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Enhanced Oil Recovery: Environmental Issues and State Regulatory Programs

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ENVIRONMENTAL SCIENCES DIVISION
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ENHANCED OIL RECOVERY: ENVIRONMENTAL ISSUES AND STATE REGULATORY PROGRAMS

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ABSTRACT

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With continued high demand for oil and decline in supplies, enhanced oil recovery (EOR) methods will be used more frequently. Enhanced oil recovery includes gas, chemical, and thermal techniques (steam injection or in situ combustion). These methods can potentially extract as much oil as originally recovered by conventional methods, and thereby significantly expand recoverable domestic oil reserves. Improvements in EOR technology and recent government incentives should further accelerate use of EOR methods.

During 1977-78, Oak Ridge National Laboratory (ORNL) prepared environmental assessments for nine EOR demonstration projects located in six states, and reviewed the oil regulations for all oil-producing states. These evaluations revealed a number of potentially important environmental impacts associated with EOR, including: (1) loss of vegetation, (2) excessive air emissions from thermal operations, (3) excessive erosion and sedimentation (mostly in hilly terrain) and subsequent deterioration of surface-water quality, (4) pollution of land and surface waters from spills or leaks of oil or other chemicals, and (5) contamination of groundwater aquifers. Potential groundwater impacts include: (1) production of toxic and carcinogenic substances from synergistic interactions among chemicals used primarily in

micellar-polymer flooding; (2) formation of acid waters with small amounts of oil and residues of metals and metal oxides from in situ combustion; and (3) corrosion of well casings and potential leaks of hydrogen sulfide, primarily from injection of miscible carbon dioxide. For EOR technology to expand in an environmentally acceptable manner, environmental planning (including monitoring, protection measures, and reclamation strategies) must be an integral part of the initial project development. Acceptable monitoring, prevention, mitigation, and reclamation procedures are available for most of the identified environmental problems, but the best techniques may not be known by operators or required by law. Most states have stringent controls for plugging of abandoned wells and disposal of waste material, but other environmental considerations (e.g., reclamation plans, water quality and other monitoring programs, or abandonment plans) are often lacking. The need for additional environmental planning and monitoring regulations specific for the oil-production industry is emphasized. States are encouraged to continue strenthening and upgrading their oil-regulatory programs to safeguard the environment.

Our evaluations also identified areas where additional information is needed. These are: (1) toxicity and carcinogenicity studies of chemicals used in injection processes; (2) evaluation of groundwater monitoring methods; and (3) studies of reclamation procedures for soils contaminated by oil and brine.

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INTRODUCTION

Conventional oil recovery methods produce oil by using natural reservoir pressure or by flooding the reservoir with water. Enhanced oil recovery (EOR) methods are those that use other techniques such as: (1) thermal enhancement (in situ combustion and steam injection), (2) chemical injection (micellar-polymer and alkaline flooding), and (3) gas injection (carbon dioxide and nitrogen). These processes move oil to production wells and promote recovery from partially depleted oil fields by minimizing capillary forces, reducing viscosity of the oil, overcoming gravity segregation, and increasing pressure in the reservoir. The EOR method used in a particular situation depends upon geologic factors and physical properties of the reservoir oil (Crull 1978, National Petroleum Council 1976).

With increasing demand for oil and declining domestic oil production, EOR is an economically attractive technology. Conventional recovery methods may remove only 30 to 35% of the oil-in-place (Crull 1978, ERDA 1976), but as much as 50% of the remaining oil may be recoverable using EOR processes (Crull 1978). Exact recoverable amounts are not known because most EOR projects, except for some thermal projects in the United States and Canada, are still in the pilot or demonstration phase (Crull 1978, Noran 1978). The National Petroleum Council (1976) estimated that oil recovery with EOR methods could exceed conventional production in the United States by the late 1980's, if EOR processes prove to be technically successful and economically feasible and are applied commercially. From 1970 through

1977, active EOR projects in the United States increased from 133 to 196, and included 24 thermal, 27 chemical, and 12 gas injection projects (Noran 1978).

The U.S. Department of Energy (DOE) is actively promoting the development and application of EOR technology by direct funding of projects and with other incentives. As of September 30, 1978, DOE had provided various degrees of support to 38 industry projects and 42 institutions in the United States (Linville 1978). The DOE now allows "qualified" producers to charge world market prices (> $18 a barrel), instead of the fixed "old" oil price (∿ $5.72 a barrel), for oil produced by EOR methods (Crull 1978). Also, DOE may release some portion of a company's crude oil production from price controls, if the company is committed to starting a qualified EOR project (The Energy Daily 1979).

Anticipating an increase in the application of EOR methods, we attempt in this paper to: (1) summarize potential environmental impacts, (2) evaluate and compare existing state regulations for oil production operations, (3) identify areas of environmental concern as a basis for possible changes in present state regulatory programs, and (4) arrange this information in a usable format.

We believe that this paper will be helpful to those preparing environmental protection requirements and guidelines for EOR projects. Early recognition of environmental regulations of a particular state will allow development and implementation of specific contract requirements for projects where additional environmental protection is warranted. Furthermore, recognition of potential problem areas might encourage states to update and strengthen their oil-regulatory programs. We consider this aspect to be especially important, because individual states will be primarily responsible for inspection and enforcement of regulations once EOR technologies move from demonstration to commercial phase.

Sources of Information

Information for this report came from ORNL site visits and environmental assessments made for the DOE Office of Fossil Energy during 1977 and 1978 of nine EOR projects in Kansas, Louisiana, Montana, Oklahoma, Pennsylvania, and West Virginia; from literature evaluations; from evaluation of rules and regulations pertaining to oil operations; and from oral and written communications with government and industry officials. Regulations for oil operations were obtained from the 41 states with recoverable reserves (Appendix A). We assume that cited rules and regulatory documents are current, but they are subject to change.

A SUMMARY OF POTENTIAL ENVIRONMENTAL CONSEQUENCES OF ENHANCED OIL RECOVERY

Our evaluation of potential environmental impacts of EOR operations does not mean that major environmental problems will necessarily occur, because EOR projects are conducted in areas that have already been disturbed by oil production, and the methods are similar to those used for conventional oil production. Acceptable methods for minimizing and controlling environmental problems are available, although not necessarily required by present regulations. But without proper planning and implementation of control measures at appropriate stages of project development, important negative environmental impacts could occur. The following are examples of such impacts and each is discussed more fully below: (1) land disturbance and associated erosion, sedimentation, and loss of biota; (2) deterioration of surface-water quality; (3) contamination of groundwater aquifers; and (4) air pollution.

Land Disturbance and Related Problems

Pipeline installation and construction of well pads, roads, waste disposal pits, sediment ponds, and plant facilities (e.g., offices, parking areas, storage tanks) are sources of land disturbance. New wells and new roads frequently are not needed because existing ones from previous oil operations are used whenever possible. For commonly used 5-spot well patterns (four injection wells and one central production well) about 1.2 ha (3 acres) of land are usually disturbed for every 4 ha (10 acres) of project area. Usually, loss of vegetation from project construction and operation is minor. However, significant impacts to endangered and threatened biota and to historic or archaeologic materials could arise without preproject planning and evaluation (U.S. Department of Interior 1976, 1977a).

Accidental oil, brine, and chemical spills can result in contamination of soils and waters with subsequent loss of biota and land productivity. Reclamation procedures for oil-contaminated soils usually involve soil aeration by plowing. Addition of lime, fertilizer, and mulch is sometimes beneficial (Schwendinger 1968). Soils contaminated with brine require reclamation procedures such as leaching with water or the application of soil amendments for removal of soluble salts (Curlin and McDermid 1961); more information is still needed on effective clean-up procedures and methods for restoration of soils contaminated with EOR-related effluents (Braxton et al. 1976, Schwendinger 1968, Curlin and McDermid 1961).

Soil erosion and sedimentation are not unique to EOR-affected areas; they usually occur with any type of land development that involves surface disturbance. The potential for erosion and sedimentation is related to the extent and duration of surface disturbance, soil characteristics, weather, and topography. In general, erosion and sedimentation are most likely to occur on steep terrain with slopes greater than 30%. Road construction in such areas, resulting in the creation of unsightly highwalls (Fig. 1) and unstable down slopes (Fig. 2), is a main cause of erosion (Diseker and Richardson 1962). Also, erosion and runoff from dirt access roads can be a major source of stream sedimentation (Fig. 3). Without adequate control measures for access roads, rates of erosion may equal 20,400 metric tons per km^2 (57,600 tons/sq mile), which is about 2000 times greater than comparative rates from an undisturbed watershed, compared with an undisturbed watershed in similar topography (U.S. Environmental Protection Agency 1976).

Guidelines for minimizing and controlling erosion and sedimentation are available from state and federal agencies and other sources (U.S. Department of Interior 1977b, U.S. Environmental

(ORNL-PHOTO 5341-78)

Fig. 1. Highwalls created during construction of access roads and well sites.

(ORNL-PHOTO 5343-78)

Fig. 2. Landslide causing erosion and sedimentation problems.

(ORNL-PHOTO 5348-78)

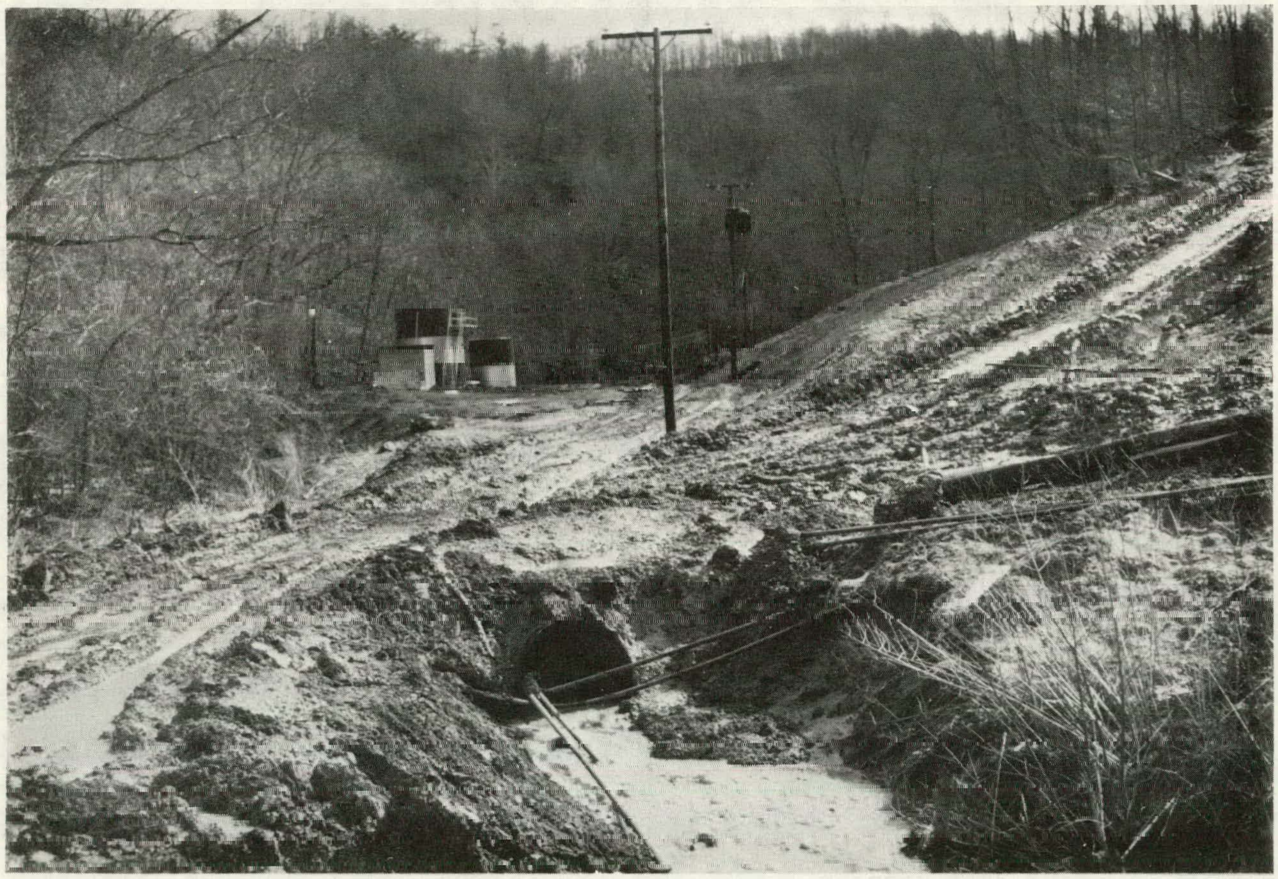

Fig. 3. Dirt access roads as a major source of erosion and stream sediment.

Protection Agency 1976, Hill 1976, Kathuria et al. 1976, U.S. Department of Agriculture 1975, West Virginia Department of Natural Resources 1975, Highway Research Board 1973, Curtis 1971, Meyer et al. 1970, Powell et al. 1970, Wischmeier and Mannering 1969, and Weigle 1965). These stress the importance of planning to reduce the surface disturbance and the interval between disturbance and revegetation. The guidelines recommend the use of mulch, terraces, revegetation plans, and proper construction and use of roads and sediment ponds (Figs. 4 and 5).

Conflicts of land use are not generally expected to be serious, since most EOR projects are developed in active or recently abandoned oil fields. In many cases, livestock grazing and timber harvesting have coexisted with oil production. Thus, EOR projects are usually a continuation of previous land use, and major impacts are not expected. However, the potential for land-use conflicts would probably be greater in heavily populated areas with many land-use needs.

Deterioration of Surface Waters

Surface disturbances and stream crossings by roads and pipelines may cause significant increases in stream sedimentation and turbidity with detrimental effects on aquatic habitats and biota (Baddaloo 1978). The extent and duration of such disturbances and the implementation of control measures will affect the degree of environmental impact.

(ORNL-PHOTO 4903-77)

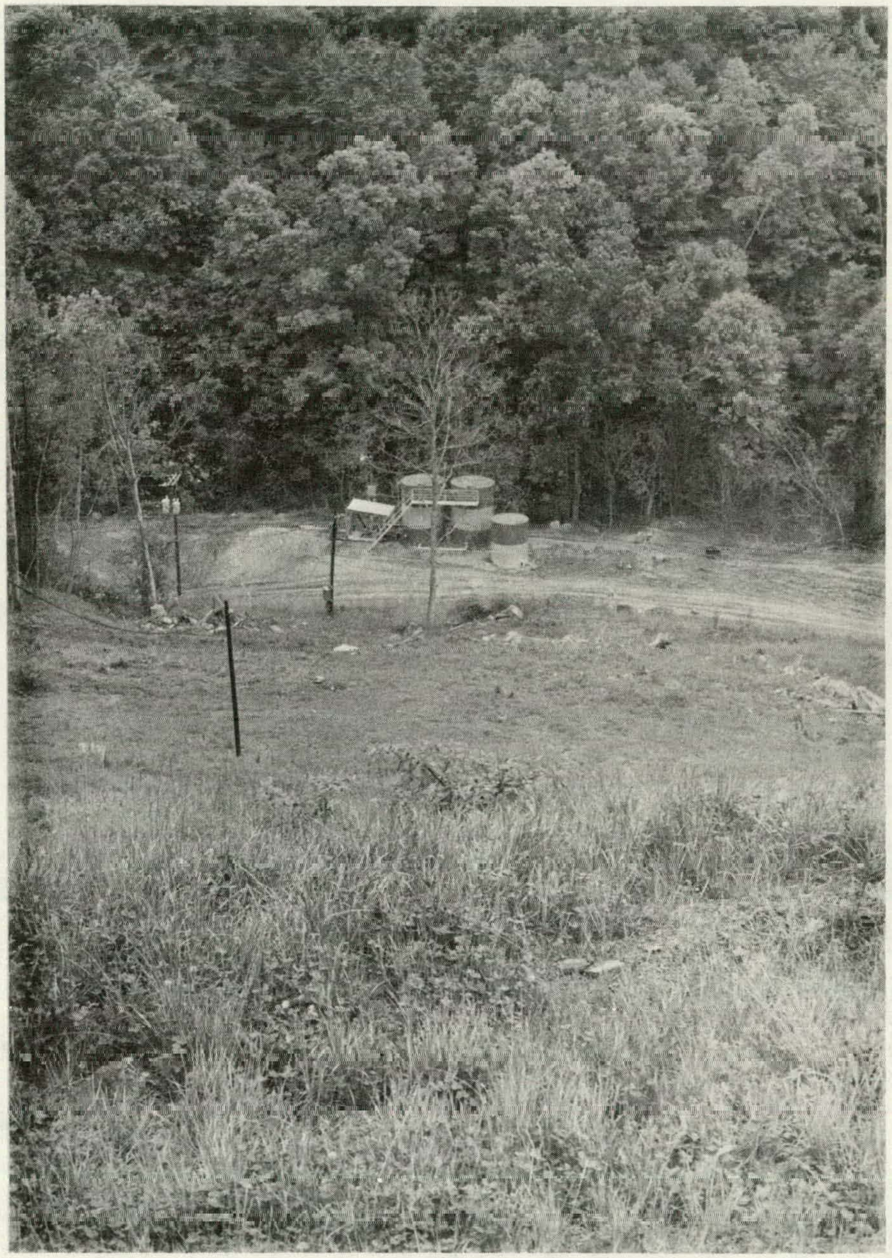

Fig. 4. A disturbed steep slope mulched and successfully revegetated with clover and fescue grass for erosion control.

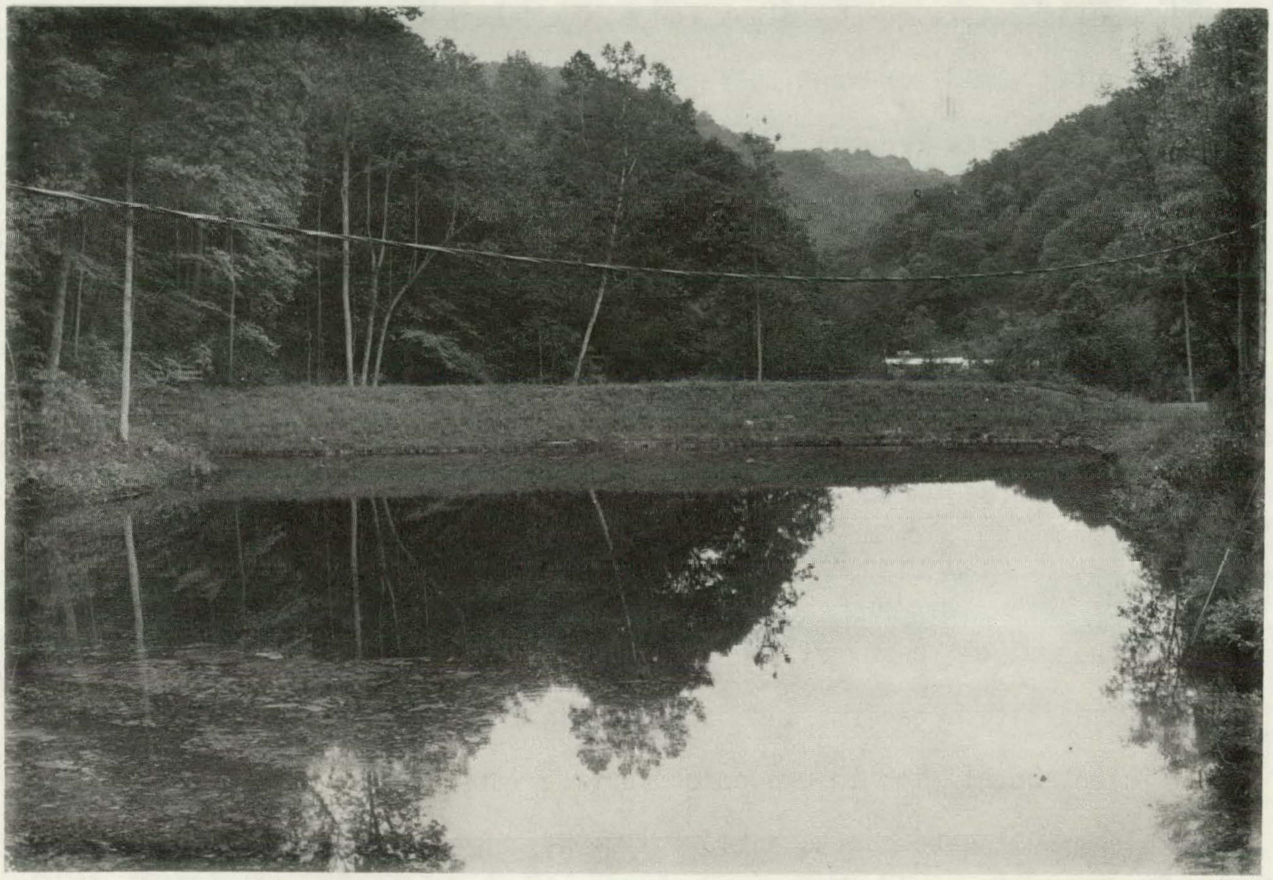

Fig. 5. Properly constructed and maintained sediment ponds to control stream sedimentation.

Other potential problems include seepage of pollutants from waste disposal pits and accidental spills of oil, brine, or other chemicals. The occurrence of accidental spills requires spill-prevention control and countermeasure (SPCC) plans for early detection and control of pollutants. Spill prevention regulations of the U.S. Environmental Protection Agency require the construction of dams, dikes, and culverts, and also surface-water monitoring. The quality of surface waters is further regulated in accordance with the Water Pollution Control Act (P.L. 92-500), the Safe Drinking Water Act (P.L. 92-523), and the Toxic Substances Control Act (P.L. 94-469) (Booz-Allen and Hamilton 1978).

Groundwater Contamination

Enhanced oil recovery processes use water-soluble chemicals, which may be toxic to organisms and carcinogenic to man if transported in sufficient quantities to ground or surface waters. For example, some petroleum sulfonate surfactants, polymers, and biocides used in the micellar-polymer technique are known to be toxic to some organisms (Booz-Allen and Hamilton 1978, Braxton et al. 1976).

Groundwater can be contaminated by: (1) thermal processes that increase subsurface temperatures and pressures leading to increased solubility of potentially hazardous compounds contained in underground formations; (2) carbon dioxide containing hydrogen sulfide; (3) seepage of chemicals and brine from waste disposal pits, especially those that are unlined; (4) escape of brines and chemical-laden produced water from oil-depleted reservoirs or disposal formations; and (5) long-term migration of chemicals by natural flow out of the reservoir into freshwater aquifers and eventually to surface waters (Braxton et al. 1976, Collins 1971). The last mechanism may cause problems long after completion of the project.

For groundwater to become contaminated, communication must exist between the pollution source and the groundwater system, or between saltwater and freshwater aquifers that are hydraulically connected. Communication and translocation of potential contaminants (e.g., brine, oil, chemicals) can occur from broken or corroded well casings in both active and abandoned wells, and through underground drainage channels, fractures, and faults (Fig. 6). In addition to extraction of contaminated groundwater from wells, freshwater zones that become polluted may have natural surface outlets (springs) that are used for drinking by humans and wildlife. In active oil fields, operators generally inspect and maintain well casings on a regular basis to reduce the possibility of well failure. Yet, casing failures with subsequent leakage do occur, as evidenced by the long-standing pollution of freshwater aquifers in and near some oil fields. Failure of well casings has been a major operational problem in several EOR demonstration projects (Noran 1978).

The potential for groundwater contamination depends on the EOR process, the age of the wells, and other interrelated site-specific characteristics such as local geochemical conditions, the number of oil wells, and seismic activity (Braxton et al. 1976). The EOR method used may increase the risk of groundwater pollution by accelerating corrosion of well casings and by further increasing fluid pressure at

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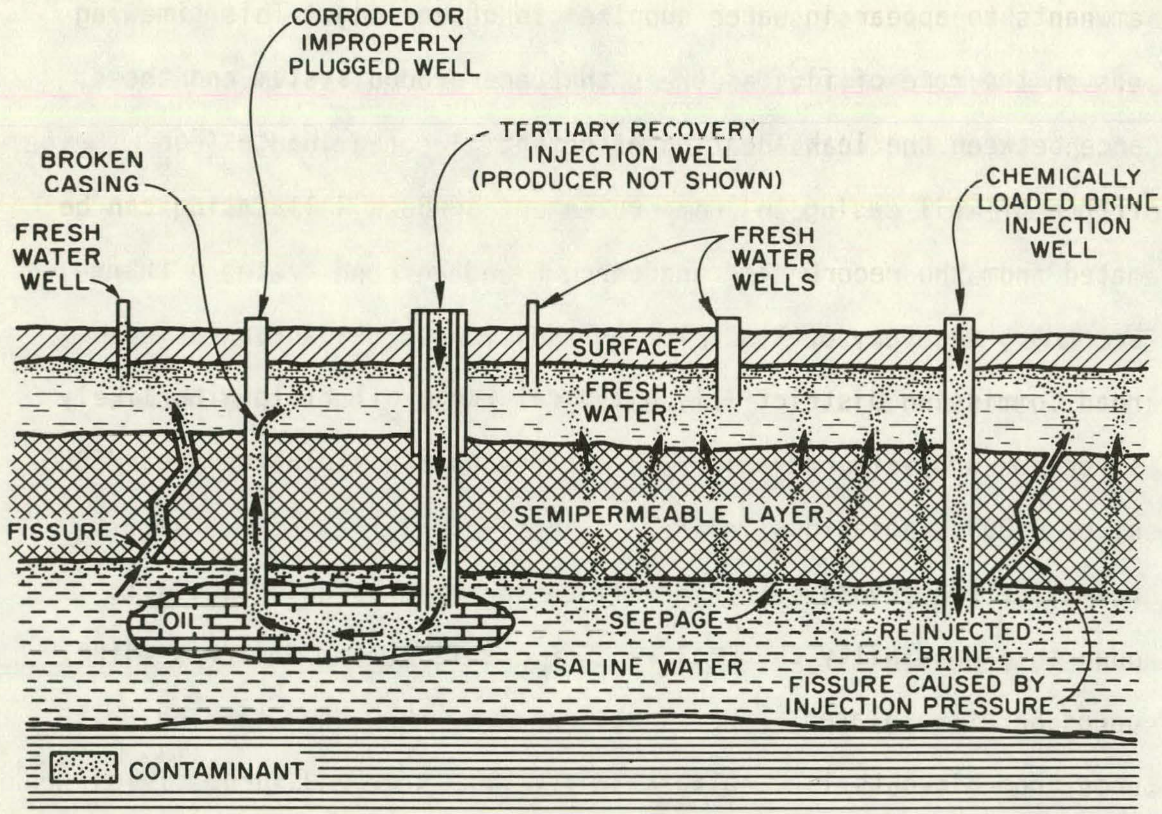

Fig. 6. Potential paths of groundwater contamination during EOR operations.

depth, leading to the formation and propagation of fractures. The chances of well failures also increase with age of the wells (Braxton et al. 1976).

The causal relationship between specific failures of well casings and groundwater contamination is difficult to assess, since the time for contaminants to appear in water supplies is often long. This time lag depends on the rate of fluid flow in the underground system and the distance between the leak and freshwater source. The chances for occurrence of well casing failures during or after EOR operation can be estimated from the record of groundwater contamination during primary and secondary recovery operations. A study of well failures in Texas Railroad Commission District III, a typical large oil field with likely sites for EOR projects, revealed five water quality violations/year/8000 wells, or 0.0006 violations/year/well (Braxton et al. 1976). This figure may be conservative, with additional violations undetected. Although this probabilty can be used as a guide to many oil reservoirs, it cannot be extrapolated to all areas. For example, the risk of well failures from blowouts is considerably greater in geopressured fields, such as those along the Gulf Coast, than in nonpressured fields.

The failure of abandoned, poorly plugged wells is also a potential problem for many EOR projects, particularly in old oil fields in the northeast. In areas with improperly plugged wells, freshwater aquifers have been polluted for as long as 50 years, and are likely to remain so for the foreseeable future. Because EOR projects are located in existing oil fields and operational procedures are similar to those of conventional waterfloods, it is necessary to locate, plug, or replug all abandoned and improperly maintained wells within and near the injection pattern to prevent possible migration of reservoir fluids to ground or surface waters. In old oil fields this task may be costly and difficult because the locations of such wells are not always known. Furthermore, many wells were abandoned before drilling and well-plugging permits were required. In addition to these water quality problems, each EOR technique is associated with potential, process-dependent impacts discussed in the following paragraphs.

A major potential problem with micellar-polymer flooding is the large quantities of chemicals that will be present in the oil-producing formation after EOR operations cease. Field-wide application of the micellar-polymer technique will result in large usage of these chemicals, thereby increasing the possibility of their migration to uncontaminated freshwater sources. In laboratory tests, retention of sulfonate (one of the chemicals used in this technique) within a typical midwestern oil-bearing sandstone amounted to an average of about 1 kg/m^3 (2500 lb/ac-ft), or 89% of the injected micellar fluid, and polymer retention was 13 g/m^3 (36 lb/acre-ft) or 30% of the injected polymer (Walker et al. 1976). In the field, most of the chemicals and water that appear at producing wells are disposed of by pumping into underground strata or into a ground-surface waste disposal pit. A small amount of sulfonate, which partitions into the oil phase, is generally piped to the refinery.

Most, but not all, chemicals used in EOR projects are considered to be relatively nontoxic (Braxton et al. 1976, National Petroleum Council 1976). However, there is little information in the literature on the toxicity and carcinogenicity of many other chemicals with potential use in EOR processes (Booz-Allen and Hamilton 1978, Braxton et al. 1976, National Petroleum Council 1976, Collins 1971). More information is needed for these chemicals to determine whether they should be used, and, if so, to establish adequate safeguards for their use and handling. For example, there is some evidence for the synergistic interaction between sulfonate surfactants and known compounds in crude oils which increases the solubilization of toxic fractions of the crude oil (Braxton et al. 1976). This solubilization may increase penetration of the organic toxicants through membrane barriers of organisms.

Specific water quality problems associated with in situ combustion include: (1) formation of water-soluble, secondary chemical compounds (e.g., metals and metal oxides) in the reservoir during the high temperature combustion process; (2) corrosion and erosion of well casings, particularly by hot sand, resulting in fluid leaks; and (3) improper disposal of low pH produced water containing small amounts of oil and residues of metallic substances from the crude oil.

There are no unique impacts on water quality from the CO_2-injection technique, but there are impacts not peculiar to CO_2 flooding such as an increased probability of casing corrosion of producing wells and possible leaks of H_2S (Braxton et al. 1976).

An additional problem area associated with all EOR techniques, not directly related to groundwater contamination, is the impact that may arise from local water shortages and encroachment of brine into freshwater aquifers. Most current EOR pilot projects use freshwater, excessive consumption of which could result in localized drawdown of water supplies. This may deter widespread application of EOR processes in the Interior Basin and Mountain Regions of the United States, which already face the prospect of severe water shortages (Braxton et al. 1976).

In summary, the possibility of groundwater contamination during EOR operations deserves close attention and will be a serious concern in areas where groundwater is a principal component of the water supply, e.g., central and coastal California. Federal legislation (e.g., Federal Water Pollution Control Act) and state regulations have provided rules and guidelines for the protection of water quality, but more data are needed on the concentration, toxicity, carcinogenicity, and synergistic reactions of chemicals that remain in the oil reservoir or appear in effluents. In areas with freshwater aquifers, groundwater monitoring programs should be instituted on a routine basis for all planned EOR projects (Booz-Allen and Hamilton 1978).

Air Pollution

Except for thermal projects, air emissions from EOR processes are not considered excessive on the basis of current standards, because well pumps are usually driven by electric motors instead of by internal combustion engines. However, steam generators used in steam-injection processes could produce significant emissions of sulfur dioxide, oxides of nitrogen, and suspended particulates; therefore, periodic sampling of the stack gases may be needed (Booz-Allen and Hamilton 1978, Braxton et al. 1976). Additional data are also needed on the characterization of hydrocarbon emissions generated during in situ combustion and steam displacement. Emissions from EOR processes are regulated in accordance with the Clean Air Act Amendments of 1977 (P.L. 95-95), and regular monitoring of potentially significant emissions is required (U.S. Congress 1977).

THE MATRIX: APPROACH AND TERMS USED FOR EVALUATION OF STATE REGULATORY PROGRAMS

Our approach in evaluating and comparing state regulations for oil operations is a matrix of selected environmental protection, mitigation, and monitoring indices and the requirements of each state's oil-regulatory program (Table 1). The indices, which include environmental evaluation and review, monitoring, abandonment plans, and reclamation plans for the operation, are grouped in three categories: (1) preoperation, (2) operation, and (3) postoperation. References to state legislation and administrative agencies are listed in columns two and three, respectively, and a directory to state information sources is provided in Appendix A. Selected terms are defined in Appendix B. All states are listed in Table 1, although nine (Connecticut, Hawaii, Maine, Massachusetts, Minnesota, New Hampshire, Rhode Island, Vermont, and Washington) have no recoverable reserves, and therefore no rules and regulations for oil operations (Miller et al. 1975).

Laws other than those we have considered (e.g., Federal Clean Air and Water Pollution Control Acts and additional state air and water pollution laws) may be applied to EOR operations as they are still applicable, and the regulatory agency is ultimately responsible, even

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Table 1. State programs for prevention of environmental impacts from oil-recovery operations[a]

State	State legislation	Administrative agency(ies)	Specific requirements for enhanced oil recovery (EOR)	Preoperation							Operation					Postoperation						
					Environmental Evaluations and Reviews Required							Monitoring Requirements				Abandonment and Reclamation Procedures						
				Permit required to drill or reopen well	Predrilling site inspection	Reclamation plan	Land use plan	Historic archeologic inventory	Spill prevention and accident control plan	Detailed analysis (EIS, EIA or equivalent)	Regulations covering disposal of waste material	Surface waters	Ground waters	Air quality	Terrestrial	Notice and/or permit required to abandon and plug	Bond required	Regulatory agency must witness plugging or inspect completed well	Restore site to approximate original contour	Revegetate disturbed areas	Remove all facilities and equipment	Other rules or remarks
Alabama	Alabama Order No. 76-100 (1977, 1979)	State Oil and Gas Board	X Rules for additional recovery methods are probably applicable to EOR	X					Only if H_2S is expected to be present		X		For disposal wells	Only if H_2S is present or expected		X	X					Requires storage pits be "returned to near natural state"
Alaska	Alaska statutes and admin. codes	Dept. of Natural Resources, Div. of Lands		X	Most of the oil and gas deposits of Alaska lie on federal lands and are thereby regulated by the appropriate federal agency												When leasing state lands					Some state rules pertain to oil and gas leasing of state land
Arizona	Title 27, Chap. 4 (1971)	Oil and Gas Conservation Commission	X EOR projects are probably covered by rules for the injection of substances for additional recovery	X							X					X	X					
Arkansas	Order No. 2-39 revised 1972	State Oil and Gas Commission	X Rules for repressuring with liquids are probably applicable	X							Must submit a disposal plan as a condition to drill					X	For pulling casings	X				Restoration decided by operator and land owner
California	Public Resources Code; Environ. Quality Act	Dept of Conservation, Div. of Oil and Gas	X Detailed plan required for EOR	X							X	May be required	X			X	X		"Returned to as near a natural state as possible"	X	X	
Colorado	Oil and Gas Conservation Act and amendments	Oil and Gas Conservation Commission	X Rules and regulations for secondary recovery are probably applicable to EOR	X							X					Detailed report of plugging required within 30 days of completion	X		"As nearly as possible to its condition at the beginning of the lease"	X		Land owner may specify post-land use
Connecticut				Connecticut has no specific legislation concerning oil and gas operations, since no known reserves occur there.																		
Delaware	Water and Air Resources Act, Title 7, Part VI, Chap. 64 (1971)	Dept. of Natural Resources and Environmental Control; Water and Air Resources Commission		X							X					X		A representative must be present at time of plugging				When leasing state land for oil or gas, many environmental factors are considered; commission may consult with other state agencies
Florida	Chap. 377, Florida statutes	Dept. of Natural Resources, Div. of Resource Management	X	X	X	X	X	If a federal or state EIS is required	If H_2S is expected (includes training programs and drills)	May be required if operation is to be in an environmentally sensitive area; EIS is required for permission to drill in a national or state forest or park	X			Only if H_2S is expected or present		X	X	X	Including access roads	X	X	Efforts taken to minimize the impact on fish and wildlife
Georgia	Act No. 366	Dept. of Mines, Mining, and Geology, Environ. Protection Div.		X												X	X					Agency may send a representative to supervise plugging

Table 1 (continued)

State	State legislation	Administrative agency(ies)	Specific requirements for enhanced oil recovery (EOR)	Preoperation: Permit required to drill or reopen well	Preoperation: Environmental Evaluations and Reviews Required: Predrilling site inspection	Reclamation plan	Land use plan	Historic archeologic inventory	Spill prevention and accident control plan	Detailed analysis (EIS, EIA or equivalent)	Operation: Regulations covering disposal of waste material	Operation: Monitoring Requirements: Surface waters	Ground waters	Air quality	Terrestrial	Postoperation: Abandonment and Reclamation Procedures: Notice and/or permit required to abandon and plug	Bond required	Regulatory agency must witness plugging or inspect completed well	Restore site to approximate original contour	Revegetate disturbed areas	Remove all facilities and equipment	Other rules or remarks
Hawaii				Hawaii has no specific legislation concerning oil and gas operations, since no known reserves occur there.																		
Idaho	Oil and Gas Conservation Act	Oil and Gas Conservation Committee, Dept. of Lands	X Rules for secondary recovery may be applicable to EOR	X							X					X	X					Earthen storage pits inspected yearly
Illinois	Oil, Gas, and Coal Act	Dept. of Mines and Minerals; Div. of Oil and Gas	Rules for secondary recovery may be applicable to EOR	X												X	X	X	"As nearly as possible in the same condition when encountered"	X	X	Earthen storage pits inspected yearly
Indiana	Indiana Code (IC) 1971, 13-4-7 amended 1972	Dept. of Natural Resources	Rules for secondary recovery may be applicable to EOR	X							X					X	X		"Nearly as possible to the condition prior to drilling"	Must "restore the surface" to the condition it was prior to drilling	X	
Iowa	Chap. 12 of Natural Resources Council Rules	Natural Resources Council, Geological Survey		X												X	X					Prohibited from drilling on a flood plain; a representative may be required to attend plugging
Kansas	Kansas statutes 55-146 and 77-415 et. seq.	Corporation Commission of Kansas	X Rules for injecting liquids into a well are probably applicable to EOR	X							X A trial test may be required					X						
Kentucky	Kentucky statutes, Chap. 353	Dept. of Mines and Minerals; Div. of Oil and Gas		X												X	X					Storage pits required to be filled
Louisiana	Act No. 157 of 1949 and numerous state orders and amendments	Dept. of Conservation; Div. of Minerals									X					X	May be required					Strict rules for underground storage of liquids
Maine				Maine has no specific legislation concerning oil and gas operations, since no known reserves occur there.																		
Maryland	Act 41, Sect. 9 of Maryland Codes; Coastal Facilities Review Act	Dept. of Natural Resources; Maryland Geological Survey		X						EIS required if drilling on or off coast; local county must approve coastal projects first	X					X	X		Only for coastal projects	For coastal projects		
Massachusetts				Massachusetts has no specific legislation concerning oil and gas operations, since no known reserves occur there.																		
Michigan	Act. 61 P.A. 1939 and Act 197 P.A. 1959	Dept. of Natural Resources; Div. of Geology	X Public hearing required to receive evidence and testimony on additional recovery methods	X							X					Agency will issue plugging instructions	X				X	Storage pits must be filled and leveled
Minnesota				Minnesota has no specific legislation concerning oil and gas operations, since no known reserves occur there.																		

Table 1 (continued)

State	State legislation	Administrative agency(ies)	Specific requirements for enhanced oil recovery (EOR)	Preoperation: Permit required to drill or reopen well	Preoperation – Environmental Evaluations and Reviews Required: Predrilling site inspection	Reclamation plan	Land use plan	Historic archeologic inventory	Spill prevention and accident control plan	Detailed analysis (EIS, EIA or equivalent)	Operation: Regulations covering disposal of waste material	Operation – Monitoring Requirements: Surface waters	Ground waters	Air quality	Terrestrial	Postoperation – Abandonment and Reclamation Procedures: Notice and/or permit required to abandon and plug	Bond required	Regulatory agency must witness plugging or inspect completed well	Restore site to approximate original contour	Revegetate disturbed areas	Remove all facilities and equipment	Other rules or remarks
Mississippi	Title 53	Oil and Gas Board; Air and Water Pollutions Control Commission		X							X					X						Storage pits shall be back-filled, leveled and compacted
Missouri	Code of State Regulations 10 CSR 50-1 through 5	Oil and Gas Council	X Encourages tertiary oil recovery and other research projects	X							X					X	X					
Montana	Oil and Gas Conservation Act of 1953	Oil and Gas Conservation Commission; Dept. of Lands	Rules for gas and water injection may be applicable to EOR	X							X					X	X		"In so far as such restoration is practicable"	X	X	Restoration must be approved for bond release
Nebraska	Chap. 57 Revised statutes	Oil and Gas Commission	X	X							X					Report required	X		"Land restored to the reasonable satisfaction of the director"	May be required		Pits back-filled and leveled
Nevada	Chap. 202 Nevada statutes	Oil and Gas Conservation Commission	Rules for secondary recovery may be applicable to EOR	X							X					Report required	X					
New Hampshire				New Hampshire has no specific legislation concerning oil and gas operations, since no known reserves occur there.																		
New Jersey	N.J.S.A. 58:4A-5 et seq.	Dept. of Conservation and Economic Development		X												X						Rules apply to all types of wells
New Mexico	N.M. statutes Chap. 65, Art. 3, 9, 13, 14; special orders No. R-1670, R-111-A, and R-3221	Oil Conservation Commission	X Rules for injecting chemicals into a well for additional recovery may be applicable to EOR	X							X					Report required	X	X			X	Pits filled, leveled, and location cleared of "junk"
New York	N.Y. statutes Chap. V, Subchap. B, Part 550-558	Dept. of Environmental Conservation	X Rules for secondary recovery may be applicable	X							X					X	X	X	"Reasonable effort to smooth the surface in a condition similar to the adjacent terrain"	X	X	Surface restoration must be approved by the regulatory agency
North Carolina	Oil and Gas Conservation Act	Dept. of Natural and Economic Resources		X							Disposal plan needed in order to drill					Agency determines the proper plugging procedure	X	X				
North Dakota	N.D. statutes Chap. 38-08	Industrial Commission of N.D.		X							Disposal facilities must be inspected					X	X					Retaining walls of a surface storage pit are monitored
Ohio	Ohio Revised Code, Chap. 1509	Dept. of Natural Resources; Div. of Oil and Gas	X Rules for secondary recovery may be applicable	X							Disposal plan required in order to drill					X	X		"Shall grade, terrace, plant, sod, or seed the distrubed areas to bind the soil . . ."		X	

Table 1 (continued)

				Preoperation							Operation					Postoperation						
					Environmental Evaluations and Reviews Required							Monitoring Requirements				Abandonment and Reclamation Procedures						
State	State legislation	Administrative agency(ies)	Specific requirements for enhanced oil recovery (EOR)	Permit required to drill or reopen well	Predrilling site inspection	Reclamation plan	Land use plan	Historic archeologic inventory	Spill prevention and accident control plan	Detailed analysis (EIS, EIA or equivalent)	Regulations covering disposal of waste material	Surface waters	Ground waters	Air quality	Terrestrial	Notice and/or permit required to abandon and plug	Bond required	Regulatory agency must witness plugging or inspect completed well	Restore site to approximate original contour	Revegetate disturbed areas	Remove all facilities and equipment	Other rules or remarks
Oklahoma	Okla. statutes Order No. 128501, 128534, 128781	Corporation Commission, Div. of Oil and Gas Conservation	X Rules for secondary recovery may be applicable	X							Disposal plan published in newspaper					X	X	X				
Oregon	Misc. Paper No. 4, Part 1	Dept. of Geology and Mineral Resources		X							X					X	X					Reclamation of oil sites may be covered by another agency's rules
Pennsylvania	Pa. Gas Operations, well-drilling, petroleum and coal mining act	Dept. of Environmental Resources, Div. of Oil and Gas		X		Included in the erosion and sedimentation plan					X					X	X		X	X	X	Requires an erosion and sedimentation plan to be prepared for all earthmoving activities
Rhode Island				Rhode Island has no specific legislation concerning oil and gas operations, since no known reserves occur there.																		
South Carolina	Act to regulate exploration, drilling, transporting, and production of oil and gas	Water resources Commission		X							X					X	X					Sea coast, estuaries, beaches shall be maintained in as "close as a pristine condition as possible"
South Dakota	S.D. statutes; Rules of the Board	Geological Survey; Bd. of Natural Resources Development	X Injection of any foreign substance into a well requires a permit	X							X					X	X					
Tennessee	Title 60; Oil and Gas and other Acts; Order No. 2	State Oil and Gas Board		X							X					Detailed plan required	X	Will check progress				Detailed plugging plan required
Texas	Title 102, Texas statutes; Docket No. 20-65518	Railroad Commission of Texas; Oil and Gas Div.	X Rules for fluid injection may be applicable to EOR	X							X					X	X					
Utah	Oil and Gas Conservation Act	Dept. of Natural Resources, Oil and Gas Div.	X	X							X					X	x					
Vermont				Vermont has no specific legislation concerning oil and gas operations, since no known reserves occur there.																		
Virginia	Title 45.1 chap. 12 chap. 12	Dept. of Labor and Industry; Oil and Gas Board		X												X	X					
Washington	Oil and Gas Conservation Act	Dept. of Natural Resources; Oil and Gas Conservation Committee		X							X					X	X					
West Virginia	Admin. Regs. chap. 22-4A, 22-4	Dept. of Mines, Oil, and Gas Division	X EOR projects covered under the heading of "additional recovery methods"	X		X					X					Detailed report required	X		"Operator . . . shall reclaim the land surface . . ."	X	X	
Wisconsin				Wisconsin has no specific legislation concerning oil and gas operations, since no known reserves occur there.																		
Wyoming	Rules, regs. and orders of the commission	Oil and Gas Conservation Commission	X Rules for "other recovery operations" are applicable to EOR	X							X					Detailed report required	X		Shall not "unreasonably damage the surface of the land"	May be required		

*When State regulations address the index identified in the Table heading, this is indicated with an "X" or a brief statement. The column is left blank if there are no such regulations.

where authority has been delegated to another agency. However, we have not assumed that such laws will be implemented for specific oil operations if they are not cited in the state's oil regulations. A survey of applicable federal laws is presented in Booz-Allen and Hamilton (1978). Although the state oil regulations we evaluated are current, it should be noted that the regulations and information in Table 1 and Appendix A are subject to change.

RESULTS AND CONCLUSIONS

All 41 states that have regulations governing oil operations require well-drilling permits, but only 19 require specific permits for EOR operations, and, except for Arkansas, all have specific rules for plugging abandoned wells. Thirty six states (88%) require posting of a bond and 38 (93%) have strict rules for disposal of wastes such as brine, injection chemicals, and oil-laden water. However, other environmental rules and regulations are frequently lacking. For example, only 13 (31%) of the states require reclamation of disturbed sites. Requirements for restoring land to its previous use and productivity and returning disturbed areas to their approximate original contour, including the elimination of highwalls, are not well defined; these requirements are characterized by such vague phrases as "reasonable effort," "as nearly as possible," and "insofar as practical." In states without reclamation requirements, many operators cooperate voluntarily with the state regulatory agency and landowners in reclaiming disturbed sites. However, we have seen examples of abandoned, unreclaimed oil fields littered with buildings, broken equipment, pipes, and other debris.

Evaluation of reclamation plans before beginning a project is required only by Florida, Pennsylvania, and West Virginia; only Florida, which has little recoverable oil, requires a land-use plan and a predrilling site visit and evaluation. Florida also requires an environmental impact analysis (EIA) of the proposed project if it is to be located in an environmentally "sensitive area"; Maryland requires an EIA for coastal projects only. In Florida and Maryland, recommendations in the EIA may lead to more stringent environmental protection measures than those listed in Table 1.

Conspicuously absent in most state programs are requirements for land (e.g., biotic inventories, soil analyses, erosion), air quality, and water quality monitoring programs. Monitoring to detect impacts to terrestrial ecosystems is not required by any state; water monitoring programs are required only by Alabama and California; and, only Alabama and Florida have air quality monitoring requirements, but they are only applicable if hydrogen sulfide is expected or present during project activities. Most states require the recording of chemical injection rates. Five states (Alabama, California, Florida, Pennsylvania, and Texas) have contingency-plan requirements for accidents and spills.

We conclude that state environmental protection requirements for oil operations are not only unsatisfactory for EOR projects, but may also be unsatisfactory for oil recovery by conventional methods. Because of the potential environmental impacts from both conventional and EOR processes, we believe that there is an urgent need for more stringent and uniform reclamation and monitoring requirements by most states. Most reclamation requirements are too general and are directed more toward the correction instead of prevention of environmental impacts. We believe more effort should be placed on implementation of environmental protection and control measures during critical stages of project development. This effort should include requirements and guidelines for describing and evaluating environmental conditions before project construction, and the use of this information for planning and implementing monitoring and other programs for preventing and mitigating impacts. Some EOR methods are identical or similar to conventional methods. However, the use of heat and injection of chemicals new to the industry (especially in micellar-polymer flooding) demand the monitoring of groundwater quality, because the movement of chemicals in groundwater systems affected by these processes is poorly understood.

In the past, oil-industry practices have included few of the environmental protection measures which will likely be required in future EOR projects. Most state oil-regulatory programs are not designed to administer the stringent regulations required by recent federal environmental legislation, yet most of the regulation and enforcement responsibilities for oil operations are assumed by the states. Some operators and state personnel charged with investigation and enforcement may have little or no experience in dealing with current environmental requirements; consequently they may not be familiar with the best available technology for controlling environmental impacts. Therefore, states should continue to strengthen and upgrade their oil-regulatory programs. Florida, which has the most comprehensive environmental regulations for oil operations, could serve as a model for other states.

We believe the real challenge to decision-makers and project officers is to recognize weaknesses in rules and regulations at the planning stage of project development. Once such weaknesses are realized, a contract that provides for prevention and mitigation of potential impacts can be prepared and used until state regulations are updated to correct inadequacies. We do not advocate the promulgation of strict, inflexible rules and regulations that place unreasonable demands on EOR or other oil-recovery operations. However, by recognizing potential environmental impacts as early as possible at various stages of development, appropriate environmental control and protection measures can be planned and implemented. Thus, minimal loss of production and optimal environmental protection will result. We hope this report will be helpful in achieving this goal.

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APPENDIX A

A State Directory of Information on Environmental Protection and Reclamation of Oil Recovery Sites

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A State Directory of Information on Environmental Protection and Reclamation of Oil Recovery Sites

State	Agency	Contact	Location
Alabama	State Oil & Gas Board	Ralph W. Adams Chairman	P.O. Drawer O, Univ., AL 35486 (205-349-2852)
Alaska	Dept. of Nat. Resour. Div. of Lands	Robert E. LeResche	323 E. 4th Ave., Anchorage, AK 99501 (907-279-5577)
Arizona	Oil & Gas Conserv. Comm. of Arizona	John Bannister Executive Secretary	1645 W. Jefferson, Suite 420, Phoenix, AZ 85007 (255-271-5161)
Arkansas	Oil & Gas Comm.	Ralph Dumas Commissioner	314 E. Oak St., Eldorado, AR 71730 (501-862-4965)
California	Dept. of Conserv. Div. of Oil & Gas	M. G. Mefferd Supervisor	1416 9th St., Room 1316, Sacramento, CA 95814 (916-322-7683)
Colorado	Oil & Gas Conserv. Comm.	Douglas V. Rogers	Room 721, 1313 Sherman St., Denver, CO 80203 (303-839-3531)
Connecticut	Dept. of Environ. Protection	Stanley J. Pac, Commissioner	State Office Bldg., 165 Capital Ave. Hartford, CT 06115 (203-566-5599)
Delaware	Dept. of Nat. Resour. & Environ. Control	Austin P. Olney, Acting Secretary	Edward Tatnall Bldg., Legislative Ave., & William Penn St., Dover, DE 19901 (302-678-4403)
Florida	Dept. of Nat. Resour.; Div. of Resour. Manage. Bur. of Geol.	Harmon Shields	Oil & Gas Adm., 903 West Tennessee St., Tallahassee, FL 32304 (904-488-1555)

APPENDIX A (continued)

State	Agency	Contact	Location
Georgia	Dept. of Nat. Resour.	Joe D. Tanner	270 Washington St., SW, Atlanta, GA 30334 (404-656-3530)
Hawaii	Dept. of Lands & Nat. Resour.	William Y. Thompson	Box 621, Honolulu, HI 96809 (808-548-6550)
Idaho	Oil & Gas Conserv. Dept. of Lands	Gordon Trombley Director of Dept. of Lands	Dept. of Lands, Statehouse, Boise, ID 83720 (208-384-3280)
Illinois	Dept. of Mines & Minerals, Div. of Oil & Gas	George R. Lane Petroleum Engineer	Room 704, William G. Stratton Bldg. Springfield, IL 62706 (217-782-7756)
Indiana	Dept. of Nat. Resour. Div. of Oil & Gas	Joseph Cloud Director	606 State Office Bldg., Indianapolis, IN 46204 (317-633-6344)
Iowa	Iowa Nat. Resour. Counc.	James R. West	Wallace State Bldg., East 9th & Grant St. Des Moines, IA 50319 (515-281-5913)
Kansas	Conserv. Div. of State Corp. Comm. of the State of Kansas	J. Louis Brock Administrator	245 N. Water, Wichita, KA 67202 (316-263-3238)
Kentucky	Dept. Mines & Minerals, Div. Oil & Gas	H. N. Kirkpatrick	P.O. Box 680, 120 Graham Ave., Lexington, KY 40586 (502-564-3019)
Louisiana	Dept. of Conserv. Div. of Minerals	R. T. Sutton Commissioner of Conservation	St. Office of Conserv., P.O. Box 44275, Capital Station, Baton Rouge, LA 70804 (504-389-5161)
Maine	Dept. of Conserv.	Richard Barringer Commissioner	State Office Bldg., Augusta, ME 04333 (207-289-2212)
Maryland	Dept. of Nat. Resour. Maryland Geol. Surv.	James Coulter, Secretary Kenneth Weaver, Director	Dept. of Nat. Resour., Tawes State Office Bldg., Annapolis, MD 21401 (301-269-3041)

APPENDIX A (continued)

State	Agency	Contact	Location
Massachusetts	Exec. Office of Environ. Affairs	Evelyn Murphy Secretary	Leverett Saltonstall Bldg., 100 Cambridge St., Boston, MA 02202 (617-727-7700)
Michigan	Dept. of Nat. Resour.	Howard Tanner Director	Box 30028, Lansing, MI 48909 (517-373-1220)
Minnesota	Dept. of Nat. Resour.	William Nye Commissioner	300 Centennial Bldg., 658 Cedar St., St. Paul, MN 55155 (612-296-2549)
Mississippi	State Oil & Gas Board	Clyde Davis Supervisor	1405 Woolfolk Bldg., P.O. Box 1332, Jackson, MS 39205 (601-354-7104)
Missouri	Dept. of Nat. Resour. Oil & Gas Counc., Div. of Geol. & Land Surv.	Wallace Howe Administrator	P.O. Box 250, Rolla, MO 65401 (314-364-1752)
Montana	Dept. Nat. Resour. & Conserv., Board of Oil & Gas	J.C. Orth Director R.A. Campbell Chairman	32 S. Ewing, Helena, MT 59601 (406-449-3647)
Nebraska	Nebraska Oil & Gas Conserv. Comm.	Paul Roberts Director	P.O. Box 399, Sidney, NE 69162 (308-254-4595)
Nevada	Dept. of Conserv. & Nat. Resour.; Div. of Mineral Resour.	Norman Hall	Capital Complex Nye Bldg., 201 S. Fall St., Carson City, NV 89710 (702-885-4380)
New Hampshire	Dept. of Resour. Econ. Dev.	George Gillman Commissioner	P.O. Box 856 St. House Annex, Concord, NH 03301 (603-271-2411)
New Jersey	Bur. of Geol. & Topography, Dept. of Environ. Protection	Kemble Widmer State Geologist	P.O. Box 2809, Trenton, NJ 08625 (609-292-2576)

APPENDIX A (continued)

State	Agency	Contact	Location
New Mexico	Oil Conserv. Comm.	P. R. Lucero Chairman J. D. Ramey Secretary & Director	P.O. Box 1148, State Fe, NM 87501 P.O. Box 2088, Santa Fe, NM 87501
New York	Dept. of Environ. Conserv.	Peter A. A. Berle Commissioner	50 Wolf Rd., Albany, NY 12233 (518-457-3446)
North Carolina	Dept. of Nat. & Econ. Resour.	Howard Lee Director	P.O. Box 27687, Raleigh, NC 27611 (919-733-4984)
North Dakota	Industrial Comm. of North Dakota, Nat. Resour. Counc.	Carolyn Fine	Governor's Office, State Capital, Bismark, ND 58585 (701-224-2200)
Ohio	Dept. of Nat. Resour., Div. of Oil & Gas	Robt. Teater Director Ted DeBrosse	Fountain Square, Columbus, OH 43224 (614-466-3770)
Oklahoma	Oklahoma Corp. Comm. Oil & Gas Conserv. Div.	Rex Privett Chairman	Room 228, Jim Thorpe Bldg., Oklahoma City, OK 73105 (405-521-2302)
Oregon	Dept. of Geol. & Mineral Industries	Donald A. Hull State Geologist	1069 State Office Bldg., Portland, OR 97201 (503-229-5580)
Pennsylvania	Dept. of Environ. Resour., Div. of Oil & Gas	Charles Updegraft	1205 Kossman Bldg., 100 Forbes Ave., Pittsburgh, PA 15222 (412-565-5075)
Rhode Island	Dept. of Nat. Resour.	Dennis Murphy	83 Park St., Providence, RI 02903 (401-277-2771)
South Carolina	S. C. Water Resour. Dev.	Lucas Dargan	P.O. Box 4515, 3830 Forest Dr., Columbia, SC 29240 (803-758-2514)
South Dakota	Dept. of Nat. Resour. Dev.	Vern W. Butler Secretary	Joe Foss Office Bldg., Pierre, SD 57501 (605-224-3151)

APPENDIX A (continued)

State	Agency	Contact	Location
Tennessee	State Oil & Gas Board	B. R. Allison Commissioner of Conservation	G-5 State Office Bldg., Nashville, TN 37219 (615-741-2301)
Texas	Railroad Comm. of Texas, Div. of Oil & Gas	Brooks Peden Sr. Legal Examiner	Ernest O. Thompson Bldg., Capital Station, P.O. Box Drawer 12967, Austin, TX 78711 (512-475-3003)
Utah	Dept. of Nat. Resour., Div. of Oil & Gas & Mining	Gordon Harmston	State Capital, Salt Lake City, UT 84114 (801-533-5356)
Vermont	Agency of Environ. Conserv. (Nat. Gas & Oil Resour. Board)	Martin Johnson Secretary	Montpelier, VT 05602 (802-828-3357)
Virginia	Dept. of Labor & Industry Div. of Mined Land & Reclamation	Edmond M. Boggs Commissioner William Roller	P.O. Drawer U, Big Stone Gap, VA 24219 (703-523-2925)
Washington	Dept. of Nat. Resour., Oil & Gas Conserv.	Frank Brouillet Commissioner	Public Lands Bldg., Olympia, WA 98504 (206-753-5327)
West Virginia	Dept. of Mines, Oil & Gas Div., Oil & Gas Conserv. Com.	Robt. L. Dodd Deputy Director Thomas Huzzey Commissioner	1613 Washington St., E. Charleston, WV 25311 (304-348-2754)
Wisconsin	Dept. of Nat. Resour.	Anthony S. Earl Secretary	Box 7921, Madison, WI 53707 (608-266-2621)
Wyoming	Oil & Gas Conserv. Comm.	Edward Boland	Wyoming Bldg., P.O. 2640, Casper, WY 82602 (307-234-7147)

APPENDIX B

GLOSSARY OF SELECTED TERMS

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GLOSSARY OF SELECTED TERMS

ABANDONED WELL: An oil well that is no longer maintained or in production.

AQUIFER: A zone, stratum, or group of strata that can store and transmit water in sufficient quantities for a specific use.

BIOCIDE: A chemical used for killing living, usually aquatic, organisms.

BIOTA: The plants and animals of an area; flora and fauna.

BRINE: Water saturated with or containing a high concentration of sodium chloride and/or other salts.

CAPILLARY FORCE: A force due to adhesion, cohesion, and surface tension in oil or other liquids that are in contact with solids, thereby causing the liquid to move within the capillary tube.

CARCINOGEN: Any substance that tends to induce cancer.

CONVENTIONAL OIL RECOVERY: Use of natural pressure in the oil reservoir or flooding the reservoir with water to move oil to a production well.

EFFLUENT: A solid, liquid, or gas waste that enters the environment.

EMULSION: A non-settling suspension of one finely divided liquid in another.

ENHANCED OIL RECOVERY (EOR): Any oil-recovery process that uses heat (steam injection or in situ combustion), injection of gases (e.g., carbon dioxide, high pressure nitrogen), or chemicals (micellar-polymer flooding) to recover oil that could not be recovered by natural pressure in the oil reservoir or by waterflooding.

ENVIRONMENTAL MONITORING: A series of analyses of an environmental component (e.g., air, water) to detect changes in quality or biotic response. Analyses of pre- and postimpact samples can be used to detect presence and extent of an impact.

EROSION: Detachment and movement of soil or rock fragments by water, wind, ice, or gravity.

FRACTURE: Any discontinuity in a body of rock produced by force exerted upon it. Fractures include fissures (cracking or splitting apart) and faults (breaks in the rock strata that cause dislocation of the strata along the fracture line).

HIGHWALL: The unexcavated face of exposed overburden (i.e., soil, plants, and rocks and mineral) in an open road cut in hilly terrain, surface mine, or entry to an underground mine.

IMPROPERLY PLUGGED WELL: An unproductive or abandoned oil well that has not been plugged according to existing legal requirements; or that allows migration of oil, gas, water, or any injected substance to strata other than those in which they occur or have been placed.

IN-SITU COMBUSTION: A process that heats oil in the reservoir to increase its movement by decreasing its viscosity. Heat is applied by igniting the oil-sand and keeping the combustion zone active by the injection of air.

LEACHING: The removal from the soil of the more soluble materials by percolating waters.

MICELLAR-POLYMER FLOODING: Micellar describes the reactive chemical injected into an oil reservoir that breaks down the surface tension between oil and water causing them to emulsify and move as one liquid. Polymer is a general term for organic chemicals that thicken water. The thickened water helps to move the micellar-oil emulsion to production wells.

MISCIBLE: Two or more substances which are able to mix together. In oil recovery, the miscible agent (e.g., carbon dioxide) mixes with the oil, forming a single homogenous phase. This eliminates or reduces capillary forces, thereby increasing the flow of oil through reservoir rock.

MULCH: A natural or artificial layer of plant residue (e.g., straw) or other materials (e.g., sand or paper) on the soil surface.

OIL RESERVES: That portion of the identified oil resource that can be extracted economically.

ORIGINAL CONTOUR: The surface configuration of land before disturbance, with all highwalls and refuse piles eliminated by backfilling and grading.

RECLAMATION: The process of reconverting disturbed lands to their former uses or other productive uses.

RESTORATION: The process of returning a site to its original condition.

SECONDARY OIL RECOVERY: Injection of water or natural gas to augment natural reservoir pressure and force oil into production wells. Usually synonymous with conventional recovery.

SEDIMENT POND: Any natural or artificial impoundment area or depression used to remove sediment from water and store sediment or other debris.

SEDIMENTATION: The process of depositing sediment, which is solid material in suspension moved from its site of origin.

SOIL AMENDMENT: Any material, such as lime, sawdust, or synthetic conditioner, that is worked into the soil to make it more amenable to plant growth.

SURFACTANT: In oil recovery, surfactants are chemicals that reduce the contractible force between oil and water. Each surfactant molecule has a polar end that is attracted to water, and an organic chain that is attracted to oil.

SYNERGISTIC: Simultaneous actions of two or more substances which have a greater total effect than the sum of their individual effects.

TERTIARY OIL RECOVERY: Third-generation oil recovery using methods other than conventional ones (including waterflooding). Often used synonomously (but sometimes erroneously) with enhanced oil recovery.

TOXIC: Refers to any substance that produces a harmful biological effect, i.e., kills, injures, or impairs an organism.

VISCOSITY: The internal resistance offered by a fluid to flow; the more viscous a substance the slower it will flow.

WATERFLOODING: An oil-recovery operation in which water is injected into an oil reservoir to create a water drive to increase production. Usually considered to be a conventional and a secondary recovery operation.

WASTE DISPOSAL FORMATION: An underground stratum or strata used for disposal of wastes resulting from oil operations.

WASTE DISPOSAL PIT: A natural or man-made depression in the surface of the ground used for disposal of wastes associated with oil operations.

WELL CASING: A heavy metal pipe or tubing lowered into a borehole during or after drilling in order to support the sides of the hole and thus prevent the walls from caving, to prevent loss of drilling mud into porous ground, and to prevent unwanted fluids from entering the hole.

WELL PAD: Oil-well site and adjacent area.

WELL PATTERN: The pattern of location of injection and oil-production wells. In enhanced oil recovery projects, the most common pattern is the "five-spot," which consists of four injection wells surrounding a central production well. An "inverted five-spot" is the reverse pattern.

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