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**CHARACTERIZATION OF OIL AND GAS WASTE DISPOSAL PRACTICES
AND ASSESSMENT OF TREATMENT COSTS**

✓ **YEARLY REPORT**

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CHARACTERIZATION OF OIL AND GAS WASTE DISPOSAL PRACTICES AND ASSESSMENT OF TREATMENT COSTS

ABSTRACT

The project consists of 3 tasks: 1) Developing a Production Environmental Database (PED) with the purpose of investigating the current industry waste storage and disposal practices by different regions, states, and types of waste and investigating the environmental impacts associated with these practices; 2) Evaluating the suitability of available and developing technologies for treating produced water and identifying applicable unit process configurations; and 3) Evaluating the costs associated with various degrees of treatment achievable by different treatment configurations.

Records of wells drilled during the years 1986 through 1991 were compiled from industry reports. Based on the collected data, the five foremost states in terms of total well completions relative to the nation were: Texas, Oklahoma, Kansas, California and Louisiana. Overall, drilling has decreased from an average of 60,000 wells/yr for the period 1981 through 1985 to 20,000/yr during 1986 through 1991. A produced water database was developed from data and information provided by the various state and federal agencies. Currently, the database has information on the production of oil, gas and brines from 24 states. The data from the produced water database indicate that for the most part, Class II Injection seemed to be the common disposal method. Other methods included evaporation, surface disposal via NPDES permit, road spreading, hauling out-of-state, and annular disposal. A survey of oil and gas operators has been developed, reviewed and edited. The survey is divided by topic into three sections: (1) drilling wastes; (2) associated wastes; and (3) produced water. The objective of the survey is to develop more current information on the waste volumes and disposal methods used during 1986 through 1991.

The possible treatment scenarios for produced water have been identified. Organic and inorganic contaminant removal, liquid/solid separation and liquid/emulsified oil separation have been identified as the main objectives of the treatment of produced water. Salinity is the most troublesome characteristic of the waste water that is being confronted. The costs incurred as a result of such treatment are being calculated. Various cost and performance models are being used to evaluate the water treatment and disposal scenarios. The levels of treatment achieved by the unit processes are being used to relate treatment costs to environmental impact.

CHARACTERIZATION OF OIL AND GAS WASTE DISPOSAL PRACTICES AND ASSESSMENT OF TREATMENT COSTS

EXECUTIVE SUMMARY

This project consists of 3 tasks: 1) Developing a Production Environmental Database (PED) with the purpose of investigating the current industry waste storage and disposal practices by different regions, states, and types of waste and investigating the environmental impacts associated with these practices; 2) Evaluating the suitability of available and developing technologies for treating the waste streams identified in Task 1 and identifying unit process configurations; and 3) Evaluating the costs associated with various degrees of treatment achievable by different treatment configurations.

Drilled Wells 1986 - 1991

Records of wells drilled during the years 1986 through 1991 were compiled from industry reports. These data indicate that drilling in the U.S. has decreased dramatically from about 60,000 wells annually from 1981 through 1985 to about 20,000 wells from 1986 through 1991.

Produced Water Database

A produced water database was developed from data and information provided by the various state and federal agencies. Currently, the database has information on the production of oil, gas and brines from 24 states. The data for produced water indicate that for the most part, Class II Injection is the common disposal method. Other methods include evaporation, surface disposal via NPDES permit, road spreading, hauling out-of-state, and annular disposal.

Literature Reviews

The U. S. EPA 1987 Oil and Gas Wastes Study. In 1987 the U.S. EPA conducted an extensive study of wastes associated with the exploration and production of oil and gas and geothermal energy. Using a set of generic reserve pit volumes and information on the number of wells drilled annually, the EPA study estimated 2.44 billion barrels of drilling wastes generated in 1985. Using data gathered from state agencies, the EPA study estimated 11.7 billion barrels of produced water generated in 1985.

The American Petroleum Institute 1985 Production Waste Survey. The American Petroleum Institute (API) conducted a study independent from that of EPA's on wastes associated with the exploration and production of oil and natural gas. It was estimated that 0.36 billion barrels of drilling wastes were generated in 1985. Based on state and industry records, it was estimated that a total of 16.3 billion barrels of produced water were generated in 1985. The survey data that were collected, however, indicated a volume closer to 20.9 billion barrels. The API study identified surface discharge and salt water

disposal as the most common disposal methods for reserve pit contents and produced water, respectively.

Other Studies. There appears to be relatively little published information related specifically to waste characterization and to waste environmental impacts. Leuterman et al. (1987) conducted a fairly extensive study in which samples were collected from reserve pits containing wastes from water based drilling operations. McHugh et al. (1993) present the results of a study completed by the Montana Board of Oil and Gas Conservation in which field samples were collected from active and inactive well sites, produced water disposal facilities, landfarms, and waste oil disposal sites. Mount et al. (1993) studied the toxicity of produced waters with the goal of developing multivariate regression equations for use in predicting the toxicity of a water on freshwater species (water fleas and fathead minnows) given measured concentrations of major ions (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^- , and HCO_3^-).

Hall (1990) presents some of the findings of EPA's investigation into the environmental impacts of oil and gas operations conducted as part of the 1987 Report to Congress. The report contains numerous photographs documenting seepage through unlined pits, breached pits, saline discharges to the land surface and freshwater streams, and vegetal and wildlife damage. Deuel (1990) outlines the effect of produced brines and other oil field wastes on plant and agricultural production. Van Sickle and Groat (1990) present a general discussion of the impact of oil field brines on coastal wetlands. Kaszuba and Buys (1993) discuss remediation strategies for seven sites in New Mexico containing brine impacted soil resulting from leakage from pipelines and reserve pits. Gros (1992) studied the environmental impacts of accidental oil spills from producing wells in Seminole County, Oklahoma.

PED Survey

A survey of oil and gas operators has been developed, reviewed and edited. The survey is divided by topic into three sections: (1) drilling wastes; (2) associated wastes; and (3) produced water. Draft copies of the survey have been distributed to the API, GRI and IPAA for their review and comment.

Industry Groups and Private Sector Contacts

In addition to the API, GRI and IPAA, three commercial companies (Petroleum Information, Dwights Energy Data, Inc. and GITI) that maintain databases on the oil and gas industry have been contacted in order to determine if their databases might contain information which is relevant to this study. Efforts are underway to evaluate and obtain data from these companies.

State Oil and Gas Field Maps

Maps of oil and gas fields in each state have been compiled. The appropriate USGS office in each state was contacted and available maps of oil

and gas resources in the state were requested. To date, maps for 26 of the states have been received.

DRASTIC Mapping

In order to determine the vulnerability of surficial aquifers to contamination from oil and gas drilling activities, the DRASTIC classification system is being considered for use in this project. The DRASTIC system classifies aquifers according to a vulnerability index calculated by weighting seven hydrogeologic parameters. Research is being conducted to obtain DRASTIC data for the producing states.

Treatment Categories

The treatment of produced water was separated into five main categories: inorganic contaminant removal, organic contaminant removal, liquid/solid separation, and liquid/emulsified oil separation. Conventional liquid/solid separation methods being used include flocculation, sedimentation and filtration. For the separation of emulsified oil and liquid, skim tanks, hydrocyclones, gas flotation cells, corrugated plate interceptors, diatomaceous earth, membrane technologies and cross flow devices are being considered. Granular activated carbon adsorption and air stripping with or without off-gas treatment will be considered for removal of organic compounds from produced water. The off-gas treatment that will be included, when appropriate, is gas phase granular activated carbon adsorption. Reverse osmosis and precipitation comprise the group of unit processes that will be considered for removing inorganic constituents from the waste stream.

Waste Water Characteristics

Produced water is a highly complex mixture of organic and inorganic components existing in various states (in solution, emulsified, in suspension, particulate, and particle adsorbed). Chemical analysis of several produced waters were obtained from several oil and gas agencies. Since the quality of the waste stream varies so widely, an effort was made to characterize the waste in general and this was accomplished by picking representative waste streams from the many analyses that were gathered.

Performance and Cost Models

Several models have been selected to estimate the treatment of produced waters and the costs associated with such treatment. Five models will be used: (1) Computer-Assisted Procedure for the Design of Wastewater Treatment Systems (CAPDET); (2) WATERMAID where MAID is an acronym for Microcomputer Assisted Interactive Design; (3) the Produced Water Management Options Model developed by the Gas Research Institute (GRI) (4) the USEPA WATER model; and (5) the USEPA WATERCOST model. These models and selected cost equations will be used both separately and in conjunction with each other to estimate cost and performance of the chosen unit processes.

Unit Process Parameters

A list of parameters for some of the unit processes was developed. Performance of a given treatment can be more easily related to cost when a design parameter such as empty bed contact time (EBCT), the amount of time that a waste water is exposed to granular activated carbon, is utilized rather than flow. When sizing a unit process or using a model based on waste stream flow rate, representative flows have been used. Flow regimes of ten thousand, one hundred thousand, and one million gallons per day have been selected based on data received from the states of California, New York, South Dakota, and Mississippi.

Baseline Costs

Baseline disposal costs, or costs currently being incurred for the disposal of produced water, have been gathered from the literature and range from \$0.10 to \$0.50 per barrel in Texas (Tomson, Oddo and Kan, 1992) to an average of \$1.50 per barrel in Ohio (Blem and Becker, 1985). Poor well maintenance for a given well or low injectability of a certain produced water can lead to the high disposal costs of almost \$2.00 per barrel when the transportation to a disposal site is made necessary.

Water Treatment Costs

During the current reporting period preliminary estimates of costs were determined for the treatment of one representative waste stream. The representative waste stream was a produced water taken from the Brentwood oil field, which is in California, on 9/25/92 and analyzed on 10/02/92. The rate of flow for the costing of this representative waste stream was assumed to be one million gallons per day. The resulting costs amounted to \$0.25 - \$0.50 per barrel.

CHARACTERIZATION OF OIL AND GAS WASTE DISPOSAL PRACTICES AND ASSESSMENT OF TREATMENT COSTS

INTRODUCTION

This project consists of 3 tasks: 1) Developing a Production Environmental Database (PED) with the purpose of investigating the current industry waste storage and disposal practices by different regions, states, and types of waste and investigating the environmental impacts associated with these practices; 2) Evaluating the suitability of available and developing technologies for treating the waste streams identified in Task 1 and identifying unit process configurations; and 3) Evaluating the costs associated with various degrees of treatment achievable by different treatment configurations.

Much progress has been achieved on all three tasks over the past year. In general, the following achievements have been completed:

Task 1

1. Records of wells drilled during the years 1986 through 1991 were obtained.
2. All state agencies responsible for regulating the oil and gas industry were surveyed.
3. An extensive literature review was conducted in relation to the objectives of this task.
4. A survey questionnaire to oil and gas operators was prepared. The survey covers all aspects of waste production and disposal as well as environmental characteristics of the exploration and production activities.
5. Most industry groups and private data companies were contacted regarding data collection and possible interaction and collaboration.
6. Maps of oil and gas fields in the producing states were compiled.
7. DRASTIC (National Water Well Association, 1987) vulnerability maps for ground water aquifers in the oil and gas producing states are being compiled.

Tasks 2 and 3

1. Five main categories of treatment for produced water were identified.

2. Produced water characteristics were researched.
3. Performance and cost models were selected.
4. The design parameters for the selected unit processes were determined.
5. Current baseline costs for the disposal of brines were investigated.
6. Preliminary produced water treatment costs were calculated.

Details of the results on each of the tasks are presented in the section entitled Project Status.

PROJECT DESCRIPTION

The proposed effort consists of 3 tasks:

Task 1. Developing a Production Environmental Database (PED) with the purpose of investigating the current industry waste storage and disposal practices and investigating the environmental impacts associated with these practices. Task 1 is composed of subtasks as follows:

1. Estimate quantities of waste generated by oil and gas extraction by state, region, and type.
2. Develop a profile for the waste characteristics by state, region, and type.
3. Determine current industry waste storage and disposal practices by state, region, and type.
4. Develop the environmentally significant characteristics of the disposal methods used.
5. Determine the hydrogeologic, surface water and exposure point characteristics of "receptor environments."
6. Investigate the predominant landuse patterns surrounding oil and gas activities.
7. Assess the environmental impacts of oil and gas activities on a state and regional basis.
8. Assess the differences in environmental impacts analyzed on a statewide and regional basis from those determined from a site-specific data.

9. Analyze the data statistically to develop distributions for some of the parameters on a state, regional and nationwide basis.
10. Assimilate all the data in a database.

Tasks 2 and 3. The environmental impacts of, and the estimated costs incurred during, the disposal/use of water produced in association with the production of oil and gas will be addressed during the completion of tasks two and three of this work. In order to avoid a negative impact on the environment by a disposal/use scenario, variable levels of treatment will possibly be necessary. Physicochemical treatment unit processes for waste water will be evaluated with respect to their suitability in treating water that has been produced in association with the production of oil and gas. Current treatment and disposal practices will be examined and added to the list of alternatives available. Several treatment scenarios representing various configurations and combinations of unit processes will be evaluated.

The costs of these scenarios will then be compared with the environmental impact resulting from a designated disposal practice or use for the treated water. Water quality will be expressed by the concentrations of specific target contaminants as well as several composite parameters. Contaminants of interest and concern will be grouped and these groups will be based on the likely similarities of both the unit processes required to remove them, and their chemical makeup. The proximity of the properties of the contaminant constituents will also be used to group contaminants. Thus, an assessment of treatment technologies and costs for the removal of one constituent within such a group may be useful in assessing the treatment and cost for the removal of another.

A database of information will be established containing chemical analyses of various produced waters that eventually will produce a representative sample for which treatment scenarios can be identified. Final use and disposal options will also be considered so that the environmental impacts that are possible given the various levels of treatment can be examined. Estimates of the costs associated with these scenarios will be calculated so that a random operator will be able to make preliminary decisions relating costs and environmental impact.

Composite parameters, such as total organic carbon (TOC), give an indication of the total concentration of several contaminants in water. In some instances, it may prove to be useful to estimate treatment costs by attributing the chemical characteristics of a representative constituent compound (e.g. toluene) to a given composite parameter (e.g. TOC). Alternatively, a solution weighted average of the characteristics of several constituent contaminants might be used. Process performance, in terms of removal efficiency and effluent concentration,

will be evaluated using simulation models for candidate unit processes. Existing cost information for these processes will be used in conjunction with performance calculations to generate trade off curves for water quality (environmental impact) and treatment cost.

PROJECT STATUS

Task 1. Significant efforts were expended in the past year on data collection for the PED. These efforts will first be summarized and then followed by a detailed discussion of the accomplishments for each item:

1. Records of wells drilled during the years 1986 through 1991 were obtained.
2. All state agencies responsible for regulating the oil and gas industry were surveyed.
3. An extensive literature review was conducted in relation to the objectives of this task.
4. A survey questionnaire to oil and gas operators was prepared. The survey covers all aspects of waste production and disposal as well as environmental characteristics of the exploration and production activities.
5. Most industry groups and private data companies were contacted regarding data collection and possible interaction and collaboration.
6. Maps of oil and gas fields in the producing states were compiled.
7. DRASTIC (National Water Well Association, 1987) vulnerability maps for ground water aquifers in the oil and gas producing states are being compiled.

Drilled Wells 1986 - 1991

Records of wells drilled during the years 1986 through 1991 were compiled from industry reports. The data were accumulated for each state into three categories: oil, gas, and dry wells as shown in Table 1. Based on the collected data, the five foremost states in terms of total well completions relative to the nation were: Texas, Oklahoma, Kansas, California and Louisiana.

These data were compared to the total completions reported by the U.S. EPA in their 1987 report to congress (U.S. EPA, 1987a; see Figure 1). The data from Table 1 and Figure 1 indicate that drilling in the U.S. has decreased

dramatically from about 60,000 wells annually from 1981 through 1985 to about 20,000 wells from 1986 through 1991.

Survey of State Agencies

All state and federal agencies responsible for regulating the oil and gas industry were surveyed for any data they might have in relation to production of oil and gas, drilling activities, volumes of wastes generated and volumes of produced water. Additionally, the states were surveyed for any data they might have on disposal practices in the state.

In general, few of the states had any data on drilling and associated wastes. Most states had some data on produced oil, gas and water, and some of the disposal methods used in the state. The results from the state phone survey are summarized as follows:

<u>Alabama</u>	Data on produced water volumes and injected volumes are available.
<u>Alaska</u>	The state has data on the volumes of oil, gas, produced water, and injected water.
<u>Arkansas</u>	The state has records of produced water and injected water volumes.
<u>California</u>	Annual volumes of produced oil, gas and water are available from 1987 to present time.
<u>Colorado</u>	Volumes of oil and gas and water production are reported to the state on an annual basis.
<u>Florida</u>	Monthly produced water data may be available. There is little information on injected volumes.
<u>Illinois</u>	Data on injected volumes are available, but are not easily accessible.
<u>Indiana</u>	Data on injected volumes (the only disposal method in the state) are available.
<u>Kansas</u>	Only data available are those of injected volumes of produced water.
<u>Kentucky</u>	The state disposes of brines by surface discharge or reinjection. Produced waters are stored in tank batteries, but record-keeping is not likely.
<u>Louisiana</u>	Produced and injected brine volumes are available as well as oil and gas production.
<u>Michigan</u>	Some information exists on the amount of produced water and injected volumes.
<u>Mississippi</u>	Data on produced volumes of water which are injected in Class II wells (only disposal method) are available.
<u>Missouri</u>	Data on produced oil, gas, and water volumes are available.

<u>Montana</u>	The state has records of oil and gas production and produced water volumes.
<u>Nebraska</u>	Monthly data on production of oil, gas and brine are available. Only 50-60% is reinjected; but the data on reinjection are not formally compiled.
<u>Nevada</u>	Monthly produced oil, gas and water data are available.
<u>New Mexico</u>	No records are kept of produced water, however records are kept of injected brines for the years 1986 through 1989.
<u>New York</u>	Annual reports of oil and gas production are available since 1985. Associated brine production data is available for 1987 through 1990 as well as disposal well injected volumes from 1987 through 1991.
<u>North Dakota</u>	Volumes of produced oil, gas, and water are available on a monthly basis.
<u>Ohio</u>	Data on an annual basis of produced oil, gas and water are available on a per well basis.
<u>Oklahoma</u>	Volumes of oil and gas produced are available as well as data on the injection of brine.
<u>Oregon</u>	Data on produced water and injected volumes are available.
<u>Pennsylvania</u>	Very little data is available.
<u>South Dakota</u>	Annual production of oil, gas and water are available as well as injected water information.
<u>Texas</u>	Annual data on reinjected volumes of produced water are available.
<u>Utah</u>	Data on the disposal of brines on an annual basis are available. Also, data on the production of oil and gas in the state.
<u>Virginia</u>	No data on volumes of produced water prior to 1991 are available.
<u>West Virginia</u>	Only monthly volumes of produced water that are injected or produced as a product of water flooding are reported to the state.

A produced water database was developed from data and information provided by the various state and federal agencies. Currently, the database has information on the production of oil, gas and brines from 24 states (see Table 2). The information provided by the 24 states ranged from brief annual summaries of total production activities to extensive information broken down by field and/or by well. The database summary provided in Table 2 is supported with three additional tables 2A, 2B and 2C. The support tables 2A through 2C reference the documents that were used to develop the summary database, and provide explanations to the coded notes in Table 2. It was not possible to compare the total volume of produced water nationwide on an annual basis to

that presented by EPA in their 1987 report to congress (U.S. EPA, 1987a; see Figure 2) due to the lack of data from some of the states.

In addition to production data, the states were specifically instructed to provide information on the disposal methods for brines used in the state. For the most part, Class II Injection seemed to be the common disposal method. Other methods included evaporation, surface disposal via NPDES permit, road spreading, hauling out-of-state, and annular disposal. The majority of the states did not collect information about the chemical characteristics of the brines produced in their state.

It should be mentioned that while data exist on produced water for most of the states, some states do not assimilate the required data in any form that is readily available. These states which include Illinois, Indiana, Kentucky, Louisiana, New Mexico and Texas; are currently on hold pending possible site visits.

Literature Reviews

An intensive literature research effort was conducted with the objective of developing a baseline of information about the environmental impact of oil and gas activities.

Background. Oil and gas drilling and production activities are conducted over most of the U.S. (Figure 3). In a 1980 statutory amendment to the Resource Conservation and Recovery Act (RCRA) Congress exempted wastes associated with the exploration and production of oil and gas from regulation under RCRA, but also required EPA to conduct detailed studies to determine if regulation of these wastes as hazardous waste under Subtitle C of RCRA is needed (Worrell, 1992). The U. S. EPA subsequently completed an in-depth analysis of the oil and gas industry and the current and alternative waste management practices (U.S.EPA, 1987a). The results of EPA's study were documented in a report to Congress (U.S.EPA, 1987b). EPA's 1988 regulatory determination concluded that oil and gas wastes should not be regulated under the existing hazardous waste program. During this same time period the American Petroleum Institute (API), in a separate effort, completed parallel studies aimed at establishing independent estimates of waste volumes and sources, waste management practices, waste disposal methods, waste characteristics, and pit closure practices. The results of API's study were documented in two unpublished reports (Wakim, 1987; and Wakim, 1988).

The U. S. EPA 1987 Oil and Gas Wastes Study. In 1987 the U.S. EPA conducted an extensive study of wastes associated with the exploration and production of oil and gas and geothermal energy. The EPA study contained an overview of the oil and gas industry with estimates for wastes generated from the industry's activities, an analysis of current and alternative waste management and disposal practices, and a human and environmental health risk assessment.

In addition, a baseline cost estimate of waste management practices was completed as well as an economic impact analysis of alternative waste management practices.

The EPA study divided oil and gas wastes into two broad categories: drilling wastes and production wastes. Estimates were made of the annual volumes of these wastes generated during the period 1981 - 1985. Drilling wastes included drilling fluids, drill cuttings, well completion fluids, packing fluids, reservoir stimulation fluids, and other miscellaneous wastes that are normally deposited in the on-site reserve pit. Using a set of generic reserve pit volumes and information on the number of wells drilled annually the EPA study estimated 2.44 billion barrels of drilling wastes generated in 1985. Production wastes included produced water and associated wastes such as tank bottoms. Using data gathered from state agencies the EPA study estimated 11.7 billion barrels of produced water generated in 1985.

The EPA study was quite extensive in its coverage, however, the main thrust of the study was to identify the risk to the environment from oil and gas activities as directed by Congress. Consequently, the work that was completed utilized nationwide scenarios that were considered to be "reasonable and representative" of a typical exploration and production site. For purposes of risk assessment modeling, constituent concentrations in drilling pit wastes (solids and liquids) and produced water were obtained from data collected as part of an earlier nationwide sampling study conducted by EPA (U.S.EPA, 1987c). Given the short time frame and funding limitations imposed by Congress on the EPA, it was impossible to collect field and site-specific data on some of the parameters that are of concern in predicting environmental impact. The alternative approach used by EPA employed ranges of values for those parameters.

As an example, in EPA's study, the distance to the nearest exposure well was assumed to have a close value of 60 m, a medium value of 200 m, and a far value of 1,500 m. Similarly, the distance to the nearest surface water intake was assumed to be close at a value of 1 km, and far at a distance of 10 km. This approach may have been sufficient from a health and risk based point of view at the time the study was completed, however, this approach did not allow for regional or state differentiated environmental impact, and did not allow for analyzing site-specific data.

The American Petroleum Institute 1985 Production Waste Survey. The American Petroleum Institute (API) conducted a study independent from that of EPA's on wastes associated with the exploration and production of oil and natural gas. In order to collect information on exploration and production wastes, the API initiated an industry survey. Exploration and production wastes were divided in the survey into three basic categories: drilling wastes, produced waters and other associated wastes.

Drilling fluids, for the purposes of the API survey, consisted primarily of drilling muds, cuttings from the well bore and chemicals added to drilling fluid systems to improve mud properties. The disposal methods for drilling wastes identified by API are listed in Table 4. Produced water consisted of formation water plus chemicals added for treatment such as corrosion inhibitors. Disposal methods for produced water are listed in Table 5. Associated wastes consisted of small volumes of waste such as tank bottoms and produced sands generated in conjunction with drilling and production operations.

The data that were collected provided estimates of volumes and disposal practices of drilling fluids for all wells drilled in 1985 based on a sample of 659 wells (about 1% of the 69,734 wells drilled in 1985). It was estimated that 0.36 billion barrels of drilling wastes were generated in 1985. The volume of associated wastes was not estimated on a nationwide basis because of the unclear relationship between the volume of associated wastes and the volume of crude oil production. Produced water estimates were arrived at through the survey process and also by reviewing records from state agencies and industry sources (operator inventories). Based on state and industry records, a total of 16.3 billion barrels of produced water were generated in 1985. The survey data that were collected indicated a volume closer to 20.9 billion barrels. No attempt was made in the API study to chemically characterize oil and gas wastes or to assess the potential environmental impacts of these wastes. The API study, however, identified the most common disposal procedures for reserve pit contents and for produced water. As shown in Figure 4, surface discharge and salt water disposal are the most common disposal methods for reserve pit contents and produced water, respectively.

Other Studies. Despite the proliferation of literature dealing with oil and gas exploration and production, there appears to be relatively little published information related specifically to waste characterization and to waste environmental impacts. This apparent discrepancy is no doubt related to the unregulated status of oil and gas wastes and to considerations given to public relations by oil and gas operators. The following sections present the literature on these subjects as researched thus far.

Oil and Gas Waste Characterization

During the period 1979 - 1986 Leuterman et al. (1987) conducted a fairly extensive study in which samples were collected from reserve pits containing wastes from water based drilling operations. Samples were collected from both the water phase and the sludge phase shortly after drilling operations ceased at 125 pits located in Texas, Oklahoma, Louisiana, California, and the Rocky Mountain states. The samples were analyzed for heavy metals and ion concentrations and the average and range of measured values are presented in the study. The results showed that more than 85% of the reserve pits had soluble heavy metal concentrations below hazardous waste standards. Lead and chromium levels were generally found to be below concentrations found in

typical soils. In all cases the mud phase samples had a higher heavy metal content than the water phase samples indicating that the metals are bound to the organic and clay particles. Conversely, the water phase samples were found to contain higher average concentrations of major ions than the mud phase. This is in contrast to EPA data that suggests the reverse to be true regarding major ions (U.S. EPA, 1987c). While the average values of ions in both phases were found to be above concentrations suitable for human use, the average values did not exceed limits for irrigation.

McHugh et al. (1993) present the results of a study completed by the Montana Board of Oil and Gas Conservation in which field samples were collected from active and inactive well sites, produced water disposal facilities, landfarms, and waste oil disposal sites. Four types of samples were analyzed from 74 sites across the state of Montana for possible classification as hazardous materials under RCRA, Subtitle C. The results are listed in Table 3. No samples were found to be corrosive or reactive. Also, no samples were found to be toxic for metals, semi-volatiles, or volatiles (except for benzene).

Mount et al. (1993) studied the toxicity of produced waters with the goal of developing multivariate regression equations for use in predicting the toxicity of a water on freshwater species (water fleas and fathead minnows) given measured concentrations of major ions (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} , and HCO_3^-). The report contained analytical data (ion concentrations) for several produced waters from Alabama. Four of the six sampled waters were found to be acutely toxic to the water flea. In addition, the study included an analysis of a produced water from Wyoming known to contain hydrogen sulfide. This water was found to be acutely toxic to fathead minnows with reduced survival observed in concentrations as low as 25% by volume.

Oil and Gas Waste Impacts

Hall (1990) presents some of the findings of EPA's investigation into the environmental impacts of oil and gas operations conducted as part of the 1987 Report to Congress. The report contains numerous photographs documenting seepage through unlined pits, breached pits, saline discharges to the land surface and freshwater streams, and vegetal and wildlife damage.

Deuel (1990) outlines the effect of produced brines and other oil field wastes on plant and agricultural production. Tolerance levels for various crop and plant types are given in terms of soil conductivity (EC) and percentage of oil and grease (O&G). Guidance levels for the land application of oil and gas wastes are given as $\text{EC} < 4 \text{ mmho/cm}$ and $\text{O\&G} < 1\% \text{ wt}$.

Van Sickle and Groat (1990) present a general discussion of the impact of oil field brines on coastal wetlands. A strong correlation was observed between areas of disappearing or rapidly deteriorating wetlands and locations of produced water discharges along the Louisiana coast. The report also includes

analytical results for four produced water discharges in south Louisiana. In addition to elevated ion levels the waters were also shown to contain benzene (1 - 3 ppm), toluene (1 - 3 ppm), and other organics.

Kaszuba and Buys (1993) discuss remediation strategies for seven sites in New Mexico containing brine impacted soil resulting from leakage from pipelines and reserve pits. The size of the investigated spills ranged from 5 barrels to 130 barrels. One site contained an unknown spill volume. Soil samples from these sites were collected and analyzed for comparison with background soils. Vegetation at all but one of the sites was noted to be dead and some sites were observed to have hard and crusted soils. Reclamation of the impacted areas involved the leaching of soluble salts from the soils through the application water containing soil amendments. The time frame for complete reclamation of the impacted areas was estimated to be 3 - 5 years.

Gros Thesis

Gros (1992) studied the environmental impacts of accidental oil spills from producing wells in Seminole County, Oklahoma. The objective of this study was to develop and test a model that could be used by a regulatory agency to rank producing wells according to the level of environmental damage that might result from a potential oil spill. The ranking was based on the geographical features that surrounded a particular well such as length and rate of ground slope, type of soil, type of ground cover, and proximity to a surface water body or water supply well as well as other properties such as type of oil, production rate, and age of the well. All of these factors were incorporated into a Geographical Information System (GIS) database. The model was evaluated by comparing the model results with the conclusions of a panel of field inspectors who visited each test site. The model used to predict surface water impacts was found to perform quite well under this validation scheme while the model used to assess soil impacts performed less favorably. No actual spills were investigated in this study. While not technically significant from an engineering perspective, the Gros study serves to illustrate the use of GIS technology for environmental impact analysis as applied to oil and gas operations. A similar approach is to be used in the current study.

PED Survey

A survey of oil and gas operators has been developed, reviewed and edited. The survey is divided by topic into three sections: (1) drilling wastes; (2) associated wastes; and (3) produced water. The overall layout of each section consists of a series of stacked cards that are sequentially numbered. Each card in the series contains questions which are relevant to a specific issue in that section of the survey. Each section in the survey contains environmental questions which are relevant to the waste being surveyed in the section. A copy of the survey has been included in Appendix I. Draft copies of the survey have been distributed to the API, GRI and IPAA for their review and comment. It is not

clear at this time whether any or all of the three industry groups will sponsor and/or participate in the widespread distribution of the survey.

Industry Groups and Private Sector Contacts

In addition to the API, GRI and IPAA, three commercial companies (Petroleum Information, Dwights Energy Data, Inc. and GITI) that maintain databases on the oil and gas industry have been contacted in order to determine if their databases might contain information which is relevant to this study. Efforts are underway to evaluate and obtain data from these companies.

State Oil and Gas Field Maps

Maps of oil and gas fields in each state have been compiled. The appropriate USGS office in each state was contacted and available maps of oil and gas resources in the state were requested. To date, maps for 26 of the states have been received.

DRASTIC Mapping

In order to determine the vulnerability of surficial aquifers to contamination from oil and gas drilling activities (see Figure 5), the DRASTIC classification system is being considered for use in this project. The DRASTIC system classifies aquifers according to a vulnerability index calculated by weighting seven hydrogeologic parameters. Research is being conducted to obtain DRASTIC data for the producing states.

Tasks 2 and 3. Significant efforts were expended in the past year on treatment options for produced water. These efforts will first be summarized and then followed by a detailed discussion of the accomplishments for each item:

1. Five main categories of treatment for produced water were identified.
2. Produced water characteristics were researched.
3. Performance and cost models were selected.
4. The design parameters for the selected unit processes were determined.
5. Current baseline costs for the disposal of brines were investigated.
6. Preliminary produced water treatment costs were calculated.

Treatment Categories

The treatment of produced water can be separated into five main categories. Included in this group of categories are inorganic contaminant removal, organic contaminant removal, liquid/solid separation, and liquid/emulsified oil separation. There are several unit processes that can fit into each of these categories. Some of the unit processes can fit into more than one

category. It is necessary, in certain instances, to combine two or more unit processes in order to achieve the treatment goals associated with a specific category. Additional unit processes are required to treat the residual waste streams created by some of the other unit processes. This last category consists of the treatment of off-gas and the handling of sludge produced during the removal of organic contaminants and liquid/solid separation, respectively. Also, the disposal of the concentrate generated during reverse osmosis is included in this last group.

Some of the treatment processes being considered here are not generally applied to waters of this nature. The decisions that have been made regarding which unit processes will be used were based on the following criteria. The removal of individual waste stream constituents drives the decision making process that is used when unit processes are chosen. Also taken into consideration are the effects of other constituents on the removal of the constituent of choice. Assumed cost efficiency is yet another factor that is taken into account. The configurations of treatment trains are yet another important aspect of the cleanup process. Table 6 lists the selected treatment categories and the different unit processes that are included in each category.

Conventional liquid/solid separation methods will be used. The list of processes that will be used to accomplish this goal includes flocculation, sedimentation and filtration. All three of these processes will be used together and in order. This block of treatment is the most appropriate method available for the removal of solids found in these types of waters. Suspended solids removal is the ultimate goal of these processes. Chemical pre-treatment prior to this treatment block with suitable coagulants and polymers is sometimes necessary. There are several types of filters that could possibly be used to treat these types of waste waters. For the treatment described here, sand filtration has been selected.

When the separation of emulsified oil and liquid is considered, the unit processes that are to be used and evaluated in this study are skim tanks, hydrocyclones, gas flotation cells, corrugated plate interceptors, diatomaceous earth, membrane technologies and cross flow devices. These unit processes represent a wide spectrum of treatment alternatives because the variable characteristics of the waste stream that are to be considered here have broad ranges from one produced water to the next. Oil concentration and the particle size distribution of the emulsions in solution are the two most important characteristics. This category of treatment is the most common and is always part of the treatment of produced water. This aspect of treatment is necessary, no matter what further treatment or disposal choices have been made.

There are just two unit processes that will be considered for removal of organic compounds from produced water: granular activated carbon adsorption and air stripping with or without off-gas treatment. The off-gas treatment that

will be included, when appropriate, is gas phase granular activated carbon adsorption. Adsorbability, gauged by isotherm constants and the ability to be stripped from solution, which is determined by the Henry's law constant, will dictate which of the organics removal techniques is used. When possible, values of these waste stream constituent properties that were determined specifically for constituents that exist in matrices similar to those of produced water will be used. Under consideration, for example, are some Henry's law constants that were derived through a laboratory bench scale test for produced water. There is a loose correlation between lack of adsorbability and a compound being easily stripped and vice versa. An attempt will be made to separate organic compounds into groups that will be removed by one or the other of the two unit processes.

Reverse osmosis and precipitation comprise the equally small group of unit processes that will be considered for removing inorganic constituents from the waste stream. These two processes have different purposes within the treatment train and are grouped together only under the broad category of inorganic constituent removal. Reverse osmosis will primarily be used to tackle the task of desalinating the produced water while precipitation will deal with heavy metals. Both unit processes can and do remove constituents other than those listed as their respective primary goals. This helps in the waste stream clean-up but can possibly harm the function of the two unit processes with respect to the main reason that they were selected. Coagulant dosage can be affected when precipitation occurs and removes constituents other than those originally intentioned. This situation would become especially critical if a more efficient method of removal exists and could be implemented before the precipitation occurs.

The sludge produced when the precipitate mentioned above is settled out of solution along with other sludges, concentrates, and off-gases will have to be dealt with. The unit processes that will be used to treat and dispose of these residual waste streams are: gas phase granular activated carbon adsorption for off-gasses produced during air stripping, sludge thickening and land filling of various sludges that will be produced during liquid/solid separation and precipitation, and deep well injection for the reject of reverse osmosis. After preliminary evaluation, these are the most cost efficient methods that can be used to treat these residual wastes.

Waste Water Characteristics

Before the performance of treatment scenarios and their associated costs can be evaluated, the individual unit processes and the order in which they will be used must be selected. The criteria on which these selections must be based are the influent and effluent quality of the waste streams. Produced water is a highly complex mixture of organic and inorganic components existing in various states (in solution, emulsified, in suspension, particulate, and particle adsorbed). The influent quality will vary widely and the effluent quality that is desired will

be defined by the final use/disposal options for a given water. A knowledge of what the produced waters contain has been obtained.

Chemical analysis of several produced waters were obtained from several oil and gas agencies that are members of the Interstate Oil and Gas Compact Commission of Oklahoma City, Oklahoma. Since the quality of the waste stream varies so widely, an effort was made to characterize the waste in general and this was accomplished by picking representative waste streams from the many analyses that were gathered. Prior to this, a list of waste stream constituents was selected to be considered. Both contaminant concentrations and bulk parameters (e.g., Total Dissolved Solids, TDS) are necessary and were included on the list. This list (Table 7) is from a 1985 study conducted by the American Petroleum Institute. Table 7 is quite an extensive list of constituents and one would not expect to find information pertaining to all of these constituents in all of the produced water analyses received. Also, even when all of these constituents are listed for a sample, considering them all separately is not feasible. Different cost and performance models contain information on selected constituents so a manner of judgment for the treatment of the vastly different waters by the same model has been ascertained.

Properties of the constituents have been gathered and listed. In addition to this, these properties have been grouped so that the removal of similar constituents can be considered together. In Table 8, an example of this grouping procedure can be found. The organic constituents found within the main list and some of the properties associated with these constituents are inventoried and they are all grouped with respect to their Henry's law constants. All organic contaminants having constants that fall within a given range of a selected constant are classified as having the same removal tendencies as the selected constituent. In this way, the lack of specific information with regard to a model or a produced water analysis can be overcome. Other properties of waste stream constituents that have been included in the data base are constants contained within adsorption isotherms describing the prediction of granular activated carbon performance, molecular weights, and solubilities. Drinking water standards have been listed, when available, for the contaminants and will be used, along with multiples of these same standards, for the purposes of quantifying treated water quality.

Performance and Cost Models

Several models have been selected to estimate the treatment of the produced waters and the costs associated with said treatment. The most important model which will be used is entitled Computer-Assisted Procedure for the Design of Wastewater Treatment Systems (CAPDET). This model was developed by the United States Corps of Engineers in 1978 to provide guidance for the selection of waste water treatment processes and systems. The model can be updated so that it can be used for the purposes of this work.

Also being used is a model entitled WATERMAID where MAID is an acronym for Microcomputer Assisted Interactive Design. This model facilitates the computer assisted preliminary design for drinking water process systems and was developed by the Drinking Water Research Division of the United States Environmental Protection Agency (USEPA). The unit processes contained within this model have been used to estimate waste water treatment with adjustments made or recognized as necessary to acquire cost and performance data that is not limited to drinking water circumstances. An example of such a modification is the substitution that will be necessary of an isotherm for the adsorption of total organic carbon onto granular activated carbon related to waste water for an isotherm related to drinking water.

Also, the Produced Water Management Options Model developed by the Gas Research Institute (GRI) for the treatment of produced water will be used. The (U.S.EPA) has developed two other models entitled WATER and WATERCOST, which evaluate the treatment and costs involved with treatment of small and large drinking water systems respectively. These models and selected cost equations will be used both separately and in conjunction with each other to estimate cost and performance of the chosen unit processes. The five models mentioned above and their relative strengths and weaknesses can be found in Table 9.

Unit Process Parameters

Each model or equation that can or will be used to evaluate a given unit treatment process requires the input of a number of parameters, sometimes designated as design parameters. These parameters are case specific with respect to required process performance, influent waste stream quality and process size or flow rate of produced water. A list of these parameters for some of the unit processes that will be used for the produced water treatment is contained within Table 10. Some of the models and equations are based on flow rate of the waste stream alone and others are based on one of the design parameters found in Table 10. Performance of a given treatment can be more easily related to cost when a design parameter such as empty bed contact time (EBCT), the amount of time that a waste water is exposed to granular activated carbon, is utilized rather than flow. The reason for this is that information on flow alone ignores water quality and the change in water quality as a result of treatment at any given time.

When sizing a unit process or using a model based on waste stream flow rate, representative flows have been used. Flow regimes of ten thousand, one hundred thousand, and one million gallons per day have been selected based on data received from the states of California, New York, South Dakota, and Mississippi. These data pertain to reported flow rates of produced water for different wells, groups of wells and fields. The information was provided by the California Department of Conservation, the New York State Department of Environmental Conservation, the State of South Dakota Department of

Environment and Natural Resources, and the Mississippi State Oil and Gas Board, respectively.

Baseline Costs

Baseline disposal costs, or costs currently being exacted for the disposal of produced water, have been gathered from the literature and range from \$0.10 to \$0.50 per barrel in Texas (Tomson, Oddo and Kan, 1992) to an average of \$1.50 per barrel in Ohio (Blem and Becker, 1985). Many factors affect the costs associated with present disposal practices. Deep well injection pervades the collection of disposal practices for produced water at onshore installations in the United States. The range of costs for the drilling of salt water disposal wells is from \$400,000 to \$3,000,000. These costs are so high because an operator must not only find a zone of aquifer processing suitable permeability and porosity, but one that contains waters above 10,000 parts per million (ppm) total dissolved solids (TDS). This last requirement necessitates expensive testing.

Poor well maintenance for a given well or low injectability of a certain produced water can lead to the high disposal costs of almost \$2.00 per barrel when the transportation to a disposal site is made necessary. Within the aforementioned range of disposal costs fall the costs of the other most common types of disposal. Among them are annular disposal, the disposal of produced water into the annulus of the well from which it was produced and land spreading. These practices are prohibited in most states.

Water Treatment Costs

During the current reporting period preliminary estimates of costs were determined for the treatment of one representative waste stream. The treatment goals and allied unit processes considered were liquid/solid separation through flocculation, sedimentation, and filtration as well as desalination via reverse osmosis and air stripping with and without off-gas treatment for the removal of volatile organics. WATERMAID was used to estimate the cost associated with reverse osmosis. The costs associated with air stripping, on the other hand were taken from (Adams and Clark, 1991). Still another source provided the equations that were used to estimate the flocculation, sedimentation, and filtration costs. These equations were taken from (Clark, 1982).

The representative waste stream was a produced water taken from the Brentwood oil field, which is in California, on 9/25/92 and analyzed on 10/02/92. The chemical analysis was performed by Chemwest Analytical Laboratories using EPA method 8020 to test for volatile aromatic organics. The rate of flow for the costing of this representative waste stream was assumed to be one million gallons per day. Three different sources were required in order to estimate the costs associated with these unit processes for this particular waste stream and flow regime. Furthermore, assumptions and compromises were made so that the chosen models could be used.

Costs for the removal of several of the organic constituents were estimated by equating their removal with that of all other constituents that fall under the same Henry's law constant classification. It was assumed that the costs of air stripping these constituents would be the same. In order for two or more constituents to fall under the same classification, they must have similar values with respect to the property under which they are being classified. The costs given in Adams and Clark were for the removal of specific concentrations of the constituents of choice. When the organic constituents to be removed from the Brentwood oil field produced water existed in solution at greater concentrations than those for which costs were given, more assumptions were made regarding the estimated costs of removing the contaminants from the Brentwood oil field water. Table 11 contains the calculated cost estimates for the treatment of the Brentwood oil field water. There will be some assumptions made for every calculation of clean up performance and costs during this project. Three models which were not used in these particular calculations are CAPDET, WATER and WATERCOST. These models will be used in future calculations once they are updated to reflect present day costs.

Information detailing the chemical makeup of produced water was procured from the Alaska Oil and Gas Conservation Commission, the Arizona Geological Society, the California Department of Conservation, Division of Oil and Gas, the Colorado Oil and Gas Conservation Commission and the North Dakota Industrial Commission, Oil and Gas Division. The inorganic constituents are among those listed within these chemical analyses much more frequently than their organic counterparts. Few packets of information received contained any data regarding organic constituents. Representative waste streams are, however, being formulated by combining this new information with the organic data that is included in the American Petroleum Institute (API) study.

Planned Activities

Task 1. The main objective for the second year is to conduct the proposed survey of oil and gas operators. More specifically, the following activities are planned:

1. Contact the USGS and obtain detailed reports of the geology in the five foremost producing states.
2. Develop alternative strategy for data collection to the survey in case the survey option does not prove feasible.
3. Conduct visits to the states which are on hold in order to obtain data from those states.
4. Initiate mapping effort to correlate oil and gas activities to environmental characteristics of the surrounding areas.

Tasks 2 and 3. During the next quarter, the objectives of tasks two and three will be reached. The database of information regarding waste water characteristics will be completed. Henry's law constants, for example, obtained

Tasks 2 and 3. During the next quarter, the objectives of tasks two and three will be reached. The database of information regarding waste water characteristics will be completed. Henry's law constants, for example, obtained specifically for constituents in a matrix similar to that of a typical produced water will be gathered and used in the cost and performance calculations that will evaluate different unit processes. Final decisions will be made designating representative waste streams. Final unit process selections as well as treatment train configurations will be unveiled. All of the estimated costs associated with the treatment of the representative produced waters will be calculated and compared to the environmental impact observed as a result of the final use/disposal scenarios, which will also be finalized during this quarter.

Summary

Data collection efforts indicated that drilling activities during 1986 - 1991 have been reduced to a third of their 1981 - 1985 counterparts. Information collected on produced water disposal methods identified Class II injection as the method of choice for most cases. No data has been found on amounts of drilling wastes generated for 1986 - 1991 or on the disposal methods used to manage these wastes. As a result, a survey of operators has been prepared and is currently being reviewed by the industry's associations.

The models that will be used to judge the performance of selected unit processes to treat the produced water and estimate associated costs have been obtained. WATERMAID, WATER, WATERCOST, PRODUCED WATER MANAGEMENT OPTIONS MODEL and CAPDET will be used along with equations found within the work of Robert Clark. Also, information was gathered from several oil and gas agencies that provided a clearer picture of the chemical makeup of produced water across the United States.

Preliminary cost estimates were prepared for one waste stream at a single flow (1MGD). The unit processes involved in this calculation were flocculation, sedimentation, filtration, sludge thickening, reverse osmosis, air stripping and granular activated carbon treatment of air stripping off gas. The realization that not a single model on its own would be able to calculate performance and costs for a given situation was reached. The combination of several models was used to estimate the cost and performance of different treatment levels for individual waste streams. Also, assumptions and generalizations were made to allow estimates to be completed for situations that are not specifically targeted in the models being used.

Report Distribution List

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Publications

None at this time

TABLE 1. RECORDS OF WELLS DRILLED IN 1986 - 1991

Page 1 of 2

		1986				1987				1988				1989				1990				1991			
		Oil	Gas	Dry	Total	Oil	Gas	Dry	Total	Oil	Gas	Dry	Total	Oil	Gas	Dry	Total	Oil	Gas	Dry	Total	Oil	Gas	Dry	Total
Alabama		31	59	131	221	27	46	102	175	24	183	125	332	14	219	101	334	33	892	130	1055	12	762	67	841
Alaska		104	3	15	122	95	0	5	100	119	3	6	128	51	1	6	58	95	2	7	104	79	4	6	89
Arizona		0	0	5	5	0	0	4	4	0	0	1	1	0	0	1	1	0	2	2	4	0	0	0	0
Arkansas		158	160	177	495	58	138	155	351	45	192	190	427	31	109	139	279	5	1	8	14	2	1	5	8
California		1875	90	148	2113	1795	68	167	2030	1491	87	150	1728	1244	58	143	1445	1865	89	146	2100	1224	52	129	1405
Colorado		309	417	321	1047	201	270	230	701	221	426	335	1018	68	337	238	643	143	690	302	1135	114	420	182	716
Florida		7	0	7	14	2	0	7	9	1	0	8	9	0	0	11	11	0	0	10	10	0	0	7	7
Georgia		0	0	2	2	0	0	0	0	0	0	2	2	0	0	1	1	0	0	1	1	0	0	0	0
Idaho		0	0	5	5	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Illinois		742	23	531	1296	624	12	430	1066	525	51	436	1012	298	32	367	697	405	25	297	727	292	5	245	542
Indiana		191	21	196	408	92	14	144	250	94	28	139	261	44	9	90	143	47	15	82	144	47	8	55	110
Iowa		1	0	2	3	0	0	1	1	0	0	1	1	0	0	5	5	0	0	2	2	0	0	0	0
Kansas		1405	388	1398	3191	860	317	1321	2498	1124	670	1261	3055	654	379	956	1989	1193	619	1105	2917	720	377	911	2008
Kentucky		263	235	446	944	111	99	176	386	1524	234	230	613	340	411	339	1090	220	399	243	862	107	198	190	495
Louisiana		930	445	897	2272	684	343	628	1655	525	411	693	1629	195	294	532	1021	431	388	573	1392	347	268	352	967
Maryland		0	0	1	1	0	0	1	1	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Michigan		126	67	329	522	74	85	273	432	75	317	245	637	46	41	157	262	33	802	155	990	29	456	82	567
Mississippi		83	32	187	302	83	34	179	296	106	30	210	346	64	41	157	262	75	58	147	280	40	21	135	196
Missouri		6	0	5	11	5	0	2	7	2	0	10	12	1	0	7	8	3	2	7	12	21	0	1	22
Montana		75	95	181	351	80	60	103	243	117	74	163	354	24	112	63	199	40	190	98	328	44	136	58	238
Nebraska		43	1	104	148	33	1	121	155	39	0	97	136	23	0	59	82	44	0	81	125	48	2	63	113
Nevada		1	0	17	18	2	0	11	13	4	0	14	18	8	0	8	16	9	0	22	31	4	0	17	21
NM		516	258	202	976	352	187	152	691	428	386	170	984	309	341	118	768	459	744	128	1331	454	529	109	1092
NY		21	198	14	233	3	65	10	78	11	146	19	176	5	45	9	59	0	2	9	11	0	0	0	0
NC		0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
ND		115	3	116	234	71	3	67	141	140	2	117	259	84	3	54	141	166	5	91	262	114	1	57	172
Ohio		1289	480	132	1901	616	217	78	911	848	399	109	1356	395	199	34	628	795	370	113	1278	355	155	53	563
Oklahoma		2103	1078	1287	4468	1244	752	812	2808	1252	936	1013	3201	786	660	624	2070	1049	868	858	2775	917	631	658	2206
Oregon		0	2	9	11	0	7	3	10	0	7	8	15	0	4	10	14	0	2	1	3	0	3	4	7
Penn		131	896	25	1052	5	342	24	371	58	797	54	909	33	479	25	537	1	408	48	457	0	57	9	66
SC										0	0	1	1												
SD		2	0	13	15	0	2	4	6	3	4	7	14	1	0	6	7	5	1	7	13	0	0	8	8
Tennessee		42	62	62	166	19	29	47	95	30	34	19	83	15	11	7	33	13	16	7	36	4	9	3	16
Texas Total		7172	1754	4366	13292	4799	1401	3269	9469	5018	1807	3025	9850	3225	1585	2306	7116	4335	1942	2460	8737	4123	1461	2288	7872
Utah		98	52	50	200	40	19	34	93	62	28	43	133	38	10	21	69	49	17	28	94	67	72	36	175
Virginia		0	130	6	136	1	8	1	10	1	1	28	31	0	8	6	14	0	6	0	6	0	0	0	0
Washington		0	0	0	0	0	0	1	1	0	0	3	3	0	0	3	3	0	0	0	0	0	0	1	1
WV		110	735	7	852	48	488	11	547	58	600	12	670	20	587	13	620	22	695	3	720	18	513	9	540
Wyoming		352	50	423	825	242	31	310	583	272	70	361	703	121	93	206	420	262	229	276	767	135	137	181	453
total		18301	7734	11817	37852	12266	5038	8884	26188	14217	7950	9283	30111	8137	6068	6821	21044	11797	9479	7447	28723	9317	6278	5921	21516

TABLE 1. RECORDS OF WELLS DRILLED IN 1986 - 1991

Page 2 of 2

	<i>All Wells</i>		<i>Oil Wells</i>		<i>Gas Wells</i>		<i>Dry Wells</i>	
	Total all yrs	% all yrs	Total all yrs	% all yrs	Total all yrs	% all yrs	Total all yrs	% all yrs
Alabama	2958	2.07	141	0.23	872	1.52	656	1.54
Alaska	601	0.42	543	0.87	443	0.77	45	0.11
Arizona	15	0.01	0	0.00	0	0.00	13	0.03
Arkansas	1574	1.10	299	0.48	142	0.25	674	1.58
California	10821	7.58	9494	15.30	7671	13.41	883	2.08
Colorado	5260	3.69	1056	1.70	1167	2.04	1608	3.78
Florida	60	0.04	10	0.02	3	0.01	50	0.12
Georgia	5	0.00	0	0.00	0	0.00	5	0.01
Idaho	7	0.00	0	0.00	0	0.00	7	0.02
Illinois	5340	3.74	2886	4.65	2149	3.76	2306	5.42
Indiana	1316	0.92	515	0.83	332	0.58	706	1.66
Iowa	12	0.01	1	0.00	0	0.00	11	0.03
Kansas	15658	10.97	5956	9.60	4928	8.61	6952	16.34
Kentucky	4390	3.08	2565	4.13	2500	4.37	1624	3.82
Louisiana	8936	6.26	3112	5.01	2450	4.28	3675	8.64
Maryland	4	0.00	0	0.00	0	0.00	4	0.01
Michigan	3410	2.39	383	0.62	713	1.25	1241	2.92
Mississippi	1682	1.18	451	0.73	389	0.68	1015	2.39
Missouri	72	0.05	38	0.06	32	0.06	32	0.08
Montana	1713	1.20	380	0.61	441	0.77	666	1.57
Nebraska	759	0.53	230	0.37	189	0.33	525	1.23
Nevada	117	0.08	28	0.05	27	0.05	89	0.21
NM	5842	4.09	2518	4.06	2531	4.42	879	2.07
NY	557	0.39	40	0.06	19	0.03	61	0.14
NC	1	0.00	0	0.00	0	0.00	1	0.00
ND	1209	0.85	690	1.11	576	1.01	502	1.18
Ohio	6637	4.65	4298	6.93	3164	5.53	519	1.22
Oklahoma	17528	12.29	7351	11.84	5879	10.28	5252	12.35
Oregon	60	0.04	0	0.00	3	0.01	35	0.08
Penn	3392	2.38	228	0.37	154	0.27	185	0.43
SC	1	0.00	0	0.00	0	0.00	1	0.00
SD	63	0.04	11	0.02	9	0.02	45	0.11
Tennessee	429	0.30	123	0.20	90	0.16	145	0.34
Texas Total	33575	23.53	16701	26.91	18162	31.74	10079	23.69
Utah	764	0.54	354	0.57	328	0.57	212	0.50
Virginia	197	0.14	2	0.00	2	0.00	15	0.04
Washington	8	0.01	0	0.00	0	0.00	8	0.02
WV	3949	2.77	276	0.44	679	1.19	55	0.13
Wyoming	3751	2.63	1384	2.23	1169	2.04	1757	4.13
Total	142673	100	62064	100	57213	100	42538	100
Avg./yr	23779	-	10344	-	9536	-	7090	-

TABLE 2. PRODUCED WATER DATABASE SUMMARY

State	Year	Prod Wells	Injec Wells	Shut In Wells	Total Wells	Oil (Bbls)	Gas (MCF)	Water (Bbls)	Brine Chemical Data	Disposal Methods	Data By Field	Data By Well
ALABAMA	1986	[7]	8	NA	NA	10,495,327	146,605,998	34,768,828	YES	(a)	YES	NO
	1987	[7]	15	NA	NA	10,089,006	155,555,275	36,494,907	YES	(a)	YES	NO
	1988	[7]	13	NA	NA	9,618,183	176,691,103	37,005,450	YES	(a)	YES	NO
	1989	[7]	29	NA	NA	8,978,248	181,001,831	45,896,929	YES	(a)	YES	NO
	1990	[7]	29	NA	NA	8,467,864	187,961,218	66,149,157	YES	(a)	YES	NO
	1991	[7]	22	NA	NA	8,858,484	224,470,382	133,392,477	YES	(a)	YES	NO
ALASKA	1986	NA	NA	NA	NA	681,634,899	1,381,888,437	174,796,180	NO	(a)	YES	NO
	1987	NA	NA	NA	NA	715,842,735	1,704,343,572	275,665,676	NO	(a)	YES	NO
	1988	NA	NA	NA	NA	738,226,829	1,952,069,158	344,293,037	NO	(a)	YES	NO
	1989	NA	NA	NA	NA	683,977,736	1,974,728,403	396,005,248	NO	(a)	YES	NO
	1990	[1]	[1]	[1]	[1]	647,309,636	2,064,522,212	449,312,128	NO	(a)	YES	NO
	1991	[1]	[1]	[1]	[1]	656,348,731	2,391,900,281	539,376,019	NO	(a)	YES	NO
ARKANSAS	1986	[7]	NA	NA	NA	15,819,000	NA	203,240,401	NO	(a)	YES	[2]
	1987	[7]	NA	NA	NA	14,230,000	NA	205,044,975	NO	(a)	YES	[2]
	1988	[7]	NA	NA	NA	13,456,000	NA	222,819,711	NO	(a)	YES	[2]
	1989	[7]	NA	NA	NA	11,428,000	NA	235,804,261	NO	(a)	YES	[2]
	1990	[7]	NA	NA	NA	12,230,000	NA	241,020,532	NO	(a)	YES	[2]
	1991	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CALIFORNIA	1986	56175	15280	19199	90,654	378,537,427	416,413,361	2,644,330,017	NO	(a)	YES	[8]
	1987	53106	15836	23765	92,707	365,934,296	382,217,947	2,604,287,666	NO	(a)	YES	[8]
	1988	52376	15824	24820	93,020	355,517,714	363,009,097	2,570,979,053	NO	(a)	YES	[8]
	1989	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	1990	51076	15280	24372	90,728	320,782,333	189,716,472	130,611,444	NO	(a)	YES	[8]
	1991	50332	17641	24332	92,305	319,235,058	335,983,693	2,320,280,525	NO	(a)	YES	[8]

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TABLE 2. PRODUCED WATER DATABASE SUMMARY

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State	Year	Prod Wells	Injec Wells	Shut In Wells	Total Wells	Oil (Bbls)	Gas (MCF)	Water (Bbls)	Brine Chemical Data	Disposal Methods	Data By Field	Data By Well
OHIO								[9]				
	1986	N/A	N/A	N/A	N/A	N/A	N/A	13,313,500	YES	(a,d,f)	NO	NO
	1987	N/A	N/A	N/A	N/A	N/A	N/A	11,342,490	YES	(a,d,f)	NO	NO
	1988	N/A	N/A	N/A	N/A	N/A	N/A	9,569,656	YES	(a,d,f)	NO	NO
	1989	N/A	N/A	N/A	N/A	N/A	N/A	9,539,350	YES	(a,d,f)	NO	NO
	1990	N/A	N/A	N/A	N/A	N/A	N/A	9,322,661	YES	(a,d,f)	NO	NO
	1991	N/A	N/A	N/A	N/A	N/A	N/A	9,419,677	YES	(a,d,f)	NO	NO
OKLAHOMA												
	1986	NA	NA	NA	NA	149,105,000	1,927,964,000	NA	NO	NO	[6]	NO
	1987	NA	NA	NA	NA	133,996,000	2,029,899,000	NA	NO	NO	[6]	NO
	1988	NA	NA	NA	NA	129,000,000	2,118,136,000	NA	NO	NO	[6]	NO
	1989	NA	NA	NA	NA	117,971,000	2,197,138,000	NA	NO	NO	[6]	NO
	1990	NA	NA	NA	NA	112,321,000	2,263,489,000	NA	NO	NO	[6]	NO
	1991	NA	NA	NA	NA	107,974,000	2,130,731,000	NA	NO	NO	[6]	NO
OREGON								[16,17,18,19]				
	1986	14	NA	NA	NA	NONE	4,549,462	45,452	YES	(a,b,c,d)	YES	YES
	1987	15	NA	NA	NA	NONE	3,811,993	72,548	YES	(a,b,c,d)	YES	YES
	1988	16	NA	NA	NA	NONE	4,016,597	37,476	YES	(a,b,c,d)	YES	YES
	1989	19	NA	NA	NA	NONE	2,551,746	47,000	YES	(a)	YES	YES
	1990	24	NA	NA	NA	NONE	2,822,561	28,095	YES	(a)	YES	YES
	1991	20	NA	NA	NA	NONE	2,739,605	33,143	YES	(a)	YES	YES
PENN.												
		[4]							[13]			
	1986	14271	NA	NA	NA	3,783,000	159,889,000	NA	YES	NO	NO	NO
	1987	13255	NA	NA	NA	3,202,000	163,318,000	NA	YES	NO	NO	NO
	1988	27218 [10]	NA	NA	NA	2,807,000	167,089,000	NA	YES	NO	NO	NO
	1989	22338 [11]	NA	NA	NA	2,602,000	191,774,000	NA	YES	NO	NO	NO
	1990	[12]	NA	NA	NA	2,601,000	177,609,000	NA	YES	NO	NO	NO
	1991	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

TABLE 2. PRODUCED WATER DATABASE SUMMARY

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State	Year	Prod Wells	Injec Wells	Shut In Wells	Total Wells	Oil (Bbls)	Gas (MCF)	Water (Bbls)	Brine Chemical Data	Disposal Methods	Data By Field	Data By Well
S. DAKOTA	1986	193	NA	NA	NA	1,586,269	2,475,831	2,846,053	NO	NO	YES	NO
	1987	205	NA	NA	NA	1,644,200	3,682,364	3,051,258	NO	NO	YES	NO
	1988	207	NA	NA	NA	1,662,293	4,306,038	3,242,449	NO	NO	YES	NO
	1989	207	NA	NA	NA	1,612,632	4,747,530	3,428,287	NO	NO	YES	NO
	1990	213	NA	NA	NA	1,649,353	4,808,125	3,861,847	NO	NO	YES	NO
	1991	206	NA	NA	NA	1,662,908	5,689,800	4,330,686	NO	NO	YES	NO
TENNESSEE	1986	1794	NA	NA	NA	644,482	3,464,266	NA	NO	NO	YES	NO
	1987	1702	NA	NA	NA	613,442	2,707,204	NA	NO	NO	YES	NO
	1988	1729	NA	NA	NA	600,466	2,102,074	NA	NO	NO	YES	NO
	1989	1615	NA	NA	NA	531,291	1,929,645	NA	NO	NO	YES	NO
	1990	1623	NA	NA	NA	508,228	2,061,413	NA	NO	NO	YES	NO
	1991	1515	NA	NA	NA	485,267	1,854,118	NA	NO	NO	YES	NO
TEXAS (on hold)	1986											
	1987											
	1988											
	1989											
	1990											
	1991											
UTAH	1986	3933	NA	NA	NA	39,171,678	238,387,788	114,754,028	[20] YES	(a,b,c)	YES	YES
	1987	4042	NA	NA	NA	35,788,209	262,282,323	114,156,298	YES	(a,b,c)	YES	YES
	1988	4099	NA	NA	NA	33,017,552	277,566,383	122,710,028	YES	(a,b,c)	YES	YES
	1989	4115	NA	NA	NA	28,415,680	277,811,296	121,212,649	YES	(a,b,c)	YES	YES
	1990	4057	NA	NA	NA	27,603,935	321,633,546	124,807,060	YES	(a,b,c)	YES	YES
	1991	4162	NA	NA	NA	24,467,862	328,329,889	124,846,442	YES	(a,b,c)	YES	YES

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TABLE 2A. PRODUCED WATER DATABASE REFERENCE GUIDE

State	Year	Prod Wells	Injec Wells	Shut In Wells	Total Wells	Oil (Bbls)	Gas (MCF)	Water (Bbls)	Brine Chemical Data	Disposal Methods	Data By Field	Data By Well
MISSISSIPPI	1986	25	NA	NA	NA	25	25	25	NA	NA	25	25
	1987	26	"	"	"	26	26	26	"	"	26	26
	1988	27	"	"	"	27	27	27	"	"	27	27
	1989	28	"	"	"	28	28	28	"	"	28	28
	1990	29	"	"	"	29	29	29	"	"	29	29
	1991	30	"	"	"	30	30	30	"	"	30	30
MISSOURI	1986	31				31	31	31		31	31	
	1987	"				"	"	"		"	"	
	1988	"				"	"	"		"	"	
	1989	"				"	"	"		"	"	
	1990	"				"	"	"		"	"	
	1991	"				"	"	"		"	"	
MONTANA	1986	32		32	32	32	32			32	32	
	1987	33		33	33	33	33			33	33	
	1988	34		34	34	34	34			34	34	
	1989	35		35	35	35	35			35	35	
	1990	36		36	36	36	36			36	36	
	1991	37		37	37	37	37			37	37	
NEBRASKA	1986	76		76		76	76				76	
	1987	77		77		77	77				77	
	1988	78		78		78	78				78	
	1989	79		79		79	79				79	
	1990	80		80		80	80				80	
	1991	81		81		81	81				81	

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TABLE 2A. PRODUCED WATER DATABASE REFERENCE GUIDE

State	Year	Prod Wells	Injec Wells	Shut In Wells	Total Wells	Oil (Bbls)	Gas (MCF)	Water (Bbls)	Brine Chemical Data	Disposal Methods	Data By Field	Data By Well
OHIO	1986							51	52	51		
	1987							51	52	51		
	1988							51	52	51		
	1989							51	52	51		
	1990							51	52	51		
	1991							51	52	51		
OKLAHOMA	1986	NA	NA	NA	NA	19	19	NA	NONE	NA	19	NA
	1987	.	.	.	.	20	20	.	.	.	20	.
	1988	.	.	.	.	21	21	.	.	.	21	.
	1989	.	.	.	.	22	22	.	.	.	22	.
	1990	.	.	.	.	23	23	.	.	.	23	.
	1991	.	.	.	.	24	24	.	.	.	24	.
OREGON	1986	67				67	67	66	66	66	67	67
	1987	67				67	67	66	66	66	67	67
	1988	67				67	67	66	66	66	67	67
	1989	67				67	67	66	66	66	67	67
	1990	67				67	67	66	66	66	67	67
	1991	67				67	67	66	66	66	67	67
PENN.	1986	54				50	50		57			
	1987	55				50	50		57			
	1988	56				50	50		57			
	1989	53				50	50		57			
	1990	50				50	50		57			
	1991											

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TABLE 2B. PRODUCED WATER DATABASE REFERENCE LIST

1. Alaska Oil and Gas Conservation Commission, 1985 - 1990 Statistical Report, page 2
(note : Gas production = dry gas + casinghead gas)
2. Alaska Oil and Gas Conservation Commission, 1991 Statistical Report, page 4
(note : Gas production = dry gas + casinghead gas)
3. Alaska Oil and Gas Conservation Commission, 1985 - 1990 Statistical Report, page 30
(note : Gas production = dry gas + casinghead gas)
4. State of Arkansas Oil & Gas Commission - Annual Oil and Gas Report for 1990,
page 63
5. State of Arkansas Oil & Gas Commission - Annual Oil and Gas Report for 1990,
6. State of Arkansas Oil & Gas Commission - Annual Oil and Gas Report for 1990,
page 66
7. Florida DNR - (FAX copy) - Annual Production Reports for 1985 to date.
8. Florida DNR - Report of Laboratory Analysis

note: For reference 9-14, # prod. wells = #active oil wells + # active gas wells
shut in wells = # inactive oil wells + # inactive gas wells

9. New York State Oil and Gas Drilling and Production - 1986, p. 53
10. New York State Oil and Gas Drilling and Production - 1987, p. 43
11. New York State Oil and Gas Drilling and Production - 1988, p. 59
12. New York State Oil and Gas Drilling and Production - 1989, p. 65
13. New York State Oil and Gas Drilling and Production - 1990, p. 38
14. New York State Oil and Gas Drilling and Production - 1991, p. 27
15. New York State Oil and Gas Drilling and Production - 1989, p. 20
16. New York State Oil and Gas Drilling and Production - 1990, p. 11
17. New York State Oil and Gas Drilling and Production - 1991, p. 7

18. Michigan Dept. of Natural Resources, 1986 - 1990 Annual Well Status Summary Report

note : # producing wells = # pumping wells + # flowing wells
total # wells = # producible oil and gas wells + # disposal wells
oil, gas and brine production, all fields, was multiplied by 365 to get an annual figure.

NOTE : For references 19 - 24, oil production = crude + condensate
gas production = natural gas + casinghead gas

19. Corp. Commission of Oklahoma, Oil and Gas Conservation Div. - 1986 Statistics

20. Corp. Commission of Oklahoma, Oil and Gas Conservation Div. - 1987 Statistics

21. Corp. Commission of Oklahoma, Oil and Gas Conservation Div. - 1988 Statistics

22. Corp. Commission of Oklahoma, Oil and Gas Conservation Div. - 1989 Statistics

23. Corp. Commission of Oklahoma, Oil and Gas Conservation Div. - 1990 Statistics

24. Corp. Commission of Oklahoma, Oil and Gas Conservation Div. - 1991 Statistics

25. Mississippi State Oil and Gas Board - Oil & Gas Prod. Annual Report, 1986, p. 5

26. Mississippi State Oil and Gas Board - Oil & Gas Prod. Annual Report, 1987, p. 5

27. Mississippi State Oil and Gas Board - Oil & Gas Prod. Annual Report, 1988, p. 5

28. Mississippi State Oil and Gas Board - Oil & Gas Prod. Annual Report, 1989, p. 4

29. Mississippi State Oil and Gas Board - Oil & Gas Prod. Annual Report, 1990, p. 4

30. Mississippi State Oil and Gas Board - Oil & Gas Prod. Annual Report, 1991, p. 4

31. State of Missouri / DNR , 1986 - 1991 oil, gas and water summary sheets.

note : for Montana, total # of oil, gas, and shut in wells can be computed from Oil and Gas Fields section of each report.

32. Montana Oil and Gas Annual Review - 1986; p. 2-3

33. Montana Oil and Gas Annual Review - 1987; p. 2-3

34. Montana Oil and Gas Annual Review - 1988; p.2-3

35. Montana Oil and Gas Annual Review - 1989; p. 2-3

36. Montana Oil and Gas Annual Review - 1990; p. 2-3

37. Montana Oil and Gas Annual Review - 1991; p. 2-3

Note: For the state of S. Dakota, annual oil, gas, and water production was computed from cumulative production at the end of each year minus the cumulative production at the end of the previous year.

38. State of S. Dakota / DENR - Oil, Gas and Water Production, 1986 (second half), p. iv and 87

39. State of S. Dakota / DENR - Oil, Gas and Water Production, 1987 (second half), p. iv and 85

40. State of S. Dakota / DENR - Oil, Gas and Water Production, 1988 (second half), p. iv and 89

41. State of S. Dakota / DENR - Oil, Gas and Water Production, 1989 (second half), p. iv and 91

42. State of S. Dakota / DENR - Oil, Gas and Water Production, 1990 (second half), p. iv and 51

43. State of S. Dakota / DENR - Oil, Gas and Water Production, 1991 (second half), p. iv and 53

44. Tennessee Oil and Gas Production Reports, 1986 - 1991, last page on each of them. Added the # of oil and gas wells to get the total # of production wells.

Note: For the state of California:

total # production wells = # oil prod. wells + # gas prod. wells

total # shut in wells = # shut in oil wells + # shut in gas wells

Injection well data from *state onshore totals only*.

Injected volumes seem to be $< 1/2$ produced volumes.

45. California 72nd Annual Report of the State Oil and Gas Supervisor, 1986, p. -38 (everything else), 125 (injection data)

46. California 73rd Annual Report of the State Oil and Gas Supervisor, 1987, p. -36 (everything else), 123 (injection data)

47. California 74th Annual Report of the State Oil and Gas Supervisor, 1988, p. -38 (everything else), 126 (injection data)

48. California 76th Annual Report of the State Oil and Gas Supervisor, 1990,

- p. -42 (everything else), 138 (injection data)
49. California 77th Annual Report of the State Oil and Gas Supervisor, 1991,
p. -40 (everything else), 134 (injection data)
 50. PA Oil and Gas 10 year Review and Forecast (1990), p. 22
 51. Ohio DNR letter from Dennis Crist
 52. Ohio DNR package form David Hodges
 53. PA Oil and Gas (1989), p. 3
 54. PA Oil and Gas (1986), p. 3
 55. PA Oil and Gas (1987), p. 3
 56. PA Oil and Gas (1988), p. 3
 57. Pennsylvania "Toxic Screenings" reports on drill cuttings and oila and gas
production.
 58. Virginia Oil and Gas Summary, 1986, p. 5, 7
 59. Virginia Oil and Gas Summary, 1987, p. 4, 6
 60. Virginia Oil and Gas Summary, 1988, p. 3, 6
 61. Virginia Oil and Gas Summary, 1989, p. 2, 5
 62. Virginia Oil and Gas Summary, 1990, p. 5, 7
 63. Virginia Oil and Gas Summary, 1991, p. 5, 6
 64. Virginia Produced waters from Coalbed methane report
 65. Virginia Injected water chemical analysis report
 66. State of Oregon Saltwater Reports for 1986 - 1991.
 67. State of Oregon, Mist Gas Field Production Report for 1979 - 1991.
 68. State of Utah Production Report, Dec., 1986, Section : Summary by County, p. 2
 69. State of Utah Production Report, Dec., 1987, Section : Summary by County, p. 2

70. State of Utah Production Report, Dec., 1988, Section : Summary by County, p. 2
71. State of Utah Production Report, Dec., 1989, Section : Summary by County, p. 2
72. State of Utah Production Report, Dec., 1990, Section : Summary by County, p. 2
73. State of Utah Production Report, Dec., 1991, Section : Summary by County, p. 2
74. State of Utah, Brine Chemical Analysis Reports (14 total)
75. State of Utah, DNR, Disposition of Produced Water Reports, 1986 - 1991
76. Nebraska Oil and Gas Production Summary - 1986, p. 1,2
77. Nebraska Oil and Gas Production Summary - 1987, p. 1,2
78. Nebraska Oil and Gas Production Summary - 1988, p. 1,2
79. Nebraska Oil and Gas Production Summary - 1989, p. 1,2
80. Nebraska Oil and Gas Production Summary - 1990, p. 1,2
81. Nebraska Oil and Gas Production Summary - 1991, p. 1,2
82. West Virginia Geologic Survey, verbal correspondence with Mary Behling.
83. West Virginia Brine Disposal Well data for 1986 - 1991
84. West Virginia Brine Secondary Recovery data for 1986 - 1991
85. West Virginia Brine Laboratory Analysis reports
86. Kansas - telecopy of stats from Rick Hestermann
87. Colorado Oil and Gas Statistics - 1990, first page of Section V
88. Colorado Oil and Gas Statistics - 1991, first page of Section V
89. Alabama Oil and Gas Production summaries (appendix A), 1986 - 1991
90. Alabama Oil and Gas Board, personal correspondence from Richard Raymond, pp. 1, 2
91. Alabama Brine analysis reports
92. Alabama "Production Summary by Fields" reports for 1986 - 1991

93. Wyoming Oil and Gas Production Statistics, 1988 , p. 91
94. Wyoming Oil and Gas Production Statistics, 1989 , p. 100
95. N. Dakota 1991 Production Report, p. IV
96. N. Dakota 1991 Production Report, p. 529

TABLE 2C. PRODUCED WATER DATABASE DISPOSAL METHODS

DISPOSAL METHODS :

- (a) Class II injection (disposal or enhanced recovery)
- (b) Evaporation, to reserve pits
- (c) Surface disposal via NPDES permit
- (d) Road spreading
- (e) Hauled out of state for disposal
- (f) Annular disposal

REMARKS :

- (1) Well totals for '90 and '91 can be computed from reports with difficulty.
- (2) Do not have data by well, only the number of producing wells in each field.
- (3) The only EP TOX and TCLP data available is from core cuttings
- (4) Total number of producing wells is for oil wells only. The numbers reflect the *reported* number of producing wells for '86 - '87 and the *estimated* number of producing wells for '88 - '89.
- (5) "Shut in" and "Total Wells" can be computed from reports.
- (6) Data available by county only.
- (7) Total number of "Producing wells" can be computed from reports.
- (8) Data available by "pool" only.
- (9) Total water is for injected volumes only. (not produced)
- (10) This is an *estimate* of producing wells. Reported number of producing wells was 17,736.
- (11) This is an *estimate* of producing wells. No reported number of wells.
- (12) Because most oil is gathered from common tanks, the number of producing wells

can no longer be reported. (PA, reference # 53)

- (13) Chemical analysis results reported on three separate printouts entitled "Results of Toxic Screenings from Oil Production", "...from Gas Production", and "...from Drill Cuttings".
- (14) Shut in total is for oil shut in wells only
- (15) Produced water volume is for 9/91 - 9/92, the only time period it had to be reported to the state.
- (16) All reported water volume data was divided by 42 gal/bbl in order to get units into barrels.
- (17) From '86 thru Aug. '89, water totals are from the *injected* water volume reports.
- (18) From Sep. '89 thru 1991, water totals are from the *produced* water volume reports.
- (19) No water data was supplied from August '91 forward. Used the average produced water volumes from January to July of that year to estimate the monthly volumes for August to December.
- (20) Have 14, high quality analyses available.
- (21) Injected water volume can be computed from available data.
- (22) Injection well total can be computed from available data.
- (23) Colorado oil and gas stats is out of print for 1987.

**TABLE 3. HAZARDOUS CHARACTERISTICS
OF OIL AND GAS WASTES**

Sample Type	# Analyzed	# Toxic (Benz.)	# Ignitable
Soil	61	2	1
Sludge	51	19	13
Water	16	9	9
Produced Oil	4	3	4

Source: McHugh et al., 1993.

TABLE 4. DISPOSAL METHODS FOR DRILLING WASTES

On-Site Methods

- Reserve Pits
- Annular Disposal of Pumpable Wastes
- Waste Solidification
- Discharge of Liquids to Land/Surface Water

Off-Site Methods

- Centralized Disposal Pits & Treatment Facilities
- Commercial Land Farming
- Reconditioning and Reuse

TABLE 5. DISPOSAL METHODS FOR PRODUCED WATER

On-Site Methods	<ul style="list-style-type: none">• Subsurface Injection• Evaporation Pits• Discharge to Surface Water• Brine Pits
Off-Site Methods	<ul style="list-style-type: none">• Road or Land Application

TABLE 6. TREATMENT CATEGORIES AND UNIT PROCESSES

CATEGORY	PROCESS
Liquid/Solid Separation	Filtration Sedimentation Flocculation
Liquid/Emulsion Separation	Gas Flotation Hydrocyclones Diatomaceous Earth Centrifugation Membrane Filters Skim Tanks
Removal of Organics	GAC Air Stripping
Removal of Inorganics	Precipitation Reverse Osmosis
Secondary Waste Stream Treatment	Off Gas - GAC Sludge Thickening Sludge Landfill

TABLE 7. PRODUCED WATER CONSTITUENTS

ORGANIC	ORGANIC	METALS
Acenaphthene	Pyrene	Antimony
Acetone	Styrene	Arsenic
Acrylonitrile	α -Terpineol	Aluminum
Anthracene	Toluene	Barium
Benzene	Trichloroethene	Cadmium
Biphenyl	1,1,1-Trichloroethane	Calcium
Bis(2-ethylhexyl)phthalate	1,1,2,2-Tetrachloroethane	Chromium
Carbazole	1,1,2-Trichloroethane	Cobalt
Carbon tetrachloride	2,4,5-Trichlorophenol	Copper
Chlorobenzene	2,4,6-Trichlorophenol	Iron
2-Chlorophenol	Vinyl chloride	Lead
4-Chloro-3-methylphenol	m-Xylene	Magnesium
Chrysene	o-Xylene	Manganese
p-Cymene	p-Xylene	Mercury
Di-n-octyl phthalate		Molybdenum
Dibenzothiophene		Nickel
1,1-Dichloroethane	INORGANIC	Selenium
1,1-Dichloroethene	Ammonia as N	Silver
1,2-Dichlorobenzene	Beryllium	Strontium
1,2-Dichloroethane	Bicarbonate	Tin
1,3-Dichlorobenzene	Boron	Titanium
1,4-Dichlorobenzene	Carbonate	Vanadium
trans-1,2-Dichloroethene	Chloride	
2,4-Dimethylphenol	Fluorene	INDICATORS
2,4-Dinitrotoluene	Hydroxide	Biological Oxygen Demand
Ethylbenzene	Nitrate + Nitrite as N	Chemical Oxygen Demand
Hexachlorobutadiene	Phosphorous as P	Oil & Grease
Hexachloroethane	Potassium	pH
Methyl ethyl ketone	Silicate as SiO ₂	pH
Methylene chloride	Sodium	Total Dissolved Solids
Napthalene	Sulfate	Total Organic Carbon
Pentachlorophenol	Sulfide	Total Cyanide
Phenanthrene	Thallium	Total Suspended Solids
Phenol	Zinc	

Source: API, 1987.

TABLE 8. GROUPING OF CONSTITUENTS

Constituent	log(K _{ow})	part. coeff.	log(K _{ow} -cum-mol)	log(K _{ow} -cum-mol)	log(t _{1/2} classes)	MW	1/n	K
Bis(2-ethylhexyl)phthalate	9.61		-6.52	8.00E-07	-6.5		1.5	11300
Phenol	1.48		-6.36	4.50E-07		94	0.54	21
Anthracene	4.63		-6.01	9.87E-07		178	0.7	376
Chrysene	5.91		-5.98	1.05E-06	-5.76	228	0.46	716
Pentachlorophenol	5.04		-5.62	2.40E-06		264	0.42	150
2,4,6-Trichlorophenol	3.61		-5.40	4.00E-06			0.4	155
2,4-Dinitrotoluene	2.01		-5.35	4.50E-06	-5.3	184	0.31	146
Pyrene	5.32		-5.29	5.10E-06		202	0.30	389
2-Chlorophenol	2.16		-4.89	1.03E-05			0.41	51
2,4-Dimethylphenol	2.5		-4.77	1.70E-05	-4.75	124	0.44	70
Di-n-octyl phthalate	9.87		-4.77	1.70E-05				
Fluorene	4.18		-4.18	6.40E-05		168.2	0.28	330
Acrylonitrile	0.25		-4.08	8.60E-05	-4	53	0.51	1.4
Acenaphthene	3.7		-4.04	9.10E-05		154	0.38	190
Biphenyl	4.63		-3.71	1.83E-04				
Phenanthrene	4.63		-3.65	2.26E-04	-3.5	178	0.44	215
1,1,2,2-Tetrachloroethane	2.56	46	-3.42	3.80E-04		166	0.37	10.6
1,1,2-Trichloroethane	2.17		-3.19	7.40E-04		132	0.6	5.81
1,2-Dichloroethane	1.45		-3.04	9.10E-04		98	0.83	3.57
Napthalene	3.87		-2.94	1.15E-03	-2.9	128	0.42	132
Methylene chloride	1.25		-2.88	1.31E-03		84	1.16	1.3
1,2-Dichlorobenzene	3.59	180	-2.74	1.80E-03		147	0.43	129
Chlorobenzene	2.98		-2.59	2.60E-03		112	0.99	91
1,4-Dichlorobenzene	3.59	4.4	-2.50	3.14E-03		147	0.47	121
1,1-Dichloroethane	1.8	19	-2.41	3.88E-03		98	0.53	1.79
Benzene	2.13		-2.26	5.50E-03	-2.4	78	1.6	1
Toluene	2.79		-2.24	5.70E-03		92	0.44	26
Trichloroethene			-2.20	6.32E-03		131		
trans-1,2-Dichloroethene			-2.18	6.60E-03		96	0.51	3.05
1,1,1-Trichloroethane	2.47	104	-1.92	1.20E-02		132	0.34	2.5
Hexachloroethane	4.62		-1.75	1.78E-02		237	0.38	98.5
1,1-Dichloroethene	1.48		-1.72	1.91E-02	-1.75	96	0.54	4.91
Vinyl chloride	0.6		-1.71	1.98E-02		62		
Carbon tetrachloride	2.73		-1.68	2.11E-02		152	0.81	11.1
Hexachlorobutadiene	4.78		-1.59	2.56E-02		260.8	0.45	258
Acetone						58		
Methyl ethyl ketone						72		
Syrene	2.95					104	0.56	120
2,4,5-Trichlorophenol	3.38							
4-Chloro-3-methylphenol								
alpha-Terpinol								
Carbazole	3.51							
Dibenzofluorene								
p-Cymene								

TABLE 9. SELECTED PERFORMANCE AND COST MODELS

	CAPDET	WATERMAID	GRI	WATER	WATERCOST
Chemical precipitation	X	X			
Sedimentation	X	X	X		
Filtration	X	X	X		
Chemical oxidation		X	X		
GAC	X	X	X		
Ultrafiltration					
Nanofiltration					
Reverse osmosis		X	X		
Evaporation			X		
Injection			X		
Air stripping	X	X			
Centrifugation	X	X			
Gravity thickening	X	X			
Landfill	X	X			
Flow rates (million gal./day)	0.3 - 500	1 - 200	0.007 - 0.4	0.25 - 0.5	1-200
Capabilities	p,c	vp,c	p,c		

vp - variable performance

p - performance

c - cost

TABLE 10. DESIGN PARAMETERS FOR UNIT PROCESSES

Parameter	Range
GAC empty bed contact time (ebct) hydraulic application rate bulk density type	15 - 35 min 1-7gpm/sq ft 300 - 375 lb/sq ft pressure, gravity
Filtration media type surface area hydraulic application rate air scour backwash rate backwash time	sand, anthracite 400 - 4000 sq ft 2 - 5 gpm/sq ft yes / no 10-20 gpm/sq ft 8-12 min
Flocculation hydraulic detention time mixing velocity gradient	10 - 40 min 10-75 fps/ft
Reverse Osmosis recovery pres. drop(membrane) feed pressure	60 - 80 % 30 - 60 psi 325-450 psi
Air Stripping air/water ratio hydraulic detention time	5 - 250 10 - 40 min
Sedimentation hydraulic detention time overflow rate shape	2 - 4 hr 300 - 600 gpm/sq ft round / square
Rapid Mix hydraulic detention time mixing velocity gradient coagulant coagulant dose	30 - 300 sec 300 - 800 fps/ft alum, ferric sulfate 10 - 100 mg/l

TABLE 11. Treatment Costs for Selected Waste Stream

Contaminant	Process	Cost
Disolved Inorganics	Reverse Osmosis	\$0.11 /bbl
Adsorbable Organics	GAC	
Volatile Organics	Air Stripping	\$0.08 -- \$0.38/bbl
Solids	Flocculation	\$0.05/bbl
	Sedimentation	
	Filtration	

FIGURE 1. TOTAL NUMBER OF WELLS DRILLED 1981-1985

Source: U.S. EPA, 1987.

FIGURE 2. PRODUCED WATER VOLUMES 1981-1985

Source: U.S. EPA, 1987.

FIGURE 3. OIL AND GAS EXPLORATION AND PRODUCTION ACTIVITIES IN THE U.S.

Note: Alaska not shown

FIGURE 4. WASTE DISPOSAL PRACTICES IN 1985

A. Reserve Pit Contents

B. Produced Water

Source: Wakim, 1987 and Wakim, 1988.

**FIGURE 5. GROUNDWATER RECEPTOR ENVIRONMENTS
RESERVE PITS**

Appendix I. PED Survey

This survey is intended to gather information for well locations where reserve pits were used (do not report on wells where closed systems were used). The survey is divided into three sections: **Drilling Wastes, Associated Wastes, and Production Waters.**

If you have any questions, please contact:

Hanadi S. Rifai, PhD., P.E.
Rice University
Department of Environmental Science
and Engineering (713)-285- 5305

Please answer each question and leave no blanks. If necessary, use zeros or NA for not applicable.

Environmental Production Database Survey

Section 1: Drilling Wastes

1.1 Name _____

Title _____

Company name _____

Company address _____

Telephone Number _____

1.2. Well location

State _____

County _____

API # _____

Latitude _____ Longitude _____

1.3a. EPA region, refer to map (check one or enter number).

1.3b. Production region.

EPA region map to
be placed here

1.4. Date Spudded

_____/_____/____

1.5. Total depth of well *in feet* (check one)

- ☐ < 3,750
- ☐ 3,751-7,500
- ☐ 7,501-15,000
- ☐ > 15,000

1.6. What is the status of the well?(check one)

- ☐ completed date ____/____/____
- ☐ abandoned date ____/____/____

Geographic Information

Drilling Wastes

1.7. Type of drilling mud system used
(check one)

- ☐ water base
- ☐ salt saturated
- ☐ oil base
- ☐ polymer
- ☐ other (specify) _____

1.8. Type of completion fluid used if discharged into the reserve pit (check one)

- ☐ acid
- ☐ air foam
- ☐ fresh water
- ☐ other (specify) _____
- ☐ gel/polymer
- ☐ oil
- ☐ salt/formation/frac water

If not discharged

- ☐ not discharged

1.9. Estimate total mud and completion fluid volume (including water phase) discharged to the reserve pit. Also rate your confidence level in this estimate. (check one)

_____ bbls

confidence level			
poor	average	good	excellent
☐	☐	☐	☐
<40%	40-60%	60-80%	>80%

Drilling Fluids

Drilling Wastes

1.10. Estimate reserve pit dimensions

length _____ ft.

width _____ ft.

depth _____ ft.

area _____ acres

1.11. Type of liner used (check one)

- ☐ bentonite in drilling mud ☐ no liner
☐ compacted clay
☐ high density polyethylene liner
☐ other (specify) _____

1.12. Estimate total volume of drill cuttings discharged to the reserve pit. Also rate your percent confidence in this estimate.

_____ bbls

confidence level			
poor	average	good	excellent
☐	☐	☐	☐
<40%	40-60%	60-80%	>80%

1.13. Estimate the volume of other discharges to the reserve pit. Also rate your confidence in this estimate.

_____ bbls rain water

_____ bbls all other water

_____ bbls circulated cement

_____ bbls formation testing fluids

_____ bbls other fluids or solids (specify) _____

confidence level			
poor	average	good	excellent
☐	☐	☐	☐
<40%	40-60%	60-80%	>80%

Reserve Pit (1)

Drilling Wastes

1.14. Explain step-by-step how the pit wastes were disposed of and how the pit was closed. (attach narrative statement if necessary)

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____

1.15. How were the pumpable liquids from the reserve pit disposed of? (Provide volume for each method used and rate your confidence in these estimates)

_____ bbls	hauled offsite	_____ bbls	incinerated
_____ bbls	buried onsite	_____ bbls	discharged to surface
_____ bbls	land spread	_____ bbls	evaporated
_____ bbls	solidified	_____ bbls	injected down annulus
_____ bbls	other (specify)	_____	_____

confidence level			
poor	average	good	excellent
☐	☐	☐	☐
<40%	40-60%	60-80%	>80%

Reserve Pit (2)

Drilling Wastes

1.16. How were the nonpumpable mud solids from the reserve pit disposed of? (Provide volume for each method used and rate your confidence in these estimates)

____ bbls hauled offsite
 ____ bbls buried onsite
 ____ bbls solidified
 ____ bbls other (specify) _____

____ bbls incinerated
 ____ bbls land spread

confidence level			
poor	average	good	excellent
☐	☐	☐	☐
<40%	40-60%	60-80%	>80%

1.17. How were the cuttings from the reserve pit disposed of? (Provide volume for each method used and rate your confidence in these estimates)

____ bbls hauled offsite
 ____ bbls buried onsite
 ____ bbls solidified
 ____ bbls other (specify) _____

____ bbls incinerated
 ____ bbls land spread

confidence level			
poor	average	good	excellent
☐	☐	☐	☐
<40%	40-60%	60-80%	>80%

1.18. Were there any chemical analyses run on the reserve pit contents before closure? (check one)

☐ Yes
☐ No

If yes, please check here if the analyses are attached.

☐

Reserve Pit (3)

Drilling Wastes

1.19. Is the site fenced?

- ☐ Yes
☐ No

1.20. Which material best describes the top three feet of soil around the reserve pit? (check one)

- ☐ silty loam ☐ clay ☐ topsoil ☐ silty clay loam
☐ sandy loam ☐ gravel ☐ other (specify) _____

1.21. Which material best describes the unsaturated zone (the zone under the reserve pit and above any shallow aquifers)? (check one or more)

- ☐ silty loam ☐ clay ☐ topsoil ☐ silty clay loam
☐ sandy loam ☐ gravel ☐ other (specify) _____

1.22. Source of information for soil and unsaturated zone material (engineering reports, judgement, etc.).

1.23. What is the thickness of the unsaturated zone? (distance from surface to saturated zone)

_____ ft

1.24. Which material best describes the saturated zone (the first shallow aquifer under the reserve pit)? (Check one or more)

- ☐ silt ☐ clay ☐ clayey silt ☐ sandy silt
☐ coarse sand ☐ fine sand ☐ gravel
☐ fractured rock ☐ other (specify) _____

Environmental Data (1)

Drilling Wastes

1.25. Direction and distance from well to nearest public or private water supply well. (check one)

Distance _____ ft or mi (circle appropriate units)

1.26. Distance to nearest:

_____ mi lake
 _____ mi flowing stream
 _____ mi other surface water body (specify) _____

1.27. Describe the landuse in a two kilometer or one mile vicinity of the drillsite. (provide percentage for each)

_____ %	pasture	_____ %	protected wilderness
_____ %	crops/ farm	_____ %	wetlands
_____ %	recreational	_____ %	national parks
_____ %	forest	_____ %	national reserves
_____ %	residential	_____ %	other (specify) _____
_____ %	commercial		

1.28. What is the distance in miles to the nearest of the following areas:

_____ mi	pasture	_____ mi	protected wilderness
_____ mi	crops/ farm	_____ mi	wetlands
_____ mi	recreational	_____ mi	national parks
_____ mi	forest	_____ mi	national reserves
_____ mi	residential	_____ mi	other (specify) _____
_____ mi	commercial		

Environmental Data (2)

Drilling Wastes

1.29. Depth to Water (ground surface to water table)

_____ ft or _____ mi

1.30. Hydraulic Gradient (slope of water table)

_____ ft/ft

1.31. Hydraulic Conductivity

_____ ft/yr or mi/yr (circle appropriate units)

1.32. Method used to estimate hydraulic conductivity (check one)

☐ Field tests ☐ Literature Values ☐ Engineering Judgement

1.33. Check the description that best summarizes the primary hydrogeologic environment underneath the reserve pit.

☐ Bedded Sedimentary Rock

☐ Metamorphic and Igneous Rock

☐ Sand and Gravel

☐ Alluvial Basins, Valleys and Fans

☐ River Valleys and Floodplains with Overbank Deposits

☐ River Valleys and Floodplains without Overbank Deposits

☐ Outwash

☐ Till and Till over Outwash

☐ Unconsolidated and Semiconsolidated Shallow Aquifers

☐ Coastal Beaches

☐ Other _____

☐ Solution Limestone

Hydrogeologic Data (1)

Drilling Wastes

1.34. Does the disposal facility have a groundwater monitoring system?

- ☐ Yes
- ☐ No

1.35. If yes, how many monitoring wells are used to evaluate groundwater quality? _____

1.36. How often are the wells sampled?

- ☐ Annually
- ☐ Quarterly
- ☐ Monthly
- ☐ Other _____

Groundwater Modeling

Drilling Wastes

Section 2: Associated Wastes

This section is intended to quantify wastes associated with exploration, development, and production of oil and gas resources.

List waste generated by state. Volumes should be expressed in barrels (42 gal) or tons (2000 lb) per year using the conversion factor 9 pounds = 1 gallon, if actual weight is unknown.

State _____

2.1. Number of active wells _____

2.2. Total produced volume

_____ oil
_____ water
_____ gas

2.3. Tank bottoms, separator sludges or pig trap solids

_____ tons/yr recycled through oil reclaimers
_____ tons/yr spread on roads
_____ tons/yr land spread
_____ tons/yr incinerated
_____ tons/yr onsite pit
_____ tons/yr onsite burial
_____ tons/yr offsite commercial facility
_____ tons/yr other (specify) _____

Associated Wastes

2.4. Used lubricating or hydraulic oils

_____ bbls/yr recycled through oil reclaimers
_____ bbls/yr returned to the crude or condensate
production stream
_____ bbls/yr spread on roads
_____ bbls/yr land spread
_____ bbls/yr incinerated
_____ bbls/yr burned as fuel
_____ bbls/yr onsite pit
_____ bbls/yr onsite burial
_____ bbls/yr offsite commercial facility
_____ bbls/yr other (specify) _____

2.5. Oily debris, filters, filter media,
contaminated soils

_____ tons/yr recycled through oil reclaimers
_____ tons/yr spread on roads
_____ tons/yr land spread
_____ tons/yr incinerated
_____ tons/yr onsite pit
_____ tons/yr onsite burial
_____ tons/yr offsite commercial facility
_____ tons/yr other (specify) _____

2.6. Untreatable emulsions - excludes
emulsion returned to the crude or
condensate production stream

_____ bbls/yr recycled through oil reclaimers
_____ bbls/yr spread on roads
_____ bbls/yr land spread
_____ bbls/yr incinerated
_____ bbls/yr onsite pit
_____ bbls/yr onsite burial
_____ bbls/yr offsite commercial facility
_____ bbls/yr other (specify) _____

Associated Wastes

2.7. Produced sand

_____	tons/yr	spread on roads
_____	tons/yr	land spread
_____	tons/yr	incinerated
_____	tons/yr	onsite pit
_____	tons/yr	onsite burial
_____	tons/yr	offsite commercial facility
_____	tons/yr	other (specify) _____

2.8. Spent iron sponge

_____	tons/yr	spread on roads
_____	tons/yr	land spread
_____	tons/yr	onsite pit
_____	tons/yr	onsite burial
_____	tons/yr	offsite commercial facility
_____	tons/yr	other (specify) _____

2.9. Dehydration and sweetening unit
wastes, including glycol and amine
waste, but excluding iron sponge.

_____	bbls/yr	spread on roads
_____	bbls/yr	land spread
_____	bbls/yr	injected
_____	bbls/yr	incinerated
_____	bbls/yr	onsite pit
_____	bbls/yr	onsite burial
_____	bbls/yr	offsite commercial facility
_____	bbls/yr	other (specify) _____

Associated Wastes

2.10. Workover swabbing, unloading, completion fluids, and spent acids disposed of other than via production facilities, such as flowlines.

_____	bbls/yr	storage for reuse
_____	bbls/yr	returned to service company
_____	bbls/yr	spread on roads
_____	bbls/yr	land spread
_____	bbls/yr	incinerated
_____	bbls/yr	evaporation pit
_____	bbls/yr	onsite pit
_____	bbls/yr	onsite burial
_____	bbls/yr	offsite commercial facility
_____	bbls/yr	other (specify) _____

2.11. Used solvents and cleaners, including caustics

_____	bbls/yr	recycled
_____	bbls/yr	spread on roads
_____	bbls/yr	land spread
_____	bbls/yr	incinerated
_____	bbls/yr	onsite pit
_____	bbls/yr	onsite burial
_____	bbls/yr	offsite commercial facility
_____	bbls/yr	other (specify) _____

2.12. Cooling water, engine and other waste water. Include waste waters disposed from sump systems that are not recycled via production facilities.

_____	bbls/yr	spread on roads
_____	bbls/yr	land spread
_____	bbls/yr	injected
_____	bbls/yr	incinerated
_____	bbls/yr	onsite pit
_____	bbls/yr	onsite burial
_____	bbls/yr	surface discharge (land, lake, bay)
_____	bbls/yr	offsite commercial facility
_____	bbls/yr	other (specify) _____

Associated Wastes

2.13. Other production solid waste such as used chemical drums, insulation, etc. Exclude office and domestic rubbish. Describe major constituents.

_____ tons/yr recycled
_____ tons/yr spread on roads
_____ tons/yr land spread
_____ tons/yr incinerated
_____ tons/yr onsite pit
_____ tons/yr onsite burial
_____ tons/yr offsite commercial facility
_____ tons/yr other (specify) _____

2.14. Other production liquid wastes such as contaminated fluids. Exclude office and domestic wastes and sewage. Describe major constituents.

_____ bbls/yr recycled
_____ bbls/yr spread on roads
_____ bbls/yr land spread
_____ bbls/yr injected
_____ bbls/yr incinerated
_____ bbls/yr evaporation pit
_____ bbls/yr onsite pit
_____ bbls/yr onsite burial
_____ bbls/yr surface discharge (land, lake, bay)
_____ bbls/yr offsite commercial facility
_____ bbls/yr other (specify) _____

Associated Wastes

Section 3: Production Water

3.1. State

3.2. Crude Oil Condensate Production

_____ bbls

3.3. Produced Gas Volume

_____ Million cubic feet

3.4. Produced Water Volume

_____ bbls

3.5. Disposition of Produced Water

_____ bbls salt water disposal

_____ bbls enhanced Oil Recovery

_____ bbls NPDES Discharge

_____ bbls other _____

Production Water

DATE

FILMED

7/19/94

END