Evaluation of Injection Well Risk Management Potential In the Williston Basin

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1.0 Executive Summary

1.1 Highlights

"Evaluation of Injection Well Risk Management Potential in the Williston Basin" developed and exercised a realistic model of a risk based data base that was constructed using individual well history and field reservoir parameters from underground injection operations in a geologic basin. This model demonstrated that:

- The risk approach to managing underground injection control (UIC) operations is a practical method of prioritizing and/or redirecting personnel and funds towards those activities that have the greatest risk of contaminating an underground source of drinking water (USDW).
- The data is available to construct a risk based data base that contains all the information necessary to carry out the risk approach to managing a UIC program.
- Efforts to incorporate the risk management approach into existing UIC programs will range from grass roots development for a state that has recently been granted regulatory authority over the program to the addition of selected risk elements to mature programs.
- The risk of endangering a USDW in the Williston basin is small. The upper bound probability of injection water escaping the wellbore and reaching a USDW is seven chances in one million well-years where surface casings cover the drinking water aquifers. Where surface casings do not cover the USDWs, the probability of contamination is six chances in one thousand well-years.

In line with a resolution adopted by the Underground Injection Practices Council (UIPC) at their 1989 summer meeting, it is recommended that all UIC programs be upgraded during the next five years to include selected elements of the risk management practices presented in this report. Federal and state funding will be needed to achieve this goal.

1.2 Background

The February 1988 American Petroleum Institute (API) study "Oil and Gas Industry Water Injection Well Corrosion"[1] developed a methodology to assess the risk of USDW contamination posed by injection well operations. The API study recommended that a pilot risk based data base be implemented in a geologic basin to evaluate the risk approach to managing underground injection operations.

In October 1988, the Underground Injection Practices Council Research Foundation (UIPCRF) commissioned Michie & Associates, Inc. to conduct a pilot study to investigate the operational feasibility of building and using a risk based data base for the Williston basin. Funding for the Williston Basin study was provided for by grants to the UIPCRF from the API and the Department of Energy.

1.3 Purpose Of Williston Basin Study

Purpose of the Williston Basin study was to test the feasibility of constructing a risk based data base and to evaluate the risk approach as a supplement to existing UIC regulatory programs.

Although the study was not designed to address the reporting aspects of UIC compliance and regulatory activities, the risk based data base contains essentially all the information needed to develop the reports required for those functions.

1.4 Reasons For Selecting Williston Basin

The Williston basin was selected for the study because:

- It contains only 731 active salt water disposal (SWD) and water injection wells which makes it manageable.
- It has a significant potential for external casing corrosion.
- It involves three states, of which North Dakota and South Dakota have regulatory authority over their UIC programs while the Environmental Protection Agency (EPA) administers the Montana program.

1.5 Conclusions

The Williston Basin study demonstrated that:

- The risk based approach is a practical and an effective way to manage UIC programs.
- The individual well and field data needed to construct a risk based UIC data base is available but the information is often located in a number of different files.
- The work needed to implement the risk management approach into existing UIC programs will range from grass roots efforts for states that have recently assumed administration of the program to addition of selected risk elements to mature programs.
- Assuming present regulations are followed, the upper bound probability of injection water reaching a USDW, due to wellbore leaks, is seven in one million well-years where surface casings cover the USDWs and six in one thousand well-years where they do not.
- Personnel requirements to construct the data base are reasonable.
- Installing risk management into an existing UIC program lends itself to phased implementation of the clearly defined elements that make up a risk based program.
- Off-the-shelf PC computers and commercial software can be used to build a risk based data base and to manage a UIC program.
- Selection of unique well identifier codes and early agreement on the exact name for each well are important first steps in starting a grass roots UIC data base.
- Incorporation of individual well USDW definition into existing UIC data bases is needed for effective monitoring of subsurface water injection.
- Early identification of wellbore leaks can be obtained by monthly monitoring of the tubing/casing annulus pressure.

- o Construction of a grass roots risk management data base would permit more effective management of the Montana UIC program.
- o With minor changes, the North Dakota UIC data management system can be upgraded to include all the elements needed for a risk based program.
- o No change is indicated in the computerized South Dakota UIC program.

1.6 Recommendations

A summary of recommendations is presented below:

- o During the next five years, all UIPC programs should be upgraded to include selected elements of the risk management practices presented in this report. Federal and state funding will be needed to achieve this goal.
- o The UIPC Research Foundation should adopt as a standard the risk based data management system developed for this study. Shortfalls in existing UIC monitoring programs, as measured against this standard, should form the basis for future state and federal implementation grants.
- o A project should be funded to conduct a survey of state and EPA managed UIC programs to determine the status of existing data management capabilities and to determine which data elements are needed to upgrade present programs to the risk concept.
- o Each UIC agency should conduct a feasibility study of the benefits, costs and timing of implementing risk into their program. Those elements of the risk approach that are attractive should be implemented into the existing program in a step-wise manner.
- o Monthly monitoring of the casing/tubing annulus pressure should be required in those states where it is not specified in either the field rules or the UIC regulations.
- o Reports of potential leaks identified by the monthly injection monitoring program should be entered into the UIC data bases.
- o The annual report on the injection monitoring program results should be shortened to two or three lines per well and entered into the UIC data bases.
- o Identification of USDW parameters at the individual well level should be included in all UIC data bases.
- o Electronic transfer of UIC data should be encouraged.
- o A risk management data base should be evaluated for management of underground injection operations in Montana.
- o North Dakota should evaluate making nominal additions of risk elements to their existing UIC data base.

2.0 Introduction

2.1 Review Of UIC Regulations

The UIC regulations promulgated by the EPA under the Safe Drinking Water Act (SDWA) provide the EPA, or an EPA approved state agency, with authority to regulate subsurface injection of fluids to protect USDWs. Those states which have been delegated primary regulatory authority over the UIC program are referred to as primacy states.

In oilfield producing operations, fluids covered by UIC regulations primarily include saline waters brought to the surface with oil and gas production and surface waters or waters from nonproducing formations injected into oil reservoirs to maintain an efficient and economic oil recovery process.

Of the five classes of injection wells addressed by the UIC program, oil and gas producing industry interests are concerned primarily with Class II wells whose uses as defined by UIC regulations are:

- o Disposal of fluids brought to the surface and liquids generated in connection with oil and gas production (SWD),
- o Injection of fluids for enhanced oil recovery (EOR), and
- o Storage of liquid hydrocarbons.

The EPA defines[2] a USDW as an aquifer or its portion:

(1)(i) Which supplies any public water system; or

(ii) Which contains a sufficient quantity of ground water to supply a public water system; and

(A) Currently supplies drinking water for human consumption; or

(B) Contains fewer than 10,000 mg/l total dissolved solids; and

(2) Which is not an exempted aquifer.

2.2 API 1988 Injection Well Corrosion Study

2.2.1 Background

In a December 1987 report to Congress, "Report to Congress: Management of Wastes from the Exploration, Development, and Production of Crude Oil, Natural Gas, and Geothermal Energy," the EPA concluded that regulation of oil and gas exploration and production wastes as hazardous under the Resource Conservation and Recovery Act (RCRA) was not necessary at that time.

As part of an overall program to provide reliable data for addressing the exploration and production waste issue, the API commissioned Michie & Associates, Inc. to conduct a study[1] of oil and gas industry subsurface water injection practices in the continental United States. Purpose of the study was to:

- o Identify areas of the U.S. where the potential existed for corrosion related failures that could allow the release of injection water into a USDW,
- o Develop a method to analyze and examine injection well failure data, and

- o Use well failure data to determine the upper limits for potential USDW contamination frequency from Class II injection well operations for subsequent use in risk analyzes of UIC programs.

2.2.2 API Study Results

The API study showed that:

- o In the continental U.S., the oil and gas industry operates 170,000 water injection wells which inject 60 million BWPD into subsurface formations in 39 geological basins.

  Of the 39 producing basins, 20 have only minor external casing corrosion and their potential for polluting a USDW is minimal. These 20 basins contain 52% of the water injection wells and inject 36% of the water in the U.S.

  Nineteen of the 39 producing basins have the potential for external casing corrosion which is categorized as possible or significant. These basins contain 48% of the water injection wells which inject 64% of the water. Although the potential for pollution of USDWs in the basins with possible or significant corrosion is small, it is in these areas where UIC regulatory efforts are likely to be most effective in reducing the risk of contamination to USDWs.
- o A risk based method was developed which uses wellbore tubular equipment failure data to calculate the probability of simultaneous failures of an injection well's tubing, production casing and surface casing going undetected and permitting injection water to escape to the borehole and possibly reach a USDW.
- o For wells in basins where there is a possible or significant potential for corrosion related failures, upper bounds for contamination of a USDW were found to be on the order of one failure per million well-years where surface casings cover USDWs and one failure per thousand well-years where surface casings do not.

  Note:
  The ranges for the probability of USDW contamination are upper bounds only and take no credit for the possibilities of fluids flowing into the well where low formation bottomhole pressures exist, of permeability barriers from compacted drilling mud and formations in the borehole or of injection water migrating from the borehole into saltwater zones occurring between casing leaks and USDWs.

2.2.3 API Study Conclusions

API study conclusions were:

- o The risk based approach to additional UIC regulatory guidelines showed promise.
- o Data such as injection volumes, leak histories, USDW definition and field reservoir parameters that are needed in the risk assessment process are generally available but the information is typically found in a number of different places and requires considerable effort to gather and incorporate into a computerized data base.

- o A pilot study of a geologic basin was needed to test the feasibility of obtaining individual well and field information needed to build a computerized UIC data base and to use the data base to evaluate the risk approach as a supplement to existing UIC monitoring and regulatory programs. It was also needed to evaluate the similarity of risk across a basin.

2.3 Reasons For Selecting Williston Basin

As a follow-up to the API study recommendations, the Williston basin was chosen for the pilot study of the feasibility of using the risk approach in managing Class II injection operations. Reasons for electing the Williston basin were:

- o It is one of the nine geologic basins which was classified in the API study as having a significant potential for external casing corrosion. This corrosive nature permitted an evaluation of the effectiveness of the injection well corrosion control measures used by industry.
- o There are 731 active, 22 shut in and 203 temporarily abandoned SWD and water injection wells in the basin. This relatively small size reduced study time.
- o The basin covers three states. North Dakota and South Dakota have primacy over the UIC programs while the EPA administers the program in Montana. This mix of regulatory methods permits identification of the advantages and disadvantages of different approaches to managing UIC data and regulating UIC programs.

2.4 Description Of The Williston Basin

The U.S. portion of the Williston basin includes the west half of North Dakota, northwestern South Dakota and a large part of northeastern Montana extending southward almost to the Wyoming border (Figure 1). Although not included in this study, the basin extends into southern Saskatchewan and the southwestern corner of Manitoba, Canada.

The Williston basin is a large roughly elliptical downwarp in the earth's crust covering 200,000 square miles. The basin is a typical sedimentary basin which sagged intermittently to permit the accumulation of unusual thicknesses of sedimentary rocks. The deepest part of the basin is located in northwestern North Dakota where more than 15,000 ft of sedimentary rock overlays the Precambrian basement[3]. For a detailed geologic description of the Williston basin, see Appendix A.

Gas was discovered in the basin in 1913 along the Cedar Creek anticline in eastern Montana and oil was discovered in 1951.

As discussed in Appendix A, many of the cities in the basin obtain their water supply from rivers. Stratigraphic units considered as underground sources of drinking water include:

- o Glacial drift found in northern portion of the basin,
- o Alluvian along streams and rivers,
- o Sandstones and lignites in the Fort Union group which occur in localized areas in the basin and

- Sandstones in the Hell Creek and Fox Hills formations which are generally present throughout the basin.

The basin is characterized by carbonate rock oil reservoirs that range in depth from 3,000 to 13,000 ft and are under waterflood operations using produced water injection supplemented by source water. Production averages 160,000 BOPD and 210 million ft^3/D from 5,400 wells. Water injection averages 469,000 B/D into 731 SWD and water injection wells.

The basin also contains eight gas injection wells that are involved in gas pressure maintenance projects and 30 air injection wells that are used in an in-situ combustion project. These wells are not included in this study.

The basin's significant potential for external casing corrosion is largely attributed to corrosive zones in the Dakota salt water aquifer which occurs at depths from 2,000 to 6,000 ft. Casing collapse associated with salt movement augmented by external corrosion occurs in the salt beds of the Spearfish, Opeche and Charles formations that are found at 4,000 to 9,000 ft in selected areas of the central and western parts of the basin. For a detailed description of the basin's corrosive and salt zones, refer to Appendix A.

2.5 Objectives Of Williston Basin Study

2.5.1 General

The broad objective of the Williston Basin study is to define requirements and to investigate the feasibility of incorporating risk management into administration of the UIC program.

The study does not address the reporting aspects of UIC regulatory and compliance activities but the data base does contain essentially all the information required to develop the reports needed to monitor those activities.

Detail study objectives are discussed below.

2.5.2 Develop Data Base

The first objective of the study was to define and build a data base which would provide the information needed to allow risk management of Class II injection operations. Database development for this proposed UIPC recommended standard involved:

- Defining data elements,
- Determining availability of the desired data,
- Obtaining the data,
- Selecting and obtaining hardware and software needed to computerize the data,
- Loading data into a computer,
- Verifying accuracy of the data once it is loaded into a computer, and
- Developing and implementing backup schemes to minimize the likelihood of loss of data in the event of hardware or software failure.

The most important factor in the successful completion of the data base was assistance received from operators and UIC program administrators in helping to define data requirements and in supplying completion, operating, Mechanical Integrity Test (MIT), monthly monitoring and leak data for the project.

As shown on Figure 2, data and comments on the database contents and query design were received from eight basin operators and four regulatory agencies involved in administering the UIC programs in the Williston basin. In addition, two operators and four other UIC regulating agencies and the Department of Energy supplied helpful comments and project guidance.

It is interesting to note that the eight companies who supplied data account for only 5% of the basin operators but they operate 56% of the Class II injection wells in the basin.

2.5.3 Incorporate Risk Analysis In Data Management Procedures

The second objective of the study was to develop risk management procedures which could be incorporated into existing UIC programs. This phase involved obtaining comments from operators and regulators as to what database queries they felt would be appropriate.

After the type and content of queries were identified, it was necessary to design reports which presented the requested information in a form that facilitated easy use of the data. This involved software programming to build the reports and construct user input screens to permit query results to be routed to a computer screen and/or printer.

2.5.4 Obtain UIPCRF Approval Of Risk Based Data Management Standard

The final objective of the Williston Basin study was to obtain approval of the UIPC Research Foundation of the risk based approach as a standard for monitoring and regulating underground injection operations. Following approval, it was planned to present results of the study as a proposed standard to state and federal UIC administrators for their review, suggestions, testing against their present programs and possible phased integration into their current UIC programs. For a detailed discussion of proposed implementation plans, see Section 6.

It is recognized that incorporating risk into existing UIC programs will require funding by state and/or federal regulatory agencies and commitment of manpower resources over at least a three- to five-year period.

2.6 Study Approach

2.6.1 Project Management

The contract for the Williston Basin study was with the Underground Injection Practices Council Research Foundation which also acted as project manager. The Foundation has its own Board of Directors and functions as a separate corporate entity from the Underground Injection Practices Council. Research Foundation board members include state and federal UIC administrators and industry personnel who are interested in UIC operations and regulations.

It was the objective of the Foundation Board in developing a recommended standard approach to risk management to provide it at no cost to interested state and federal regulatory agencies.

2.6.2 Project Funding

Funding for the Williston Basin study was provided by the API and the Department of Energy. Funding arrangements for the joint industry/government project were made by UIPCRF. As provided by the contract, invoices for completed work were submitted to the Foundation for subsequent payment.

2.6.3 Project Approvals

Prior to awarding the contract, the project was reviewed with the Foundation Board of Directors. In addition, reviews were held with selected operators and UIC administrators who were not members of the Board. The meetings provided valuable input as to project concept.

Following the reviews, a written proposal was submitted to the Foundation for final approval. This proposal included study objectives, procedures, costs and timing. Contract execution followed Board approval of the written proposal.

2.6.4 Computer Selection

The computer chosen for the study is a desktop PC which uses a Zenith Z-386™ 32-bit 80386 microprocessor with a 150 megabyte hard disk, 2 megabytes of RAM and a ZCM-9490™ VGA color monitor. Software file backup is provided by a 60 megabyte tape drive which supplements short term diskette backup.

The computer system selected for the study provided more computing capability than was needed to construct and operate the Williston basin data base. As an example, after project completion, the data base was installed in a laptop computer that contained a 80286 microprocessor with a 42 megabyte hard disk and 1 megabyte of RAM. This laptop is suitable for field usage and data entry by field regulatory personnel.

2.6.5 Software Selection

Selection of the software was limited to commercial database programs that could be supported by the PC computer. The computer software selected was dBase IV™ by Ashton-Tate Corporation for the data base and R&R Report Writer™ by Concentric Data Systems, Inc. for query, sort and report generation.

See Appendix B for additional information on software capabilities.

2.6.6 Database Definition

The first phase of the project involved definition of the data elements needed to administer a risk based UIC program.

In order to utilize the experience of personnel knowledgeable in UIC operations, comments on a proposed database structure were requested from 27 UIC administrators and industry representatives. Response to the request was excellent and the suggestions proved helpful in defining database elements. For details of databyase file definitions, see Appendix D.

2.6.7 Database Design

The database design utilizes identical relational data bases for each of the three states. The three data bases can be used separately to generate queries, sorts and reports. They can also be linked by software so they appear to the user as a single data base.

As shown in Figure 3, each data base consists of:

- o One well master file which contains selected information that is unique for each well,
- o Sixteen name/type ID files which contain alpha or numeric codes that are translated into names or types for English language reporting, and
- o Ten data files which contain individual well and field information.

For detailed information on database construction, refer to Appendix D.

2.6.8 Problems With Multiple Sources Of Raw Data

A major part of the study work was gathering and verifying raw data for entry into the data base. The data was obtained from a number of sources on both paper and diskettes. For example, the well identifiers (well name, file numbers and location) were obtained from state records in North Dakota and South Dakota and required a minimum of verification time. On the other hand, identification of the Montana wells required use of data from the EPA, the state and the operators together with maps and technical reports to identify wells. As a result, an estimated 15% of the study time was spent in identifying Montana wells.

In general, raw data needed to construct the Williston Basin study data base was found to be available but it was often difficult to obtain and verify.

A summary of the diverse information sources utilized in constructing the data base is presented below:

	Data Sources		
	Montana	North Dakota	South Dakota
Well Identification	E/O/S/T	S	S
Completion Data	O/P/S	O/S	O/P/S
MIT Tests	E/O	S	S
Injection Volumes	E/O	S	S
Leak History	O	O	O
Workover History	E/O	O/S	N
USDW Data	T	S/T	T
API Numbers	O/S	S	S

Legend:

E = EPA records and reports
N = Data not collected for Williston Basin study
O = Operator data
P = Petroleum Information Corporation (a commercial petroleum data management company)
S = State records and reports
T = Technical reports and maps (operator, state and federal)

2.6.9 Raw Data Media

Eighty percent of the raw data received for entry into the data base was on paper. The information that was on paper required considerable personnel time to manually encode, verify and transfer to the computer system. Additional time was also needed to verify the accuracy of the transfer.

Note:

A large portion of the UIC information that operators report to regulating agencies is transcribed from operator computer records to regulatory paper reports. This situation presents an opportunity to improve regulatory agency and operator administrative efficiencies by increasing the use of electronic media to transfer the data.

Twenty percent of the information transferred into the Williston basin data base was on diskettes. This data required a minimum of personnel time to enter the information into the data base. The time required to verify the accuracy of the transfer was minimal.

A summary of the raw data media is shown below:

	Raw Data Media		
	Montana	North Dakota	South Dakota
Completion Data	P	P	P
MIT Tests	D	P	P
Injection Volumes	D/P	P	P
Leak History	P	P	P
Workover History	P	P	P
USDW Data	P	P	P
Name/Type IDs	D/P	P	P

Legend:

D = On diskettes
P = On paper

2.6.10 Problems With Multiple Sources Of Raw Data
Typical of the problems with multiple sources of raw data were those associated with identifying Montana injection wells. For example, a Chevron operated SWD well in Brush Lake Field was identified by three separate groups as:

Data Source	WELL NAME
EPA	Brush Lake SWD 1
Chevron	BRUSH LAKE SALT WATER DISPOSAL 1
Montana	MELBY WTR DI <> 1

These differences in names for the same well precluded the use of computer matching, thus adding considerable time to database verification and construction.

The problem of using data from several sources was often compounded by errors in one of the source reports. As an example, one of the source reports listed the Brush Lake SWD 1 well as being in section 11 of township 33N and range 58E when it is actually in section 1 of township 33N and range 58E.

2.6.11 Query Definition
Query definition was handled in the same manner as database definition. Comments on queries that were felt to be useful in UIC risk management were requested from 27 UIC regulatory and operating personnel who were knowledgeable in the area. Replies to the request were then used in designing the database queries.

For a detailed discussion of database queries, refer to Section 7.0 and Appendix C.

2.6.12 Review Study Results With UIC Administrators
Following completion of the study, the results were reviewed with selected UIC administrators. Objective of these reviews was to obtain their critique of the study in order to assure that study conclusions were factual and recommendations were practical.

2.6.13 Final Report
This final report was prepared after reviewing study results with UIC administrators and the UIPC Research Foundation Board of Directors. Comments of the UIC administrators were considered along with all other informative sources. However, the study conclusions and recommendations are solely those of Michie & Associates, Inc.

2.6.14 Study Follow-Up With UIC Administrators
As a follow-up to this report, it is planned to review conclusions and recommendations and to demonstrate system query capabilities with state and federal administrators who express interest in the risk management approach to UIC regulation.

After the reviews are completed, it is recommended that a survey be conducted of UIC regulatory programs to determine existing data management capabilities and to develop areas of possible implementation interest. Funding for the survey has not been arranged.

If a UIC director or the EPA feels the risk approach has possible application in their program, a joint scoping study headed by a member of their staff will be initiated. If the study indicates the addition of risk management is attractive, a written proposal detailing costs, project timing, software, hardware and personnel requirements can be prepared. Funding for scoping studies has not been investigated.

2.6.15 Study Follow-Up With Regional Oil And Gas Associations

As part of the study follow-up, it is planned to demonstrate the database capabilities and review the study recommendations with regional oil and gas associations. One objective of these reviews is to pursue possible funding for adding selected elements of the risk based data base to existing UIC programs. Funding for these reviews has not been investigated.

2.6.16 Study Follow-Up With Operators

Although the study was directed toward incorporating risk management into existing state and federal UIC programs, there are incentives for operators to maintain and utilize selected portions of the risk management data base. As a study follow-up, it is planned to review the conclusions and demonstrate the system's query capabilities with those operators who express an interest in using the risk approach to maintain information, monitor their underground injection operations and streamline their data handling procedures.

Funding for those reviews has not been investigated.

3.0 Data Elements Requirements

3.1 General

As discussed in Section 2.6.6, the data elements needed to construct a data base to allow risk management decisions concerning Class II injection well operations were defined based on necessary geologic and engineering data and comments from operators and administrators who were knowledgeable in UIC operations. The elements were then used in the design of file structures for each of the 27 database files that make up the three identical relational data bases for Montana, North Dakota and South Dakota. Because they have identical file structures, the individual state data bases can be used separately or combined by software to appear to the user as a single data base.

Data elements of the Williston Basin study data base consist of the eight clearly defined categories listed below:

- o Well Identification
- o Wellbore Mechanical Construction
- o MIT Tests
- o USDW Information
- o Injection Monitoring
- o Field Level Reservoir Parameters
- o Tubing and Casing Failure History
- o Workover History

The purpose of this Section is to discuss the major elements of the data base and to review the data sources for those elements.

3.2 Relational Data Base

A relational data base consists of one or more database files each of which contain a number of data records. Each data record is divided into data fields that contain the data elements that belong to a single well entry. Each data record has a unique identifying name or number which permits the database management system to organize and manage the records so they can be easily located, sorted in a desired order and linked through indexing. This permits the user to arrange the data base through queries and sorts into meaningful reports.

The database management system used for the Williston Basin study data base is dBase IV™ which is one of several commercially available relational database management systems that are designed for use with a personal computer. It was desirable to utilize a commercial software package to minimize study computing time and to permit easy upgrading as software technology evolved.

An added benefit to using dBase IV™ is that California, Montana, Oklahoma and EPA Region VIII are currently using dBase III plus™ which can be easily upgraded to dBase IV™.

This software compatibility would simplify transfer of selected elements of the risk management technology in event any of these agencies decide to incorporate them into their existing system.

3.3 Well Identifiers

In the Williston basin data base, the master file is one of 27 files that comprise the data base (Figure 3). The master file contains one data record for each water injection well completion which injects water into a single formation or zone.

Each master file record contains 36 data fields. Each of the 36 data fields contains information such as well name, formation/zone, location and total depth that are uniquely associated with each well. Three of the 36 data fields contain the API Well Number whose sole purpose is to uniquely identify a drilled hole throughout the life of a well. The three data fields which comprise the API Well Number are:

State Code - Two numeric digits
County Code - Three numeric digits
Unique Well Code - Five numeric digits

The API Number is used as the identifier which links the well master file to well information such as production casing which resides in another data file. In event a given wellbore contains two or more injection well completions, the three alpha character formation/zone ID code is used in conjunction with the API Well Number to provide a unique identifier code for each completion.

For detailed information on file structure, see Appendix D.

3.4 Problems With Assigning API Well Numbers

The API Well Number is widely accepted as a standard for the unique identification of wells. However, several problems were encountered during the construction of the Williston Basin study data base that made it difficult to identify the API Well Number for each injection well. These included:

- o In North Dakota, SWD wells which are drilled for salt water disposal are not assigned API Well Numbers. In this case, the five digit numeric File Number assigned to each well by the state was used as a pseudo API well code.
- o For identification of individual injection wells in Montana, the Montana Oil and Gas Division and Petroleum Information use API well numbers while EPA Region VIII uses an 11 digit alpha numeric file number to identify wells. Most operators do not use the API well number as their primary well identifier. Since it was necessary to use state, EPA, operator and Petroleum Information data to construct the Montana data base, resolving well identifier problems associated with those multiple sources of raw data was time consuming.

  For example, well names were usually printed differently for a given well. In these cases, it was found that well location (such as NW SE Sec 11-7N-59E or 1980 FSL and 1980 FEL Sec 11-7N-59E) was the best way to resolve well identification problems. However in many cases, neither the quarter/quarter section location nor the feet from the section line locations were available. Where the API number could not be determined, pseudo API well codes were assigned to the well using the last five numeric digits of the EPA file number.

- o At the beginning of the study, the API supplied diskettes containing the complete API files of all Williston basin wells stored in their Washington, D.C. computerized data base. After several unsuccessful attempts to match API Well Numbers with well names from multiple data sources, further attempts to use API Well Numbers from the API supplied data base were discontinued. This was because:
  - oo One-half of the Montana Williston Basin study injection wells were not in the API data base. This was largely due to the fact that the API's Washington, D.C. data base does not contain API Well Numbers for wells drilled prior to 1970 even though the three states have retroactively assigned API numbers to those wells.

    Note:

    A request was made to Petroleum Information Corporation (PI) to supply completion data for 110 Montana SWD and water injection wells whose only identification was well name and API Well Number. PI was able to match submitted API Well Numbers with those in their data base and supply the requested data for 104 wells.

  - oo Williston basin wells that were in the API supplied files listed the name of the operator who drilled the well which is typically not the current operator.
  - oo For those Williston Basin study wells that were in the API files, the differences in well names precluded attempts to computer match well names. For example, API Well Number 25 091 21099 which is an SWD well in the Flat Lake Field, Montana, was listed as follows:

Data Source	Well Name
API	00005P SOLBERG
EPA	P.Solberg 5
Montana	5
Chevron	FLERU PEDER SOLBERG 5

Note:

The well name as entered in Williston basin data base is P.SOLBERG 5. The selection of which of the four well names to use was influenced by the fact that the EPA administers the UIC program in Montana and their MIT test data was supplied on diskette. The name was capitalized to comply with a generally accepted database construction practice of using all capitals for alpha entries.

A unique well identifier is required in order to construct a relational data base such as used in the Williston Basin study. From the standardization standpoint, it is preferable to use the API Well Number as the well identifier.

However, if a large number of the wells to be entered into a data base do not have API Well Numbers assigned, it is recommended that a unique number be generated by the regulatory agency and assigned to each injection well. This procedure has worked well in the Texas UIC program where a unique UIC Control Number is assigned to each injection well completion and in the North Dakota system where the API Well Number is available but the North Dakota File Number is the primary well identifier code.

In summary, the most important step in implementing either a conventional or risk oriented UIC data base is the early development and acceptance of a common well identifier. At present, a usable nationwide well identifier system does not exist.

3.5 USDW Information

3.5.1 General

The basic premise of the UIC program is to protect USDWs from the unlikely event of contamination from injection water which escapes into the wellbore and migrates into a USDW.

In order to monitor the effectiveness of the Class II injection well portion of the UIC program it is necessary to know the location of the USDWs for each individual well. For the 956 active, shut-in and temporarily abandoned SWD and water injection wells in the Williston basin, identifying the deepest USDW formation for each well and loading that data into the computer took approximately eight weeks of technical time.

From this, it can be seen that the identification of the deepest USDW for each of the 170,000 active Class II injection wells operated by oil and gas industry in the U.S. represents a major undertaking. Some states such as California and Texas have already spent considerable technical efforts in defining USDWs. In other states, work toward defining USDWs at the well level has not been initiated. In all cases, USDW information is an important basic element whose inclusion into a UIC regulatory system should be given priority.

3.5.2 USDW Geology

3.5.2.1 Background

Although USDW aquifers in the Williston basin extend across broad geographic areas, their presence and characteristics vary to some extent from field to field. Because of this variance, definition of the lowermost USDW at the individual well level for the Williston basin injection wells would require a separate study by a geologist who is familiar with the basin and is knowledgeable in electric log interpretation.

Since a rigorous geologic definition of the lowermost USDW at the individual well level was beyond the scope of this study, it was necessary to make simplifying assumptions in order to obtain the individual well USDW data needed to demonstrate the usefulness of that information.

Details of the procedure used to define the USDW are presented in Section 3.5.3.

3.5.2.2 Description Of USDW Geology

In the Williston basin stratigraphic units that are considered USDWs for this report are:

USDW Formation	Maximum Thickness[4] - Ft
Alluvian	50
Glacial drift	1000
Sentinel Butte	650
Bullion Creek	650
Slope	200
CannonBall	200
Ludlow	200
Hell Creek	500
Fox Hills	400

3.5.3 USDW Definition At Individual Well Level

Since the approach used for defining the deepest USDW for each Class II injection in North Dakota is similar for that used for Montana and South Dakota, only the North Dakota procedure will be described in this section.

In North Dakota, the Fox Hills sandstone typically occurs at a subsurface depth of 1,200 ft (depth ranges from surface outcrops to 2,300 ft subsurface). For the purpose of this report, the Fox Hills is considered to be the deepest USDW formation in the oil and gas producing areas of the state.

In the North Dakota portion of the Williston basin, the Pierre formation of the Cretaceous period[4] is a thick (up to 2,300 ft), relatively impermeable shale that is present throughout the basin. The Pierre is conformably overlaid by Fox Hills except for a small area in the southwestern part of the state along the Cedar Creek anticline where it is exposed[5].

The first step in defining the USDW for each Class II injection well in North Dakota was to identify those wells where the Fox Hills was not the deepest USDW. In this case, the 12 active injection wells in the Cedar Creek field, where the Pierre outcrops, were the only wells where the Fox Hills was not the deepest USDW.

The next step in USDW definition was to determine the base of the Fox Hills for all injection wells except those in the Cedar Creek field. This was done by using a structure map contoured on 100 ft intervals on top of the Pierre formation[5] which directly underlies the Fox Hills. The location of each well was spotted on the structure map and the depth above sea level of the top of the Pierre (which is the same as the base of the Fox Hills) was read and entered into the computer in a temporary field in the master data file. The subsea base of the Fox Hills was then subtracted from the ground elevation which is stored in the master data file to obtain the subsurface depth of the base of the Fox Hills.

The top of the Fox Hills was obtained by reading the thickness of formation for each injection well location from an isopach map[6] that gave the thickness of the formation on 50 ft contours. The thickness for each injection well was then subtracted from the subsurface base of the Fox Hills to obtain the subsurface formation top. A computer program was written to calculate the arithmetic average base and top for the Fox Hills for each field. These data were entered in the field data base which will be discussed in Section 3.5.4.

Since the subsurface base of Fox Hills calculation was estimated to be accurate to within plus or minus 150 ft, a computer query was conducted to determine which wells had surface pipe set 150 ft or less above the base of the Fox Hills. For each of those wells, the base of the Fox Hills was determined from electric logs. Where the base of the Fox Hills calculated from the structure map differed from that determined from the electric log, the base determined from the electric log was used.

3.5.4 Field Database File

The purpose of the field database file is to provide field level information that is useful in assessing the risk of USDW contamination.

Information in the field file includes the name, depth top, depth base, temperature, pressure, injected water TDS and produced water TDS for each of the formation types listed below:

- Producing
- Water Injection
- Gas Injection
- Air Injection
- Salt Water Disposal
- Corrosive Zone
- Salt Water Aquifer
- Salt Section
- USDW
- No USDW Present
- Exempt Aquifer
- Other

For a specific well which has a fixed wellbore configuration at a given point in time, the key to preventing injection water reaching a USDW is early identification of casing and tubing leaks followed by stopping injection as soon as the problem is identified. If leak identification and repair is performed in accordance with existing UIC regulations, the probability of water escaping from the wellbore into the borehole and reaching a USDW is low. In the unlikely event water does reach the borehole, an intervening aquifer has the potential for greatly reducing the volume of water that will be injected into the USDW.

An example of how the field file can be used to quantify the effect of an intervening aquifer is presented in the following discussion.

In the Beaver Lodge field, North Dakota, waterflood operations are being carried out by injecting water into 20 wells completed in the Duperow formation. Beaver Lodge field also has five active SWD wells which are completed in the Dakota formation.

The deepest USDW in the Beaver Lodge field is the Fox Hills formation. Fourteen water injection wells and one SWD well have surface pipe set below the base of the Fox Hills.

Assuming normal formation pressure gradients exist in the Fox Hills, Dakota and Duperow formations, undetected leaks that simultaneously occur in the tubing and production casing will permit water to reach to the Fox Hills under the following conditions:

Formation Information USDW	Fox Hills Aquifer	Dakota Intervening Formation	Duperow Water Inj Formation
Top of formation - ft	1,200	4,300	9,970
Base of formation - ft	1,430	4,700	10,000
Formation water sp gr	1	1	1
Reservoir steady state pressure - psia	636	2,055	4,355
Formation thickness - ft	230	400	30
Formation permeability - millidarcies	100	1,000	100

Assumptions

Bottom of surface casing is above top of Fox Hills
Tubing leak is present and undetected
Casing leak is present and undetected
Casing leak is deeper than 4,300 ft
Surface casing setting depth is 650 ft
Injection water specific gravity is 1
Injection water viscosity is 1 centipoise
Maximum surface injection pressure is 3,000 psig
Maximum injection volume is 2,000 B/D
Friction loss down tubing and down casing/tubing annulus is negligible
Fox Hills, Dakota and Duperow formations have normal pressure gradient of 0.434 psi/ft of depth x water sp gr
Darcy's law for steady state radial flow applies
Effective radius of wellbore is 0.5 ft
Effective radius from wellbore to reservoir steady state pressure is 100 ft
There are no flow restrictions between the outside of the production casing and the borehole from the point the casing leak occurs to the top of the Fox Hills

Then:

$$Q = 7.07 \frac{kh}{\mu} \cdot \frac{P_2 - P_1}{\ln r_e / r_w}$$

Where:

Q = Injection rate - B/D
k = Formation permeability - darcies
h = Formation thickness - ft
μ = Viscosity - centipoise
P_1 = Reservoir steady state pressure - psia
P_2 = Formation pressure at wellbore - psia
r_e = Effective radius from wellbore to P_1 - ft
r_w = Effective wellbore radius - ft

Then:

Q_t = Total injection rate
Q_1 = Injection rate into Fox Hills
Q_2 = Injection rate into Dakota
Q_3 = Injection rate into Duperow
k_1 = Permeability of Fox Hills
k_2 = Permeability of Dakota
k_3 = Permeability of Duperow
h_1 = Thickness of Fox Hills
h_2 = Thickness of Dakota
h_3 = Thickness of Duperow

Where:

$$C = \text{Constant} = \frac{7.07(P_2 - P_1)}{\mu \ln(r_e / r_w)}$$

Then:

$Q_1 = k_1 h_1 C$
$Q_2 = k_2 h_2 C$
$Q_3 = k_3 h_3 C$

Therefore:

$Q_t = Q_1 + Q_2 + Q_3$
2000 B/D = 23C + 400C + 3C
426C = 2000 B/D
C = 4.7 B/D

Then:

Q_1 = Fox Hills injection rate = 23 x 4.7 = 108 B/D
Q_2 = Dakota injection rate = 400 x 4.7 = 1878 B/D
Q_3 = Duperow injection rate = 3 x 4.7 = 14 B/D

From this it can be seen that the distribution of the injection water between the Fox Hills, Dakota and Duperow is a function of each formation's permeability multiplied by its thickness. Since the Dakota is a thick formation which has a relatively high permeability it will receive most of the total water that is being injected into the well.

Note:

The example calculation assumes that the surface casing does not cover the Fox Hills, which is the lowermost USDW. In Beaver Lodge field, 14 of the 20 active water injection wells have surface casing that is set 2,400 ft below the base of the Fox Hills. In those 14 wells, it would be highly unlikely that any water would reach the Fox Hills. In that case, 1,985 B/D/well would be injected in the Dakota and 15 B/D/well into the Duperow.

It should be pointed out that any wellbore permeability restrictions between the Dakota and the Fox Hills will reduce the amount of water being injected into the Fox Hills.

Location of a production casing leak between the Dakota and the Fox Hills would yield the same distribution of injection water as experienced with a leak below the top of the Dakota. However, any restriction in wellbore permeability between the point of the leak and Dakota would increase the volume being injected into the Fox Hills. Likewise, a permeability restriction between the leak and the Fox Hills would increase the volume injected into the Dakota.

As shown in this example, in the unlikely event that water escapes the wellbore and enters the borehole, an intervening aquifer can significantly reduce the volume of injection water that would reach a USDW.

3.6 Wellbore Information

3.6.1 General

As shown in Figure 4 and described below, the wellbore of an injection well consists of fixed and removable components.

- o Fixed components are put in place during completion of a well and cannot normally be removed or modified. These components include conductor pipe, surface casing, intermediate casing, liners, production casing and stage cementing tools.
- o Removable components are installed during completion but can be removed with procedures which are relatively expensive but fall within the framework of normal oilfield maintenance practices. These components include tubing, packer and wellhead equipment.

This section reviews the functions of the wellbore as they pertain to USDW protection and discusses sources of the wellbore information used in the Williston Basin study. A more detailed discussion of wellbore completion practices is presented by Bourgoyne.[7]

3.6.2 Fixed Components

3.6.2.1 Conductor Pipe

Conductor pipe is a fixed component whose application is largely dictated by maintaining a stable hole when the well is initially spudded. With firm stable soil at the surface, conductor pipe is often not run. Where surface soil consists of gravel or other unstable soils, up to 200 ft of conductor pipe will often be run. Conductor pipe typically has a range of ODs from 16 to 18 in. Conductor pipe is usually cemented in place if it is run in a drilled hole. If the conductor pipe is driven into the ground, it is not cemented in place.

In regards to the USDW, conductor pipe provides a fourth level of protection to USDWs from subsurface leaks (the first three levels are tubing and packer, production casing and surface casing). Conductor pipe also may provide protection of shallow USDWs from wellhead leaks.

Since conductor pipe information is not normally a part of UIC data bases, an accurate determination of conductor pipe usage in the Williston basin was not made.

3.6.2.2 Surface Casing

Surface casing is a fixed component that is found in essentially all wells drilled in the last 45 years. Surface casing ODs typically range from 10-3/4 to 9-5/8 in. with the maximum outside diameter dictated by the internal and external pressures it must withstand during drilling and production operations and by the inside diameter of the conductor pipe through which it is set. Surface pipe minimum inside diameter is dictated by the outside diameter of the intermediate casing and production casing that must be run inside the surface casing as the well is drilled to total depth.

Surface casing on new completions is required to cover the lowermost USDW and is generally cemented to surface.

Wells drilled before the advent of UIC regulations typically set surface casing through the base of all potable waters that were located at depths that were reasonably accessible for agricultural and domestic use. Although it varies from state to state, these wells usually have surface pipe cemented to surface.

External corrosion rates of uncemented surface casing are low due to the low salinity and temperature of the USDWs. Where a good cement bond exists between the surface casing and the formation, external corrosion rates would generally be low enough that penetration of the surface casing would not occur during the well operating lives that are normally experienced in oil field operations.

As a protective measure against the unlikely event of simultaneous failures of the tubing/packer, production casing and surface casing, surface casing is the most important element in determining the probability of USDW contamination. For example, if the probability of water from an injection well reaching a USDW in a given year is one chance in one million (10^{-6}), the tubing/packer and production casing elements of the triad will typically account for one chance in one thousand (10^{-3}) while surface casing accounts for the other half of the probability (10^{-3}).

In the Williston basin, 57% of the injection wells have surface casing set below the base of the lowermost USDW.

3.6.2.3 Intermediate Casing

Wells with total depths in the range of 20,000 ft are expected to encounter lost circulation zones, abnormally pressured formations, unstable shale sections or salt beds that may require one or more intermediate casing strings between the bottom of surface casing and the bottom of the well.

Williston basin injection wells have total depths that are less than 15,000 ft, and only 1% of the basin injection wells have intermediate casing strings.

3.6.2.4 Drilling And Production Liners

As shown in Figure 4, drilling liners are casing strings which do not extend to the surface but are suspended from the bottom of the next larger casing string and cemented in place. Drilling liners typically have several hundred feet overlap above the bottom of the next larger casing string. After the drilling liner has been cemented in place, drilling continues to total depth and production casing is run and cemented in a conventional manner.

Production liners are casings set through producing or injection formations as an alternate to running the production casing to total depth. Generally, the production liner is cemented in place. After cementing, production liners are connected to the wellhead using an uncemented tie-back casing string. After the tie-back is run, the production liner is perforated opposite the producing or injection formation to establish communication between the formation and the wellbore.

Drilling and production liners are only used in 2% of the injection wells in the Williston basin.

Note:

One method of repairing casing leaks in a well is to cement a liner across that portion of the casing where leaks are located. Repair of casing leaks with a liner is generally not used unless previous repair attempts by squeeze cementing were unsuccessful. Only 2% of the injection wells in the Williston basin were found to have repair liners.

3.6.2.5 Production Casing

Production casing is attached to the surface wellhead and is set through the producing or injection formation and cemented in place. After cementing the casing is perforated opposite producing or injection formations and the well is completed in a conventional manner.

All Williston basin wells have production casing.

3.6.2.6 Stage Cementing Tool

When a stage cementing tool is used, it is run as an integral part of the intermediate or production casing string. The stage cementing tool permits a cement column in the casing/borehole annulus to be raised to a height that will cover a corrosive zone, salt section or lost circulation zone. The stage tool is typically used in cases where the weight of the cement column could fracture an intervening subsurface formation if the cement was displaced from the bottom of the casing string.

For example, a stage tool would be run if a well which had production casing set at 10,000 ft would fracture a formation at 9,000 ft while attempting to place cement across a corrosive formation at 4,500 ft. In this case, a stage cementing tool would be placed in the producing casing string so the tool would be located at a depth of 4,800 ft after the casing is run in the borehole. The casing would then be cemented in a conventional manner. After the cement hardens, a bomb would be dropped down the casing to open a port in the staging tool. The second stage cement would then be pumped through the port and circulated above the top of the corrosive formation. The producing or injection formation would then be perforated and the well completed in a normal manner.

One-quarter of the injection wells in the Williston basin used stage cementing to cover either salt sections or corrosive formations.

3.6.3 Removable Components

Wellbore components that can be removed by routine oilfield maintenance procedures are discussed below.

3.6.3.1 Wellhead Equipment

Wellhead equipment includes the two major assemblies discussed below and reviewed in more detail by Bradley.[8]

- o The Christmas-tree assembly is an arrangement of valves and fittings used to control injection rates, measure injection volumes, monitor pressures, obtain fluid samples and provide access for various tools to the injection tubing string. The Christmas tree is connected to a wellhead assembly through a lower master valve and its associated tubinghead adapter flange.
- o The wellhead assembly consists of the equipment that supports the tubing and casing strings and connects to the Christmas-tree's tubinghead adapter flange through the upper tubinghead flange. It includes the tubing hanger, tubing head, casing hangers and casing heads. The assembly includes seals which provide pressure isolation between the tubing and casing strings. It also contains sample valves for measuring pressure and obtaining fluid samples in the annuli between the tubing and casing strings.

  Wellhead equipment requires little maintenance and component replacement is seldom required.

3.6.3.2 Tubing

Purpose of the tubing is to conduct injection fluid from the surface to a point immediately above the injection zone. Tubing is attached to a Christmas tree through a tubinghead adapter flange and is run inside the casing. In most cases, tubing is set on a packer which seals against the casing ID and insulates the inside of the tubing from the casing/tubing annulus.

In typical injection wells, tubing OD is either 2-3/8 or 2-7/8 in. In the Williston basin, many operators internally coat the tubing with a baked-on 5 to 20 mil coating of plastic to reduce corrosion. In severe corrosion injection operations, some operators have installed fiberglass tubing.

In the Williston basin, all injection wells have a single string of tubing. However, there are wells in other basins that have two or more strings of tubing, with each string used to inject water into a separate zone.

3.6.3.3 Packer

Packers are used to provide pressure isolation between the injection water inside the tubing and the casing/tubing annulus.

In most Williston basin injection wells, a retrievable packer is run on the end of tubing to a depth immediately above the injection zone. The packer has elastermic elements which are expanded against the casing to provide the pressure isolation seal between the inside of the tubing and casing/tubing annulus.

In the Williston basin, some operators use a permanent packer which is run and set in the casing before the tubing is run. The tubing is equipped with a seal assembly which seats in the packer and provides a pressure seal.

Ninety-nine percent of the Williston basin injection wells have tubing set on a packer.

3.6.4 Elements Required For Wellbore Information

As discussed in Section 2.6.8, sources of wellbore information were different for each state. The elements of wellbore information required to construct a risk based data base are listed below in order of priority.

	Priority		
	Necessary	Desirable	Not Needed
Conductor Pipe			
Size		x	
Weight and Grade			x
Depth - Bottom		x	
Cement Top		x	
Surface Casing and Production Casing			
Size	x		
Weight and Grade			x
Depth - Bottom	x		
Cement Top	x		

	Priority (Cont'd)		
	Necessary	Desirable	Not Needed
Intermediate Casing and Liners			
Size	x		
Weight and Grade			x
Depth - Top	x		
Depth - Bottom	x		
Cement Top	x		
Stage Cementing Tool			
Depth - Bottom	x		
Cement Top	x		
Perforations			
Interval	x		
Formation Name	x		
Wellhead Equipment		x	
Tubing			
Size	x		
Weight and Grade			x
Depth	x		
Packer			
Type			x
Depth	x		

Conductor pipe information is not normally available in existing UIC data bases and the information often is not available on regulatory agency hard copy. However, the importance of conductor pipe in protecting against USDW contamination from shallow leaks makes its inclusion in the data base desirable.

3.7 Well Completion Data

Completion data in conjunction with the casing leak data are used to determine the length of time the casing was in the well before a leak develops. This information is used in calculating the probability of potential USDW contamination due to simultaneous undetected failures of an injection well's tubing/packer, production casing and surface casing.

3.8 First Injection Date

The first injection date is used to identify wells which were in water injection service before a state received primacy.

3.9 Well Status

An accurate well status is a critical item in a UIC data base. For example, a temporarily abandoned injection well may be defined as a well that has no present use as an injection well but may be useful in a future enhanced recovery project. This well would normally have the tubing removed and plug set above the injection formation. The temporarily abandoned well will remain on the MIT test schedule but be dropped from the injection monitoring report. Without accurate and timely status reporting, it is difficult to monitor and control this type of activity in the UIC program.

3.10 Workovers

Workover data is important because a workover often results in a change in the tubing/packer size and depth, perforated interval, tubing and casing leak history, cement top, injection formation and well type. This information is generally available from existing workover forms submitted by the operator but the data is not entered into the UIC computer data base on a routine basis.

For effective monitoring of the risk of USDW endangerment, it is recommended that workover data be included in the UIC data base. It is further recommended that workover reports be reviewed to eliminate unneeded data and to add data that is needed to effectively monitor the UIC program.

After a workover is completed, UIC regulations require a MIT test before a well can be returned to injection. Routine tracking of the post workover MIT test requirement could be handled by utilizing the "repair due date" field in the Williston basin data base. Software could be written to automatically trigger an exception report if the date is past due and an MIT test has not been run.

3.11 Tubing And Casing Leak Data

Tubing and casing leak data are needed to determine the probability of potential endangerment of a USDW. Data from the Williston Basin study shows that leak data from similar fields can be used to develop risk guidelines for use in assigning priorities in the monitoring of underground injection operations.

In building a risk data base, it is recommended that tubing and casing leak data be solicited from those operators who have a large number of injection wells in a given field or producing trend. This data could then be used to determine the risk potential for all injection wells which operate in similar fields. Future data can be collected as part of routine reporting associated with loss of mechanical integrity.

3.12 MIT Information

3.12.1 General

The Williston basin data base has provisions to handle any of the various MIT tests that are approved for use in verifying that:

- There are no significant leaks in the casing, tubing or packer, and
- There is no significant fluid movement into a USDW through vertical channels adjacent to the injection wellbore

3.12.2 MIT Tests To Verify No Significant Leaks

In the Williston basin, verification that there are no significant casing, tubing or packer leaks is usually done with a pressure test of the casing/tubing annulus. These MIT pressure tests are run:

- o Every five years or more often if circumstances indicate the need for more frequent tests,
- o Before a newly drilled or converted injection well is placed on injection, and
- o Before an injection well that has been worked over is returned to injection.

3.12.3 Tests For Behind Pipe Fluid Movement Into A USDW

Verification that there is no significant fluid movement into a USDW through vertical channels adjacent to the wellbore is normally done after a well is drilled for injection service or after a producing well is converted to injection. The most common verification methods used in the Williston basin are cementing records where cement is circulated to surface and cement bond logs where cement is not circulated.

3.12.4 MIT Test Database File Contents

Items available in the MIT test database file include:

Test date
Test pressure
Test failed or passed
Test method
Test frequency
Next test due date
Test witnessed
If test failed:

- o Failure type
- o Failure cause
- o Repair type
- o Repair completion date - actual
- o Repair completion date - due
- o Repair successful or unsuccessful

3.13 Analysis Of MIT Test Failure Rates

3.13.1 Overall MIT Failure Rates

In the Williston basin, the failure rate for all the MIT tests conducted since the start of the UIC program was found to be 14% as shown below:

	Passed	Number MIT Tests Failed	Total	% Failed
Montana	572	109	681	16
North Dakota	769	116	885	13
South Dakota	44	0	44	0
Total	1385	225	1610	14

The relatively high MIT test failure rates in Montana and North Dakota indicated the need for an analysis of MIT test failures in those states. Results of that analysis are presented in Section 3.13.2.

3.13.2 Analysis Of MIT Test Failures

Monthly monitoring of tubing pressure, casing/tubing annulus pressure and injection volumes is the most cost effective method of early identification and correction of potential USDW contamination problems. The key element in this program is monthly monitoring of the annulus pressure. An increase in annulus pressure will normally indicate a tubing or packer leak for wells injecting with a positive tubing pressure. Depending on the pressure of the formation opposite a casing leak, monthly monitoring of the annulus pressure is also an effective tool in identifying potential casing leaks.

The EPA, which has primacy in Montana, specifies that monthly monitoring of the annulus pressure is optional. As shown in Figure 5 and Table 1, the MIT test failure rates for Montana wells that have positive tubing pressures have steadily declined from an initial high of 17% in 1985 to 1% in 1988. Although many factors are involved in this reduction in MIT failure rates, one possible conclusion is that the operators are finding many of the wellbore failures with the monthly monitoring tests and that those failures are repaired before the MIT test is run.

North Dakota's UIC regulations specify that each month the operator shall report for each injection well the volume of water injected and the injection pressure. Through its field rules, the state also requires that the operator monitor the casing/tubing annulus pressure on a monthly basis.

As shown in Figure 5 and Table 2, North Dakota MIT failure rates for wells that have positive tubing pressures have declined from an average of 18% during the first three years of the UIC program to an average of 10% for 1987 and 1988. One reason the MIT failure rates have remained relatively high is that a failure found by the monthly monitoring program is recorded as a failed MIT test. This reporting procedure makes it difficult to evaluate the relative effectiveness of the monthly monitoring program and the MIT test program.

3.14 Injection Monitoring Reports

Injection monitoring reports are probably the best and most cost effective method the operators and UIC administrators have for early identification and correction of potential

USDW contamination problems. However, many regulating agencies are not utilizing the full potential of these tools.

The present injection monitoring phase of the UIC program consists of two parts. The first is a noncompliance report which typically requires an oral report of a problem within 24 hours followed by a written report within five days. These exception reports are often not made a part of the UIC data base and are only available on hard copy in the individual well files.

The second phase of injection monitoring reporting is an annual report for each well that contains monthly injection volumes, average and maximum tubing pressures during the month and average and maximum casing/tubing annulus pressures observed during the month.

> **Note:**
> In most states, monitoring of the casing/tubing annulus pressure is optional.

The annual report has little value as a regulatory oversight tool and essentially serves only to document compliance, as attested by the signature of a company official. Because of the large number of keystrokes required to enter this data into a computer system, most UIC regulatory agencies store these reports on hard copy.

In order to more effectively use the injection monitoring reports, an alternate approach to noncompliance reporting and yearly reporting of monthly monitoring data is recommended. This approach consists of the following elements:

- The operator would monitor the injection rate, tubing pressure, and casing/tubing annulus pressure of each injection well on at least a monthly basis. Wells which the UIC agency considers a high risk would be monitored on a more frequent basis.

  > **Note:**
  > If monthly monitoring of the casing/tubing annulus pressure is optional in a given state, it is recommended that the state add annulus pressure monitoring to the monthly monitoring program.

- The results of the monthly monitoring would be reported annually to the UIC agency. The report would include operator name, field name, well name, UIC file number, barrels of water injected during the year, maximum tubing pressure observed during the year and maximum casing/tubing annulus pressure observed during the year.

  Since the annual report would take only two or three lines per well, more than one well could be reported on the same page. This yearly data could be entered into the UIC agency computer system making individual well injection statistics available for subsequent UIC studies. In order to cover any statutory documentation requirements, the yearly reports could be signed by the operator and stored on paper in the agency files.
- There would be no change in the present practice of verbally reporting within 24 hours any significant changes in pressure or other monitoring data indicating the presence of a leak in the well. The operator would continue to confirm the verbal

report in writing within five working days. This information would be entered into the UIC data base in addition to being stored on hard copy.

Computerization of the annual report and of the noncompliance report would allow UIC regulators to reduce the amount of administrative paper work while more quickly identifying and focusing on problem areas.

3.15 Sources Of Information

The two primary sources of information for building a risk based data base are the UIC regulating agencies and the operators.

Although essentially all the information needed to build the data base is available from the regulating agency or the operator, it is often more practical to obtain the data from other sources. In some instances, the alternate sources may have the same data in a form that makes it easier to enter into the data base.

Sources of information used in building the Williston basin data base are summarized below:

EPA, Region VIII
Montana Oil and Gas Conservation Division
North Dakota Industrial Commission, Oil and Gas Division
South Dakota Department of Water and Natural Resources
Operators

- o Amerada Hess
- o Apache
- o Chevron
- o Conoco
- o Koch
- o Shell
- o Oryx (formerly Sun)
- o Texaco

USGS
Montana Bureau of Mines and Geology
North Dakota Geological Survey
South Dakota Geological Survey
Montana Geological Society
American Petroleum Institute
Society of Petroleum Engineers
Underground Injection Practices Council
Petroleum Information

As might be expected, it was not an easy task to construct the Williston basin data base. However, the benefits include the ability to conduct analysis and to easily obtain rapid and accurate information on a well, operator or field by a simple query of the risk based data base.

4.0 Current Individual Well Data Management Practices

4.1 Individual Well Records UIC Data Management Practices

A summary of current UIC data management practices as they pertain to storage of individual well records by the three Williston basin states is printed below.

	Montana (EPA)	North Dakota	South Dakota
Records Stored in Computer:			
Well Completion Information		x	
MIT Tests	x	x	x
Injection Monitoring			
Annual (Barrels/Pressures)		x	x
Records Stored on Paper:			
Well Completion Information	x		x
Injection Monitoring Reports			
Annual (Barrels/Pressures)	x		
Noncompliance (Possible Leaks)	x	x	x
Workover Completion Reports	x	x	x
Individual Well USDW Data	x	x	x
Casing/Tubing Leak Reports	x	x	x

4.2 User Access To Individual Well Data

In those cases where individual well records are stored on paper, it is easy to obtain data for a given well. However, it is labor intensive to make a statistical study of a group of individual wells involving an operator, a field or the total state.

For example, a study of the Montana portion of the Williston basin of the depth of the surface casing of each Class II injection well in the basin in relation to the deepest USDW in each well would take several months using existing regulatory agency records. The same study using the data base concept developed for the Williston Basin study would take less than one day.

5.0 Computing Requirements

Computing requirements to handle a risk based UIC data management program vary for each state. For example, the data management system needed to handle South Dakota's 42 Williston basin Class II injection wells is very different from that needed to handle Texas' 68,000 injection wells.

This section discusses approaches to handling the wide range of UIC data management requirements that are encountered in the various states.

5.1 Mainframe Computer System

Most UIC regulatory agencies have access to a mainframe computing system. Typically, the mainframe computer is operated by a separate data processing division that develops software for the system and provides computing services to all state agencies at a cost per unit of computing time. This billing of mainframe computer costs to the user often is a consideration that influences a potential user not to run a needed report because of the mainframe computer cost.

The mainframe offers state-of-the-art computing power to both the local and remote users at a relatively low cost. However, by necessity, users must follow a strict protocol system that may prevent accessing data in a real time basis. Also, mainframe software development is typically performed by data processing programers who may not be familiar with the UIC program. This arrangement often creates problems in writing software in a timely basis and settling for less than the desired software capability. Because of these problems, most UIC regulating agencies have elected not to use the mainframe computers to handle all of their data management requirements.

5.2 Mainframe Computer/PC Computer System

As shown in Figure 6, many regulating agencies have found the combination of a mainframe computer connected to a PC file server networked to several PC local and remote computers provides the best approach to handling UIC data processing needs.

The mainframe is used to:

- o Store data,
- o Perform routine error checking of data,
- o Generate and download UIC user requested reports from one or more of its data files, and
- o Download large blocks of user requested data files to the PC file server.

The PC computing system typically consists of a PC file server that is networked to a group of PCs or work stations with printers which are located locally and at remote field offices. The PC file server is connected to local terminals by coaxial cable or modems and to remote terminals by modems via dedicated phone lines.

The PC network is used to:

- o Input data to mainframe,
- o Perform error checking of data,
- o Initiate requests to mainframe for reports,
- o Print reports routed from the mainframe, and
- o Develop and implement reports that are generated solely by the PC system.

Generally the PC file server is interfaced to the mainframe in a batch mode at the specific request of the UIC computing personnel. Typically large blocks of UIC data are down loaded into the PC file server from the mainframe on a periodic basis. This scheme allows the PC system to act as a stand-alone data base until another file update is requested.

5.3 PC Computer System

Use of a dedicated PC computer system to handle UIC data management needs provides the best system when:

- o A mainframe computer system is not available or does not contain sufficient useable UIC data, or
- o The number of injection wells is too small to justify the hardware and software costs associated with using the mainframe computer system.

Where a PC computer system is used, commercial software and hardware is readily available. As shown in Figure 7, a typical PC system would consist of a PC file server connected to local and remote PC computers or work stations with printers. File structure for the stand-alone PC system would be similar to that developed for the Williston Basin study.

5.4 Commercial Hardware And Software

Commercial hardware and software which can handle all PC computer system requirements are readily available from a number of reliable suppliers. The use of commercial products has the following advantages:

- o Competitive installation costs,
- o Reliable operational support,
- o Good system documentation, and
- o Periodic updates to improve system capabilities.

5.5 PC Computing Requirements For Williston Basin Data Base

The PC computing requirements to design and demonstrate the risk based UIC data base for the Williston basin are listed below:

Software

- o dBase IV™ for database
- o R&R Report Writer™ for queries and reports

Database Development Hardware

- o Zenith Z-386™ with an 80386 microprocessor with a 150 megabyte hard disk and 2 megabytes of RAM

Database Demonstration Hardware

- o Zenith SupersPort 286™ laptop computer with an 80286 microprocessor with a 42 megabyte hard disk and 1 megabyte of RAM
- o EIKI DD 1000™ digital display unit

SWD and Water Injection Wells in Data Base

	Number Wells
Active	731
Shut-in	22
Temporarily Abandoned	203
P&A	230
Total Injection Wells	1,186

Computing Space Used

	Megabytes	
Program Files		
dBase IV™	2.8	
R&R Report Writer™	1.0	
Sub Total Program Files	3.8	
Data Files	5.9	(5 kilobytes per injection well)
Total Megabytes	9.7	

It is of interest to note that the entire Williston basin risk based data base fits comfortably on the $4,000 laptop computer.

5.6 Field Office Capability

Most UIC regulatory agencies install PC computers and printers in their field offices. These remote terminals are generally connected to a headquarter's PC file server by modems which communicate over dedicated phone lines.

Since the use of remote terminals with a printer provides field office personnel with the same on line capabilities for entering data and requesting reports as the UIC headquarters personnel, the installation of on line computing capability in field offices is recommended.

Although the concept of using laptop computers for field inspections has not been evaluated at this time, it would appear to have merit to have selected field inspectors equipped with laptop computers. This would allow inspectors to make on-site compliance checks and entries of field test results into the laptop computer files for subsequent electronic transfer into the UIC data base.

5.7 EPA Reporting Requirements

The EPA has established a UIC Data Management Workgroup which has the responsibility of developing a minimum data set to handle state, EPA regions and EPA headquarters information needs.

The study group is addressing the data needs for the following categories:

- o Inventory of basic geologic, construction and operation information,
- o MIT activities,
- o Field inspections,
- o Tracking potential USDW contamination cases,
- o Permit activities, and
- o Compliance and enforcement activities.

Of the data outlined above, the Williston basin data management system can either currently handle or can readily be modified to handle all the categories except the reporting requirements associated with permitting and compliance activities.

The EPA is also establishing an agency wide workgroup to consider developing and instituting uniform standards for electronic reporting of data.[9] The development of a uniform standard by the EPA would represent a significant step in encouraging operators, states and the EPA to use electronic media to transfer UIC data between computers.

Note:

The Railroad Commission of Texas is currently accepting magnetic tape transfer of selected data into their UIC data base that is resident on the mainframe computer in Austin.[10]

6.0 Incorporation Of Risk Management Into UIC Programs

The Underground Injection Practices Council has adopted as a goal the encouragement of all UIC administrators to continue incorporation of risk management concepts into their existing UIC data management and regulatory programs.

This section presents a method for incorporating selected portions of a risk approach into an existing UIC program. The section also reviews the approach for starting a grass roots risk data management program in a state that has recently received, or is about to receive, primacy.

For these discussions, refer to Figure 8.

6.1 Enhancement Of An Existing UIC Data Management System

6.1.1 General

Many states currently use risk based approaches in managing selected segments of their UIC programs. In these states, stepwise enhancement of additional elements of the risk program into their existing data management system may be attractive.

6.1.2 Design Phase

As shown in Figure 8, the first step in evaluating the cost/benefit aspect of the risk approach is to develop a detailed implementation plan. The plan would evaluate hardware and software requirements, personnel needs, costs, timing and benefits.

If the plan shows the risk approach is attractive, the next step is to obtain approval. Following approval, funding must be obtained from state, federal and other sources before implementation can proceed.

After funding is obtained, the next step involves selecting personnel, defining data sources, purchasing equipment, defining file structures, developing data input procedures and designing file backup schemes. In most cases where the risk approach is added to an existing system, the hardware, software and other items discussed above are already in place and it becomes a matter of building on the existing system as opposed to designing a new system.

6.1.3 Review Of Existing Reports

An important part of the design phase is to conduct a critical review of all UIC reports to be sure they supply the needed information in a useable form and that two or more reports are not furnishing the same data. Results of this review may indicate the need for redesign, addition or elimination of one or more forms.

6.1.4 Incorporation Of Minimum Data Elements

After the design is complete, the minimum data elements needed to monitor a UIC program would be incorporated into the existing data management system.

In most existing systems, the well identifiers, MIT test data, and well completion data are already a part of the data management system. In that case, the two areas to address are the computerization of the injection monitoring data and the definition of lowermost USDW at the individual well level. These projects would normally be handled by different groups and their implementation can proceed as independent projects.

6.1.5 Install Risk Data Elements

As shown on Figure 8, there are three data sets that contain the elements of a risk management data base. These are:

- o Data which is used to define relationships at the field level of USDWs, corrosive zones, injection formations, SWD zones, intervening aquifers and salt sections;
- o Tubing and casing leak data which are used in calculating the probability of USDW endangerment; and
- o Workover data which supplies information to the tubing and casing leak files, triggers the need for a MIT test and provides data for the well completion file that results from changes in well equipment due to workovers.

6.1.6 Implementation Of Risk Management Program

Adding risk management to an existing UIC data base can be done in a stepwise manner. As each risk data set is added and associated software is developed, that phase of the program can be implemented.

For example, when individual well tubing and casing leak data is entered into a computer, the probabilities of simultaneous tubing, production casing and surface casing leaks permitting USDW endangerment can be determined. At that time, UIC monitoring priorities can be established and that phase of the program can be implemented.

6.1.7 System Documentation

A part of a computer system that is often overlooked is hardware and software documentation. Documentation should be specifically identified in the implementation plan and the UIC personnel responsible for designing and installing the system should perform the documentation as each phase of the project is completed.

6.1.8 Training System Users

Key hardware and software personnel who were involved in the project since the plan development phase are the most logical candidates to conduct user training.

Ideally the training would involve several short training sessions interspersed with several weeks of working with the risk based system. Documentation manuals make excellent texts for this training.

6.2 Implementing A Grass Roots Risk Based UIC Program

6.2.1 Recent Primacy States Are Ideal Candidates

Those states which have recently received or are about to receive UIC primacy are ideal candidates for the installation of a grass roots risk based UIC program. Starting a system from scratch offers the advantage of having few existing hardware and software constraints to consider in the design of the system.

6.2.2 Developing An Implementation Plan

Installation of a new risk based UIC data management system would follow the basic steps outlined in Figure 8. In the case of a new system, development of the plan is one of the most important parts of the implementation program. Time spent in clearly defining each step needed for implementation will result in a functional system that can be brought on line with a minimum of surprises.

It is critical that the UIC staff members responsible for operating the system be involved in its development and implementation.

6.2.3 Well Identifiers

In building a new system, selection of unique well identifiers is of primary importance. Unless most of the injection wells have API numbers, it is recommended that a unique UIC number be assigned to each well. It is important that the UIC number and its associated well name be used from that point forward in all data management records.

6.2.4 Use Of Temporary Files During Database Construction

As discussed in Section 2.6.7, the data base design utilizes identical relational data bases for each of the three states. Each relational data base consists of one well master file that contains one record of unique well information such as location for each well. The master file is linked via the unique well identifier to data files which contain variable individual well data such as MIT tests which will change with time.

In constructing the Williston Basin study data base, it was found that it was useful to first construct a working flat file for each well. This flat file contained all of the unique and the variable information associated with each well. When all the data base information had been loaded into the individual well flat files and its accuracy verified, the information was then transferred using software programs to the various relational data files.

It was found that the use of flat files greatly reduced the time in checking errors. The flat file also facilitated correcting an individual well record in the event incorrect information was entered into the data base.

6.2.5 Error Checking Schemes

As discussed in Section 2.6.10, most of the time spent in error checking during construction of the Williston basin data base was in the area of matching well identifying numbers with well names. The large bulk of this checking involved manually looking at data from several sources and making a judgement decision as to which well name went with which well identifying number. Once the wells were identified, most error checking was accomplished using a software routine developed in R&R Report Writer™.

6.3 Phased Implementation

Implementation of a risk based program into an existing UIC system and the start up of a new system both lend themselves to phased implementation. The use of phased implementation permits the UIC regulator to budget, fund, install and test a portion of the total risk management system before committing to the total program. In states that have several field offices, this approach could be further segmented by implementing a portion of the program in one field office before committing to state-wide implementation.

For example, the development of the depth of the lowest USDW at the individual well level is a stand alone project that is probably most suited to the talents of a geologist knowledgeable in well log interpretation. A project to determine the lowest USDW depth for each well under the jurisdiction of one field office could be assigned to a geologist. At the same time, USDW software development could proceed.

After the data gathering is completed, the USDW system would be brought on line, tested and debugged before proceeding with the remainder of the state. This method permits evaluation of each risk data element in a timely manner with a minimum commitment of manpower and funds.

6.4 Reporting Requirements

6.4.1 Report Format

Most users who make routine data requests want to look at the data on the CRT before deciding whether to route the report to the printer. This makes it important that the report be formatted so it fits a CRT screen. Also, the letters for each report should be large enough to be easily read by the user.

6.4.2 Report Menu System

Most of the reports in a UIC data management system will be called up by the user from a menu on the CRT. When designing the menu, it should be assumed that the user is not knowledgeable in computer operations. Therefore, the user must be carefully lead through each step in accessing the data base and in routing the report to the screen or the printer.

6.4.3 Custom Reports

Development of custom reports should be infrequent once the UIC data base becomes fully operational and reaches maturity. Usually special report development would be done by personnel responsible for the UIC software or by engineers and geologists who are knowledgeable in the computer system.

6.5 Computer Security

Computer security consists of physical protection and backup of the programs and data files.

6.5.1 Physical Protection

Physical protection of the UIC computing system may include:

- o Physical protection from fire with smoke alarms and Halon™ systems,
- o Protection from theft through various mixes of card keys, security guards and computer locks, and
- o Protection from unauthorized access to the data base by operator code assignments and computer key locks.

6.5.2 Software Protection

Protection of software will typically include:

- o Protection from computer virus by using proven commercial programs purchased through reliable suppliers and by assigning unique control numbers to each operator who electronically transfers data into the system. Where software contamination is suspected, software programs to locate and eliminate the virus are available.
- o A software backup system that involves a tape backup system that typically will:
    - oo Backup the system each night with on site storage of tape for 10 days,
    - oo Backup the system each week with offsite storage of the tape for six weeks and
    - oo Backup the system each month with offsite storage of the tape for two years.

6.6 Personnel Support Requirements

For a UIC computer system to operate effectively it should have UIC staff support of at least two people at the software level. Both these individuals should be knowledgeable in use of commercial software, data transmission and computer configuration. In addition, they should be capable of running diagnostic programs to determine if a computer problem is due to software, hardware or people.

In the hardware area, the UIC staff should be able to identify a hardware problem. However, manufacturers will normally supply the hardware support. It is important that the UIC staff verify that the manufacturer has trained personnel and an adequate stock of spare parts to maintain the hardware.

7.0 Williston Basin Database Queries

7.1 General

As with all existing UIC data bases, the Williston basin risk based system lends itself to rapid user access to individual well information. This type information is vital to the regulator in answering the questions and making the decisions that are needed on a day-to-day basis to effectively administer a UIC program.

The unique feature of the Williston basin data base is that it contains information such as individual well USDW definition and tubing and casing leak data which provides the user with a wide mix of information that has a direct bearing on underground injection operations. These broad based information capabilities are especially valuable in determining trends at the operator, field, well type and state levels that are not easily discernable from the individual well data. This capability of being able to rapidly analyze a number of different variables for a large group of wells provides the regulator with solid data for establishing work priorities, adding new regulations where needed and eliminating regulations that are no longer useful.

7.2 Query Development

Development of queries of the data base originated from the replies to a letter to 27 UIC regulators and interested operators asking for suggestions on queries they felt would be helpful in administering UIC programs. Ideas for queries that evolved from the letter request were reinforced by visits to five different UIC regulatory agencies.

For additional details on query development, see Appendix C.

7.3 Query Software

The software used for developing queries was R&R Report Writer™ by Concentric Data Systems, Inc. R&R allows the user to create, modify and print reports from dBase IV™ files using Lotus™ like commands and menus.

R&R can report from up to 10 files at once. The user can easily select records through plain English queries with range and list comparison operators, logical connectors and full nesting of parenthesis. The program has the capability of sorting on up to eight different fields.

7.4 Typical Database Query Results

7.4.1 General

Query and reporting capabilities of the data base provide the regulator with a powerful tool for administering a UIC program. The query results presented in the following sections are typical of the types of information that a user can easily obtain from the data base.

7.4.2 Tubing Leak Data

Tubing leak data presented in Tables 3, 4 and 5 was furnished by eight operators. The leak data is from 412 wells which represent 56% of the 731 SWD and water injection wells in the basin.

As discussed below, there are several interesting points brought out by the data.

- o Tubing leaks for Montana SWD and water injection wells averaged 0.17 per well-year compared to 0.15 per well-year for North Dakota. Data supplied by the operators for the API study[1] showed an average tubing failure rate of 0.10 per well-year with a range from zero to 0.24 per well-year.
- o Tubing leaks ranged from 0.40 to 0.57 per well-year for Montana Operator D and Field H and North Dakota Operator E and Field E. These leak rates translate into tubing lives of about two years which are much shorter than would be expected for normal water injection operations.
- o Tubing leaks for South Dakota SWD and water injection wells averaged 0.06 per well-year. However, the sample size is too small for the data to be meaningful.

7.4.3 Casing Leak Data

Casing leak data presented in Tables 5, 6 and 7 was furnished by eight operators from 412 SWD and water injection wells.

The total casing leak rate for both Montana and North Dakota averaged 0.05 per well-year. No casing leaks were reported for South Dakota.

The Montana and North Dakota leak rates were obtained from extrapolation of the plots of the log of accumulated casing leaks versus time shown in Figures 9 and 10.

Since the extrapolation of a plot of the log of accumulated leaks versus time is the generally accepted method used to predict casing leak failures, it was necessary to incorporate leak data from the dBase IV™ casing leak file into a Harvard Graphics™ graphing program in order to construct the casing leak plots and to develop the casing leak rates shown on Tables 6 and 7.

For comparison, the API Study[1] data for 6,600 injection wells from 14 geologic basins showed an average casing leak rate of 0.02 per well-year. The API data ranged from 0.002 to 0.08 leaks per well-year.

7.4.4 High Side Probabilities Of USDW Contamination

As shown on Table 8, queries from the data base were used in a method developed by Michie[1] to determine the upper bound probability of simultaneous leaks occurring in the tubing, production casing and surface casing and reaching a USDW. Included in the tabulation are the 177 injection wells along the Cedar Creek anticline of Montana and North Dakota which do not have any USDWs.

Results of Table 8 for the Williston basin are summarized below:

Upper Bound Probability Of Injection Water
Leaking Into A USDW In Williston Basin

Surface Casing Coverage of USDW	Total Number Wells	Probability One Well Leaking In a Year	Wells Leaking/Yr	Bbls Reaching USDWs
Adequate	313	7.2×10^{-6}	0.0023	24
Short	241	5.8×10^{-3}	1.4	14,010
No USDWs	177	0	0	0
	==	=====	====	====
Total	731	1.9×10^{-3}	1.4023	14,034

Note:
An important assumption in Table 8 is that the operator monitors tubing pressure, casing/tubing annulus pressure and injection rates on a monthly basis. It is further assumed that the well is shut-in and repaired when a monthly monitoring inspection indicates a leak.

Based on the casing leak history supplied by the operators, it is estimated that three-fourths of the 241 wells that have short surface casing will have leaks that occur below an intervening aquifer. Assuming that the logic presented in Section 3.5.4 applies, an order of magnitude estimation of the maximum water that could reach a USDW in the Williston basin during a year would be reduced from 14,000 barrels to 4,000 barrels. This estimate does not include possible further reductions in the 4,000 barrels per year due to wellbore restriction and low injection formation pressures.

Table 9 presents calculations of the upper bound possibilities of simultaneous leaks permitting injection water to reach a USDW for selected operators in the basin. Of the 99 wells which have short surface casing, 50 have intervening aquifers. Using the logic developed in Section 3.5.4, an order of magnitude estimate of the maximum water escaping to a USDW in a year would be reduced from 5,000 to 3,000 barrels.

7.4.5 Surface Pipe Depth In Relation To Base Of USDW

One of the most important factors in assigning the risk of USDW endangerment to a well or group of wells is the relationship of the bottom of the surface pipe to the base of the lowermost USDW. Since the depth of the surface pipe and base of the lowermost USDW information for each well reside in the database master file, it is relatively easy to develop the information shown on Table 10. From this it can be seen that two-thirds of the injection wells in the Williston basin either have surface casing covering the base of the USDW or they do not have a USDW zone. This data indicates that the 241 injection wells with short surface casing should receive a majority of the UIC staff's available monitoring time.

Note:

As discussed in Section 3.6.2.2, the wells which have surface casing that does not cover the lowermost USDW wells were, in most cases, drilled before the advent of the UIC regulations. These wells typically have surface casing set through the deepest usable potable water supply.

Depending on the user's needs, this same type data presented above can be reported to the CRT and/or printed in hard copy for an individual well and for any number of wells grouped by operator, field or other similar aggregations.

7.4.6 Presence Of An Intervening Salt Water Aquifer

In the Williston Basin data base, the information relating to each intervening aquifer resides in the field file.

As discussed in Section 3.5.4, the presence of a salt water aquifer between a production casing leak and the base of a USDW provides one of several major obstacles to injection water reaching a USDW in the unlikely event of simultaneous tubing, production casing and surface casing leaks.

An example of the type of report available to relate the depths of an individual well casing leak with the base of the lowest USDW and the possible presence of an intervening aquifer is shown on Table 11. For Montana Operator B, it can be seen that of the nine production casing leaks, only one leak occurred below an intervening aquifer. From this report, it can also be seen that seven of the nine leaks occurred in wells which have their surface casing set below the base of the USDWs.

7.4.7 MIT Tests

The use of queries in evaluating the effectiveness of a MIT program is one of the more valuable tools of a UIC data base. For a discussion of analysis of MIT test failures, see Section 3.13.2.

7.4.8 Other Queries

The queries discussed above demonstrate only a few of the type of queries that can be helpful in administering a UIC program. Other types of user queries of a risk data base include:

- Use of leak records to identify corrosive zones for possible modification of drilling and workover practices,
- A report of scheduled MIT tests that have not been run,
- Identification of wells that have not had a MIT test in last five years,
- Identification of wells that have had a workover but have not had a follow-up MIT test,
- List of wells that have been shut in longer than a specified length of time such as 90 days,

- List of wells that have injection rates above permitted rates,
- List of wells that have injection pressures above permitted injection pressures, and
- Location of production casing top-of-cement in relation to depth of USDWs.

8.0 Conclusions

Conclusions developed from the Williston Basin study are summarized below.

8.1 Conclusions Applicable To Expanding The Risk Based Concept

8.1.1 Risk Based UIC Regulatory Programs Are Viable

A number of regulating agencies are currently using risk based regulatory practices in their UIC programs. For example, North Dakota uses risk management by specifying cement coverage of the corrosive Dakota formation during injection well completions and conversions and by allocating a larger portion of the staff's available monitoring time to the historically higher risk SWD wells.

8.1.2 Risk Analysis Concepts Developed In The API Study Are Practical

The Williston Basin study demonstrated that the risk analysis concepts developed in the API study "Oil and Gas Industry Water Injection Well Corrosion"[1] can be practically applied in making risk based decisions. Since geologic basins exhibit consistent depositional characteristics for USDWs, intervening aquifers, corrosive zones and producing horizons, they can be used to characterize UIC operations. Well bore failure frequency data and analysis methodology can be gathered and applied to quantifying the upper bounds of the probability of USDW contamination.

8.1.3 Implementation Of UIC Risk Management Should Be Five-Year Goal

Collecting MIT test and injection monitoring information, identifying USDW resources to be protected, developing tubing and casing leak histories, compiling completion data and use of data management tools that will allow applying engineering analysis to make risk decisions should be a high priority for the UIC program.

The initial step toward nationwide application of risk based concepts to injection well monitoring was taken at the 1989 UIPC summer meeting, where the UIPC approved a resolution adopting as a goal the inclusion of risk management into existing and new UIC programs.

8.1.4 Implementation Requirements Different For Each State

The hardware, software and personnel needed to install a risk based UIC program will be unique for each state. For example, efforts necessary to incorporate risk into state and EPA administered UIC programs will range from grass roots developments to relatively minor enhancements of existing programs.

8.2 Database Design Considerations

8.2.1 Data Elements And Database Queries Are Based On User Surveys

A survey of industry, state and federal regulatory personnel was the basis for the Williston Basin study's choice of the data elements necessary to run a risk based UIC program. A similar survey obtained industry and regulatory personnel recommendations on the database queries needed to risk manage UIC programs.

Feedback from the two surveys was a major factor in development of the proposed UIPCRF UIC data management standard.

8.2.2 Data Elements Are Clearly Defined

Data elements of the Williston Basin study data base consist of the eight clearly defined categories listed below:

- o Well Identification
- o Wellbore Mechanical Construction
- o MIT Tests
- o USDW Information
- o Injection Monitoring
- o Field Level Reservoir Parameters
- o Tubing and Casing Failure History
- o Workover History

8.3 Database Implementation Considerations

8.3.1 Manpower Needs Are Nominal

Manpower resources are manageable. The entire Williston basin data base was defined, built, loaded with data and analyzed in 10 months under the direction of a single engineer.

8.3.2 Off-The-Shelf Computers Can Handle Hardware Requirements

Computer hardware resources needed to implement UIC risk management data bases are nominal. The entire data base for the Williston basin, including all commercial software, was stored and manipulated on a $4,000 laptop computer. Memory requirements for the data associated with 1,186 wells was only 5 kilobytes per well. The capability of using laptop computers in field monitoring activities could easily be provided field inspection personnel.

8.3.3 Commercially Available Software Is Preferred

Commercially available database management and reporting software was successfully used. Use of commercial products are preferred for the following reasons:

- o Minimizes regulatory agency investment for programming and maintenance,
- o Ease of transition to new products as technology changes,
- o Minimum effort necessary for user friendly menu and query development. This allows regulatory personnel to concentrate on analysis and compliance responsibilities,
- o Ease of transferring existing computer records to the commercial database software package, and
- o Consistency with operator database records easing implementation of electronic data transfer.

8.3.4 Data Availability

8.3.4.1 Unique Nationwide Wellbore ID Numbers Are Not Available

A usable source of unique national wellbore identification numbers is not available and it's development is not recommended. State and federal UIC programs should continue their existing practice of assigning unique in-house generated numbers to each wellbore. In those states where API numbers are presently used as the well identifier, their use should be continued. When API well numbers are readily available, they should be used as a secondary well identifier.

8.3.4.2 Wellbore Construction Details Are Available From Operators

Wellbore mechanical construction information is generally available and kept by operators. However, wellbore details are not always reported to regulatory agencies and when they are reported they are often not entered into UIC records. As a result, this information is tracked in current data bases to varying degrees.

8.3.4.3 Most Risk Data Is Currently Being Collected And Stored

Much of the needed data is already being collected and stored on hard copy or electronic media by operators and UIC agencies. In many cases, the volume of data and the fact that it is located in a number of different files precludes its timely use in monitoring UIC operations and in making regulatory decisions.

8.3.5 Early Involvement of UIC Staff Personnel Is Critical

System analyst and engineering personnel who will be responsible for the long term operation of a UIC risk management system should be involved in all phases of design, implementation and debugging of the system.

8.3.6 Phased Implementation Is Practical

The risk approach to UIC data management lends itself to phased implementation of selected segments of the data management system. Thus, the degree and the timing of the implementation effort can be tailored to state or federal program needs, grant availability and information collection constraints.

After project approval has been obtained and funding has been secured, the steps necessary to implement and manage a risk based program include:

- Selecting personnel,
- Purchasing computer hardware,
- Defining file structure and purchasing data management and reporting software,
- Establishing a system for obtaining, verifying and inputting data,
- Developing database backup procedures,
- Collecting basic well identification information,
- Collecting and tracking wellbore completion information and MIT tests,
- Identifying USDWs to be protected,

- o Collecting and tracking injection monitoring data, field parameters and wellbore failure histories, and
- o Providing user friendly analysis, enforcement and reporting capabilities.

8.4 Williston Basin Conclusions

8.4.1 Sedimentary Rocks Are Similar Throughout Williston Basin

The basin exhibits similar depositional sequences for USDWs, intervening aquifers, corrosive zones, salt sections, SWD zones, water injection formations and producing reservoirs.

8.4.2 Injection Monitoring Report Potential Is Often Not Achieved

The effectiveness of the injection monitoring reports can be improved by:

- o Where not now specified, add operator monitoring of the casing/tubing annulus pressure on a monthly basis to the requirement of monthly monitoring of injection volume and tubing pressure.
- o For high risk injection wells, increase operator monitoring frequency from monthly to weekly.
- o Enter a record into the UIC data base for each written monitoring report that documents an injection well's loss of mechanical integrity.
- o Reduce the annual injection monitoring report to two or three lines per injection well. The report should show field, well number, operator, file number, barrels injected per year, maximum tubing pressure observed during the year and maximum casing/tubing annulus pressure observed during the year. This information should be entered into the UIC data base.

  In order to satisfy any statutory documentation requirements, the annual report should be signed by the operator and stored on paper in the agency files.
- o Establish a goal for a UIC field inspector to visit each injection well periodically (perhaps yearly).

8.4.3 Field Parameters Are Important In Risk Management

Field level reservoir parameters such as location of USDW aquifers, water injection zones, SWD zones, intervening aquifers and corrosive zones are an important part of a risk management data base. This information permits an analysis of leak data in conjunction with intervening aquifer information to evaluate the downside risks of water movement into a USDW in the unlikely event of simultaneous tubing, production casing and surface casing leaks.

8.4.4 Probability Of USDW Endangerment Is Small

The likelihood of endangering a USDW in the Williston basin is small for properly conducted Class II injection operations. Upper bound probability limits predicted for potential USDW contamination ranged from seven incidents per million well-years for wells that have surface casing covering the USDWs to six incidents per thousand well-years for wells without adequate surface casing. These limits are conservative since they do not include allowances for the existence of intervening aquifers, shale or mud presence in the wellbore, surface casing cement or conductor pipe presence.

8.4.5 Leak Histories Are Keys To Probability Determinations

Tubing and casing leak data are the keys to calculating the probability of simultaneous tubing, production casing and surface casing leaks. This data can be initially obtained from selected operators in a basin and applied in similar fields in that basin. The information can be kept current and the leak data built over a period of time by documenting failures as they are recorded in the MIT and/or workover reports.

8.4.6 Leak Histories Can Be Initially Used For Similar Fields

Tubing and casing failure data for the basin can be estimated from less than 100% coverage. Tubing and casing leak histories were obtained from eight operators who operate 56% of the Williston basin injection wells.

8.4.7 Most Williston Basin Injection Wells Have Tubing Set On A Packer

Ninety-nine percent of Williston basin injection wells are single zone, conventional completions which have tubing set on a packer. This completion scheme lends itself to early identification of tubing and casing leaks, thus reducing the probability of potential USDW contamination.

8.5 Montana Conclusions

EPA Region VIII presently administers the Montana UIC program. However, the Oil and Gas Conservation Division of the Department of Natural Resources and Conservation of the State of Montana is currently planning to apply for UIC primacy.

8.5.1 Montana MIT Test Results Should Be Maintained In A UIC Data Base

Montana MIT tests are coordinated by EPA inspectors who are located in the field office in Helena, Montana. All injection wells have had MIT tests run in the last five years and 60% of the MIT tests were witnessed by either EPA or contract personnel. MIT test results are stored on a personal computer in a dBase III™ database program that is maintained by the Helena office personnel.

From the field inspection standpoint, the present system of storing MIT tests on a computer is effective. However; since MIT tests results are not integrated into an overall UIC data base, the information cannot be effectively used to determine the risk of USDW endangerment for individual wells or groups of wells.

8.5.2 Montana Well And Injection Data Should Be Computerized

Basic well completion data, workover results and injection monitoring reports are only available on hard copy and cannot be analyzed without considerable technical and accounting time to assemble in a manageable form. In most cases, individual well USDW data is not available.

As discussed below, the well completion, workover, injection monitoring and MIT test data should be maintained in a UIC data base.

8.5.3 Grass Roots UIC Risk Program Would Benefit Montana

Montana is currently considering applying for UIC primacy. Regardless of whether Montana is granted primacy or the EPA continues to administer the program, implementation of a grass roots risk data management system would strengthen their UIC program.

8.5.4 A Review Of Montana Operator Reports Is Indicated

Since the EPA has primacy over the Montana UIC program and the Montana Oil and Gas Conservation Division has control of oil and gas operations, some duplication of reporting is expected. EPA and state reviews of operator reporting requirements would be helpful in identifying duplicate reporting for possible elimination.

8.6 North Dakota Conclusions

North Dakota successfully utilizes risk based regulatory concepts to effectively protect USDWs in a potentially hostile corrosive environment.

8.6.1 North Dakota Has Strong Commitment To UIC Program

As discussed below, North Dakota has made a strong commitment in technical and field manpower to support the UIC program.

8.6.1.1 UIC Data Management Computer System

The North Dakota UIC data management system is part of the Oil and Gas Division's computer system that is used in the regulation of oil and gas operations. The system consists of a PC file server which communicates with two data processing mainframe computers. The PC file server is connected to local display stations and to three field office PC computers with printers.

A system analyst is responsible for designing the system, developing software, preparing reports and maintaining the system.

It was the writer's experience that the information in the UIC data base is high quality and that all report requests were promptly and efficiently handled.

8.6.1.2 Technical Staff

The North Dakota technical staff is committed to making the UIC program work. In addition to the UIC program, the staff is responsible for the management of all oil and gas regulatory matters.

It was the writer's experience that the staff was knowledgeable in the engineering, geological and operational aspects of the UIC program. These comments are based on numerous phone calls, letter requests and Bismarck office work sessions spent in gathering data for the study. It was also observed that the staff made effective use of the display stations to obtain information from the UIC data base.

8.6.1.3 Field Inspectors

North Dakota has 13 field inspectors who have the responsibility for conducting field inspections of all oil and gas operations, including the UIC program. The fact that they witness all well plugging operations and 87% of the MIT tests is an indication of their effectiveness in the field oversight of the UIC program.

8.6.2 North Dakota USDW Contamination Probability Is Small

Conservative estimates of potential failures from injection wells average seven per million well-years for wells with adequate surface pipe to cover the USDWs to five per thousand well-years for those without.

Low contamination potential is further reduced because intervening aquifers exist in 40% of North Dakota's 422 active injection wells and 3% of wells were found not to have USDWs present.

8.6.3 Surface Casing In Most Wells Is Set Below USDWs

Fifty-seven percent of North Dakota's active injection wells either are located in areas where a USDW is not present or have surface pipe set below the base of the USDW. Wells which have surface pipe set above the base of the USDW were drilled before the current USDW definition was created. Those wells have surface casing set to protect USDWs currently being used as sources of drinking water.

8.6.4 North Dakota's Risk Based Approach Has Proven Successful

Risk based regulatory requirements to add cement across the Dakota formation in new wells and the use of cathodic protection where risk warrants have largely controlled the failure potential of the highly corrosive Dakota formation. Only 3% of casing leaks now occur in the Dakota.

8.6.5 Intervening Aquifers Are Important In North Dakota

Based on operator supplied data from 190 injection wells, tubing failures averaged 15% per well-year and casing failures averages 5% per well-year. Of the reported casing leak failures, 62% occurred below an intervening aquifer. Although an intervening aquifer cannot be relied on to prevent USDW contamination, it is an important factor in minimizing the amount of potential contamination in the unlikely event that simultaneous tubing, production casing and surface casing leaks go undetected.

8.6.6 MIT Test Monitoring Is Effective In North Dakota

The state effectively monitors wells for MIT compliance. In 1988, 179 MIT tests were conducted and all wells were tested within the last five years. Eighty-seven percent of the MIT tests conducted in the last five years were witnessed.

8.6.7 Nominal Changes Towards A Risk Based Program

Enhancements to upgrade the North Dakota UIC program to incorporate additional risk management concepts are indicated in the following areas:

- o Expand display station screen menus available to the user for query and analysis purposes,
- o Install printers for selected local display stations for easier user access to hard copy reports,
- o Implement tracking of MIT tests of temporarily abandoned wells in the existing UIC data base,
- o Include in the UIC data base all monitoring tests which indicate a potential leak,
- o Maintain all MIT tests in the existing data base, and
- o Include individual well USDW information in the UIC data base.

8.7 South Dakota Conclusions

The South Dakota portion of the Williston basin contains only 5 water injection, 7 SWD and 30 air injection wells. All MIT tests were witnessed in 1988. Production and injection reports are handled by a personal computer using a Lotus 1-2-3™ computer spread sheet program. At this time, additional emphasis on field inspection or data management does not appear to be warranted.

8.8 Operators Conclusions

Although the study was directed toward incorporating risk management into existing state and federal UIC programs, there are incentives for operators who have a significant number of water injection wells in a given state to utilize selected portions of the risk management concept by developing their own risk based data bases.

Potential operator incentives for implementing the risk based concept include:

- o Electronic data reporting,
- o Compliance monitoring,
- o Tracking of tubing and casing failures information,
- o Reduced liability of USDW contamination and remediation,
- o Compatibility with UIC reporting requirements, and
- o Rapid accessibility and analysis of geologic and wellbore mechanical information for injection wells.

9.0 Recommendations

Recommendations of follow-up to the Williston Basin study are summarized below.

9.1 Enhancing UIC Data Management Should Be A Five-Year Goal

Enhancement of existing data collection and data management practices offers the largest potential for improvement of the UIC program and should be a major goal and target for UIC grants over the next five years. A goal of having all UIC programs at least partially based on the risk management approach by 1994 is recommended.

9.2 Williston Basin Data Base Is Recommended As A Standard

The data base and the associated risk monitoring techniques developed in the Williston Basin study should be adopted by the UIPCRF as a recommended standard to be utilized in evaluating existing UIC programs. Shortfalls in existing UIC monitoring programs as measured against the UIPCRF standard should form the basis for future state and federal grants.

9.3 Inventory Of Data Management Capabilities Is Needed

UIPC members should continue to adopt data management and risk based decision making as a primary objective and assist in funding UIPCRF studies to achieve that goal. A recommended first step is authorizing a project to determine for each state the status of existing data management capabilities and to develop a list of the desired enhancements needed to upgrade to a risk based UIC data base.

9.4 State/Federal Funding Is Needed For Risk Programs

Risk management program implementation should be funded by joint state/federal programs. Federal funding should be contingent on state commitments to assign office and field personnel needed to design, install and maintain the systems.

Phased grants should be considered to first allow system definition and collection of information on well identification, well completion, MIT tests and injection monitoring. When these phases are complete, they should be followed by the step-wise addition of USDW, field, workover and failure data to the UIC data base.

9.5 Monitoring Frequency Should Be Tied To Risk

Wells which have a relatively low probability of endangering a USDW should continue to be monitored monthly for possible leaks and a MIT test should be run every five years. Increasing leak monitoring and MIT test frequencies should be investigated for those wells which present a higher risk of potential USDW contamination.

9.6 Casing/Tubing Annulus Pressure Monitoring Should Be Employed

Monthly monitoring of the casing/tubing annulus pressure should be required where it is not presently specified in the regulations.

9.7 Annual Injection Monitoring Report Should Be Streamlined
The annual injection monitoring report should be limited to two or three lines per well. Results of the annual reports should be entered into the UIC data base.

9.8 Monitoring Reports Of Potential Leaks Should Be Included In UIC Data Base
UIC data bases should include results from each written monitoring report that indicates possible loss of mechanical integrity or a leak.

9.9 Data Bases Should Be Tailored To Individual State Requirements
UIC risk management data bases should be designed to meet the requirements dictated by specific needs for that state. Federal data requirements should be directed toward what data is needed but each state should specify the file structures for storing the information.

9.10 Electronic Transfers Of Data Should Be Encouraged
Electronic media is recommended as the preferred method of transferring data from operators to the states and from the states to federal UIC administrators.

9.11 Montana Should Evaluate A Risk Management UIC Data Base
It is recommended that a grass roots risk based data base be evaluated for management of Montana's UIC program. A joint EPA/state study should be initiated to develop a plan and evaluate the potential for installation of a computerized data management system.

9.12 North Dakota Should Evaluate Adding Selected Risk Elements To UIC Data Base
It is recommended that North Dakota evaluate making additions of selected risk elements to enhance their existing UIC data base.

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Software	
David M. Johnson	Aftermarket
B. H. Roark	Consultant

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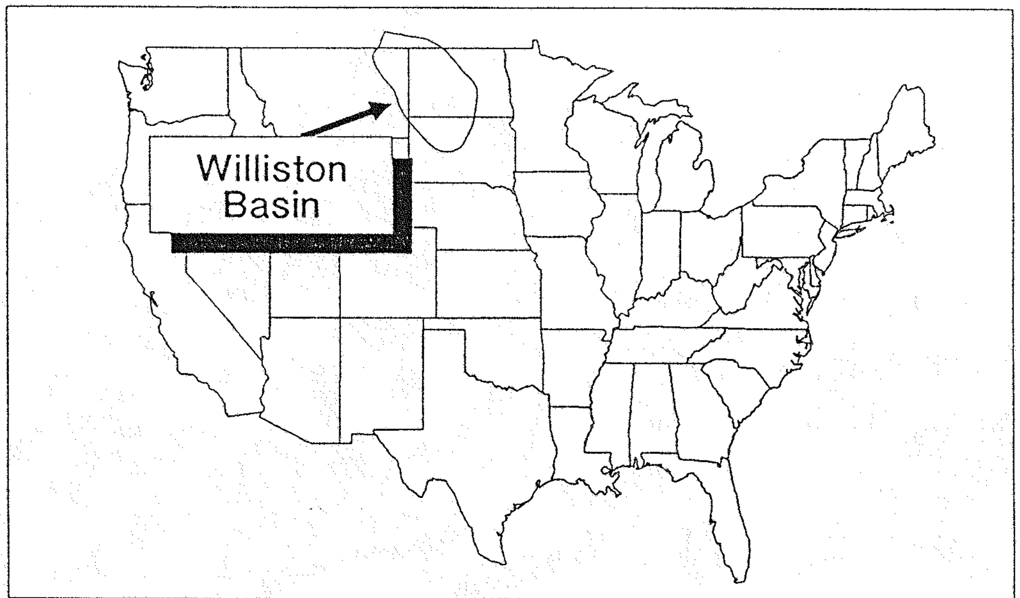
Figure 1



	Montana	North Dakota	South Dakota	Total
Active EOR Wells	201	170	5	376
Active SWD Wells	96	252	7	355
Total Injection Wells	297	422	12	731

Figure 2

Contributors to Williston Basin Study

Data and Comments		Comments
Basin Operators	**Basin Regulators**	**Others**
Amerada Hess	EPA	ARCO
Apache	Montana	California
Conoco	North Dakota	DOE
Chevron	South Dakota	Exxon
Koch		Kansas
Sun		Oklahoma
Shell		Texas
Texaco		

Figure 3

Database File Structure

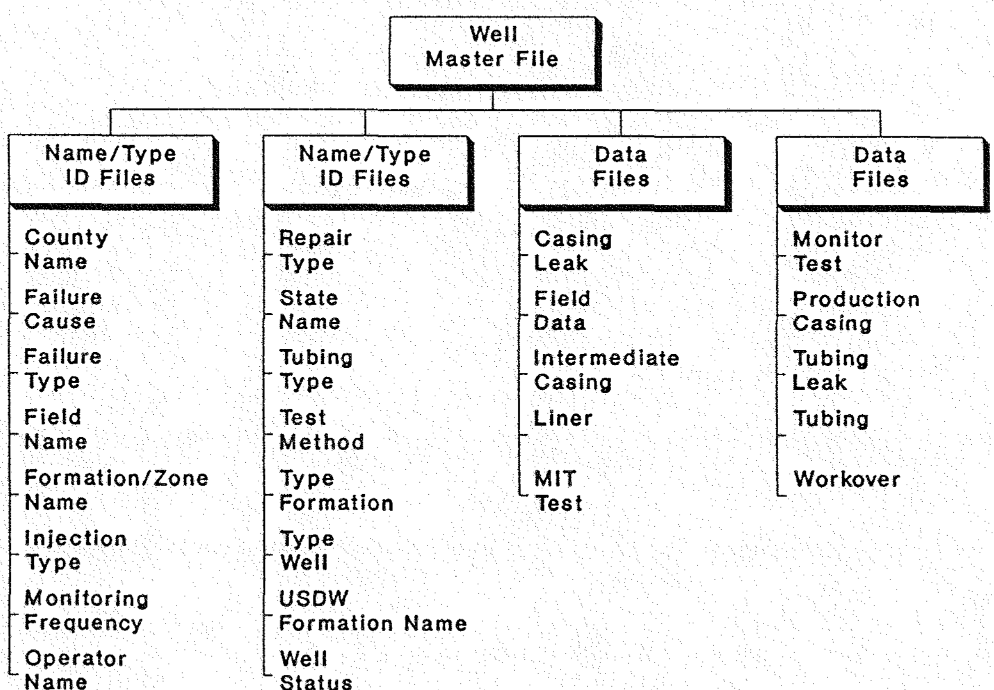
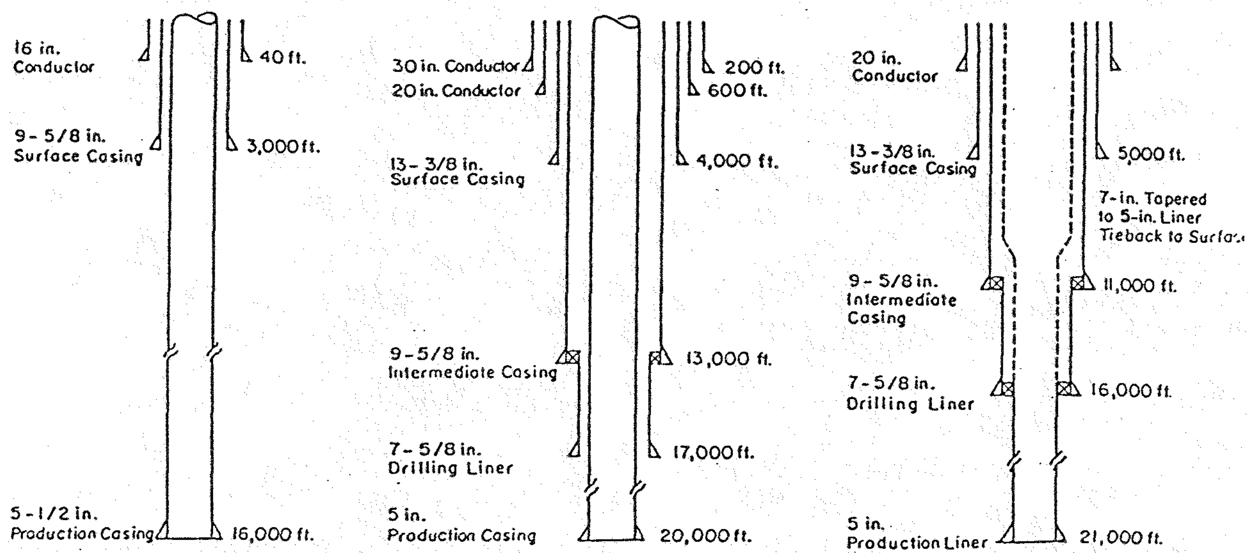


Figure 4

Example Casing and Liner Programs



Conventional Casing Program

Deep Well Program With Intermediate Casing and Drilling Liner

Deep Well Program With Intermediate Casing, Drilling Liner And Production Liner

Depths apply to deep wells located outside Williston basin

MIT Test Failure Rates For Wells With Positive Tubing Pressure

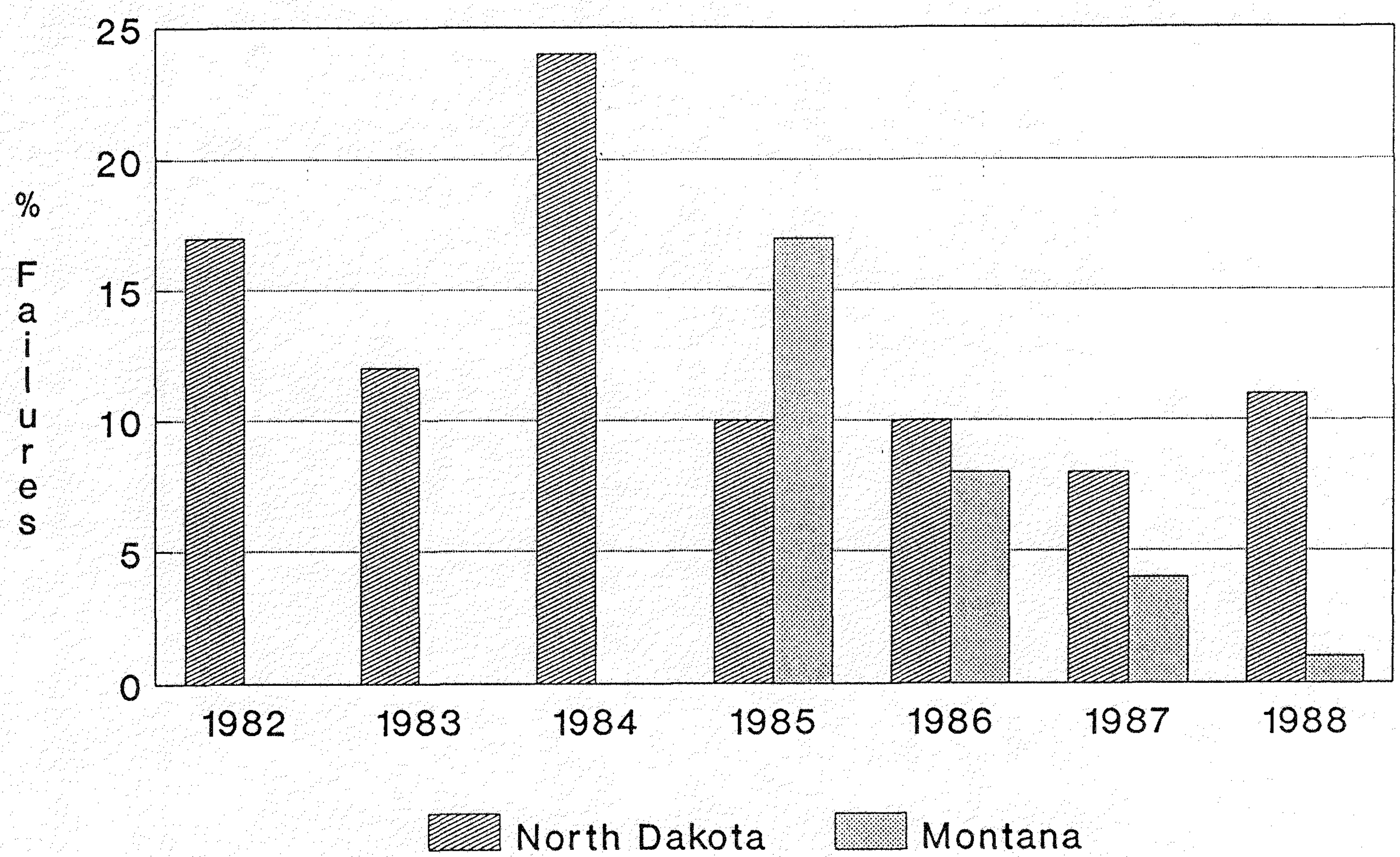
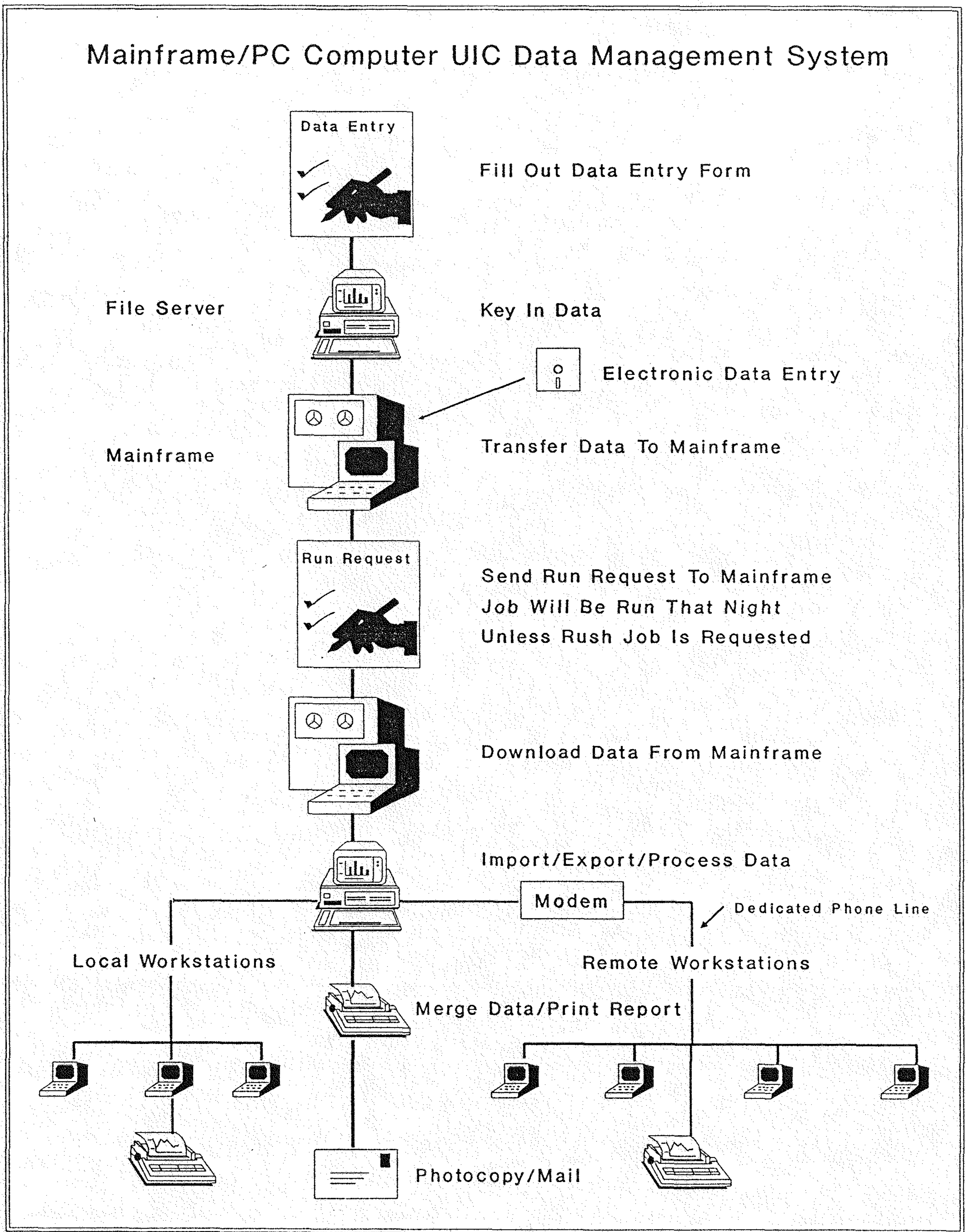


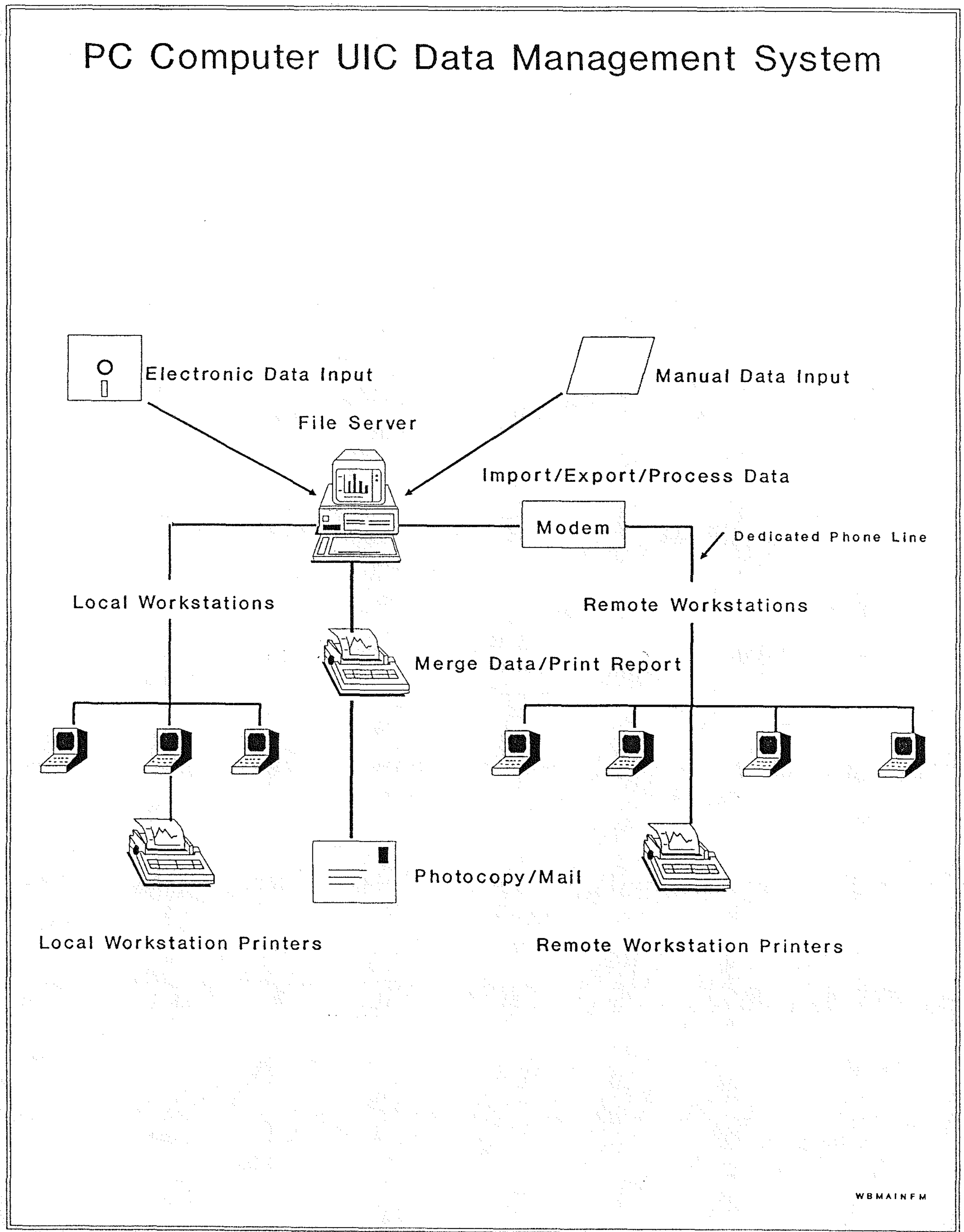
Figure 5

Figure 6

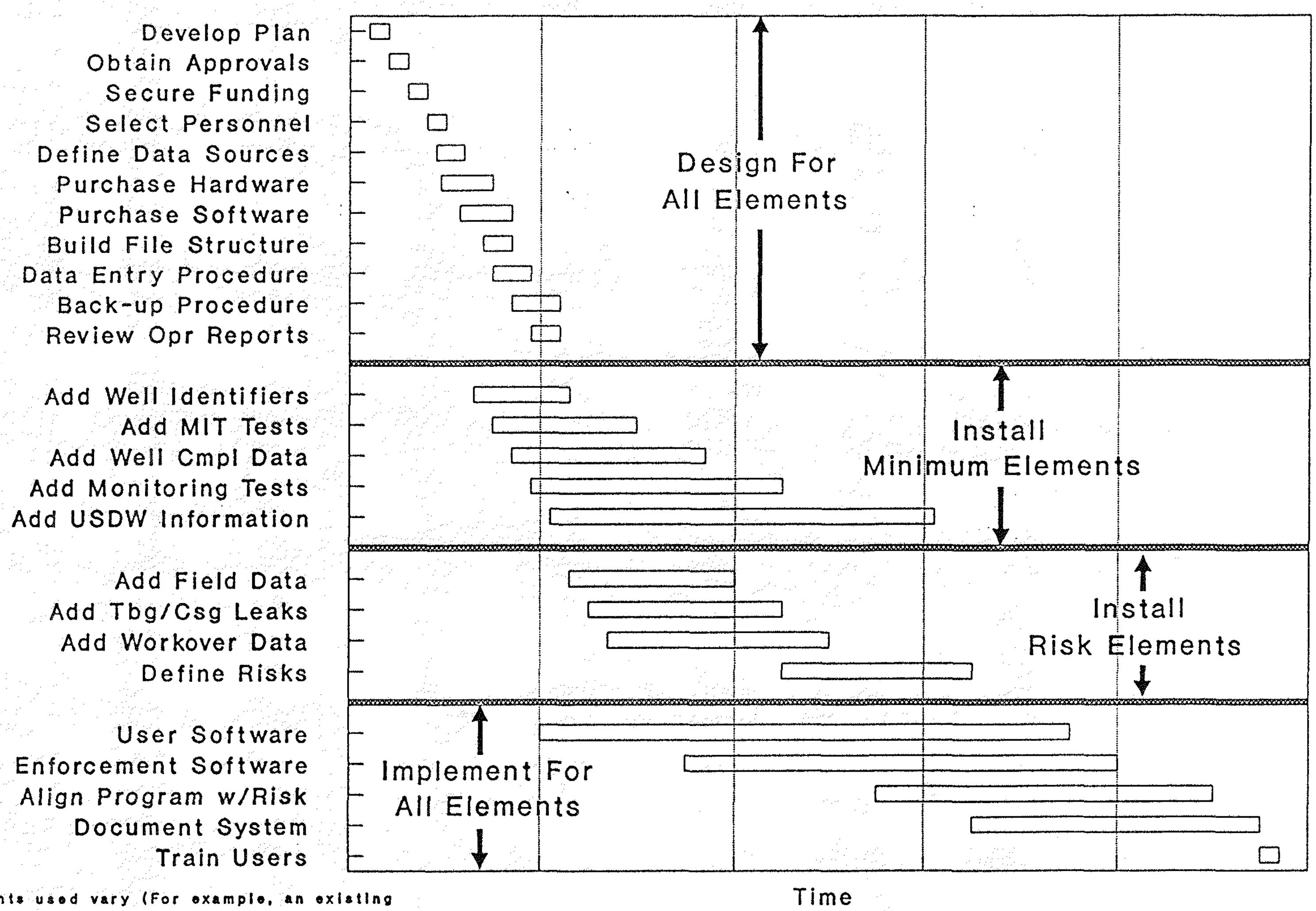


Mainframe/PC Computer UIC Data Management System
Data Entry
Fill Out Data Entry Form
File Server
Key In Data
Electronic Data Entry
Mainframe
Transfer Data To Mainframe
Run Request
Send Run Request To Mainframe
Job Will Be Run That Night
Unless Rush Job Is Requested
Download Data From Mainframe
Import/Export/Process Data
Modem
Dedicated Phone Line
Local Workstations
Remote Workstations
Merge Data/Print Report
Photocopy/Mail

Figure 7


PC Computer UIC Data Management System
Electronic Data Input
Manual Data Input
File Server
Import/Export/Process Data
Modem
Dedicated Phone Line
Local Workstations
Remote Workstations
Merge Data/Print Report
Photocopy/Mail
Local Workstation Printers
Remote Workstation Printers
WBMAINFM

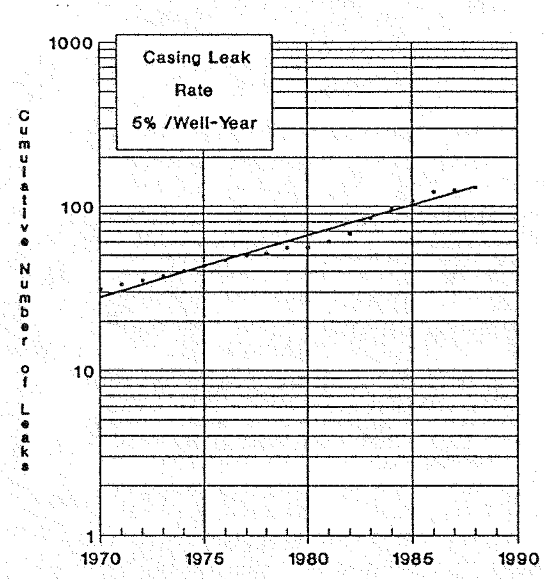
Plan for Implementing Risk Management Into Existing UIC Programs



Elements used vary (For example, an existing UIC program may add only USDW data while a new program may use all of the elements)

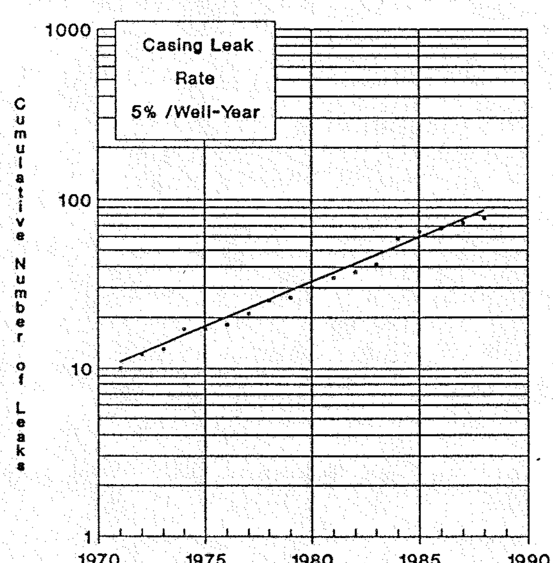
Figure 8

Figure 9
Montana SWD/Water Injection
Well Casing Leak History



Leak data for 215 wells from 5 operators

Figure 10
North Dakota SWD/Water Injection
Well Casing Leak History



Leak data for 190 wells from 7 operators

Table 1

MIT Test Results for SWD and Water Injection Wells In Montana Portion of the Williston Basin

All Wells Tested

Year	Passed	Failed	Total Tests	% Failed
	Number of MIT Tests			
1985	257	89	346	26
1986	109	12	121	10
1987	73	6	79	8
1988	133	2	135	1
Total	572	109	681	16

Wells Tested Which Had a Positive Tubing Pressure

1985	202	40	242	17
1986	74	6	80	8
1987	66	3	69	4
1988	115	1	116	1
Total	457	50	507	10

Table 2

MIT Test Results for SWD and Water Injection Wells In North Dakota Portion of the Williston Basin

All Wells Tested

	Number of MIT Tests			
Year	Passed	Failed	Total Tests	% Failed
1982	5	1	6	17
1983	168	20	188	11
1984	144	35	179	20
1985	110	16	126	13
1986	99	15	114	13
1987	84	9	93	10
1988	159	20	179	11
Total	769	116	885	13

Wells Tested Which Had a Positive Tubing Pressure

1982	5	1	6	17
1983	128	18	146	12
1984	103	32	135	24
1985	63	7	70	10
1986	60	7	67	10
1987	60	5	65	8
1988	119	15	134	11
Total	538	85	623	14

Table 3

Salt Water Disposal and Water Injection Wells Tubing Leak History from Five Montana Operators

	Number of Years	Total Active Wells	Tubing Leaks Total	Tubing Leaks Per Well-Year
Totals From Five Operators				
SWD Wells	5	17	14	0.16
WI Wells	5	198	170	0.17
Total	5	215	184	0.17
Total SWD And WI Wells By Operator				
Operator A	5	183	150	0.16
Operator B	5	7	4	0.11
Operator C	5	22	25	0.23
Operator D	5	2	4	0.40
Operator E	5	1	1	0.20
Total	5	215	184	0.17
Total SWD And WI Wells By Selected Fields				
Field A	5	27	33	0.24
Field B	5	83	39	0.09
Field C	5	30	29	0.19
Field D	5	16	18	0.23
Field E	5	11	14	0.25
Field F	5	14	6	0.09
Field G	5	7	6	0.17
Field H	5	4	11	0.55
Field I	5	4	3	0.15
Field J	5	3	3	0.20

Table 4

Salt Water Disposal and Water Injection Wells Tubing Leak History from Seven North Dakota Operators

	Number of Years	Total Active Wells	Tubing Leaks Total	Tubing Leaks Per Well-Year
Totals From Seven Operators				
SWD Wells	5	48	17	0.07
WI Wells	5	142	126	0.18
Total	5	190	143	0.15
Total SWD And WI Wells By Operator				
Operator A	5	92	79	0.17
Operator B	5	40	13	0.07
Operator C	5	19	18	0.19
Operator D	5	12	12	0.20
Operator E	5	9	19	0.42
Operator F	5	8	0	0.00
Operator G	5	10	2	0.04
Total	5	190	143	0.15
Total SWD And WI Wells By Selected Fields				
Field A	5	25	16	0.13
Field B	5	12	12	0.20
Field C	5	19	18	0.19
Field D	5	42	31	0.15
Field E	5	6	0	0.00
Field F	5	4	6	0.30
Field G	5	7	20	0.57
Field H	5	5	5	0.20

Table 5

Salt Water Disposal and Water Injection Wells Leak History from Two South Dakota Operators

TUBING LEAKS

	Number of Years	Total Active Wells	Tubing Leaks Total	Tubing Leaks Per Well–Year
Totals From Two Operators				
SWD Wells	5	2	1	0.10
WI Wells	5	5	1	0.04
Total	5	7	2	0.06
Total SWD And WI Wells By Operator				
Operator A	5	5	1	0.04
Operator B	5	2	1	0.10
Total	5	7	2	0.06

CASING LEAKS

	Total Active Wells	Csg Leaks Per Well–Year
Totals From Two Operators		
SWD Wells	2	0.00
WI Wells	5	0.00
Total	7	0.00

Table 6

Salt Water Disposal and Water Injection Wells Casing Leak History from Five Montana Operators

	Total Active Wells	Casing Leaks Per Well–Year
Totals From Five Operators		
SWD Wells	17	0.04
WI Wells	198	0.05
Total	215	0.05
Total SWD and WI by Selected Operators		
Operator A	183	0.05
Operator B	7	0.06
Operator C	22	0.01
Total SWD and WI by Selected Fields		
Field A	27	0.13
Field B	83	0.03
Field C	30	0.05
Field D	16	0.01
Field E	11	0.04
Field F	14	0.04
Field G	7	0.07

Table 7

Salt Water Disposal and Water Injection Wells
Casing Leak History from Seven North Dakota Operators

	Total Active Wells	Casing Leaks Per Well–Year
Totals From Five Operators		
SWD Wells	48	0.06
WI Wells	142	0.04
Total	190	0.05
Totals by Selected Operators		
Operator A		
SWD Wells	20	0.12
WI Wells	72	0.03
Total Operator A	92	0.05
Operator B (SWD and WI)	40	0.04
Operator C (SWD and WI)	19	0.09
Operator D (WI)	12	0.11
Total SWD and WI by Selected Fields		
Field A	25	0.05
Field B	12	0.11
Field C	19	0.09
Field D	42	0.04
Field E	6	0.17

Table 8
Probability of Leaks Reaching a USDW - Williston Basin

Summary by State and Williston Basin of Upper Bound Probability of an Injection Well Leak Contaminating a USDW

Category	Wells w/USDWs: No. Wells/w Adequate Surf Csg	Wells w/USDWs: No. Wells/w Short Surf Csg	No. Wells Without USDWs	Total No. Active Inj Wells	Leaks Per Well-Yr: Tbg	Leaks Per Well-Yr: Prod Csg	Leaks Per Well-Yr: Surf Csg	Probability of One Injection Well Leaking to a USDW: Adequate Surf Csg	Probability of One Injection Well Leaking to a USDW: Short Surf Csg	Total Water Inj B/D	Adequate Surf Csg: No. Wells Leaking In Year	Adequate Surf Csg: Total Bbl Leaking In Year	Short Surf Csg: No. Wells Leaking In Year	Short Surf Csg: Total Bbl Leaking In Year
Montana - SWD	54	36	6	96	0.16	0.04	0.0011	7.0E-06	6.4E-03	84000	0.0004	5.0	0.2	3066
Montana - Wtr Inj	18	24	159	201	0.17	0.05	0.0014	1.2E-05	8.5E-03	93000	0.0002	1.5	0.2	1435
Montana - Total	72	60	165	297	0.17	0.05	0.0014	8.2E-06	7.2E-03	177000	0.0006	6.5	0.4	4501
N Dakota - SWD	139	113	0	252	0.07	0.06	0.0016	6.9E-06	4.2E-03	202000	0.0010	11.7	0.5	5786
N Dakota - Wtr Inj	90	68	12	170	0.18	0.04	0.0011	7.9E-06	7.2E-03	85000	0.0007	5.4	0.5	3723
N Dakota - Total	229	181	12	422	0.15	0.05	0.0014	7.3E-06	5.3E-03	287000	0.0017	17.1	1.0	9509
S Dakota - SWD	7	0	0	7	0.10	0	0.0000	0.0E+00	0.0E+00	3000	0.0000	0.0	0.0	0
S Dakota - Wtr Inj	5	0	0	5	0.04	0	0.0000	0.0E+00	0.0E+00	2000	0.0000	0.0	0.0	0
S Dakota - Total	12	0	0	12	0.06	0	0.0000	0.0E+00	0.0E+00	5000	0.0000	0.0	0.0	0
Williston Bsn - SWD	200	149	6	355	0.10	0.05	0.0014	6.7E-06	4.7E-03	289000	0.0013	16.7	0.7	8852
Williston Bsn - Wtr Inj	113	92	171	376	0.17	0.04	0.0011	8.1E-06	7.5E-03	180000	0.0009	6.9	0.7	5158
Williston Bsn - Total	313	241	177	731	0.16	0.05	0.0014	7.2E-06	5.8E-03	469000	0.0023	23.6	1.4	14010

Memo:
- o Adequate surface casing is casing set below base of lowest USDW. Short surface casing is casing set above base of lowest USDW.
- o Tubing and production casing leaks per well-year are based on data supplied by eight operators from 412 injection wells.
- o Surface casing leaks per well-year are calculated based on operator supplied production casing leak data adjusted for resistivity and temperature of the waters opposite the production casing leak zone and the USDW zone.
- o Probability of simultaneous tubing, production casing and surface casing leaks permitting injection water to reach a USDW does not consider the effects of low injection formation pressures, intervening aquifers and permeability restrictions in the borehole.
- o For procedure used in calculating state SWD and state Wtr Inj leak probabilities, see API study "Oil and Gas Industry Water Injection Well Corrosion."
- o Calculation of total bbl leaking in a year assumes monthly monitoring of casing/tubing annulus pressure.
- o State totals and Williston Basin subtotals and totals are derived from state SWD and state Wtr Inj totals.

Table 9
Probability of Leaks Reaching a USDW - Selected Operators

Summary by Selected Operators
Calculation of Upper Bound Probability of a SWD or Water Injection Well Leak Contaminating a USDW in the Williston Basin

		Wells w/ USDWs						Probability of One Injection Well Leaking to a USDW			Adequate Surf Csg		Short Surf Csg	
Category	Total No. Inj Wells	No. Wells/w Adequate Surf Csg	No. Wells/w Short Surf Csg	No. Wells Without USDW	Leaks Per Well-Year Tbg	Leaks Per Well-Year Prod Csg	Leaks Per Well-Year Surf Csg	Adequate Surf Csg	Short Surf Csg	Total Water Inj B/D	No. Wells Leaking In Year	Total Bbl Leaking In Year	No. Wells Leaking In Year	Total Bbl Leaking In Year
ND - Oper A	92	63	29	0	0.17	0.05	0.0014	1.2E-05	8.5E-03	45000	0.00073	5.5	0.247	1834
ND - Oper B	40	10	30	0	0.07	0.04	0.0011	3.1E-06	2.8E-03	36000	0.00003	0.4	0.084	1150
ND - Oper C	19	3	16	0	0.19	0.09	0.0025	4.2E-05	1.7E-02	8800	0.00013	0.9	0.274	1927
ND - Oper D	12	0	0	12	0.2	0.11	0.0030	0.0E+00	0.0E+00	3900	0.00000	0.0	0.000	0
MO - Oper A	183	17	1	165	0.16	0.05	0.0014	1.1E-05	8.0E-03	85000	0.00019	1.3	0.008	57
MO - Oper B	7	5	2	0	0.11	0.06	0.0016	1.1E-05	6.6E-03	2700	0.00005	0.3	0.013	77
MO - Oper C	22	1	21	0	0.23	0.01	0.0003	6.3E-07	2.3E-03	7100	0.00000	0.0	0.048	237

Memo:
- o Adequate surface casing is set below base of lowest USDW. Short surface casing is set above base of lowest USDW.
- o Tubing and production casing leaks per well-year are based on data supplied by four operators.
- o Surface casing leaks per well-year are calculated based on operator supplied production casing leak data adjusted for resistivity and temperature of the waters opposite the production casing leak zone and the USDW zone.
- o Probability of simultaneous tubing, production casing and surface casing leaks permitting injection water to reach a USDW does not consider the effects of low injection formation pressures, intervening aquifers and permeability restrictions in the borehole.
- o For procedure used in calculating leak probabilities, see API study "Oil and Gas Industry Water Injection Well Corrosion."
- o Calculation of total bbl leaking in a year assumes monthly monitoring of casing/tubing annulus pressure.

Table 10

Relationship Between Bottom of Surface Casing And Base of Lowest USDW for Active SWD and Water Injection Wells in the Williston Basin

	Montana	North Dakota	South Dakota	Total Basin
SWD Wells				
Short Surface Casing	36	113	0	149
Adequate Surface Casing	54	139	7	200
With No USDWs	6	0	0	6
Total SWD Wells	96	252	7	355
Water Injection Wells				
Short Surface Casing	24	68	0	92
Adequate Surface Casing	18	90	5	113
With No USDWs	159	12	0	171
Total WI Wells	201	170	5	376
Total SWD and WI Wells				
Short Surface Casing	60	181	0	241
Adequate Surface Casing	72	229	12	313
With No USDWs	165	12	0	177
Total SWD and WI Wells	297	422	12	731

Memo: Short surface casing does not cover the base of the lowest USDW.

Adequate surface casing covers the base of the lowest USDW.

The 177 wells with no USDWs are located along the Cedar Creek anticline in Montana and North Dakota.

Casing Leak History from Operator B - Montana

Casing Leak History from Operator B for SWD/WI Wells in Montana
Sorted on Well Name/Repair Date   Based on Leak Data for Active Wells Only (7 Total)

File #	Well Name	Operator	Field	Type	Stat	S Csg Size	S Csg Dpth	Fail Cau	Frm Zone	Intervening Aquifer	USDW Aquifer: Frm Zone	USDW Aquifer: Dpth Top	USDW Aquifer: Dpth Btm	Leak Dpth Related To Intervening Aquifer: Deeper	In Aquifer	Shallower	No Report	Leaks Thru This Record	Rpr Date
MTS2000-1469	"G" NCT -4- 1 NPRR	B	DEER CREEK	SWD	ACT	13-3/8	343	0	SWI	No Intervening Aquifer	FH	1	200			6600		1	10/01/53
MTS2000-1469	"G" NCT -4- 1 NPRR	B	DEER CREEK	SWD	ACT	13-3/8	343	0	SWI	No Intervening Aquifer	FH	1	200			3439		2	06/01/62
MTS2000-1469	"G" NCT -4- 1 NPRR	B	DEER CREEK	SWD	ACT	13-3/8	343	0	SWI	No Intervening Aquifer	FH	1	200			1186		3	04/01/83
MTS2000-1469	"G" NCT -4- 1 NPRR	B	DEER CREEK	SWD	ACT	13-3/8	343	0	SWI	No Intervening Aquifer	FH	1	200			3488		4	04/01/83
MTS2333-0193	NP "G" #1	B	SAND CREEK	SWD	ACT	10-3/4	521	0	SWI	Intervening Aquifer: Frm Zone: DAK, Dpth Top: 4500, Dpth Btm: 4700	FH	500	600	4754				5	04/01/86
MTS2000-1501	NP"G"(NCT-12)NO.1	B	WOODROW	SWD	ACT	10-3/4	383	C	DAK	No Intervening Aquifer	FH	500	600			1000		6	01/01/76
MTS2117-0422	STATE "D" #3	B	GLENDIVE	SWD	ACT	13-3/8	323	0	SWI	No Intervening Aquifer	ALL	1	100			6964		7	05/01/73
MTS2184-0194	STATE D-1	B	GLENDIVE	SWD	ACT	13-3/8	312	0	SWI	No Intervening Aquifer	ALL	1	100			351		8	12/01/63
MTS2184-0194	STATE D-1	B	GLENDIVE	SWD	ACT	13-3/8	312	0	SWI	No Intervening Aquifer	ALL	1	100			1600		9	01/01/65

Leak Depths In Relation To Intervening Aquifers

	Number of Leaks	Average Depth
Deeper	1	4754
Within	0	
Shallower	8	3079
Depth Not Reported	0	
Total	9	3265

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Appendix A
Geologic Description Of The Williston Basin

Appendix A
Geologic Description Of The Williston Basin

A-1.0 Description Of The Williston Basin

The Williston basin is a large roughly elliptical downwarp in the earth's crust that covers 200,000 square miles in northwestern South Dakota, western North Dakota, northeastern Montana, southern Saskatchewan and the southwestern corner of Manitoba. This geologic description is confined to the U.S. portion of the basin.

The basin is a typical sedimentary basin which has sagged intermittently to permit an unusual thickness of sedimentary soils. The deepest part of the basin is located in northwestern North Dakota where more than 15,000 ft of sedimentary rock overlies the Precambrian basement.[3] Glacier advancement during the Quaternary period left up to 1,000 ft of glacial drift which extends to the vicinity north and east of the Missouri river in the central part of the basin.

The basin is essentially an oil producing province, with major production occurring from carbonate rock reservoirs of the Mississippian, Devonian, Silurian and Ordovician periods. Oil producing depths range from 3,000 to 13,000 ft.

Gas was discovered in the basin in 1913 along the Cedar Creek anticline in eastern Montana. Oil was discovered in 1951 along the Nesson anticline in North Dakota.

A total of 25,000 wells have been drilled in the basin. Currently, 5,400 oil and gas wells are producing 160,000 BOPD and 210 million ft^3/D. Essentially all the gas is produced in association with the oil.

Water injection averages 469,000 B/D into 355 SWD wells and 376 water injection wells. The basin also contains eight gas injection wells that are involved in gas pressure maintenance projects and 30 air injection wells that are used in an in-situ combustion project.

A-2.0 Williston Basin Geology

A description of geology for each Williston basin state is presented below.

A-2.1 Montana Geology

A-2.1.1 General

As shown in Figure A-1, the Montana portion of the Williston basin includes the northeastern corner of the state. This area contains 1,500 oil and gas wells which produce 47,000 BOPD and 26 million ft^3/D. Water injection averages 177,000 B/D into 96 SWD wells and 201 water injection wells.

A-2.1.2 Montana Stratigraphy

A generalized stratigraphic correlation chart[11] for the Williston basin portion of Montana is shown on Figure A-2. A description of stratigraphic units that pertain to this study is presented below.

A-2.1.3 Montana USDWs

Drinking water supply wells include wells completed in:

- o Alluvial deposits along rivers and streams,
- o Fort Union and Lance Creek formations which occur as low yield localized aquifers in the basin, and
- o Upper Cretaceous Hell Creek and Fox Hills formations.

The Hell Creek and Fox Hills are major aquifers which supply drinking water throughout eastern Montana except in areas along the crest of the Cedar Creek anticline, as discussed below. The Fox Hills conformably overlies the Bearpaw formation which is a thick (up to 1,500 ft), relatively impermeable shale. The Bearpaw is identified as the Pierre formation in North Dakota and South Dakota.

USDWs below the Bearpaw are erratic in their occurrence, with the Judith River and Eagle formations being used for domestic water supplies in a few areas of the basin, while in other areas they have greater than 10,000 mg/l TDS.

The Lower Cretaceous Dakota formation is an extensive aquifer that underlies essentially all of the Williston basin. In Montana, the Dakota occurs at depths from 3,000 to 6,000 ft and has a thickness of up to 450 ft. The Dakota is used as disposal zone in 69 of the 96 SWD wells. The Dakota formation water TDS normally exceeds 10,000 mg/l; however, there are areas where lower TDS occur.

A-2.1.4 Montana Oil And Gas Production

Oil production for the Montana portion of the basin is largely from carbonate rock reservoirs of the Mississippian, Devonian, Silurian and Ordovician periods which range in depth from 5,000 to 13,000 ft. Many of the Silurian and Ordovician reservoirs are undergoing waterflood operations to increase ultimate recovery.

Gas reservoirs are limited to a few fields completed in the Upper Cretaceous Judith River and Eagle formations.

A-2.1.5 Cedar Creek Anticline Of Montana, North Dakota And South Dakota

A major structure in the Williston basin is the Cedar Creek anticline which extends in a remarkably straight line from northwestern South Dakota, across the southwestern corner of North Dakota and into Montana in a northwesterly direction for over 100 miles to near the town of Glendive, Montana[3] (Figure A-1).

Oil production from this sharp upfold is from 11 fields which produce 21,000 BOPD from carbonate rocks of the Ordovician, Silurian, Devonian and Mississippian periods. Waterflood operations to increase ultimate oil recovery are being carried out by 193 water injection wells which inject 86,000 BWPD into the Interlake, Stony Mountain and Red River formations. A total of 10 SWD wells are disposing of 6,000 BWPD into the Judith River, Dakota, Swift, Minnelusa, Mission Canyon and Red River formations.

As discussed under Section A-2.3.5, an in-situ combustion project is being carried out in the Red River formation in the South Dakota portion of the anticline.

A unique feature of the injection wells along the crest of the Montana and North Dakota portions of the Cedar Creek anticline is that they do not have a USDW present. Along the crest of the anticline the Bearpaw (or the Pierre in North Dakota) is exposed at the surface. The shallower Fox Hills, Hell Creek and Fort Union formations are exposed at the surface along the eastern and western flanks of the anticline.[12] Of the 195 SWD and water injection wells on the Montana and North Dakota portions of Cedar Creek anticline, 177 do not have a USDW formation and 17 have surface casing set below the base of the USDWs (see Table 9 for data on operator A in Montana and operator D in North Dakota).

A-2.1.6 Montana Salt Formations

The Montana portion of the Williston basin has several areas, including the Cedar Creek anticline fields, that contain large salt intervals in the Spearfish, Opeche and Charles formations. These salts occur at depths from 4,000 to 9,000 ft and have thicknesses of up to 500 ft.

Completing wells which penetrate massive salt formations has caused problems in obtaining cement placement across the salt intervals. The poor cement coverage coupled with the high plasticity of the salt causes it to flow which can result in non-uniform loading on the casing string and subsequent casing collapse.[13]

A-2.1.7 Montana Corrosive Formations

In terms of potential external casing corrosion, the main corrosive zone in the Montana portion of the Williston basin is the Dakota formation.

Note:

Casing leak data from five Montana operators showed that, of the 111 casing leaks for which the leak depth was recorded, none occurred opposite the Dakota formation. This shows that the practices of placing cement across the Dakota and installing cathodic protection on the wells has controlled the Dakota casing corrosion.

A-2.1.8 Montana Intervening Salt Water Aquifers

As discussed in Section 3.5.4, an intervening salt water aquifer is a major aquifer that lies between a USDW and the point of a potential hole in the casing from which injection water might escape from the wellbore in the unlikely event that simultaneous tubing and casing leaks go undetected.

The Dakota formation is the main intervening salt water aquifer that has the potential for intercepting a majority of the water that escapes the wellbore below the Dakota and travels up the borehole towards a USDW.

A-2.2 North Dakota Geology

A-2.2.1 General

All of North Dakota's oil production is from the Williston basin which covers 50,000 square miles in the western half of the state (Figure A-3). The area contains 3,600 oil wells which produce 108,000 BOPD. Gas production of 176 million ft^3/D is largely produced in association with the oil production. Water injection averages 287,000 B/D into 252 SWD wells and 170 water injection wells.

A-2.2.2 North Dakota Stratigraphy

A generalized stratigraphic correlation chart[14] of the North Dakota portion of the Williston basin is shown in Figure A-4. A discussion of the stratigraphic sections that are pertinent to this study is presented below.

A-2.2.3 North Dakota USDWs

The Missouri river and shallow aquifers with high quality water supply all of North Dakota's drinking water needs. Stratigraphic units that are considered USDWs[14] are:

- o Alluvial deposits along rivers and streams,
- o Sands and gravel of glacial drift in the northern half of the state,
- o Sandstones and lignites in the Fort Union group, and
- o Sands in the Hell Creek and Fox Hills formations.

Note:

The Dakota aquifer (consisting of the Newcastle and Inyan Kara formations of the Dakota group) contains greater than 10,000 mg/l TDS in the western two-thirds of the producing area shown on Figure A-3. In the eastern one-third of the producing area, the Dakota is an exempted aquifer because it is not now used nor is ever likely to be used in the future as a source of drinking water.[14]

A-2.2.4 North Dakota Oil And Gas Production

Oil production for the North Dakota portion of the basin is largely from carbonate rock formations of the Mississippian, Devonian, Silurian and Ordovician periods. Most of the waterflood operations to increase ultimate oil recovery are underway in Mississippian reservoirs.

Gas reservoirs are limited to the Eagle formation and formations of the Ordovician period.

A-2.2.5 Nesson Anticline

As shown in Figure A-3, the Nesson anticline is the most prominent upfold in the North Dakota part of the Williston basin. It has a north-south trend that extends for more than 100 miles. Most of the reservoirs along the upfold are carbonate rocks of the Mississippian period which are undergoing water flood operations to increase ultimate oil recovery. Fields located on the anticline account for about one-fifth of North Dakota's oil production.

A-2.2.6 North Dakota Salt Formations

Several areas in western North Dakota, including fields located along the Nesson anticline, encounter massive salt sections in the Spearfish, Opeche and Charles formations. These salt sections range in depths from 4,000 to 9,000 ft and have thicknesses of up to 500 ft.[13] Because of difficulties associated with obtaining a good cement bond across the salt sections, the salt tends to flow. Where cement does not adequately cover the casing, salt movement results in nonuniform loading of the casing which often results in casing collapse.

A-2.2.7 North Dakota Corrosive Formations

The major formation for potential external casing corrosion is the Dakota which occurs at depths of 2,000 to 6,000 ft.

Note:
Regulatory requirements to add cement across the Dakota coupled with widespread operator application of well cathodic protection have controlled the potentially corrosive Dakota to the extent that only 3% of the casing leaks now occur opposite the Dakota.

A-2.2.8 North Dakota Intervening Salt Water Aquifers

In North Dakota, the Dakota formation is the main intervening aquifer that has the potential of intercepting a major portion of any water that escapes the wellbore below the Dakota and travels up the borehole toward a USDW.

A-2.3 South Dakota Geology

A-2.3.1 General

As shown in Figure A-5, the South Dakota portion of the Williston basin includes the northwestern corner of the state. This area contains 140 oil wells which produce 4,000 BOPD. Gas production of 12 million ft^3/D is largely produced in association with the oil production. Water injection averages 5,000 B/D into seven SWD wells and five water injection wells.

A-2.3.2 South Dakota Stratigraphy

A generalized stratigraphic correlation chart is shown in Figure A-4. Stratigraphic details pertaining to this study are presented below.

A-2.3.3 South Dakota USDWs

USDWs in the South Dakota portion of the Williston basin consist of alluvial aquifers found along major streams, thin beds of lignite in the Fort Union and Hell Creek formations and the sandstones of the Fox Hills formation.[15]

Note:
The Dakota-Newcastle aquifer, which is a major source of drinking water in the state, either is not present or is a silty shale which is nonwater bearing in most of the Williston basin.[16]

A-2.3.4 South Dakota Oil And Gas Production

Oil production from the South Dakota portion of the Williston basin is largely from carbonate rocks of the Red River formation (Ordovician) which occur at a depth of 8,600 ft.

The two gas fields in the basin produce 2 million ft^3/D from the reservoirs of the Tertiary period that are found at a depth of 1,500 ft.

A-2.3.5 Buffalo Field

The Buffalo field is the largest field in South Dakota, with 98 oil wells producing 3,100 BOPD and 10 million ft^3/D. The field is located on the Cedar Creek anticline near its southern terminus in the northwest corner of the state.[3] Production is from the Red River carbonate rocks which occur at a depth of 8,600 ft.

The Buffalo field is unique in that it has an in-situ combustion project in the Red River formation, which makes it one of the deepest firefloods of a carbonate reservoir in the world. Oxygen to support the combustion for this additional recovery project is supplied by 30 air injection wells.

A-2.3.6 South Dakota Salt Formations

Massive salt sections have been identified as a problem in the Pine salt member of the Spearfish formation of the South Dakota portion of the Williston basin.

A-2.3.7 South Dakota Corrosive Formations

The Dakota and Pierre formations have been identified as formations that have the greatest potential for external casing corrosion.

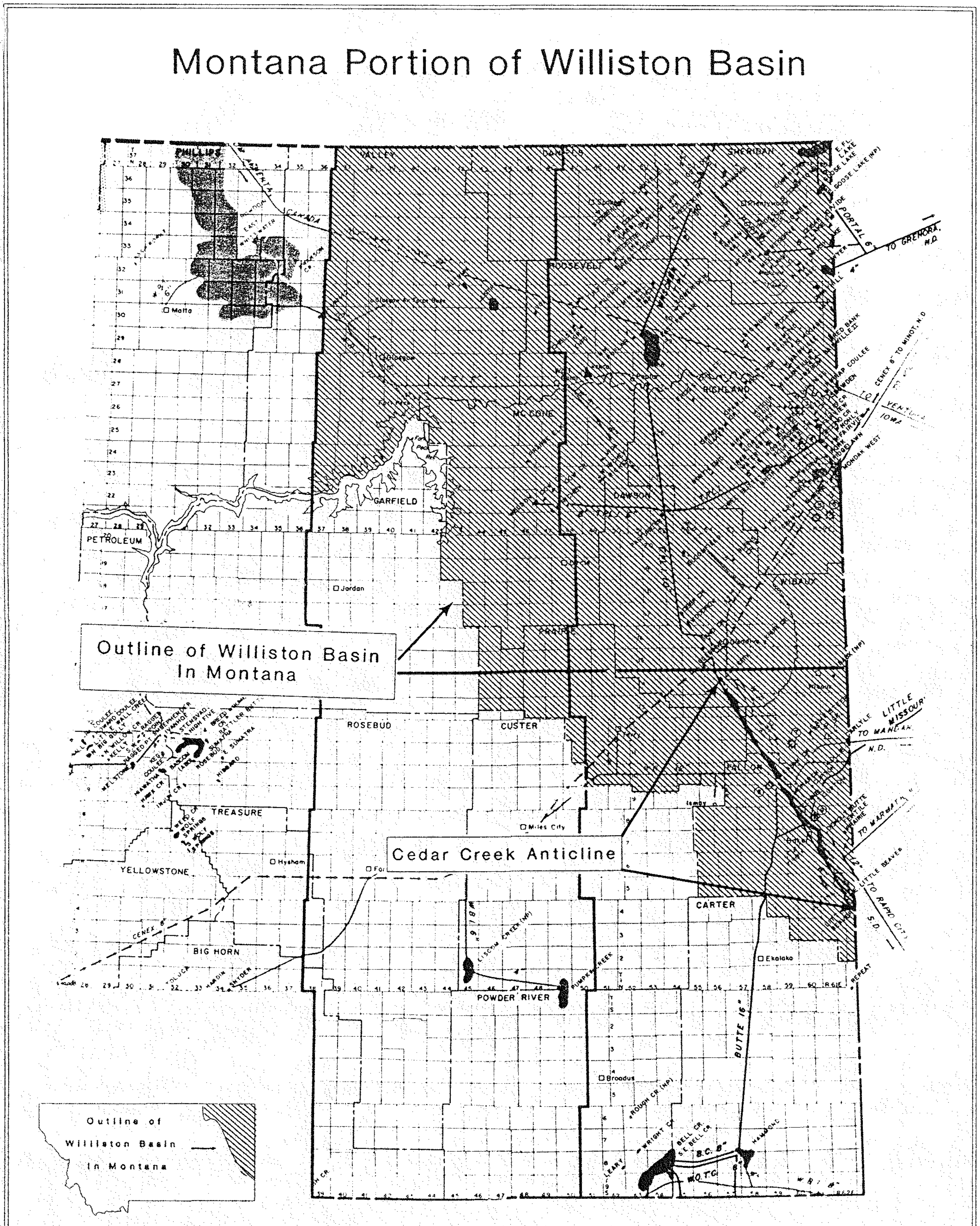
Note:

There were no casing leaks reported in the South Dakota operator survey, indicating the corrosion potential of the Dakota and Pierre is under control.

A-2.3.8 South Dakota Intervening Salt Water Aquifers

Where it lies between a USDW and a point where injection water may escape the wellbore, the Dakota formation provides an intervening aquifer which has the potential of intercepting a major portion of the escaping water before it reaches a USDW.

Figure A-1


Montana Portion of Williston Basin
Outline of Williston Basin In Montana
Cedar Creek Anticline
PHILLIPS
VALLEY
DANIELS
SHERIDAN
ROOSEVELT
RICHLAND
MC CONE
GARFIELD
DAWSON
PETROLEUM
PRAIRIE
WIBAUX
ROSEBUD
CUSTER
FALLON
TREASURE
YELLOWSTONE
CARTER
BIG HORN
POWDER RIVER
Jordan
Miles City
Ekalaka
Broodus
TO GRENORA, N.D.
TO RAPID CITY S.D.
Outline of Williston Basin In Montana

Generalized Stratigraphic Correlation Chart of Montana Portion of Williston Basin

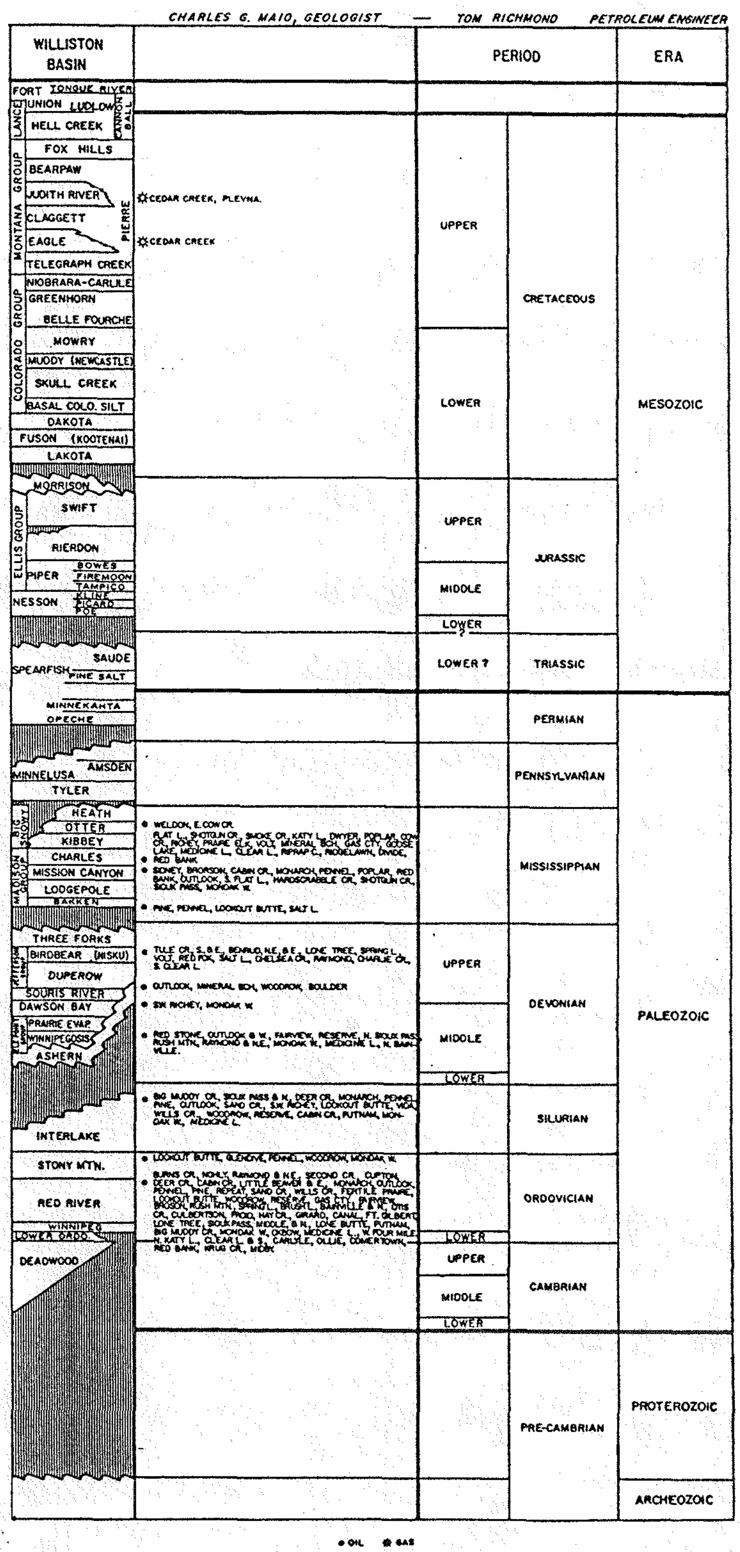
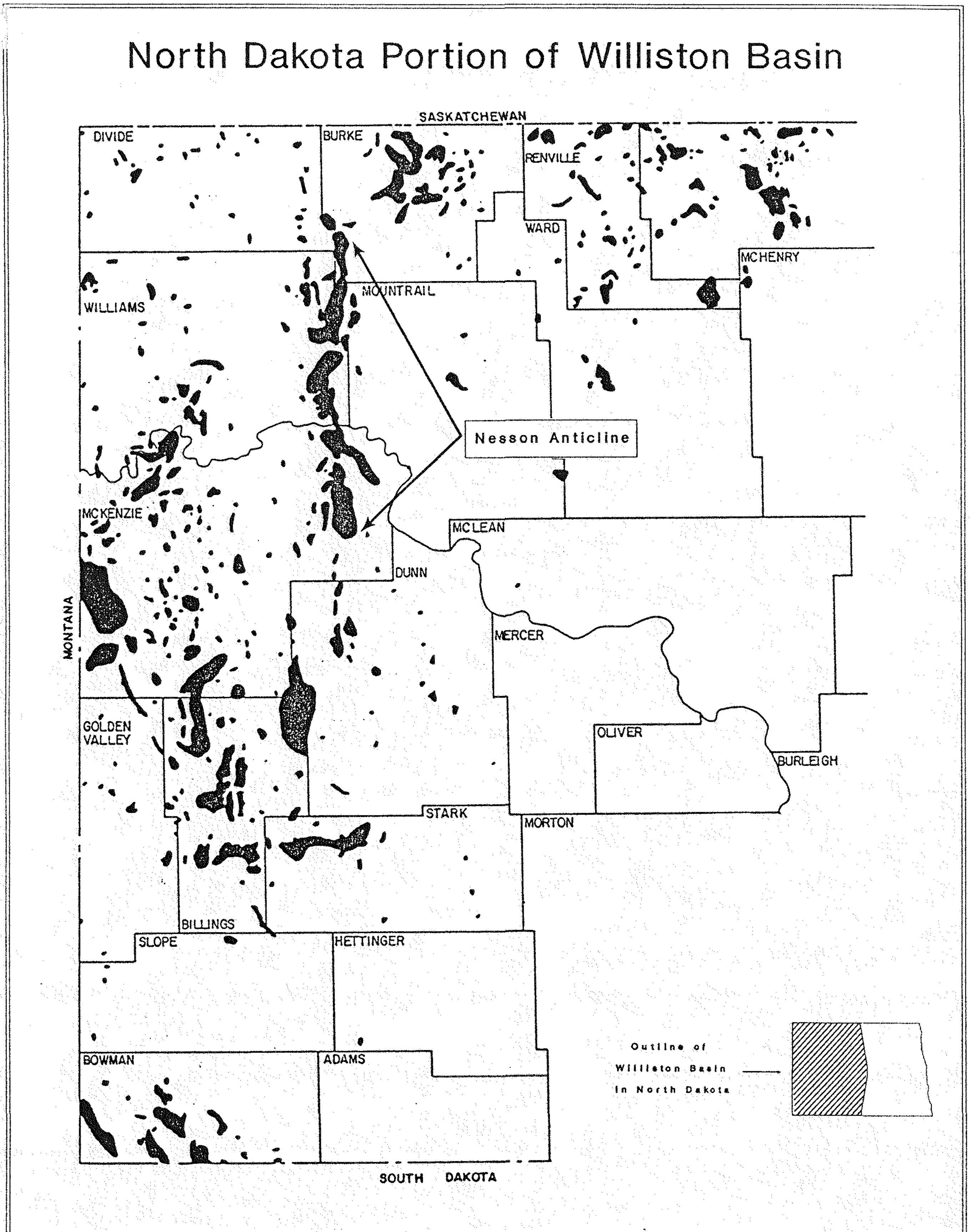


Figure A-3



North Dakota Portion of Williston Basin
SASKATCHEWAN
DIVIDE
BURKE
RENVILLE
WARD
MCHENRY
WILLIAMS
MOUNTRAIL
Nesson Anticline
MCKENZIE
MCLEAN
DUNN
MONTANA
MERCER
GOLDEN VALLEY
OLIVER
BURLEIGH
STARK
MORTON
BILLINGS
SLOPE
HETTINGER
BOWMAN
ADAMS
SOUTH DAKOTA
Outline of Williston Basin in North Dakota

Generalized Stratigraphic Correlation Chart of North Dakota and South Dakota Portions Of Williston Basin

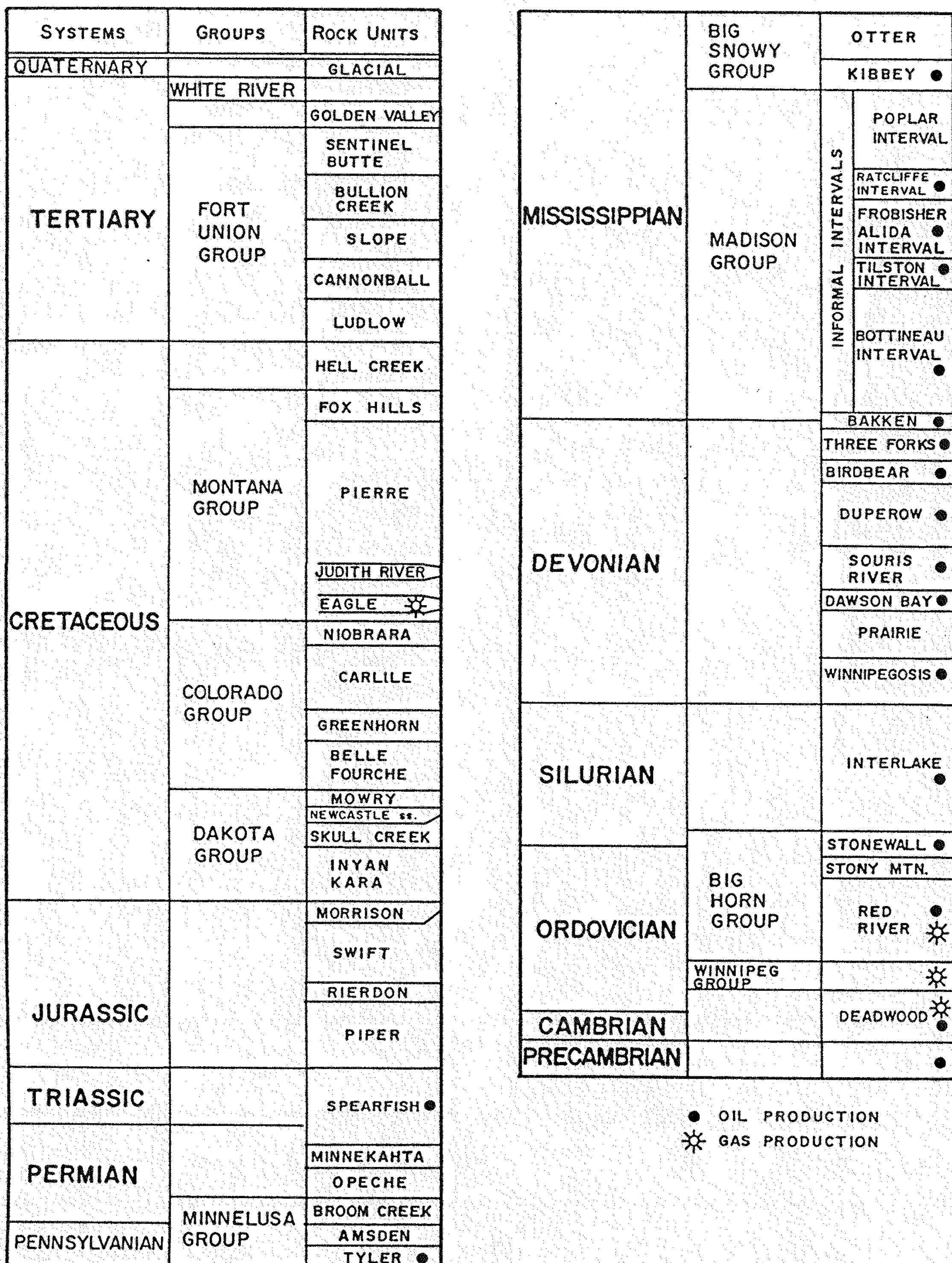
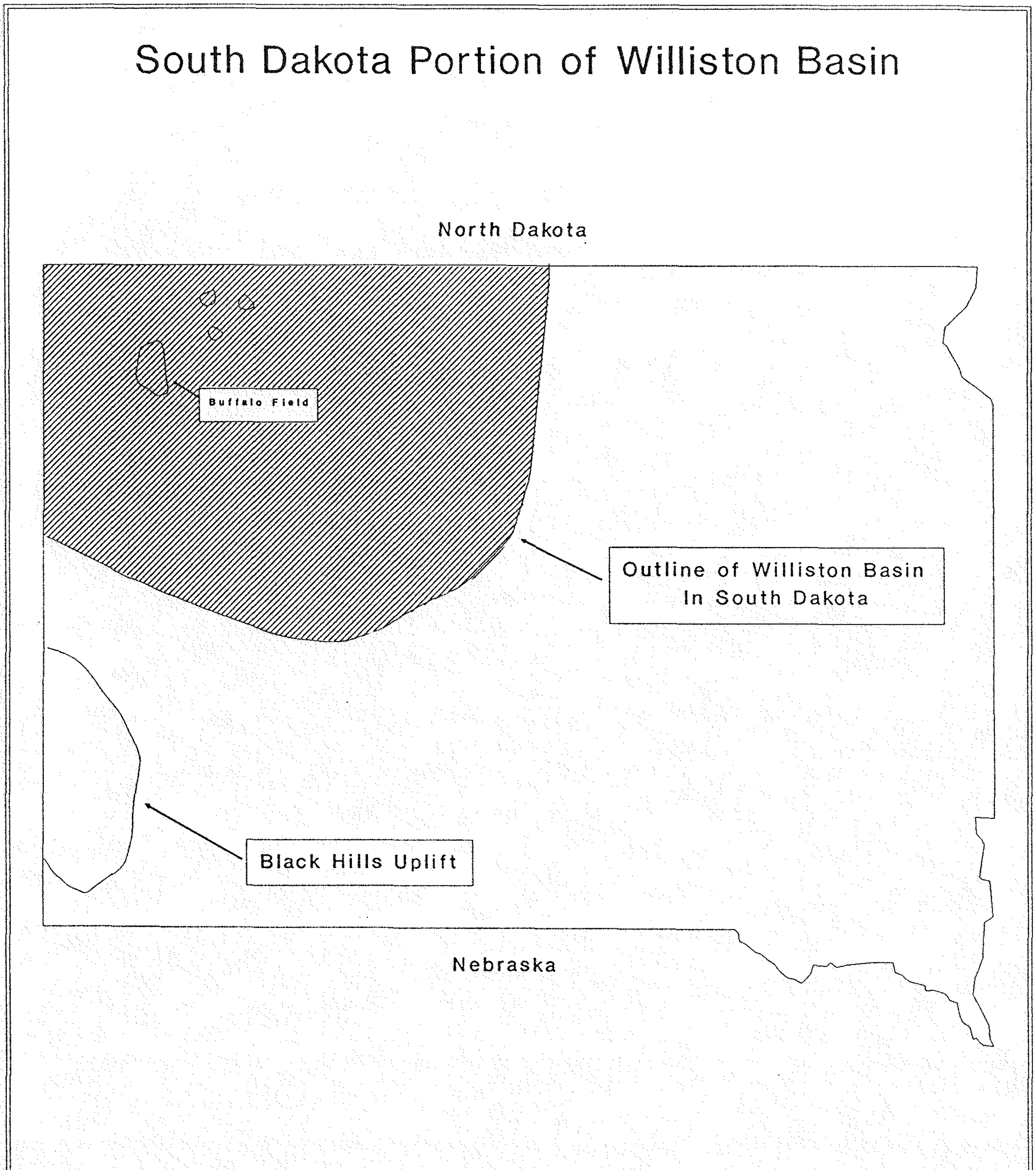


Figure A-5


South Dakota Portion of Williston Basin
North Dakota
Buffalo Field
Outline of Williston Basin
In South Dakota
Black Hills Uplift
Nebraska

Appendix B
Software Applications For Database Construction

Appendix B
Software Applications For Database Construction

B-1.0 Purpose Of Appendix B

The purpose of Appendix B is to provide the reader with information relating to selected software applications that were found useful in constructing the Williston Basin study data base.

B-2.0 Background

The Williston Basin study data base was constructed using an 80386 microprocessor with a 150 megabyte hard disk, 2 megabytes of RAM and a VGA color monitor. The printer used during database construction was a laser jet.

Note:
Although the 150 megabyte hard disk was larger than needed to design, build and load the Williston Basin study data base, (the completed data base and program files used less than 10 megabytes of disk storage), the speed of the 80386 microprocessor was very helpful in loading data, checking for errors, preparing reports and performing the other tasks associated with building the data base.

The laser jet printer was also helpful in handling the large volume of printing required during the database loading and error checking activities.

The software packages used in the Williston Basin study were dBase IV™ (dBase) by Ashton-Tate Corporation to build the data base and R&R Report Writer™ (R&R) by Concentration Data Systems, Inc. to conduct queries and generate reports from the database files.

This mix of commercial computer hardware and software products proved to be a good combination for building the data base.

B-3.0 Checking Input Data For Errors

As pointed out in Section 2.6.9, 80% of the data entered into the data base was from paper records. In addition to the large number of keystrokes required to enter the data into the data base, considerable time was required to verify that the information was entered correctly and to verify that information from two or more data sources was in agreement.

One error checking scheme that proved useful was the R&R report shown on Figure B-1. This sample report compares API numbers, well statuses and well names from the North Dakota master file and the MIT file. The program compares the two data fields for each of the selected variable for each well in the data base. If two records are not identical, the report prints out "PROBLEM," as shown by the fields opposite the arrows.

The linking field for this example was file number; however, any unique field that is common to both files may be used as the linking field.

B-4.0 Data Entry Screens

Because of the large volume of information that had to be entered through the keyboard, extensive use was made of data entry screens such as shown in Figure B-2.

The advantages of entering data using the screen format compared to entering the data directly into a dBase file are:

- o Fixed format reduces operator entry errors,
- o Data screens have error checking capabilities (such as not accepting alpha characters in a numeric field), and
- o Data entry is faster using the entry screens.

As shown in Figure B-2, if December 1988 injection monitoring data is to be entered into a monitoring file that contains an injection record for each of the previous 11 months in 1988, the screen can be formatted so the keypunch operator is not concerned with the injection data for the other 11 months in 1988. The advantage of focusing on the data to be entered, rather than on all the data in a database record, reduces errors and speeds the data entry process.

B-5.0 Use Of Flat Files During Database Construction

In constructing the Williston Basin study data base, it was found that it was useful to first construct a working flat file for each well. This flat file contained all of the unique and the variable information associated with each well. After all the database information was loaded into the individual well flat files and its accuracy verified, the information was then transferred using software programs to the various relational data files.

It was found that the use of flat files greatly reduced the time in checking errors. The flat file also facilitated correcting an individual well record in the event incorrect information was entered into the data base.

An example of a flat file is MOMON_2.DBF (Figure B-3), which is the file structure that stores Montana injection monitoring data for one year for one well on a single data record. Of the 77 data fields in the flat file, 16 are used to identify the well and to list its unique features. One field is used to identify the year. The other 60 fields consist of five fields repeated 12 times for each month in the year.

After the flat file is loaded with the injection information and its accuracy has been verified, the data is transferred to MOMONTR2.DBF (Figure B-4) which is the relational data file used to store injection monitoring data for one month for one well on a single data record. This is accomplished by taking one record from the flat file, which contains 12 months of data, and transferring it to an empty relational file as 12 separate records (one record for each month). As shown on Figures B-3 and B-4, the number of data records increased from 283 to 3,396 when the data base was unflattened.

The software program to translate the 283 records from the flat file into 3,396 records in the relational file is presented in Table B-1. The time required for the 80386 computer to restructure the records was approximately five minutes.

Figure B-1

Example of an Error Checking Report

Report to Check NDMASTER.DBF and NDMIT.DBF for Differences in
API Well Number, Well Status, and Well Name
Data Files Are Linked and Sorted on File Number

		FILE #	COUNTY-API #	STATUS	WELL NAME
	NDMASTER:	50	105-00013	P&A	BEAVER LODGE-MADISON UNIT #F-2-D
	NDMIT:	50	105-00013	P&A	BEAVER LODGE-MADISON UNIT #F-2-D
	NDMASTER:	62	105-00023	P&A	TIOGA-MADISON UNIT #H-124
	NDMIT:	62	105-00023	P&A	TIOGA-MADISON UNIT #H-124
PROBLEM	NDMASTER:	67	105-00027	TA	BEAVER LODGE-MADISON UNIT #BB-27I ←
	NDMIT:	67	105-00027	TA	BEAVER LODGE #BB-27I
	NDMASTER:	71	105-00031	P&A	BEAVER LODGE-MADISON UNIT #O-12
	NDMIT:	71	105-00031	P&A	BEAVER LODGE-MADISON UNIT #O-12
	NDMASTER:	73	105-00032	P&A	BEAVER LODGE-MADISON UNIT #Z-31-D
	NDMIT:	73	105-00032	P&A	BEAVER LODGE-MADISON UNIT #Z-31-D
	NDMASTER:	88	105-00044	P&A	BEAVER LODGE-MADISON UNIT #R-25
	NDMIT:	88	105-00044	P&A	BEAVER LODGE-MADISON UNIT #R-25
PROBLEM	NDMASTER:	99	061-00001 ←	TA	TIOGA-MADISON UNIT #K-141
	NDMIT:	99	061-85203	TA	TIOGA-MADISON UNIT #K-141
	NDMASTER:	114	105-00060	TA	TIOGA-MADISON UNIT #J-126
	NDMIT:	114	105-00060	TA	TIOGA-MADISON UNIT #J-126
PROBLEM	NDMASTER:	118	105-00063	TA	TIOGA-MADISON UNIT #D-130 ←
	NDMIT:	118	105-00063	TA	TIOGA-MADISON #D-130
	NDMASTER:	121	105-00065	TA	BEAVER LODGE-MADISON UNIT #K-19
	NDMIT:	121	105-00065	TA	BEAVER LODGE-MADISON UNIT #K-19
PROBLEM	NDMASTER:	132	061-00004	P&A ←	TIOGA-MADISON UNIT #M-143
	NDMIT:	132	061-00004	TA	TIOGA-MADISON UNIT #M-143
PROBLEM	NDMASTER:	140	105-00078	TA ←	BEAVER LODGE-MADISON UNIT #N-22
	NDMIT:	140	105-00078	P&A	BEAVER LODGE-MADISON UNIT #N-22

Note: An arrow (←) indicates a data entry error.

Figure B-2

Example of a Screen Format Template

FILE NO XXXXXXXXXXXX

WELL NAME XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

OPERATOR XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

FIELD XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

SEC XX TWNP XXXX RNGE XXXX WELL TYPE XXX STATUS XXX

YEAR 9999

	TBG AVG PSI	TBG MAX PSI	BARRELS	CSG MIN PSI	CSG MAX PSI
DECEMBER	99999	99999	999999	99999	99999

Example of Data Entered Into a Screen Format Template

FILE NO MTS2000-0895

WELL NAME 201

OPERATOR OPERATOR X

FIELD SIDNEY

SEC 09 TWNP 24N RNGE 058E WELL TYPE SWD STATUS ACT

YEAR 1988

	TBG AVG PSI	TBG MAX PSI	BARRELS	CSG MIN PSI	CSG MAX PSI
DECEMBER	965	1120	44576	450	550

Figure B-3
File Structure for a Flat File

Structure for database: D:\WILBASIN\MONTANA\MOSTORE\STORE\MOMON_2.DBF
Number of data records: 283
Date of last update : 09/16/89

Field	Field Name	Type	Width	Dec	Index
1	FILE_NO	Character	12		N
2	COUNTYNAME	Character	20		N
3	OPRCODE	Character	5		N
4	OPRNAME	Character	42		N
5	WELL_NAME	Character	40		N
6	FRM_ZONE	Character	3		N
7	SECTION	Character	2		N
8	TOWNSHIP	Character	4		N
9	RANGE	Character	4		N
10	WELLTYPE	Character	3		N
11	W_STAT	Character	3		N
12	FLDCODE	Character	5		N
13	FLDNAME	Character	32		N
14	STATE	Character	2		N
15	COUNTY	Character	3		N
16	API_WELLNO	Character	5		N
17	YEAR	Numeric	4		N
18	JAN_AVGPSI	Numeric	5		N
19	JAN_MAXPSI	Numeric	5		N
20	JAN_BBL	Numeric	6		N
21	JAN_CSGMIN	Numeric	5		N
22	JAN_CSGMAX	Numeric	5		N
23	FEB_AVGPSI	Numeric	5		N
24	FEB_MAXPSI	Numeric	5		N
25	FEB_BBL	Numeric	6		N
26	FEB_CSGMIN	Numeric	5		N
27	FEB_CSGMAX	Numeric	5		N
28	MAR_AVGPSI	Numeric	5		N
29	MAR_MAXPSI	Numeric	5		N
30	MAR_BBL	Numeric	6		N
31	MAR_CSGMIN	Numeric	5		N
32	MAR_CSGMAX	Numeric	5		N
33	APR_AVGPSI	Numeric	5		N
34	APR_MAXPSI	Numeric	5		N
35	APR_BBL	Numeric	6		N
36	APR_CSGMIN	Numeric	5		N
37	APR_CSGMAX	Numeric	5		N
38	MAY_AVGPSI	Numeric	5		N
39	MAY_MAXPSI	Numeric	5		N
40	MAY_BBL	Numeric	6		N
41	MAY_CSGMIN	Numeric	5		N
42	MAY_CSGMAX	Numeric	5		N
43	JUN_AVGPSI	Numeric	5		N
44	JUN_MAXPSI	Numeric	5		N
45	JUN_BBL	Numeric	6		N
46	JUN_CSGMIN	Numeric	5		N
47	JUN_CSGMAX	Numeric	5		N
48	JUL_AVGPSI	Numeric	5		N
49	JUL_MAXPSI	Numeric	5		N
50	JUL_BBL	Numeric	6		N
51	JUL_CSGMIN	Numeric	5		N
52	JUL_CSGMAX	Numeric	5		N
53	AUG_AVGPSI	Numeric	5		N
54	AUG_MAXPSI	Numeric	5		N
55	AUG_BBL	Numeric	6		N

56	AUG_CSGMIN	Numeric	5	N
57	AUG_CSGMAX	Numeric	5	N
58	SEP_AVGPSI	Numeric	5	N
59	SEP_MAXPSI	Numeric	5	N
60	SEP_BBL	Numeric	6	N
61	SEP_CSGMIN	Numeric	5	N
62	SEP_CSGMAX	Numeric	5	N
63	OCT_AVGPSI	Numeric	5	N
64	OCT_MAXPSI	Numeric	5	N
65	OCT_BBL	Numeric	6	N
66	OCT_CSGMIN	Numeric	5	N
67	OCT_CSGMAX	Numeric	5	N
68	NOV_AVGPSI	Numeric	5	N
69	NOV_MAXPSI	Numeric	5	N
70	NOV_BBL	Numeric	6	N
71	NOV_CSGMIN	Numeric	5	N
72	NOV_CSGMAX	Numeric	5	N
73	DEC_AVGPSI	Numeric	5	N
74	DEC_MAXPSI	Numeric	5	N
75	DEC_BBL	Numeric	6	N
76	DEC_CSGMIN	Numeric	5	N
77	DEC_CSGMAX	Numeric	5	N
** Total **			502	

Figure B-4
File Structure for a Relational File

Structure for database: D:\WILBASIN\MONTANA\MOSTORE\STORE\MOMONTR2.DBF
Number of data records: 3396
Date of last update : 10/07/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FILE_NO	Character	12		N
5	FRM_ZONE	Character	3		N
6	WELLZONE	Character	6		N
7	WELL_NAME	Character	40		N
8	WELLTYPE	Character	3		N
9	W_STAT	Character	3		N
10	FLDNAME	Character	32		N
11	OPRNAME	Character	42		N
12	MONTH	Character	2		N
13	YEAR	Character	4		N
14	TBGPSI_AVG	Numeric	5		N
15	TBGPSI_MAX	Numeric	5		N
16	TBGPSI_PRM	Numeric	5		N
17	INJ_BBL_MO	Numeric	6		N
18	INJ_MCF_MO	Numeric	9		N
19	CSGPSI_MIN	Numeric	5		N
20	CSGPSI_MAX	Numeric	5		N
21	MON_FREQ	Character	1		N
22	WITNESSED	Character	1		N
** Total **			200		

Table B-1

Program to Transfer Data From a Flat File to a Relational File

```
** Program name is MOMON_2.PRG
** A program module to move data from MOMON_2.dbf into MOMONTR2.dbf
**      (MOMON_2.dbf is a "flat" file, whereas MOMONTR2.dbf will have
**      one record for each month)
** Created 10-07-89 by Mark A. Hebert based on an orginal concept
**      developed by B. H. Roark
** To edit program, highlight program in Pathminder and press E for EDIT
** To save program after editing, press ESC, then Q for QUIT, then U
**      for UPDATE

** To run program, enter DO MOMON_2 at dot prompt


CLOSE DATABASES

CLEAR

SET TALK OFF

SELECT A
USE MOMON_2

SELECT B
USE MOMONTR2

SELECT A

DO WHILE .NOT. EOF()

@ 12,20 say "Now replacing record # "
@ 12,43 say recno()

SELECT B
APPEND BLANK

        REPLACE B->STATE WITH A->STATE
        REPLACE B->COUNTY WITH A->COUNTY
        REPLACE B->API_WELLNO WITH A->API_WELLNO
        REPLACE B->FILE_NO WITH A->FILE_NO
        REPLACE B->FRM_ZONE WITH A->FRM_ZONE
        REPLACE B->WELL_NAME WITH A->WELL_NAME
        REPLACE B->WELLTYPE WITH A->WELLTYPE
        REPLACE B->W_STAT WITH A->W_STAT
        REPLACE B->FLDNAME WITH A->FLDNAME
        REPLACE B->OPRNAME WITH A->OPRNAME

        REPLACE B->MONTH WITH "01"
        REPLACE B->YEAR WITH A->YEAR
        REPLACE B->TBGPSI_AVG WITH A->JAN_AVGPSI
        REPLACE B->TBGPSI_MAX WITH A->JAN_MAXPSI
```

```
REPLACE B->INJ_BBL_MO WITH A->JAN_BBL
REPLACE B->CSGPSI_MIN WITH A->JAN_CSGMIN
REPLACE B->CSGPSI_MAX WITH A->JAN_CSGMAX

APPEND BLANK

REPLACE B->STATE WITH A->STATE
REPLACE B->COUNTY WITH A->COUNTY
REPLACE B->API_WELLNO WITH A->API_WELLNO
REPLACE B->FILE_NO WITH A->FILE_NO
REPLACE B->FRM_ZONE WITH A->FRM_ZONE
REPLACE B->WELL_NAME WITH A->WELL_NAME
REPLACE B->WELLTYPE WITH A->WELLTYPE
REPLACE B->W_STAT WITH A->W_STAT
REPLACE B->FLDNAME WITH A->FLDNAME
REPLACE B->OPRNAME WITH A->OPRNAME

REPLACE B->MONTH WITH "02"
REPLACE B->YEAR WITH A->YEAR
REPLACE B->TBGPSI_AVG WITH A->FEB_AVGPSI
REPLACE B->TBGPSI_MAX WITH A->FEB_MAXPSI
REPLACE B->INJ_BBL_MO WITH A->FEB_BBL
REPLACE B->CSGPSI_MIN WITH A->FEB_CSGMIN
REPLACE B->CSGPSI_MAX WITH A->FEB_CSGMAX

APPEND BLANK

REPLACE B->STATE WITH A->STATE
REPLACE B->COUNTY WITH A->COUNTY
REPLACE B->API_WELLNO WITH A->API_WELLNO
REPLACE B->FILE_NO WITH A->FILE_NO
REPLACE B->FRM_ZONE WITH A->FRM_ZONE
REPLACE B->WELL_NAME WITH A->WELL_NAME
REPLACE B->WELLTYPE WITH A->WELLTYPE
REPLACE B->W_STAT WITH A->W_STAT
REPLACE B->FLDNAME WITH A->FLDNAME
REPLACE B->OPRNAME WITH A->OPRNAME

REPLACE B->MONTH WITH "03"
REPLACE B->YEAR WITH A->YEAR
REPLACE B->TBGPSI_AVG WITH A->MAR_AVGPSI
REPLACE B->TBGPSI_MAX WITH A->MAR_MAXPSI
REPLACE B->INJ_BBL_MO WITH A->MAR_BBL
REPLACE B->CSGPSI_MIN WITH A->MAR_CSGMIN
REPLACE B->CSGPSI_MAX WITH A->MAR_CSGMAX

APPEND BLANK

REPLACE B->STATE WITH A->STATE
REPLACE B->COUNTY WITH A->COUNTY
```

```
REPLACE B->API_WELLNO WITH A->API_WELLNO
REPLACE B->FILE_NO WITH A->FILE_NO
REPLACE B->FRM_ZONE WITH A->FRM_ZONE
REPLACE B->WELL_NAME WITH A->WELL_NAME
REPLACE B->WELLTYPE WITH A->WELLTYPE
REPLACE B->W_STAT WITH A->W_STAT
REPLACE B->FLDNAME WITH A->FLDNAME
REPLACE B->OPRNAME WITH A->OPRNAME

REPLACE B->MONTH WITH "04"
REPLACE B->YEAR WITH A->YEAR
REPLACE B->TBGPSI_AVG WITH A->APR_AVGPSI
REPLACE B->TBGPSI_MAX WITH A->APR_MAXPSI
REPLACE B->INJ_BBL_MO WITH A->APR_BBL
REPLACE B->CSGPSI_MIN WITH A->APR_CSGMIN
REPLACE B->CSGPSI_MAX WITH A->APR_CSGMAX

APPEND BLANK

REPLACE B->STATE WITH A->STATE
REPLACE B->COUNTY WITH A->COUNTY
REPLACE B->API_WELLNO WITH A->API_WELLNO
REPLACE B->FILE_NO WITH A->FILE_NO
REPLACE B->FRM_ZONE WITH A->FRM_ZONE
REPLACE B->WELL_NAME WITH A->WELL_NAME
REPLACE B->WELLTYPE WITH A->WELLTYPE
REPLACE B->W_STAT WITH A->W_STAT
REPLACE B->FLDNAME WITH A->FLDNAME
REPLACE B->OPRNAME WITH A->OPRNAME

REPLACE B->MONTH WITH "05"
REPLACE B->YEAR WITH A->YEAR
REPLACE B->TBGPSI_AVG WITH A->MAY_AVGPSI
REPLACE B->TBGPSI_MAX WITH A->MAY_MAXPSI
REPLACE B->INJ_BBL_MO WITH A->MAY_BBL
REPLACE B->CSGPSI_MIN WITH A->MAY_CSGMIN
REPLACE B->CSGPSI_MAX WITH A->MAY_CSGMAX

APPEND BLANK

REPLACE B->STATE WITH A->STATE
REPLACE B->COUNTY WITH A->COUNTY
REPLACE B->API_WELLNO WITH A->API_WELLNO
REPLACE B->FILE_NO WITH A->FILE_NO
REPLACE B->FRM_ZONE WITH A->FRM_ZONE
REPLACE B->WELL_NAME WITH A->WELL_NAME
REPLACE B->WELLTYPE WITH A->WELLTYPE
REPLACE B->W_STAT WITH A->W_STAT
REPLACE B->FLDNAME WITH A->FLDNAME
REPLACE B->OPRNAME WITH A->OPRNAME
```

```
REPLACE B->MONTH WITH "06"
REPLACE B->YEAR WITH A->YEAR
REPLACE B->TBGPSI_AVG WITH A->JUN_AVGPSI
REPLACE B->TBGPSI_MAX WITH A->JUN_MAXPSI
REPLACE B->INJ_BBL_MO WITH A->JUN_BBL
REPLACE B->CSGPSI_MIN WITH A->JUN_CSGMIN
REPLACE B->CSGPSI_MAX WITH A->JUN_CSGMAX

APPEND BLANK

REPLACE B->STATE WITH A->STATE
REPLACE B->COUNTY WITH A->COUNTY
REPLACE B->API_WELLNO WITH A->API_WELLNO
REPLACE B->FILE_NO WITH A->FILE_NO
REPLACE B->FRM_ZONE WITH A->FRM_ZONE
REPLACE B->WELL_NAME WITH A->WELL_NAME
REPLACE B->WELLTYPE WITH A->WELLTYPE
REPLACE B->W_STAT WITH A->W_STAT
REPLACE B->FLDNAME WITH A->FLDNAME
REPLACE B->OPRNAME WITH A->OPRNAME

REPLACE B->MONTH WITH "07"
REPLACE B->YEAR WITH A->YEAR
REPLACE B->TBGPSI_AVG WITH A->JUL_AVGPSI
REPLACE B->TBGPSI_MAX WITH A->JUL_MAXPSI
REPLACE B->INJ_BBL_MO WITH A->JUL_BBL
REPLACE B->CSGPSI_MIN WITH A->JUL_CSGMIN
REPLACE B->CSGPSI_MAX WITH A->JUL_CSGMAX

APPEND BLANK

REPLACE B->STATE WITH A->STATE
REPLACE B->COUNTY WITH A->COUNTY
REPLACE B->API_WELLNO WITH A->API_WELLNO
REPLACE B->FILE_NO WITH A->FILE_NO
REPLACE B->FRM_ZONE WITH A->FRM_ZONE
REPLACE B->WELL_NAME WITH A->WELL_NAME
REPLACE B->WELLTYPE WITH A->WELLTYPE
REPLACE B->W_STAT WITH A->W_STAT
REPLACE B->FLDNAME WITH A->FLDNAME
REPLACE B->OPRNAME WITH A->OPRNAME

REPLACE B->MONTH WITH "08"
REPLACE B->YEAR WITH A->YEAR
REPLACE B->TBGPSI_AVG WITH A->AUG_AVGPSI
REPLACE B->TBGPSI_MAX WITH A->AUG_MAXPSI
REPLACE B->INJ_BBL_MO WITH A->AUG_BBL
REPLACE B->CSGPSI_MIN WITH A->AUG_CSGMIN
REPLACE B->CSGPSI_MAX WITH A->AUG_CSGMAX
```

```
APPEND BLANK

REPLACE B->STATE WITH A->STATE
REPLACE B->COUNTY WITH A->COUNTY
REPLACE B->API_WELLNO WITH A->API_WELLNO
REPLACE B->FILE_NO WITH A->FILE_NO
REPLACE B->FRM_ZONE WITH A->FRM_ZONE
REPLACE B->WELL_NAME WITH A->WELL_NAME
REPLACE B->WELLTYPE WITH A->WELLTYPE
REPLACE B->W_STAT WITH A->W_STAT
REPLACE B->FLDNAME WITH A->FLDNAME
REPLACE B->OPRNAME WITH A->OPRNAME

REPLACE B->MONTH WITH "09"
REPLACE B->YEAR WITH A->YEAR
REPLACE B->TBGPSI_AVG WITH A->SEP_AVGPSI
REPLACE B->TBGPSI_MAX WITH A->SEP_MAXPSI
REPLACE B->INJ_BBL_MO WITH A->SEP_BBL
REPLACE B->CSGPSI_MIN WITH A->SEP_CSGMIN
REPLACE B->CSGPSI_MAX WITH A->SEP_CSGMAX

APPEND BLANK

REPLACE B->STATE WITH A->STATE
REPLACE B->COUNTY WITH A->COUNTY
REPLACE B->API_WELLNO WITH A->API_WELLNO
REPLACE B->FILE_NO WITH A->FILE_NO
REPLACE B->FRM_ZONE WITH A->FRM_ZONE
REPLACE B->WELL_NAME WITH A->WELL_NAME
REPLACE B->WELLTYPE WITH A->WELLTYPE
REPLACE B->W_STAT WITH A->W_STAT
REPLACE B->FLDNAME WITH A->FLDNAME
REPLACE B->OPRNAME WITH A->OPRNAME

REPLACE B->MONTH WITH "10"
REPLACE B->YEAR WITH A->YEAR
REPLACE B->TBGPSI_AVG WITH A->OCT_AVGPSI
REPLACE B->TBGPSI_MAX WITH A->OCT_MAXPSI
REPLACE B->INJ_BBL_MO WITH A->OCT_BBL
REPLACE B->CSGPSI_MIN WITH A->OCT_CSGMIN
REPLACE B->CSGPSI_MAX WITH A->OCT_CSGMAX

APPEND BLANK

REPLACE B->STATE WITH A->STATE
REPLACE B->COUNTY WITH A->COUNTY
REPLACE B->API_WELLNO WITH A->API_WELLNO
REPLACE B->FILE_NO WITH A->FILE_NO
REPLACE B->FRM_ZONE WITH A->FRM_ZONE
```

```
        REPLACE B->WELL_NAME WITH A->WELL_NAME
        REPLACE B->WELLTYPE WITH A->WELLTYPE
        REPLACE B->W_STAT WITH A->W_STAT
        REPLACE B->FLDNAME WITH A->FLDNAME
        REPLACE B->OPRNAME WITH A->OPRNAME

        REPLACE B->MONTH WITH "11"
        REPLACE B->YEAR WITH A->YEAR
        REPLACE B->TBGPSI_AVG WITH A->NOV_AVGPSI
        REPLACE B->TBGPSI_MAX WITH A->NOV_MAXPSI
        REPLACE B->INJ_BBL_MO WITH A->NOV_BBL
        REPLACE B->CSGPSI_MIN WITH A->NOV_CSGMIN
        REPLACE B->CSGPSI_MAX WITH A->NOV_CSGMAX

        APPEND BLANK

        REPLACE B->STATE WITH A->STATE
        REPLACE B->COUNTY WITH A->COUNTY
        REPLACE B->API_WELLNO WITH A->API_WELLNO
        REPLACE B->FILE_NO WITH A->FILE_NO
        REPLACE B->FRM_ZONE WITH A->FRM_ZONE
        REPLACE B->WELL_NAME WITH A->WELL_NAME
        REPLACE B->WELLTYPE WITH A->WELLTYPE
        REPLACE B->W_STAT WITH A->W_STAT
        REPLACE B->FLDNAME WITH A->FLDNAME
        REPLACE B->OPRNAME WITH A->OPRNAME

        REPLACE B->MONTH WITH "12"
        REPLACE B->YEAR WITH A->YEAR
        REPLACE B->TBGPSI_AVG WITH A->DEC_AVGPSI
        REPLACE B->TBGPSI_MAX WITH A->DEC_MAXPSI
        REPLACE B->INJ_BBL_MO WITH A->DEC_BBL
        REPLACE B->CSGPSI_MIN WITH A->DEC_CSGMIN
        REPLACE B->CSGPSI_MAX WITH A->DEC_CSGMAX

    SELECT A
    SKIP

    ENDDO

    SET TALK ON
```

Appendix C
User Input Screens For Database Queries

Appendix C
User Input Screens For Database Queries

C-1.0 Purpose Of Appendix C

The purpose of Appendix C is to provide the reader with a conceptual understanding how the user input screens were developed and how they are used for querying the Williston basin data base.

C-2.0 Background

The Williston Basin study covers the eastern portion of Montana, western North Dakota and the northwestern corner of South Dakota. The study utilizes identical relational database file structures for each of the three states. The three data bases can be used separately to generate queries, sorts and reports. They can also be linked by software so they appear to the user as a single data base.

The software package used for the data base is dBase IV™ (dBase) by Ashton-Tate Corporation. For a detailed discussion of the dBase file structure used in the three data bases, see Appendix D.

The software used to query, sort and generate reports out of the dBase database files is R&R Report Writer™ (R&R) by Concentrics Data Systems, Inc.

C-3.0 Overview Of R&R Capabilities

Capabilities of R&R, when reporting out of dBase files, are summarized below.

- Relate and report from up to 10 database files at once,
- Calculate new fields with either predefined or user defined functions,
- Sort on up to eight fields including calculated fields,
- Compute running sums, counts, averages, minimums, maximums, variance and standard deviations,
- Select records through plain English queries with range and list comparison operators, logical connectors and full nesting of parentheses, and
- Provide user with options of routing completed reports to the CRT screen and/or the printer.

C-4.0 Typical R&R Applications

Applications of R&R to query the data base and construct reports during the Williston Basin study included:

- Construction of special reports for debugging and error checking during the design and construction of the data base,
- Construction of special reports for querying the data base during the preparation of this final report of the Williston Basin study, and
- Construction of permanent input screens for queries of the Williston Basin study data base.

Note:
Use of the special reports is facilitated if the user is knowledgeable in dBase and R&R. Use of the permanent input screens does not require a background in computers.

C-5.0 Construction Of User Input Screens

C-5.1 General

As a part of the Williston Basin study, input screens were constructed using dBase and R&R to generate reports from the Williston Basin study database files in response to user queries. Purpose of the screens was to provide a realistic model that demonstrates the ease of constructing and implementing relatively complex queries of a risk based data base.

For the following discussion of how the interface between the user and the data base is accomplished, refer to Figures C-1 through C-5.

C-5.2 Example Report Generated From A User Query

Figure C-1 presents an example report generated from a user request for data from the Williston Basin study data base using the seven input screens discussed below.

In response to a user request, three of operator B's active SWD wells which have surface casing that is set above the base of the lowermost USDW were selected from the 795 individual well records that reside in the North Dakota master file. In addition to showing information such as well name, field, location and operator, the report presents data on the deepest USDW, well tubulars, tops of cement and perforations.

The user input requests that generated the report shown on Figure C-1 are shown by the arrows on the seven sample input screens in Figures C-2 through C-5. The user selection for each of the seven screens is listed below.

User Input Screen	Nature of Query
Main Menu	North Dakota
Subject Selection	USDW Queries
USDW Subject Selection	All Wells Considered
USDW Single Well Report	(Input Screen Not Used)
Data Query - Page 1	Active SWD Wells All Fields Operator B
Data Query - Page 2	Bottom of Surface Pipe Above Base of USDW
Data Query - Page 3	Sorted on Field Name

C-5.3 Software Requirements To Build User Screens
The software requirements to build the seven input screens are shown below.

User Input Screen	Lines of Software Coding
Main Menu	300
Subject Selection	150
USDW Subject Selection	120
USDW Single Well Report	170
Data Query - Page 1	170
Data Query - Page 2	170
Data Query - Page 3	170
Total Lines of Code	1,250

Figure C-1

North Dakota USDW Query Report

NORTH DAKOTA UNDERGROUND SOURCE OF DRINKING WATER QUERY REPORT

FILE # 832 FIELD: CHARLSON OPER: OPERATOR B

WELL NAME: CHARLSON SWD #1

SEC: 18 TWNP: 153N RNGE: 095W ELEV: 2291 TYPE: SWD STAT: ACT

COMP DATE: 03/18/55 PERMIT DATE: 06/04/84

============== USDW/SURFACE CASING/PRODUCTION CASING INFORMATION ===============

TYPE	SIZE	DEPTH	TOC	TOP	BTM	FORMATION
DEEPEST USDW				1106	1336	FH
SURF CASING	13-3/8	621	SURF			
PROD CASING	5-1/2	8830	4596			
PERFORATIONS				4860	4990	DAK

FILE # 2028 FIELD: DIMMICK LAKE OPER: OPERATOR B

WELL NAME: DIMMICK LAKE SWD #1

SEC: 20 TWNP: 151N RNGE: 096W ELEV: 2345 TYPE: SWD STAT: ACT

COMP DATE: 09/23/58 PERMIT DATE:

============== USDW/SURFACE CASING/PRODUCTION CASING INFORMATION ===============

TYPE	SIZE	DEPTH	TOC	TOP	BTM	FORMATION
DEEPEST USDW				1350	1530	FH
SURF CASING	9-5/8	618	SURF			
PROD CASING	5-1/2	9299	4764			
PERFORATIONS				5150	5380	DAK

FILE # 2169 FIELD: KEENE OPER: OPERATOR B

WELL NAME: L. WISNESS #2

SEC: 03 TWNP: 152N RNGE: 096W ELEV: 2320 TYPE: SWD STAT: ACT

COMP DATE: 02/19/59 PERMIT DATE:

============== USDW/SURFACE CASING/PRODUCTION CASING INFORMATION ===============

TYPE	SIZE	DEPTH	TOC	TOP	BTM	FORMATION
DEEPEST USDW				1195	1385	FH
SURF CASING	10-3/4	620	SURF			
PROD CASING	4-1/2	11056	6047			
PERFORATIONS				8968	8982	MAD

Cumulative Wells Selected at End of This Page 3
Total Wells in Data Base 795
14:09:42 10/15/89 Page 1 of 1

Note: This example user query is for:
Active North Dakota SWD wells for Operator B with surface casing that does not cover the USDW.

Figure C-2

User Screens - Main Menu/Subject Selection Menu

Williston Basin UIC Database	Main Menu
	Montana
	→ North Dakota
	South Dakota
	Total Williston Basin
	R&R Relational Report Writer
	Quit

Williston Basin UIC Database	Subject Selection Menu
	Individual Well Detail
	→ Underground Source of Drinking Water Queries
	Injection Monitoring Queries
	Mechanical Integrity Testing Queries
	Workover Queries
	Leak Queries
	Quit

Figure C-3

User Screens - USDW Selection/USDW Single Well Report

Williston Basin UIC Database — USDW Subject Selection Menu

Single Well

→ All Wells Considered

Quit

Williston Basin UIC Database — USDW Single Well Report

(C)ode (N)ame	File No	Well Name

This input screen was not used because "Single Well" was not requested on the previous input screen.

Figure C-4

User Screens - Data Query - Page 1/Data Query - Page 2

```
Williston Basin UIC Database                          Data Query - Page 1

W  l Type:    Water Injection N   Salt Water Disposal Y <--
                Gas Injection N        All Well Types N

Well Status:           Active Y <--          Shut In N
              Temp Abandoned N   Plugged & Abandoned N
            All Well Status N

        (A)ll,
        (C)ode,
        (N)ame     Code      Name

Field:   A <--  (Selects all fields)

Oper:    N                B <--  (Selects operator B)
```

Continue/Modify/Quit?

```
Williston Basin UIC Database                          Data Query - Page 2

                                        --> (A)bove Base of USDW
                                            (B)elow Base of USDW
                                            (N)/A

         Bottom of Surface Pipe              A <--

         Production Casing Top of Cement     N
```

Continue/Modify/1stPg/Quit?

Figure C-5

User Screen - Data Query - Page 3

```
Williston Basin UIC Database                        Data Query - Page 3

     Non Unique Sort Keys

          Operator Name N
                                   Please indicate desired sort order
             Field Name 1 <--      using N or 1-4.  Use N,N,N,N if
                                   order is not important, or one of
              Well Type N          the unique keys below is the
                                   primary key.
            Well Status N


     Unique Sort Keys
                                   (L)ocation     (F)ile Number
          Choice N                 (W)ell Name    (A)PI Well Number
                                   (N)/A

Print/View/Modify/1stPg/2ndPg/Quit?
```

Appendix D
Database File Definition

Appendix D
Database File Definition

D-1.0 Purpose Of Appendix D

The purpose of Appendix D is to provide the reader with the information needed to build each of the individual data file structures that are used in the Williston Basin study risk based data base.

D-2.0 Background

The Williston Basin study covers the eastern portion of Montana, western North Dakota and the northwestern corner of South Dakota. The study utilizes identical relational database file structures for each of the three states. The three data bases can be used separately to generate queries, sorts, and reports. They can also be linked by software so they appear to the user as a single data base.

The software package used for the data base is dBase IV™ by Ashton-Tate Corporation.

D-3.0 Overview Of Williston Basin Study Database File Structure

As shown in Figure D-1, each of the three data bases consists of:

- o One well master file which contains selected information that is unique to each well,
- o Sixteen name/type ID files which contain alpha or numeric codes that are translated into identifying names for reporting purposes, and
- o Ten data files which contain individual well and field information.

D-4.0 Discussion Of Williston Basin Database File Structure

For this discussion of the Williston Basin study database file structure, the file structures used to construct the North Dakota data base are used for illustrative purposes. The North Dakota file structures are identical to those used for the Montana and South Dakota data bases, with only the identifying file names changed where appropriate.

D-4.1 General

For the following discussion of the data contained in the well master file and each of the 26 dependent files, refer to Figure D-1. For a listing of the file structures, see Tables D-1 through D-13.

D-4.2 Well Master File (NDMASTER.DBF)

The structure of the 36 data fields in the well master file is shown in Table D-1 and discussed below.

Fields 1 through 3 - These fields comprise the API Well Number which is unique to each well in the U.S. The API Well Number links the well master file to the nine data files that contain information relating to an individual well. As discussed below, the field file is linked to master file by the field code.

Field 4 - This field contains a code which identifies the formation/zone that is associated with each well. If a well is completed in more than one zone, the well master file will contain a separate record for each completion. The formation/zone field is combined with the API Well Number to link the well master file to one or more of the nine data files that contain individual well information.

Fields 5 and 6 - Reserved for state and UIC file numbers

Field 7 - Name of the well

Fields 8 through 11 - Location of well

Field 12 - Elevation in relation to sea level

Field 13 - Total depth

Field 14 - Plug back total depth

Field 15 - Indicates the path down the wellbore that the injected fluid travels

Field 16 - Code for well type

Field 17 - Code for the current well status

Field 18 - Date that the current well status became effective

Field 19 - Completion date

Field 20 - Permit date

Field 21 - First injection date

Field 22 - Code for the field name (links field file to master file)

Field 23 - Name of the field

Field 24 - Code for the operator name

Field 25 - Name of the operator

Field 26 - Code which identifies the deepest USDW associated with each well

Field 27 - Depth of the base of the deepest USDW in relation to the surface

Field 28 - Depth of the top of the deepest USDW in relation to the surface

Field 29 - Depth of the base of the deepest USDW in relation to sea level

Field 30 - Surface casing size

Field 31 - Surface casing depth

Field 32 - Surface casing top of cement

Field 33 - Conductor pipe size

Field 34 - Conductor pipe depth

Field 35 - Conductor pipe top of cement

Field 36 - Field that shows if the well is cathodically protected

D-4.3 Name/Type ID Files

The file structures of the 16 name/type ID files are shown in Tables D-2 through D-8 and discussed below.

D-4.3.1 County Name (COUNTYID.DBF)

API state codes
API county codes
County names

D-4.3.2 Failure Cause (FAILCAUS.DBF)

Failure cause codes
Failure causes
- Mechanical
- Corrosion - general
- Corrosion - internal
- Corrosion - external

Poor cement
No cement
Salt collapse
Other

D-4.3.3 Failure Type (FAILTYPE.DBF)

Failure type codes
Failure types
- Tubing
- Packer
- Wellhead
- Casing
- Behind pipe
- Other

D-4.3.4 Field Name (FLDID.DBF)

Field name codes
Field names

D-4.3.5 Formation/Zone Name (FRMZONE.DBF)

Formation/zone codes
Formation/zone names

D-4.3.6 Injection Type (INJTYPE.DBF)

Injection type codes
Injection down
- Tubing
- Tubing/casing annulus
- Tubing and tubing/casing annulus
- Casing
- Production casing/surface casing annulus
- Other

D-4.3.7 Monitoring Frequency (MONFREQ.DBF)

Monitoring frequency codes
Monitoring frequency
- Daily
- Weekly
- Monthly
- Yearly
- Five years
- Other

D-4.3.8 Operator Name (OPRID.DBF)

Operator name codes
Operator names

D-4.3.9 Repair Type (RPRTYPE.DBF)

Repair type codes
Repair types
- Replace tubing
- Replace tubing and packer
- Repair wellhead
- Squeeze casing
- Run liner
- Other

D-4.3.10 State Name (STATEID.DBF)

State name codes
State names

D-4.3.11 Tubing Type - (TBGTYPE.DBF)

Tubing type codes
Tubing types
- Bare steel
- Fiberglass
- Plastic coated
- Stainless steel
- Cement lined
- Other

D-4.3.12 Test Method (TESTMTHD.DBF)

Test method codes
Test methods
- Read tubing
- Read casing
- Pressure tubing
- Pressure casing
- Radioactive log
- Temperature log
- Oxygen activation log
- Noise log
- Cement review
- Ada pressure test
- Flow meter

- Dual completion
- Water in annulus
- Other

D-4.3.13 Type Formation (TYPEFRM.DBF)

- Formation type codes
- Formation types
  - Producing
  - Water injection
  - Gas injection
  - Salt water disposal
  - Corrosive zone
  - Salt water aquifer
  - Salt section
  - USDW
  - No USDW present
  - Exempt aquifer
  - Air injection
  - Other

D-4.3.14 Type Well (TYPEWELL.DBF)

- Well type codes
- Well types
  - Water injection
  - Gas injection
  - Air injection
  - Water alternate gas injection
  - Salt water disposal
  - Oil well
  - Gas well
  - Dry hole
  - Exploration test
  - Observation well
  - Other

D-4.3.15 USDW Formation Name (USDWZONE.DBF)

- USDW formation codes
- USDW formation names

D-4.3.16 Well Status (WELLSTAT.DBF)

- Well status codes
- Well status
  - Active
  - Shut in
  - To be abandoned
  - Dry hole
  - Temporarily abandoned
  - Plugged and abandoned
  - Exploration test
  - Cancelled
  - Permitted
  - Workover
  - Drilling
  - Producer now abandoned

D-4.4 Data Files

The file structures of the 10 data files are shown in Tables D-9 through D-13 and discussed below.

D-4.4.1 General

The data fields used to link each of the following files to the well master file are the field code and formation/zone code for the field data file (NDFLDDAT.DBF) and the API Well Number codes and formation/zone code for the other nine data files.

From the database management standpoint, those linking fields are the only fields necessary to link each data file to the appropriate well in the master file. From the practical standpoint, however, it is best to include other identification fields such as operator name, field name and well name to reduce errors when entering data into those data files from the keyboard.

D-4.4.2 Casing Leak (CSGLEAK.DBF)

- API Well Number codes
- Formation/zone code
- State file number
- Field name
- Operator name
- Well name
- Well type
- Current well status

Leak
- Average depth
- Repair date
- Failure cause code
- Repair type code

Remarks

Note:
There will be one record prepared for each casing leak. All casing leaks will be maintained in the active file.

D-4.4.3 Field Data (NDFLDDAT.DBF)

Field code
Field name
Formation/zone code
Formation type code
Formation
- Depth - top
- Depth - bottom
- Reservoir pressure
- Fracture pressure
- Maximum permitted injection pressure
- Temperature
- Water total dissolved solids

Injection water total dissolved solids
Remarks
Cathodic protection
- Date it was introduced to that field
- Number of wells in that field it

Number of wells in that field with bare steel tubing
Number of wells in that field with fiberglass tubing
Number of wells in that field with plastic coated tubing
Number of wells in that field with cement lined tubing
Number of wells in that field with stainless steel tubing
Number of wells in that field with any other type of tubing

Note:
There will be one record for each formation type (such as USDW zone, SWD zone, EOR injection zone).

D-4.4.4 Intermediate Casing (INTCSG.DBF)

API Well Number codes
Formation/zone code
State file number
Intermediate casing
- Size
- Depth
- Top of cement

Note:
There will be one record prepared for each string of intermediate casing.

D-4.4.5 Liner (LINER.DBF)

API Well Number codes
Formation/zone code
State file number
Liner
- Date run
- Size
- Depth - top
- Depth - bottom
- Top of cement

Note:
There will be one record prepared for each liner.

D-4.4.6 MIT Test (NDMIT.DBF)

API Well Number codes
Formation/zone code
State file number
Field name
Operator name
Well name
Well type
Current well status
MIT test
- Date run
- Pressure
- Test method code
- Monitoring frequency code
- Test passed or failed?

If test failed:
- Failure type code
- Failure cause code
- Repair type code
- Repair completion date
- Repair completion due date
- Repair success or failure?

Date next scheduled MIT test
Was test witnessed?
Remarks

Note:
There will be one record for each MIT test. All MIT tests will be retained in the active file.

D-4.4.7 Monitor Test (MONITOR.DBF)

API Well Number codes
Formation/zone code
State file number
Field name
Operator name
Well name
Well type
Current well status
Injection record
- Number of month
- Year
- Average tubing pressure
- Maximum tubing pressure
- Maximum permitted tubing pressure
- Injection volume - barrels per month
- Injection volume - MCF per month
- Minimum casing pressure
- Maximum casing pressure
- Monitoring frequency
- Was test witnessed?

Note:
There will be one record for each month. Records will be maintained in this active file for two years. After two years the records will be permanently stored on diskettes or tape.

D-4.4.8 Production Casing (PRODCSG.DBF)

- API Well Number codes
- Formation/zone code
- State file number
- Production casing
  - Size
  - Depth
  - Top of cement
- Perforations
  - Openhole?
  - Depth - top
  - Depth - bottom
- DV tool
  - Depth
  - Top of cement

Note:
There will be one record for each string of production casing.

D-4.4.9 Tubing Leak (TBGLEAK.DBF)

- API Well Number codes
- Formation/zone code
- State file number
- Field name
- Operator name
- Well name
- Well type
- Current well status
- Leak
  - Repair date
  - Average depth
  - Failure type code
  - Failure cause code
- Tubing
  - Size
  - Type code
- Remarks

Note:
There will be one record for each tubing leak. All tubing leaks will be recorded including those caused by corrosion, mechanical failure, packer leaks, and wellhead leaks. A history file of ten years will be maintained in the active file. After 10 years, the leak records will be permanently stored on tape or diskettes.

D-4.4.10 Tubing (TUBING.DBF)

- API Well Number codes
- Formation/zone code
- State file number
- Tubing
  - Size
  - Depth
  - Type code
- Packer depth
- Injection type code

Note:
There will be one record for each string of tubing.

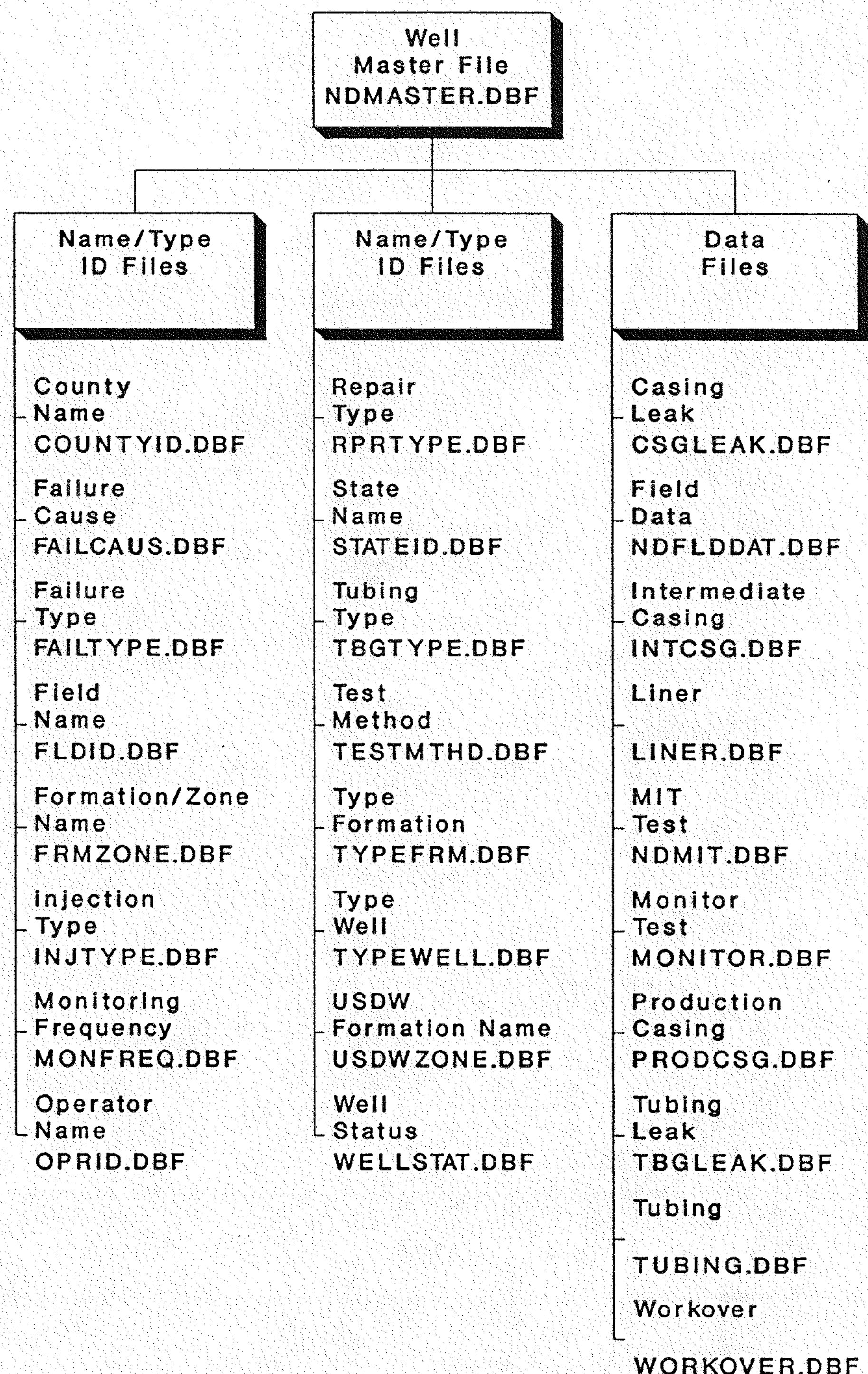
D-4.4.11 Workover (WORKOVER.DBF)

- API Well Number codes
- Formation/zone code
- State file number
- Field name
- Operator name
- Well name
- Well type
- Current well status
- Workover
  - Start date
  - Failure type code
  - Failure cause code
  - Completion date
  - Average leak depth
  - Remarks

Note:
There will be one record for each workover performed on each injection well. All workovers will be maintained in the active file.

Figure D-1

Williston Basin Database File Structure



Names with .DBF are dBase IV file names.

Table D-1

Structure for database: D:\WILBASIN\ND\NDSTORE\NDMASTER.DBF
Number of data records: 795
Date of last update : 10/05/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FRM_ZONE	Character	3		N
5	FILE_NO	Character	12		N
6	UIC_NO	Character	11		N
7	WELL_NAME	Character	40		N
8	SECTION	Character	2		N
9	TOWNSHIP	Character	4		N
10	RANGE	Character	4		N
11	LOCATION	Character	30		N
12	ELEVATION	Numeric	5		N
13	TOTAL_DPTH	Numeric	5		N
14	PBTD	Numeric	5		N
15	INJ_TYPE	Character	1		N
16	WELLTYPE	Character	3		N
17	W_STAT	Character	3		N
18	WSTAT_DATE	Date	8		N
19	COMP_DATE	Date	8		N
20	PERM_DATE	Date	8		N
21	FIRST_INJ	Date	8		N
22	FLDCODE	Character	5		N
23	FLDNAME	Character	32		N
24	OPRCODE	Character	5		N
25	OPRNAME	Character	42		N
26	USDW_ZONE	Character	3		N
27	BUSDW_SSUR	Numeric	5		N
28	TUSDW_SSUR	Numeric	5		N
29	BUSDW_SSEA	Numeric	5		N
30	SCSG_SIZE	Character	6		N
31	SCSG_DPTH	Numeric	5		N
32	SCSG_TOC	Numeric	5		N
33	CNDTR_SIZE	Character	6		N
34	CNDTR_DPTH	Numeric	5		N
35	CNDTR_TOC	Numeric	5		N
36	CATH_P_Y_N	Character	1		N
** Total **			306		

Table D-2

```
Structure for database: D:\WILBASIN\WB\DBFFILES\COUNTYID.DBF
Number of data records:      33
Date of last update   : 02/27/89
Field  Field Name  Type       Width    Dec    Index
    1  STATE       Character      2               N
    2  COUNTY      Character      3               N
    3  COUNTYNAME  Character     20               N
** Total **                      26
```

Record#	STATE	COUNTY	COUNTYNAME
1	25	019	DANIELS
2	25	021	DAWSON
3	25	025	FALLON
4	25	055	MCCONE
5	25	079	PRAIRIE
6	25	083	RICHLAND
7	25	085	ROOSEVELT
8	25	091	SHERIDAN
9	25	105	VALLEY
10	25	109	WIBAUX
11	33	007	BILLINGS
12	33	009	BOTTINEAU
13	33	011	BOWMAN
14	33	013	BURKE
15	33	023	DIVIDE
16	33	025	DUNN
17	33	033	GOLDEN VALLEY
18	33	041	HETTINGER
19	33	049	MCHENRY
20	33	053	MCKENZIE
21	33	055	MCLEAN
22	33	057	MERCER
23	33	061	MOUNTRAIL
24	33	075	RENVILLE
25	33	087	SLOPE
26	33	089	STARK
27	33	101	WARD
28	33	105	WILLIAMS
29	40	047	FALL RIVER
30	40	033	CUSTER
31	40	063	HARDING
32	40	019	BUTTE
33	40	041	DEWEY

Table D-3

Structure for database: D:\WILBASIN\WB\DBFFILES\FAILCAUS.DBF
Number of data records: 8
Date of last update : 07/06/89

Field	Field Name	Type	Width	Dec	Index
1	FAIL_CAU	Character	1		N
2	FAILNAME	Character	18		N
** Total **			20		

Record#	FAIL_CAU	FAILNAME
1	M	MECHANICAL
2	C	CORROSION-GENERAL
3	I	CORROSION-INTERNAL
4	E	CORROSION-EXTERNAL
5	P	POOR CEMENT
6	N	NO CEMENT
7	S	SALT COLLAPSE
8	O	OTHER

Structure for database: D:\WILBASIN\WB\DBFFILES\FAILTYPE.DBF
Number of data records: 6
Date of last update : 07/06/89

Field	Field Name	Type	Width	Dec	Index
1	FAIL_TYP	Character	1		N
2	FAILNAME	Character	11		N
** Total **			13		

Record#	FAIL_TYP	FAILNAME
1	T	TUBING
2	P	PACKER
3	W	WELLHEAD
4	C	CASING
5	B	BEHIND PIPE
6	O	OTHER

Structure for database: D:\WILBASIN\WB\DBFFILES\FLDID.DBF
Number of data records: 487
Date of last update : 04/14/89

Field	Field Name	Type	Width	Dec	Index
1	FLDCODE	Character	5		N
2	FLDNAME	Character	32		N
** Total **			38		

Structure for database: D:\WILBASIN\WB\DBFFILES\FRMZONE.DBF
Number of data records: 197
Date of last update : 05/25/89

Field	Field Name	Type	Width	Dec	Index
1	FRM_ZONE	Character	3		N
2	FRMNAME	Character	35		N
** Total **			39		

Structure for database: D:\WILBASIN\WB\DBFFILES\INJTYPE.DBF
Number of data records: 6
Date of last update : 07/06/89

Field	Field Name	Type	Width	Dec	Index
1	INJ_TYPE	Character	1		N
2	INJNAME	Character	25		N
** Total **			27		

Record#	INJ_TYPE	INJNAME
1	T	TUBING
2	A	TBG/CSG ANNULUS
3	B	TBG & TBG/CSG ANNULUS
4	C	CASING
5	S	PROD CSG/SURF CSG ANNULUS
6	O	OTHER

Structure for database: D:\WILBASIN\WB\DBFFILES\MONFREQ.DBF
Number of data records: 6
Date of last update : 07/06/89

Field	Field Name	Type	Width	Dec	Index
1	MON_FREQ	Character	1		N
2	FREQNAME	Character	7		N
** Total **			9		

Record#	MON_FREQ	FREQNAME
1	D	DAILY
2	W	WEEKLY
3	M	MONTHLY
4	Y	YEARLY
5	5	5 YEARS
6	O	OTHER

Table D-5

Structure for database: D:\WILBASIN\WB\DBFFILES\OPRID.DBF
Number of data records: 1080
Date of last update : 06/17/89

Field	Field Name	Type	Width	Dec	Index
1	OPRCODE	Character	5		N
2	OPRNAME	Character	42		N
** Total **			48		

Structure for database: D:\WILBASIN\WB\DBFFILES\RPRTYPE.DBF
Number of data records: 6
Date of last update : 07/06/89

Field	Field Name	Type	Width	Dec	Index
1	RPR_TYPE	Character	1		N
2	RPRNAME	Character	12		N
** Total **			14		

Record#	RPR_TYPE	RPRNAME
1	T	REPL TBG
2	P	REPL TBG/PKR
3	W	RPR WELLHEAD
4	S	SQUEEZE CSG
5	L	RUN LINER
6	O	OTHER

Structure for database: D:\WILBASIN\WB\DBFFILES\STATEID.DBF
Number of data records: 3
Date of last update : 06/29/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	STATENAME	Character	20		N
** Total **			23		

Record#	STATE	STATENAME
1	25	MONTANA
2	33	NORTH DAKOTA
3	40	SOUTH DAKOTA

Structure for database: D:\WILBASIN\WB\DBFFILES\TBGTYPE.DBF
Number of data records: 6
Date of last update : 07/06/89

Field	Field Name	Type	Width	Dec	Index
1	TBG_TYPE	Character	1		N
2	TBGNAME	Character	15		N
** Total **			17		

Record#	TBG_TYPE	TBGNAME
1	B	BARE STEEL
2	F	FIBERGLASS
3	P	PLASTIC COATED
4	S	STAINLESS STEEL
5	C	CEMENT LINED
6	O	OTHER

Structure for database: D:\WILBASIN\WB\DBFFILES\TESTMTHD.DBF
Number of data records: 14
Date of last update : 07/06/89

Field	Field Name	Type	Width	Dec	Index
1	TST_MTHD	Character	2		N
2	TSTNAME	Character	18		N
** Total **			21		

Record#	TST_MTHD	TSTNAME
1	RT	READ TUBING
2	RC	READ CASING
3	PT	PRESSURE TUBING
4	PC	PRESSURE CASING
5	RA	RADIOACTIVE LOG
6	TL	TEMPERATURE LOG
7	OA	OXY ACTIVATION LOG
8	NL	NOISE LOG
9	CR	CEMENT REVIEW
10	AD	ADA PRESSURE TEST
11	FM	FLOW METER
12	DC	DUAL COMPLETION
13	WA	WATER IN ANNULUS
14	OT	OTHER

Table D-7

Structure for database: D:\WILBASIN\WB\DBFFILES\TYPEFRM.DBF
Number of data records: 12
Date of last update : 10/14/89

Field	Field Name	Type	Width	Dec	Index
1	FRM_TYPE	Character	1		N
2	FRMTYPE	Character	19		N
** Total **			21		

Record#	FRM_TYPE	FRMTYPE
1	P	PRODUCING
2	W	WATER INJECTION
3	G	GAS INJECTION
4	D	SALT WATER DISPOSAL
5	C	CORROSIVE ZONE
6	A	SALT WATER AQUIFER
7	S	SALT SECTION
8	U	USDW
9	N	NO USDW PRESENT
10	E	EXEMPT AQUIFER
11	R	AIR INJECTION
12	O	OTHER

Structure for database: D:\WILBASIN\WB\DBFFILES\TYPEWELL.DBF
Number of data records: 11
Date of last update : 07/06/89

Field	Field Name	Type	Width	Dec	Index
1	WELLTYPE	Character	3		N
2	WTYPENAME	Character	19		N
** Total **			23		

Record#	WELLTYPE	WTYPENAME
1	WI	WATER INJECTION
2	GI	GAS INJECTION
3	AI	AIR INJECTION
4	WAG	WATER ALTERNATE GAS
5	SWD	SALT WATER DISPOSAL
6	OIL	OIL WELL
7	GAS	GAS WELL
8	DRY	DRY HOLE
9	EXP	EXPLORATION TEST
10	OBS	OBSERVATION WELL
11	OTH	OTHER

Structure for database: D:\WILBASIN\WB\DBFFILES\USDWZONE.DBF
Number of data records: 14
Date of last update : 05/25/89

Field	Field Name	Type	Width	Dec	Index
1	USDW_ZONE	Character	3		N
2	USDWNAME	Character	35		N
** Total **			39		

Record#	USDW_ZONE	USDWNAME
1	ALL	ALLUVIAN
2	DAK	DAKOTA
3	EAG	EAGLE
4	FH	FOX HILLS
5	FU	FORT UNION
6	HC	HELL CREEK
7	JR	JUDITH RIVER
8	NOU	NO USDW FORMATION PRESENT
9	GLA	GLACIAL DRIFT
10	SEN	SENTINEL BUTTE
11	BUL	BULLION CREEK
12	SLP	SLOPE
13	CAN	CANNON BALL
14	LUD	LUDLOW

Structure for database: D:\WILBASIN\WB\DBFFILES\WELLSTAT.DBF
Number of data records: 12
Date of last update : 07/06/89

Field	Field Name	Type	Width	Dec	Index
1	W_STAT	Character	3		N
2	W_STATNAME	Character	25		N
** Total **			29		

Record#	W_STAT	W_STATNAME
1	ACT	ACTIVE
2	SI	SHUT IN
3	TBA	TO BE ABANDONED
4	DRY	DRY HOLE
5	TA	TEMPORARILY ABANDONED
6	P&A	PLUGGED AND ABANDONED
7	EXP	EXPLORATION TEST
8	CAN	CANCELLED
9	PER	PERMITTED
10	WO	WORKOVER
11	DRL	DRILLING
12	PNA	PRODUCER NOW ABANDONED

Table D-9

Structure for database: D:\WILBASIN\ND\NDSTORE\CSGLEAK.DBF
Number of data records: 814
Date of last update : 07/08/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FILE_NO	Character	12		N
5	FLDNAME	Character	32		N
6	OPRNAME	Character	42		N
7	WELL_NAME	Character	40		N
8	WELLTYPE	Character	3		N
9	W_STAT	Character	3		N
10	FRM_ZONE	Character	3		N
11	AVG_DEPTH	Numeric	5		N
12	RPR_DATE	Date	8		N
13	FAIL_CAU	Character	1		N
14	RPR_TYPE	Character	1		N
15	REMARKS	Character	30		N
** Total **			191		

Structure for database: D:\WILBASIN\ND\NDSTORE\NDFLDDAT.DBF
Number of data records: 453
Date of last update : 09/14/89

Field	Field Name	Type	Width	Dec	Index
1	FLDCODE	Character	5		N
2	FLDNAME	Character	32		N
3	FRM_ZONE	Character	3		N
4	FRM_TYPE	Character	1		N
5	DEPTH_TOP	Numeric	5		N
6	DEPTH_BTM	Numeric	5		N
7	RESVR_PSI	Numeric	5		N
8	FRACT_PSI	Numeric	5		N
9	PRM_INJPSI	Numeric	5		N
10	TEMP	Numeric	3		N
11	FRMWTR_TDS	Numeric	6		N
12	INJWTR_TDS	Numeric	6		N
13	REMARKS	Character	30		N
14	CATHP_DATE	Date	8		N
15	CATHP_WELL	Character	4		N
16	TBGNO_STL	Character	3		N
17	TBGNO_FGLS	Character	3		N
18	TBGNO_PLCT	Character	3		N
19	TBGNO_CTLN	Character	3		N
20	TBGNO_SSTL	Character	3		N
21	TGBNO_OTHR	Character	3		N
** Total **			142		

Table D-10

Structure for database: D:\WILBASIN\ND\NDSTORE\INTCSG.DBF
Number of data records: 7
Date of last update : 06/03/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FILE_NO	Character	12		N
5	FRM_ZONE	Character	3		N
6	INTCSG_SZE	Character	6		N
7	INTCSG_DPT	Numeric	5		N
8	INTCSG_TOC	Numeric	5		N
** Total **			42		

Structure for database: D:\WILBASIN\ND\NDSTORE\LINER.DBF
Number of data records: 45
Date of last update : 06/03/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FILE_NO	Character	12		N
5	FRM_ZONE	Character	3		N
6	DATE_RUN	Date	8		N
7	LINER_SIZE	Character	5		N
8	LINER_TOP	Numeric	5		N
9	LINER_BTM	Numeric	5		N
10	LINER_TOC	Numeric	5		N
** Total **			54		

Structure for database: D:\WILBASIN\ND\NDSTORE\NDMIT.DBF
Number of data records: 1159
Date of last update : 07/20/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FILE_NO	Character	12		N
5	FLDNAME	Character	32		N
6	OPRNAME	Character	42		N
7	WELL_NAME	Character	40		N
8	WELLTYPE	Character	3		N
9	W_STAT	Character	3		N
10	FRM_ZONE	Character	3		N
11	TST_DATE	Date	8		N
12	PRESSURE	Character	4		N
13	TST_MTHD	Character	2		N
14	MON_FREQ	Character	1		N
15	TST_OK_Y_N	Character	1		N
16	FAIL_TYP	Character	1		N
17	FAIL_CAU	Character	1		N
18	RPR_TYPE	Character	1		N
19	RPR_CMP_DT	Date	8		N
20	RPR_DUE_DT	Date	8		N
21	MIT_DUE_DT	Date	8		N
22	RPR_OK_Y_N	Character	1		N
23	WITNESSED	Character	1		N
24	REMARKS	Character	30		N
** Total **			221		

Structure for database: D:\WILBASIN\ND\NDSTORE\MONITOR.DBF
Number of data records: 10464
Date of last update : 10/11/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FILE_NO	Character	12		N
5	FRM_ZONE	Character	3		N
6	WELL_NAME	Character	40		N
7	WELLTYPE	Character	3		N
8	W_STAT	Character	3		N
9	FLDNAME	Character	32		N
10	OPRNAME	Character	42		N
11	MONTH	Character	2		N
12	YEAR	Character	4		N
13	TBGPSI_AVG	Numeric	5		N
14	TBGPSI_MAX	Numeric	5		N
15	TBGPSI_PRM	Numeric	5		N
16	INJ_BBL_MO	Numeric	6		N
17	INJ_MCF_MO	Numeric	9		N
18	CSGPSI_MIN	Numeric	5		N
19	CSGPSI_MAX	Numeric	5		N
20	MON_FREQ	Character	1		N
21	WITNESSED	Character	1		N
** Total **			194		

Table D-12

Structure for database: D:\WILBASIN\ND\NDSTORE\PRODCSG.DBF
Number of data records: 795
Date of last update : 08/29/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FILE_NO	Character	12		N
5	FRM_ZONE	Character	3		N
6	PCSG_SIZE	Character	6		N
7	PCSG_DPTH	Numeric	5		N
8	PCSG_TOC	Numeric	5		N
9	PERF_OPNHL	Character	1		N
10	PERF_TOP	Numeric	5		N
11	PERF_BTM	Numeric	5		N
12	DVTOOL_FT	Numeric	5		N
13	DVTOOL_TOC	Numeric	5		N
** Total **			63		

Structure for database: D:\WILBASIN\ND\NDSTORE\TBGLEAK.DBF
Number of data records: 902
Date of last update : 07/04/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FILE_NO	Character	12		N
5	FLDNAME	Character	32		N
6	OPRNAME	Character	42		N
7	WELL_NAME	Character	40		N
8	WELLTYPE	Character	3		N
9	W_STAT	Character	3		N
10	FRM_ZONE	Character	3		N
11	RPR_DATE	Date	8		N
12	AVG_DEPTH	Numeric	5		N
13	FAIL_TYP	Character	1		N
14	FAIL_CAU	Character	1		N
15	TBG_SIZE	Character	5		N
16	TBG_TYPE	Character	1		N
17	REMARKS	Character	30		N
** Total **			197		

Table D-13

Structure for database: D:\WILBASIN\ND\NDSTORE\TUBING.DBF
Number of data records: 366
Date of last update : 06/03/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FILE_NO	Character	12		N
5	FRM_ZONE	Character	3		N
6	TBG_SIZE	Character	6		N
7	TBG_DPTH	Numeric	5		N
8	TBG_TYPE	Character	1		N
9	PACKERDEPT	Numeric	5		N
10	INJ_TYPE	Character	1		N
** Total **			44		

Structure for database: D:\WILBASIN\ND\NDSTORE\WORKOVER.DBF
Number of data records: 839
Date of last update : 06/05/89

Field	Field Name	Type	Width	Dec	Index
1	STATE	Character	2		N
2	COUNTY	Character	3		N
3	API_WELLNO	Character	5		N
4	FILE_NO	Character	12		N
5	FLDNAME	Character	32		N
6	OPRNAME	Character	42		N
7	WELL_NAME	Character	40		N
8	WELLTYPE	Character	3		N
9	W_STAT	Character	3		N
10	FRM_ZONE	Character	3		N
11	WO_STR_DT	Date	8		N
12	FAIL_TYP	Character	1		N
13	FAIL_CAU	Character	1		N
14	WO_CMPL_DT	Date	8		N
15	AVG_DEPTH	Numeric	5		N
16	REMARKS	Character	30		N
** Total **			199		