VI. Environmental Issues

VI. Environmental Issues

Physiographic Regions

For the purpose of this assessment, the continental United States was divided into four general types of physiographic regions, each of which has certain specific characteristics and vulnerabilities to environmental damage. The four physiographic regions are: 1) the Continental Shelf which includes the broad, shallow gulf coast shelf, the steeper sloping Atlantic shelf, and the narrow steep-edged pacific coast shelf; 2) the Coastal Plains adjoining the Pacific Ocean, Atlantic Ocean, and the Gulf of Mexico, particularly those of California, Texas, and Louisiana; 3) the Interior Basins, such as the Great Plains, Great Lakes, and the central valley of California; and 4) the Rocky *Mountains* and other mountainous regions.

Continental Shelf

The Continental Shelf, a shallow, flat, submerged land area at the margin of the continent, slopes gently downward away from the shoreline. The width of the shelf ranges from less than 5 miles along portions of the southern California coastline, to a few hundred miles along parts of the gulf coast. The topography of a shelf is highly dependent on its location; the Atlantic Continental Shelf is relatively flat and shallow compared to the deeper southern California borderland which has a series of parallel steep-walled ridges and subsea canyons.

Hazards common to all Continental Shelf oil recovery operations include tidal action, wave action, storm waves, and collisions with ships. In addition, hurricanes in the gulf and Atlantic coasts, landslides and earthquakes in the southern California borderland, difficulty of control, and unstable bottom substrate pose further hazards.

Coastal Plains

The Coastal Plains along the Atlantic and gulf coasts are as much as 100 to 200 miles wide, and make up nearly 10 percent of the land in the contiguous 48 states. With minor exceptions, the variance in elevation is less than 500 feet and for more than half of the Coastal Plains is less than 100 feet. This low topographic relief results in extensive marshy areas. Coastal marshes, estuaries, and near-shore waters are all considered part of the Coastal plains area. In contrast, the coastal plain in California is narrow, limited by the coastal mountains, and has a poorly developed marsh system.[1]

The geologic formations are quite young, usually Cretaceus, Tertiary, and Quaternary in age. These sedimentary deposits represent various onshore, nearshore, and offshore environmental depositions. The formations generally dip gently seaward and outcrop in belts roughly parallel to the inner and outer edges of the Coastal Plains.[2]

Although many coastal wetlands have been designated as wildlife refuges and recreation areas, large parts of the Nation's Coastal Plains are covered by major population centers. In the arid Southwest, Coastal Plain inhabitants rely heavily on local ground water supplies. The U.S. Coastal Plains which have the potential for the greatest EOR activity are those of southern California, Louisiana, and Texas.[3]

Interior Basins

The Interior Basins include all land areas of the United States except the mountainous areas and the Coastal Plains. Within the interior drainage basins, there are geologic basins which may contain large quantities of oil entrapped beneath the surface. Generally; the geologic formations are older than those in the Coastal Plains.

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[1]Charles B. Hunt, *Physiography of the United States,* W. H. Freeman and Company, San Francisco, Calif. 1967.

[2]Ibid.

[3]*Enhanced Oil Recovery,* National Petroleum Council, December 1976.

Some EOR activity is expected to take place in the Interior Basins, particularly those of the mid-continent and central California. Typically, the urban centers and farm areas of these basins depend heavily on local ground water supplies. The ground water aquifers of these basins are recharged by local rivers and by runoff from bordering mountains.

Mountain Ranges

The mountainous areas are rich in timber and minerals. Some EOR operations are anticipated in the Rocky Mountains, particularly in Wyoming. These mountain areas offer diverse benefits to society since they are prime wildlife and recreational areas; with their relatively high snowpack, they are frequently a major source of ground water for adjacent plains. These generally are remote unpopulated areas, where direct EOR impacts on the human population are limited but where adverse impacts on the natural environment can be significant.

Causes of Environmental Effects

The following elements and processes are common to all EOR methods: a recovery fluid; an injection system; surface processing; and disposal of spent materials.

The processes and the materials used within the confines of the system pose no environmental threat. Environmental problems result only when the materials are allowed to escape. The following mechanics may be responsible for such escape:

1) Transit Spills—Spills which may occur when material is being prepared at or transported to the field site.
2) Onsite Spills—Spills which may occur at the field site from surface lines and/or storage facilities.
3) Well System Failure--Escape of materials which may occur from failure of the injection or producing well due to casing leaks or channeling.
4) Reservoir Migration--Fluid may migrate outside of the confining limits of a reservoir through fractures or through a well bore which interconnects reservoirs.
5) Operations—The effects caused by routine activities and by the support facilities and activities associated with EOR production. To determine environmental problems during operations, the effect of each of the following must be considered: disposal of spent material; consumption of site-associated natural resources; discharge emissions; fugitive emissions; and off site supply and support efforts.

A simple matrix model was developed to compare the relative significance of environmental impacts from spills, well failure, reservoir leaks, and operations from thermal, miscible, and chemical EOR methods in each of the four physiographic regions. The matrix reflects a subjective assessment and relative ranking of the significance of potential impacts from negligible or nonexistent (1), to potentially significant (4). The values assigned on table 35 are comparable only when applied to a specific EOR process and environmental component such as thermal and air.

Table 35 relates to potential hazards from each EOR project by physiographic area. To **suggest** possible total impact of each EOR process, table 36 was developed. This matrix attempts to predict the relative degree of development of the EOR method as a function of the physiographic area. Should time and/or experience indicate different values, they could be substituted without invalidating the matrix presented.

By selecting the appropriate value from table 36 and multiplying it by the value for the same process and physiographic area on table 35, an estimate of the weighted environmental impact of any or all effects can be calculated. Table 37 is

Table 35
Matrix Evaluation of Relative Potential for
Environmental Impacts for Enhanced Oil Recovery
Impact Model [illegible]owing Relative Impacts of Process-Effect and Environmental Compon[illegible]

Process	Process of effect	Air				Water				[illegible]				Biota			
		CS	CP	m	MT	CS	CP	m	MT	CS	CP	m	MT	CS	CP	B	MT
Thermal	Spills	1	1	2	1	1	2	2	2	-	-	1	-	1	2	1	2
Steam	Well Failure	1	2	2	1	1	2	2	2	-	-	1	-	1	1	1	1
In Situ	Reservoir Leaks	1	1	2	1	1	2	2	2	-	-	1	v	1	1	1	1
Hot Water	Operational	2	4	3	2	2	3	4	3	-	-	1	.	2	4	4	4
Miscible	Spills	1	2	2	1	1	2	1	1	-	l-	1	l--	1	2	1	1
CO_2	Well Failure	1	2	2	1	1	2	2	2	-		1		1	2	2	2
Hydrocarbons	Reservoir Leaks	1	1	1	1	1	2	2	2	-	l-!-m	1	.-l-n	1	1	1	1
	Operational	2	3	3	2	2	2	3	2	-		2		2	4	3	3
Chemical	Spills	1	1	1	1	2	4	3	4	.	~	1	-	2	4	3	4
Polymer	Well Failure	1	1	1	1	2	3	2	3	.	-	1	-	2	3	2	3
Surfactant/	Reservoir Leaks	1	1	1	1	2	2	2	2	.	-	1	-	2	2	2	2
Polymer	Operational	2	2	2	2	2	3	4	3	r	m	2	-	2	4	4	4

Scale Units: From 1 negligible or nonexistent, to 4 the most significant.

CS - Continental Shelf; CP - Coastal Plains; IB - Interior Basins; MT - Mountains

EMARKS: Spills - Includes both onsite and transit spills of materials used in process.
Well Failure - Includes leaks from well system of EOR materials.
Reservoir Leaks - Includes the migration from the zone that the EOR process is operative into the external system.
Operational - Includes disposal of spent material, consumption of site natural resources, discharge emissions, and offstie supply of EOR materials.

the sum of each environmental component in a physiographic area times the appropriate value from table 36. After determining the value for each of the physiographic areas for an EOR process, they are total led and the value transferred to table 37.

The values in table 37 suggest possible relative environmental impacts. For example, chemical EOR projects may have the greatest potential for environmental impacts and thermal the least, or the biota may be the most impacted and land the least. Sweeping conclusions should be drawn with caution, however, because individual sites and production conditions for EOR, and thus possible environmental impacts, vary significantly from setting to setting.

Tabie 36
Potential Distribution of Environmental Impacts for Enhanced Oii Recovery

(Prediction of the Relative Degree of Development of the EOR Method as a Function of Physiographic Areas)

Method	Physiographic Area			
	Continental Shelf	Coastal Plain	Interior Basin	Mountains
Thermal. . .	1	4	2	2
Miscible . .	1	3	3	2
Chemical. .	1	3	4	2

SCALE UNITS: 1 - Improbable; 2- Negligible; 3- Moderate; 4- Significant; 5- Extensive

Table 37
Cross Plot of Environmental Impacts for Enhanced Oil Recovery

(This Model Cross Plots the Impact Matrix With the Distribution Model To Obtain a Relative Analysis of the Total Process Impacts)

Method	Environmental Components				
	Air	Water	Land	Biota	Total
Thermal .	65	79	36	67	247
Miscible .	63	67	46	88	264
Chemical	50	112	50	117	329
Total. . . .	178	258	132	272	

Potential Impacts on the Environment

There are at least seven media in which EOR operations could have environmental impacts: air, surface water, ground water, land use, seismic disturbances and subsidence, noise, and biological and public health. While each of the four physiographic regions can experience environmental repercussions in these seven media, certain types of impacts will be far more important in some regions than in others. For example, air pollution is a concern primarily in urbanized portions of the Coastal Plains and in Interior Basins where air quality is already in violation of Clean Air Act standards.[4] Similarly, land-use conflicts arise in heavily populated areas where land values tend to be high and multiple-potential uses exist for a given parcel of land. Ground water use and pollution is a grave concern in areas where ground water is a principal component of the water supply, such as in central and coastal California. Surface water pollution is important in areas with high surface runoff and at sites adjacent to surface water bodies. Noise is a concern in both urban and open areas, although natural ecosystems differ widely in their sensitivity to noise.

The matrix described previously attempts to identify the physiographic regions most likely to experience each type of environmental impact. The most likely means of generating these impacts are discussed below. Although some effort is made to quantify these impacts, it is not possible to do so precisely with the data available.

Air Quality Impacts

While all EOR methods (thermal, miscible, and chemical) can cause air pollution, thermal methods are most likely to generate air pollution impacts. Steam and hot-water flooding rely on steam generators. These generators usually use the fuel supply available on location (oil being

[4] *Monitoring and Air Quality Trends Report,* U.S. Environmental Protection Agency, Office of Air and Waste Management, 1976.

the most common fuel source), and emit sulfur dioxide (SO_2), oxides of nitrogen (NO_x), hydrocarbons, carbon monoxide (CO), carbon dioxide (CO_2, and other combustion products from exhaust pipes, In situ combustion can release these same compounds as fugitive emissions and as exhaust from high volume air compressors. These types of impacts from thermal EOR activities are likely to be localized and to be significant primarily in areas that are already in violation of, or are near the limits of, the Federal Ambient Air Quality Standards. In addition, NO_x released together with hydrocarbons escaping from the oil production process constitute a mixture with the potential to generate oxidant far downwind from the point of release. Further, nondegradation requirements may become important in remote areas.

The following sections discuss the mechanisms by which air quality impacts are generated and attempts to assess environmental air quality effects of various EOR methods in the four physiographic regions. The impact estimates are based on data which are now available. As more data become available, more meaningful projections of air pollution impacts will be possible.

Air Pollution Impacts of Thermal Recovery Methods

Although some estimates of the air pollutant emissions from steam flooding projects are available, there are very few quantitative data. Estimates of air pollution impacts of steam flooding can be made if both the amount of fuel to be burned and the emissions per unit volume of the fuel burned are known. Emissions from the oil production, (i.e., hydrocarbons, hydrogen sulfide (H_2S), and other emissions escaping from the production wells), are in addition to these exhaust gases.

Emission factors for fuel oil combustion are shown on table 38. Most thermal EOR processes will burn fuel oil or comparable petroleum products and will fall into the residual oil classification. The powerplant classification would apply only to the largest boilers used in EOR. Oxides of nitrogen (NO_x) emissions from powerplants and other large sources are higher because of the higher combustion temperatures encountered, while hydrocarbon and particulate emissions are lower because of better combustion regulation and more efficient burner designs

Table 38
Emission Factors for Fuel Oil Combustion
(Pounds Emitted per 1,000 Gallons Burned)

Pollutants	Power-plant	Residual oil	Domestic sources
Aldehydes, ., ...	1	1	2
Hydrocarbons	2	3	3
co.	3	4	5
NO_x (as NO_2.	105	40-80	12
SO*	157 S*	157 s“	142 S*
Particulate	8	23	10

S• = Percent sulfur in oil

Steam generator emissions in pounds emitted per 1,000 barrels of oil produced can be calculated from table 38 using the values given for residual oil. The results of this calculation are given in table **39.** Estimates in table 39 are based on the consumption of 0.3 barrel of oil for every 1.0 barrel of gross production. This level of consumption approximates commercial-scale steam generator operations in the San Joaquin Valley in California. The emission factors presented in table 39 are estimates only and do not necessarily portray accurate emissions of in-field EOR steam generators. The figures in the table can be linearly scaled to account for variations in consumption.

Recently, there has been serious consideration of use of coal as an inexpensive fuel to provide steam for thermal recovery, including use in California. Use of coal could cause somewhat higher emissions in every category.

Table 39
Steam Generator Emissions
[Pollutants Emitted per 1,000 Barrels of Gross Oil Produced)

Hydrocarbons	40 lbs
SO*	4,000 lbs
NO,. . . . . . . , ...	800 lbs
Particulate. , , , ... , , ... , ., ... , ...	280 lbs

• For crude containing 2 percent sulfur, without flue gas desulfurization.

NOTE: This table assumes that 0.3 barrel of fuel oil is burned for every 1.0 barrel of gross production. Due to a shortage of data, fugitive **emissions are excluded for** the **analysis.**

[5] J. A. Eldon and J. A. Hill, “Impacts of OCS Oil Development on Los Angeles Air Quality, ” In *Southern California Outer Continental Shelf Oil Development: Analysis of Key Issues*, U. C.L.A. Environmental Science and Engineering Program, Los Angeles, Calif., 1976.

The new performance standards for fuel oil combustion were not used in making this calculation because oilfield steam generators rarely exceed the 250 million British Thermal Units (Btu) per hour capacity covered by these regulations.

A probable density of steam generators, and a level of steam generation required for a given well production rate, must be considered in order to estimate the overall pollution impact of a steam flood project.

The total emission rates from a field can be calculated using data in table 39. The resulting emission estimates can then be used in the evaluation of the impact of steam flood EOR on any specific region. As an example, the Wilmington Oil Field produced 67 million barrels of crude oil in 1973[6] by primary production; the field may eventually be a candidate for EOR. Steam flooding may be applicable due to the low American Petroleum Institute (API) gravity (high density) and high viscosity of California crude, and the considerable thickness of the oil-bearing stratum. The production of 30 million barrels per year by steam flooding (a potential for the Wilmington field) would involve the combustion of some 9 million barrels per year of fuel in the field steam generators. With the emission factors developed above, this combustion rate corresponds to the air pollutant emissions rate given in table 40.

Table 40
Projected Emissions from Steam Flooding of a Major Oil Field Compared to Los Angeles County Emissions

Pollutant	Emissions from a 30 million bbl/year field	Los Angeles County Total
NO_x	32 tons/day	1,000 tons/day
Particulate . .	12 tons/day	120 tons/day
SO_2	81 tons/day*	300 tons/day
Hydrocarbons.	2 tons/day	1,000 tons/day

*An 011 sulfur content of 2 percent was assumed

Table 40 also shows the total current emissions for Los Angeles County. Enhanced oil recovery emissions calculated for this example, with the exceptions of hydrocarbons and oxides of nitrogen, would be a significant fraction of the total emissions of Los Angeles County, Extensive exhaust gas scrubbing, consumption of low-sulfur fuel oil, and reduced scale of operation would be necessary in order to reduce SO_2 emissions to acceptable levels. Although these processes could reduce the emissions to lower levels, the resultant emissions will still be significant, at least on a local scale, since they are released into a heavily polluted airshed. Furthermore, they are released from a relatively small source area by comparison with the entire county, and could produce substantial impacts along a downward trajectory over a heavily populated region.

Emissions from in situ combustion are highly dependent on the oil formation, the type of crude oil, and the manner in which the project is operated. The high density of the crude oil in California and low economic returns experienced thus far indicate a low potential for in situ combustion, even though most oilfields in California can be spontaneously ignited by unheated air injections alone. To date, there are very few data available regarding the emissions from in situ combustion projects. It is anticipated that in order to meet air-quality pollution-control standards, especially in some areas of southern California, gas collection and treatment systems will be required,

In situ combustion and steam flooding are expected to have the greatest air-quality impacts in regions of low inversions, low wind speeds, and already polluted air, such as California's coastal plains and central valley. In remote mountainous regions, if background air quality is generally good and meteorological dispersion is favorable, a smaller impact may be expected. It should be noted, however, that high mountain valleys often experience severe inversions and air stagnation. Furthermore, nondegradation standards may apply for mountainous recreational areas. Thus air pollution impacts cannot be disregarded for such areas. While light air-pollution emission over the Continental Shelf would normally be considered inconsequential, there are areas in which these emissions must be carefully controlled, as in the southern California borderland. Any emissions released there have a high probability of being transported to shore, where they will contribute

[6] *California Oil and Gas Fields,* Vol. 2, California Division of Oil and Gas, Report No. TR12, 1974.

to an already serious air pollution problem.[7] Due to the low thermal and mechanical turbulence of air over water, dispersion of air pollutants over water is much slower than over land.[8] The Atlantic coast is just the reverse of the California situation in that the prevailing winds are from the west, so that emissions generated along the coast usually would be transported out over the Atlantic Ocean. The gulf coast tends to be a combination of the Atlantic and Pacific coast situations; depending upon the time of the year, the prevailing wind direction can be either from the north or the south.

Air Pollution Impact of Miscible Flooding Recovery Methods

Because miscible flooding does not involve high rates of either fuel combustion or in situ combustion, it is probable that CO_2 injection will have a much smaller air-quality impact than will the thermal methods discussed earlier. However, if hydrogen sulfide (H_2S) is injected into a reservoir and subsequently escapes, poisoning of humans and wildlife could result. There have been instances of this in the past. However, it is very unlikely that H_2S will be used as a primary constituent in any future major gas injection projects. Carbon dioxide is nontoxic, but capable of causing suffocation if concentrations are high enough. It will most likely be obtained from industrial activities (coal gasification), or natural reservoirs. The main air pollution impact resulting from CO_2 recovery methods will be the release of hydrocarbons and H_2S from formations into which CO_2 is injected. An important air quality concern is that CO_2 combined with H_2S in a gas mixture might have inadequate buoyance to disperse quickly, With the reduced buoyance, H_2S remains concentrated at ground level long enough to pose a threat to human and animal life because of its toxicity. Such effects are difficult to quantify without detailed information concerning concentrations of H_2S and CO_2 that would be emitted from gas injection recovery projects.

Because there has been considerable concern and a large degree of misunderstanding about H_2S and its potential safety and health threat to humans, the environment, and to equipment, further discussion is warranted. Concern has been generated to a large degree from an incident that occured at Denver City, Tex., in 1975, which resulted in nine fatalities. Hydrogen sulfide is toxic, flammable, explosive, corrosive, and may be naturally present in reservoirs. The concentration of H_2S which constitutes a harmful quantity depends upon the subject being considered, whether humans, the environment, or equipment. Therefore, regulations have been adopted by various governmental agencies to require all stages of H_2S operations to conform to safety and environmental standards.[9] Smith, the principal author of Texas Rule 36 which regulates this injection method, states that a dangerous condition would prevail if leaks of a certain volume exist, weather conditions complimentary to gas cloud ground accumulation exist, and persons unaware of the situation are present.[10] Texas Rule 36 and regulations adopted by other States have been formulated to prevent the above conditions from occurring. Hydrogen sulfide emission can be associated with normal oil production and is not necessarily complicated by any of the EOR processes, although the amounts encountered would be amplified by increased production. Therefore, while the H_2S problem exists for oil production in general, excessive concern for magnified H$ problems related to EOR is unwarranted.

Air Pollution Impacts of Chemical Recovery Methods

Chemical recovery methods do not produce emissions during application. Any air quality emissions from chemical EOR methods would be

[7] J. A. Eldon and J. A. Hill, "Impacts of OCS Oil Development on Los Angeles Air Quality, " In *Southern California Outer Continental Shelf Oil Development: Analysis of Key Issues*, U. C.L.A. Environmental Science and Engineering Program, Los Angeles, Calif., 1976.

[8] P. Michael, G. S, Raynor, and R. M. Brown, "Atmospheric Dispersion from an Offshore Site," in Physical Behavior of *Radioactive Contaminants* in the Atmosphere, p. 91, International Atomic Energy Agency, Vienna, 1974.

[9] *Enhanced Oil Recovery,* National Petroleum Council, December 1976.

[10] C. D. Ehrhardt, Jr., "Environmental and Safety Regulations in Sour Gas and Crude Operations, " in Society of *Petroleum Engineers of AIME Paper Number SPE 5191, 1974.*

indirect, in that they would occur from the production of various chemicals and the power generation required in the pumping process. In the case of the chemicals, air pollution impacts from production plants are already covered by existing air quality control regulations. Some light hydrocarbons, ethers, or alcohols are expected to be used in chemical recovery methods. These would presumably be derived from petroleum refineries whose air pollution emissions are of concern, but these may not be new emissions arising solely from EOR. If EOR were not utilized, the same refineries would very possibly manufacture other petrochemical products from the same raw materials. Therefore, the air pollution impacts of the chemical recovery methods "will be secondary in nature and covered by existing EPA State regulations.

Surface Water

Enhanced oil recovery methods will require significant quantities of water over and above primary recovery methods. It is anticipated that the EOR fresh water requirements would be higher than the demand in present techniques of waterflooding. A review of the literature did not provide firm data on the amount of water required for EOR. In order to quantify the water requirement, it is assumed in this assessment that one to six barrels of fresh water is needed for each barrel of oil recovered, This quantity of water consumption would have a greater effect on the environment in most regions than any other EOR impact.

As shown in figure 14, California, Texas, and western Louisiana are areas where water use is high and supplies short.[11] In fact, severe shortages are predicted by the year 2000. Although large quantities of water are required for EOR, the environmental impact on surface waters from EOR activities is anticipated to be only slightly greater than that from secondary recovery (waterflood) methods. The extent of hydrologic environmental effects will depend upon the characteristics and previous development of a reservoir. Geographic location, reservoir depth, and condition of the wells are factors which determine the potential adverse impacts of EOR activity on the hydrologic environment. The main environmental impact on the surface waters will be the actual consumptive use of the water. In semiarid areas, water may be required which is now being used for agriculture or other purposes.

Of the three EOR methods considered, chemical methods have the greatest potential for adverse impacts on surface water resources because water consumed (fresh water) 1) would be equal to or greater than for miscible or thermal EOR methods used, and 2) spills of concentrated chemicals would be environmentally more detrimental to water supplies than spills or emissions from other EOR processes. The likelihood that well failures or reservoir leakage due to breakdown of the reservoir would lead to contamination of surface waters is considered to be minimal.

The environmental effects on surface water of thermal EOR methods will be greater than those of miscible methods but less than those from chemical processes. As with chemical EOR methods, fresh water consumption in routine operations will have the greatest impact on the environment. Past experience has shown that spills, well fractures, and reservoir leakage are infrequent and basically nondetrimental during thermal EOR operations.

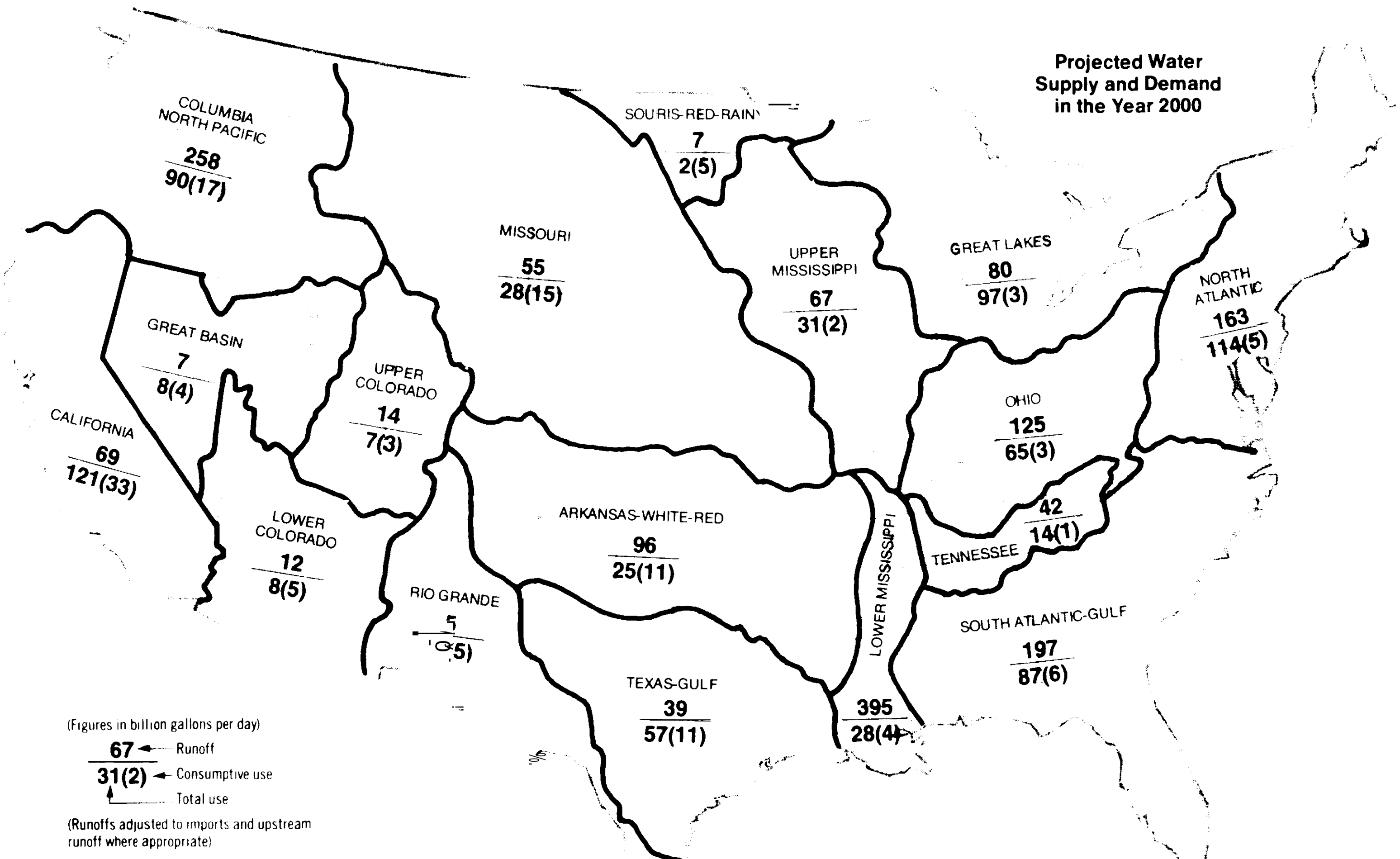
Miscible EOR methods will have the smallest environmental effect on surface water. As with the previous two methods, the quantities of water consumed in this EOR process—which presumably would be diverted from farming and other activities—would constitute the greatest environmental impact.

Surface water requirements will be largest for EOR activity in the Interior Basins, smaller in the Coastal Plains, and smallest on the Continental Shelf where few EOR projects are expected to occur.

Within the Continental Shelf area, it is anticipated that routine operations would cause the most environmental damage. Chemical spills, well failure, and reservoir leakage are thought to

[11] Water Information Center Publication, *Water Atlas of the United States,* Water Information Center, Inc., Port Washington, N. Y., 1973.

Figure 14. Water Use and Supplies



Source: U.S. Water Resources Council 1958.

be the only mechanisms by which environmental effects would occur other than those which are a part of routine operations.

On the Coastal Plains, consumptive water use would frequently have the greatest environmental impact from EOR production. One exception to this would be chemical spills which could occur in this environmentally sensitive physiographic area. Thermal EOR methods might have a slightly greater environmental impact than miscible EOR methods. For regions where air quality already is poor, of course, air pollution impacts from thermal methods could be substantial.

Interior Basins would most likely be affected by chemical EOR methods. Miscible EOR methods would have the least environmental impact of the three EOR methods. Almost without exception, the greatest environmental effect on the Interior Basins would be water use. As with the Coastal Plains, the Interior Basins could also experience a significant environmental impact from chemical spills, primarily in transit to the injection well sites. The mountainous geographic areas might be relatively less affected even though they are environmentally sensitive areas.

Ground Water

potential for ground water contamination resulting from fluid injections associated with EOR operations appears minimal. This conclusion is supported by the lack of ground water contamination problems associated with conventional waterfloods. Only 74 ground water injection problems resulted from operating 44,000 injection. wells in Texas between 1960 and 1975 (an incidence rate of 1.1/10,000 per year); only 3 of these occurred during the last decade (an incidence rate of .02/10,000 per year). Similar safe operating records exist in the other major oil-producing States with large numbers of waterfloods. Because EOR injection operations are basically the same as waterfloods, often using the same injection wells in the same formations, an increase in the rate of ground water contamination is not expected. In fact, it is anticipated that the safety record will improve because EOR injection fluids are more costly than the water now used in waterfloods and operators could be expected to take additional precautions to prevent loss of these fluids during the EOR process.

As with surface waters, use of water from aquifers for EOR operations could put a strain on freshwater supplies in areas where reserves were limited. In areas where the rate of consumption exceeds the rate of recharge, the impacts would be severe. Recent field tests indicate that brine-tolerant EOR processes are feasible, and could significantly reduce the impact of EOR operations on freshwater aquifers if used.

Land Use

The impact of EOR operations on land use will not be significant. Additional surface facilities required for EOR activities will be relatively small, even for large projects. Relatively few additional flow lines and pipelines will be needed outside of the reservoir area, except in the case of CO_2 injections. Where large quantities of CO_2 are required, pipelines will be required to deliver economically the CO_2 to the project sites. Construction of these pipelines poses potential environmental hazards.

For some EOR projects additional wells will be drilled, and redrilling of wells will occur in older fields. These activities will cause minor disturbances for short periods but no long-term impacts will be evident, provided care is taken in the field development.

Geologic Hazards

Potential geologic hazards connected with EOR methods are subsidence and possible seismic activity. A great deal of subsidence data associated with primary oil recovery have been collected in the Long Beach, Calif., area.[12] When compared with primary recovery methods, it is anticipated that subsidence actually will be reduced during EOR operations. The reason for this reduction is that fluids will be left in the

[12] M. N. Mayuga, and D. R. Allen, "Long Beach Subscidence," *Focus on Environmental Geology,* R. W. Pank, Oxford University Press, New York, N. Y., p. 347, 1973.

reservoir after the oil is removed, except when in situ thermal methods are used.

There has been some research relating seismic activity to the use of secondary recovery methods. Results of this research imply that seismic activity will not be increased by EOR methods. The Rocky Mountain Arsenal near Denver, Colo., conducted deep well injections which resulted in an increase in seismic activity in the Denver Area[13] It should be noted, however, that these injections were generally made into deep crystalline rock which did not ordinarily contain fluids. Injected fluid acted as a lubricant to the existing stress zone which is believed to have caused the increased seismic activity. Obviously, oil recovery from reservoirs would not be considered analogous to the Rocky Mountain Arsenal situation.

Noise

Although the compressors and other equipment used in EOR generate high levels of noise, it is unlikely that this noise will cause any serious environmental impact. The loudest noises, such as those which would accompany preparation for the fracturing of the reservoir or injection of steam in a cyclic steam process, are of short duration. In regions where the local biota or human population would be adversely affected by noise, maximum muffling and noise abatement procedures will need to be imposed. Occupational Safety and Health Act (OSHA) regulations will serve as a standard for safeguarding humans.[14]

Biota

Enhanced oil recovery technologies present a variety of potential biological effects. These are summarized according to relative significance in table 35, and most do not appear very serious. While some do pose potentially significant problems, most can be adequately addressed and avoided.

Many areas where EOR activities would take place have already undergone primary and secondary development, and environmental impacts will therefore not result from EOR activities alone. Some of the potential impacts are common-to all processes, while others are the result of or dependent upon a particular process. Table 41 identifies the activities that might be expected to create biological impacts.

Table 41
Potential Biological Impacts Resulting From EOR

Process - Independent Impacts	
Consumption of water	
New well drilling (land-use/habitat impacts)	
Extended time frame of activities	
Pipeline to provide water	
Increased refinery effluents	
Process - Dependent Impacts	
Thermal:	Air emissions
	Cooling and consumptive water use
	Energy source
Miscible:	Air emissions
	Pipeline and source of CO_2
	pH changes
Chemical:	Manufacturing, handling, and disposal of chemicals

Process Independent Impacts

Probably the most significant potential adverse biological impact of EOR will result from the increased water consumption associated with this technology. Because fresh water (rather than saline water) is generally required, EOR process consumption of water will not only compete directly with domestic, agricultural, and other industrial uses, but could result in a localized drawdown of surface water, severely affecting aquatic flora and fauna within the area of the drawdown.

The Interior Basin and Mountain regions may be the most seriously affected by this consumptive use of water. Interior Basin areas already face some of the most serious water allocation problems, and wetland or aquatic ecosystems have already been substantially affected in many parts of this zone. While they have not experienced the same demands for water use, Mountain wetland areas are comparatively more

[13] "Geophysical and Geological Studies of the Relationships between the Denver Earthquakes and the Rocky Mountain ARsenal Well-Part A," *Quarterly of the Colorado School of Mines,* Vol. 63, No. 1, 1968.

[14] A. P. G. Peterson and E, E. Cross, Jr. *Handbook Of Noise Measurement,* General Radio Corp, 7th Ed., 1974.

fragile and vulnerable to drawdown. Also, consumptive use of water in the Coastal Plains could increase salt water intrusion, and significantly alter coastal wetland communities.

Potentially serious impacts may also result from new well drilling activity. Because EOR techniques will always be applied in areas of previous drilling activity, support facilities and access roads will generally be available. However, depending on the density of facilities needed for EOR, new construction may be significant. In the past, significant impacts have resulted from well drilling activities in wetland and aquatic areas, particularly in the Coastal Plains and mountain areas. These impacts have generally resulted from loss of habitat associated with a well drilling site, or from alterations (such as canals, ditches, and roads) to provide access. Canals used as access for drilling operations in coastal areas have caused significant adverse effects on shallow aquatic habitat and on marsh wetlands. These impacts have largely been caused by alteration of the hydroperiod and the fresh water—salt water interface. The changed salinity regimes which have resulted have caused severe alteration of wetland types as well as the fauna inhabiting them. The activities associated with construction of access to sites in the Coastal Plains, particularly dredging and filling, have also created substantial impacts.[15] The resulting changes may be permanent.

Because of the fragile nature of mountain ecosystems and the long times they frequently need to recover from impacts, road construction in Mountain regions also poses a threat of significant impact.

"These impacts are not a necessary consequence of new well drilling activity. Although potentially significant, most can be avoided by a thorough initial understanding of the system which may be disturbed, followed by careful construction and drilling practices. Because EOR activity occurs in areas of previous activity, economics dictate that maximum usage will generally be made of existing roads, facilities, and other structures,

Although EOR techniques may, on occasion, permit more rapid production of oil, they will generally extend the time during which production activities take place by 10 to 20 years. This will result in continued traffic, noise, dust and air emissions, and other actions of potential impact on biota. These will not usually be important, since the areas will already have been subject to primary recovery activity and because the remaining biota often will have adapted to man's routine activities after an initial period of displacement or disturbance. Some exceptions include activities adjacent to or otherwise affecting breeding and nesting areas or migratory routes. Some particular species (frequently endangered species) are not compatible with man's activities. Continued operations might preclude their return or survival in localized areas, although this would be an infrequent occurrence.

Because EOR processes will often require new or increased supplies of water, or water of different quality, the construction of water supply pipelines could also affect the biological environment. Such activity will result in direct loss of some habitat, and could affect the biota in other ways. For example, construction of pipelines across wetlands may be accompanied by the digging of a ditch, canal, or diked road; these would interrupt or alter the surficial sheetflow of water. Again, these impacts can be reduced through careful route selection and methods of construction. Frequently, pipelines will already exist to deliver water to production fields. It may be possible to use the opportunity created by new construction to rectify problems caused by existing pipelines.

Process Dependent Impacts

Each EOR process could have some specific biological impact. It appears that some of these will be of less significance than the potential impacts previously described. All of the EOR processes will result in air and water emissions, which must be controlled to be in compliance with the applicable air and water quality standards. However, it is important to recognize that attainment of standards will not avoid all biological impacts.

[15] Edward T. LaRoe, *Effects of Dredging, Filling, and Channelization on Estuarine Resources*, **pp. 134-144; "Proceedings, Fish and Wildlife Values of the Estuarine Habitat, A Seminar for the Petroleum Industry," p. 184, U.S. Department of the Interior, Fish and Wildlife Service, 1973.**

Therrnal.-Steam injection processes will have large demands for water, creating a potential for increased impacts caused by water consumption and the need for water pipelines.[16] Steam injection will also require substantial energy for steam generators and compressors. Existing facilities are usually powered by onsite generators fueled by petroleum products (oil or gas) produced at the well. These are noisy and air polluting. If EOR operations become widespread, the industry might desire to switch to electrically powered air compressors and other equipment. The off site production and supply of electricity (very likely from coal) could result in off site biological effects which would vary in significance with the type and location of power generation.

The air emissions produced by both steam injection and in situ combustion thermal EOR techniques WIll pose potentially slgnificant biological impacts. If uncontrolled, the impacts of these emissions could be most severe in the California coastal plain and Interior Basin areas because these areas not only appear the most likely regions for use of thermal EOR techniques but also have dirtier air than most other regions. The most critical effects would be on humans and vegetation, although the chronic effects on wildlife could also be significant. Air pollutants from EOR operations can probably be controlled; however, there has been little applied research in this direction to date. It is reasonable to expect that a serious research effort would make possible considerably reduced impacts.

Thermal projects also need to dispose ot heated water after it has been used for coo!ing. If discharged into surface waters, hot water can lead to changes in marsh and aquatic plant and anirnal life and promote the growth of phytoplankton algae, including blue-green algae, which can harm natural flora, fish, and wildlife. The thermal impact could be avoided by the use of cooling ponds, which could create localized air impacts of generally small consequence. Well failures or reservoir leakage could also result in the release of thermal pollutants; however, the impact of such discharge would generally be very localized and of little significance.

Thermal EOR processes frequently result in recovery of large amounts of oil-associated water, which is usually reinfected.[17] However, if the water is not reinfected and is discharged without treatment, the chronic release of this water, with entrained oil and traces of heavy metals, could adversely affect aquatic biota.

Thermal processes will also produce solid waste material, including fly ash from scrubbers used to control air emissions. The most direct impact will be in the need for land area to dispose of solid wastes (and the loss of habitat which that may cause). Shipment of material to suitable sites will cause some adverse impacts. Biological impacts of an efficiently designed and operated system can be kept small.

Miscible.--+robably the most significant potential biological impacts resulting from the CO_2 miscible EOR process will be those relating to the supply and transportation of CO_2. For EOR use, CO_2 will originate from CO_2 wells, or as a byproduct of other industrial activity. It will usually be transported to the field by pipelines, although in small projects CO_2 may be transported by refrigerated truck or tank car. While CO_2 itself is not toxic, the activities associated with its collection and transportation may have adverse biological impacts. Carbon dioxide pipelines can have the same biological impacts discussed for water pipelines above. The primary areas presently identified for CO_2 production are the Four Corners area, the northeast New Mexico-southeast Colorado area, central Mississippi, Texas, Utah, and Wyoming. These areas, and places along the pipeline routes to Texas, will have the most significant potential for impact, but the impacts will be localized That is, they will be restricted to the immediate area of CO_2 production and the pipeline route.

As with thermal processes, miscible processes will result in increased air emissions. The release of CO_2 itself would not have adverse biological effects, although adverse effects could result

[16] *Enhanced Oil Recovery,* National **Petroleum Council, December 1976.**

[17] Ibid

from the release of other gaseous contaminants, such as H_2S. If properly treated, or if reinfected, these emissions will have insignificant impacts.

1 he release of CO_2 under pressure to aquatic systems, as might occur with well failures or reservoir leakage, could result in a decrease in pH of the water body. The biological significance of this pH change would depend on the size of the water body, amount of CO_2 released, and the duration of release. However, aquatic life, especially freshwater fish, is particularly susceptible to increased acidity. While the potential for such an occurrence is extremely small, the impact, if it occurred, could be locally significant.

Chemical.-Although several chemicals that could be used in EOR processes have been described in literature, it appears in practice that only a few will actually have extensive use. Table 42 lists chemicals described in patent literature. Chemicals commonly used include broad spectrum petroleum and synthetic petroleum sulfonates; alcohols; polyacrylamide and polysaccharide polymers; sodium dichlorophenol and sodium pentachtorophenol; sodium hydroxide and sodium silicate.[18] These do not appear particularly hazardous in the concentrations used, nor do they become concentrated in food chains. However, the manufacturing, handling, and disposal of these chemicals pose potential biological impacts.

If chemical flooding methods are widely adopted, there must be a substantial increase in the production of some of these chemicals, especially the surfactants. Expanded manufacturing capacity could result in localized adverse impacts through loss of habitat and potential air and" water emissions.

Transportation of the chemicals commonly used for EOR operations is not likely to pose a major hazard. Many are frequently shipped as solids, which reduces the potential for a spill. Small spills of liquids, both during transportation

[18] *Enhanced Oil Recovery,* National Petroleum Council, December 1976.

Table 42
Potential Chemicals Used in Chemical Flooding

Chemicals Proposed for *Surfactant Flooding:*
- **•Broad spectrum petroleum sulfonates**
- **•Synthetic petroleum sulfonates**
- *** Sulfated ethoxylated alcohols**
- *** Alcohols**
- **" Ethoxylated alcohols**

Chemicals Proposed as Bactericldes:
- *** Sodium dichlorophenol**
- *** Sodium pentachlorophenol**
- **Formaldehyde**
- **Gluteraldehyde**
- **Paraformaldehyde**
- **Alkyl phosphates**
- **Alkylamines**
- **Acetate salts of coco diamines**
- **Acetate salts of coco** amines
- **Acetate salts of tallow diamines**
- **Alkyldlmethl ammonium chloride**
- **Coco dlmethyl ammonium chloride**
- **Sodium salts of phenols**
- **Substituted phenols**
- **Sodium hydroxide**
- **Calcium sulfate**

Chemicals Proposed for *Alkdline Flooding:*
- *** Sodium hydroxide**
- *** Sodium silicate**
- **Ammonium hydroxide**
- **Sodium carbonate**
- **Potassium Hydroxlde**

Chemicals Proposed *for Mobility Control:*
- *** Polyacrylamide**
- *** Polysaccharide**
- **Aldoses B Series**
- **Aldoses L Series**
- **Car boxy methylcellulose**
- **Carboxyvinyl polymer**
- **Dextrdns**
- **Deoxyribonucleic acid**
- **Ketoses B Series**
- **Ketoses L Series**
- **Polyethylene oxide**
- **Polyisobutylene in benzene**
- **Conjugated saccharides**
- **Disaccharides**
- **Monoosaccharides**
- **Tetrasaccharldes**

Chemicals Proposed as Oxygen **Scavengers:**
- **Sodium hydrosulfite**
- **Hydrazine**
- **Salts of bisulfite**

"Most commonly used
The above table was modified from *Enhanced 011 Recovery,* National Petroleum Council, December 1976.

and onsite use, are to be expected, but the biological impact will be limited since they are primarily of low toxicity.

Even though tests have shown that chemicals common l y used i n EOR processes have a 10 w acute toxicity, the long-term effect of such chemicals on the environment has not been evaluated. Not until such long-term studies have been conducted on the chemicals used in EOR processes can the potential for adverse environmental impacts be dismissed.

Disposal of produced water containing the chemicals will pose another potential water-quality impact. Most chemicals will be absorbed within the reservoir and the amount produced will be small. Although the chemicals are not particularly toxic, some (particularly the polysaccharide polymers) could act to increase biological oxygen demand (BOD) in the receiving water and this would adversely affect fish species. Potential biological impact can be avoided by disposing of chemically laden produced water by either relnjecting it into the oil-producing reservoir, injecting it into other saline aquifers, or treating it to remove contaminants before disposal into surface waters.