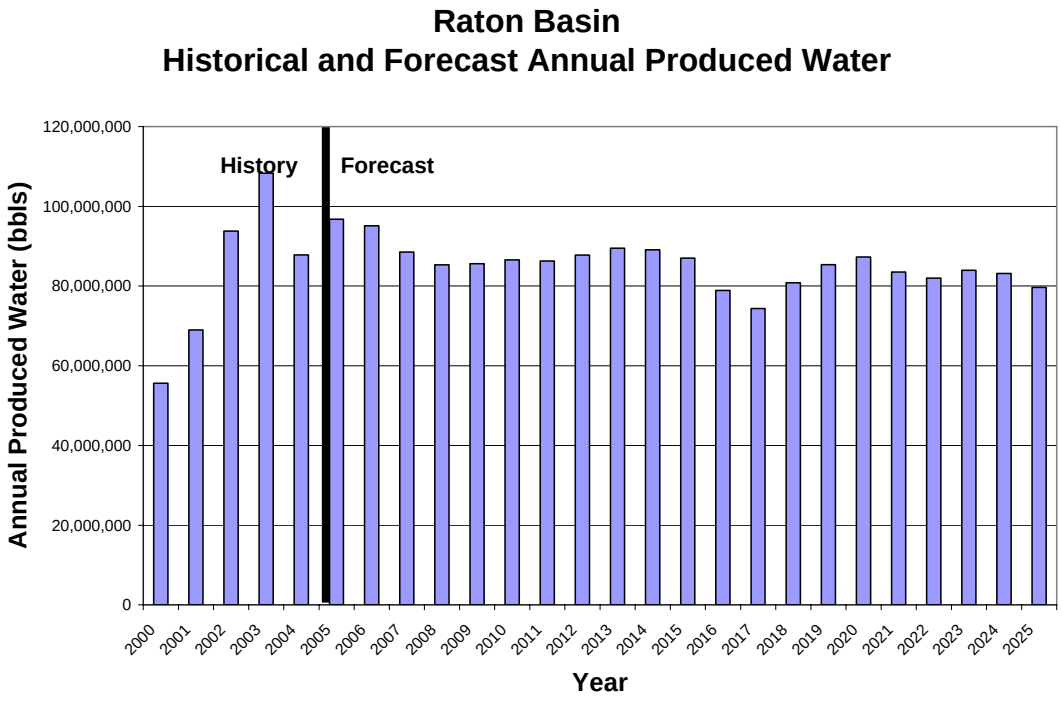


Figure 4-13 Raton Basin Produced Water History + Forecast

4.6.2 Produced Water Quality Statistics

Water Quality data for the Raton basin is derived from two sources. The USGS database for this basin contains only 20 usable samples. An additional 1,947 samples were obtained from COGCC. Of these samples, a total of 1,838 were classified as “New Data” meaning they were sampled in the last 10 years. Even the older samples were still much more recent than the USGS samples. Figure 4-14 and Table 4-6 present statistics regarding the Total Dissolved Solids concentrations of the Raton basin water samples. The low TDS value of the water samples from this basin reflects the fact that production is coalbed methane.

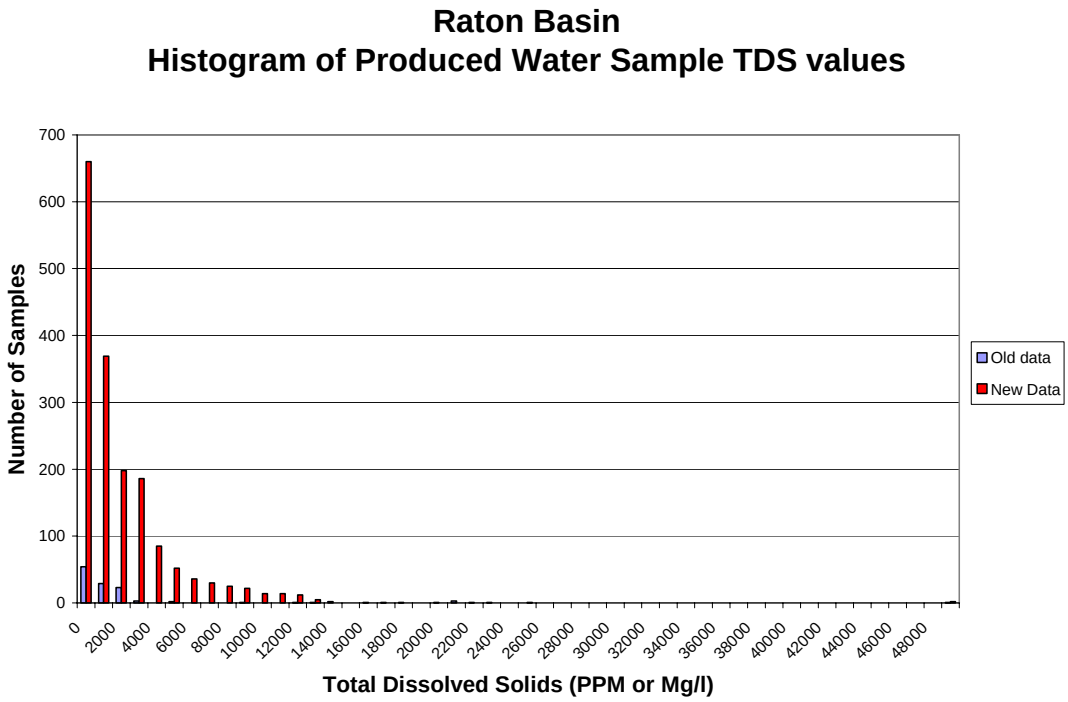


Figure 4-14 Raton Basin Histogram of TDS values

	Old Data (Pre 1995)	New Data (1995 - 2005)
Number of Samples	129	1,838
Average TDS Value	4,460	3,379
Median TDS Value	2,250	2,349

Table 4-6 Raton Basin Water Sample TDS Statistics

4.7 Paradox Basin

4.7.1 Produced Water Forecast

Figure 4- 15 shows both historical and forecast water production in the Paradox basin for years 2000 – 2025. The produced water projections are projected to decrease from just over 50 million barrels per year to around 35 million barrels per year by 2025. Since there was no basin level forecast available from the 2005 AEO forecast for the Paradox basin, the projections basically reflect a combination of the regional decline in conventional NA and AD gas over this time period applied to the latest value of WGR from the historical data.

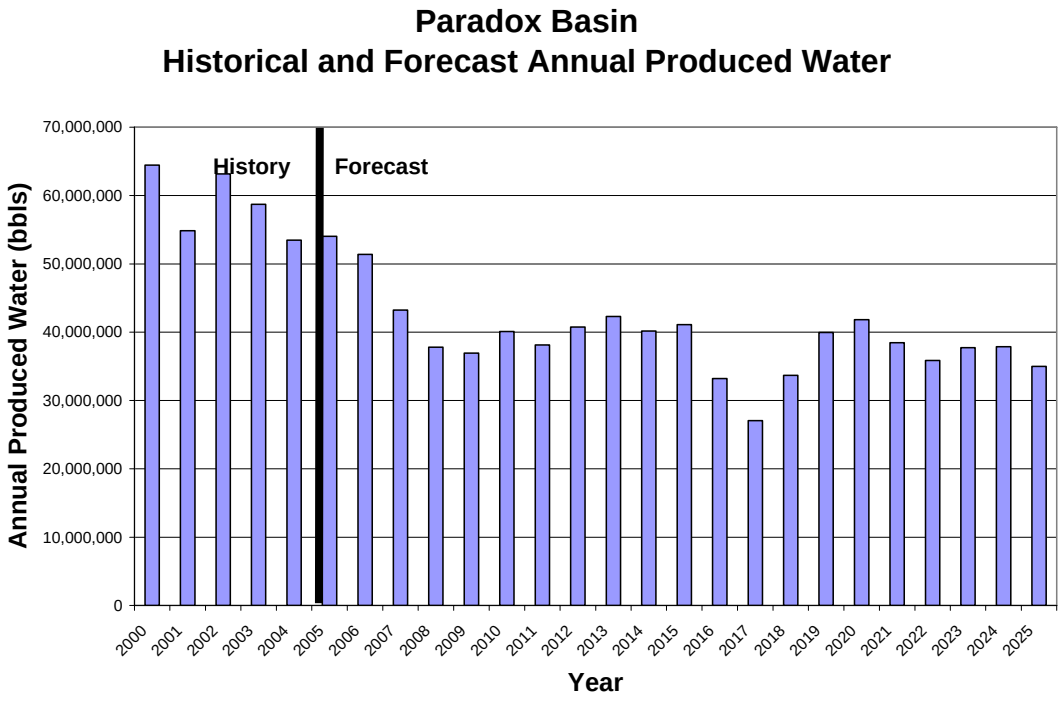


Figure 4-15 Paradox Basin Produced Water History + Forecast

4.7.2 Produced Water Quality Statistics

Water Quality data for the Paradox basin is derived from two sources. The USGS database for this basin contains 518 samples which are 1977 vintage and earlier. A total of 9 samples were obtained from the COGCC database. All 9 of these were very recent samples and are classified as “New Data”. Figure 4-16 and Table 4-7 present statistics regarding the Total Dissolved Solids concentrations of the Paradox basin water samples. The TDS values of the water samples from this basin are considerable higher than those from the other 9 basins in the Rocky Mountain region.

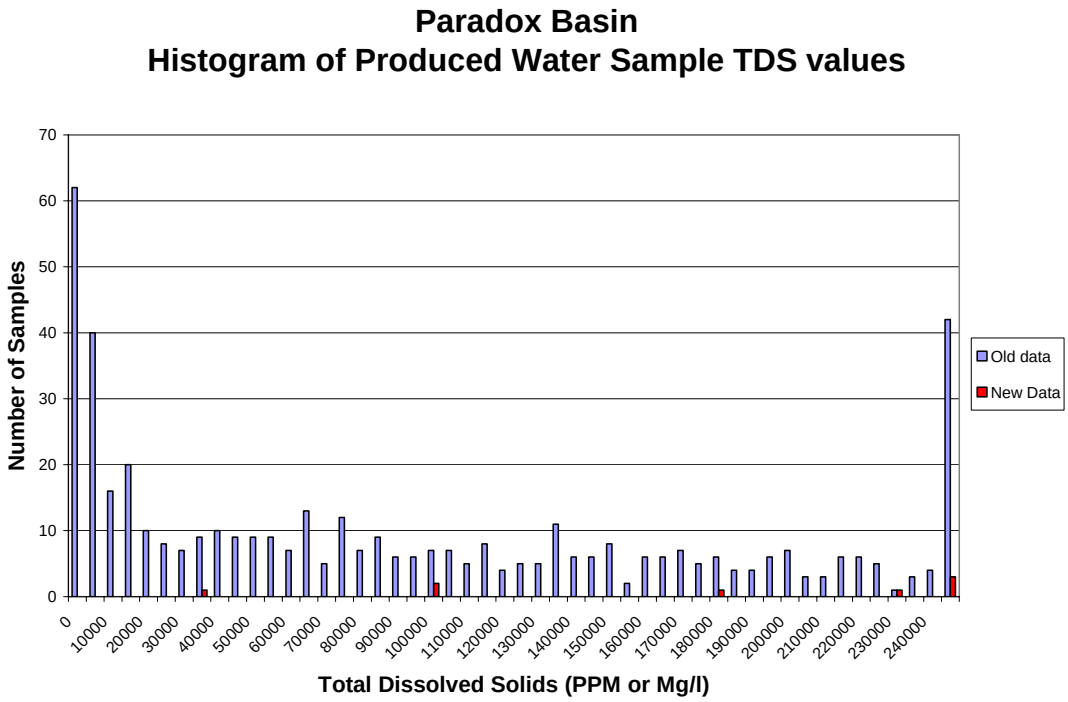


Figure 4-16 Paradox Basin Histogram of TDS values

	Old Data (Pre 1995)	New Data (1995 - 2005)
Number of Samples	518	9
Average TDS Value	95,319	169,790
Median TDS Value	66,984	188,000

Table 4-7 Paradox Basin Water Sample TDS Statistics

4.8 Uinta Basin

4.8.1 Produced Water Forecast

Figure 4- 17 shows both historical and forecast water production in the Uinta basin for years 2000 – 2025. The produced water projections are projected to increase from just over 70 million barrels per year to around 90 million barrels per year by 2025. This increase in produced water is reflective of AEO 2005 forecasts which project increases in both coalbed methane and tight gas production in this basin. These increases were applied to a constant WGR reflective of the latest historical production.

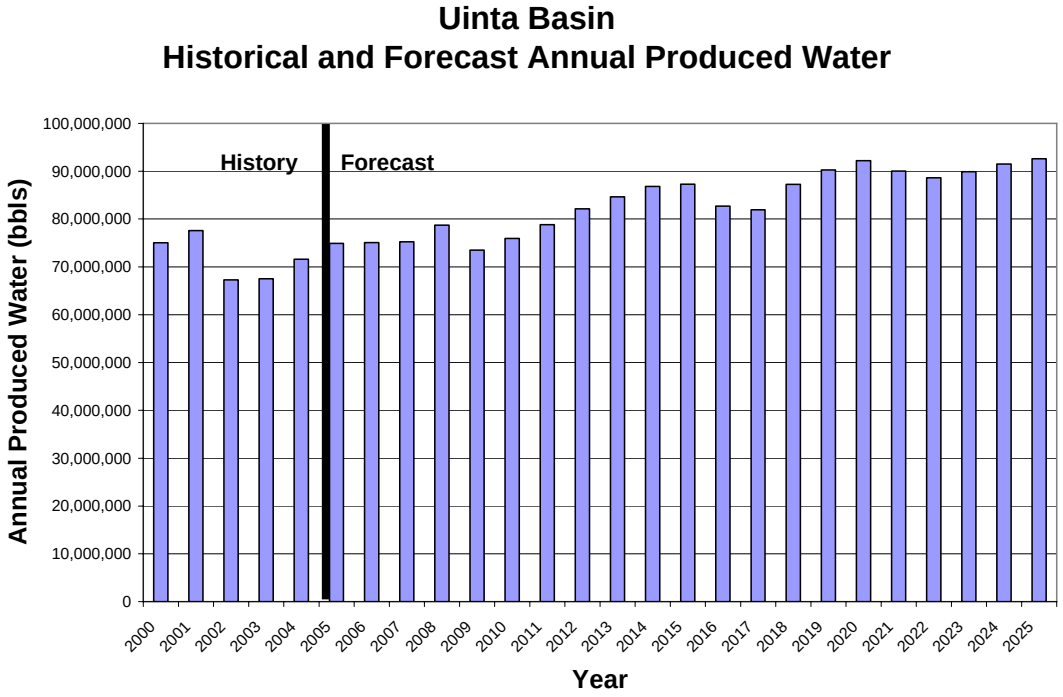


Figure 4-17 Uinta Basin Produced Water History + Forecast

4.8.2 Produced Water Quality Statistics

The only water quality samples for produced water in the Uinta basin available for analysis in this report were derived from the USGS database. The newest of these water samples are almost 30 years old so it is not clear if they are reflective of the quality of water currently produced in the basin. More work is needed to acquire more up to date samples from the state of Utah. The USGS database includes 625 samples which reflect a wide range of salinities from fresh water to strong brine. Figure 4-18 graphically presents a histogram of the distribution of TDS values of the water samples in the USGS database. Table 4-8 presents statistics regarding this distribution.

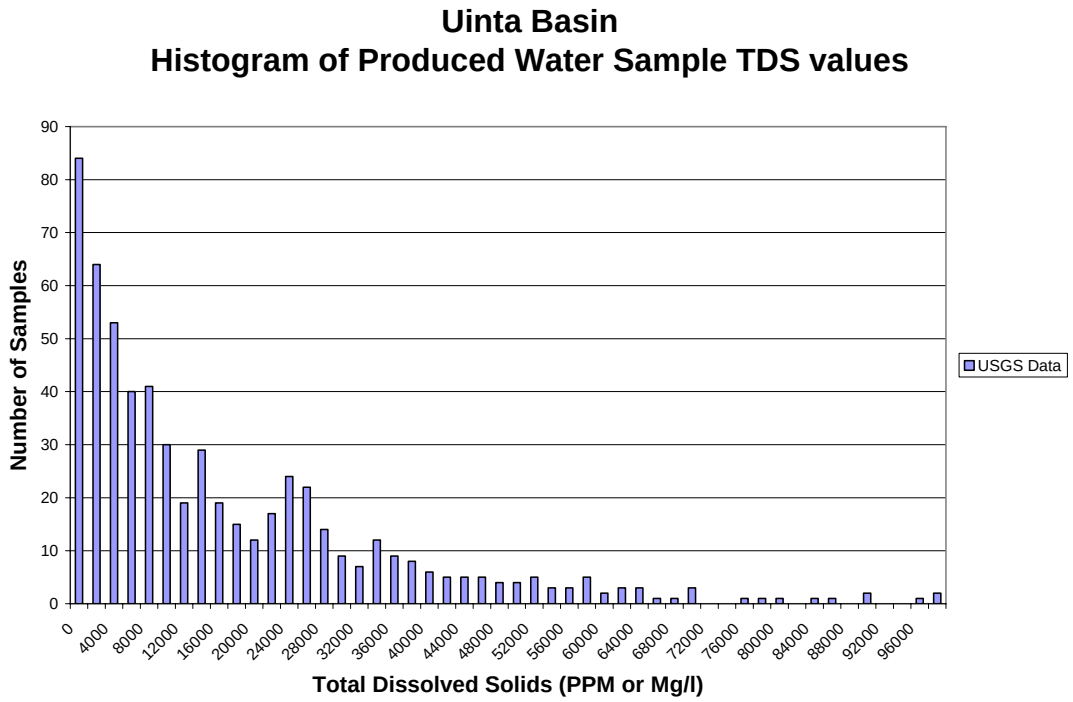


Figure 4-18 Uinta Basin Histogram of TDS values

	Old Data (Pre 1995)	New Data (1995 - 2005)
Number of Samples	518	N/A
Average TDS Value	18,948	N/A
Median TDS Value	12,089	N/A

Table 4-8 Uinta Basin Water Sample TDS Statistics

4.9 San Juan Basin

4.9.1 Produced Water Forecast

Figure 4- 19 shows both historical and forecast water production in the San Juan basin for years 2000 – 2025. The produced water projections increase slightly from the current value of 50 million barrels, start declining around 2013, and finally fall below 40 million

barrels per year by 2025. This behavior is reflective of the tight gas and coalbed methane projections for this basin from the AEO 2005. These projections were applied to a WGR derived from historical data which has been fairly consistent over time.

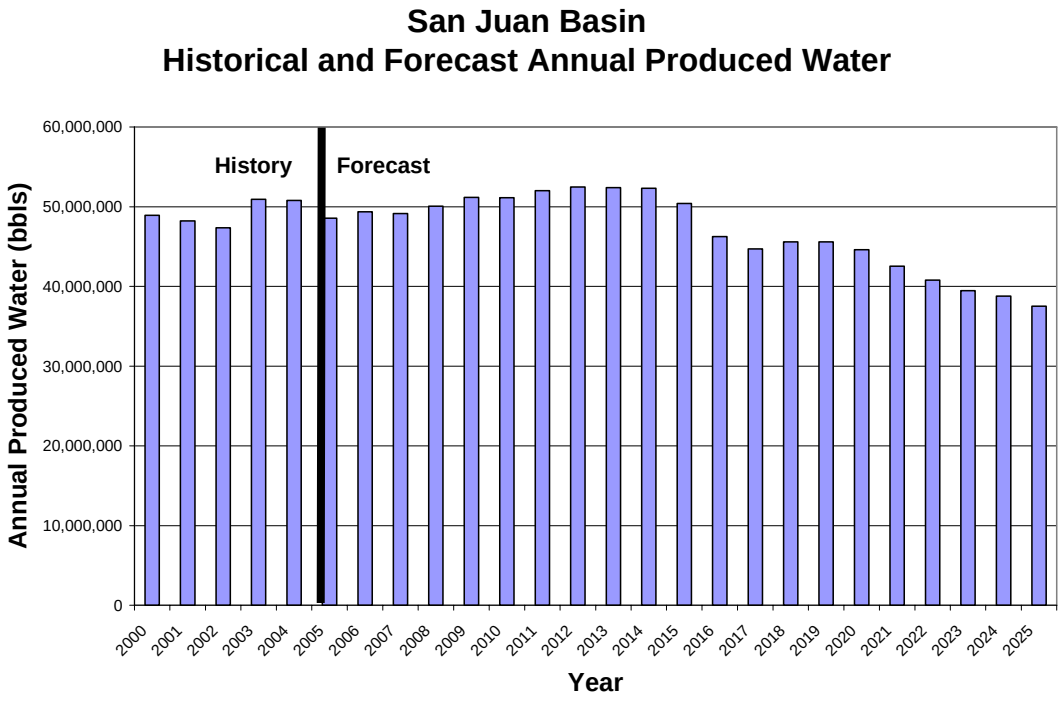


Figure 4-19 San Juan Basin Produced Water History + Forecast

4.9.2 Produced Water Quality Statistics

Water quality data in the San Juan basin was available from three different sources. Data for both Colorado and New Mexico portions of the basin were available in the USGS database. Additional samples from Colorado counties were available from the COGCC database. A large number of samples were available for New Mexico counties from the New Mexico Water and Infrastructure data system(NM WAIDS). After removal of duplicate samples from the three data sources, there were a total of 3,529 samples with at least TDS data. Of these, 445 samples were collected in the last 10 years and are referred to as “New Data”. Figure 4-20 and Table 4-9 present statistics regarding the Total Dissolved Solids concentrations of the San Juan basin water samples.

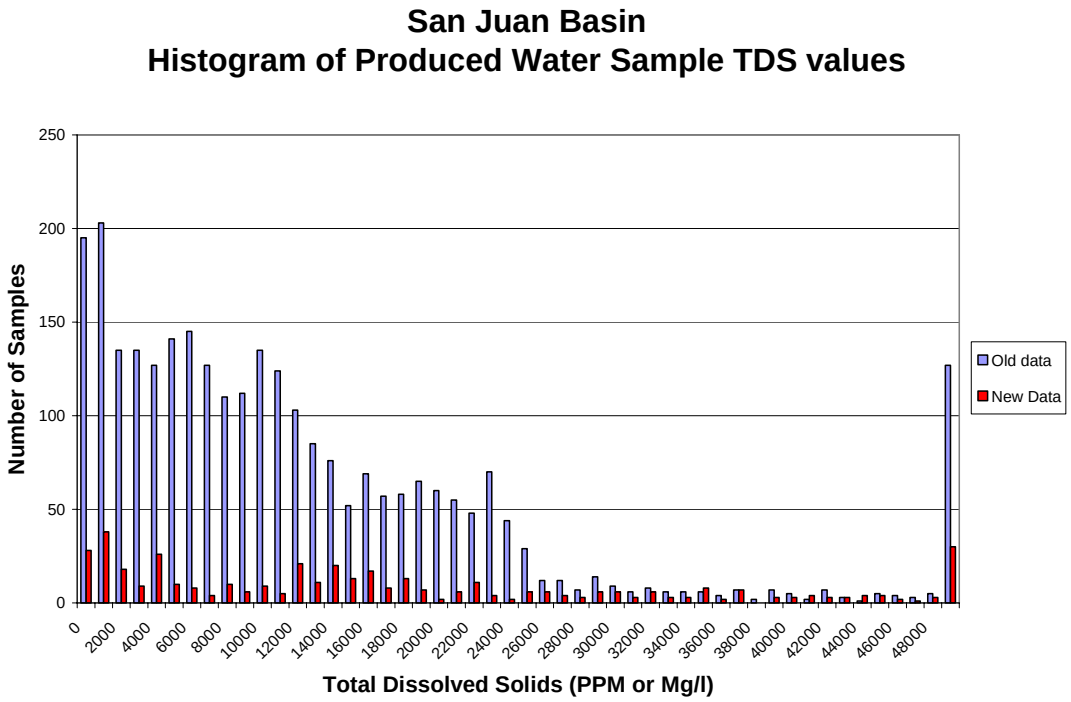


Figure 4-20 San Juan Basin Histogram of TDS values

	Old Data (Pre 1995)	New Data (1995 - 2005)
Number of Samples	3,084	445
Average TDS Value	14,517	23,523
Median TDS Value	9,718	15,186

Table 4-9 San Juan Basin Water Sample TDS Statistics

4.10 Greater Green River Basin

4.10.1 Produced Water Forecast

Figure 4- 21 shows both historical and forecast water production in the Greater Green River basin for years 2000 – 2025. The produced water projections increase over time from about 130 million barrels per year to over 190 million barrels per year by 2025. This behavior is reflective of the increase in tight gas projections for this basin from the AEO 2005. These projections were applied to a WGR derived from historical data which has been very consistent over the five year historical production period.

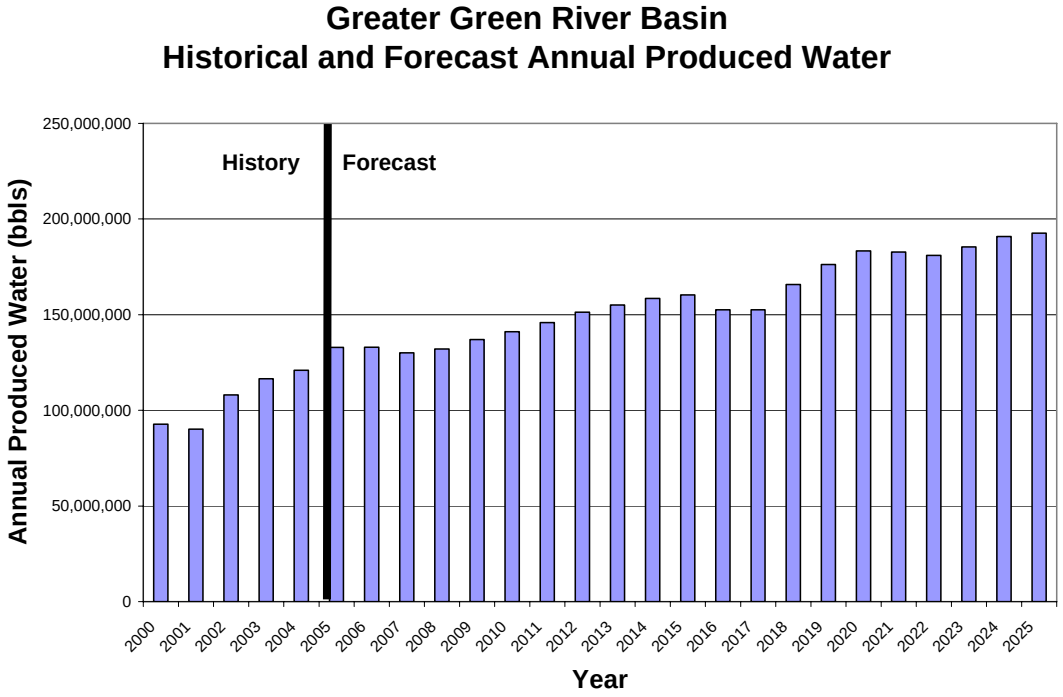


Figure 4-21 Greater Green River Basin Produced Water History + Forecast

4.10.2 Produced Water Quality Statistics

Water quality data in the Greater Green River basin was available from two sources, the USGS database and a database containing 5,537 samples obtained from NETL[19]. The USGS database contains about 2,721 usable samples. Of these samples, a total of 734 were classified as "New Data" meaning they were sampled in the last 10 years. After accounting for duplicated samples between the databases, a total of 4,682 unique samples remained which contained at least Total Dissolved Solids concentrations. Figure 4-22 and Table 4-10 present statistics regarding the Total Dissolved Solids concentrations of the Wind River basin water samples.

[19] http://www.netl.doe.gov/scngo/index.html

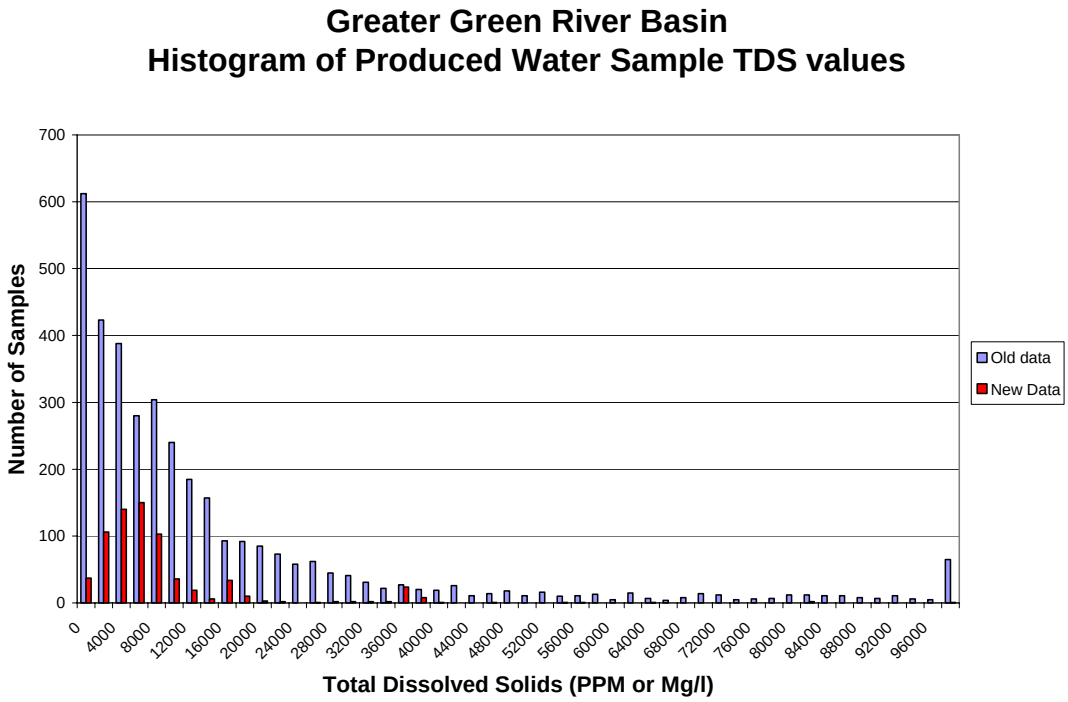


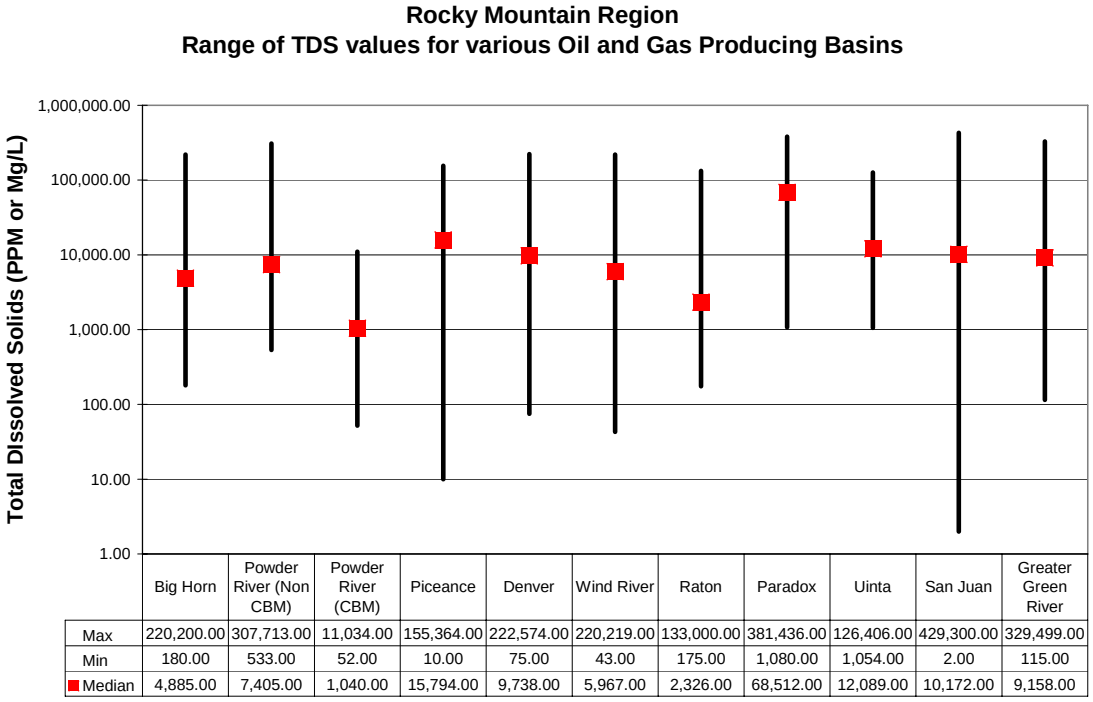
Figure 4-22 Greater Green River Basin Histogram of TDS values

	Old Data (Pre 1995)	New Data (1995 - 2005)
Number of Samples	3,948	734
Average TDS Value	17,393	10,961
Median TDS Value	9,531	8,500

Table 4-10 Greater Green River Basin Water Sample TDS Statistics

4.11 Basin Water Quality Comparison

Figure 4-23 presents a basin level comparison of the Total Dissolved Solids concentration statistics from the data used in this report. This figure compares the low, high, and median solids concentrations observed in all of the samples from the 10 basins. The median value is the TDS concentration at which half of the samples are greater and half of the samples are less.



	Big Horn	Powder River (Non CBM)	Powder River (CBM)	Piceance	Denver	Wind River	Raton	Paradox	Uinta	San Juan	Greater Green River
Max	220,200.00	307,713.00	11,034.00	155,364.00	222,574.00	220,219.00	133,000.00	381,436.00	126,406.00	429,300.00	329,499.00
Min	180.00	533.00	52.00	10.00	75.00	43.00	175.00	1,080.00	1,054.00	2.00	115.00
Median	4,885.00	7,405.00	1,040.00	15,794.00	9,738.00	5,967.00	2,326.00	68,512.00	12,089.00	10,172.00	9,158.00

Figure 4-23 Basin by Basin Comparison of Rocky Mountain Region TDS samples

Observation of the data shown in Figure 4-23 show that the coalbed methane producing wells of the Powder River basin and the Raton basin generally produce the highest quality water. The San Juan and Piceance basins produce water with the greatest range of salinities. Some wells in these basins produce very fresh water while others produced some of the highest salinity brines. The Paradox, Uinta, and the non CBM portions of the Powder River basins produce the lowest quality water based strictly on averaging of available water quality samples.