Produced Water from Oil and Gas Operations in the Onshore Lower 48 States

White Paper – Phase I

By:
Robert A. Welch
Dwight F. Rychel

December, 2004

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

Produced Water from Oil and Gas Operations in the Onshore Lower 48 States

White Paper – Phase I

By

Robert A. Welch

Dwight F. Rychel

December, 2004

Prepared For
U.S. Department of Energy
National Energy Technology Laboratory

Work Performed under Contract No.
DE-AD26-00NT00612

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

Table of Contents

Introduction 6
Background 7
A-Produced Water Data 8
Background 8
Data Summary 10
AEO-2004 Forecast and Water Production 17
Production "West of 98th" 24
Federal Lands Production 26
Production Data Validation 30
National Water Consumption 31
B-Produced Water Issues 35
Major Produced Water Areas 35
Volumes 35
Land Ownership 35
Unique Chemistry (water quality data) 41
USGS Produced Water Database 41
Oil Field Brine Analyses DB 47
NETL Comprehensive Brine Database 50
Bureau of Economic Geology (BEG) Brine Formation Database 50
Water Treatment Techniques 51
Water Treatment Costs Issues 52
Potential for Beneficial Use 60
Implications for CO_2 Sequestration 60
C-Bibliography of current or recent research 61
Research Areas 61
Produced Water Bibliography 62
Appendix 1:Data Sources for Water Production, Water Quality & GIS Information 74
Appendix 2:Sources of Water Quality Data and Production Data 81
Appendix 3:Background Information on AEO-2004 Supply Regions 83
Appendix 4:Federal Production by State (historical and forecast) 87

List of Tables

Table 1: Reported Conventional Oil, Gas and Water Production sorted by Wp 11
Table 2: Total Reported Hydrocarbon Liquids, Gas & Water Production sorted by Wp. 12
Table 3: 2004 Projected Wp based on Conventional Oil and Gas AEO-2004 Forecast.. 20
Table 4: 2004 Projected Wp based on Unconventional Gas AEO-2004 Reference Case 20
Table 5: All Lands & Federal Lands Total Liquids, Gas & Water Production for 2003.. 28
Table 6: Comparison of EIA Production Data to that from States' Websites 31
Table 7: Comparison of MMS to BLM Production Data 31
Table 8: Water Consumption Rate and Resource Development 33
Table 9: Water Usage by Sector 34
Table 10: Statistical Analysis of Key Water Quality Parameters 45
Table 11: Distribution of USGS and OFBA Water Quality Sample Counts by State...... 49
Table 12: Disposal Costs of Produced Water at Offsite Commercial Facilities............... 53
Table 13: Produced Water Handling & Total Disposal Costs: Mid-Continent Region.... 54
Table 14: Produced Water Handling & Total Disposal Costs: Rocky Mountain Region 55
Table 15: Produced Water Management Costs... 56
Table 16: Powder River Basin Water Treatment Cost Summary 57

List of Figures and Maps

Figure 1: Conventional Water Oil Ratio (WOR) by State from Table 1 14
Figure 2: Total Annual Water Production by State from Table 2.................................... 14
Figure 3: AEO Conventional Oil and Gas Regions WOR... 15
Figure 4: AEO Conventional Oil and Gas Regions WGR... 15
Figure 5: Unconventional Gas CBM Average WGR's.. 16
Figure 6: Conventional Oil AEO-2004 Reference Case Forecast 17
Figure 7: Conventional Gas AEO-2004 Reference Case Forecast 18
Figure 8: Unconventional Gas AEO-2004 Reference Case Forecast 18
Figure 9: Total Conventional Oil and Gas AEO-2004 Reference Case Forecasts 19
Figure 10: Produced Water by Resource Type based on AEO-2004 Reference Case 21
Figure 11: Produced Water Forecast for Unconventional CBM 21
Figure 12: Contribution of Forecasted AEO-2004 Water Production by Resource Type 23
Figure 13: 98th Meridian and the AEO-2004 Supply Regions... 24
Figure 14: Produced Water Forecast by AEO-2004 Supply Region 25
Figure 15: Five-Year Cumulative Wp Forecast... 26
Figure 16: WLER Comparison of Federal Lands and All Lands 27
Figure 17: Federal Lands Wp Projection 29
Figure 18: Comparison of Wp from All Lands, Fed Lands and Fed Lands West of 98th. 30
Figure 19: Consumptive Use and Renewable Water Supply by Water Resource Region 32
Figure 20: Federal and State Land Surface Ownership by State, %................................ 37
Figure 21: Federal and State Land Ownership by State, acres 38
Figure 22: Federal and State Land Ownership by State excluding Alaska, acres 39
Figure 23: Federal Lands Areas and Oil and Gas Fields in the United States................. 40
Figure 24: Distribution of USGS Water Sample Count (by year).................................. 42
Figure 26: Comparison of Water Quality Parameters by AEO-2004 Supply Region 44
Figure 27: Distribution of TDS Samples (values > 213,000 ppm).................................. 47
Figure 28: Distribution of USGS and OFBA Water Quality Sample Counts.................. 48
Figure 29: Bureau of Economic Geology Brine Formation Database Study Areas 50
Figure 30: Hypothetical Representation of Average Water Treating Costs 59
Map 1: Conventional Oil and Gas Supply Regions 83
Map 2: CBM Basins... 84
Map 3: Gas Shale Basins 85
Map 4: Tight Gas Sands Basins 86

The intent of this paper is to provide background material and information on produced water from Lower 48 onshore oil and gas operations and project water volumes to the year 2025 based on the U.S. Department of Energy, Energy Information Agency's Annual Energy Outlook 2004 Oil and Gas Forecast[1]. It is designed to aid DOE Program Managers with structuring the Oil and Gas Environmental Program and provide a basis for future research and/or field demonstration solicitations.

Introduction

The consumption of water in the United States is staggering. Per-capita usage is ~350 gal/day/person[2] based on 1995 data from the U.S. Geological Survey (USGS). The western half of the United States, and in particular the Rocky Mountain and Southwestern States, are becoming increasingly arid. Changing weather patterns such as El Niño may be responsible but the reasons are irrelevant. At the same time, these areas are experiencing growing populations, especially Nevada and Arizona. The issue is that water is becoming increasingly scarce for selected local/regional areas and the foreseeable trends do not show signs of change.

Produced water volumes from oil and gas operations are projected to be approximately 2.45 Billion gals/day (bgd)[3] for the current (2004) year - a small but potentially significant fraction of the national consumption rate of approximately 100 bgd[4]. The American Petroleum Institute (API) estimates[5] that 71% of produced water is being used for Improved Oil Recovery (IOR), 21% is being injected for disposal, 5% to beneficial use such as livestock, irrigation, etc. and 3% to percolation and evaporation ponds. The potential addition to the beneficial category of ~0.59 bgd (24%) could provide some relief in selective areas of the country for specialized use. In those areas where there is no IOR, essentially all of the produced water could be seen as an additional water resource.

The technology of treating water economically (relative to the disposal of the same water) has been demonstrated[6] to be viable - as long as transportation costs are not included. Transportation costs are usually prohibitive ($1–$3/bbl to transport, cents/bbl to dispose) so any beneficial use of treated water generally must occur relatively close to its source.

---

[1] U.S. Department of Energy, Energy Information Agency, Annual Energy Outlook 2004, DOE/EIA-0383(2004) January 2004. Hereafter referred to as AEO-2004.

[2] Calculated from data in "Estimated Use of Water in the United states in 2000", U.S. Geological Survey Circular 1268

[3] Volume estimated based on AEO-2004 projections of conventional oil and gas and unconventional gas production, Table 9 of this document.

[4] Email communication w/Joan Kenny, USGS Oct. 19, 2004 – 1995 data, no more recent data available from USGS.

[5] "Overview of Exploration and Production Waste Volumes and Waste Management Practices in the United States", table 2.4, pg 11, prepared by ICF Consulting for the American Petroleum Institute, Washington, DC, May 2000.

[6] See Section B of this report, Produced Water Issues, Cost Issues

The traditional downhole approaches of the past 10-20 years to minimize water production may no longer be an acceptable paradigm. It may be time to investigate maximizing water production in some of the more arid regions of the country where there are also petroleum operations (to the extent oil and gas productivity is not hindered). Downhole operations to minimize water production are designed to reduce water handling costs and therefore overall operating costs but today the water may have more value if produced.

Another technique that might be worth revisiting is graduate work performed at LSU in the early to mid 1980's called Co-Production[7], where bottom water drive gas reservoirs are perforated in the saturated water zone and produced to both reduce average reservoir pressure and slow/stop the encroachment of water, which effectively increases the recovery of gas. The resulting water production would be treated and reused. Unfortunately, many reservoirs that fall into this category are located in the Gulf Coast where water consumption is not as much an issue. On the other hand, Coal Bed Methane (CBM) wells are dewatered but the water is removed in order to allow production of gas – usually CBM produced water requires minimal cleanup for beneficial use and most wells are in areas where additional water resources would be welcome.

This report concentrates on developing how produced water volumes will look in the future for the Lower 48 states and onshore production, using the AEO-2004 Reference Case for oil and gas production as its basis. The Lower 48 states, and specifically onshore production areas, are considered to have the more critical water needs and are therefore the focus of this work. Water quality is equally important but in this report it is addressed only to the extent of providing a summary of what is historically available. Tying more recent water quality data to produced water volumes and determining geographically where water consumption issues are expected to occur will be the focus of Phase 2 of this work.

Ultimately, water consumption and demand will be the driving force for both increasing water resource volumes and improving water cleanup technologies. Old-timers in West Texas have said "*…if we don't stop contaminating the water (referring to the Ogallala aquifer, circa 1980) no amount of oil will keep people here*." How prophetic they may have been. Water may become a revenue generator where once it was only a nuisance and a cost burden.

Background

One of the key missions of the DOE is to ensure an abundant and affordable energy supply for the Nation. In support of that mission, DOE, through its National Energy Technology Laboratory (NETL, and predecessor organizations), plans and manages a comprehensive environmentally-focused RD&D program (Environmental Solutions). This program is comprised of technology development, process changes, data

[7] Screening study of the MA-10 Sand, Garden City Field by the Dept of Petroleum Engineering at Louisiana State University and funded by the Gas Research Institute of Chicago, Illinois.

development, analytical studies, and other activities all focused on energy (crude oil and natural gas) production in cost effective, least (environment) impact methods.

As part of the process of producing oil and natural gas, operators must manage large quantities of water that are found in the same underground formations. The quantity of this water, known as produced water, generated each year is so large that it represents a significant component in the cost of producing oil and gas.

In the United States, produced water comprises approximately 98% of the total volume of exploration and production (E&P) waste generated by the oil and gas industry and is the largest volume waste stream generated by the oil and gas industry. According to the API, about 18 billion barrels (bbl) of produced water was generated by U.S. onshore operations in 1995 (API 2000)[8]. Additional large volumes of produced water are generated at U.S. offshore wells and at thousands of wells in other countries. Khatib and Verbeek[9] estimate an average of 210 million bbl of water was produced each day in 1999 worldwide. This volume represents about 77 billion bbl of produced water for the entire year.

Produced water constituents can affect both the environment and operations. Produced water volumes can be expected to grow as onshore and offshore wells age (the ratio of produced water to oil increases as wells age) and coal bed methane production increases to help meet projected natural gas demand. In addition, hydrocarbon production from deep offshore production is expected to increase, and treating produced water prior to discharge may become increasingly difficult due to space limitations and motion on the rigs, which limit the use of conventional offshore oil/gas/water treatment technologies. This growth will increase produced water management challenges for which a knowledge and understanding of the constituents of produced water and their effects will be critical.

Clearly, the issue of managing produced water is significant and DOE recognized this and has had a "produced water" focus of its environmental RD&D program. Going forward, the DOE will continue to focus on produced water issues but seeks contemporary (produced water) data/information to support the direction of the R&D.

A-Produced Water Data

Background

[8] "Overview of Exploration and Production Waste Volumes and Waste Management Practices in the United States", prepared by ICF Consulting for the American Petroleum Institute, Washington, DC, May 2000.

[9] Khatib, Z., and P. Verbeek, 2003, "Water to Value – Produced Water Management for Sustainable Field Development of Mature and Green Fields," *Journal of Petroleum Technology*, Jan., pp. 26-28.

Production data for this project was collected by state at the lowest level possible and ultimately aggregated to the EIA's AEO-2004 Supply Regions[10]. Conventional oil and gas production forecasts are reported by AEO-2004 Oil and Gas Supply Regions and unconventional gas (CBM, Gas Shale and Tight Gas Sands) is reported by basin. Maps showing these reporting regions are documented in Appendix 3.

Most data were collected at the field level and is primarily volume based. Water quality data, when it exists, is not stored with volume data and most of it dates back to the 1980's as will be seen later in this report. Water quality data, to the extent that it can be quantified and tied to water volumes, will be addressed in more detail in the second phase of this work.

Some states only report data by lease, pool or county. Virtually all data collected came from the states' web pages but in a few cases the state agencies were contacted for more information. The only exceptions were obtaining water production from Arkansas, Kansas, Louisiana, Oklahoma, and Texas where estimated volume data were taken from a paper prepared by John Veil[11]. Veil's data was used because the states mentioned do not report their water production publicly – and Kansas and Oklahoma do not require its reporting. Veil's source of produced water came from direct contact with state Underground Injection Control (UIC) officials – but it is unknown what their source was (real data, estimated, etc). Oklahoma data was based on API statistical estimates as noted in the paper. Other sources for Texas and Louisiana water production, where water production is allocated based on Initial Potential (IP) tests and annual well tests, is available but only for a fee[12]. For some of the other smaller producing states Veil's WOR was used and applied against the state's oil production to determine water production.

The original approach to this study was to group data at the USGS play or province level but it soon became apparent that available databases containing field names[13] and USGS[14] nomenclature were not compatible and considerable resources would be required to match even a fraction of the data. Another approach considered was to perform spatial queries using ESRI®[15] ArcMap™ Geographic Information System (GIS) software but almost none of the states carry long/lat coordinate data for the fields. Some states have begun this effort (Kentucky[16], Louisiana[17], Illinois[18], Appalachian Project[19] and New

---

[10] U.S. Department of Energy, Energy Information Agency, Annual Energy Outlook 2004, DOE/EIA-0383(2004) January 2004

[11] "A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane", John Veil, et al, Argonne National Laboratory, January 2004.

[12] From IHS Energy (~$6,000)

[13] Nehring and Associates,

[14] In-house db

[15] ESRI – Environmental Systems Research Institute, Redlands, CA. (http://www.esri.com/)

[16] http://www.uky.edu/KGS/gis/geology.html

[17] http://sonris-www.dnr.state.la.us/www_root/sonris_portal_1.htm

[18] http://www.isgs.uiuc.edu/oilgas/iloil/

[19] http://ims.wvgs.wvnet.edu/website/pttc/viewer.htm

Mexico[20]), but most of these are online interactive mapping applications. It was just too early in the process of implementing this technology (GIS) by the states to consider this an option.

In the end, data were aggregated to the state level for convenience but the data also needed to be aggregated to the AEO-2004 Supply Regions. There are six Lower 48 Onshore Supply Regions defined by AEO (see Appendix 3). The states that are included in the supply regions are contained wholly defined by their state boundaries with the exception of New Mexico and Texas. Fortunately, there was a fairly good match of field data and GIS coordinates for New Mexico and the majority of the fields fell in the two extreme corners of the state making the split into supply regions relatively easy. In Texas, respective county polygon and production data were joined and spatial queries performed to split production into the three supply regions comprising the state.

Many of the sources of state production data (web links - URL, Uniform Resource Listing) are presented in Appendix 1. Included are some links that also contain related and useful information. A list of mostly water quality database sources appears in Appendix 2.

Data Summary

Current oil, gas and water production data was collected in order to calculate a water-oil-ratio (WOR – bbl/bbl) and/or water-gas-ratio (WGR – bbl/mcf). Most of the data is from 2003. These ratios are fixed-in-time and applied to the AEO-2004 oil and gas reference case forecast for years 2004 through 2025 to project water production volumes. The level of effort and time constraints dictated this approach, fully realizing that WOR/WGR ratios generally increase with time and that oil and gas production rates usually decrease with time. Certainly numerical modeling could have been employed or perhaps DCA (decline curve analysis) for a more complex and rigorous approach - but the order of magnitude of the water issue implications probably would not have been different. **This is an important assumption to note - even though oil production is declining the water production forecasts are most likely quite conservative because the WOR/WGR values are being held constant as 2003 values.** Normally these ratios will be increasing with time but there is no way to forecast their future values with any certainty.

Table 1 is a listing of the 32 states which reported conventional oil (Np) and associated-dissolved gas production (Gp) and its associated water production (Wp)[21]. Table 2 is the same listing but includes all hydrocarbon liquids (oil, NGL, condensate), unconventional gas and all water. Alaska is included in the tables here and elsewhere in this report only for completeness and for comparison - its production volumes are not used in the Wp projections presented later in this report or in the calculation of water-oil or water-gas ratios - the focus of this report is on the Lower 48 states and onshore production. In

[20] http://daihatsu.nmt.edu/waterquality/

[21] All production is reported in barrels for liquids (bbls) or thousands of cubic feet (mcf) for gases unless otherwise stated.

addition, a Pennsylvania WOR/WGR/WLR is not calculated because the state's water production data could not be associated in the proper proportions to with either oil or gas production.

Table 1: Reported Conv. Oil, Assoc. Gas and Water Production sorted by Wp

	State	Oil Prod, Np MMbbl	Gas Prod, Gp Bcf	Water Prod, Wp MMbbl	Water Inj, Wi MMbbl	WOR bbl/bbl
1	Texas	366	4,894	5,032	5,367	14
2	Wyoming	52	1,829	2,115	-	40
3	California	257	240	2,091	-	8
4	Oklahoma	63	68	1,253	-	20
5	Kansas	34	421	1,175	-	35
6	Louisiana	51	81	1,080	1,572	21
7	Alaska	356	3,400	801	-	2
8	New Mexico	67	1,704	636	622	10
9	Colorado	21	1,332	440	-	21
10	Mississippi	17	164	298	-	17
11	Illinois	10	-	177	-	18
12	Montana	19	87	128	-	7
13	North Dakota	29	58	108	-	4
14	Arkansas	7	13	90	461	12
15	Utah	9	190	87	-	10
16	Nebraska	3	1	51	-	18
17	Florida	2	2	42	-	19
18	Alabama	5	6	39	-	8
19	Indiana	2	-	35	-	18
20	Michigan	7	34	29	-	4
21	West Virginia	3	188	8	-	3
22	Ohio	5	71	4	-	1
23	South Dakota	1	12	3	-	3
24	Pennsylvania	1	-	3	-	-
25	Kentucky	3	82	3	-	1
26	Missouri	0	-	1	-	13
27	Virginia	0	18	0.5	-	25
28	Tennessee	0	2	0.4	-	1
29	Arizona	0	-	0.1	-	1
30	Nevada	0	-	0.1	-	5
31	New York	-	-	-	-	
32	Oregon	-	-	-	-	
	Totals	1,390	14,897	15,729	8,021	11.3
	Totals ex PA/AK	1,003	11,497	14,925	8,021	14.4

Table 2: Total Reported Hydrocarbon Liquids, Gas & Water Production sorted by Wp

	State	Total Liq (MMbbl)	Total Gas (Bcf)	Total Wp (MMbbl)	WLR bbl/bbl
1	Texas	366	4,894	5,032	14
2	Wyoming	52	1,829	2,115	40
3	California	257	326	2,093	8
4	Oklahoma	64	1,444	1,253	20
5	Kansas	34	421	1,175	35
6	Louisiana	80	1,261	1,080	13
7	Alaska	383	3,598	801	2
8	Colorado	21	1,847	737	36
9	New Mexico	67	1,704	636	10
10	Mississippi	17	164	298	17
11	Illinois	10	-	177	18
12	Montana	19	87	128	7
13	North Dakota	29	58	108	4
14	Alabama	5	327	101	21
15	Arkansas	7	13	90	12
16	Utah	9	190	87	10
17	Nebraska	3	1	51	18
18	Florida	2	2	42	19
19	Indiana	2	-	35	18
20	Michigan	8	34	29	4
21	West Virginia	3	188	8	3
22	Ohio	5	71	4	0.8
23	South Dakota	1	12	3	3
24	Pennsylvania	1	128	3	2
25	Kentucky	3	82	3	0.9
26	Missouri	0	-	1	13
27	Virginia	0	81	0	25
28	Tennessee	0	2	0	1.0
29	New York	-	27	0	-
30	Arizona	0	0	0	1.3
31	Nevada	0	-	0	5
32	Oregon	-	1	-	-
	Totals	1,448	18,793	16,090	11
	Totals ex PA/AK	1,064	15,067	15,286	14

Of these 32 states, 21 have water production (Wp) data available from various state agencies and/or geologic societies. Arkansas, Kansas, Louisiana, Oklahoma, and Texas do not collect water production data. Originally, water injection (Wi) data was going to be substituted in Arkansas, Texas and Louisiana as a surrogate for Wp. But Veil's[22] Wp data is considered more accurate because injection data can also contain disposal and makeup water volumes. Comparing Wi to Wp in these three states shows there is a significant difference in volumes and supports the assumption disposal and/or makeup water is included in Wi. Estimated water production data for these three states and Kansas and Oklahoma was obtained by Veil from state authorities and used in this report. The Kansas data reportedly contains an unknown quantity of CBM (coal bed methane) water.

In 4 states, other products, such as NGL (natural gas liquids) and condensate were reported separately – that data was collected but not included in the Table 1 Np totals. However, a total liquids volume was used for comparisons to Federal Lands production where a WLER (water liquids equivalent ratio) was determined. WOR values for the states ranged from 40.4 to less than 1. Eight states reported Dry Gas (DG or non-associated gas) production but only 2 of them reported Wp attributed to the DG.

The following two graphs (Figures 1 and 2) show the differences and range of average WOR and total annual produced water volumes between the states. Both graphs are sorted by decreasing Wp from Tables 1 and 2, respectively. It should be obvious from these graphs and the tabular data that total water production and WOR do not necessarily share the same directional magnitude.

[22] "A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane", John Veil, et al, Argonne National Laboratory, January 2004.

Figure 1: Conventional Water Oil Ratio (WOR-bbl/bbl) by State from Table 1

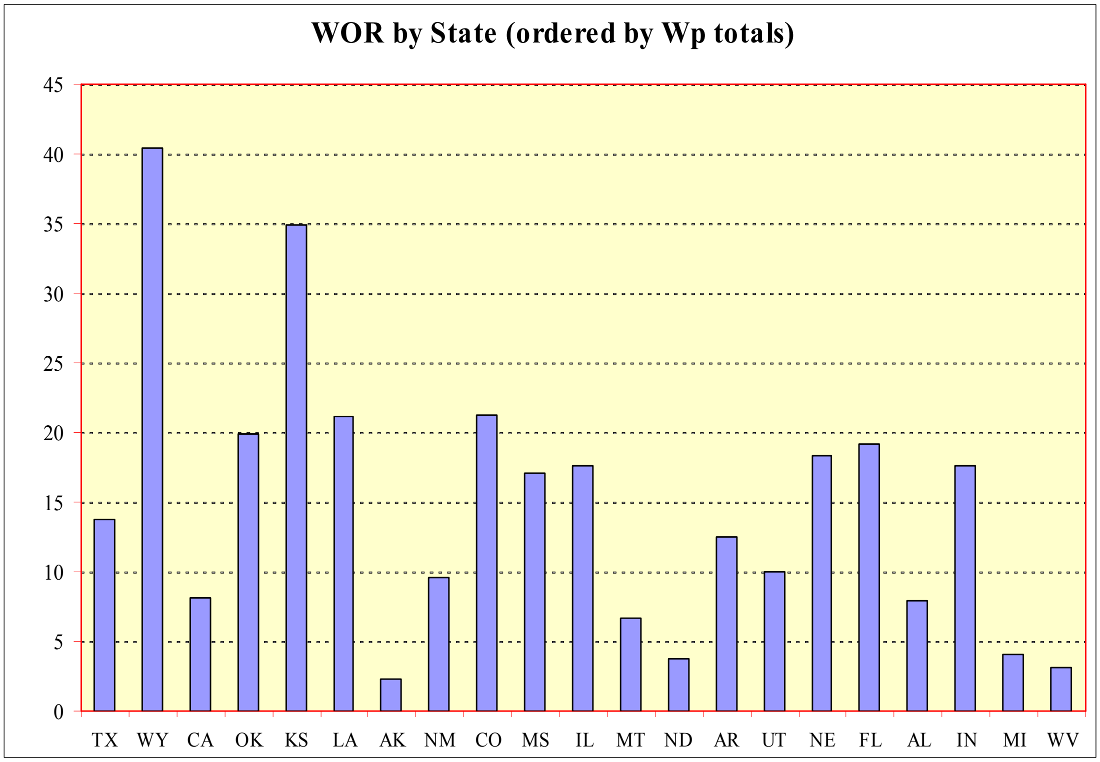
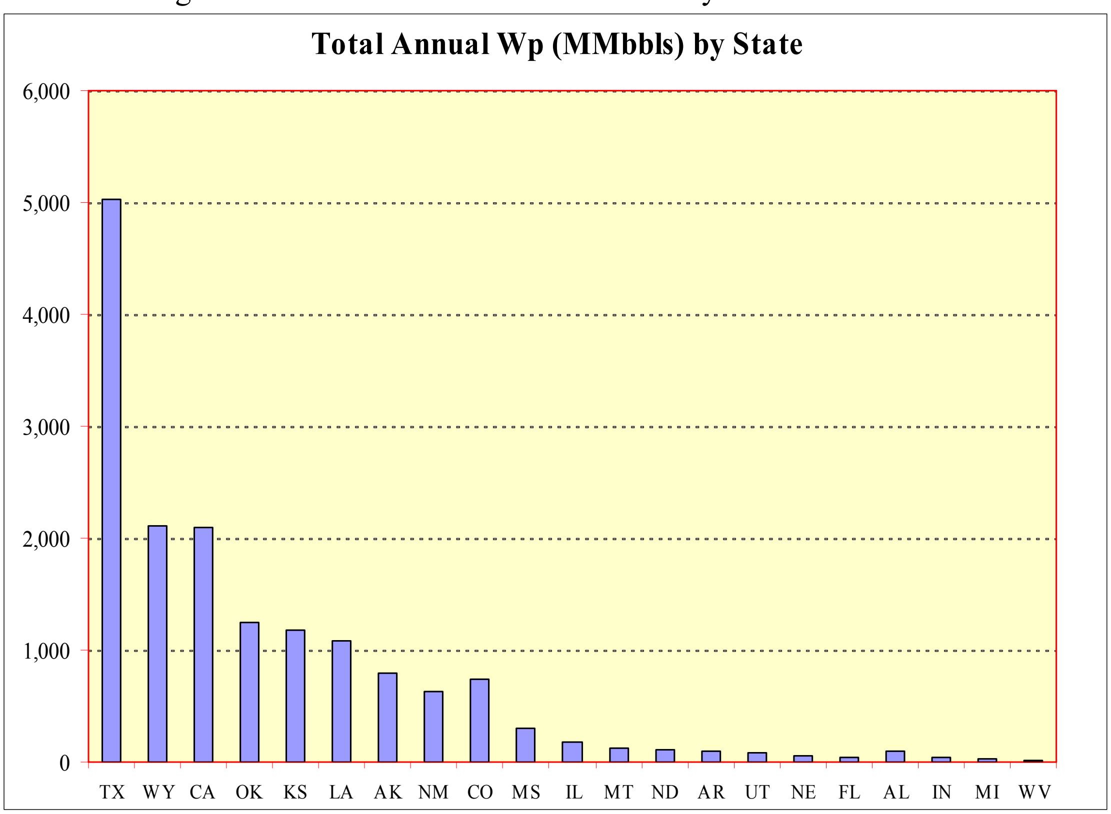
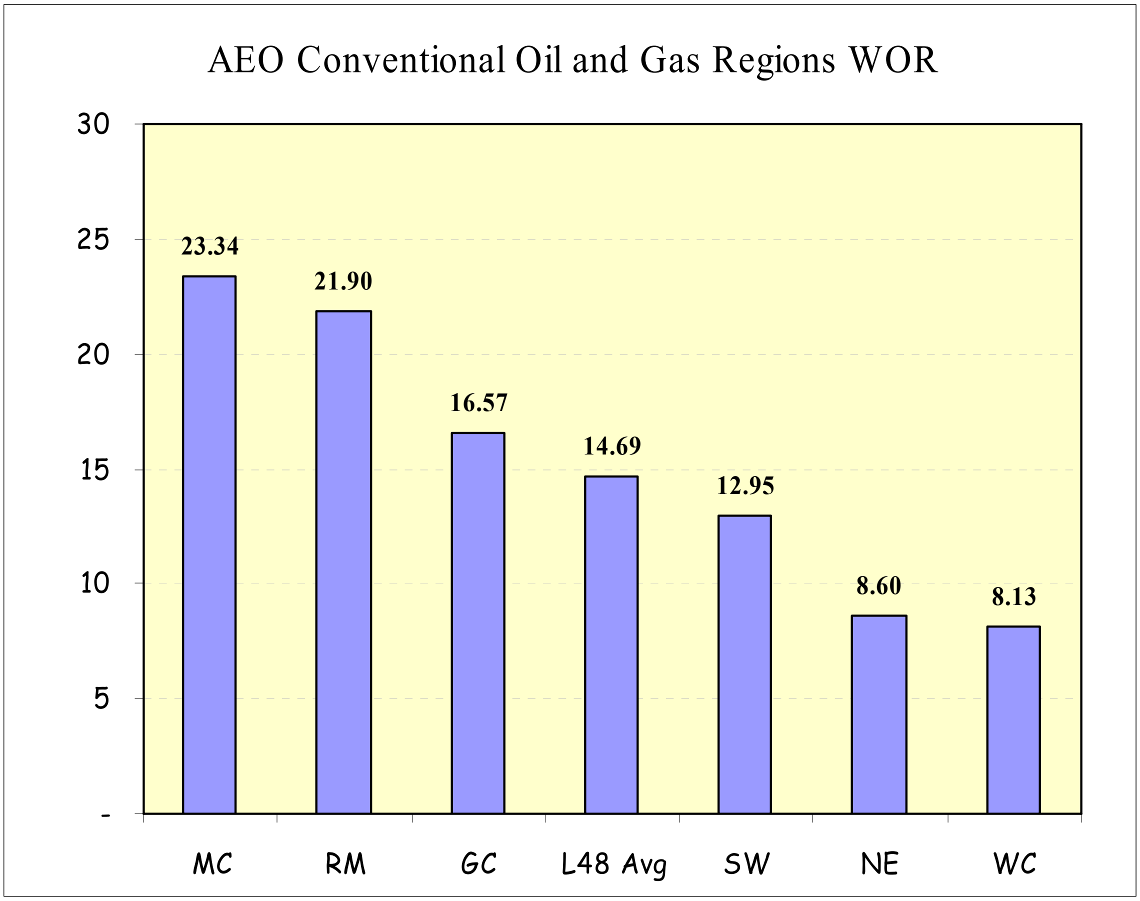


Figure 2: Total Annual Water Production by State from Table 2



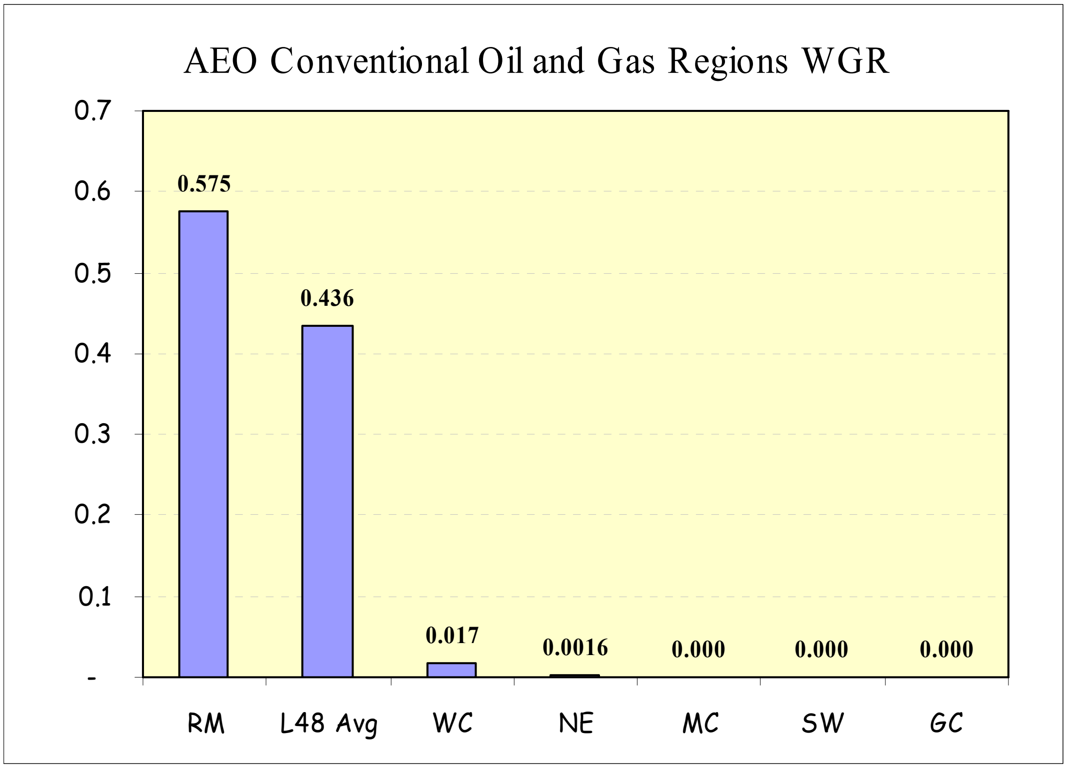
Using the information at the state level, aggregate average WOR values were determined for each of the AEO Lower 48 Onshore Oil and Gas Supply Regions. The resulting WOR's ranged from a high of ~23 for the Mid-Continent (a very mature region) to a low of ~8 for the West Coast. The Lower 48 overall average is ~15.

Figure 3: AEO Conventional Oil and Gas Regions WOR (bbl/bbl)



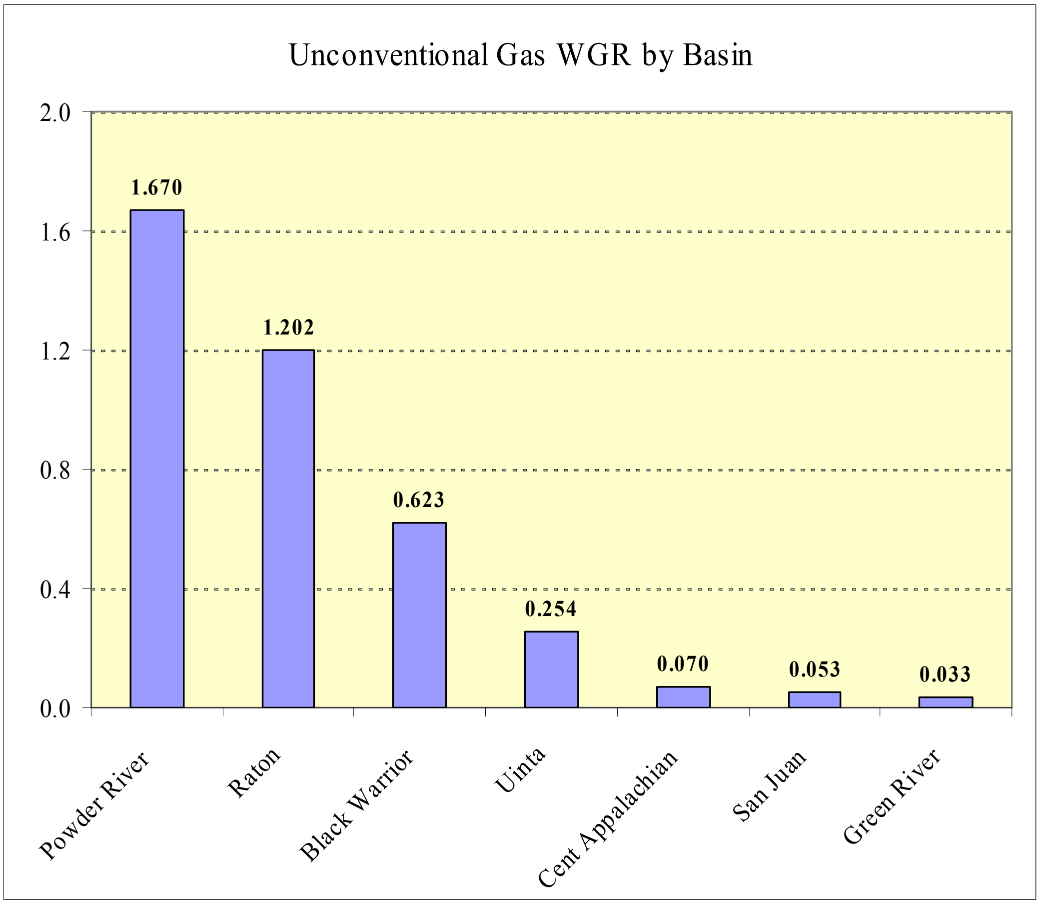
The average WGR value for the four regions where non-associated gas production and water production data were available is shown in Figure 4. Non-associated (NA or dry gas) gas production and its associated water production is reported only by a handful of states.

Figure 4: AEO Conventional Oil and Gas Regions WGR (bbl/mcf)



Similarly, the average WGR's for unconventional CBM (coal bed methane) gas production by the major producing basins is shown in Figure 5.

Figure 5: Unconventional Gas CBM Average WGR's (bbl/mcf)



AEO-2004 Forecast and Water Production

The AEO-2004 reference case forecasts[23] for conventional oil, associated-dissolved gas and unconventional gas are shown in Figures 6, 7 and 8, respectively. Figure 9 presents the totals of Figures 6, 7 and 8. The AEO's Unconventional gas forecast is shown in Figures 9. These projections are made annually by the EIA and are the basis for forecasting water production in this report.

Figure 6: Conventional Oil AEO-2004 Reference Case Forecast

[23] U.S. Department of Energy, Energy Information Agency, Annual Energy Outlook 2004, DOE/EIA-0383(2004) January 2004

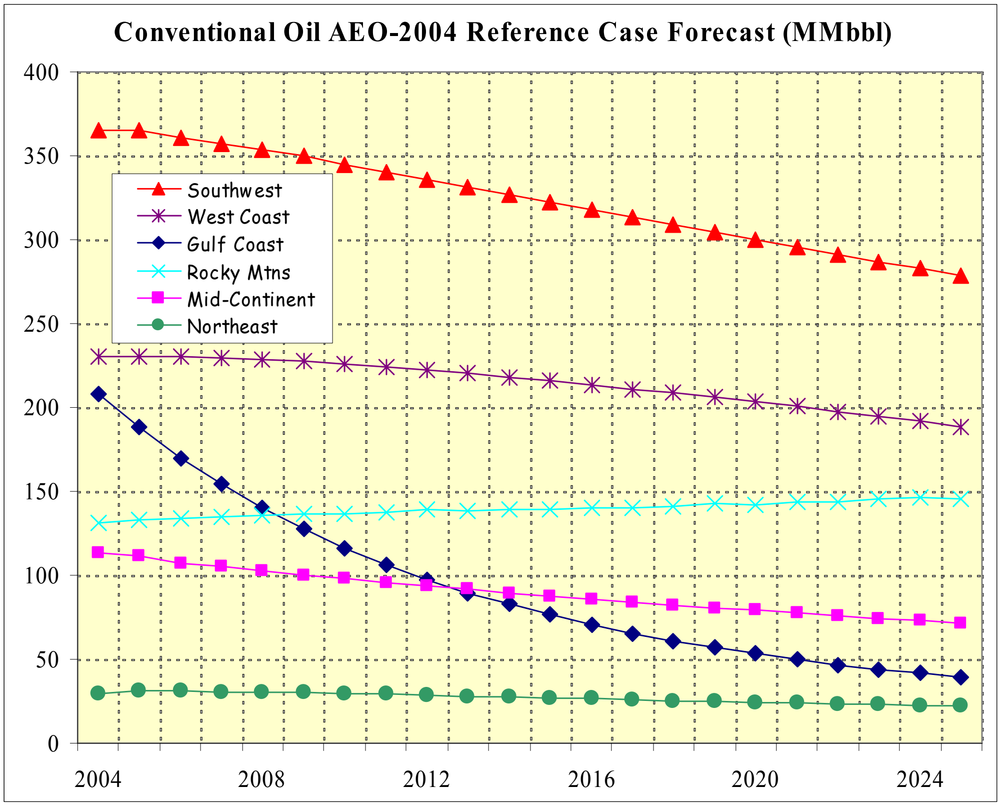


Figure 7: Conventional Gas AEO-2004 Reference Case Forecast

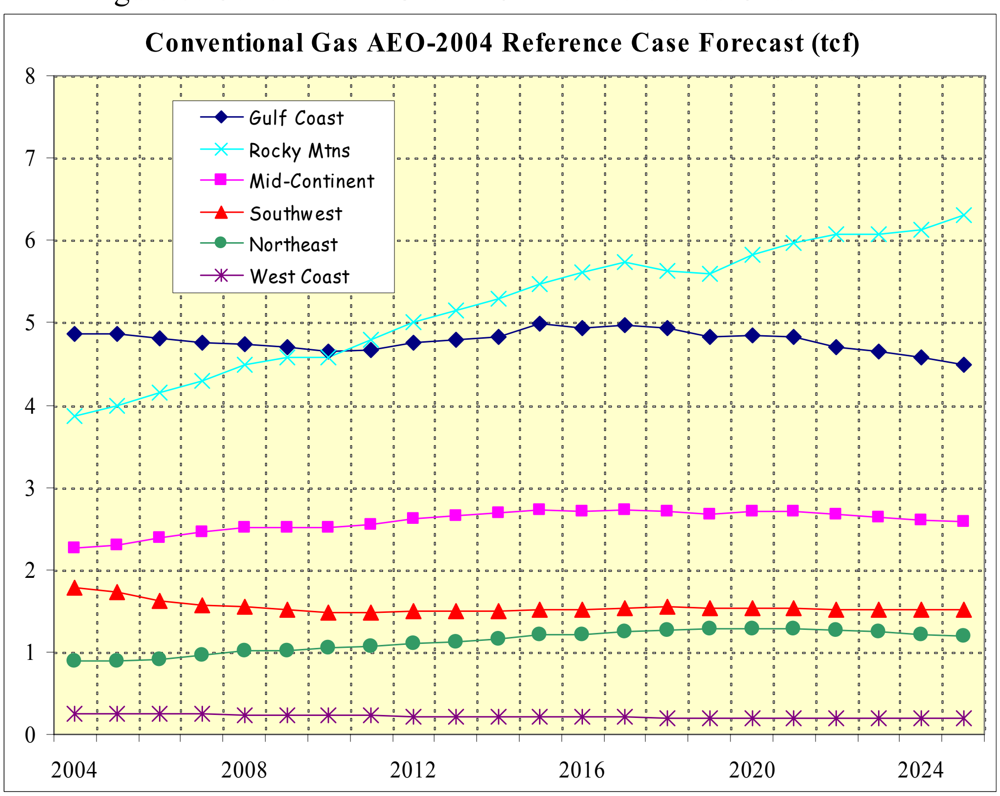


Figure 8: Unconventional Gas AEO-2004 Reference Case Forecast

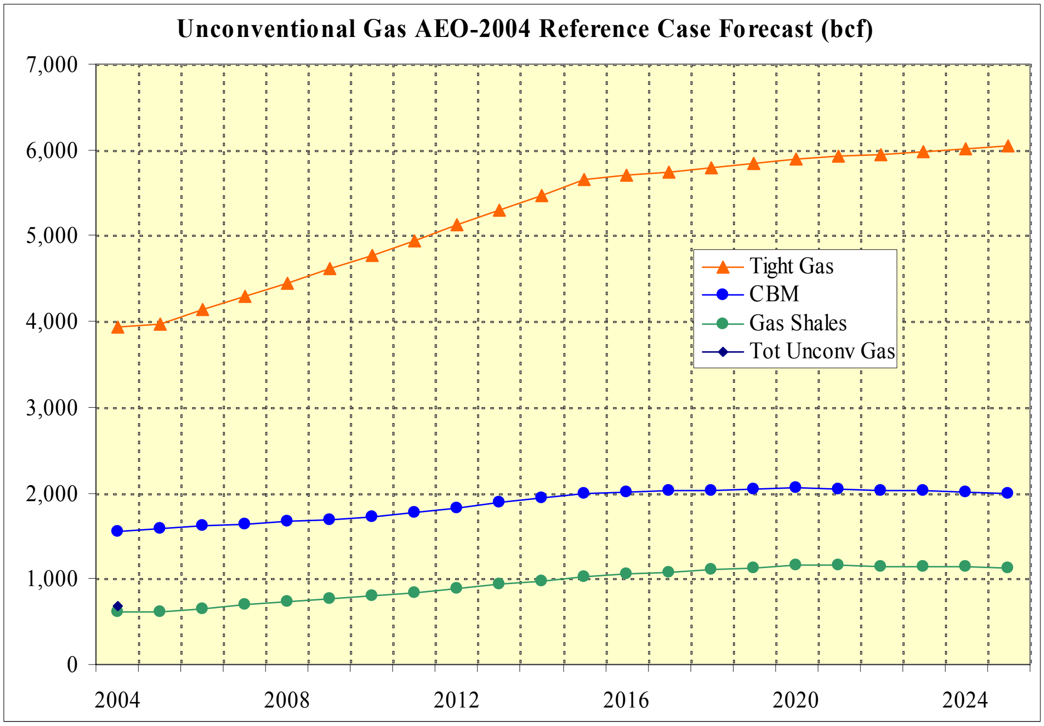
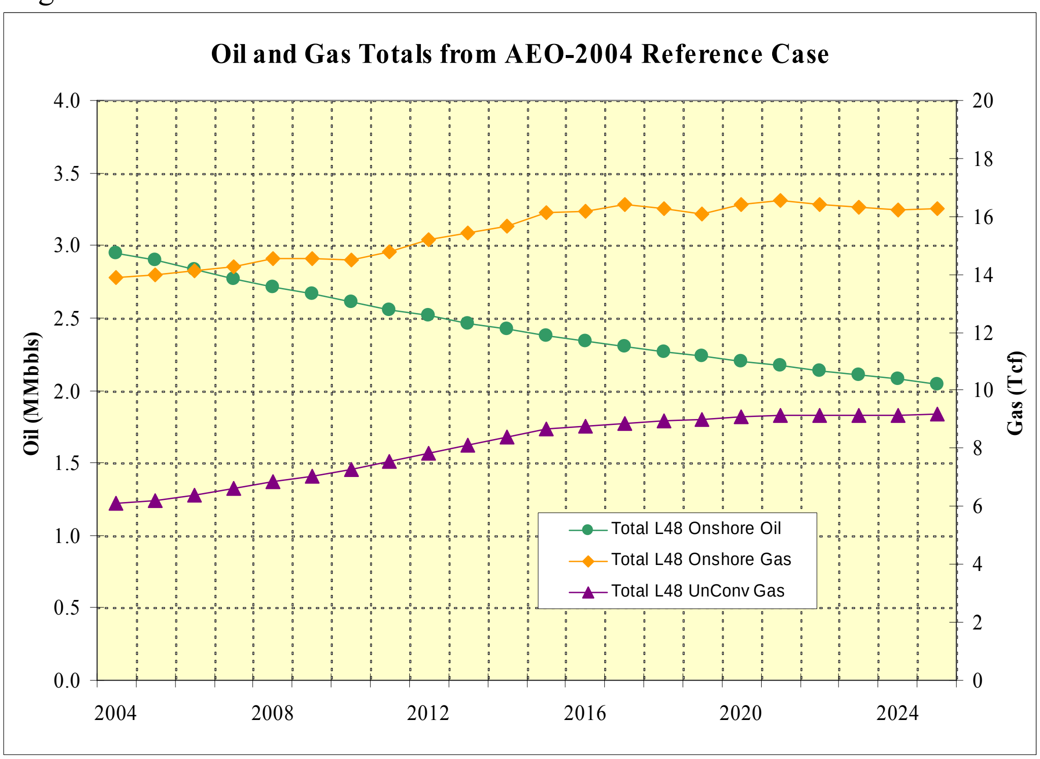


Figure 9: Total Conventional Oil and Gas AEO-2004 Reference Case Forecasts



The average WOR and WGR ratios calculated for the supply regions were applied to the AEO-2004 conventional oil and gas production reference case forecasts to project water production volumes. Unfortunately WGR could only be calculated for three (NE, RM and WC) of the six supply regions because of limited data on NA Gas so the average

WGR for the three was used to determine Wp for the remaining three (GC, MC and SW). A summary table (Table 3) follows for the year 2004:

Table 3: 2004 Projected Wp based on Conventional Oil and Gas AEO-2004 Forecast

Year 2004 Projected Wp based on Conventional Oil and Gas AEO-2004 Reference Case Forecast					
Region	Np-bbls	Wp-bbls	Gp-mcf	Wp-bbls	Tot-Wp
Northeast	29,199,999	251,148,811	886,966,900	1,426,502	252,575,312
Gulf Coast	208,049,997	3,447,076,010	4,871,829,000	2,095,983,013	5,543,059,023
Mid-Continent	113,150,001	2,641,188,927	2,258,326,000	971,588,480	3,612,777,407
Southwest	365,000,000	4,727,475,816	1,787,085,000	768,848,784	5,496,324,601
Rocky Mountains	131,400,005	2,878,178,345	3,861,237,000	2,218,972,027	5,097,150,372
West Coast	229,949,998	1,868,851,569	249,655,200	4,204,987	1,873,056,556
Lower 48 Onshore	**1,076,750,001**	**15,813,919,477**	**13,915,099,100**	**6,061,023,793**	**21,874,943,271**

This process was repeated for unconventional gas production. Very little data on water production from gas production was available for Gas Shales and Tight Gas Sands. Gas Shale WGR values are relatively low - the highest value found was about 0.001[24] and for Tight Gas Sands a WGR value of 0.17[25], both from the literature. Applying these WGR values to the AEO-2004 unconventional gas production reference case forecasts yielded the Wp volumes for 2004 shown in Table 4:

Table 4: 2004 Projected Wp based on Unconventional Gas AEO-2004 Reference Case

2004 Projected Wp based on Unconventional Gas AEO-2004 Reference Case Forecast									
Region	Gp (bcf)			Wp (MMbbl)			Total		WGR
	CBM	Gas Shales	Tight Gas	CBM	Gas Shales	Tight Gas	Gp	Wp	
Northeast Region	85	387	212	6	0.2	36	684	42	0.062
Gulf Coast Region	113	-	1,453	69	-	248	1,566	318	0.203
Midcontinent Region	17	-	316	10	-	54	333	64	0.191
Southwest Region	-	226	239	-	-	41	465	41	0.088
Rocky Mountain	1,343	-	1,722	729	-	295	3,065	1,024	0.334
Totals	**1,558**	**613**	**3,942**	**813**	**0.2**	**674**	**6,113**	**1,488**	**0.243**

Projecting water production to 2025 for both unconventional and conventional oil and gas yields the trends shown in the following graphs. Produced water from conventional oil

---

[24] Based on data from "Gas Potential of Selected Shale Formations in the Western Canadian Sedimentary Basin" by Basim Faraj, etal, GTI E&P Services Canada - Gas Tips, Winter 2004.

[25] Based on data from "Tight Gas Technologies for the Rocky Mountains" by James Ammer, NETL SCNG, Gas Tips, Spring 2002, pg 21.

production will decline slightly over the period while water production from both conventional and unconventional gas sources will increase slightly (Figure 10). Most of the anticipated water increase in unconventional gas comes from the Rocky Mountain Region (Tight Gas Sands) and the Powder River Basin (CBM), reflecting the AEO-2004 reference case gas projections shown previously in Figure 8.

Figure 10: Produced Water by Resource Type based on AEO-2004 Reference Case

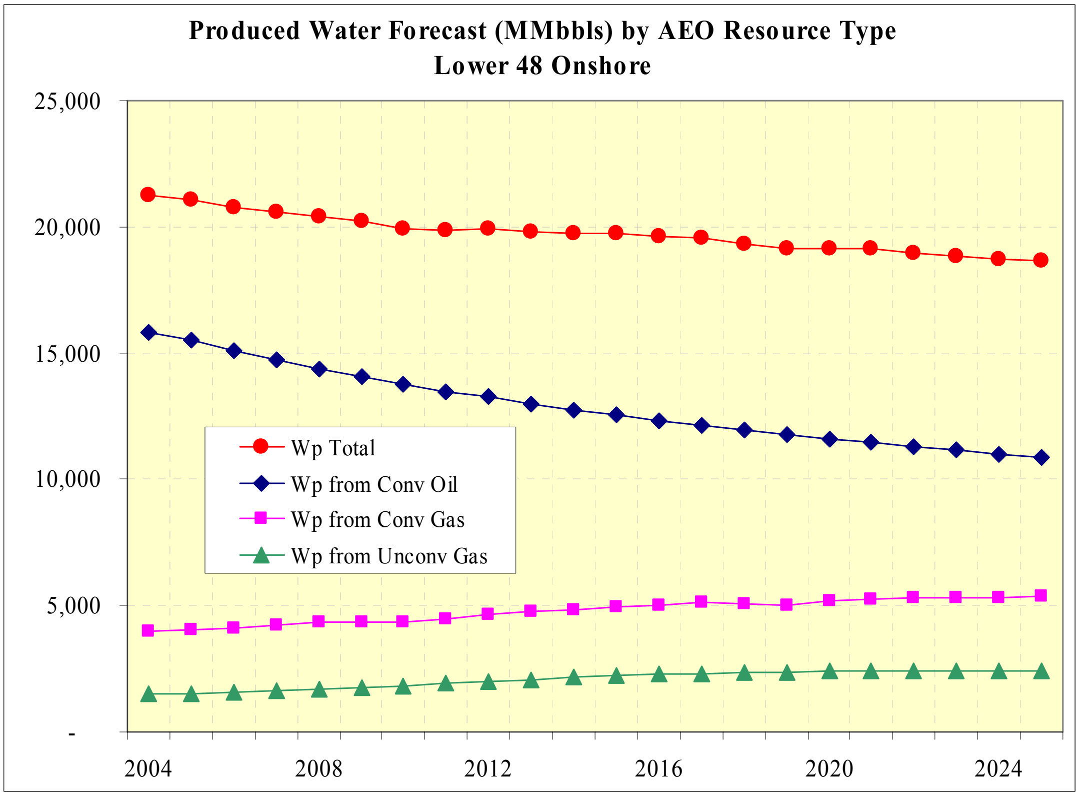
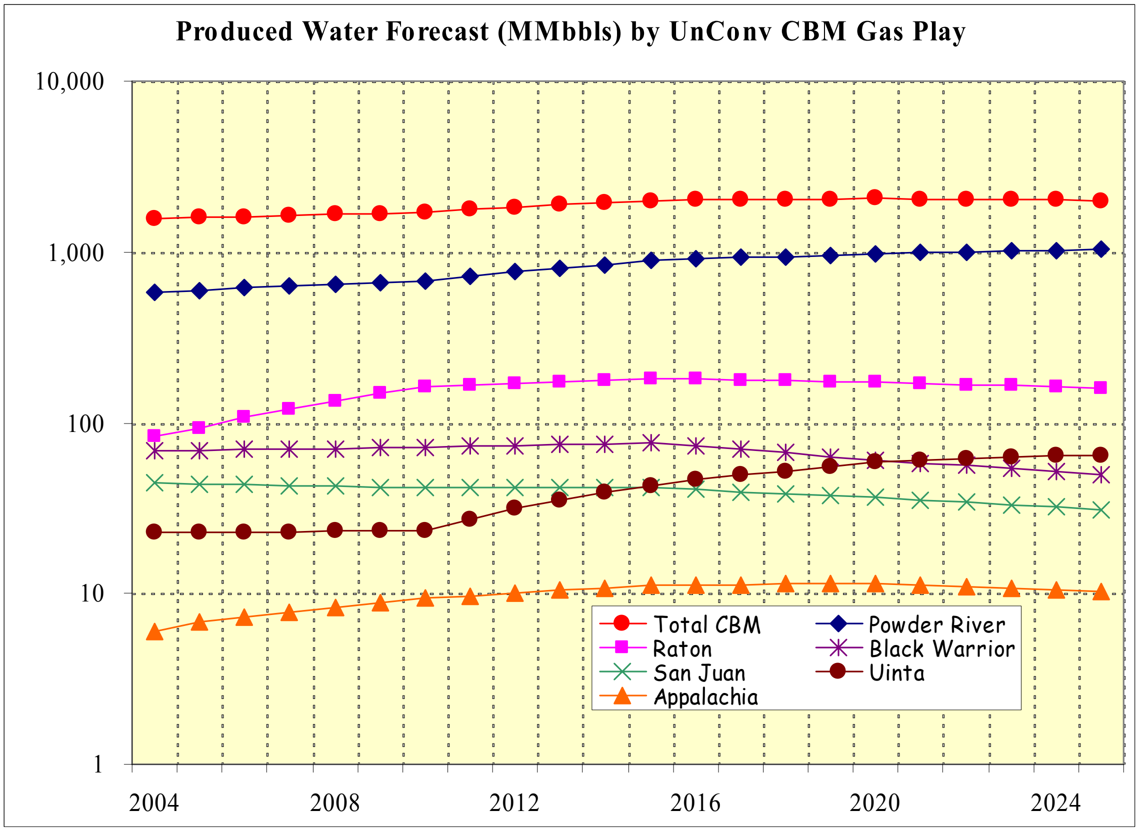
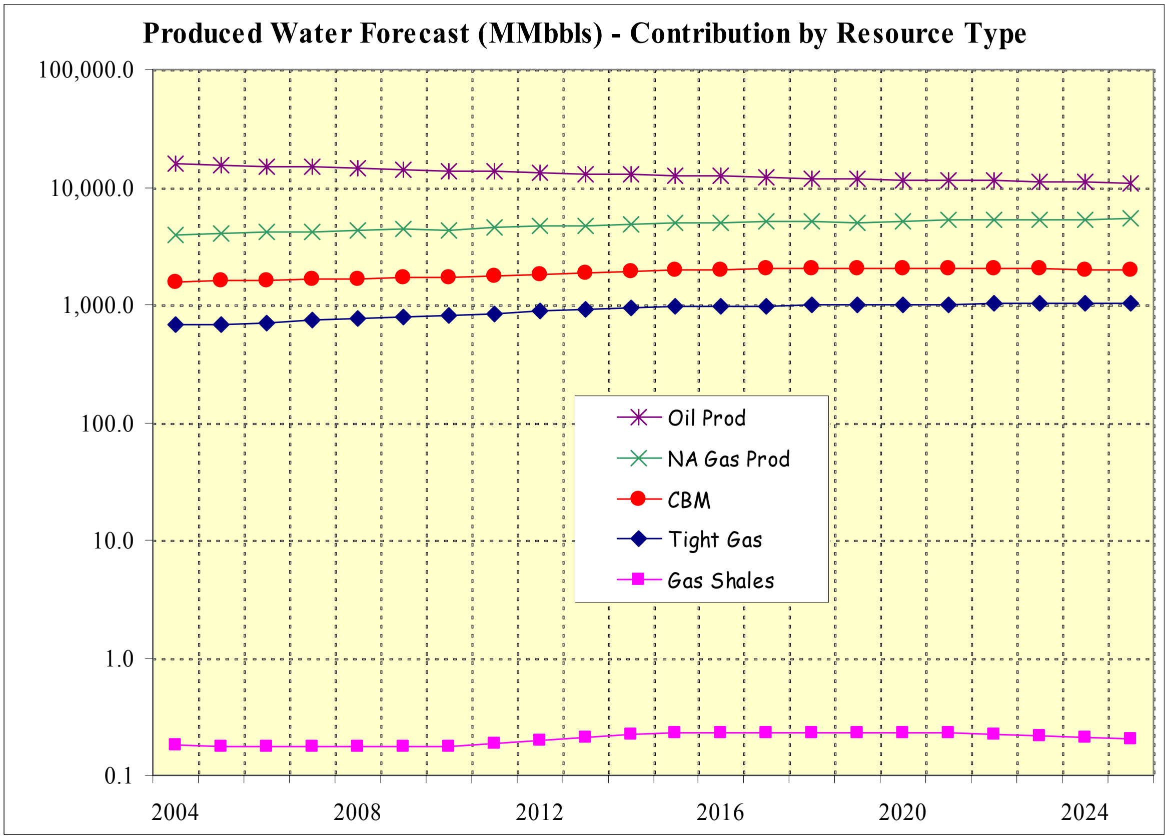


Figure 11: Produced Water Forecast for Unconventional CBM



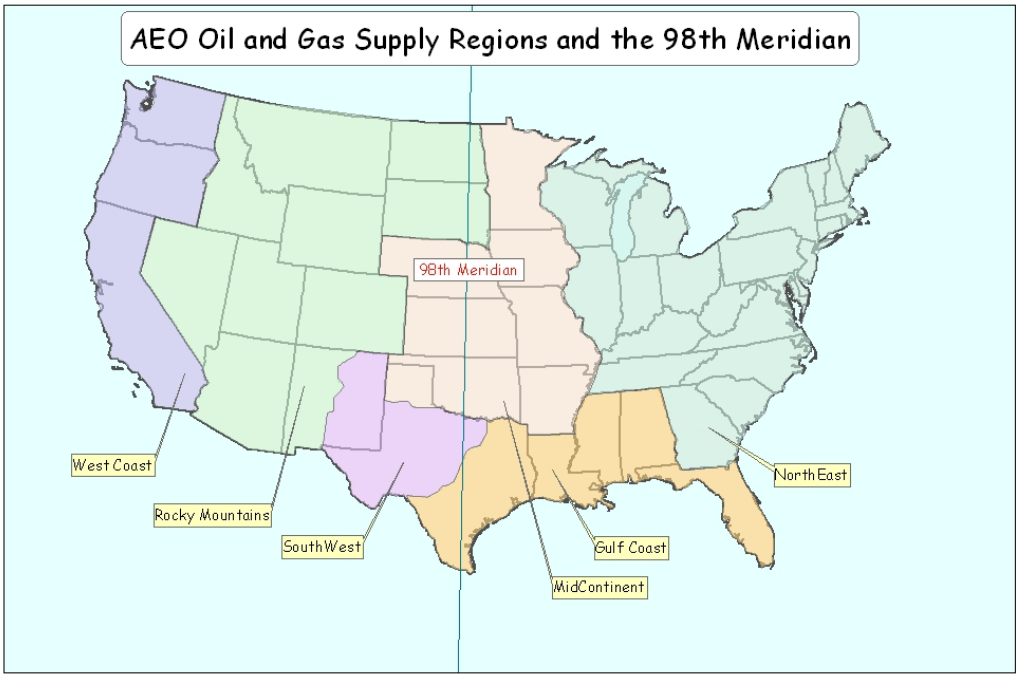
Putting all of this into perspective, Figure 12 shows the contribution to AEO-2004 forecasted water production by resource type: oil, non-associated gas, CBM, Tight Gas and Gas Shales. Conventional oil and gas operations contribute the vast majority of water produced and even thought CBM development is on the rise, and specifically the Powder River Basin is expected to double over the next twenty years, its contribution to the total water produced is small.

Figure 12: Contribution of Forecasted AEO-2004 Water Production by Resource Type



Of most interest, however, seems to be the production of water West of the 98th Meridian and specifically on Federal Lands. Figure 13 shows the location of the 98th Meridian and the AEO-2004 Supply Regions boundaries.

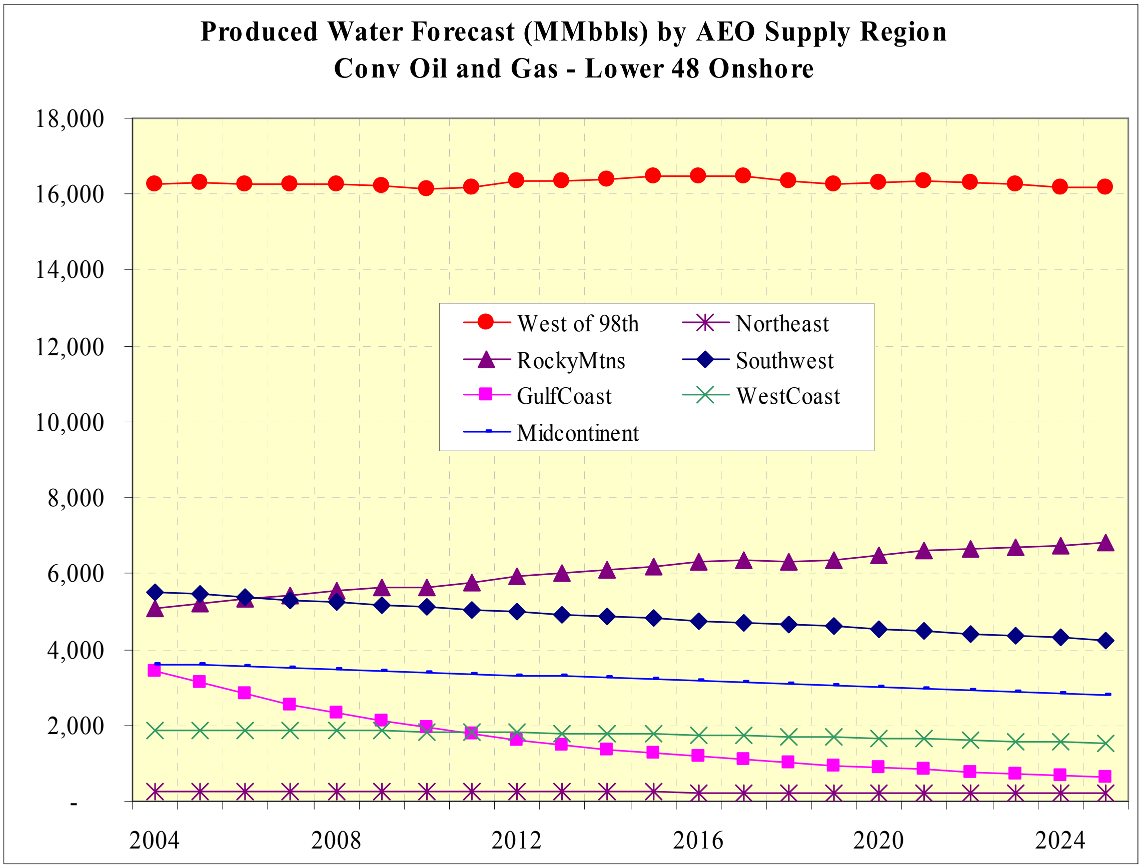
Figure 13: 98th Meridian and the AEO-2004 Supply Regions



Production "West of 98th"

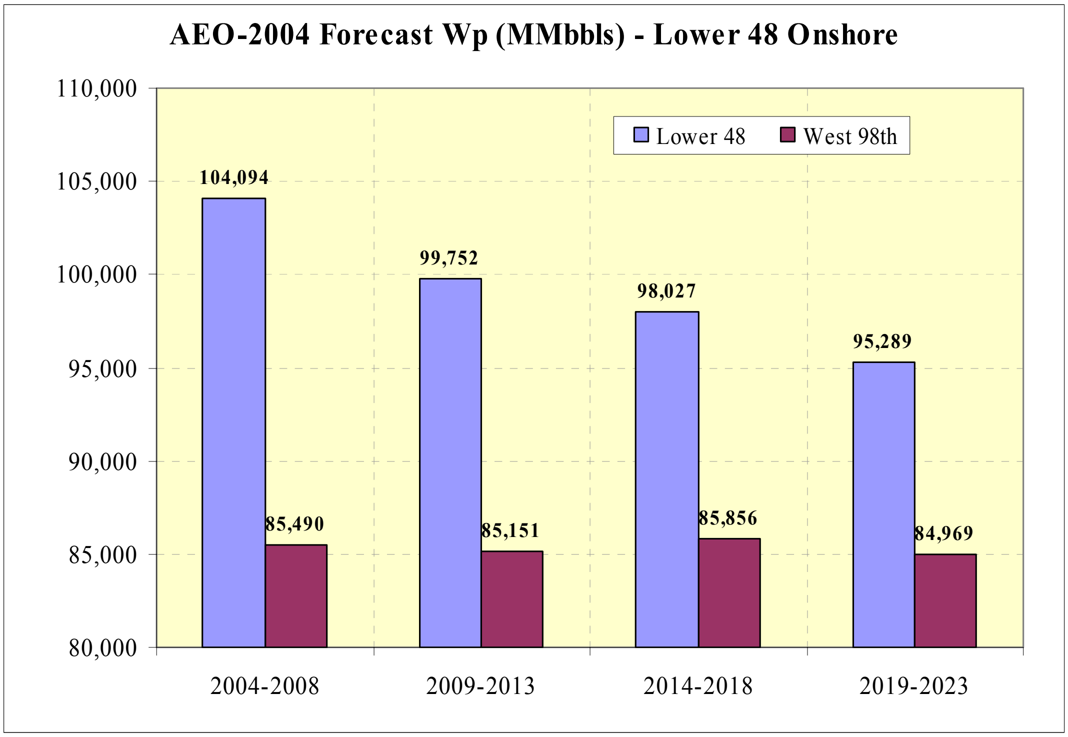
Production "West of 98th" could only be estimated. Ideally with long/lat coordinates, GIS spatial queries could be employed to define a very accurate regional boundary and subsequent production, but as mentioned earlier there is no spatial referencing for the data. Therefore, scaling factors were estimated for each of the four regions (Rocky Mountains, South West, Mid-Continent and Gulf Coast) that the meridian line traversed to estimate production allocation to assign to the west side of the meridian. The factors were based simply on a visual estimate of surface acreage and the resulting aggregate portions approximate the larger "West of 98th" region. The West Coast Region (California, Oregon and Washington) was excluded. Approximately 43% of the National Wp occurs West of the 98th Meridian. That production volume is compared to the regional values and presented in Figure 14.

Figure 14: Produced Water Forecast by AEO-2004 Supply Region



A 5-year cumulative summary of total Wp and "West of 98th " volumes in Figure 15 shows the total Wp forecast decreasing and the "West of 98th " essentially flat to 2023 – both reflecting the AEO 2004 annual projections and constant WOR/WGR values.

Figure 15: Five-Year Cumulative Wp Forecast



Federal Lands Production

Federal Lands 2003 production was obtained from the Minerals Management Service (MMS) which effectively received the data from the Bureau of Land Management (BLM)[26]. A comparison of water liquid equivalent ratios (WLER–including condensates, NLG's and converting gas to equivalent barrels) on Federal Lands and All Lands is shown in Figure 16. WLER was used because the federal production data did not differentiate between hydrocarbon liquids nor whether the water production was associated with the oil or gas. The Federal Lands and All Lands production includes conventional oil and gas, condensates, NGLs and unconventional gas. Since the data sources are different for All Lands (state records) and Fed Lands (MMS) and reporting levels vary (lease, field, and county) it is difficult to say why there are some striking differences in WLER, notably that the Fed Lands' generally is higher than the All Lands values.

[26] "BLM Safety Net Royalty Relief Analysis of Natural Gas and Oil Production and Public Section Revenues for United States Onshore Federal Lands" Aug 2004 (http://www.netl.doe.gov/scngo/Analysis%20&%20Planning/Pubs/NETL_BLM_final.pdf).

Figure 16: WLER Comparison of Federal Lands and All Lands

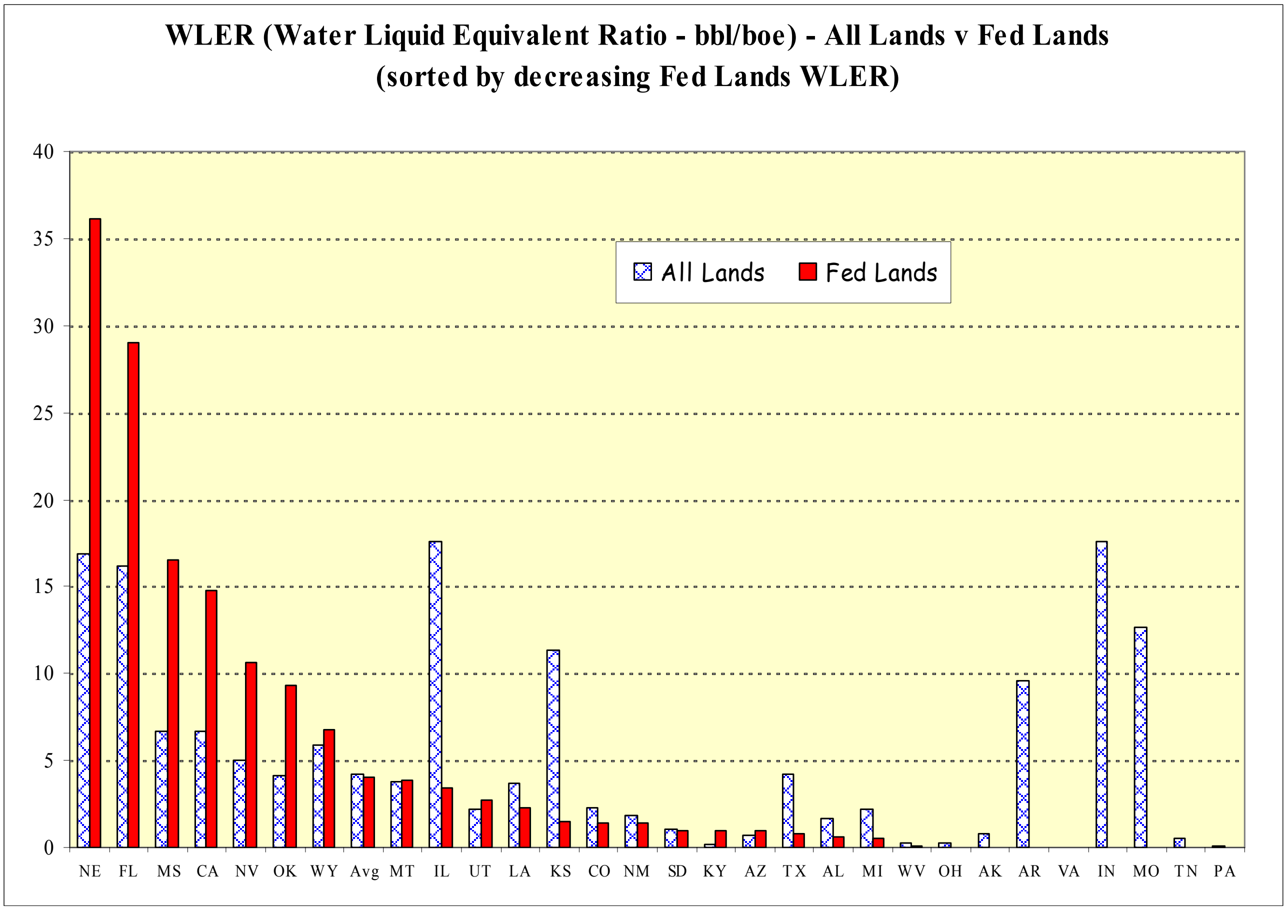


Table 5 is a breakout by state of production from All Lands and Federal Lands for 2003. Whether a validation that the collected All Lands production data is accurate or coincidental, Federal Lands volumes are always less than All Lands volumes with the exception of Utah and Nevada. Utah's overage is close but probably within reporting error limits. Nevada's data is way off and it may be that the state does not report federal production in its totals.

Nationally (Lower 48 States onshore), the Federal Lands portion of production is 14.8% of Np, 22.6% of Gp and 19.4% of Wp. Overall WLER for Federal Lands is 4.08 versus All Lands with 4.25. Here again, Alaskan production values are included in these tables but its production was not included in the projected water production forecasts – only onshore lower 48 states were included.

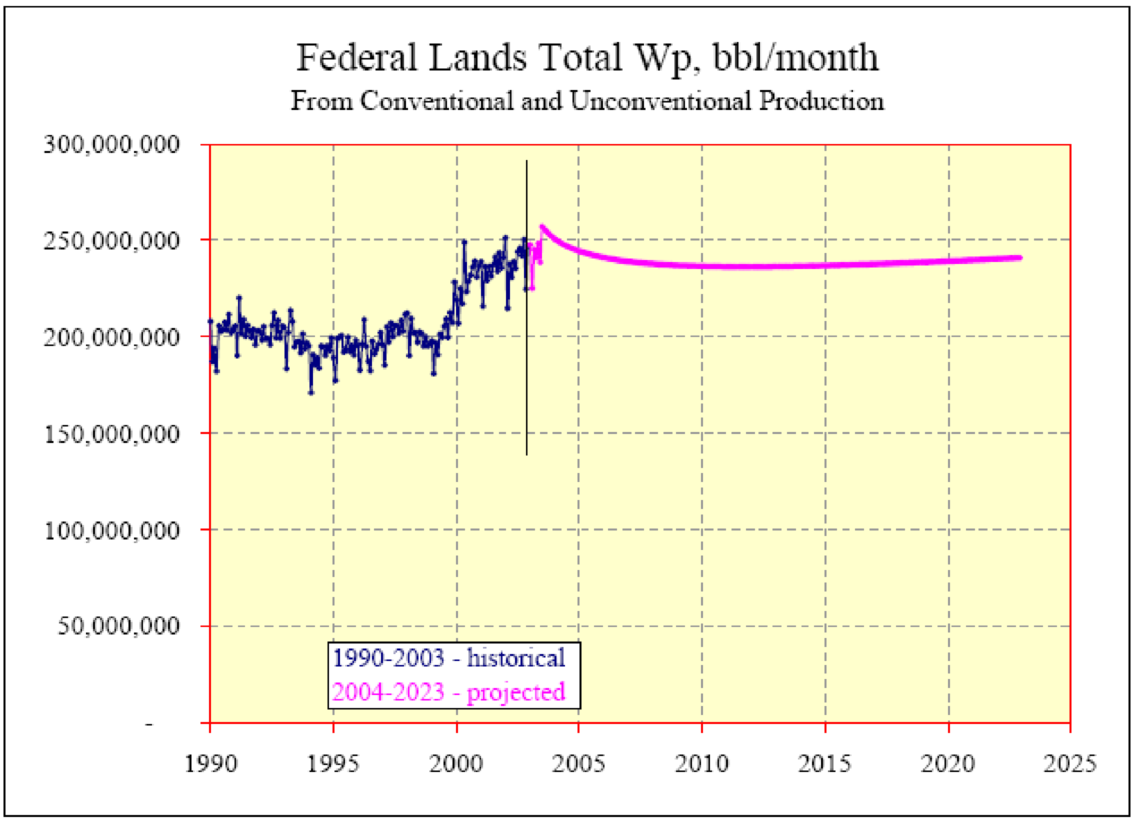
Table 5: All Lands & Federal Lands Total Liquids, Gas & Water Production for 2003

State	Np - total liquids				Gp - all gas				Wp - all water				WLER (bbl/boe)	
	All Lands	Federal	% Fed	Δ	All Lands	Federal	% Fed	Δ	All Lands	Federal	% Fed	Δ	All Lands	Fed Lands
Alabama	4,909,889	1,216,260	24.8%	3,693,629	327,317,674	39,355,788	12.0%	287,961,886	101,467,369	4,836,766	4.8%	96,630,603	1.71	0.62
Alaska	382,798,746	78,813	0.0%	382,719,933	3,597,700,989	65,512,605	1.8%	3,532,188,384	801,154,867	167,105	0.02%	800,987,762	0.82	0.02
Arizona	60,297	33,271	55.2%	27,026	307,000	161,694	52.7%	145,306	80,195	58,095	72.44%	22,100	0.72	0.96
Arkansas	7,234,727	23,547	0.3%	7,211,180	12,986,194	10,863,177		2,123,017	90,331,000	26,758	0.03%	90,304,242	9.61	0.01
California	257,343,068	29,447,844	11.4%	227,895,224	326,441,480	9,973,839	3.1%	316,467,641	2,092,944,678	458,676,614	21.9%	1,634,268,064	6.71	14.74
Colorado	20,686,190	7,544,200	36.5%	13,141,990	1,847,082,139	537,583,897	29.1%	1,309,498,242	736,570,535	139,371,248	18.9%	597,199,287	2.24	1.43
Florida	2,197,087	48	0.0%	2,197,039	2,419,065	3	0.0%	2,419,062	42,083,845	1,408	0.003%	42,082,437	16.18	29.03
Illinois	10,039,844	14,675	0.1%	10,025,169	-	7,260		(7,260)	176,701,254	55,058	0.031%	176,646,196	17.60	3.47
Indiana	1,962,078	-		1,962,078	-	-		-	34,532,573	-		34,532,573	17.60	
Kansas	33,625,370	165,233	0.5%	33,460,137	420,927,709	19,450,148	4.6%	401,477,561	1,174,641,000	5,012,952	0.4%	1,169,628,048	11.32	1.47
Kentucky	2,798,073	2,017	0.1%	2,796,056	81,722,990	246,389	0.3%	81,476,601	2,518,266	41,869	1.7%	2,476,397	0.15	0.97
Louisiana	80,031,907	1,965,850	2.5%	78,066,057	1,261,011,259	24,723,035	2.0%	1,236,288,224	1,079,805,000	14,134,274	1.3%	1,065,670,726	3.72	2.32
Michigan	7,719,157	92,429	1.2%	7,626,728	33,943,561	17,031,882	50.2%	16,911,679	29,162,650	1,581,395	5.4%	27,581,255	2.18	0.54
Mississippi	17,412,245	388,666	2.2%	17,023,579	164,170,149	694,958	0.4%	163,475,191	297,604,172	8,337,222	2.8%	289,266,950	6.65	16.53
Missouri	106,057	-	0.0%	106,057	-	-			1,339,500	-		1,339,500	12.63	
Montana	19,375,308	9,155,496	47.3%	10,219,812	86,722,976	38,568,106	44.5%	48,154,870	128,233,408	59,950,569	46.8%	68,282,839	3.79	3.85
Nebraska	2,753,335	193,033	7%	2,560,302	1,466,112	4,368	0.3%	1,461,744	50,570,218	6,993,163	13.8%	43,577,055	16.87	36.09
Nevada	13,123	399,428	3044%	(386,305)	-	2,262		(2,262)	65,615	4,249,211	6476%	(4,183,596)	5.00	10.63
New Mexico	66,527,150	35,678,648	53.6%	30,848,502	1,704,294,341	1,271,679,943	74.6%	432,614,398	635,741,061	348,609,402	54.8%	287,131,659	1.81	1.41
New York	-	-			27,335,653	226,666	0.8%	27,108,987	144,576	-		144,576	0.03	-
North Dakota	29,079,380	13,619,537	47%	15,459,843	57,883,981	22,837,116	39%	35,046,865	107,940,836	44,062,723	40.8%	63,878,113	2.79	2.53
Ohio	4,674,034	28,561	0.6%	4,645,473	71,356,659	556,143	0.8%	70,800,516	3,847,683	5,130	0.1%	3,842,553	0.23	0.04
Oklahoma	64,096,702	6,706,543	10.5%	57,390,159	1,443,660,284	115,867,012	8%	1,327,793,272	1,252,870,000	242,873,113	19.4%	1,009,996,887	4.11	9.33
Oregon	-	-			689,102	-		689,102	-	-			-	
Pennsylvania	1,223,558	-	0.0%	1,223,558	128,205,755	-		128,205,755	2,612,807	-	0.0%	2,612,807	0.12	
South Dakota	1,237,690	845,579	68.3%	392,111	11,604,552	10,338,078	89.1%	1,266,474	3,484,450	2,526,814	72.5%	957,636	1.10	0.98
Tennessee	386,428	-	0.0%	386,428	2,002,812	-	0.0%	2,002,812	386,428	-		386,428	0.54	
Texas	366,087,783	471,357	0.1%	365,616,426	4,894,219,603	31,286,294	0.6%	4,862,933,309	5,031,945,000	4,322,844	0.1%	,027,622,156	4.26	0.76
Utah	8,763,569	8,938,635	102.0%	(175,066)	190,161,289	163,842,139	86.2%	26,319,150	87,256,984	98,907,480	113%	(11,650,496)	2.16	2.73
Virginia	18,489	-	0.0%	18,489	80,795,583	573,185	0.7%	80,222,398	462,225	49	0.01%	462,176	0.03	0.00
West Virginia	2,590,131	-	0.0%	2,590,131	187,723,330	762,069	0.4%	186,961,261	8,029,406	7,657	0.1%	8,021,749	0.24	0.06
Wyoming	52,331,267	40,208,355	76.8%	12,122,912	1,828,958,842	1,110,809,984	60.7%	718,148,858	2,115,341,682	1,526,662,277	72.2%	588,679,405	5.92	6.77
Totals	1,448,082,682	157,218,025	10.9%	1,288,902,579	18,793,111,083	3,492,958,040	18.6%	15,300,153,043	16,089,869,283	2,971,471,196	18.5%	3,082,063,838	3.51	4.02
Totals ex AK	1,065,283,936	157,139,212	14.8%	906,182,646	15,195,410,094	3,427,445,435	22.6%	11,767,964,659	15,288,714,416	2,971,304,091	19.4%	2,281,076,076	4.25	4.08

Federal Lands water production from 2004 to 2023 was projected and is shown in Figure 17. This forecast was generated from the TORIS[27] Decline Model and is based on 2003 oil and gas production from Federal Lands lease data obtained from the MMS. This forecast does not take into account future oil and gas resource development; unlike the All Lands forecast where future development is estimated as part of the AEO-2004. Lease level WOR and WGR values were determined and the ratios used were the greater of the last years' (2003) ratio or the average ratio from the period of 1997 to 2003. For the oil forecast, the WOR value was declined at a rate equal to -1.14%/year based on observations of increasing WOR in the latter years of historical production. WGR values were held constant. Both ratios were then applied to the decline model oil and gas lease production stream forecasts and aggregated to a total.

The total average water production rate for the period 2004 to 2033 is ~239 MMbbl per month. Graphs of each state's forecasted oil, gas and water production and a Federal Lands total are presented in Appendix 4.

Figure 17: Federal Lands Wp Projection

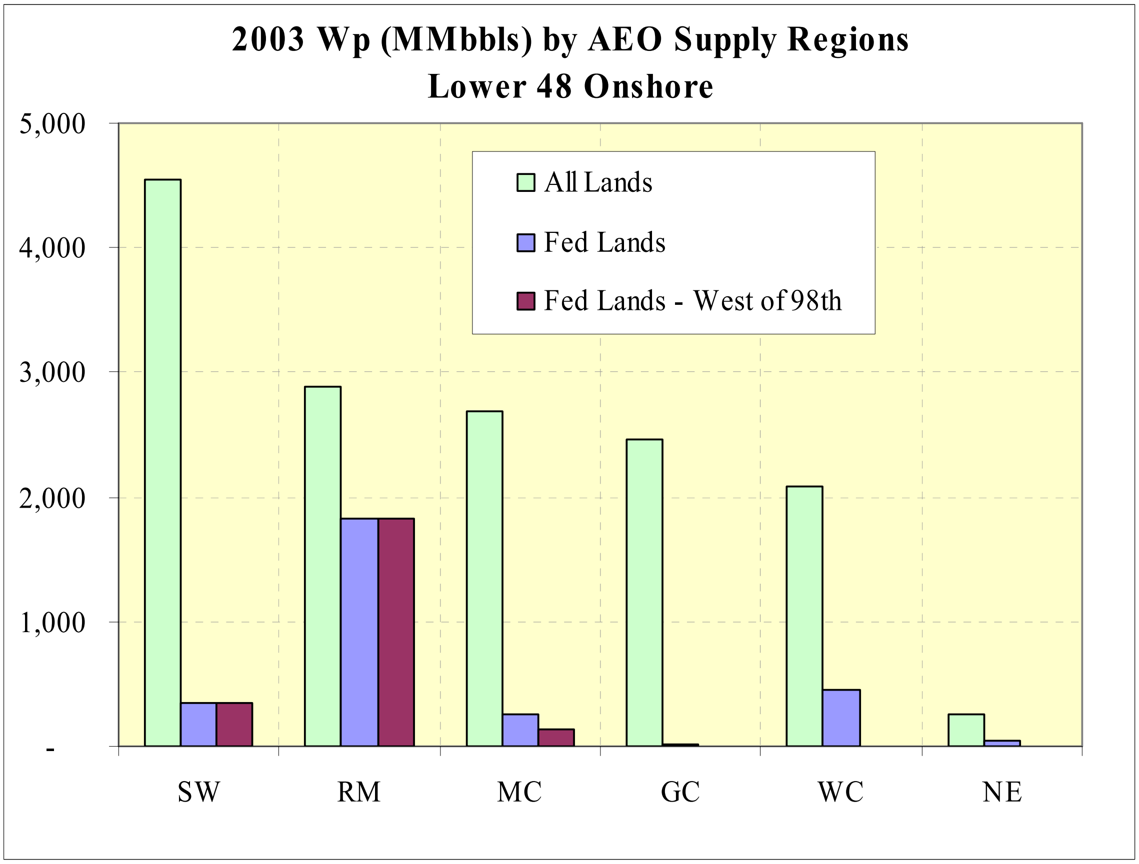


A comparison of 2003 water production from All Lands (data collected from individual states) and Federal Lands (MMS 2003 data) by AEO Supply Regions is presented in

[27]Total Oil Recovery Information System (TORIS) – modeling system developed at the Strategic Center for Natural Gas and Oil (SCNGO) of the National Energy Technology Laboratory (NETL) at Tulsa by Northrop Grumman Missions Systems.

Figure 18. Seventy-eight percent (2,321 MMbbls) of the water produced on Federal Lands is produced in the "West of 98th" region and that percentage increases to Ninety-four percent (2,779 MMbbls) if one includes the West Coast Region. The Rocky Mountain Region has the greatest contribution of Fed Land production to the total of all the regions and that is no coincidence since most of the hydrocarbon bearing fields are located in this region.

Figure 18: Comparison of Wp from All Lands, Fed Lands and Fed Lands West of 98th



Production Data Validation

Data validation is a necessary but often ambiguous process because one never knows how accurate the used data is compared to the "good" data. Generally, if both sets of data are in fair agreement we usually feel pretty good about them. The availability of supporting or validating data sources can be limited and sometimes the data cannot be directly compared without making some assumptions. It is also apparent that not all reporting sources honor consistent nomenclature, e.g., associated-dissolved and non-associated gas seems to be a big problem. For that reason, wherever possible total gas is reported and all liquids, if available, are reported, for total liquid boe values. Additionally, the individual state level data differences can cover a large range – since we are primarily concerned with total resulting water production only the lower 48 totals are compared here.

The All Lands data, taken primarily from the states' websites, was compared to data from the EIA's, "*Distribution and Production of Oil and Gas Wells by State for 2002*"[28] (2003 data was not available). Table 6 summarizes the totals for oil, gas and total liquids on a boe basis for those states that have production data in common. Of the 32 ALL Lands states there was a match of 24 for oil, 28 for gas and 26 for the total liquids. This was much better agreement than was expected.

Table 6: Comparison of EIA Production Data to that from States' Websites

Hydrocarbon	**EIA**	**All Lands**	**% All Lands**
Oil, bbls	964,774,513	1,034,612,172	107.2%
Gas - all, mcf	15,576,886,372	14,643,602,965	94.0%
Total, boe	3,560,923,314	3,567,180,521	100.2%

A similar process was undertaken for the Federal Lands production but finding another unrelated source was not possible. The BLM sourced Federal Lands data was compared to a Minerals Revenue Report[29] published by the MMS, the latest of which that was available is for the year 2000. A summary is presented in Table 7. Unfortunately, a direct comparison cannot be made between these sources. The BLM data is total production from federal lands and the MMS data is sales volume data that reflects net revenue interests. Given the disparity in the data a difference of 32% in total liquids is probably not unrealistic.

Table 7: Comparison of MMS to BLM Production Data

Hydrocarbon	**MMS**	**BLM**	**% BLM**
Oil, bbls	121,215,321	157,218,025	145%
Gas, mcf	2,417,323,315	3,492,944,147	165%
Total Liquids, boe	558,636,113	739,377,698	132%

Both sets of data are for Lower 48 onshore and American Indian lands production. Additionally, MMS total liquids data includes Gas Plant liquids. Of the 32 states with production 28 states are listed to have federal production. For oil there were 25 states in common, 24 for gas and 27 for total liquids.

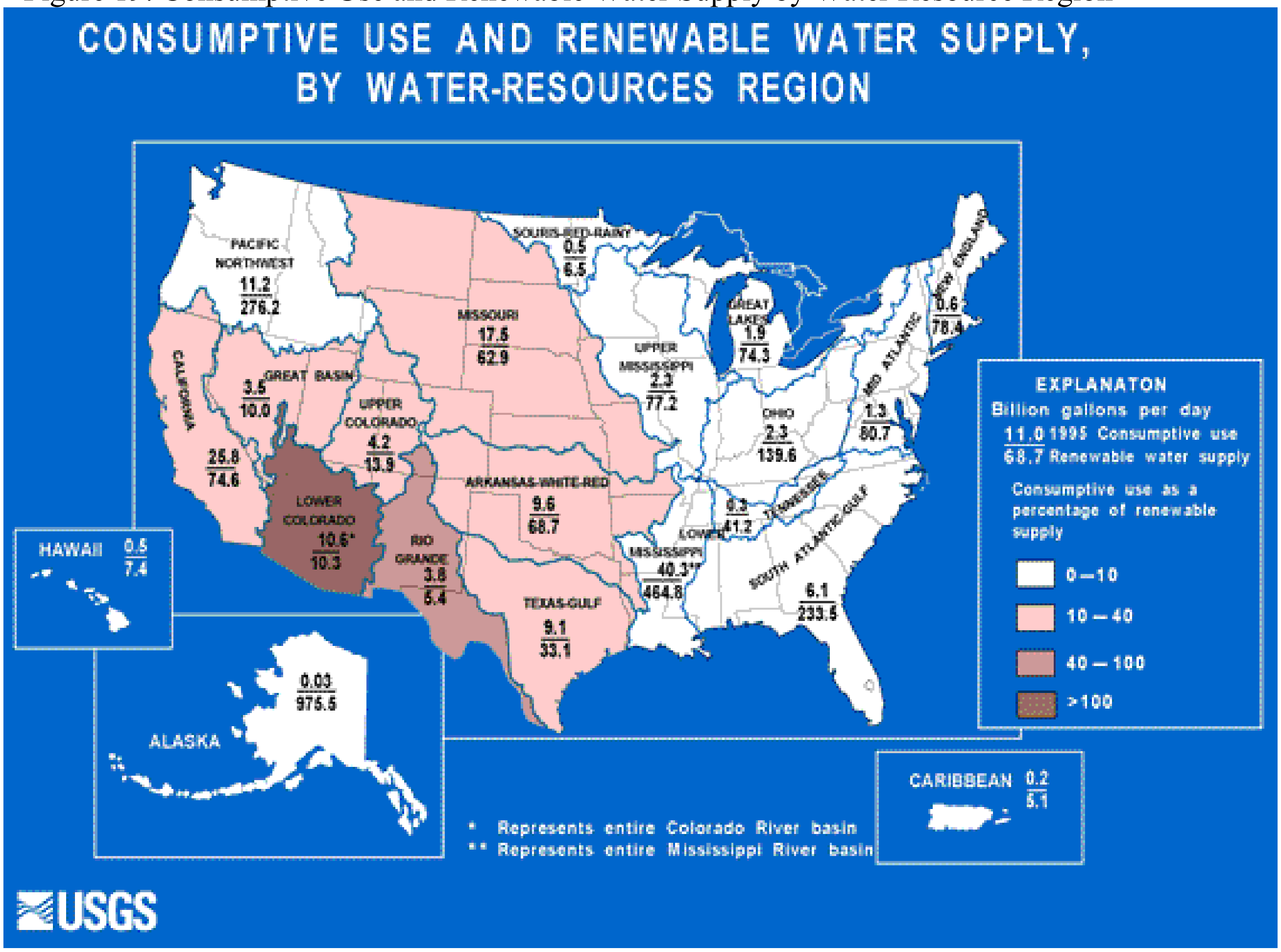
National Water Consumption[30]

The USGS devotes a portion of its budget to understanding the water resources in the United States and in particular water consumption and what its long term implications

[28] http://www.eia.doe.gov/pub/oil_gas/petrosystem/petrosysog.html , this data may have come from IHS Energy but that has not been verified.
[29] "Mineral Revenues 2000", http://www.mrm.mms.gov/Stats/mr.htm
[30] all data in this section taken from the USGS website: http://water.usgs.gov/

might be. Figure 19, a graphic taken from the USGS website[31], shows consumptive use and the renewable water supply by region.

Figure 19: Consumptive Use and Renewable Water Supply by Water Resource Region



This graphic is explained on the USGS site as follows:

"*The renewable water supply is the sum of precipitation and imports of water, minus the water not available for use through natural evapo-transpiration and exports. Renewable water supply is an implified upper limit to the amount of water consumption that could occur in a region on a sustained basis. Requirements to maintain minimum flows in streams leaving the region for navigation, hydropower, fish, and other instream uses limit the amount of the renewable supply available for use. Also, total development of a surface-water supply is never possible because of increasing evaporative losses as more reservoirs are used. Nevertheless, the renewable supply compared to consumptive use is an index of the degree to which the resource has already been developed.*"

The Mid-Continent, Rocky Mountain, Southwest, and Pacific regions in general are those areas that have water issues, their resource development ratio is considerably higher than

---

[31] http://water.usgs.gov/watuse/misc/consuse-renewable.html

the Eastern and Northwestern portions of the country, and for the most part, produce most of the hydrocarbons used in this country. It is within these same regions where a significant additional source of water, from oil and gas operations, could be obtained.

Table 8 provides the same information in tabular form:

Table 8: Water Consumption Rate and Resource Development

Water Resources Region	Consumption Rate	Max Sustainable Renewable Rate	Resource Development
	billion gal/day		Rate, %
Pacific-Northwest	11.2	276.2	4.1%
California	25.8	74.6	34.6%
Great Basin	3.5	10.0	35.0%
Lower Colorado	10.6	10.3	102.9%
Upper Colorado	4.2	13.9	30.2%
Rio Grande	3.8	5.4	70.4%
Texas-Gulf	9.1	33.1	27.5%
Arkansas-White-Red	9.6	68.7	14.0%
Missouri	17.5	52.9	33.1%
Scours-Red-Rany	0.5	6.5	7.7%
Upper Mississippi	2.3	77.2	3.0%
Great Lakes	1.9	74.3	2.6%
Ohio	2.3	139.6	1.6%
Lower Mississippi	40.3	454.8	8.9%
Tennessee	6.2	41.2	15.0%
South Atlantic Gulf	6.1	233.5	2.6%
Mid-Atlantic	1.3	80.7	1.6%
New England	0.6	78.4	0.8%
Lower-48 totals	156.8	1,731.3	9.1%

This does not include water used for industrial purposes. A breakout of total water usage is shown here in Table 9.

Table 9: Water Usage by Sector

Item	Year 2000		
	Billions gal		Billions bbls
Population (millions)	285.3		
Water Usage (billion gal/day)	407.5		9.7
Public supply	43.2		
Rural domestic & livestock	9.1		
Self-supplied domestic		3.6	
Livestock & aquaculture		5.5	
Irrigation	137.0		
Industrial	218.2		
Thermoelectric-power		195.0	
Other industrial		23.2	
Water usage per person (gal/day)	1,428		34.0
Non-Industrial Water Usage (not recycled) – 1995 report			
Water Usage (billion gal/day)	100.0		2.4
Water usage per person (gal/day)	350.5		8.3

Once again from the USGS, "*The 408 billion gallons per day for 2000 are total water withdrawals, which includes some water that is returned to the environment after use. For example, much of the water withdrawn for thermoelectric power generation is for once-through cooling and is not consumptively used. The 157 bgd on the (attached) map represents consumptive use, which is that part of the water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise unavailable for re-use. The figure referenced (157 bgd) was originally published in the 1983 National Water Summary and was based on 1980 data. Estimation of consumptive use is important for evaluating the relation of water withdrawals to renewable water supply, but consumptive use was not shown in Circular 1268 due to the difficulty of estimating those quantities for all States and categories. The 1995 report (Circular 1200) showed total consumptive use of 100 bgd.*"[32]

The total water consumption in the United States, 408 bgd, is a large almost unimaginable amount - water consumptive usage per person of 100 bgd is a sizeable amount also. In contrast, the amount of water production forecast from oil and gas operations is 2.1 bgd. This is a small fraction of the total and even if all of it could be converted into beneficial usage it would not have a large impact at the national level. However, regional or local levels may find this water to be very valuable. Water consumption data is available at the county level for the United States and Phase 2 of this work will address specific regions (by county) where water supply and demand ratios could be critical and whether potentially beneficial volumes of water are in close proximity.

[32] email communication with Joan Kenny, USGS

More specific water issues addressing agriculture and water supply can be found at the U.S. Drought Monitor[33], and the National Drought Mitigation Center (NDMC)[34]. According to their website, "*The NDMC, established in 1995, is based in the School of Natural Resources at the University of Nebraska–Lincoln. The NDMC's activities include maintaining an information clearinghouse; drought monitoring, including participation in the preparation of the U.S. Drought Monitor and maintenance of the web site (drought.unl.edu/dm); drought planning and mitigation; drought policy; advising policy makers; collaborative research; K–12 outreach; workshops for federal, state, and foreign governments and international organizations; organizing and conducting seminars, workshops, and conferences; and providing data to and answering questions for the media and the general public." The Drought Monitor is a "synthesis of multiple indices, outlooks and news accounts that represents a consensus of federal and academic scientists*."

B-Produced Water Issues

Major Produced Water Areas

Volumes

The API[35] estimates that 71% of produced water is being used for Improved Oil Recovery (IOR), 21% is being injected for disposal, 5% to beneficial use such as livestock, irrigation, etc. and 3% to percolation and evaporation ponds.

Applying these percentages to the Lower 48 Produced Water forecast for the period of 2004-2025, there will be 282 MMMbbls used for IOR, 83 MMMbbls to disposal, 20 MMMbbls applied to beneficial usage and 12 MMMbbls water evaporated/percolated in surface ponds. Thus, there is the potential of some fraction of 95 MMMbbls that could be diverted to beneficial use plus whatever volumes of water used for IOR that could be redirected as a result of abandoned water floods.

Land Ownership

Figures 20, 21 and 22 show federal and state land ownership by percentage and by state with and without Alaskan acreage data. The data for these graphs were taken from a table produced in 1995 by the National Wilderness Institute[36] and detail "*state and federal government ownership of lands open to public access in the United States. This includes parks, forests and grasslands; it excludes land used for such purposes as office buildings, prisons, or irrigation projects. Military bases and tribal lands are included*

[33] http://drought.unl.edu/dm/current.html
[34] http://drought.unl.edu/about.htm
[35] "Overview of Exploration and Production Waste Volumes and Waste Management Practices in the United States", table 2.4, pg 11, prepared by ICF Consulting for the American Petroleum Institute, Washington, DC, May 2000.
[36] These graphs, Figures 18-20, are based on information from the 1995 by National Wilderness Institute (http://www.nwi.org/Maps/LandChart.html).

because both can represent a significant percentage of "non-private" land ownership in a state even though public access may be restricted. Note that neither military nor tribal lands are included in the columns totaling state and federal land ownership. Where possible, with the exception of land owned by the Army Corps of Engineers, acreage figures refer, only to land area and do not include water areas, leases or easements. In several cases, however, federal and state agencies were uncertain if the figures provided included the latter or were unable to provide differentiated figures. All data have been corroborated, expanded and, where necessary, corrected and updated…"

Figure 23 depicts graphically the Federal Lands of the United States and also shows the major oil and gas fields. Reiterating, in the Lower 48 States, the Federal Lands portion of production is 14.8% of Np, 22.6% of Gp and 19.4% of Wp. According to AEO-2004[37], 7% of undeveloped unconventional gas reserves are off limits to drilling or surface occupancy, 26% are considered developmentally constrained because of environmental and/or pipeline regulations and 15% are accessible but have lease stipulations. This leaves 53% of the resource on Federal Lands without leasing stipulations or on private land. This significant oil, gas, and beneficial produced water resource has not been exploited to date and much of these areas fall within New Mexico, Colorado, Utah and Wyoming, as can be seen from the tables and graph.

One may not agree with the political position of the Environmental Working Group[38] but they do present a fairly thorough discussion of federal leasing programs and their interpretation of the problems associated with it. Future oil and gas development may see significant access rights issues because most of the potential increase in production will probably come from unconventional gas sources in the Rocky Mountains and on federal lands. It is unclear if water production associated with hydrocarbon production has the same ownership. Water rights and environmental liability issues will also no doubt come into play.

[37] U.S. Department of Energy, Energy Information Agency, Annual Energy Outlook 2004, DOE/EIA-0383(2004) January 2004, pages 38-39

[38] http://www.ewg.org/oil_and_gas/execsumm.php

Figure 20: Federal and State Land Surface Ownership by State, %

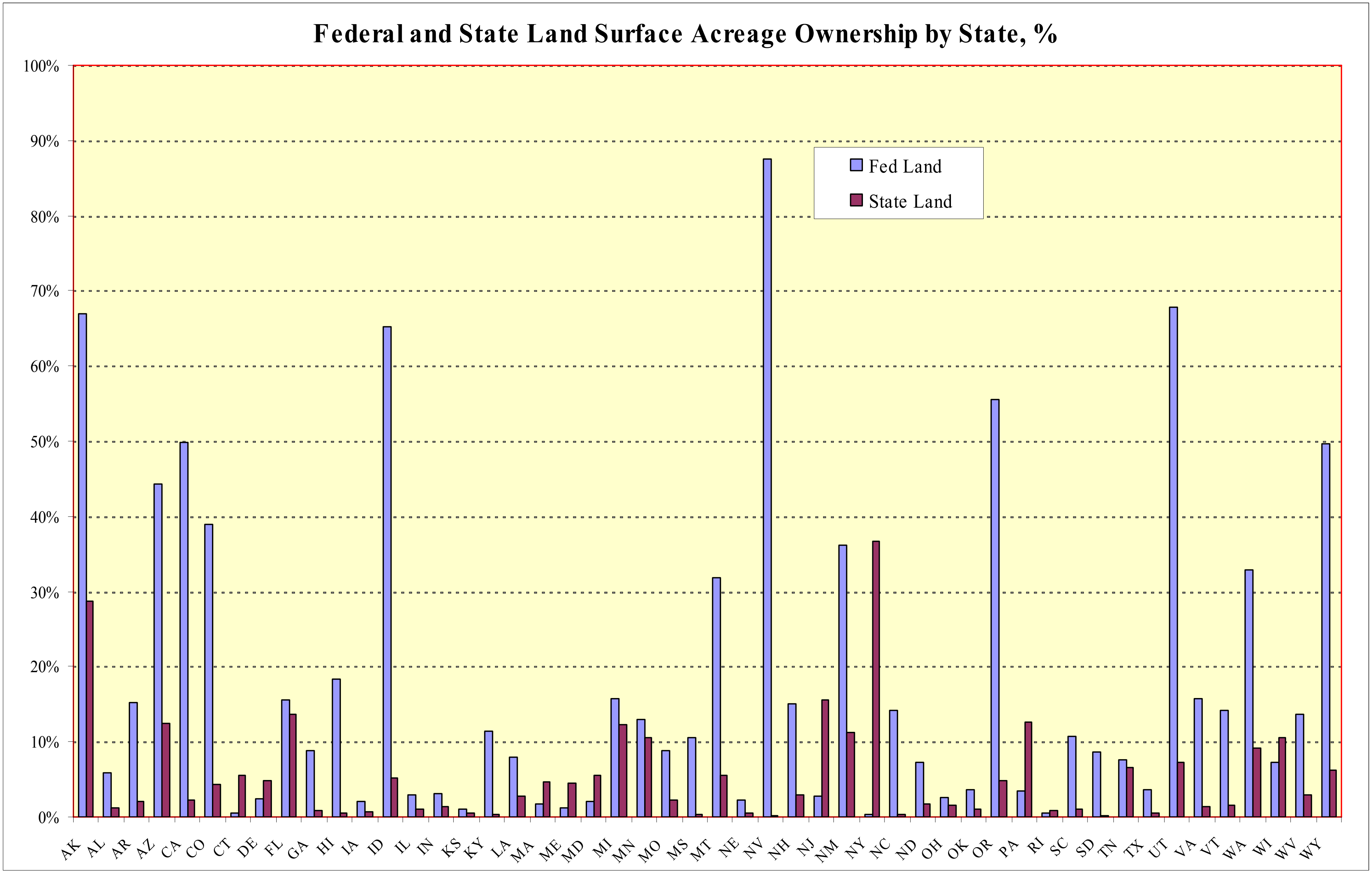


Figure 21: Federal and State Land Ownership by State, acres

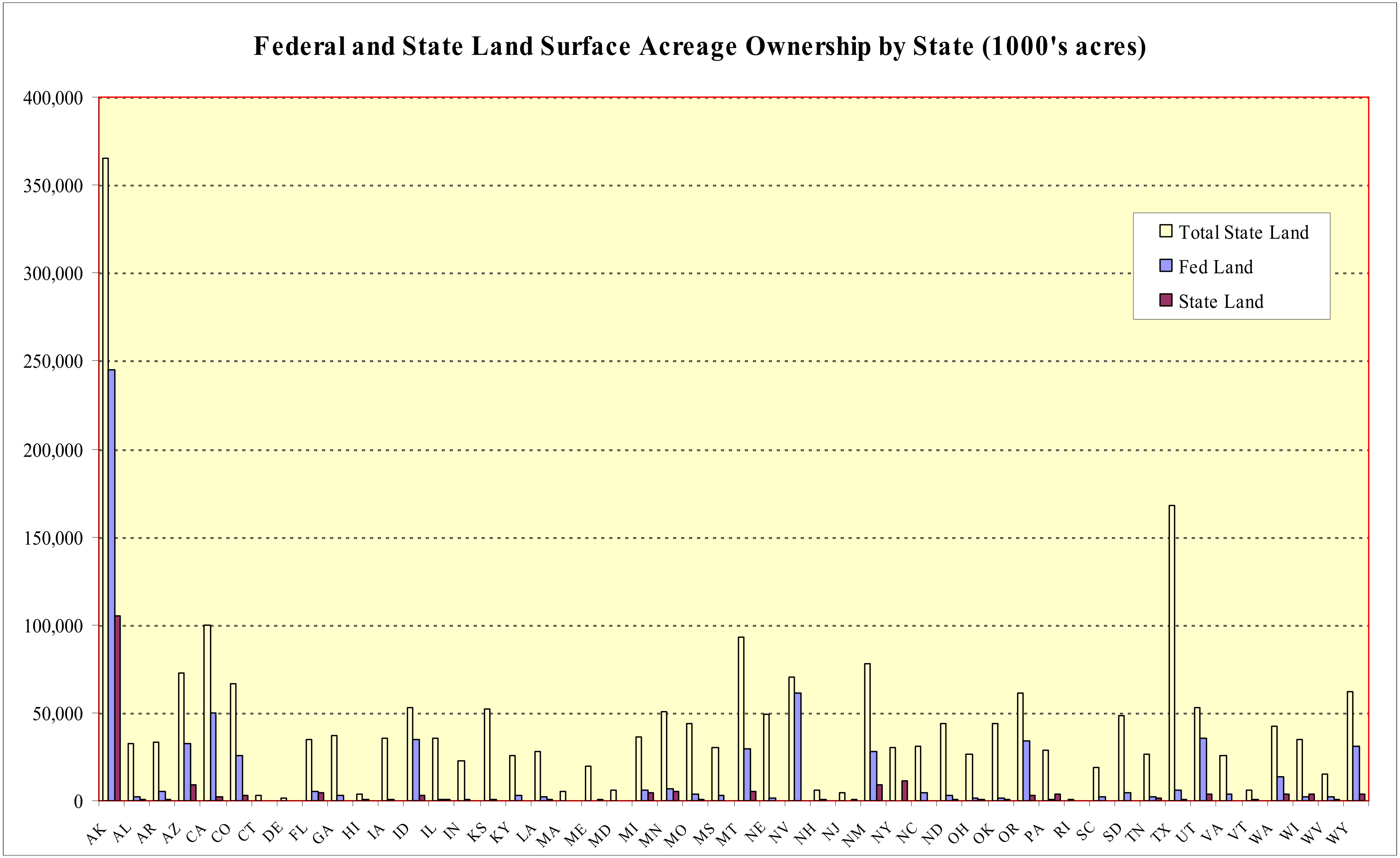


Figure 22: Federal and State Land Ownership by State excluding Alaska, acres

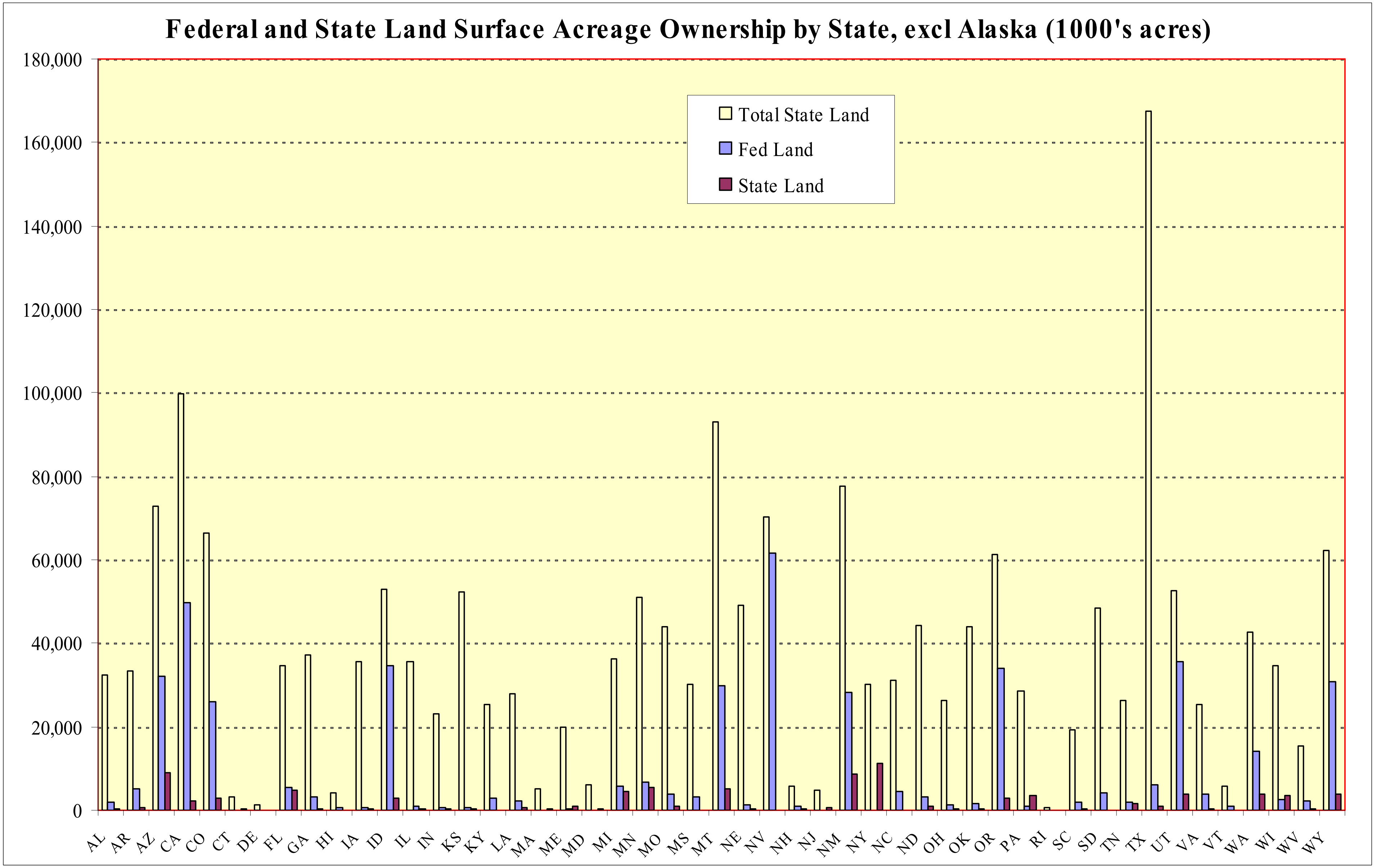
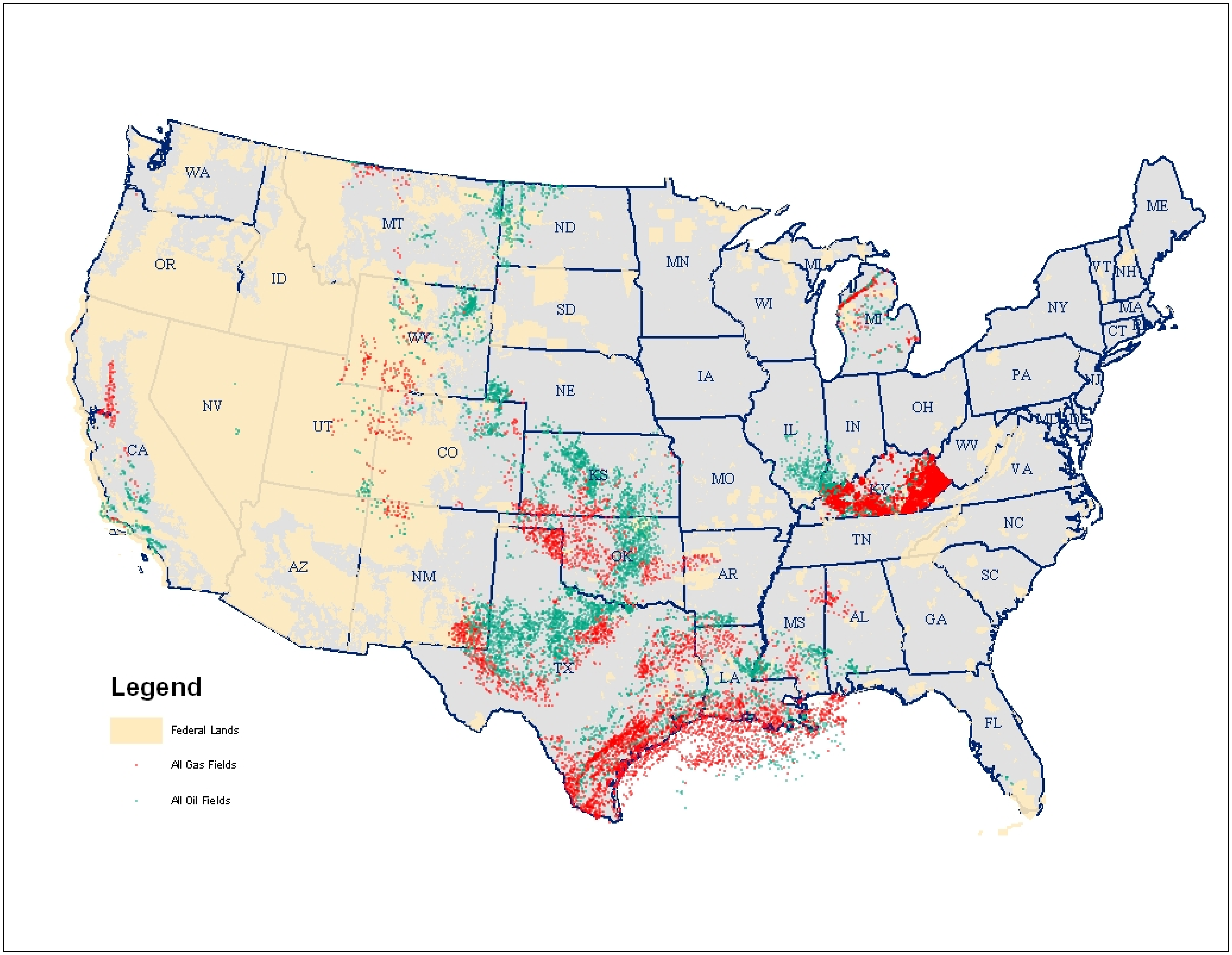


Figure 23: Federal Lands Areas and Oil and Gas Fields in the United States



Unique Chemistry (water quality data)

There are several sources of historical water quality data but most apparently stem from the same original work performed at the Petroleum Laboratory in Bartlesville, Oklahoma (and a large part of it was performed circa 1955-85 under Gene Collins) that was originally operated by the U.S. Bureau of Mines (BoM) and subsequently by the Department of Energy. The historical data presented in this section is meant to show the large effort and commitment, primarily in the 50's and 60's, to collecting data on water quality from oil and gas operations. With water close to becoming a commodity it would seem that better and more current data needs to be collected and maintained in published databases.

In Phase II of this work we will further investigate the role that this data may play in trying to tie water volumes to water quality in specific areas of the country. It will be compared and/or supplemented wherever possible with data from sources like the EPA's NPDES[39] (National Pollutant Discharge Elimination System) to the historical data presented here.

USGS Produced Water Database

This produced water database is a subset of a larger database originally provided to the USGS[40] by GeoINFORMATION at the University of Oklahoma. After the USGS received the data it was re-examined and duplicates removed. There are 50,605 records in the database containing water quality information including several new entries that were made to the original db. With the exception of the new entries made by USGS, all of the data is pre-1980, as shown in Figure 24. This dates the information somewhat but it still has value from a historical perspective.

[39] http://cfpub.epa.gov/npdes/

[40] http://energy.cr.usgs.gov/prov/prodwat/dictionary.htm

Figure 24: Distribution of USGS Water Sample Count (by year)

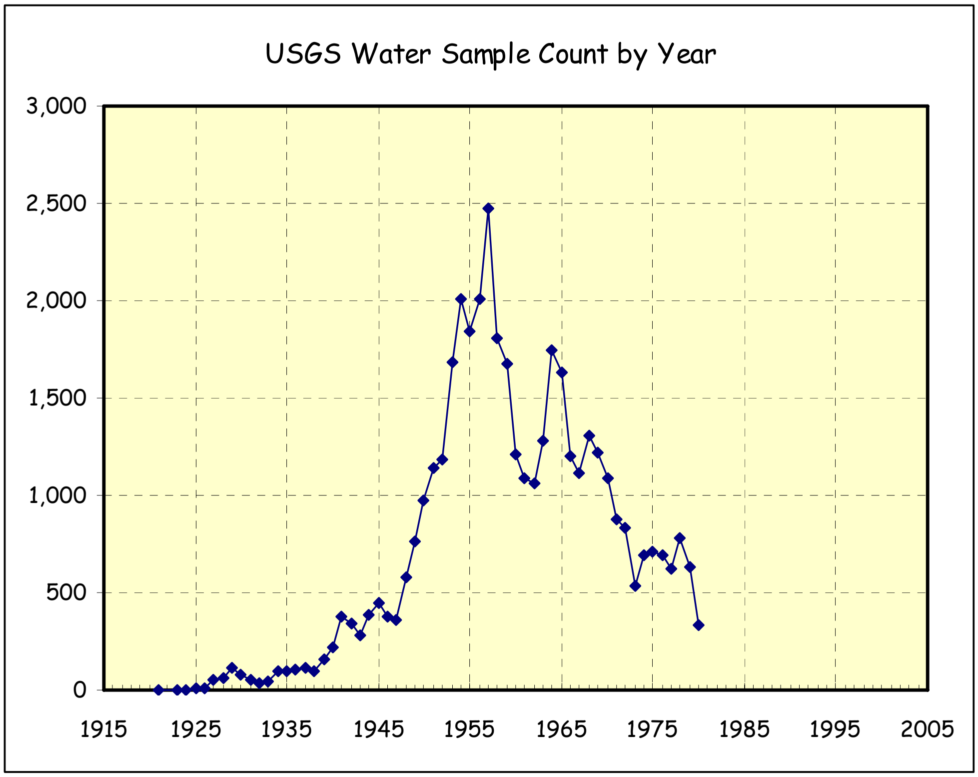
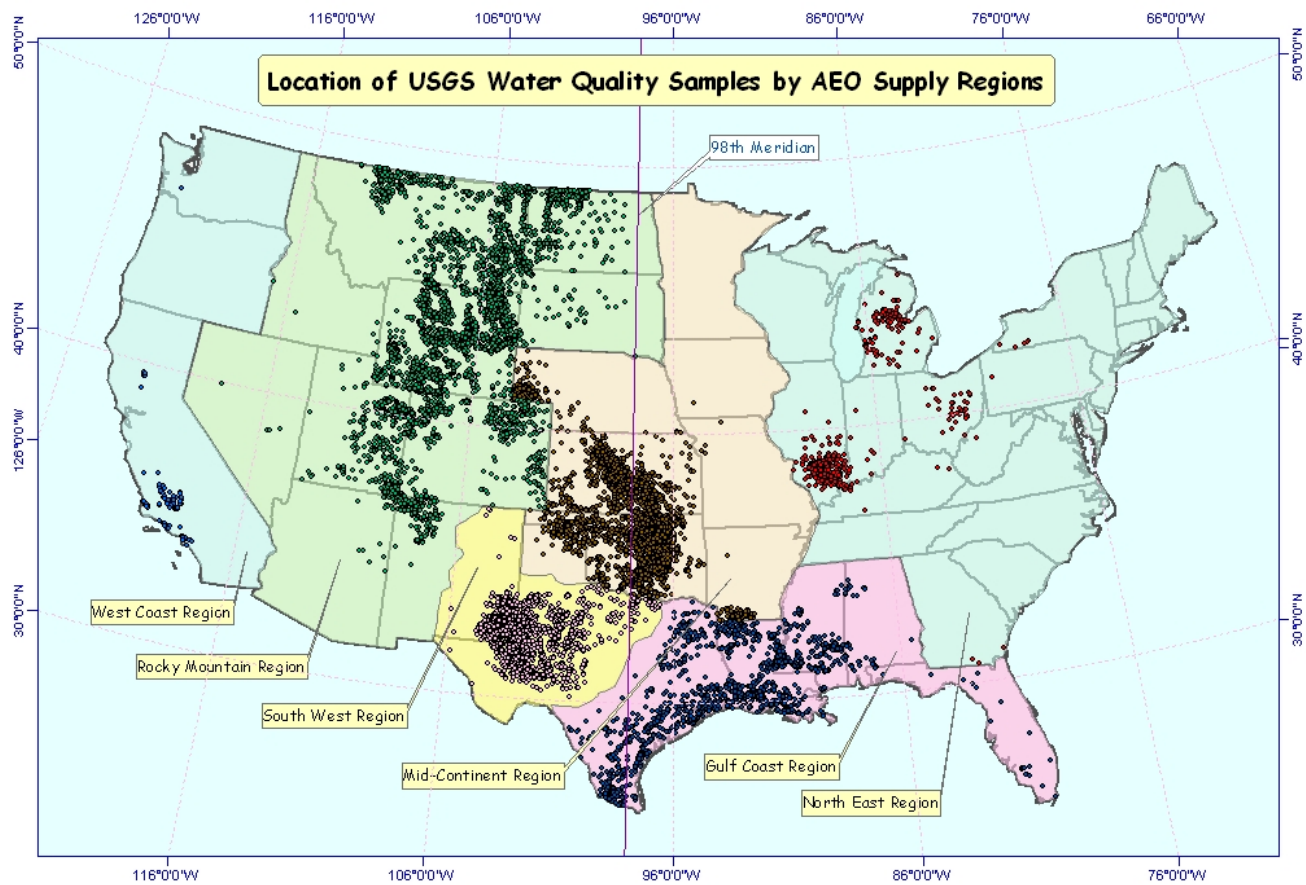


Figure 25 shows that the locations of the 58,706 samples in the database correspond to the major producing areas in the Rocky Mountains, Mid-Continent and Gulf Coast regions.

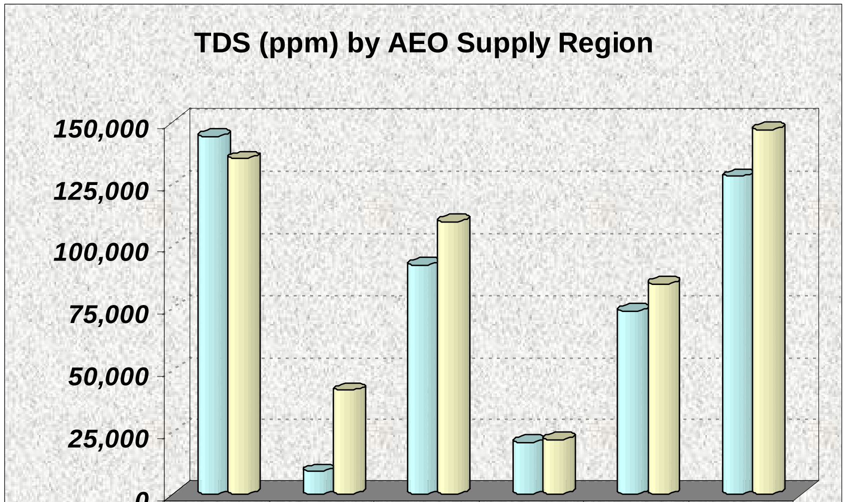
Figure 25: AEO-2004 Supply Regions and Water Quality Sample Locations



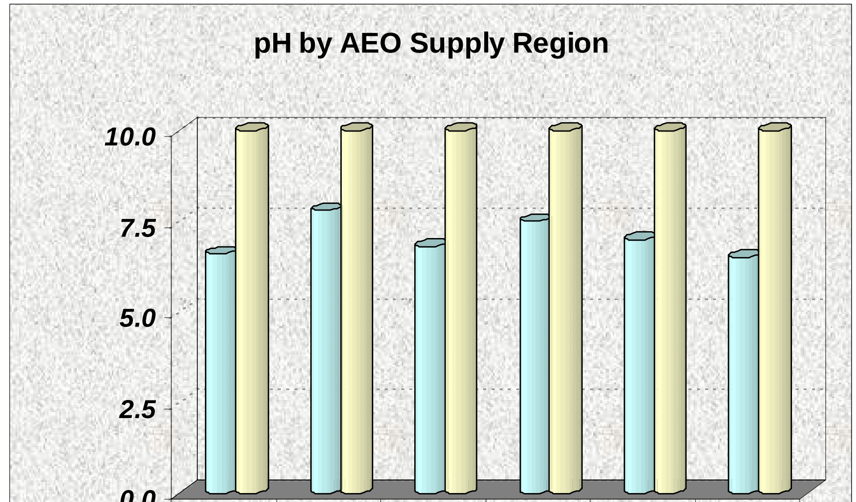
In Figure 26, the arithmetic mean and average values of TDS (total dissolved solids), pH (percent hydrogen concentration), Sodium, and Chloride water quality parameters is shown from these samples in the database by AEO-2004 Supply Regions.

Table 10 presents tabular statistical data for all of the water quality parameters in the database (pH, Bicarbonate, Calcium, Chloride, Magnesium, Potassium, Pot-Sodium, Sodium, Sulfate and TDS). These regional statistics could be used in the Phase II work, in the absence of any additional data, to determine volume weighted information on produced water cleanup cost estimates.

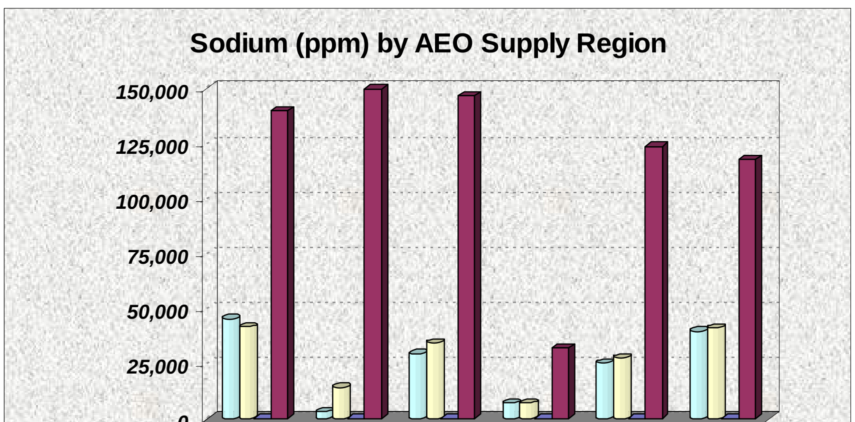
Figure 26: Comparison of Water Quality Parameters by AEO-2004 Supply Region



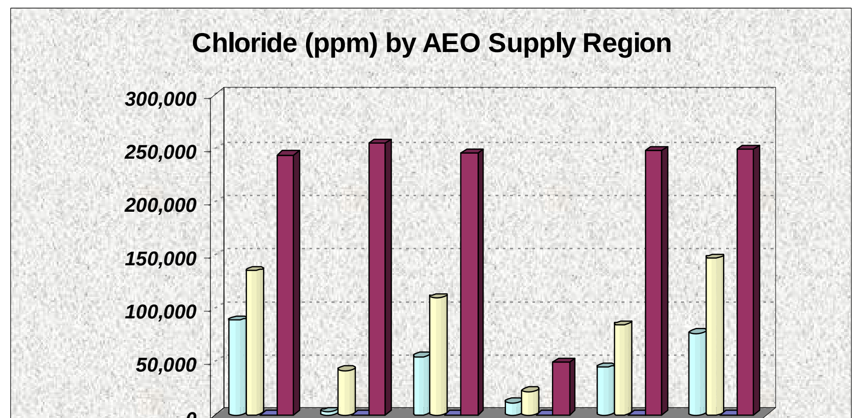
	MidCon	RockyMtn	SouthWest	WestCoast	GulfCoast	NorthEast
Median Value	144,216	9,247	92,288	21,108	73,832	128,236
Avg Value	135,364	41,922	110,020	22,010	84,658	147,148



	MidCon	RockyMtn	SouthWest	WestCoast	GulfCoast	NorthEast
Median Value	6.6	7.8	6.8	7.5	7.0	6.5
Avg Value	82,899	23,511	66,012	12,191	51,324	90,261



	MidCon	RockyMtn	SouthWest	WestCoast	GulfCoast	NorthEast
Median Value	45,404	3,104	29,703	7,148	25,400	39,663
Avg Value	41,710	14,186	34,468	7,155	27,617	41,289
Min Value	0	0	0	0	0	0
Max Value	140,041	149,836	146,770	32,000	123,775	118,000



	MidCon	RockyMtn	SouthWest	WestCoast	GulfCoast	NorthEast
Median Value	88,800	3,200	54,879	11,613	44,640	77,019
Avg Value	135,364	41,922	110,020	22,010	84,658	147,148
Min Value	11	0	0	114	99	175
Max Value	244,323	254,923	245,700	49,546	248,000	249,492

Table 10: Statistical Analysis of Key Water Quality Parameters

Total of All Regions (unit values are 84% mg/l and 16% ppm) (Values ≥ 0

	pH (>0)	BICARB	CALCIUM	CHLORIDE	MAGNESIUM	POTASSIUM	POT-SODIUM	SODIUM	SULFATE	TDS
count	40,937	56,926	58,530	58,692	58,223	9,023	6,183	52,518	55,757	58,667
maximum	9.0	14,750	74,185	254,923	46,656	14,840	151,000	149,836	15,000	399,943
minimum	5.0	0	0	0	0	0	0	0	0	0
average	7.1	676	4,892	53,648	1,037	453	31,553	27,516	1,191	89,327
median	7.2	342	1,920	36,256	443	79	26,920	19,333	439	61,718

West Coast Region (Values ≥ 0)

	pH (>0)	BICARB	CALCIUM	CHLORIDE	MAGNESIUM	POTASSIUM	POT_SODIUM	SODIUM	SULFATE	TDS
count	266	298	300	300	300	69	47	253	281	300
maximum	8.8	7,430	13,613	49,546	1,500	362	24,557	32,000	2,952	84,891
minimum	5.7	0	5	114	0	0	0	0	0	1,136
average	7.4	1,331	970	12,191	150	96	6,653	7,155	114	22,010
median	7.5	1,080	249	11,613	70	80	5,611	7,148	32	21,108

Rocky Mountain Region (Values ≥ 0)

	pH (>0)	BICARB	CALCIUM	CHLORIDE	MAGNESIUM	POTASSIUM	POT_SODIUM	SODIUM	SULFATE	TDS
count	15,875	17,270	17,187	17,320	16,904	5,849	401	16,928	16,582	17,323
maximum	9.0	14,750	65,582	254,923	25,772	11,000	109,698	149,836	15,000	399,943
minimum	5.0	0	0	0	0	0	0	0	0	0
average	7.6	1,196	1,613	23,511	317	368	6,767	14,186	1,760	41,922
median	7.8	805	273	3,200	62	45	1,714	3,104	1,050	9,247

Southwest Region (Values ≥ 0)

	pH (>0)	BICARB	CALCIUM	CHLORIDE	MAGNESIUM	POTASSIUM	POT_SODIUM	SODIUM	SULFATE	TDS
count	5,834	9,483	9,686	9,689	9,678	806	3,576	6,114	9,511	9,682
maximum	8.9	11,960	66,381	245,700	37,620	7,960	151,000	146,770	14,900	397,572
minimum	5.0	0	0	0	0	0	0	0	0	0
average	6.8	551	5,805	66,012	1,812	753	32,604	34,468	1,933	110,020
median	6.8	359	3,174	54,879	1,077	439	25,780	29,703	1,491	92,288

Mid-continent Region (Values ≥ 0)

	pH (>0)	BICARB	CALCIUM	CHLORIDE	MAGNESIUM	POTASSIUM	POT_SODIUM	SODIUM	SULFATE	TDS
count	4,609	12,990	13,920	13,931	13,909	758	1,174	12,577	12,815	13,916
maximum	8.9	11,606	73,832	244,323	21,937	14,840	103,407	140,041	14,482	395,306
minimum	5.0	0	0	11	0	0	0	0	0	0
average	6.6	260	8,595	82,899	1,736	670	34,402	41,710	744	135,364
median	6.6	107	7,940	88,800	1,748	215	33,460	45,404	315	144,216

Gulf Coast Region (Values ≥ 0)

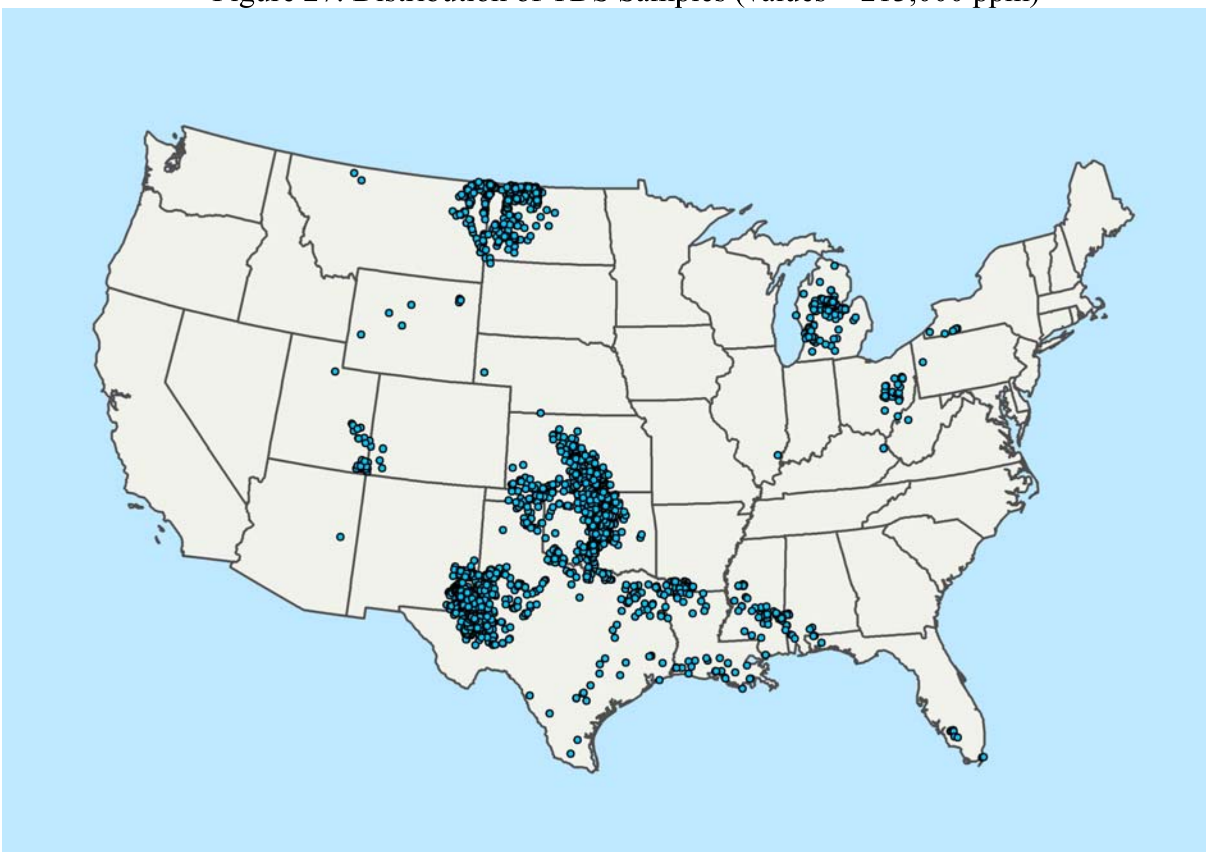
	pH (>0)	BICARB	CALCIUM	CHLORIDE	MAGNESIUM	POTASSIUM	POT_SODIUM	SODIUM	SULFATE	TDS
count	9,333	9,889	10,232	10,245	10,234	868	97	10,147	9,669	10,241
maximum	9.0	10,980	56,300	248,000	26,668	13,500	87,500	123,775	14,100	398,024
minimum	5.0	0	0	99	0	0	0	0	0	1,000
average	6.9	540	4,189	51,324	565	476	37,511	27,617	258	84,658
median	7.0	320	1,752	44,640	320	117	43,917	25,400	30	73,832

Northeast Region (Values ≥ 0)

	pH (>0)	BICARB	CALCIUM	CHLORIDE	MAGNESIUM	POTASSIUM	POT_SODIUM	SODIUM	SULFATE	TDS
count	424	1,189	1,232	1,232	1,230	79	75	1,157	1,176	1,232
maximum	8.5	2,995	74,185	249,492	15,963	5,500	95,230	118,000	13,407	398,470
minimum	5.0	0	5	175	0	0	0	0	0	1,874
average	6.5	193	11,450	90,261	1,468	1,301	38,547	41,289	846	147,148
median	6.5	115	5,037	77,019	0	1,200	40,479	39,663	485	128,236

The results of a GIS spatial query using ESRI®[41] ArcMap™ software are shown in Figure 27. This graphic shows the location of TDS values that exceed 213,000 ppm taken from the USGS database. This example is presented to demonstrate how powerful and versatile a tool GIS has become for displaying large amounts of complicated data. GIS will become more prevalent in this and many other fields as the need for tying data to geography becomes more common and recognized.

Figure 27: Distribution of TDS Samples (values > 213,000 ppm)



Oil Field Brine Analyses DB

The Oil Field Brine Analyses (OFBA) database contains information on 77,650 oil field water samples. The original dataset, from Dwights EnergyData, reportedly contains samples from 26 states, the District of Columbia and the Gulf Federal area. Dwights EnergyData and PI merged in 1995 and were then subsequently acquired by IHS Energy[42] in 1997. The original dataset is now available from IHS Energy. We possess two datasets (brinppm and brinmgl) that are subsets of the original. Brinppm contains 4,018 records and Brinmgl contains 11,744 records. Both datasets contain data from AZ, KS, NE and OK.

[41] ESRI – Environmental Systems Research Institute, Redlands, CA. (http://www.esri.com/)
[42] http://www.ihsenergy.com

The unique field sample count for the OFBA (77,650) and USGS (50,605 total, 42,681 unique samples) databases are different (as are some of the entries) but plotting the sample dates against each other shows remarkable similarities (Figure 28). It may very well be that these datasets had the same origin – but a detailed comparison has not been performed to determine that.

Figure 28: Distribution of USGS and OFBA Water Quality Sample Counts

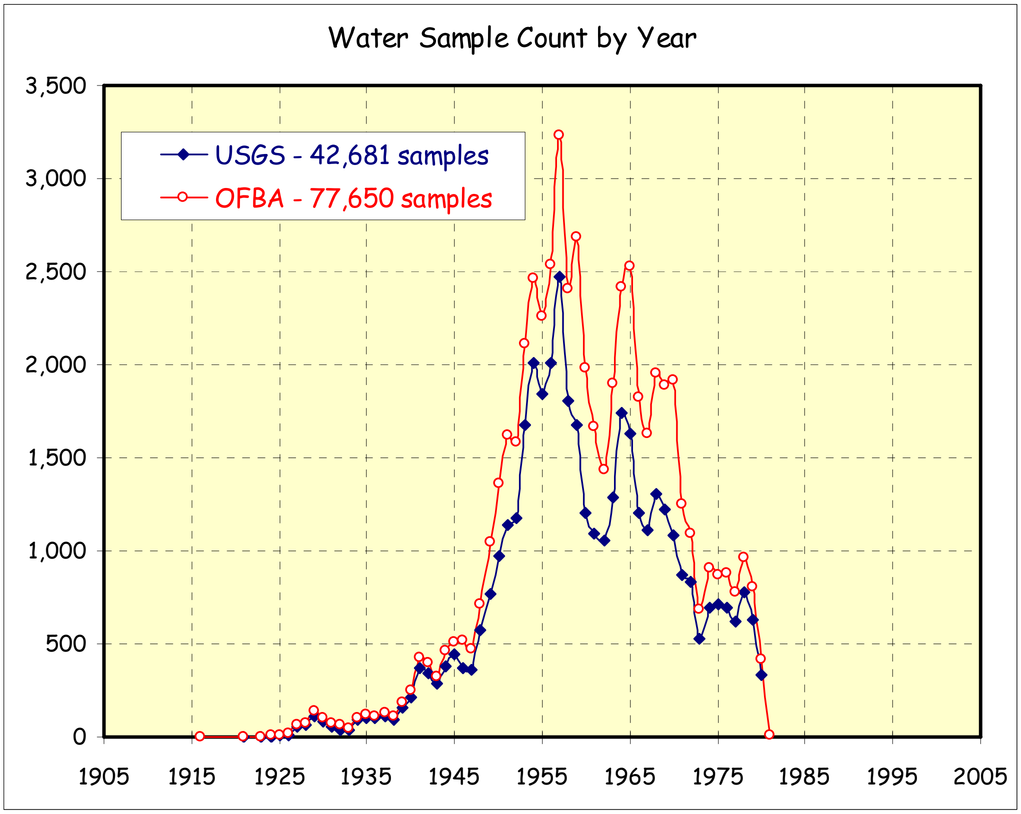


Table 11 is a list of the states and the number of unique field samples for the two databases.

Table 11: Distribution of USGS and OFBA Water Quality Sample Counts by State

State_Name	Unique Field Count	
	USGS	OFBA
Alabama	125	239
Alaska	51	131
Arizona	67	80
Arkansas	734	1,162
California	541	806
Colorado	1,813	2,851
Florida	66	110
Georgia	4	12
Idaho	1	21
Illinois	896	1,487
Indiana	45	293
Iowa	-	4
Kansas	4,065	5,537
Kentucky	67	364
Louisiana	4,101	6,519
Michigan	204	494
Mississippi	1,473	2,142
Missouri	-	10
Montana	1,953	3,177
Nebraska	456	649
Nevada	9	20
New Mexico	2,997	4,339
New York	5	14
North Dakota	1,090	1,586
Ohio	8	92
Oklahoma	7,676	9,497
Oregon	-	4
Pennsylvania	-	11
South Dakota	108	182
Texas	12,651	21,701
Utah	899	1,544
Virginia		1
Washington	3	6
West Virginia	1	7
Wyoming	8,496	12,558
	50,605	77,650

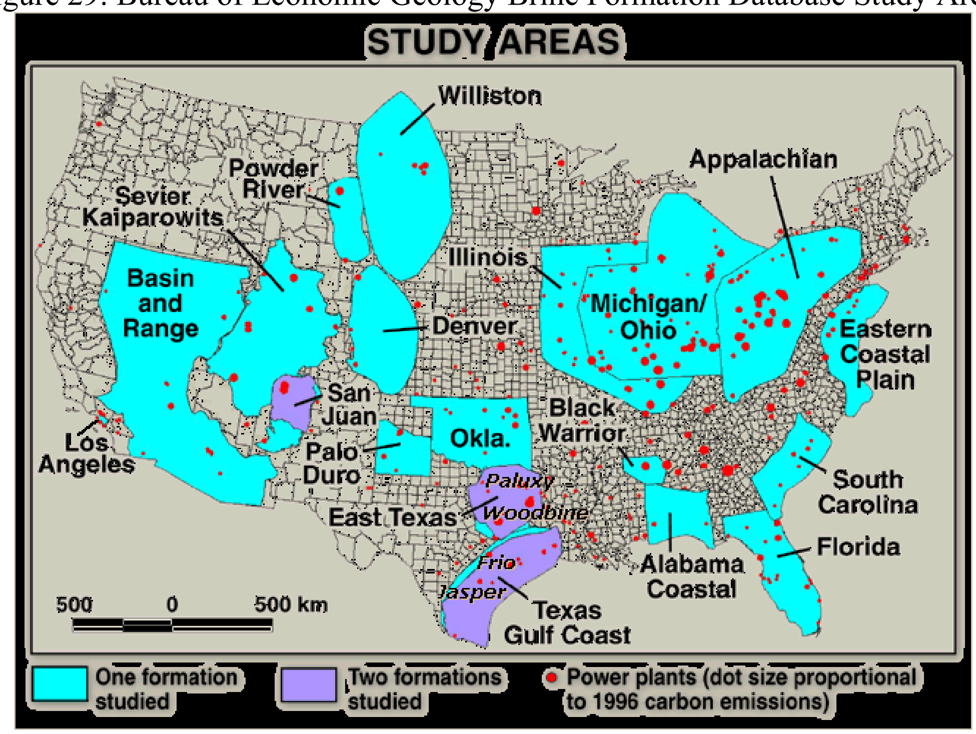
NETL Comprehensive Brine Database[43]

From the National Energy and Technology Laboratory (NETL) website: "*A comprehensive brine database that can be used for CO_2 sequestration studies has been prepared by researchers at the NETL. Sources for this extensive database include: a preliminary brine database tabulated by the Texas Bureau of Economic Geology under contract with DOE that consists of some two hundred and fifty tabulated wells; the extensive brine database tabulated by the U.S. Geological Survey that includes data on over 63,000 brines was provided to NETL for inclusion; and, an additional seven hundred plus well data sets provided by various State Geologic Surveys, oil and gas reports, and other published literature sources have been added to the database by NETL researchers.*"

Bureau of Economic Geology (BEG) Brine Formation Database[44]

The BEG Brine Formation Database contains information on 16 parameters in 19 basins (depth, permeability, formation and net sand thickness, % shale, continuity, top seal thickness, hydrocarbon production, fluid residence time, flow direction, formation temperature and pressure, water salinity, rock/water interaction, porosity, water chemistry and rock mineralogy). This database has not been compared to the USGS db but a cursory review indicates it does not appear to be redundant to the USGS db. The Study Area map shown in Figure 29 was taken from their website.

Figure 29: Bureau of Economic Geology Brine Formation Database Study Areas



43 http://www.netl.doe.gov/coalpower/sequestration/pubs/BrineCD.pdf
44 http://www.beg.utexas.edu/environqlty/co2seq/dispslsalnt01.htm

Water Treatment Techniques

Water treatment technologies are summarized on the first page of the Produced Water Bibliography in Section C and described in detail in the ALL Consulting Report[45] (reference 31 of the bibliography)[46] and the Boysen Report[47] (reference 56).

The following list summarizes most of the unique treatment types:

Ref #	Treatment Technology
2.	Softening, ion exchange, reverse osmosis (RO)
5.	Bioreactor, aerobic bio-filter
7.	RO
8.	Nano-filtration, RO
9.	Organic material removal
10.	Freeze-thaw
11.	Ionic
16.	SO_2 removal
17.	RO, Ion Exchange, Capacitive desalination
26.	RO
32.	Freeze-thaw
33.	RO
34.	UV Light
35.	Ion Exchange
36.	Capacitive De-Ionization Technology
37.	Electrodialysis Reversal
38.	Distillation
39.	Artificial Wetlands
50.	Rapid Spray Evaporation
58.	Bioreactor
62.	Ion sorption, nano-filtration, capacitive deionization
68.	Electrodialysis
78.	Bioreactor
79.	Bioreactor

Similarly, beneficial uses of produced water (with or without treatment) are summarized in Section C of this report and described in detail in references 49, 31, 18. Papers in the bibliography describing a specific application are annotated with the particular application employed.

The membrane processes reverse osmosis (RO), electrodialysis (ED) and nano-filtration (NF) are used in seawater desalination plants as are thermal process like multi-stage flash

[45] "Handbook on Coal Bed Methane Produced Water: Management and Beneficial Use Alternatives", July 2003, ALL Consulting.
[46] All references hereafter noted as "reference xx" will be found in Section C of this report.
[47] "Produced Water Management Handbook", Boysen, etal, B.C. Technologies, Ltd., GRI-03/0016.

evaporation (MSF), multiple effect evaporation (ME), and vapor compression (VC). The MSF and RO processes dominate the worldwide market for seawater and brackish water desalination, sharing about 88% of the total installed capacity.[48]

Water Treatment Costs Issues

There is a fair amount of cost information, both on the treatment technology and the beneficial use, in the literature but a wide variance. Generally speaking:

(1) If the water has to be transported to where it is to be used, or disposed in a well, the transportation cost overwhelms the application or disposal costs: $1–$3/bbl to transport, cents/bbl to dispose.

(2) Capital intensive treatment or disposal (an expensive plant or deep well) will tilt the costs to the high end of the spread.

(3) Low space velocity treatments are much more expensive than faster treatments, and

(4) The more that has to be removed and the greater number of separate stages, the more expensive treatment is. That said, in general if the water is disposed of on site, treatment and beneficial use is in the general range of cost of disposal.

To put some numerical value to these generalities, Veil, Boysen, and Hodgson have done an excellent job of summarizing the various costs associated with disposal, handling, and management efforts. Their data is presented in the next several tables.

Veil[49] (Table 12, reference 49) cites commercial injection costs from 9 states in 1997. The values range from $0.20/bbl to $4.50/bbl. With no treatment or transportation they are in the $0.40 - $0.50/bbl range.

---

[48] "Evaluating the Costs of Desalination and Water Transport", Yuan Zhoua, Richard S.J. Tol, December 9, 2004 (http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/DesalinationFNU41_revised.pdf)

[49] "A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane", John Veil, et al, Argonne National Laboratory, January 2004.

Table 12: Disposal Costs of Produced Water at Offsite Commercial Facilities

State	Number of Facilities Using This Process	Type of Disposal Process	Costs[a], $/bbl
CA	1	Evaporation/injection	0.01-0.09
KY	1	Injection	1.00
LA	23	Injection	0.20-4.50
NM	4	Evaporation	0.25-0.81
NM	1	Evaporation/injection	0.69
NM	1	Injection	0.69
OK	1	Injection	0.30
PA	3	Treat/discharge	1.00-2.10
PA	1	Treat/POTW	1.25-1.80
PA	1	POTW/road spread	1.30-4.20
PA	2	POTW	0.65-1.50
TX	9	Injection	0.23-4.50
UT	5	Evaporation	0.50-0.75
WY	10	Evaporation	0.50- 2.50
WY	1	Treat/injection or discharge	0.96
WY	3	Injection	0.60-8.00

[a] Costs are those reported by disposal company operators in 1997.

Boysen[50] (Table 13, reference 56) reports similar disposal costs in six producing basins in the Mid-Continent Region and also specifically for the Rocky Mountain Region (Table 14).

[50] "Produced Water Management Handbook", Boysen, etal, B.C. Technologies, Ltd., GRI-03/0016.

Table 13: Produced Water Handling & Total Disposal Costs: Mid-Continent Region

State and Basin	Water Handling Method Reported	Water Handling Charges Reported, $/bbl	Total Handling & Disposal Costs, $/bbl
Illinois			
Illinois Basin	Almost all interview respondents reported utilizing water gathering systems; a few reported utilizing commercial water hauling services	0.50 - 1.50	0.10 - 1.25
Kansas			
Anadarko Basin	Almost all interview respondents reported utilizing water gathering systems; a few reported utilizing commercial water hauling services	0.25	0.075 - 1.30
Louisiana			
Gulf Coast Region	Most interview respondents reported utilizing pipeline systems; a few reported utilizing commercial water hauling services.	Not Provided	0.05 - 8.00
Arkla Basin	Most interview respondents reported utilizing pipeline systems.	Not Provided	0.25
Michigan			
Antrim Shale Formation	Almost all interview respondents reported utilizing water gathering systems; a few reported utilizing company owned water hauling trucks	1.00 - 1.50	0.10 - 1.70
Oklahoma			
Anadarko Basin	Almost all reported utilizing commercial water hauling services; some reported using water gathering systems	0.25	0.05 - 2.25

Table 14: Produced Water Handling & Total Disposal Costs: Rocky Mountain Region

State and Basin	Water Handling Method Reported	Water Handling Charges Reported	Total Handling & Disposal Costs, $/bbl
Colorado			
Denver Basin	Commercial trucking or water gathering system		1.00 - 1.75
Las Animas Arch	Combined use of commercial trucking & water gathering system	$.40 - $.65/bbl or $55/hour	0.50 - 1.50
Paradox Basin	Water gathering system		1.33
Piceance Basin	Combined use of commercial trucking and water gathering system		0.05 - 0.25
Sand Wash Basin	Commercial trucking or water gathering system		1.75
San Juan Basin	Water gathering system, occasionally commercial water		0.30 - 1.50
Montana			
Central MT Uplift	Commercial trucking or water gathering system		0.05 - 2.00
Sweetgrass Arch	Water gathering system		0.05 - 0.06
New Mexico			
San Juan Basin	Water hauling truck and water gathering system	$.70 -- $3.20/bbl	0.50 - 4.20
Utah			
Uinta Basin	Commercial trucking or water gathering system		0.05 - 1.00
Wyoming			
Greater Green River Basin	Generally commercial water hauling service; some pipeline systems	$.80 - $1.00/bbl; $80/hour	0.50 - 5.05
Powder River Basin	Almost all respondents reported utilizing a water gathering and distribution system		0.01 - 0.80

Veil[51] (Table 15, reference 49) cites costs for 13 different water management costs. Excluding the $1.00-$5.50 water hauling, the costs range from $0.01-$0.80 for surface discharge, $0.02-$0.64/bbl for electrodialysis and $2.65-$5.00/bbl for freeze-thaw.

Table 15: Produced Water Management Costs

Management Option	Estimated Cost ($/bbl)
Surface discharge	0.01-0.80
Secondary recovery	0.05-1.25
Shallow reinjection	0.10-1.33
Evaporation pits	0.01-0.80
Commercial water hauling	1.00-5.50
Disposal wells	0.05-2.65
Freeze-thaw evaporation	2.65-5.00
Evaporation pits and flowlines	1.00-1.75
Constructed wetlands	0.001-2.00
Electrodialysis	0.02-0.64
Induced air flotation for deoiling	0.05
Anoxic/aerobic granular activated carbon	0.083
Source: Jackson and Myers[52,53] (2002, 2003).	

Hodgson[54] (Table 16, reference 18) of Marathon analyzed 19 separate treatment techniques for their production in the Powder River Basin looking at the "all in" cost with amortized capital and operating expenses. On the high side was freeze-thaw evaporation at 29.5 cents/bbl, Reverse Osmosis plus evaporator and crystallizer at 20.9 cents/bbl and Reverse Osmosis plus evaporator and disposal of the permeate at 18.3 cents/bbl. On the low side was the creation of an artificial wetland at 1.6 cents/bbl and Ion Exchange plus reverse osmosis at 4.3 cents/bbl. These compare with disposal in a shallow disposal well at 2.6 cents/bbl.

[51] "A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane", John Veil, et al, Argonne National Laboratory, January 2004.
[52] "Alternative Use of Produced Water in Aquaculture and Hydroponic systems at Naval Petroleum Reserve No. 3," Jackson and Myers, 2002 Ground Water Protection Council Produced Water Conference, Colorado Springs, CO, Oct. 16-17.
[53] "Design and Construction of Pilot Wetlands for Produced-Water Treatment", Jackson and Myers, SPE 84587, 2003.
[54] "CBM Produced Water Treatment Options", Brian A. Hodgson, GWPC Produced Water Conference, Oct 16, 2002.

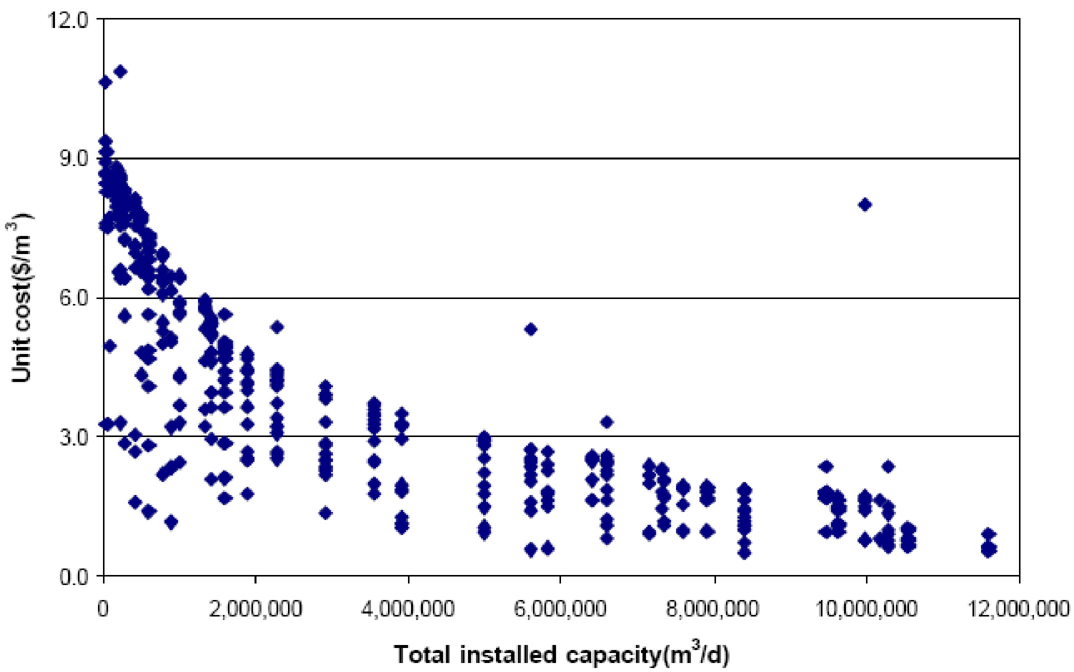
Table 16: Powder River Basin Water Treatment Cost Summary

Case	Facilities Description	Capacity BWPD	Treatment Percent Recovery	Investment $M	Investment $/bwpd	Amortized Investment 10yr/10% $M/yr	Investment cents/bbl	Estimated Operating Costs, $M/year	Estimated Operating Costs, cents/bbl	Estimated Total cost, cents/bbl
1	Shallow Water Disposal Well			200	28.57	32	1.3	35	1.4	2.6
2	Five Water Disposal Wells	35,000		1,000	28.57	160	1.3	175	1.4	2.6
3	Reverse Osmosis Purchase	35,000	80	2,500	71.43	400	3.1	550	4.3	7.4
4	RO Purchase+ WDW	35,000	80	2,700	77.14	432	3.4	585	4.6	8.0
5	RO Lease (10 yr.) + WDW	35,000	80	200	5.71	32	0.3	1000	7.8	8.1
6	RO + Evaporator + WDW	35,000	98	7,520	214.86	1195	9.4	1140	8.9	18.3
7	R0 + Evaporator + Crystallizer	35,000	100	8,500	242.86	1350	10.6	1320	10.3	20.9
8	Electrodialysis Reversal	35,000	87.5	1,800	51.43	285	2.2	430	3.4	5.6
9	EDR + RO on reject	35,000	94	2,000	57.14	320	2.5	465	3.6	6.1
10	EDR + RO + WDW	35,000	94	2,120	60.57	335	2.6	490	3.8	6.5
11	Ion Exchange/RO + WDW	35,000	95	1,300	37.14	210	1.6	335	2.6	4.3
12	Freeze Thaw Evaporation	35,000	100	10,175	290.71	1600	12.5	2165	16.9	29.5
13	Artificial Wetland	35,000	100	1,000	28.57	160	1.3	50	0.4	1.6
14	Land-based Wastewater Treatment	35,000	67	600	17.14	560	4.4	200	1.6	5.9
15	EWP Carbon Fiber	35,000	95	4,060	116.00	645	5.0	390	3.1	8.1
16	EWP Carbon Fiber+WDW	35,000	95	4,110	117.43	653	5.1	403	3.2	8.2
17	Advanced EWP + WDW	35,000	95	2,480	70.86	393	3.1	272	2.1	5.2
18	CDT Aerogel + WDW	35,000	95	2,430	68.00	383	3.0	355	2.8	5.8
19	Rapid Spray Evaporation	35,000	95	7,500	214.29	1190	9.3	740	5.8	15.1

Estimated operating costs for a Powder River Basin
Labor: 1man-year@$100,000
Electricity estimated at $0.05/kWh
Chemicals and other consumables
Maintenance@5% of initial capital expense/year

Annual cost of amortized investment over 10 years at
No disposal costs included for solid waste in Case 7
No costs included for water handling outside of irrigation season in Case 14

The thermal process multistage flash evaporation process (MSF) utilized in seawater desalination doesn't seem to be very popular in the United States when it comes to produced water treatment and probably because the economics (in the 1960's and 1970's) required very large singular sources like the ocean and close proximity to the water source. But, unit costs for desalination processes have come down considerably from the 1960's. The following graph shows unit costs for MSF plants from 1960 to present for total installed cumulative capacity.[55] One cubic meter is approximately 6.3 bbls.



The 9 $/m^3 to ~1 $/m^3 unit costs equate to 1.43 $/bbl to 0.16 $/bbl, respectively. This reduction certainly would seem to make MSF processes competitive today.

Similar analyses for desalination RO processes, which are employed in the U.S., performed by Zhoua and Tol show that average unit costs have declined from 5 $/m^3 (0.79 $/bbl) in 1970 to less than 1 $/m^3 (0.16 $/bbl) today. Costs for desalting brackish, river, and pure-water has been reduced to less than 0.6 $/m^3 (0.095 $/bbl).

"*By the end of this year (2004), the city of Long Beach, Calif., expects to begin operating the largest federally funded water desalination plant in the United States, says the U.S. Bureau of Reclamation, which is helping fund the project's construction. Like most of the growing number of desalination projects around the world, Long Beach is creating drinking water from seawater using reverse osmosis membranes. This technology's rising popularity is mainly attributable to technical improvements that have improved its reliability and cost, and the Long Beach plant will demonstrate a new approach that*

---

[55] "Evaluating the Costs of Desalination and Water Transport", Yuan Zhoua, and Richard S.J. Tol

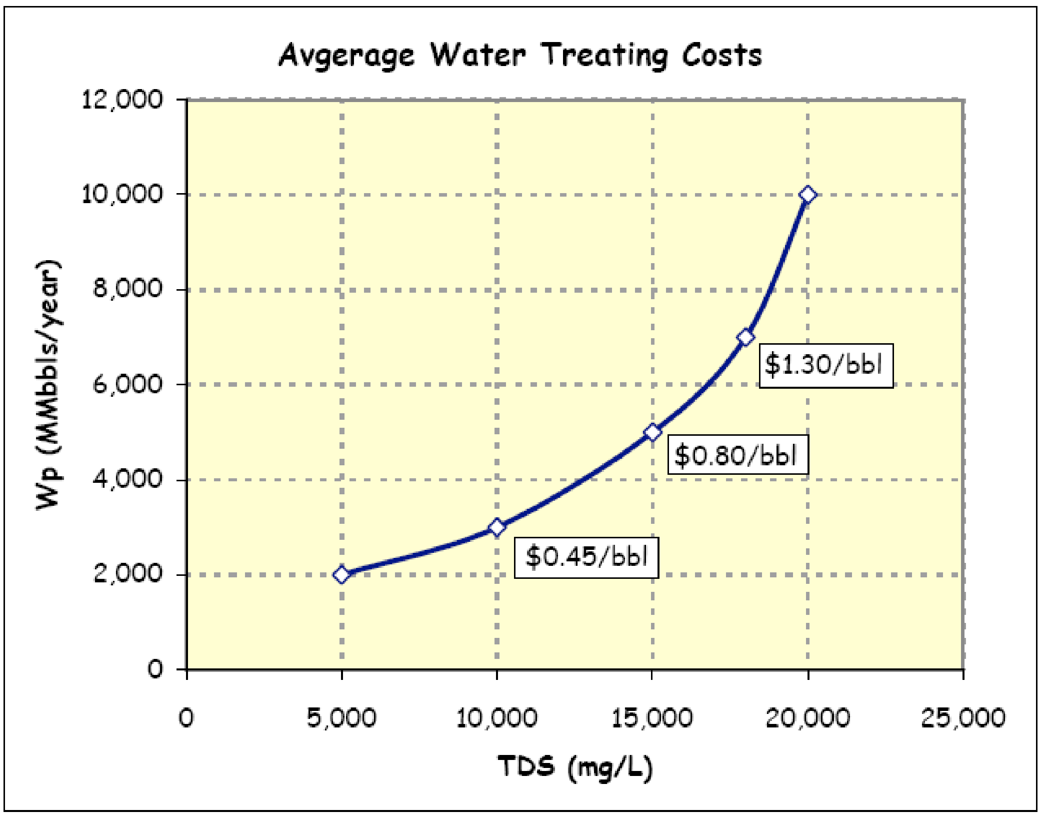
promises to advance the technology even further…Operating a desalination plant in the United States can involve 20 or more permits and agencies, and the permitting process can take 2–4 years…"[56]

It should be noted that desalination water is used for all purposes (industrial, drinking, municipal, and tourism) and not just for drinking water, so the level of treatment relative to the quality of the water being treated will greatly impact ultimate treating costs.

One very different aspect of the desalination plants is that unlike produced water transportation costs, where water is primarily moved by truck, desalination transportation costs are small (neglecting capital costs) relative to the desalination process because the water is moved by pipeline. Zhoua and Tol estimate that water would have to be pumped/transported almost 1600 km (994 miles) before the transportation and treating costs are equal.

A very useful correlation to summarize all of this type of data would be to construct a graph showing a general relationship between Wp, TDS and $/bbl operating costs such as the hypothetical example in the following graph, Figure 30:

Figure 30: Hypothetical Representation of Average Water Treating Costs



[56] "Desalination, Desalination Everywhere", Environmental Science & Technology Online, May 2004
http://pubs.acs.org/subscribe/journals/esthag-w/2004/may/tech/kb_desalination.html

Each successive point on the graph, with poorer influent water quality, would reflect an (assumed) increasing treating cost in $/bbl for a constant minimum effluent TDS. It is unknown whether there is sufficient data available to establish such a relationship - but this information would probably be helpful to planners for estimating volumes of water impacted at various cost levels, economies or water quality. A contract has been let to West Virginia University (Spring 2005) to undertake a search for the data that may make construction of this graph possible.

Salt water concentration definitions vary but here is a general list. The general term for all water over 1,000 ppm (mg/L) total dissolved solids.[57]

* Fresh Water: <1,000 TDS
* Brackish: 1,000-5,000 TDS
* Highly Brackish: 5,000-15,000 TDS
* Saline: 15,000-30,000 TDS
* Sea Water: 30,000-40,000 TDS
* Brine: 40,000-300,000+ TDS

Potential for Beneficial Use

At a minimum, the bulk of the CBM water produced in the basins Black Warrior, Raton, San Juan, and Powder River is available for beneficial use at a cost competitive with disposal. Excluding transportation charges, most relatively low saline (7,000 ppm or less) produced water can be processed to near potable quality for 20-40 cents/bbl. (reference 2).

Implications for CO_2 Sequestration

In a recently completed project, Reeves (reference 80) at ARI created a numerical simulator for predicting the performance of deep unmineable coal seams undergoing injection of Nitrogen and CO_2. In a case where it was forecast that 250 mcf/day of CO_2 injection began after 60 months of methane and produced water production, the methane production nearly more than doubled within 30 months and the produced water initially increased, then declined at a slower rate than before the CO_2 injection, ultimately producing 25% more at the end of the project. To the degree the incremental water is relatively fresh there is the potential for incremental beneficial use from the wells.

[57] http://www.tcn.zaq.ne.jp/membrane/english/DesalE.htm

C-Bibliography of current or recent research

Research Areas

Research Categories		
Treatment Technologies		
	Freeze-Thaw/Evaporation	
	Reverse Osmosis & other membrane technology	
	Rapid Spray Evaporation	
	Ion Exchange	
	Capacitive Deionization	
	Electrodialysis Reversal (EDR)	
	Distillation	
	Artificial Wetlands	
	Settling Ponds	
Beneficial Uses (with or without treatment)		
	Impoundments	
		Wildlife and Livestock water
		Fish farm
		Recharge Aquifer ponds
		Recreation
		Evaporation Ponds
	Agriculture	
		Stock Watering (non-impoundment)
		Irrigation
	Industrial Use	
		Coal Mine use
		Feedlots
		Cooling tower - power plants
		Improved oil recovery
		Carwash
		Road treatment - dust, ice
Regulatory Issues		
Data and Modeling		

Produced Water Bibliography

This following Bibliography is the result of a comprehensive search of both the private sector and government sponsored research.

	The following are from the October, 2002 Ground Water Protection Council Produced Water Meeting	http://www.gwpc.org/Meetings/PW2002/Papers-Abstracts.htm			
	Title	**Author**	**Participants**	**Research Area**	**Comments**
1	Overview of Coal Bed Methane Development and Associated Environmental Issues of Concern	J. Daniel Arthur	ALL Consulting	Regulatory	Overview presentation, only the abstract is available
2	Evaluation of Technical and Economic Feasibility of Treating Oilfield Produced Water to Create a "New" Water Resource	Roger Funston, Rahigioakab Ganesh, Lawrence Y.C. Yeong	Kennedy/Jenks Consultants, Arco, et al	Treatment: softening, ion exchange, reverse osmosis	Pilot project complete in 2002, estimated cost to bring relatively low saline produced water from black oil reservoir to drinking quality estimated at $0.41/bb.
3	A National Produced Water Geochemistry Database	James K. Otton, George N. Briet, Yousif K. Kharaka nd Cynthia A. Rice	U.S. Geological Survey	Database and Modeling	Documentation of existing geochemistry database begun in Bartlesville
4	Characterization and Modeling of Produced Water	Joanna McFarlane, Debra T. Bostick, Huimin Luo	University of Tennessee, Oak Ridge National Lab, Petroleum Energy Research Forum , DOE DE-AC05-00OR22725	Database and Modeling	Complete in 2002, goal was to provide data for a predictive model for water-soluble organic content in produced GOM water
5	Hybrid Bioreactors - Cost Saving Processes for Decontamination of Water and Air	Jeffrey L. Boles, Johnny R. Gamble	TVA	Treatment: Bioreactor, aerobic biofilter	Complete in 2002, technology to remove VOCs and other pollutants from air and water
6	Stochastic and Well Optimization Modeling to Evaluate Injection Potential of a California Oilfield	J. A. Anderson, R.C. Fontaine, W.A. Hunter, D.H. Tubbs	Geomega Inc., ChevronTexaco	Database and Modeling	Model created to predict injectivity
7	Strategies for Produced Water Handling in New Mexico	Robert Lee, Rand Seright, Mike Hightower, Allan Sattler, Marth cather, Brian McPherson, Lori Wrotenbery, David Martin, Mike Whitworth	NM Tech (PRRC), Sandia National Lab, Martin & Assoc., NM Oil Conservation Div., U of Missouri, Rollo	(1) Downhole technology, (2) Database and Modeling, (3) Treatment, (4) Treatment - Membrane RO	Documents four different ongoing DOE projects listed individually elsewhere

8	Overview of Texas A & M's Program for the Beneficial Use of Oil Field Produced Water	David Burnett, William Fox, Gene L. Theodori	Texas A&M, DOE	Treatment - nanofiltration, RO	Ongoing DOE project. Black oil, high salinity, 25% brought to ag quality for $1.60/bbl fresh water
9	Organic Species in Produced Water: Nature, Distribution and Implications to Water Reuse	Yousif K. Kharaka	U.S. Geological Survey	Treatment - organic	See Paper on Placerita above
10	The Freeze-Thaw/Evaporation Process for the Commercial Treatment and Beneficial Use of Oil and Gas Produced Water	John Boyson, Deidre Boyson, Timothy Larson	BC Technologies, GTI, DOE	Treatment - freeze/thaw	Abstract for presentation of results from a 1992 DOE/GTI project
11	Purification of Brackish Waste Water Using Electronic Water Purification	Robert Atlas	Sabrex of Texas	Treatment - Ion (Electronic Water Purifier)	Ongoing research - claims to purify CBM water for 6 cents/bbl versus 30 cents for RO.
12	Alternative Use of Produced Water in Aquaculture and Hydroponic Systems at Naval Petroleum Reserve No. 3	Lorri Jackson, Jim Myers	DOE RMOTC, ChevronTexaco	Use-Impoundment-Aquaculture	Pilot uses CBM produced water for fish and vegetables, further studies planned.
13	Produced Water: An Oasis for Arid & Semi-Arid Rangeland Restoration	William E. Fox, David Burnett	Texas A&M, DOE	Use-Agriculture-Irrigation	Project just begun to study the cost of using treated water for rangeland restoration
14	Water Quality Monitoring at the Kern River Field	Dale F. Brost	ChevronTexaco	Use-Agriculture-Irrigation Treatment - Flotation, filter	Separates oil from essentially fresh water 800,000 B/D
15	Capacitive Deionization Technology: A Cost Effective Solution for Brackish Ground Water Remediation	Tobie Welgemoed	Lee & Ro, Inc. (also see http://www.cdtwater.com)	Treatment - Capacitive Deionization Technology	New, possibly breakthrough technology that uses less energy than RO and EDR. Seeking commercial applications.
16	Beneficial Use of Produced Water Project - Indian Basin Field	Paul Peacock	Marathon	Treatment-H2S removal Application - Drilling operations	Ongoing application of modest volumes
17	Comparative Analysis of Water Quality Impacts to the Tongue River, Rowder River Basin	Brian Bohm, Tom Richmond	ALL Consulting, Montana Bureau of Oil and Gas Conservation	Database and Modeling	Study potential impacts of CBM discharge in the PRB
18	CBM Produced Water Treatment Options	Brian A. Hodgson	Marathon	Treatment-RO, Ion exchange, Capacitive desalination Applications - Impoundment-	Compares effectiveness and cost of a variety of treatment and application options

				artificial wetland, agriculture-irrigation	
19	Preparation of Water Management Plans for the Development of Coal Bed Methane in the Powder River Basin	Jon Seekins, J. Daniel Arthur, Tom Richmond	ALL Consulting, Montana Board of Oil and Gas Conservation	Regulatory	How to put together a produced water management plan in Montana and Wyoming
20	Water Rights and Beneficial Use of Produced Water in Colorado	Dick Wolfe, Glenn Graham	Colorado Division of Water Resources	Regulatory	How to put together a produced water management plan in Colorado
21	Demonstrated Economics of Managed Irrigation for CBM Produced Water	R. Jonathan Paet, Steel Maloney	Cascade Earth Sciences	Applications-Agriculture - Irrigation	Completed pilot on 100 acres, cost to build system and amend water is 6 to 11 cents/bbl
22	Strategic Produced Water Management and Disposal Economics in the Rocky Mountain Region	Deidre B. Boysen, John E. Boyson, Jessica A. Boysen	BC Technologies, GTI	Database and Modeling	Survey of 250 producers in the Rockies of water management practices and costs
23	Using a Three-tiered Approach for Managing the Environmental Risk of CBM Operations: Risk Analysis, Environmental Management, and Quality Assurance	Anthony Gorody	Anthony Gorody, BP, COGCC	Regulatory	Documents study of contamination of well water by CBM operations
24	Fruitland Coal Bed Methane Seepage Modeling Study and Fruitland Coal Aquifer Recharge	Dave O. Cox, Paul R. Onsager, and Russell C. Schucker	Questa Engineering Corporation	Database and Modeling	Reservoir simulation of San Juan CBM production and aquifer level
25	Management of Produced Water from Coal Bed Methane Wells: Discharge, Inject, or Reuse	John Veil	Argonne National Laboratory	Regulatory	National Discharge Regulations
26	Reuse of Produced Water Using Nanofiltration and Ultra-low Pressure Reverse Osmosis to Meet Future Water Needs	Christopher Bellona, Jorg E. Drewes	Colorado School of Mines	Applications-Treatment-Reverse Osmosis	Promising lab testing of tight nanofilters and low pressure RO membranes can reduce TDS to secondary drinking water level
27	Updated Information on Analysis of Water Management Alternatives and Beneficial Uses of Coal Bed Methane Produced Water	J. Daniel Arthur, Matt Janowiak	ALL Consulting, DOE, Ground Water Protection Consortium, BLM	Database and Modeling	Ongoing research to evaluate technical and regulatory feasibility of all beneficial uses

28	Utilization of Water Produced from Coal Bed Methane Operations at the North Antelope Rochelle Complex Campbell County, Wyoming	Philip A. Murphree	Powder River Coal Company	Applications-Impoundments Wildlife water Applications-Industrial Coal Mine dust	Ongoing application
29	Developing Sustainable Practices for CBM Produced Water Irrigation	Aaron J. DeJoia	Cascade Earth Sciences, Williams	Applications-Irrigation	95 Acre, 2 year pilot evaluating soil amendment. No economics
30	Using Geospatial Techniques to Develop Best Management Practices and Produced Water Beneficial Use Options Relative to the Development of Coal Bed Methane	Jason Patton, Jim Halvorson, J. Daniel Arthur	ALL Consulting, Montana Board of Oil & Gas Conservation	Database and Modeling	GIS technologies for addressing environmental concerns
31	Handbook on Coal Bed Methane Produced Water: Management and Beneficial Use Alternatives	www.all-llc.com/CBM/BU/index.htm	ALL Consulting, DOE, BLM, GWPRF	Database and Modeling	A comprehensive handbook of all aspects of CMB produced water
	The following are cited in the above Handbook (ref 31) on CBM Produced Water	A partial listing of an exhaustive Bibliography			
32	Evaluation of the Natural Freeze-Thaw Process for the Desalination of Groundwater from the Dakota Aquifer to Provide Water for Grand Forks, North Dakota	John Harju	Amoco, GTI	Treatment-Freeze-Thaw/Evaporation	2002 - 80% of 12,800 mg/l TDS made potable for 24 cents/bbl, 32 cents/bbl to dispose of remainder
33	What is Reverse Osmosis?	www.gewater.com/index.jsp	GE Osmotics	Treatment-Reverse Osmosis	Removes most dissolved solids from 50 to 90%. Remaining concentrate must be disposed. If cheap disposal, cost 8 - 10 cents/bbl
34	UV Lights for Water Treatment	www.mpshu.on.ca/	Muskoka-Parry South Health Unit	Treatment-UV Light	Process to sterilize water before reinjecting
35	Ion Exchange	www.gewater.com/index.jsp	GE Osmotics	Treatment-Ion Exchange	Removes hardness, works well with RO Marathon estimates combined cost at 4.3 cents/bbl
36	Capacitive Deionization for Elimination of Wastes	Lawrence Livermore National Laboratory	Lawrence Livermore, DOE (See also http://www.cdtwater.com)	Treatment-Capacitive Deionization technology	New technology, high capital, low operating cost. Marathon estimates costs at 5 - 10 cents/bbl
37	Electrodialysis Reversal (EDR)	www.serve.com/damien/solarweb/	University of Pennsylvania	Treatment-Electrodialysis	GTI tests indicate costs from 27 to 40 cents/bbl

				Reversal EDR	
38	Clean Water Series - Treatment Systems for Household Water Supplies: Distillation	Russel Derickson, Fred Bergrud, Bruce Seelig	U of Minnesota, Dept. of Agriculture	Treatment-Distillation	Does not remove solvents with similar boiling point. Supposedly cheaper than RO (1992)
39	Reed Beds and Constructed Wetlands for Wastewater Treatment	P.F. Cooper, M.B. Green, R.B.E. Shutes	Water Research Centre Publications, 1996	Treatment-Artificial Wetlands	1 to 2 cents/bbl, but very slow. Doesn't improve SAR
40	Surface Mine Impoundments as Wildlife and Fish Habitat	Mark Rumble	U.S. Dept. of Agriculture Forest Service	Use-Impoundments-wildlife and livestock water	With or without treatment depending on geochemistry
41	Fish Ponds-Construction and Management. A manual of Wildlife Conservation	M.D. Marriage, V.E. Davison	The Wildlife Society	Use-Impoundments-Fish ponds	1971
42	Efficiency of a Storm water Detention Pond in Reducing Loads of Chemical and Physical Constituents in Urban Stream Flow	I.H. Cantrowitz, W,M. Woodham	U.S. Geological Survey	Use-Impoundments-Aquifer recharge	1995
	SWPTTC 2004 Produced Water Forum	http://octane.nmt.edu/sw-pttc/ProducedWater04Proc/ProceedingsPW.asp	The Presentations below can be accessed on the website to the left		
43	San Juan Generating Station - a ZeroNet Perspective	PNM Resources	PNM, Arizona Public Service Co., Navajo Nation, Jicarilla Apache Nation	Treatment-Reverse Osmosis Use-Industrial-Cooling tower (power plant)	Under construction, will process 50,000 B/D
44	Managing Coal Bed Methane Produced Water for Beneficial Uses	Mike Hightower, Allan Sattler, Mark Phillips, Brian Brister, Rick Arnold, Martha Cather, Brian McPherson	Sandia National Lab, NM Bureau of Geology and Minera Resources, NM Sate Univ. Agricultural Exp. Station, NMPRRC, DOE	Data (Water), Treatment-ion sorption, nano-filtration, capacitive deionization Application-Agriculture-irrigation, livestock	Starting 2nd year of 3 year project
45	Produced Water Pilot Project	Yates Petroleum Corporation	Yates Petroleum	Treatment-Process unknown	Completed in 2002,. Previously injecting 100,000 b/d, limited success at treating
46	New Mexico Coalbed Methane Produced Water Issues	William C. Olson	New Mexico Oil Conservation Division	Regulatory	Discussion of new regulations on NM Produced Water, possible uses and rules for pits

47	Ventures to Make Non-traditional (Brackish) Water Sources Available for Beneficial Reuse in New Mexico	Allan R. Sattler, Michael M. Hightower, David J. Borns	Sandia National Lab, U.S. Dept. of Interior Bureau of Reclamation	Data and Modeling	Proposal for Tularosa Basin National desalination research facility and documenting GE Osmonics RO membrane technology
48	Assessment of Water Resources in Dewey Lake and Santa Rosa Formations, Lea County, New Mexico	Allan Sattler, Jerry Fant	Sandia National Lab, BLM	Data and Modeling	A proposal to hire a consultant to determine if a deeper horizon than current thought has fresh water
	Other Papers - various sources				
49	A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane	John A. Veil, Markus G. Puder, Deborah Elcock, Robert J. Redweik, Jr.	Sandia National Laboratory, DOE	Data and Modeling	A comprehensive paper on produced water and its constituents, volumes, regulatory aspects, disposal and use options and costs (January, 2004) with references
50	The Aquasonics Technology http://www.aquasonics.com/tech.html	Aquasonic International	Aquasonic International	Treatment-Rapid Spray Evaporation	New technology, requires waste heat from a power plant or other source to vaporize the droplets
51	Managing Water - From Waste to Resource Oilfield Review, Summer, 2004	Mike Hightower, et al	Sandia National Lab, DOE, NMState U, Texas A&M,ConocoPhillips, ChevronTexaco, Shell, PSC of NM	Data and Modeling	General article on how water is produced, current disposal and treatment options and beneficial uses.
52	Seawater Desalination	F. Cesar Lopez, Jr.	San Diego County Water Authority	Data and Modeling	Excellent summary of worldwide large scale desalination plants - variable expense less than 1 cent/gallon
53	Brine Disposal From Land Based Membrane Desalination Plants: A Critical Assessment	Julius Glater, Yoram Cohen	University of California, Los Angeles, Metropolitan Water District of Southern California	Data and Modeling	Good discussion of the pros and cons of what to do with the waste brine from inland desalination projects
54	Membrane Filtration of Oil and Gas Field Produced Water	www.gewater.com/library/tp/1158_Membrane_Filtration.jsp	GE Osmonics	Data and Modeling	A primer of RO and other membrane filtration of produced water and state of the art products

55	Decision and Risk Analysis Study of the injection of Desalination By-products into Oil and Gas-producing zones SPE 86526	David B. Burnett, John A. Veil	Argonne National Laboratory, Texas A&M, DOE	Data and Modeling	Discussion and analysis of waste brine from desalination project injected into producing formations
56	Produced Water Management Handbook	Deidre Boysen, John Boysen, Jessica Boysen, Tim Larsen	B.C. Technologies Inc., Gas Technology Institute	Treatment, Regulatory, Data and Modeling	A comprehensive report on Produced Water Regulation, Disposal Economics and Treatment Technologies
57	Profile of the International Membrane Industry, 3rd addition	Elsevier Advanced Technology ($1421 for print Copy	www.mindbranch.com/listing/product/R513-0011.html	Treatment-Membranes, Data and Modeling	184 Pages, Worldwide demand, supply, 30 research and commercial technology providers, all membrane technologies
	Active NETL Research in Produced Water				
58	Treatment of Produced Waters Using a Surfactant Modified Zeolite/Vapor Phase Bioreactor	DE-FG-26-03NT15461	U of Texas at Austin, Los Alamos National Lab	Treatment-Bioreactor	Removes organic materials
59	NM WAIDS: A produced Water Quality and Infrastructure GIS Database for NM Oil Production	DE-FC-26-02NT15134 See GWPC papers above	NM Tech PRRC	Data and Modeling	
60	Recovery of More Oil-in-place at Lower Production Costs While Creating a Beneficial Water Resource	DE-F26-02NT15463	Aera Energy, LLC Kennedy-Jenks consulting	Regulatory, Treatment-TBD, Use-Agriculture-irrigation	Investigate the regulations and build full field treatment plant for beneficial use of produced water
61	Use of Produced Water in Recirculated Cooling Systems at Power Generating Facilities	DE-FC26-03NT41906 See also SWPTTC papers above	EPRI, PNM, PSO of Arizona	Treatment-RO, Use-Industrial-Cooling Tower	
62	Managing Coal Bed Methane Produced Water for Beneficial Uses, Initially Using the San Juan and Raton Basins as a Model	FEW-62962 See also Papers in SWPTTC section	Sandia National Lab, NM Bureau of Geology and Minera Resources, NM Sate Univ. Agricultural Exp. Station, NMPRRC, DOE	Data (Water), Treatment: ion sorption, nano-filtration, capacitive deionization: Application-Agriculture,irrigation,livestock	Starting 2nd year of 3 year project
63	Use of Ionic Liquids in Produced Water Clean-up	FEAC332	Oak Ridge National Laboratory	Treatment-Ionic	Separates Oil from water, ends 7/9/05

64	Novel Cleanup Agents for Membrane Filters Used to Treat Oil Field Produced Water for beneficial Purposes	DE-FC-26-04NT15543 See also GWPC papers	Texas A&M TEES	Treatment-Pretreatment to protect membrane	ends 8/31/07
65	Advanced Membrane Filtration Technology for Cost Effective Recovery of Fresh Water from Oil & Gas Produced Brine	DE-FC26-03NT15427	Texas A&M TEES	Treatment-RO with new membranes	ends 9/29/06
66	Evaluation of Phytoremediation of Coal Bed Methane Product Water and Water of Quality Similar to that Associated with Coalbed Methane Reserves of the Powder River Basin Montana and Wyoming	DE-FG26-01BC15166	Montana State University	Treatment-Artificial Wetlands Use-Livestock Watering	Project period from 8/01 to 8/06 Goals include data gathering of produced CBM water quality and quantity, developing guidelines for selection of wetland plants, develop management plan for utilizing water for forage based livestock.
	2004 Projects Awarded	http://www.fossil.energy.gov/news/techlines/2004/tl_oilgas_awards_081604.html			
67	Identification, Verification and Compilation of Produced Water Management Practices for Conventional Oil and Gas Production Operations	DE-FC26-04NT15545	IOGCC, ALL Consulting, Alaska Oil and Gas Conservation Division, Kansas Corporation Commission, Montana Board of Oil & Gas Conservation, Oklahoma Corporation Commission, Wyoming Oil and Gas Conservation Commission	Data and Modeling	Two year project kicked off Nov. 1, 2004. Best practices in management of produced water from conventional wells
68	Produced Water Management from Production Through Treatment and Beneficial Use	TBA	Colorado School of Mines, GTI, ALL Consulting, University of Wyoming, Stanford, Montana Bureau of Mines and Geology, Montana Tech, Argonne National Lab	Treatment-RO, Electrodialysis Use-Irrigation Data and Modeling, Regulatory	Ten tasks, by ten investigators, with 10 distinctive research areas. Should be awarded late this year.
69	Long Term Field Development of a Surfactant modified Zeolite Vapor Phase Bioreactor System for Treatment of Produced Water for Power Generation	DE-FC26-04NT15546	Univ. of Texas	Treatment-Bioreactor Application-Cooling Tower (power generation)	Three year project, starting 9/16/04 (removes organics)

70	Novel Cleanup Agents for Membrane Filters Used to Treat Oil Field Produced Water for Beneficial Purposes	DE-FC26-04NT15547	Univ. of Texas	Treatment-Reverse Osmosis	Three year project, starting 8/23/04
71	New Practices to Remove Plugging Materials and to Restore Microfilter and Reverse Osmosis Membrane Performance	DE-FC26-04NT15543	Texas A&M TEES	Treatment-Reverse Osmosis	Two year project awarded 9/27/04
72	Field Validation of Toxicity Tests to Evaluate the Potential for Beneficial Use of Produced Water	DE-FC26-04NT15544	Oklahoma State University	Data and Modeling	Three year project awarded 10/01/04
73	Treating Coal Bed Methane Produced Water for Beneficial Use of MFI Zeolite Membranes	DE-FC26-04NT15548	New Mexico Institute of Mining and Technology PRRC	Treatment-Reverse Osmosis	Three year project awarded 8/31/04
	Selected NETL Sponsored Research Projects recently completed				
74	Northern Cheyenne Reservation Coal Bed Natural Gas Resource Assessment and Analysis of Produced Water Disposal Options	FEW4340-72	Idaho National Engineering and Environmental Laboratory	Data and Modeling	Two and a half year projects completed 4/30/04 studying and designing produced water injection facilities
75	Monitoring of Water Profiles and Impact of CBM Production in the Powder River Basin	OST-37-04	NETL - Pittsburgh	Data and Modeling	Two year project ending 9/30/04 examining transport of produced water in impoundment, irrigation and surface discharge
76	Fate and Transport Analysis of Produced CBM waters Using Remote Sensing Technologies	OST-41-1	NETL - Pittsburgh	Data and Modeling	Companion project to above, utilizing Airborne frequency domain electromagnetic technology
77	Cost Effective Approaches to Enhance Domestic Oil and Gas Production and Ensure the Protection of the Environment	DE-FC26-01BC15371	Ground Water Protection Research Foundation	Regulatory	Three year project completed 9/30/04 developed the Risk Based Data Management System for use by regulatory agencies
78	Treatment of Produced Waters Using a Surfactant-Modified Zeolite/Vapor Phase Bioreactor System	FEW02FE20	Los Alamos National Laboratory	Treatment-Bioreactor	Two year project completed 9/11/04. Precursor of current University of Texas Project
79	Treatment of Produced Oil and Gas waters with Surfactant-modified Zeolite/MEGA	DE-AC26-99BC15221	University of Texas	Treatment-Bioreactor	Four year project ending 9/23/03. See 2004 projects for successor U of T research

80	Geologic Sequestration of CO_2 in Deep, Unmineable Coalbeds: An Integrated Research and Commercial-Scale Field Demonstration Project.	DE-FC26-00NT40924	Advanced Resources International Inc.	Data and Modeling	ECBM simulator created based on results from Amoco's Tiffany N2 ECBM project and Burlington's Allison Unit CO_2 ECBM Project
	Upcoming Meetings				
81	Membrane Technology Conference & Exposition	March 6 - 9, 2005 Phoenix, Arizona	Sponsored by International Water Association, American Water Works Association, European Desalination Society	Treatment-Membranes	International conference on membrane and filtration technology - workshops and over 200 technical paper presentations

The following projects are on the Department of Energy's Office of Science and Technology site (http://rd.osti.gov/)

Project ID	Project Title	Start Date	Completion Date	Description
P/NPTO--G4P60823	Application of Biosorb, a Novel Technology for the Treatment of Produced Water from Oil E&P Operations	15-Aug-96	14-Feb-97	Provide a one step cost-effective, technically efficient, remediation system for the mitigation of organics, sulphur species, metals at lower concentrations and remove radio nuclides (where applicable) from the produced waters including wastewaters from oil and gas production sites; render the produced water useful or fit for disposal under the zero discharge regulatory constraints.
P/ORNL--FEAC316	Characterization of Soluble Organics in Produced Water	1-May-99	30-Sep-02	ORNL will identify water-soluble organics in produced water and characterize these compounds quantitatively by accurate measurements of equilibrium solubility's and associated thermo-physical properties taken on unique equipment located in the Department of Energy's Physical Properties Research Facility national user facility.
P/INEEL--DPR5A107	Crow Reservation Coal Bed Natural Gas	1-Mar-02	31-Mar-04	The Idaho National Engineering and Environmental Laboratory in partnership with the Northern Cheyenne Tribe, and in conjunction with the Montana Bureau of Mining and Geology and the Bureau of Indian Affairs propose to conduct a complete analysis of the coal bed methane production potential for coal assets underlying the Northern Cheyenne Indian Reservation of Montana. Because of the environmental concerns associated with coal water production in Montana, special emphasis will be placed upon identifying environmentally acceptable and cost-effective methods for producing gas while managing potentially large volumes of water.
P/NPTO--DE-FC22-95MT95008	Developing a Cost Effective Environmental Solution for Produced Water and Creating a 'New' Water Resource	25-Sep-95	31-Dec-97	Identify and test water treatment processes that can be used to convert oilfield produced water from the Placerita Oil Field in California into water that meets California potable or reuse standards (some of the strictest requirements in the US) at a competitive cost

P/ANL--000302	Energy and Environmental Impact Analysis	1-Nov-94	None	Argonne analyzes water and waste issues related to gas and oil exploration and production. Examples of these issues include ocean discharge criteria, wetlands rules, management of coal-bed methane produced water, and regulations for cooling water intake structures.
P/NPTO--97-A06Task08	Environmental Research - Lower Cost Produced Water Disposal	1-Nov-96	31-Oct-97	Identify the regulatory requirements, candidate technologies, and demonstration sites; and conduct the demonstrations
P/NPTO--DE-AC22-92MT92001	Environmental and Economic Assessment of Discharges from Gulf of Mexico Region Oil and Gas Operations	23-Jun-92	30-Jun-97	To increase scientific knowledge concerning: 1) the fate and environmental effects of organics, trace metals, and NORM in water, sediment, and biota; 2) characteristics of produced water and sand discharges as they pertain to organics, trace metals, and NORM viability; 3) ,,,,
P/NPTO--DE-FG21-95MT32061	Field Test for Cost Effectiveness of Water Disposal in Low-Pressure Gas Reservoirs	30-Sep-95	29-Sep-99	Test the mechanical and economic feasibility of disposing of produced water through underground injection in an environmentally safe manner, utilizing deep low pressured gas reservoirs
P/ANL--002424	Management Of Produced Water	1-Aug-03	None	ANL will develop extensive data and identify and analyze issues on produced water (from oil development) and its management
P/NETL--FEW-62962	Managing Coal Bed Methane Produced Water for Beneficial Uses, Initially Using the San Juan and Raton Basins as a Model (PARTNERSHIP)	8-May-03	7-May-04	no description
P/NETL--DE-FC26-00BC15326	Modified Reverse Osmosis System for Treatment of Produced Water	1-Sep-00	31-Aug-03	Develop two water treatment systems that will process water produced with oil into water with re-usable potential, reducing current disposal costs by as much as 90%.
P/ORNL--FEAC307	Ozone Treatment of Soluble Organics in Produced Water	1-May-98	30-Sep-02	This project will extend previous research to improve the applicability of ozonation for treating produced water. It will address the industry-wide problem of handling soluble organics resulting from deep-water operations. The goal of this project ,,,,,
P/ANL--001981	Reducing Chemical Use and Toxicity in Produced Water Systems	1-Oct-97	None	This project is focused on reducing chemical use and toxicity in produced water systems. The use of biocides, corrosion inhibitors, and other chemicals in produced-water handling and disposal systems is a significant problem because of the high costs of chemical treatments and environmental liabilities.

P/FETC-MGN--DE-FC21-93MC3009845.0	Small-Scale Demonstration of the Freeze-Thaw Evaporation Process to Treat Oil and Gas Produced Waters	1-Aug-95	31-Dec-96	1. Acquisition of the required regulatory approval for the demonstration. This task will be conducted primarily by Amoco personnel, with assistance from EERC and B.C. Technologies. 2. Construction of three pits and installation of piping, pumps, and instrumentation required to conduct the demonstration. This task will be conducted by Amoco with B.C. Technologies and EERC assisting. 3. Operation of the FTE process to collect sufficient climate, water quality, and evaporation performance data. Evaporation will be performed by Amoco with B.C. Technologies and EERC responsible for data collection. 4. Operation of the FTE process to confirm the technical and economic feasibility, and environmental acceptability of the process. This task will be conducted primarily by B.C. Technologies and EERC with Amoco assisting. 5. Conduct overall technical and economic evaluation and potential market survey.
P/FETC-PGH--AC22-92MT92009	The evaluation of freeze--thaw evaporation for the treatment of produced waters	6-Aug-92	5-Aug-96	To develop a waste treatment process that uses the natural processes of water freezing and melting in the winter and evaporating in the summer to treat produced water associated with oil and gas operations. Tasks include the following: 1) a literature survey of freeze-thaw and evaporation, and preliminary economic analyses, 2) laboratory-scale process evaluation, and 3) evaluation of a field demonstration of the Freeze-Thaw/Evaporation (FTE) process in the San Juan Basin of New Mexico.

Appendix 1:Data Sources for Water Production, Water Quality & GIS Information

This is a listing of the URL addresses where the states provide access to their production data. These links can change quite quickly, therefore there is no guarantee they will remain valid for the long-term. There is also a list of related sites that were used in this study.

	State/Entity	URL
1	**Alabama**	
		http://www.ogb.state.al.us/
2	**Alaska**	
		http://aogweb.state.ak.us/publicdata/
		http://www.dog.dnr.state.ak.us/oil/products/publications/annual/report.htm#2003report
3	**Arizona**	
		http://www.azgs.state.az.us/OGCC.htm
4	**Arkansas**	
		http://www.aogc.state.ar.us/
5	**California**	
		http://www.clwa.org/awqr2002.htm
		http://www.iogcc.state.ok.us/NACA/caagencies.htm
		http://www.consrv.ca.gov/DOG/index.htm
		http://www.consrv.ca.gov/DOG/prod_injection_db/index.htm
6	**Colorado**	
		http://oil-gas.state.co.us/
7	**Florida**	
		http://www.dep.state.fl.us/geology/gisdatamaps/water_production.htm
		http://www.dep.state.fl.us/geology/programs/oil_gas/
8	**Idaho**	
		http://www2.state.id.us/lands/bureau/Minerals/min_leasing/leasing.htm
		http://www.idahogeology.org/
9	**Indiana**	
		http://www.in.gov/dnr/
		http://www.in.gov/dnroil/
		http://igs.indiana.edu/pdms/

10	**Illinois**	
		http://www.isgs.uiuc.edu/oilgas/iloil/launchims.htm
		http://www.isgs.uiuc.edu/
		http://www.isgs.uiuc.edu/oilgas/annual/index.htm
		http://www.isgs.uiuc.edu/oilgas/iloil/
		http://www.isgs.uiuc.edu/oilgas/oilgas.html
11	**Kansas**	
		http://www.kgs.ukans.edu/Magellan/WaterWell/index.html
		http://www.kgs.ukans.edu/Magellan/WaterLevels/index.html
		http://www.kgs.ukans.edu/PRS/petroDB.html
		http://www.ogs.ou.edu/fossilfuels/coal.htm
		http://www.pttc.org/solutions/513.htm
		http://www.kdhe.state.ks.us/water/tech.html
		http://www.oznet.ksu.edu/urbanwater/state_federal_agencies.html#STATE
		http://www.kwo.org/Reports%20&%20Publications/KWOFactSheets/No_23_State_Water_Agencies.pdf
12	**Kentucky**	
		http://kentucky.gov/Portal/OrgList.aspx
		http://www.dmm.ky.gov/oandg/
		http://www.dmm.ky.gov/oandg/Oil+and+Gas+Maps+and+Manuals.htm
		http://www.uky.edu/KGS/home.htm
		http://www.uky.edu/KGS/emsweb/data/ogdata.html
		http://www.uky.edu/KGS/emsweb/toris/toris.html
		http://www.uky.edu/KGS/emsweb/data/2001/og2001.html
		http://www.uky.edu/KGS/emsweb/data/2001/oghistory.txt
13	**Louisiana**	
		http://www.dnr.state.la.us/SEC/EXECDIV/TECHASMT/data/index_oil_gas.htm
		http://sonris-www.dnr.state.la.us/www_root/sonris_portal_1.htm
		http://www.dnr.state.la.us/SEC/EXECDIV/TECHASMT/division/index.html
		http://www.dnr.state.la.us/SEC/EXECDIV/TECHASMT/data/oil_gas/index.html
		http://www.dnr.state.la.us/SEC/EXECDIV/TECHASMT/data/annual_reports/index.html
14	**Michigan**	
		http://www.michigan.gov/deq/0,1607,7-135-3311_4111_4231---,00.html

	Missouri	
		http://www.dnr.state.mo.us/geology/geosrv/wellhd/oil.htm
15	**Mississippi**	
		http://www.ogb.state.ms.us/
		http://www.ogb.state.ms.us/welldatamenu.php
16	**Montana**	
		http://bogc.dnrc.state.mt.us/
		http://bogc.dnrc.state.mt.us/eProduction.htm
		http://bogc.dnrc.state.mt.us/JDPloginWeb.htm
17	**Nebraska**	
		www.nogcc.ne.gov
18	**Nevada**	
		http://minerals.state.nv.us/forms/forms_ogg.htm
		http://minerals.state.nv.us/forms/ogg_oilpatch/OilPatch20040102.pdf
19	**New Mexico**	
		http://geoinfo.nmt.edu/resources/petroleum/home.html
		http://wrri.nmsu.edu/wrdis/wrdis.html
		http://www.emnrd.state.nm.us/ocd/
		http://octane.nmt.edu/data/ongard/
		http://daihatsu.nmt.edu/waterquality/
20	**New York**	
		http://www.nysm.nysed.gov/esogis/locationSearch.cfm?queryLocation=SAPINO
		http://www.dec.state.ny.us/website/dmn/
		http://www.dec.state.ny.us/website/dmn/brinesum.htm
		http://www.dec.state.ny.us/website/dmn/ogdata.htm
21	**North Dakota**	
		http://www.oilgas.nd.gov/
		http://www.oilgas.nd.gov/subscriptionservice.html
22	**Ohio**	
		http://www.ohiodnr.com/publications/water/oilgasfields.htm
		http://www.ohiodnr.com/mineral/oil/index.html
23	**Oklahoma**	

		http://www.occ.state.ok.us/Divisions/OG/ogdatafiles.htm
		http://www.occ.state.ok.us/Divisions/OG/ogmonth-apr.pdf
		http://sec.ou.edu/who.php
		http://www.ogs.ou.edu/fossil.htm
		http://www.ogs.ou.edu/fossilfuels/coal.htm
		http://welldata.oil-law.com/
24	**Oregon**	
		http://www.oregongeology.com/oil/Mist-2003.htm
25	**Pennsylvania**	
		http://www.dcnr.state.pa.us/topogeo/oilandgas/index.aspx
		http://www.dcnr.state.pa.us/gasleasing/faq.htm
		http://www.dcnr.state.pa.us/topogeo/oilandgas/oilandgas_basemaps.aspx
		http://www.dcnr.state.pa.us/topogeo/oilandgas/wis_home.aspx
		http://www.dcnr.state.pa.us/topogeo/oilandgas/prodreports.aspx
		http://www.dcnr.state.pa.us/topogeo/oilandgas/production_statistics.aspx
		http://www.dcnr.state.pa.us/topogeo/maps/map10.pdf
26	**South Dakota**	
		http://www.state.sd.us/denr/DES/mining/mineprg.htm
		http://www.state.sd.us/denr/DES/mining/Oil&Gas/O&Ghome.htm
27	**Tennessee**	
		http://www.state.tn.us/environment/permits/oil&gas.htm
		http://www.state.tn.us/environment/tdg/staff.php
		http://www.state.tn.us/environment/tdg/programs.php
		http://www.state.tn.us/environment/permits/oil&gas.htm
28	**Texas**	
		http://www.rrc.state.tx.us/divisions/og/og.html
		http://www.rrc.state.tx.us/other-information/automated/itsslist2.html
		http://www.rrc.state.tx.us/divisions/og/uic/statewidewells.htm
		http://www.rrc.state.tx.us/divisions/og/information-data/stats/ogisopwc.html
		http://www.rrc.state.tx.us/divisions/og/information-data/stats/ogisgpwc.html
		http://webapps.rrc.state.tx.us/PDQ/mainReportAction.do
		http://www.rrc.state.tx.us/divisions/og/uic/statewidewells.htm

		http://www.rrc.state.tx.us/divisions/og/form-library/purpose.html
		http://www.utlands.utsystem.edu/cgi-shl/foxweb.exe/utl/well/wellapi
		http://www.rrc.state.tx.us/commissioners/williams/producedwater.html
29	**Utah**	
		http://www.utah.gov/services/index.html
		http://ogm.utah.gov/oilgas/PUBLICATIONS/Reports/2003_prd/book0803.htm
		http://ogm.utah.gov/oilgas/qref_Find_data.htm
30	**Virginia**	
		http://www.mme.state.va.us/
		http://www.mme.state.va.us/Dgo/default.htm
		http://www.mme.state.va.us/DMR/DOCS/Digit/ddb2.html#oil
31	**Washington**	
		http://www.dnr.wa.gov/geology/energy.htm#exploration
32	**West Virginia**	
		http://www.dep.state.wv.us/item.cfm?ssid=23
		http://gis.wvdep.org/
		http://gis.wvdep.org/mapping/oog/
		http://www.wvgs.wvnet.edu/
		http://www.wvgs.wvnet.edu/www/maps/maps.htm
33	**Wyoming**	
		http://wogcc.state.wy.us/warchoiceMenu.cfm?Skip='Y'&oops=ID54437
		http://wogcc.state.wy.us/grouptrpMenu.cfm?Skip='Y'&oops=ID63018
		http://waterplan.state.wy.us/sdi/BH/BH07ES01.html
34	**Appalachian Region Oil and Gas Data**	
		http://ims.wvgs.wvnet.edu/website/pttc/viewer.htm
		http://www.iogcc.oklaosf.state.ok.us/COMMPGS/DIRECTOR.HTM
35	**EPA**	
		http://toxics.usgs.gov/sites/ph20_page.html
36	**ARI-NETL Rocky Mtn Proposal**	
		http://www.netl.doe.gov/publications/press/2001/tl_lowperm_2more.html
37	**IHS Group / Energy**	
		http://www.ihsenergy.com/products/usdata/production/index.jsp

		www.ihsgroup.com
	IHS Energy Group includes the following companies:	
	· Petroleum Information/Dwights, based in Denver, Colo./Houston, Texas	
	· Petroconsultants/IEDS, based in Geneva, Switzerland/Tetbury, England	
	· PI (ERICO), based in London, England	
	· Petroconsultants-MAI, based in London, England	
	· Data Logic, based in Houston, Texas	
38	**Nehring & Associates**	
39	**API**	
		Rocky Mtn Coalbed Natural Gas Forum: Produced Water
	http://api-ep.api.org/training/index.cfm?objectid=39E81F32-E40E-4F52-987AC5A9F3B413C6&method=display_body&er=1&bitmask=002005002000000000	
	Exploration and Production Waste Mgmt (produced water, drilling fluids, etc)	
	http://api-ep.api.org/environment/index.cfm?objectid=CACC5F06-F8A1-4573-BC027E537C23BB35&method=display_body&er=1&bitmask=002008003002000000	
	Water Conservation and Natural Gas Production	
	http://api-ec.api.org/environ/index.cfm?objectid=72CA6461-8DE6-11D5-BC6B00B0D0E15BFC&method=display_body&er=1&bitmask=001003004005000000	
40	**USGS**	
		http://energy.cr.usgs.gov/prov/prodwat/data2.htm
41	**SW PTTC**	
		Produced Water Forum - New Mexico
		http://octane.nmt.edu/sw-pttc/producedwater04Proc/proceedingspw.asp
42	**GTI/BC Technologies**	
		Produced Water Management Handbook - 2002
		Produced Water Atlas Series - 2002
		Produced Water Decision Tree Model- 2002
43	**GWPC - Ground Water Protection Council**	
		http://www.gwpc.org/Meetings/PW2002/10-9.htm
44	**SPE**	
		http://www.spe.org/spe/jsp/basic/0,,1104_1575_1040464,00.html

45	**NETL - Argonne**
	Up-To-Date Information on Produced Water Now Available
	The U.S. Department of Energy/Office of Fossil Energy (FE) and its National Energy Technology Laboratory (NETL) continually seek to gain a better understanding of produced water – its constituents, volumes generated, how it is managed in
	different settings, and the cost of water management. As such, NETL engaged Argonne National Laboratory staff to prepare a
	white paper that compiles information on these topics. A white paper is now available on this topic. The paper documents
	an extensive research effort covering all key aspects of produced water. This paper is available at by clicking on the following link:
	A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coalbed Methane [PDF-399KB]
46	**Coal Bed Methane**
	http://gcmd.nasa.gov/records/GCMD_EARTH_CRUST_USGS_COAL_NCRDS_DB.html
	http://www.ogs.ou.edu/fossilfuels/coal.htm
47	**Oil Sands**
	*Bulletin 43. Oil sands and production relations, by H. C. George and W. F. Cloud. 1927. 142 pages, 19 figures.
	*Circular 7. Correlation of the oil sands in Oklahoma, by Fritz Aurin. 1917. 16 pages, 1 plate (correlation chart).

Appendix 2:Sources of Water Quality Data and Production Data

Data Source	Description	Availability/Cost
USGS Produced Waters Database	This version of the produced water database is a subset of a larger database originally provided to the USGS by GeoINFORMATION at the University of Oklahoma. The origin of the database is traced to the Petroleum Laboratory at Bartlesville, Oklahoma that was originally operated by the U.S. Bureau of Mines and subsequently by the Department of Energy. There are 58,706 records in the database containing water quality information and a description of the contents is at the end of this document.	We have in house and have linked to the Integrated (GSAM/TORIS) Model Reservoir Data
(GSAM/TORIS) Integrated Reservoir Database	This is a reservoir level database (more than 20,000) reservoirs' that also includes production data. Discovered oil and gas data is based on NRG and undiscovered is based on USGS and MMS. This dataset does not include water production histories.	NRG was purchased by NETL (~$60K/year) Other data is free.
BLM - OGOR Database	This is well by well database of all oil and gas wells (about 62,000 active) on Federal Lands. We have monthly production – and water production history from 1990 through 2003.	Provided by BLM/MMS
BLM - Automated Fluid Minerals Support System (AFMSS)	This is a BLM database of well test and status information. It is a national database application for nine state offices and 31 field offices, as well as outside users such as MMS and State Governments. AFMSS has an electronic commerce component that is web based and supports electronic business with oil and gas operators.	Do not have in house, but I assume that Paul Brown or Bob Fields with BLM would provide to DOE. Email dated 06/17/2004 from Brown indicates “AFMSS does contain water production but not water quality parameters.”
State of Wyoming Oil and Gas Data	This has detailed oil and gas production data. It includes water production but not water quality data	Free. We have in house and have analyzed the 13,000 CBM wells in the Powder River Basin.
BEG Brine Atlas (CO_2 Seq)	No water quality data	
MMS – Offshore Data	Contains both production and water quality test. Data is at the completion level and contains monthly water production for all federal offshore wells.	Free. We have in-house.
Kansas Geological Society	Water quality data. 3,799 records for Kansas properties. Data is from 1900 to 1971 with 13 new entries from 2001 for a CO_2 project. Some early data documented as from US BoM - this could be redundant to USGS data. USGS has 4,634 Kansas records	Free. Downloaded from website. We have in-house.

GWPC – Ground Water Protection Council	Reviewing material – not sure what we have	Contacted Ben Grunewald. Produced Water Conference held in 2002 in Colorado Springs. Presentations and Proceedings available on their website. http://www.gwpc.org/Meetings/PW2002/Papers-Abstracts.htm and http://www.gwpc.org/Meetings/PW2002/Presentations-Page.htm
IOGCC – Interstate Oil and Gas Compact Commission	No information yet.	Contacted Gerry Baker – is checking out status for us. http://www.iogcc.oklaosf.state.ok.us/
NETL Brine Database on CD	Compilation of USGS, Texas BEG, State Geological Surveys, oil and gas reports and other published sources	Contacts are James Knoer and Robert Eldstrodt out of Coal Group.
OFBA (Oil Field Brine Analyses) Database files	This has detailed water quality data of ~77,000 samples. Names of the two files we have are “brinppm” and “brinmgl”. There are 139 fields. Obtained from Dwights EnergyData in 1994. Origin unknown.	Free. We have partial db in-house. Full db cost from IHS Energy is $20,000.

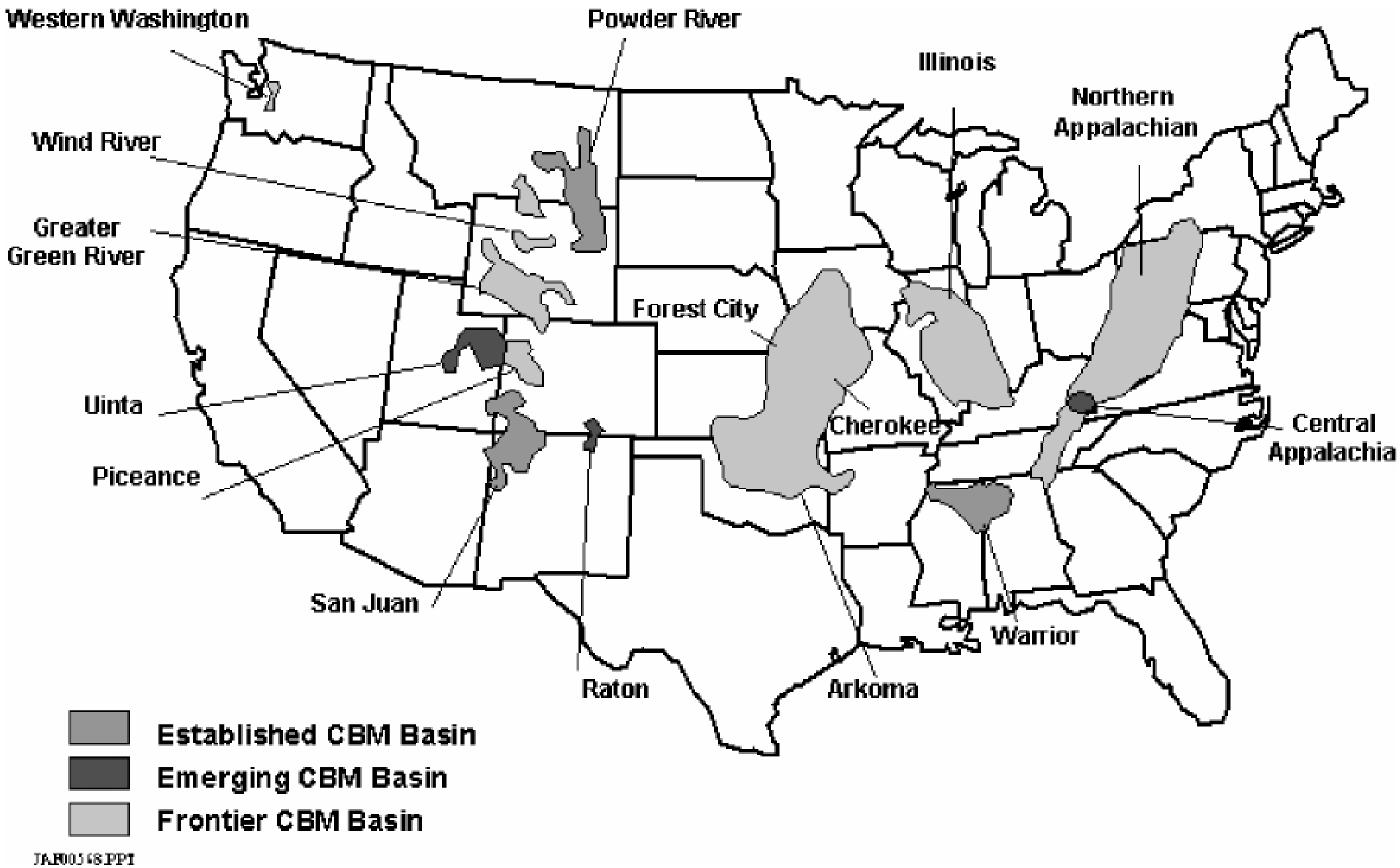
Appendix 3:Background Information on AEO-2004 Supply Regions

The Annual Energy Outlook (AEO) uses the National Energy Marketing System (NEMS), a computer-based model which produces annual projections of energy markets for 2002 to 2025. Conventional oil and gas production is aggregated to Oil and Gas Supply Regions as noted in Map 1[58]. Unconventional gas (CBM, Gas Shales and Tight Gas) is grouped by Basin. The major basins for each are shown in the maps 2- 4

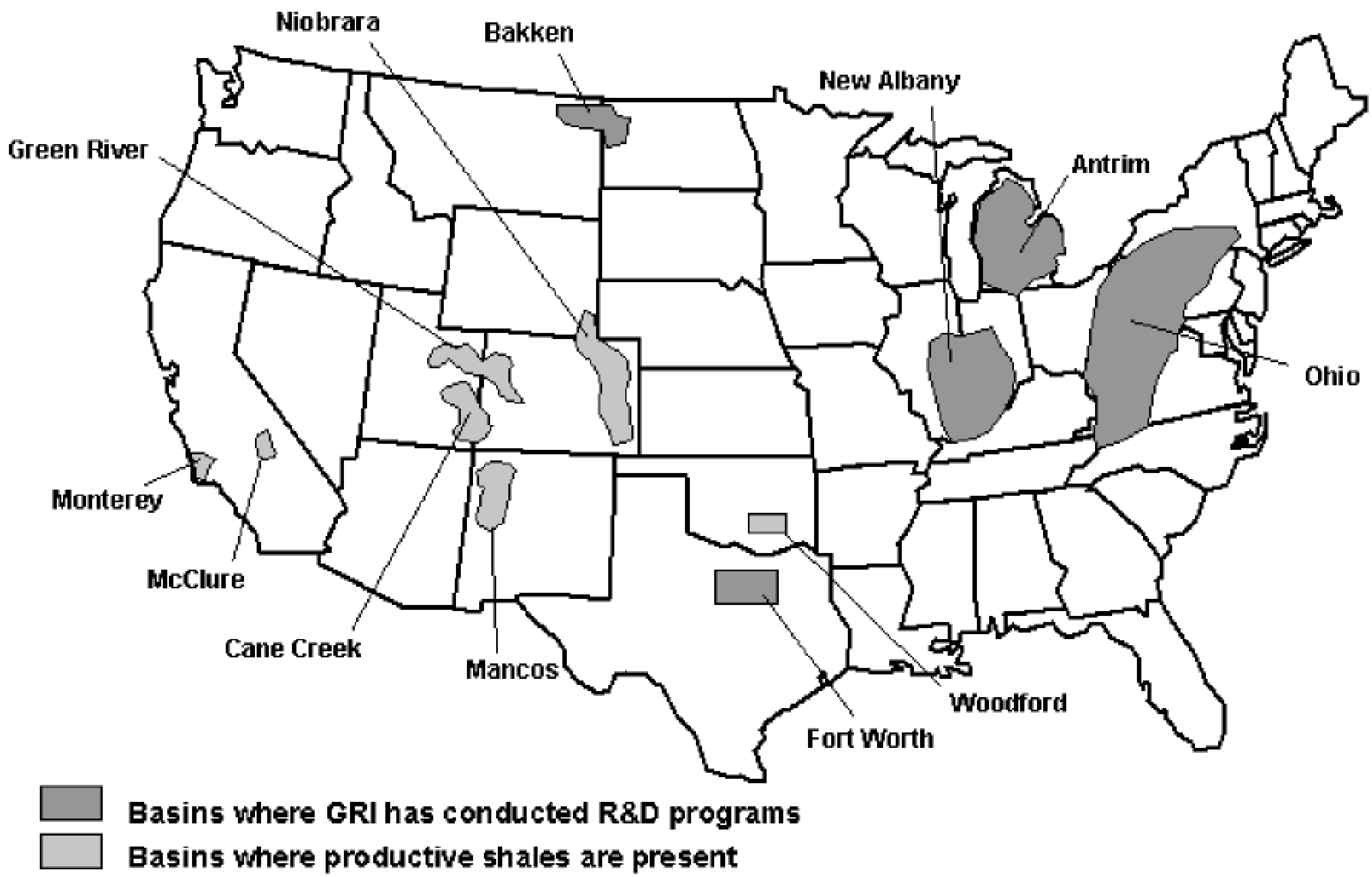
Map 1: Conventional Oil and Gas Supply Regions

[58] "Documentation of the Oil and Gas Supply Module (OGSM)", March 2004, Energy Information Administration, Oil and Gas Division, Office of Integrated Analysis and Forecasting.

Map 2: CBM Basins

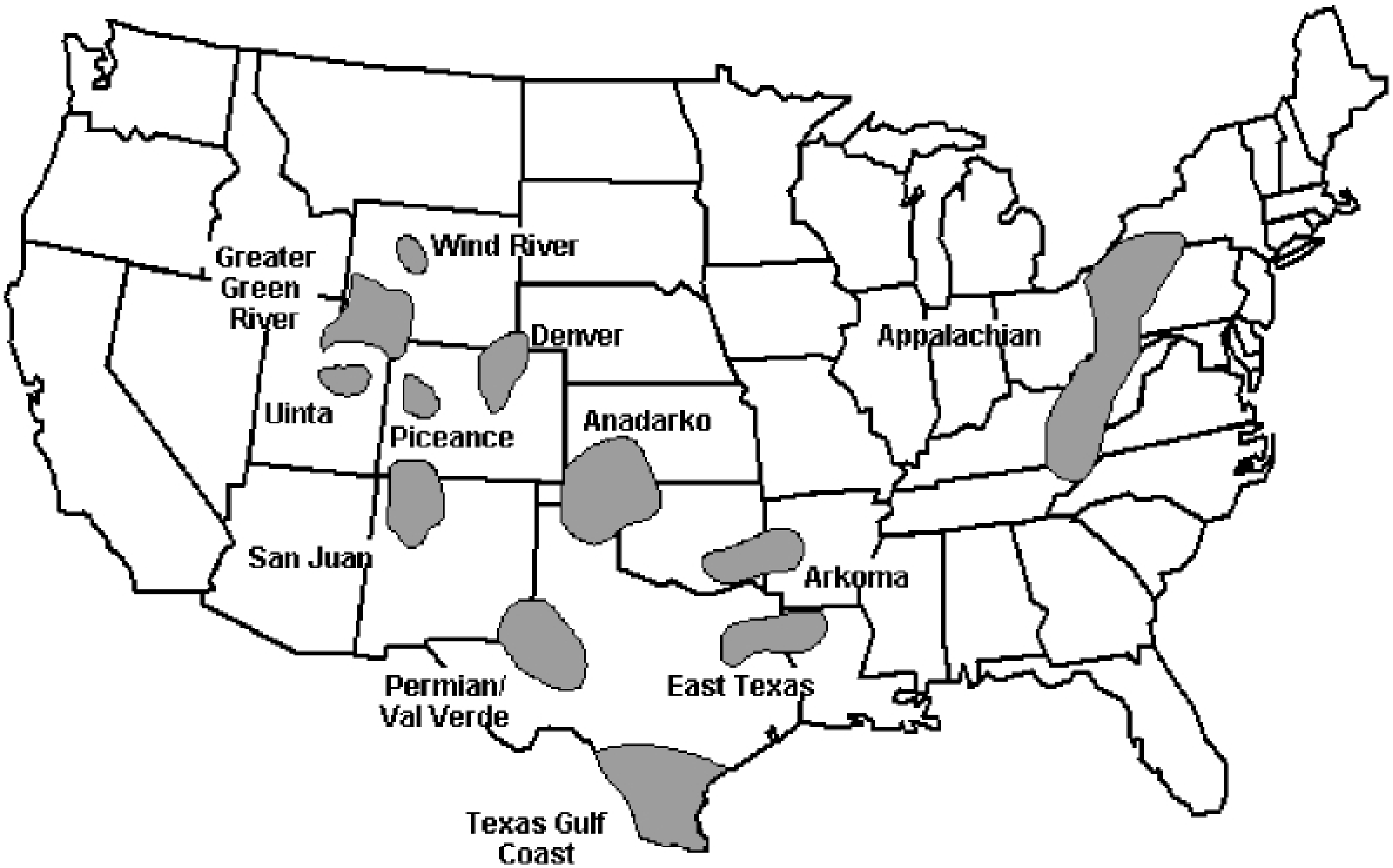


Map 3: Gas Shale Basins

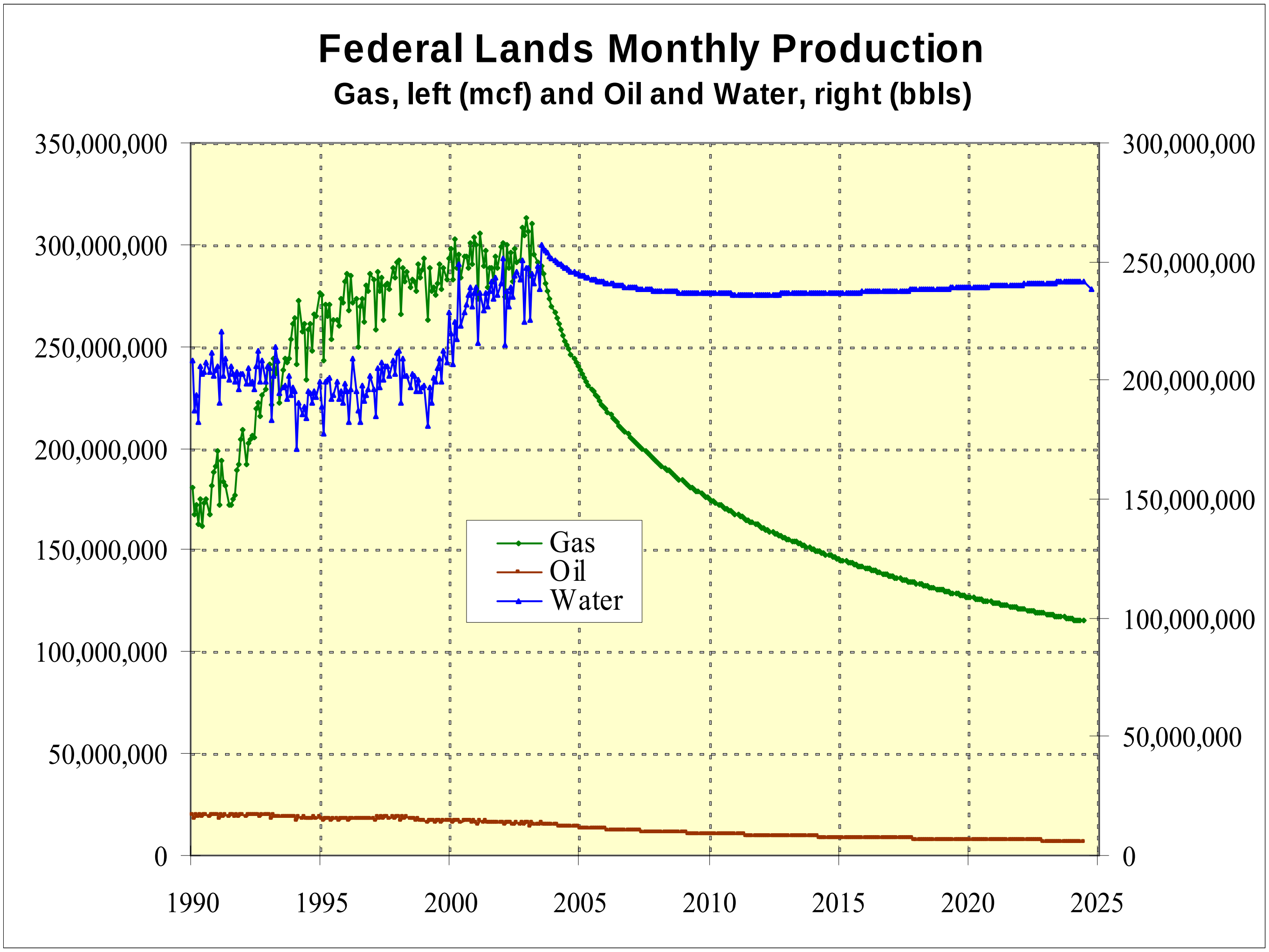


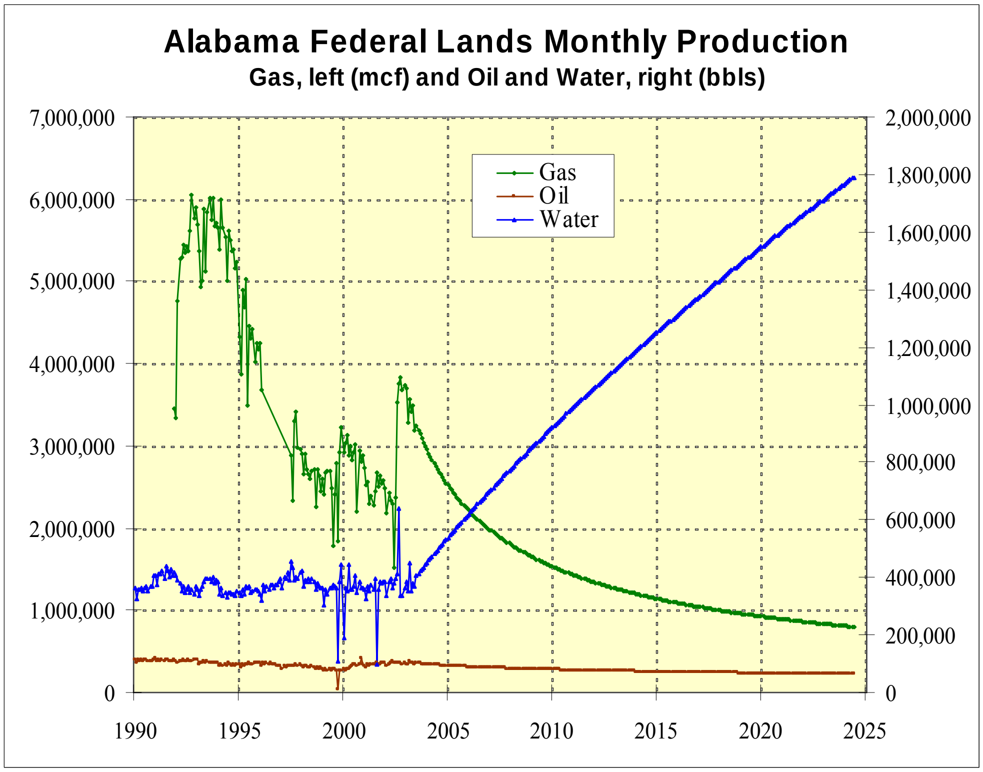
JAF00548.PPT

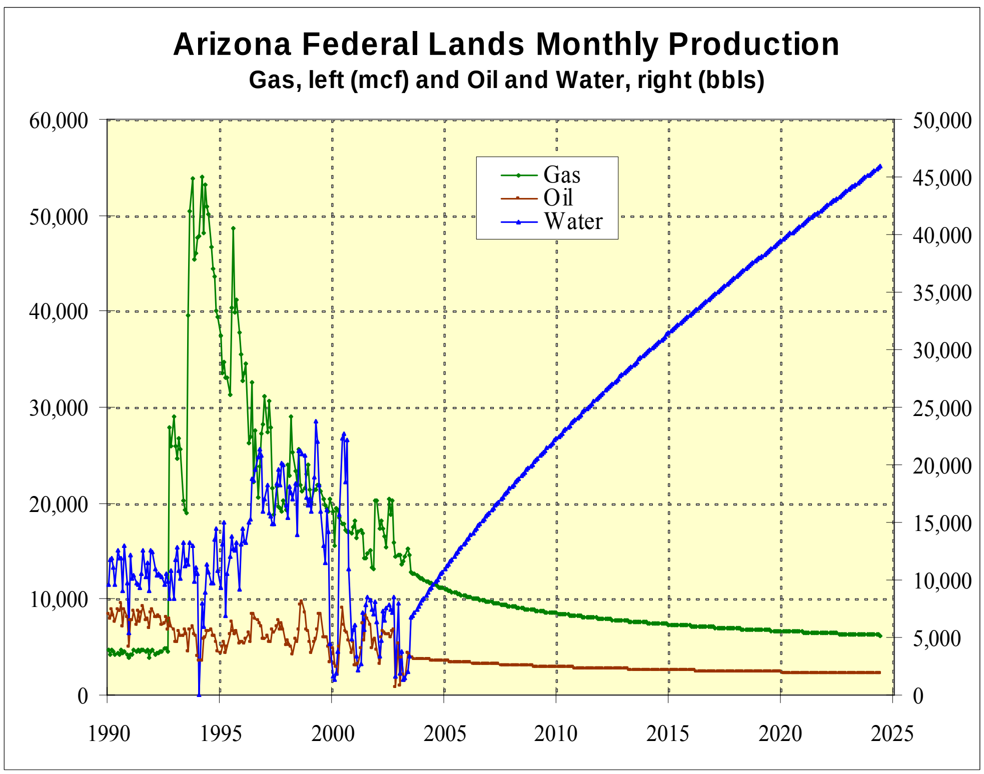
Map 4: Tight Gas Sands Basins

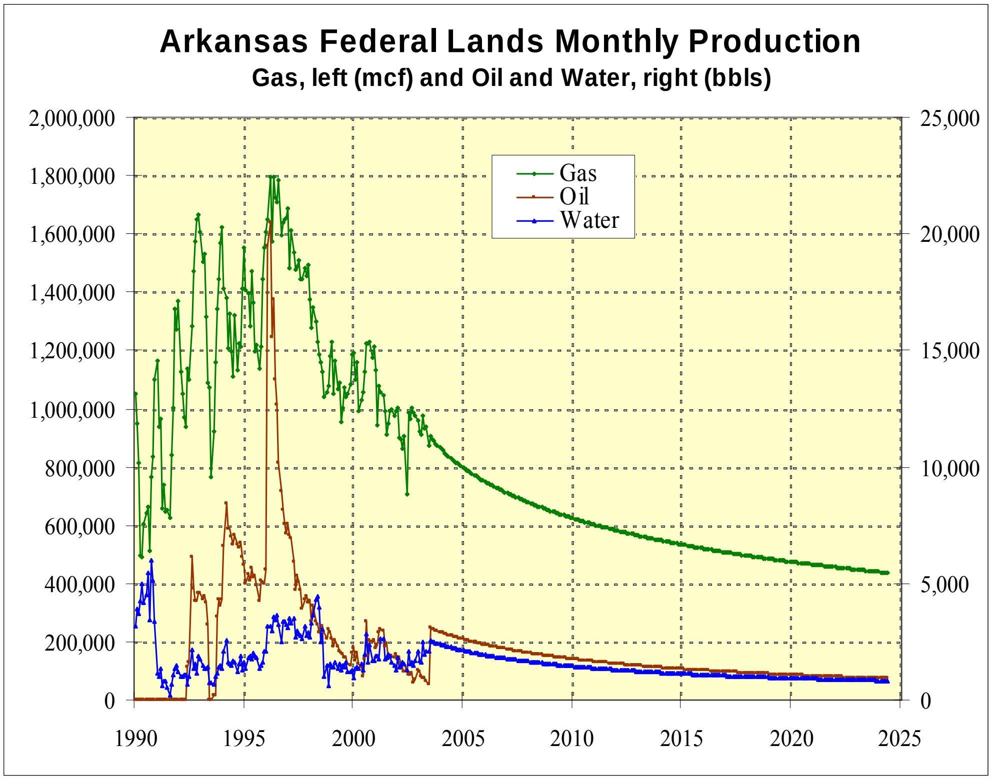


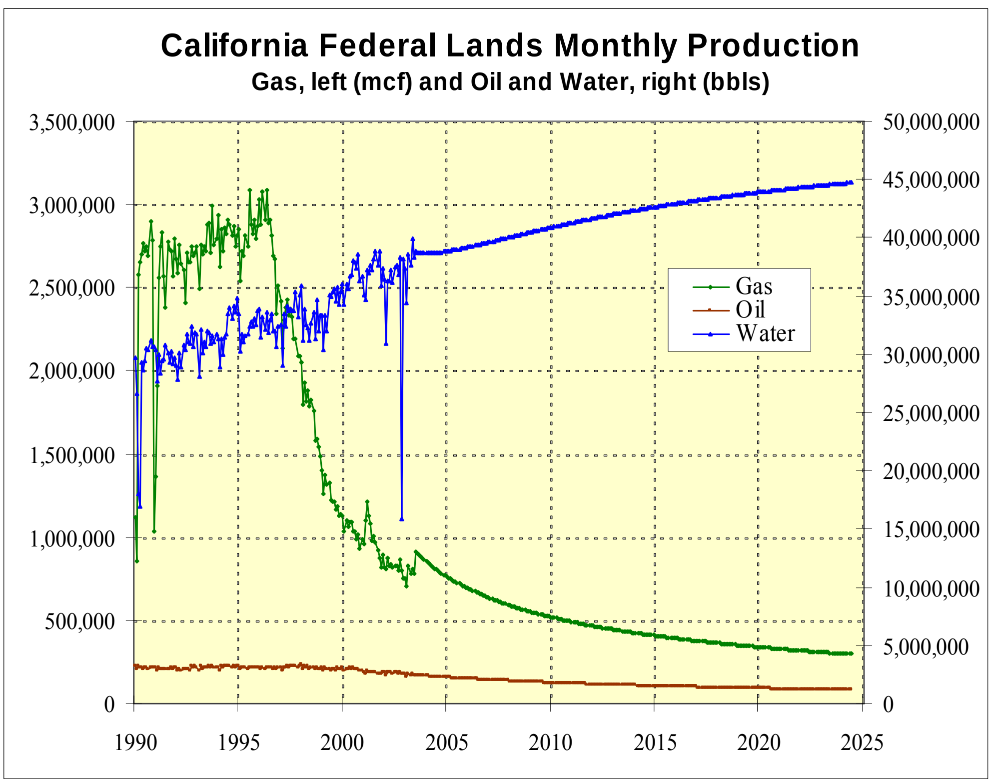
UAppendix 4:Federal Production by State (historical and forecast)

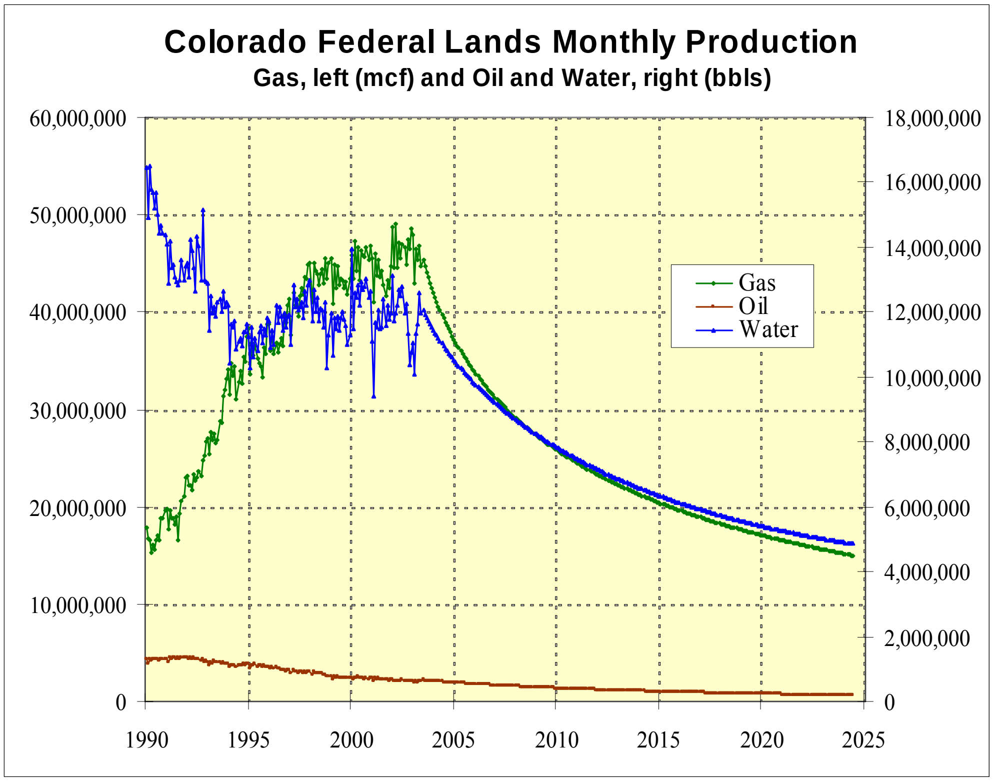


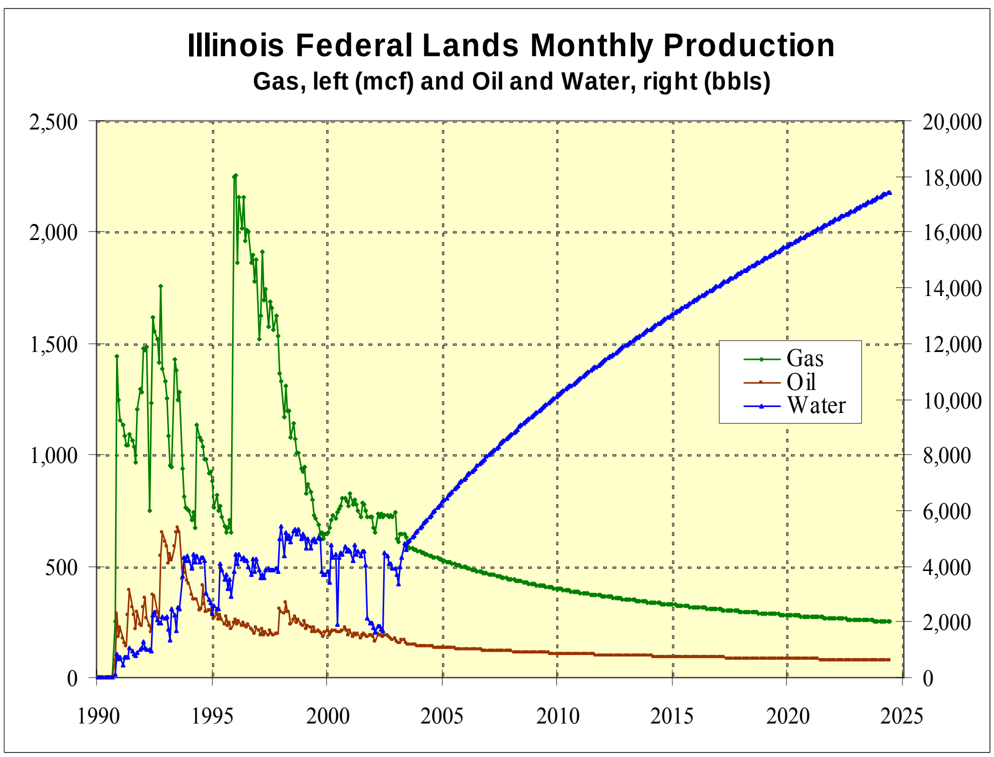

Alabama Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
Gas
Oil
Water
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1990
1995
2000
2005
2010
2015
2020
2025

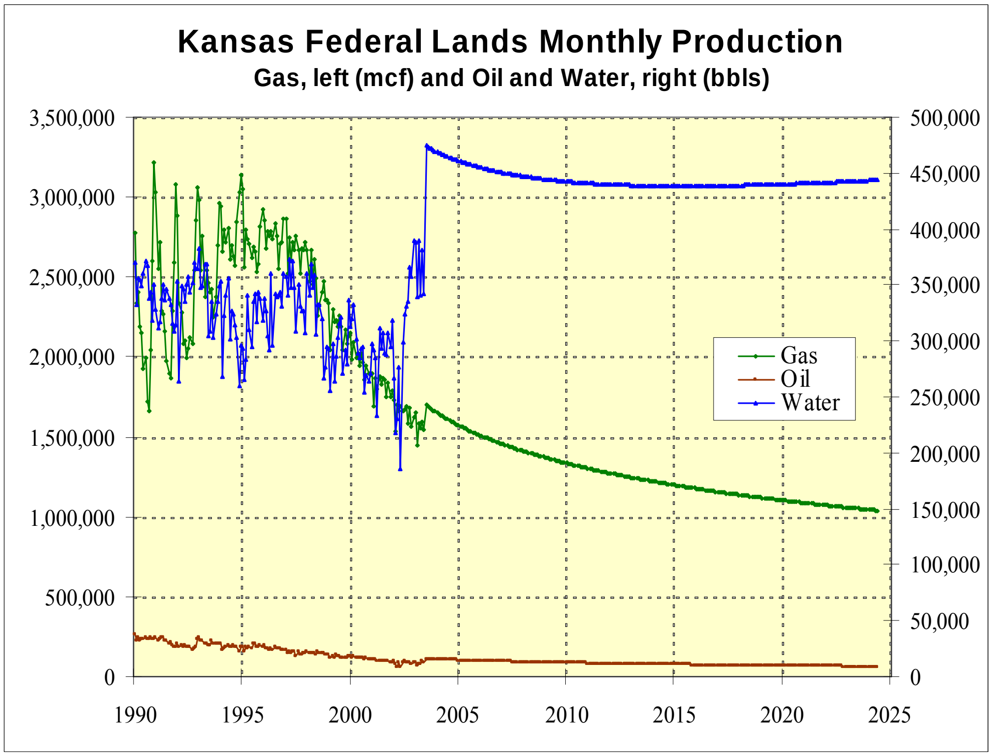

Arizona Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
Gas
Oil
Water
60,000
50,000
40,000
30,000
20,000
10,000
0
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1990
1995
2000
2005
2010
2015
2020
2025

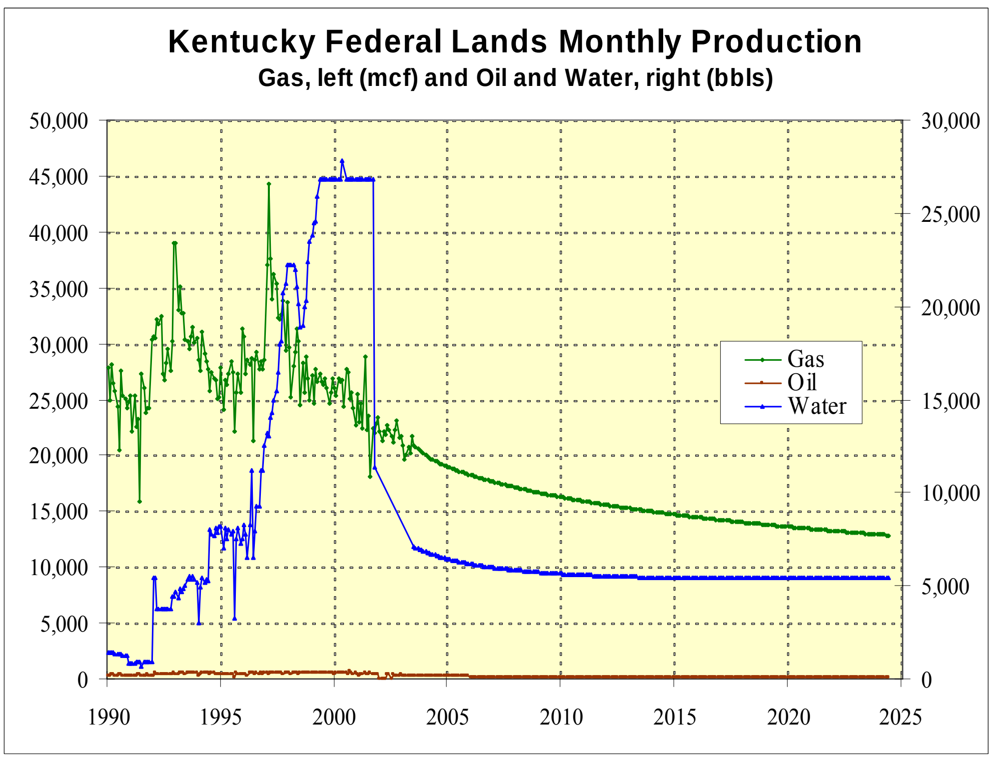

Arkansas Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
Gas
Oil
Water
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
25,000
20,000
15,000
10,000
5,000
0
1990
1995
2000
2005
2010
2015
2020
2025

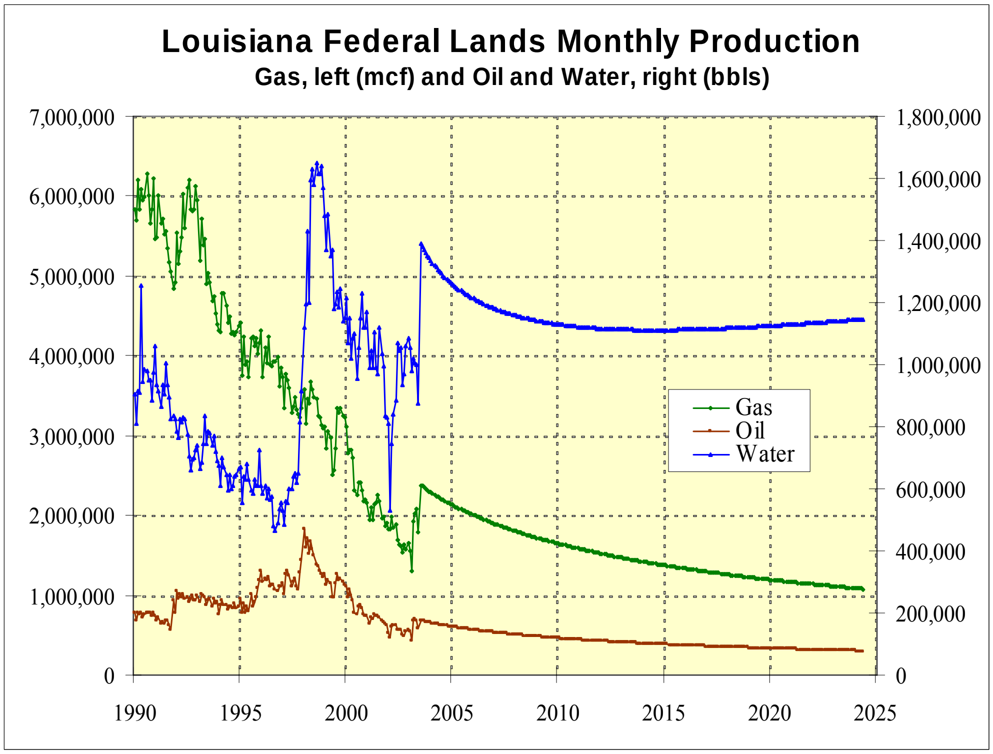

California Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
Gas
Oil
Water
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
50,000,000
45,000,000
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
1990
1995
2000
2005
2010
2015
2020
2025


Colorado Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
0
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

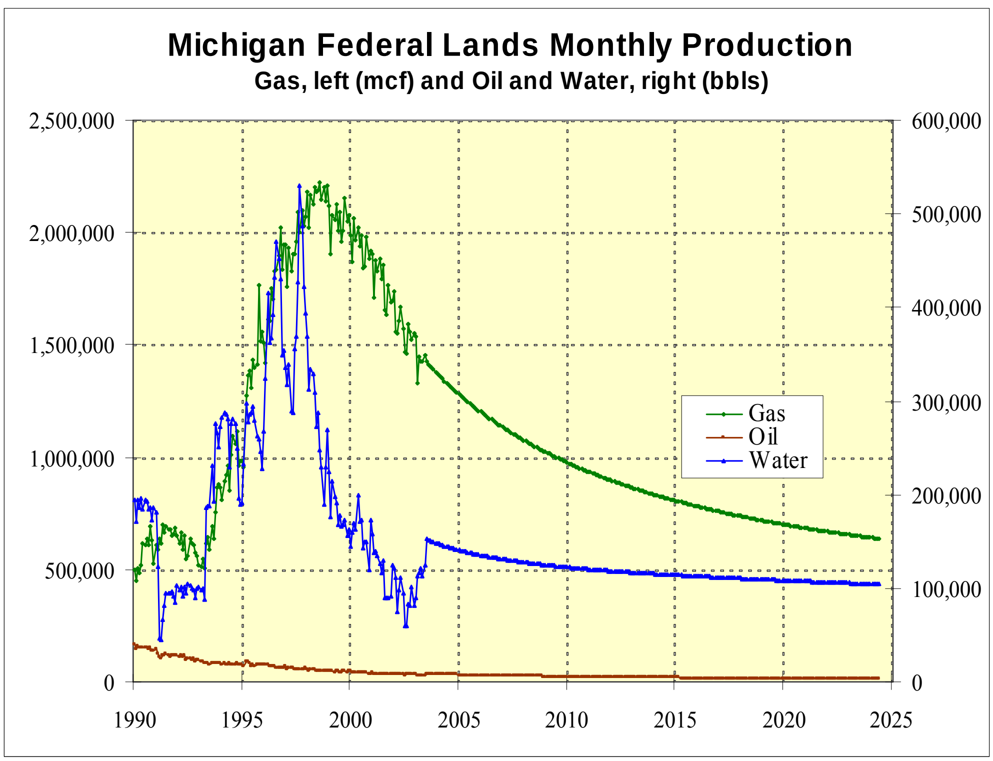

Illinois Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
2,500
2,000
1,500
1,000
500
0
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water


Kansas Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

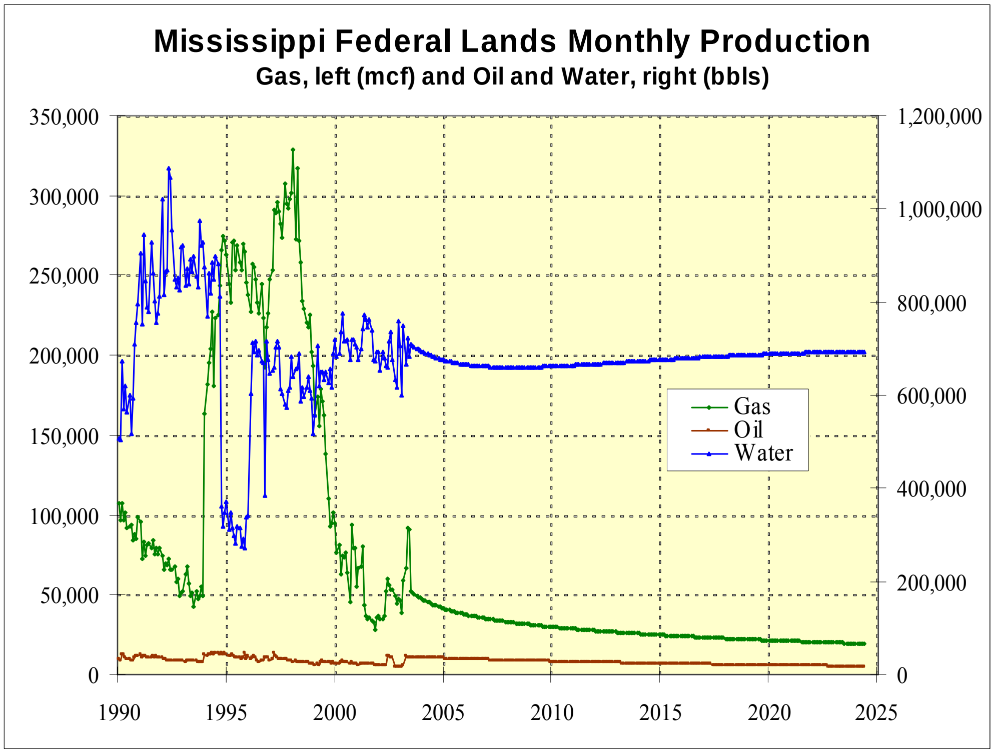

Kentucky Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
30,000
25,000
20,000
15,000
10,000
5,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

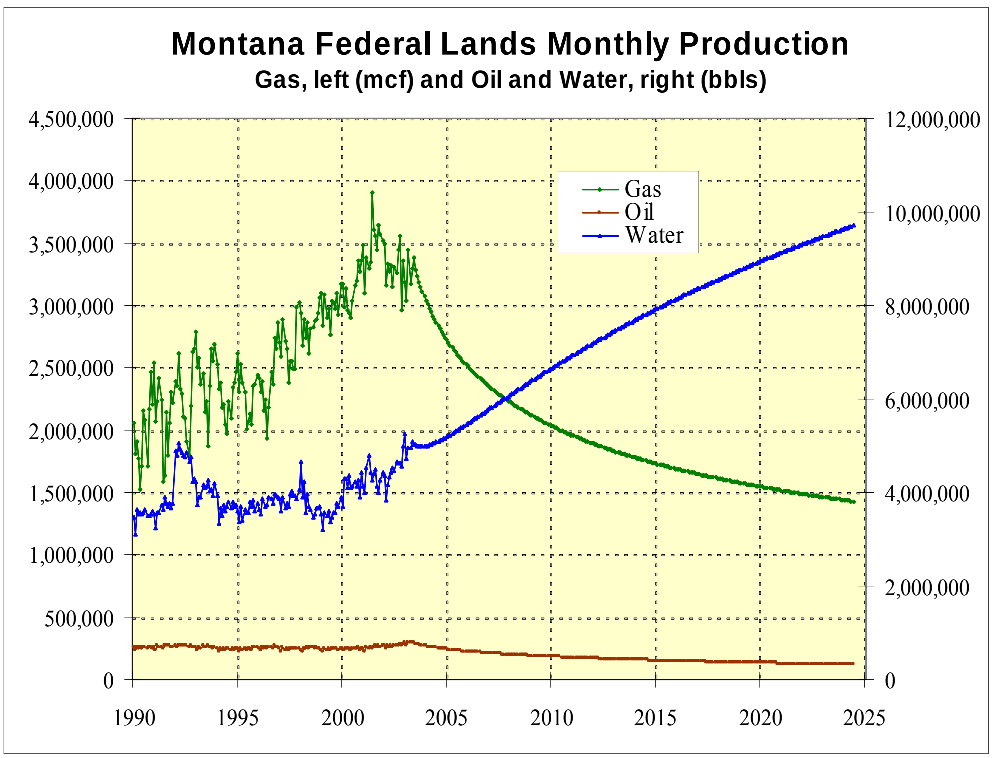


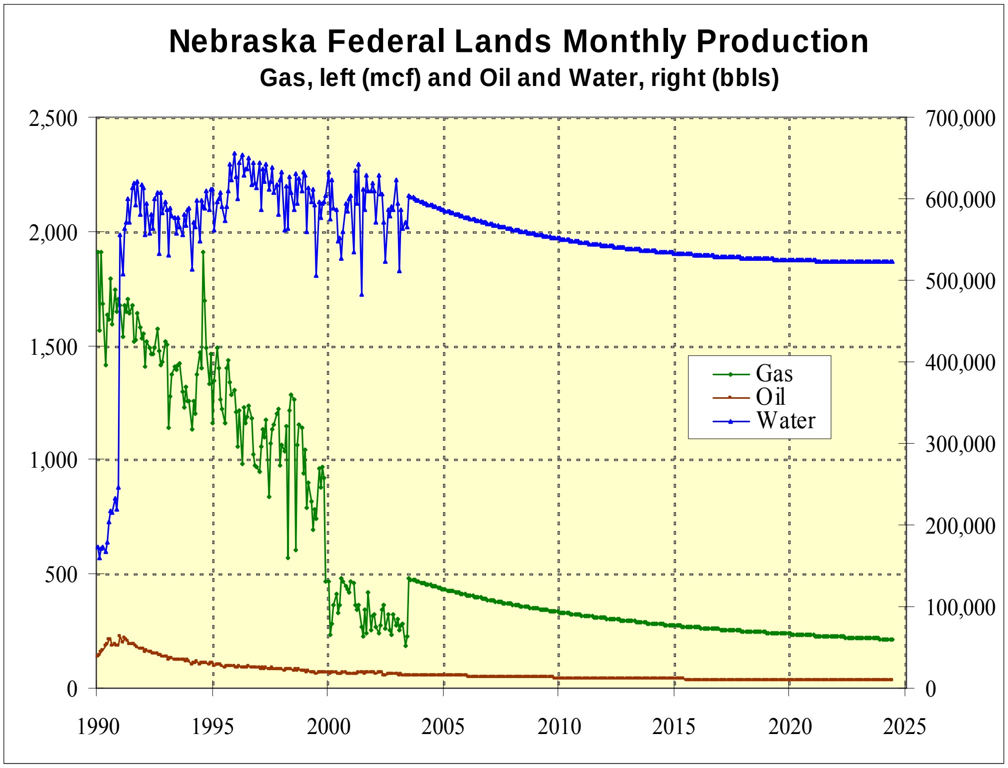
Louisiana Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

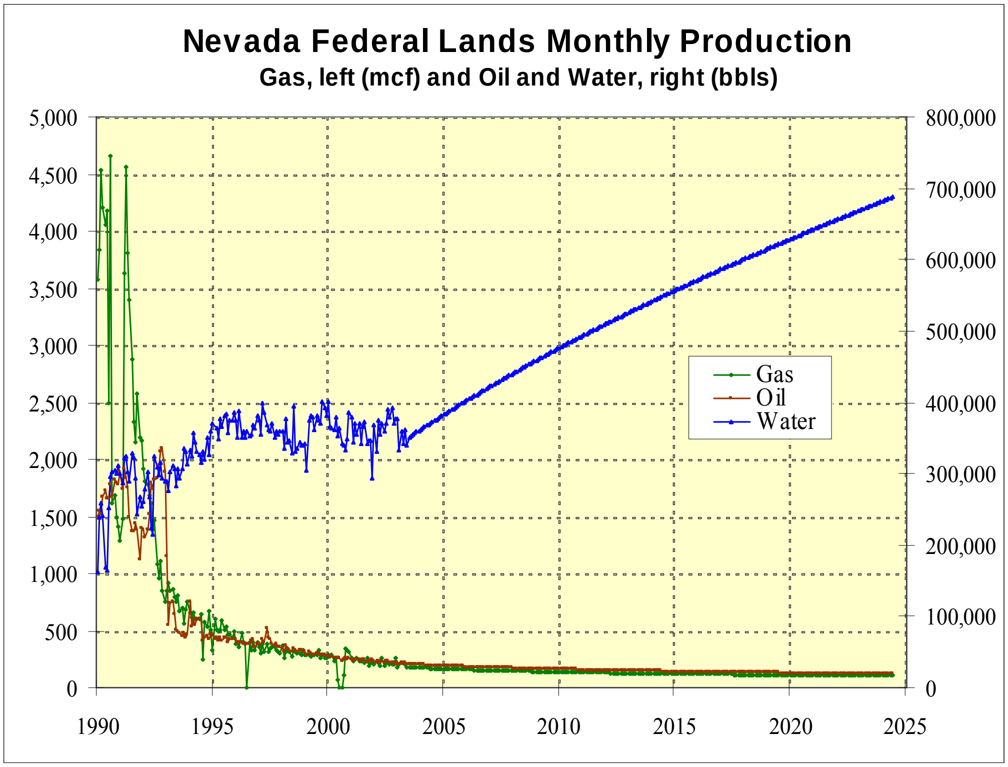


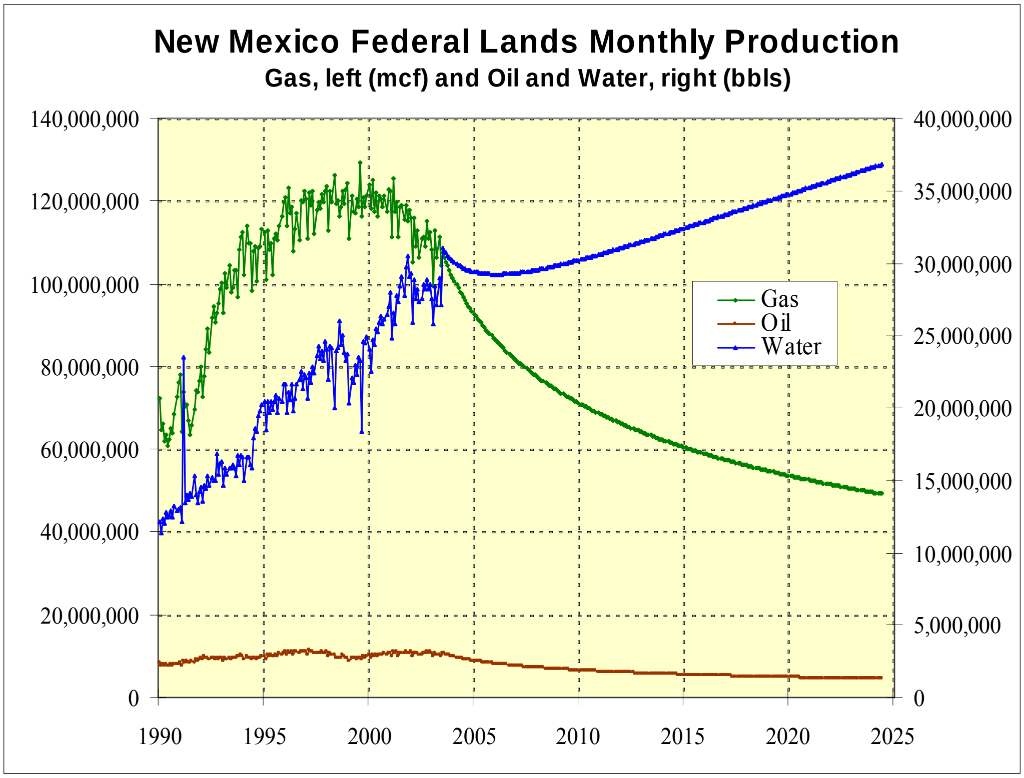
Michigan Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
600,000
500,000
400,000
300,000
200,000
100,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

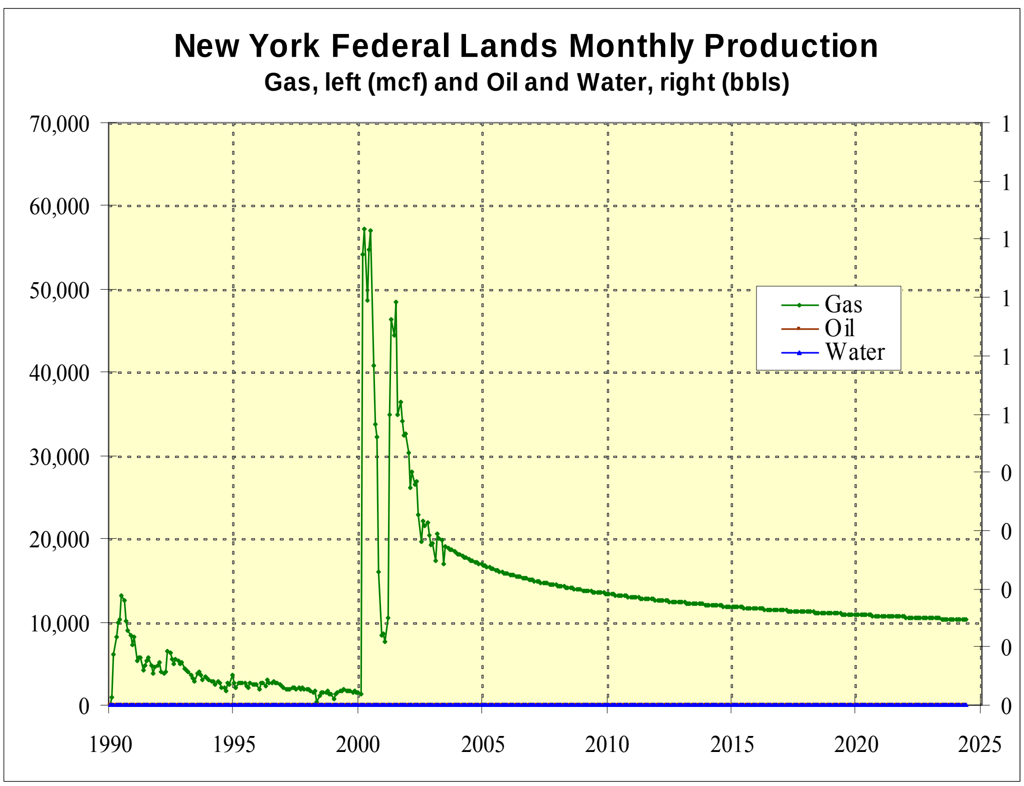

Mississippi Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

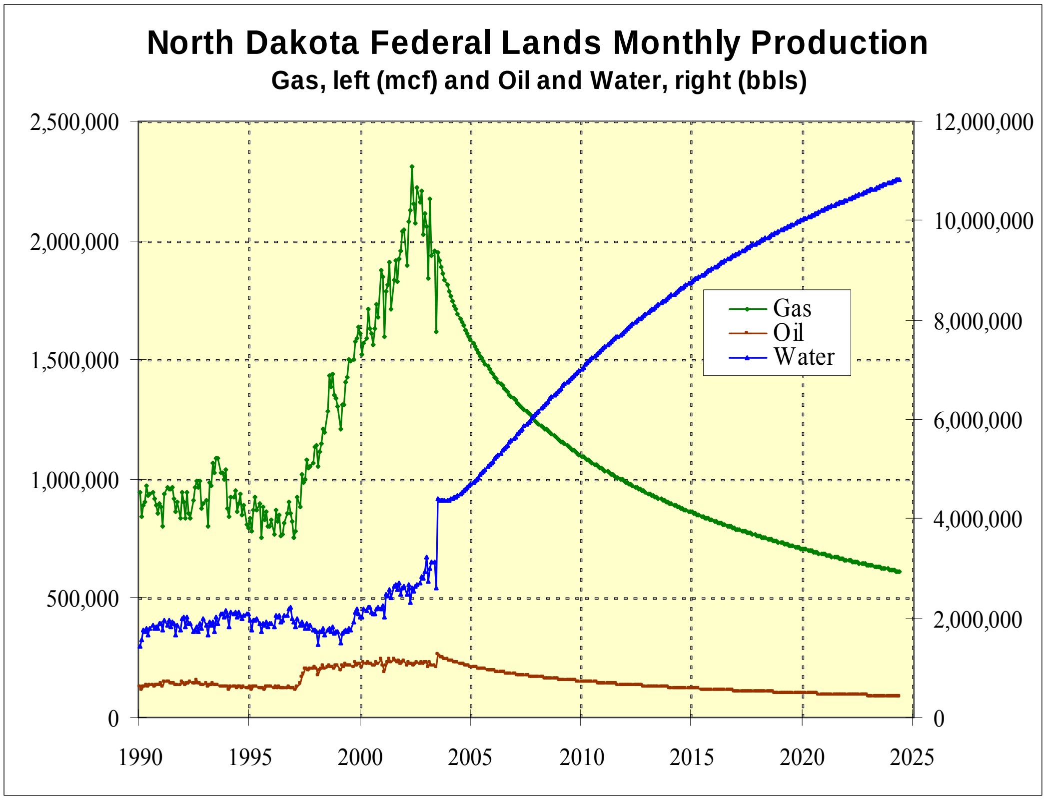

Montana Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

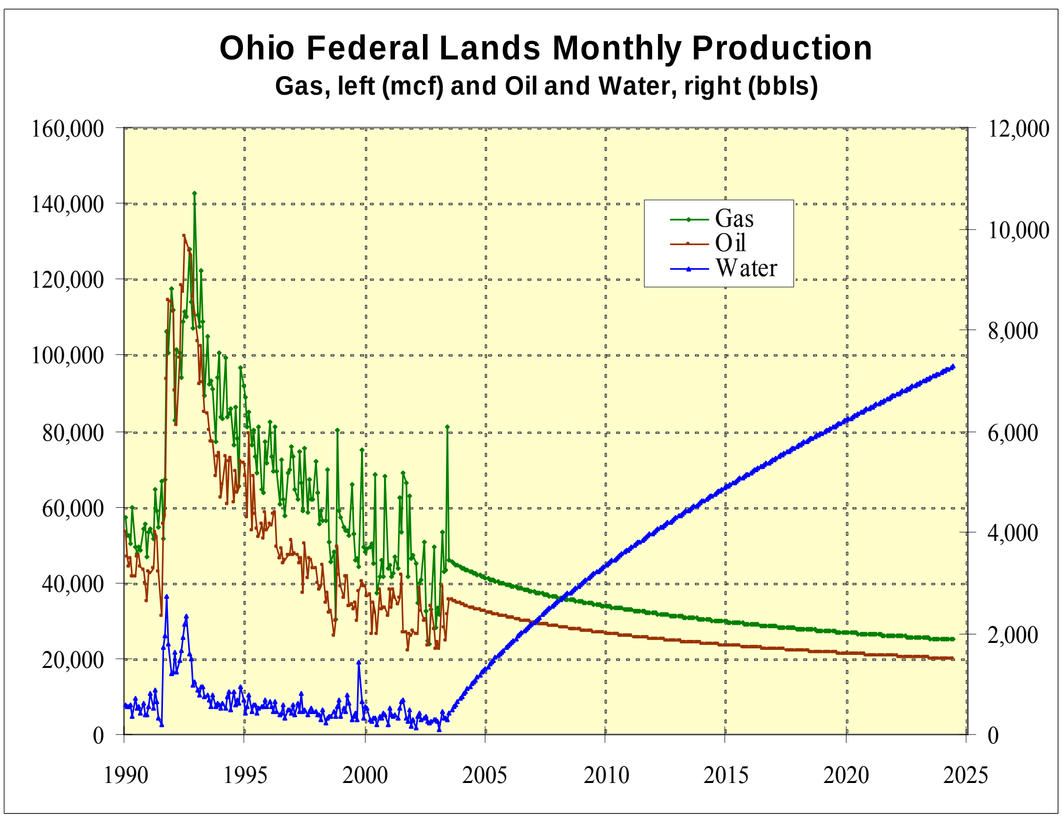

Nebraska Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
2,500
2,000
1,500
1,000
500
0
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

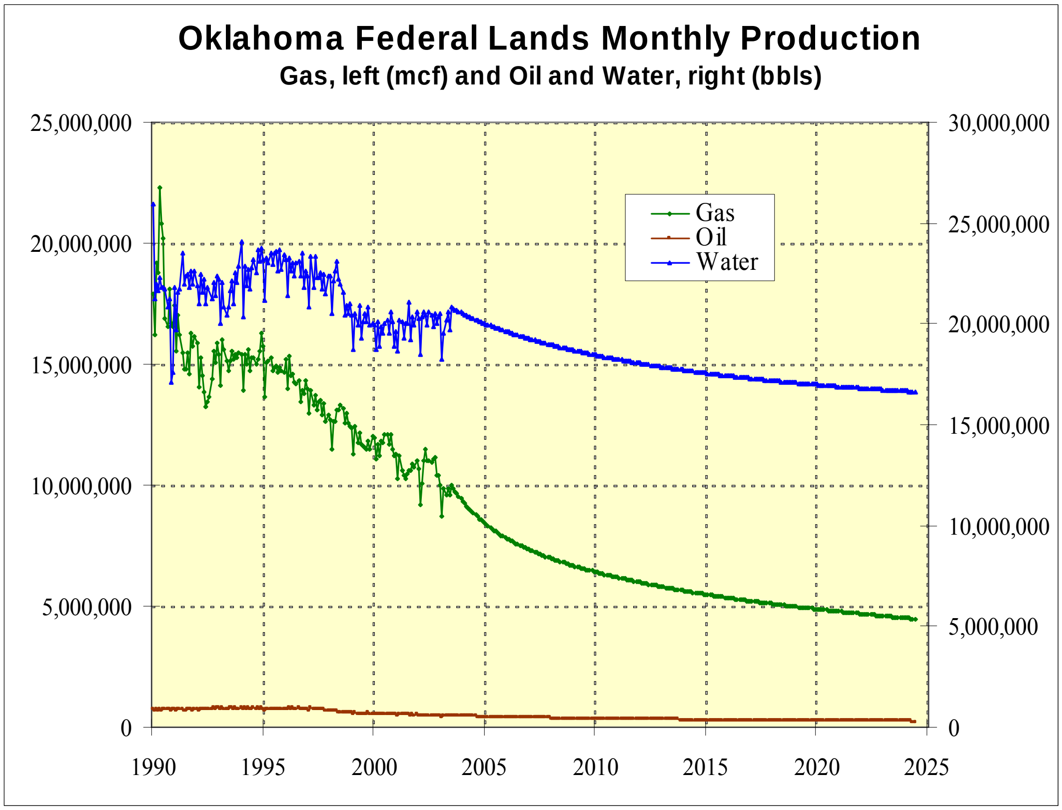

Nevada Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

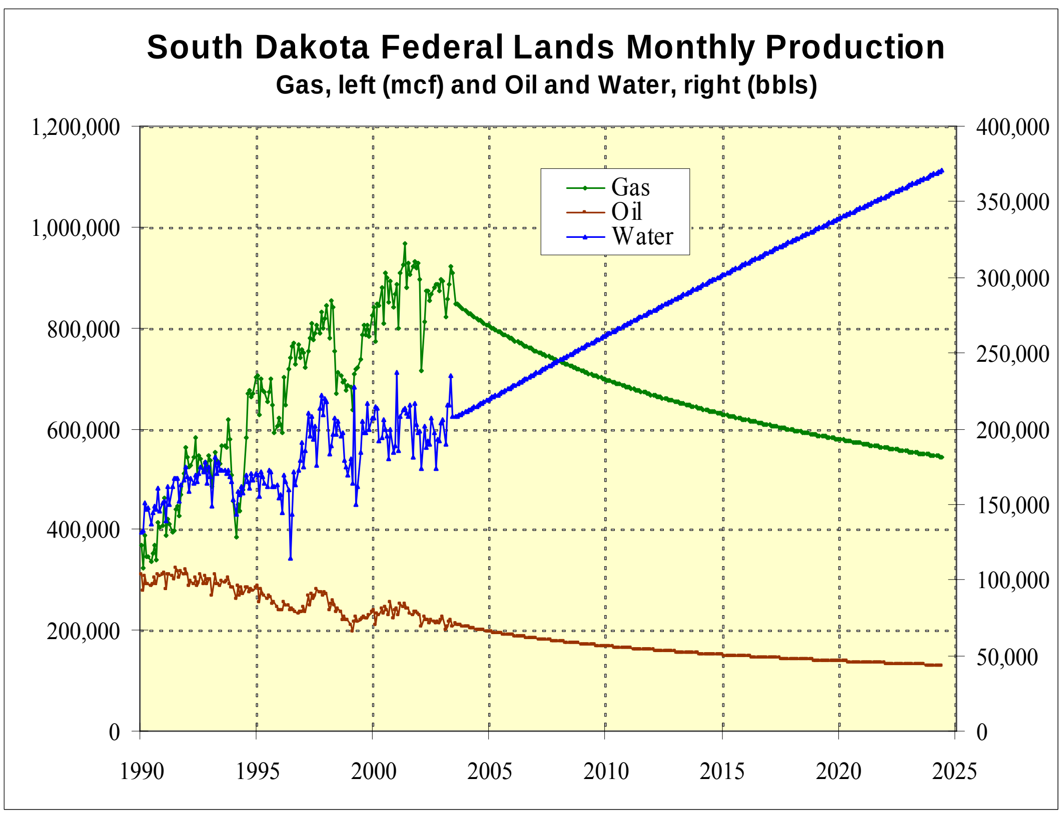

New Mexico Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

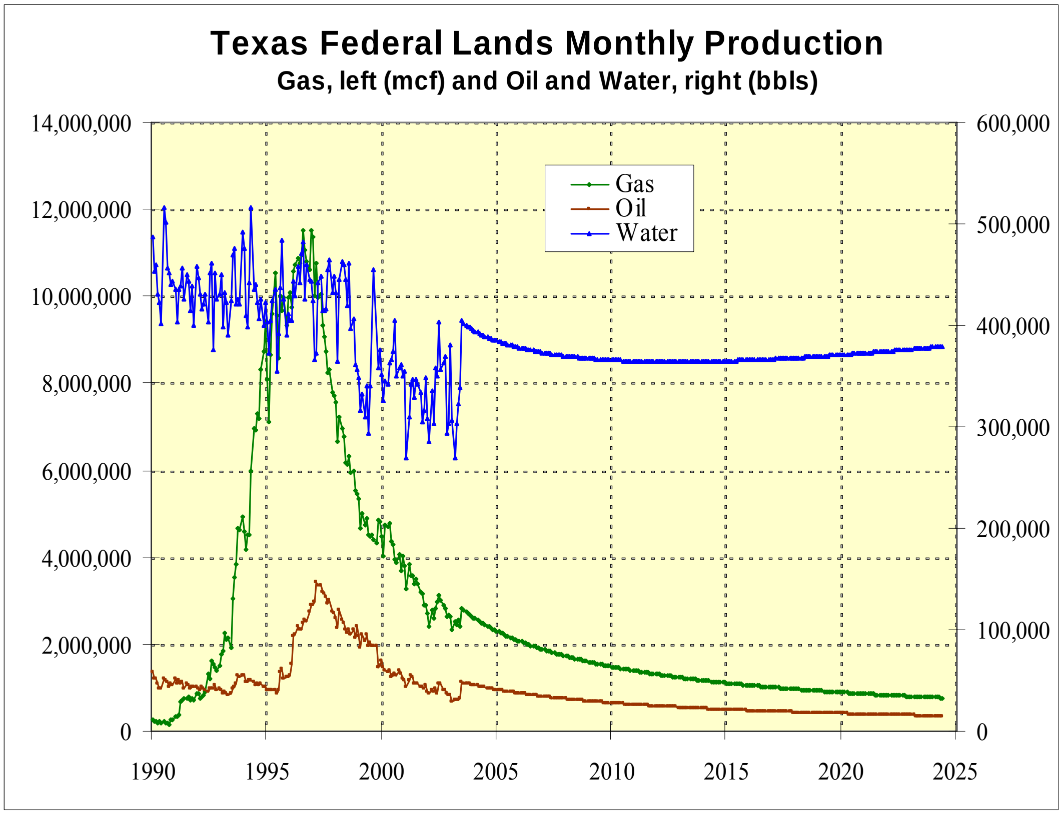

New York Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1
1
1
1
1
1
0
0
0
0
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

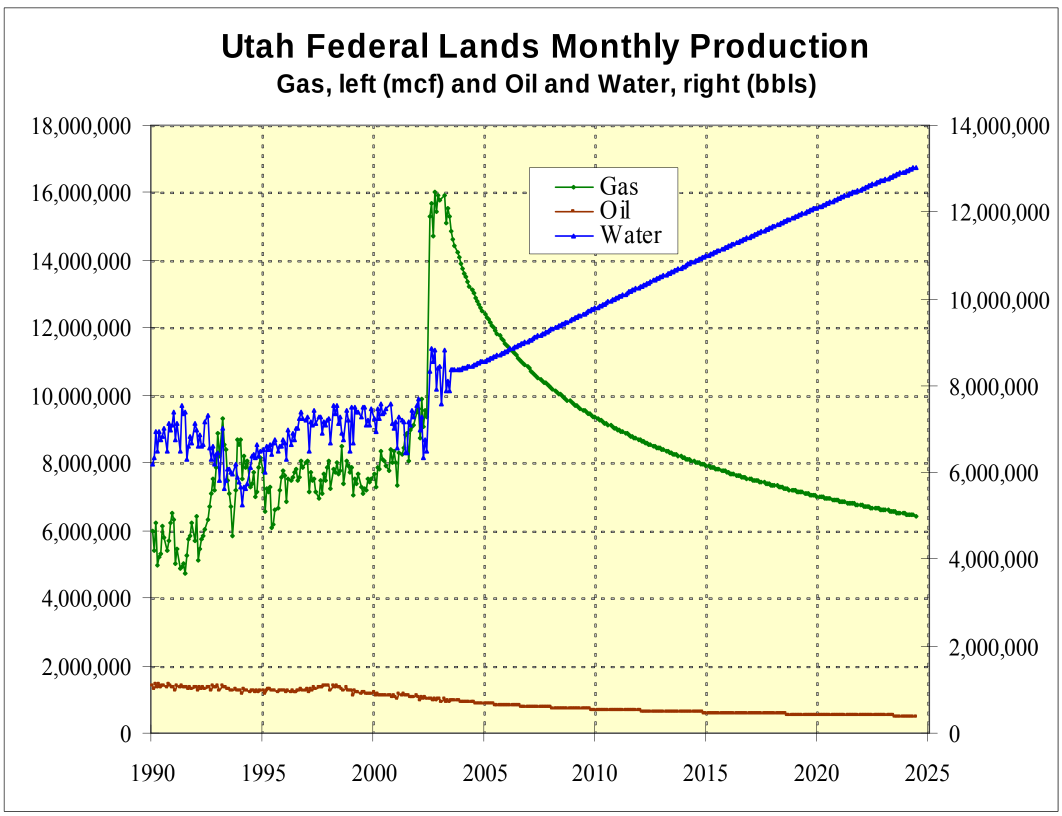

North Dakota Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

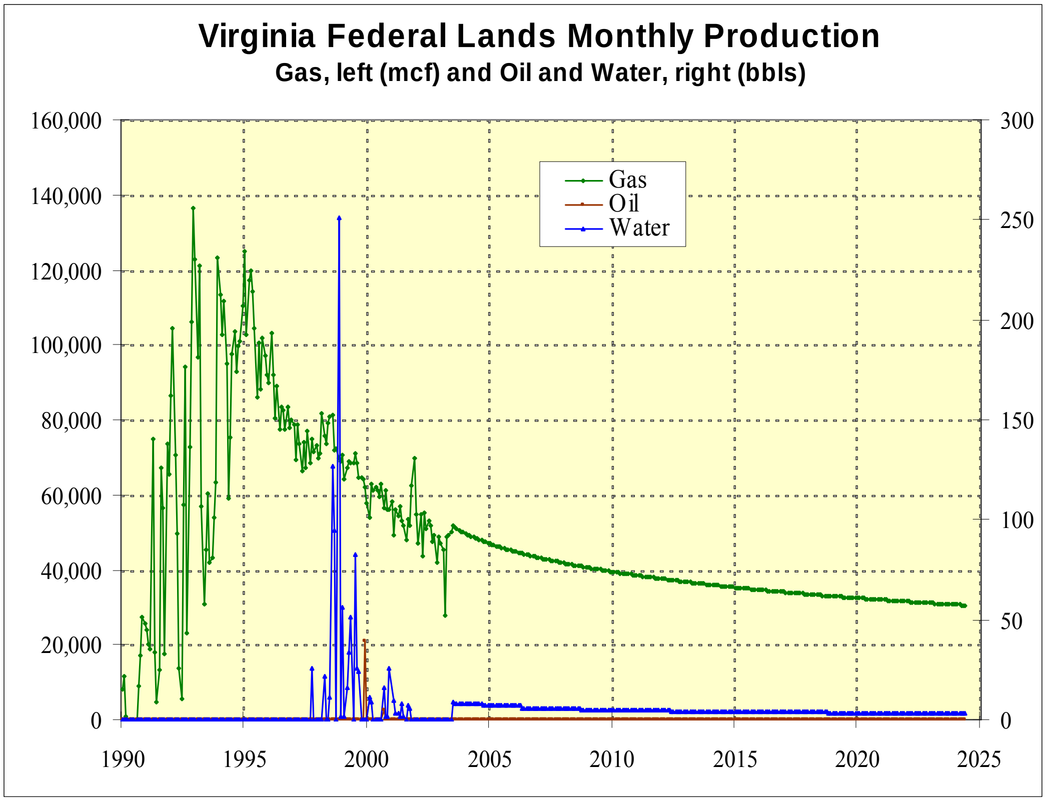

Ohio Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
12,000
10,000
8,000
6,000
4,000
2,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

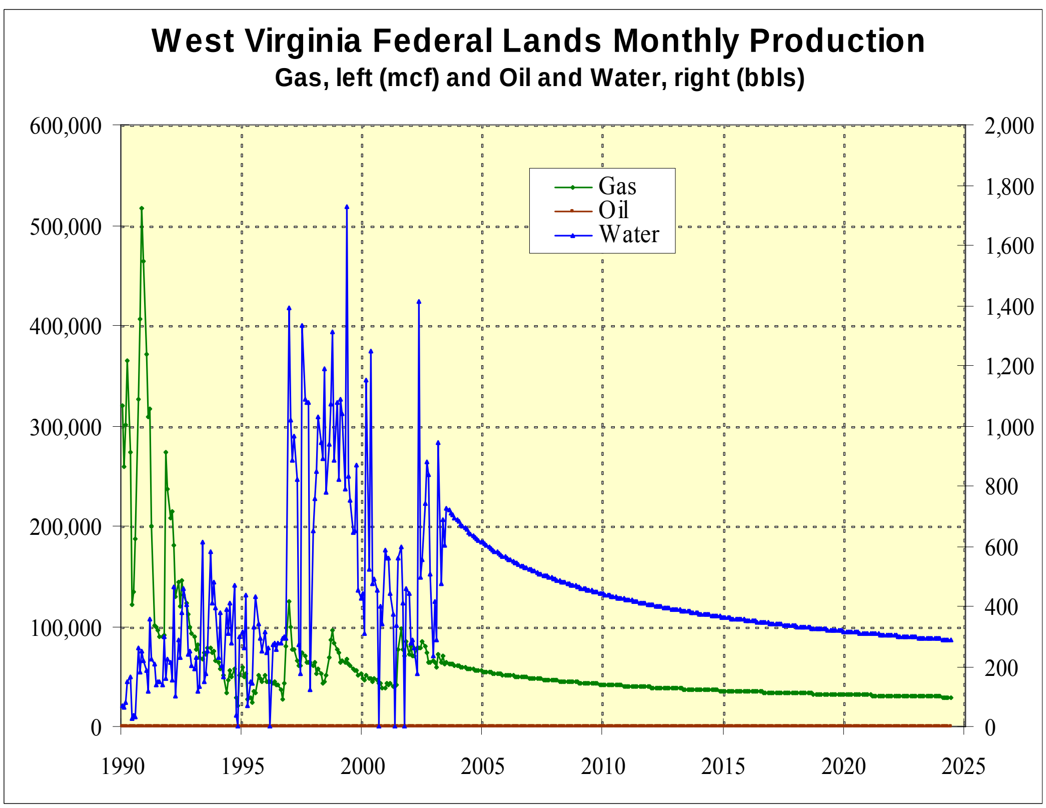

Oklahoma Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water

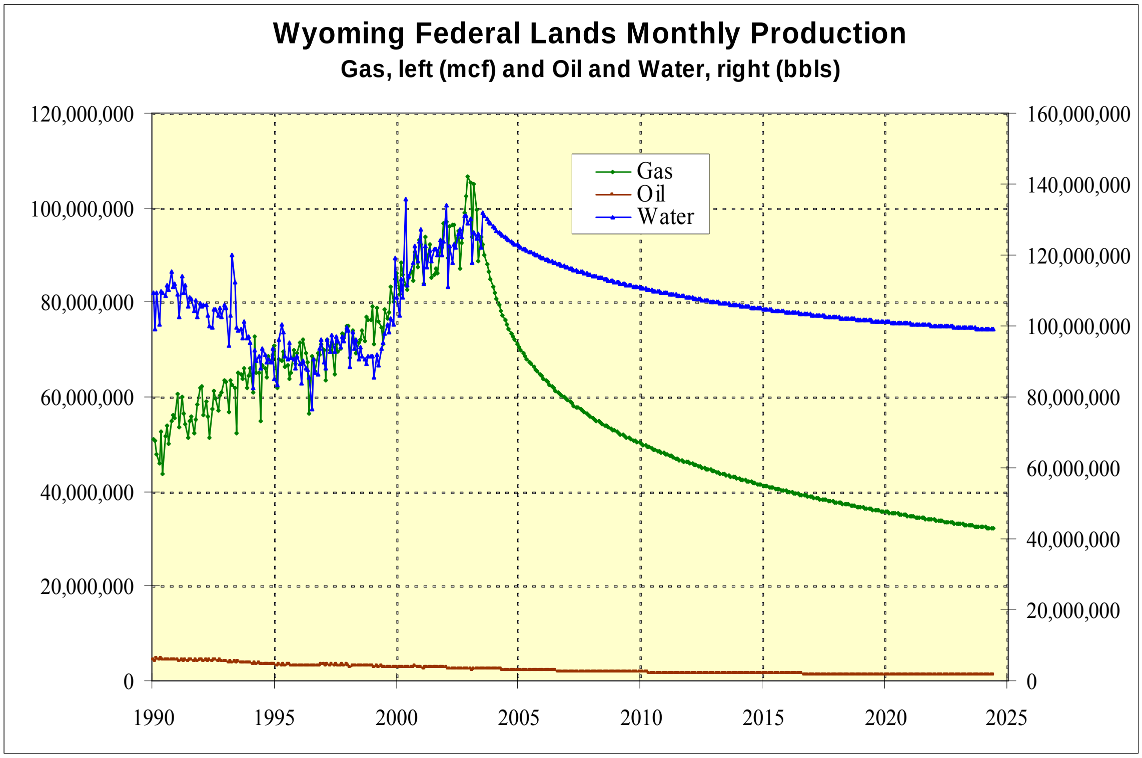

South Dakota Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water


Texas Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
600,000
500,000
400,000
300,000
200,000
100,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water


Utah Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water


Virginia Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
Gas
Oil
Water
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
300
250
200
150
100
50
0
1990
1995
2000
2005
2010
2015
2020
2025


West Virginia Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
Gas
Oil
Water
600,000
500,000
400,000
300,000
200,000
100,000
0
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1990
1995
2000
2005
2010
2015
2020
2025


Wyoming Federal Lands Monthly Production
Gas, left (mcf) and Oil and Water, right (bbls)
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
160,000,000
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
1990
1995
2000
2005
2010
2015
2020
2025
Gas
Oil
Water