

HANDBOOK ON
OIL AND GAS TECHNOLOGIES AND
ASSOCIATED ENVIRONMENTAL EFFECTS

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I. INTRODUCTION

A. Handbook Purpose

This handbook is a guide for park and regional staff who evaluate the technological aspects and the associated environmental effects of oil and gas operations proposed inside, or adjacent to, units of the National Park System. The handbook is to aid in the following:

- o Understanding the equipment and methods of operation used by the petroleum industry
- o Providing background to assess environmental effects of oil and gas activities
- o Providing background on potential mitigation measures for environmental impacts

The purpose of the handbook is not to provide an exhaustive presentation of the oil and gas industry but to highlight those facets which are important to the evaluation of an oil and gas operation from a National Park Service (NPS) viewpoint.

Since the handbook addresses a great variety of oil and gas technologies that may be developed in divergent natural, cultural and recreational environments in the 48 contiguous states, the chapter discussions are general. Therefore, the users should, if necessary, collect additional reference material specific to their activity or plan of operations for more detail on technologies, and types and degree of potential resource damage. Key reference material is identified in appropriate places in the handbook. As needed, the user should call upon expert help for additional reference information. NPS staff and other resource professionals, such as state oil and gas inspectors and agencies, are identified in the handbook.

B. Background

Persons may propose to explore for, or develop, oil and gas in the exercise of either nonfederally owned oil and gas rights, or in connection with oil and gas leased from the federal government.

Nonfederal oil and gas rights exist within units of the National Park System when (1) the land, including the right to the oil and gas, is nonfederally owned in fee or (2) the oil and gas rights were severed from the surface estate and the United States did not acquire any part of the mineral estate. Approximately 200 units of the National Park System contain nonfederally owned mineral rights, including oil and gas rights. Active development of these nonfederally owned minerals is now occurring in seven units. Approximately 40 additional park units could potentially have oil and gas activities based on known geological potential in the area and nonfederally owned mineral rights.

How operations are conducted in connection with nonfederal oil and gas rights is governed by the regulations found at 36 CFR Part 9, Subpart B. These regulations require that the National Park Service verify whether the oil and gas rights proposed for development are valid, and thus whether operations may be conducted in the affected unit. Please refer to the manual titled "NPS Procedures for Managing Nonfederal Oil and Gas Operations" for specific policy, procedural and legal guidance on proper implementation of the Service's regulatory responsibilities under 36 CFR 9B. The NPS Procedures serves as a reference which assists NPS personnel to process and evaluate proposed plans of operations, to monitor operations and to enforce the terms of an approved plan. Copies of the NPS Procedures are available from any of the following locations: units managing nonfederal oil and gas operations (Alibates Flint Quarries National Monument, Big Cypress National Preserve, Big Thicket National Preserve, Cuyahoga Valley National Recreation Area, Big South Fork National River and Recreation Area, Gulf Islands National Seashore, Lake Meredith Recreation Area and Padre Island National Seashore); the NPS Southwest, Southeast and Midwest Regional Offices and the Energy, Mining and Minerals Branch.

Federally owned oil and gas may be leased only in the four NPS units that are open to leasing under regulation at 43 CFR 3100. These units are Lake Mead, Glen Canyon, Whiskeytown and Ross Lake National Recreation Areas (NRAs). Regulations at 43 CFR 3100 govern federal oil and gas leasing. Refer to the manual titled "NPS Procedures for Managing Federal Mineral Leasing and Operations" for specific policy, procedural and legal guidance on the proper implementation of the Service's responsibilities under 43 CFR 3100. These NPS Procedures assist NPS personnel to evaluate lease or permit applications and to decide whether the NPS should consent to a lease or permit of operations in connection with leasable federal oil and gas within the four NPS units. Copies of these NPS Procedures are available from any of the following locations: the four NRAs listed above; the Rocky Mountain, Western, or Pacific Northwest Regional Offices and the Energy, Mining and Minerals Branch.

Although the National Park Service does not exercise regulatory control over oil and gas operations adjacent to a park unit, the Service may be able to influence the conduct of operations to protect unit resources. For example, operators must generally secure permits from the state or other federal agencies for operations conducted or proposed adjacent to the unit. The NPS may contact the appropriate state regulatory agency, such as an Oil and Gas Commission, Department of Natural Resources or State Historic Preservation Officer, to express NPS concerns over the permitted activity.

Where operations are conducted or proposed adjacent to a park unit in connection with federal oil and gas, the NPS may work directly with appropriate state or local office of the Bureau of Land Management (BLM), Minerals Management Service (MMS) or the U.S. Forest Service. The BLM is the leasing agency for onshore federal lands in the United States. Therefore, the BLM must determine whether actions it proposes or permits in a resource management plan for public lands are consistent with officially approved management plans of other federal agencies, including plans that the Service prepares for the units under NPS administration.

Similarly, the MMS is the leasing agent for offshore federal minerals. When the MMS proposes an action, such as a lease sale, they ask for and accept comments from affected federal, state and local agencies. The NPS may also wish to comment directly on a particular lease application, lease, notice of intent to conduct oil and gas geophysical operations or drilling permit that the local BLM or MMS office is considering.

C. Overview of Contents

Oil and gas activities often progress through five phases that are in part sequential but may overlap in time: preliminary exploration, exploratory drilling, development, production and abandonment and reclamation. The sequence is shown on Figure I-1. This handbook is divided into chapters on Preliminary Exploration, Drilling, Production and Abandonment and Reclamation.

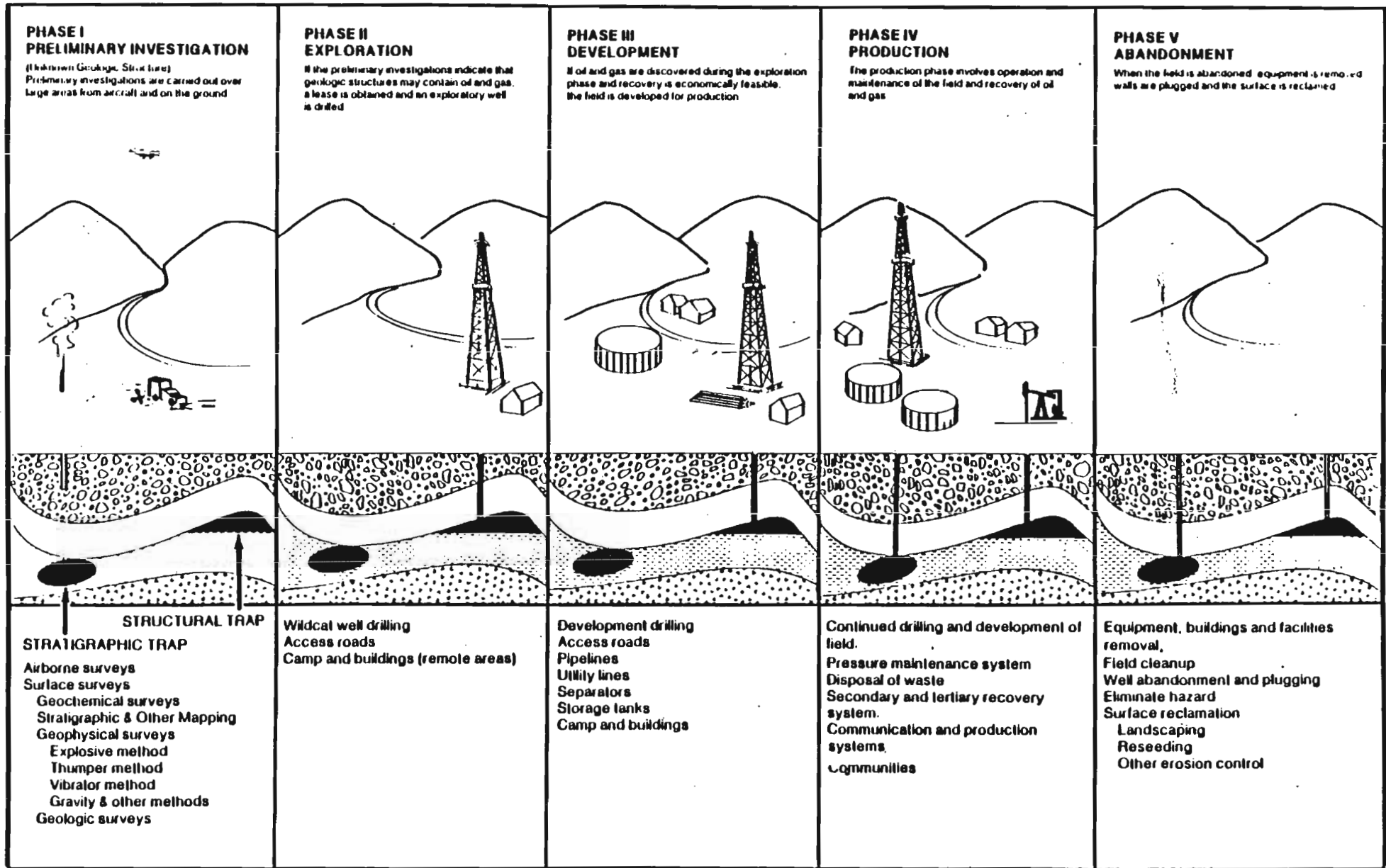
Exploratory operations use a variety of geological and geophysical techniques to identify geological structures likely to contain deposits of oil and gas. Drilling operations include stratigraphic test wells, wildcat wells which test the potential of geological structures identified by exploratory work, and development wells which ascertain the size of an oil or gas field and bring it into production. Production operations are usually concurrent with development drilling and include completion of drilled wells and the installation of permanent facilities such as pipelines and tank batteries. Abandonment and reclamation take place when a wildcat well is determined to be dry, or when an oil or gas field is depleted.

The following format is used for the Exploration, Drilling, Production and Abandonment and Reclamation chapters:

- o Information on the appropriate oil and gas technologies and equipment (including alternatives)
- o Potential environmental effects associated with the above technologies and equipment are discussed. Possible effects include surface disturbance (soils and vegetation), water, fish and wildlife, air quality, noise, aesthetic quality, geological features and cultural resources
- o Possible mitigation measures for the potential environmental effects
- o Summary of major technologies/equipment which may impact the environment
- o Summary of potential mitigation measures for the potential impacts

The petroleum industry has developed a unique language over its hundred years of history. A glossary is presented at the end of the handbook to help the reader understand the jargon and terms frequently used in the oil field.

SEQUENCE OF OPERATIONS IN AN OIL AND GAS FIELD



SOURCE: U. S. Department of Interior, Bureau of Land Management, 1972.
Preliminary draft, Upland Oil & Gas Leasing Programmatic
Environmental Impact Statement.

Figure I-1

A bibliography is also included at the end of the handbook to help the reader identify sources of material used in the handbook and find additional reference material for special problems.

II. EXPLORATORY OPERATIONS

The objective of exploratory operations is to define and describe geological structures which are favorable for oil and gas accumulation in the earth's crust. If the geology is well exposed throughout a large area, hydrocarbon traps can often be predicted by the geologist from surface studies. Potential traps where oil and gas might occur, such as anticlines, faults or formations with favorable porosity and permeability, can be mapped and located with the aid of aerial photographs and field studies. However, most subsurface geological structures are more difficult to locate, map and characterize. In these situations, geologists search for underground structures using sophisticated equipment and highly technical surveys in a process generally referred to as geophysical prospecting. The following discussion addresses geological exploration and geophysical exploration including gravitational surveys, magnetic surveys and seismic surveys.

A. Geological Exploration

Surface studies comprise the first stage of exploratory fieldwork. Geological surveys of the land surface are made using aerial photographs, satellite photographs, maps of surface outcrops of specific formations or rock types, and geochemical analyses.

Creating maps of surface outcrops and geochemical analyses require fieldwork. Little equipment is needed other than surveying gear and rock and soil sampling supplies. These activities require a small field party of 2 to 4 persons which can work out of a single vehicle or on foot. Access to remote areas can be gained by a four-wheel drive vehicle or helicopter, and subsequent walking. Shallow estuarial and near-shore areas may be accessed by a small boat. Constructing roads or digging channels for boats in shallow water areas is not required at this early stage.

Geochemical analysis often requires subsurface samples to be taken from a ditch or a shallow corehole. The coreholes are not usually big, but cuttings require clean up.

B. Geophysical Exploration

Subsurface geology is not always accurately indicated by surface outcrops. In such cases geophysical prospecting is used. These surveys provide an extrapolation of surface geological observations and an indication of subsurface structure and stratigraphy. Three subsurface characteristics are usually measured by geophysical methods: gravitational field, magnetic field and seismic reflection.

Exploration can be viewed as having three possible levels. First, gravitational and magnetic field studies yield regional or reconnaissance type data. Widely spaced seismic surveys also give regional data. Second, detailed seismic surveys or corehole drilling can indicate specific sites with potential for oil and gas traps. And finally drilling a well offers the ultimate proof for the presence of petroleum.

Each level of exploration involves radically different land operations and subsequent environmental effects. Within each geophysical step are specific operations that help define appropriate drill sites. The following sections examine the operations and techniques involved in regional and detailed surveys and their general environmental impacts.

1. Gravitational Surveys

Gravitational surveys detect variations in gravitational attractions caused by differences in the density of various types of rock below the surface. This is generally done with small, portable instruments called gravity meters or gravimeters. The number and placement of measurement points in a gravity survey depend on the site's characteristics. These include feasibility of access and the spacing pattern necessary to detail the features selected for mapping. The field party required is not large, usually 3 to 6 people. Travel on foot is possible with the smaller portable gravimeters. Progress, however, is slow, so most surveys use four-wheel drive vehicles. In marshy areas, the use of special swamp or marsh buggies is quite common with gravity survey crews. Airborne survey operations are not yet practical due to present instrument limitations and the relatively large and rapid changes in altitude and acceleration inherent to aircraft.

It must be noted that the objectives of most surveys can be achieved when gravity stations are confined to existing roads or waterways. Disturbance of the land surface is minimal when established access is already available. The access to roadless areas is similar to that required for Geological Exploration described in Section A. The surveying technique itself does not require any physical disturbance of the surface.

2. Magnetic Surveys

Magnetic surveys are often used in place of or to supplement gravity surveys. These surveys are done with relatively small airborne or portable ground instruments called magnetometers. Flight patterns usually consist of a series of parallel lines at 1 to 2 mile intervals.

Airborne surveys require geodetic and ground control points. These must be installed on the ground before the survey can take place, if not already present. A majority of the lower 48 states have been surveyed so these points are already in place. If not, however, the area must be accessed by overland vehicles or helicopters. The size of the field party required is not large. The access to roadless areas is similar to that required for Geological Exploration described in Section A. The surveying technique itself does not require any physical disturbance of the surface.

3. Seismic Surveys

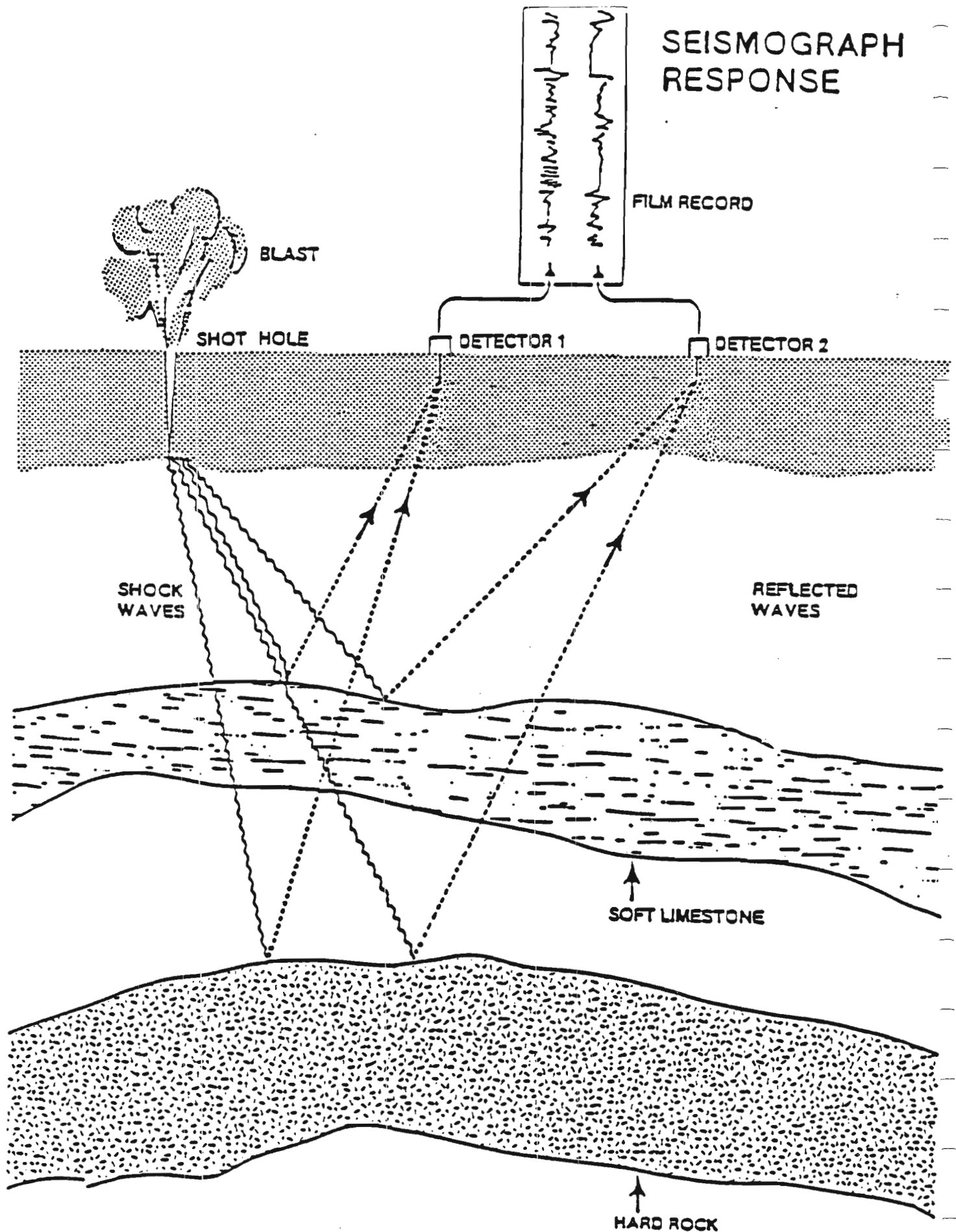
Seismic surveys are the most popular of the geophysical methods and seem to give the most reliable results. A seismic survey is a method of gathering subsurface geological information by recording impulses from an

artificially generated shock wave. The common procedure used in reflection seismic surveys on land consists of creating shock waves and recording, as a function of time, the resultant seismic energy as it arrives at groups of vibration detectors. These detectors are 1/2- to 5-pound seismometers or geophones arrayed on the ground at predetermined intervals. The arrays of geophones are connected by cable or radio to a recorder truck that receives and records the reflected seismic energy. Portions of the seismic energy reach the geophones by several different routes. One portion spreads over the ground as a surface wave. Another travels along a subsurface layer and is refracted to the surface. The third and most important portion travels downward until it reaches an abrupt change in rock characteristics and is then reflected back to the surface (Figure II-1).

The seismic sensors and energy sources are located along lines in a grid pattern or can be located in a single line depending on the detail of data required. In remote areas where there is little known subsurface data, a series of short seismic lines may be required to determine the attitude of the subsurface formations. After this, the pattern of seismic lines or grids is designed to make the final data more accurate and valuable. The size of the grids and length of the lines can range from a couple of miles to grids with several hundred miles of lines involved. Although alignment is fairly critical, spacing of the lines can often be changed up to a quarter of a mile on a 1-mile grid before the results will affect the investigation program.

Whether the lines are long or short, the lines are "shot" in segments usually less than a mile in length. After one section is finished the equipment is moved ahead on the same line to the next segment. Existing roads are used if possible, but reaching some lines may require clearing vegetation and loose rock to improve access for the crews and the trucks. Each mile of seismic line cleared to a width of 8-14 feet represents disturbance of about an acre of land. A network of low-standard temporary roads and trails can result from this operation. The alignment of these trails usually consists of straight lines dictated by the grid, often with little regard for steep slopes or rough terrain. Level topography with few trees and shrubs would require little or no trail construction. An area with rugged topography or larger vegetative types such as trees and large shrubs would require more trail preparations. Temporary roads and trails are usually constructed with bulldozers.

Seismic methods are usually referred to by the various methods of generating the shock wave. These include weight drop, vibrators, dinoseis and explosives. No matter what method of generating energy is used, the procedures for preparing the line and recording the data are relatively similar. The procedure for "shooting" a line consists of first surveying and flagging the locations for the geophones and the positions of the energy sources. Second, the geophones and the connecting cable is laid down. The cable is either connected with more cable to the recording truck or to a radio transmitter to send the data to the recording truck. Normally the recording truck will be within a short distance of the transmitter or within line of sight. Once the geophones and ground cable are in place, the energy source is put in place. The detonation of the energy source, whether by truck or by



SOURCE: U.S. Department of the Interior, Plain Facts about Oil, 1963.

Figure II-1

explosive, is controlled by the recording truck. The shock wave is set off, and the seismic signal recorded. Once the signal is recorded, the cable is picked up and the entire process repeated on the next segment of the line.

Seismic crews consist of several surveying people, people for laying and retrieving the cable and geophones, the truck drivers or drillers for the energy source, personnel in the recording truck and miscellaneous water truck drivers, cleanup people and field crew managers. The size of seismic crews can vary from 15 to 80 people. On most seismic jobs, the people and equipment are transported in trucks or four-wheel drive vehicles, but the surveying, cable laying and sometimes the drilling can be done on foot in some situations.

The following are some of the more common methods of generating the shock waves. Sketches of the geophysical trucks are in Figure II-2.

a. Weight Drop

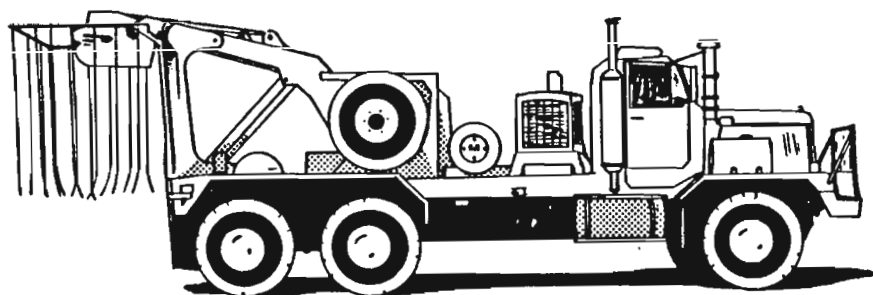
The weight drop method involves dropping a steel slab weighing about 3 tons to the ground. The weight is attached by cables to a crane on a special truck. Weight drop is advantageous in remote locations where repetitive drops or "shots" are required and the transportation of explosives difficult. The timing of the drop is controlled by the recording truck which synchronizes the entire operation. The weight drop truck is large and heavy. The trucks are often equipped with oversize or balloon tires to aid offroad travel.

b. Vibroseis

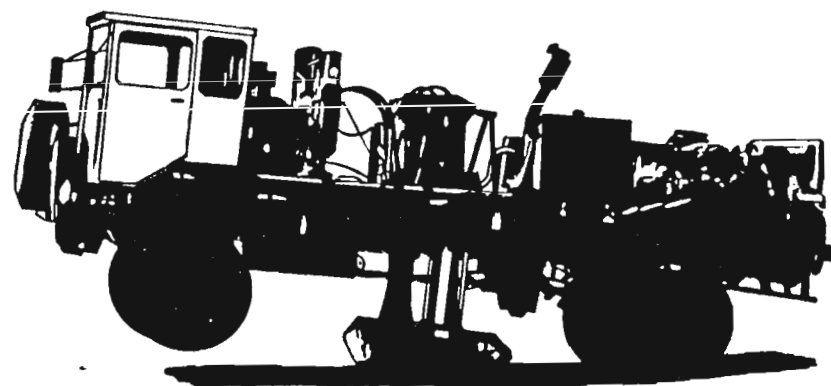
The vibrator or vibroseis method is widely used and is replacing the explosive method in accessible areas. A typical operation would use three or four special trucks or tractors, each equipped with a vibrator pad mounted between the front and back wheels. The vibrator pads are about 4 feet square and weigh approximately 2 tons. Once the pads are lowered to the ground, the vibrators on all trucks are triggered electronically from the recorder truck. After the seismic data are recorded, the trucks move forward a short distance to the next segment of the line and the process is repeated. The vibrator trucks are similar to the weight drop trucks because they are large and heavy. They are also often equipped with oversize or balloon tires to aid in offroad travel.

c. Dinoseis and Land Air Guns

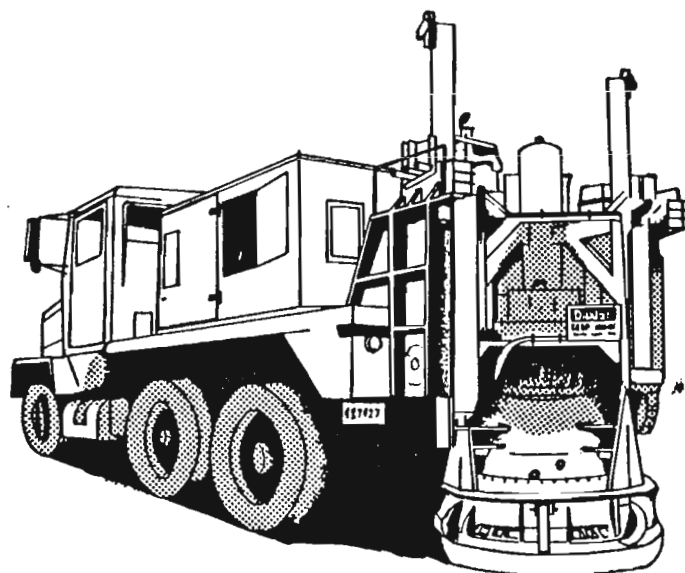
The dinoseis method and land air guns can be used with a variety of vehicles. The dinoseis device consists of a bellshaped chamber mounted underneath a vehicle. The seismic energy is imparted to the ground through the spark ignition of a propane and oxygen mixture confined in the chamber. This method causes little environmental damage.



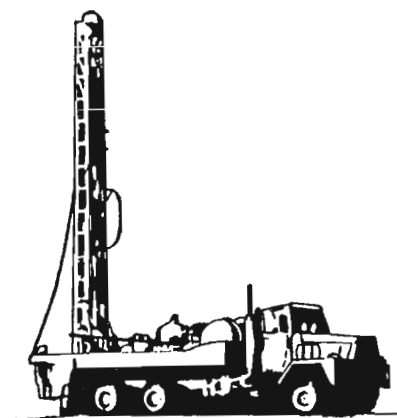
WEIGHT-DROP TRUCK



VIBRATOR TRUCK



LAND AIR GUN



DRILL TRUCK For Subsurface Explosives

FIGURE II-2

d. Explosives

Historically, explosives have been the most widely used way to generate seismic shock waves. The explosives are used in two different methods: subsurface and surface.

1) Subsurface Explosives

In the subsurface explosive method, 5 to 100 pounds of explosive charge are detonated at the bottom of a 25-to 200-foot drillhole. The hole is usually 2 to 6 inches in diameter and drilled with a truck-mounted drill. Detonation of the charge in some areas causes no surface disturbance while in other areas a small crater up to 6 feet in diameter may be created. The same hole may be reloaded and shot several times to find the depth and charge returning the best signal. Bentonite mud and cement is often used to plug the shothole after the shooting is complete. Cuttings from the well are normally scattered by hand near the shothole, put back in the shothole if the hole is shallow or hauled to a suitable disposal site.

Drill trucks are equipped to travel offroad. Swamp and marsh operations use drill rigs with large tires which can traverse soft ground and leave less surface expression than regular tires. Other types of vehicles which are commonly adapted for use in wetland-marsh areas are the Marsh-Buggy and Rolligon units.

Where access limitations, topography or other restraints prevent use of truck-mounted drill rigs, lightweight portable drill equipment can be used. Various kinds of portable drills can be backpacked or delivered by helicopter to the area. These portable operations use a pattern of holes drilled to a depth of approximately 25 feet or less. The holes are loaded with smaller explosives and detonated simultaneously. The combination of the shots gives a shock wave similar to the larger explosives in the deeper holes.

In shallow water areas, where it is too deep for marsh work and too shallow for normal marine operations, Teleseis telemetry systems may be used in seismic reflection recording operations. These units act as buoyed instrument packages which are connected to underwater geophones and transmit the detected seismic signals by radio telemetry to the recording instruments located onshore.

2) Surface Explosives

The surface explosive charge methods involve placing explosives directly on the ground, on snow, or on a stake or platform. Paper cones, survey stakes, laths or 2x4s up to 8 feet in length have been used as supports with varying success in different areas. Placing explosives on tall stakes or on the surface of deep snow results in good seismic data in some areas and creates little visible surface disturbance.

A given area may be explored with seismic methods several times by the same or different companies over a long period of time. The companies are using new or different techniques of obtaining data or do not have a cooperative agreement to share data.

C. Possible Effects and Mitigations

This section provides more specific information on the possible effects and mitigations of exploratory and seismic operations. This, however, cannot and should not be applied to a site-specific project without an interdisciplinary team of specialists to review and interpret the specific information.

The environmental resource values identified in this section are those most often affected by oil and gas activity on NPS lands. Those values with the most potential for significant impact are addressed first in this section.

1. Surface Disturbance (Soil and Vegetation)

a. Soil Compaction and Vegetation Damage

Soil compaction occurs when pressure on the surface causes pore spaces in the soil to collapse. Compacted soils often do not support vegetation because of reduced water-holding capacity and an inability of roots to gain adequate penetration. Compacted soils also have a lower infiltration capacity, resulting in greater runoff of precipitation and subsequent downslope erosion. Compaction impacts are most severe when soil moisture is at or near field capacity (during spring or the wet season).

Geological and geophysical exploration involving gravitational and magnetic surveys will cause limited compaction due to the use of overland vehicles in roadless areas. These vehicles may leave tracks in low-lying vegetation. These effects can be mitigated by requiring crews to travel by horseback or on foot over easily compacted soils or during the wet season. Compaction can also be lessened by completing the work during the dry season or by requiring crews to repair the ruts caused by the vehicles.

Geophysical exploration including seismic surveys will cause greater compaction and vegetation damage due to construction of temporary trails and use of heavy vehicles. The more rugged the topography, the more extensive the trail preparation may be. Seismic lines should be shifted if possible to avoid easily compacted soils. Effects can be minimized by requiring cross-country access with all-terrain vehicles with large tires or, if the area is sensitive, requiring crews to use pack animals or travel on foot. Also, the area of compaction can be limited by requiring all the vehicles, four-wheel drive vehicles for survey crews and cable laying, trucks for drilling or vibrating and the cleanup crews, to travel in the same path.

Seismic surveys involving heavy equipment which pound or vibrate the earth to create shock waves will cause compaction. Damaging effects may be especially noticeable where topsoils are left intact. Compaction effects can be minimized by limiting the use of mechanical equipment on easily compacted soils according to the season, weight of equipment, type of equipment, and the duration of use. Effects can also be minimized by ripping compacted soil horizons and revegetating.

b. Topsoil and Vegetation Removal and Alteration

Geophysical exploration involving seismic surveys will cause greater disturbance than magnetic or gravitational surveys to the topsoil and vegetation due to the construction of temporary trails and development of shotholes. Seismic lines may require the clearing of loose mineral material and vegetation to improve truck access. The survey crew will have to cut enough vegetation to provide a line of site from one survey point to the next. Both crews can be limited in the type and size of vegetation or trees that can be cut down or cleared. Effects can be minimized by requiring cross-country access with all-terrain vehicles or, if the area is sensitive, requiring the use of pack animals or foot travel which will reduce the width of trail needed to access an area. Effects can also be mitigated by requiring immediate rehabilitation of disturbed areas and including specific details on seed mixtures and rates, fertilizer requirements and rehabilitation.

c. Surface Erosion and Stability

Disturbances which leave the ground barren of natural vegetation render the productive surface soil horizons susceptible to removal by the erosive forces of gravity, wind and water. The erosion potential of a soil increases geometrically with slope. Less productive and excessively drained soils are more susceptible to long-term erosion than more fertile soils because the former do not have the ability to revegetate as rapidly.

The concentrated use of mechanized equipment may significantly compact soils and therefore measurably reduce soil infiltration. Geophysical exploration involving seismic surveys will cause erosion impacts due to the construction of temporary trails, use of heavy equipment and development of shotholes.

Effects can be minimized by requiring cross-country access with all-terrain vehicles, and where conditions permit, allowing conventional vehicles access over natural terrain rather than involving road construction; or if area is sensitive, requiring use of pack animals or entrance on foot. Erosion losses can be minimized by requiring that surface disturbances be confined to specified work areas and gentle slopes whenever possible. As with topsoil and vegetation removal, erosion can be mitigated by requiring immediate rehabilitation of disturbed areas and including ripping techniques, fertilizing and reseeding. Mass movement stability hazards will not be significant in preliminary exploration.

2. Water Quality

a. Sedimentation

Preliminary terrestrial exploration may cause increased sedimentation and water contamination problems. Increases in sedimentation may occur due to construction and use of temporary roads and trails in unstable soils near streams. Sedimentation in streams can also increase with runoff

from access roads and trails especially the slopes associated with cut or filled areas.

Effects may be mitigated by minimizing crossing of all streams, and prohibiting crossing of streams with unstable banks or bottoms. Reduced water quality from sedimentation may be minimized by prohibiting or reducing surface disturbance. Avoiding the removal of the protective vegetation mat in areas where surface runoff may enter stream channels may be required. Finally, effects can be mitigated by installing sediment traps in streams to catch and settle out sediments where temporary use of equipment is necessary in or near the stream.

Preliminary exploration in an aquatic environment is much the same as for terrestrial exploration, except for the mode of access. There is minimal impact to soils or vegetation from the use of boats in water deep enough to accommodate them. Greater impacts arise in marshy and estuarine areas where the water is neither deep enough to float a vessel nor dry enough to allow overland travel. Impacts can be lessened by crews walking or wading to set the charges and to place the geophones. Signals from the geophones can be sent to recorder truck or boat radio placed on a buoy.

Impacts to the hydrology and ecology of sensitive marshy and estuarine areas by the construction of access routes can be mitigated by avoiding sensitive areas. Impacts can also be minimized by the use of shallow draft vessels known as marsh buggies.

b. Groundwater Contamination

Shotholes and drilling muds used during preliminary exploration may cause groundwater contamination due to cross contamination of aquifers. Detailed discussion of these water quality problems will be discussed in Chapter III entitled Drilling Operations.

3. Fish and Wildlife

Because of the diversity of animal species and their unique habitat needs, the effects of oil and gas exploration on wildlife will vary immensely. There are, however, some common effects.

Additional trails and vehicle travel will increase harassment of animals. These effects may be mitigated by limiting exploration activity in certain periods of the year such as during wildlife winter stress periods, spring calving, breeding or nesting seasons, spawning seasons or migration periods.

Impacts can arise from the use of unconfined explosives in aquatic seismic surveys, which lead to fish kills. Fish kills can be mitigated by the use of any number of other systems capable of generating a low frequency shock wave, such as confined explosives or an air gun. Impacts can also be minimized by avoiding sensitive areas or by scaring fish away before detonating.

Exploratory activities which disturb terrestrial and aquatic plant communities will affect fish and wildlife species that require these

ecological niches for survival and reproduction. Vegetation and bottom-dwelling organisms directly in the path of a trail or channel will be disrupted or destroyed. An interruption of water flow patterns can lead to a significant decline in the viability of the ecosystems which require continued freshwater input or tidal changes. Before a seismic line is run, the hydrologic pattern of the area should be described in enough detail to determine whether the potential ruts or vegetation removal caused by line will change the pattern. If the disturbance will affect the hydrology, different methods of access should be chosen, a reclamation plan which restores the original flow pattern developed or the pattern of lines shifted out of the sensitive area.

Surface and channel disturbances resulting in increased erosion and sedimentation will smother fish spawning beds and aquatic insect producing areas. Contamination of surface waters entering riparian zones (bank areas of a natural watercourse) will have serious adverse effects on critical habitat and therefore dependent wildlife species. Mitigation may involve locating exploratory activities away from important habitat areas, such as riparian zones, or special measures to prevent surface water contamination such as plugging shotholes with bentonite and cement.

4. Air Quality

Preliminary exploration effects on air quality result primarily from vehicles used in seismic operations. Dust raised during trail construction, especially during dry and windy conditions, increases air particulate content. Particulate matter resulting from the initial surface disturbance is generally small. The main air pollutants during this stage are dust from vehicles travelling on access roads. To a lesser degree, smoke from internal combustion engines, especially diesel engines, contributes to particulate loading.

To reduce the amount of particulates introduced into the atmosphere from access roads, the following procedures could be stipulated:

- o Limit the number and size of vehicles allowed
- o Place speed limits on the roads
- o Spray dusty roads with water
- o Stress the maintenance and use of applicable pollution control devices on internal combustion engines

5. Aesthetic Quality

Disruption of surface vegetation for temporary trails and seismic lines is a source of visual impact. Also, overland vehicles can leave ruts which have a visual impact. Roads and trails should be restricted to areas which are not highly visible to mitigate the impact. Also, heavy traffic should be limited during spring thaw or wet weather to minimize the visual impact due to ruts.

Heavy equipment and trucks associated with exploratory operations will be a source of visual impact in a setting such as a national park. Impacts can be mitigated by restricting activities to areas which are not highly visible and minimizing use during heavy visitation periods.

6. Noise

Noise from geological exploration and geophysical reconnaissance surveys will have an impact on the natural environment. Field equipment makes little noise, except for motorized trench-digging or core-drilling equipment used for subsurface sampling in geochemical prospecting (approximately 70 dBA). The greatest source of noise will come from the vehicle used to access the area, whether it be an offroad vehicle, boat, airplane or helicopter. Passage of these vehicles will temporarily disrupt an otherwise quiet environment existing in roadless areas, frightening wildlife. Brief noise levels associated with helicopters may be as high as approximately 90 dBA. Repeated passage of these vehicles, however, would be disruptive for persons using the area for recreational purposes, especially in the case of helicopters.

Seismic exploration will have a greater environmental impact on noise levels. Vehicles used will be larger and heavier and will generate more noise. Also, they will be greater in number to accommodate increased crew size. Temporary trails have to be constructed in roadless areas. This may require the use of noisy bulldozers if the area is heavily vegetated or topographically diverse. The duration of the impact may increase; crews may linger, working in an area for several hours or days.

The use of explosives in seismic surveys also impacts the environment's normal noise level. Most explosives are used below the surface thereby minimizing the sound which can be heard. But wildlife can often feel the shock waves from the blast even if no sound can be heard, resulting in fright. The noise impact on humans is negligible because people, other than the exploration crew, are not allowed in the blasting area.

The potential for mitigation measures in preliminary exploration is low. The NPS may, however, limit use of offroad vehicles, boats or aircraft and require walk-in crews where possible. Where seismic surveys are involved, explosives may be limited to subsurface rather than surface operations. The NPS may choose to allow activities only during slack recreational periods or outside of critical wildlife breeding and migration periods. These particular periods will vary from park to park.

7. Geological Features

Delicate formations, such as balanced rocks, natural arches, spires or cave formations, can be weakened by the ground vibrations generated by seismic operations. To a lesser degree, formations may also be weakened by ground vibrations associated with the movement of large trucks. Hard, rocky ground will transmit more vibrations than sandy or soft soils. Exposure to vibrations associated with exploratory operations will be of short duration.

Seismic surveys and access roads should be located as far away as possible from rock formations or other geological resources that may be sensitive to damage from ground tremors. A quarter to a half mile buffer should be adequate.

Deposits of collectable minerals and rocks and petrified wood can be destroyed or damaged if they lie within the proposed disturbance zone. NPS base maps and data should be reviewed to identify areas where these resources exist. Reconnaissance of the area can also identify deposits and possible protection measures. Once again, the best protection is avoiding the resources by relocating the seismic survey and access road.

8. Cultural Resources

Cultural resources are sites, structures, objects and districts significant in history, architecture, archaeology or culture. Impacts due to exploratory operations can be similar to disturbances on geological features. Any surface disturbing activity such as seismic surveys and access road construction may impact nearby cultural resources through ground vibrations, disruption of soil and vegetation and increased erosion and sedimentation. The best protection is avoiding the resources by relocating the seismic surveys. Additionally, impacts can be minimized by any of the previously discussed mitigation measures for the conservation of soil and protection of vegetation.

Artifacts can be destroyed or damaged if they lie within the proposed disturbance zone. Once again, the best protection is avoiding the resources by relocating access roads and trails and seismic surveys.

If cultural resource sites are discovered that will be impacted, the operation should be stopped until measures specific to the project/cultural resource site can be designed in cooperation with the State Historic Preservation Office, Advisory Council on Historic Preservation and NPS Historical Specialists. Such measures might involve modification of the project, rerouting of the access, or recovery of the cultural resource by excavation or other means, or a combination of these.

D. Summary

Table II-1 lists the major exploratory operations and their alternatives, and presents key potential impacts by environmental/resource area. Table II-2 presents potential mitigation measures for those impacts.

Table 11-1
Potential Environmental Impacts Associated with Exploratory Operations
Environmental/Resource Value

Operation	Soil and Vegetation	Water Quality	Fish and Wildlife	Air Quality	Visual Quality	Noise	Geological Features	Cultural Resources
<u>Geological Exploration</u>								
Mapping	Compaction and vegetation damage from overland vehicles.				Ruts and vegetation damage from overland vehicles.	Temporary noise due to transportation.		
Geochemical	Compaction and vegetation damage from overland vehicles. Disturbances due to subsurface sampling.				Ruts and vegetation damage from overland vehicles.	Temporary noise due to transportation and subsurface sampling.		
<u>Geophysical Exploration</u>								
Gravitational Survey	Compaction and vegetation damage from overland vehicles.				Ruts and vegetation damage from overland vehicles.	Temporary noise due to transportation.		
Magnetic Survey	Compaction and vegetation damage from overland vehicles.				Ruts and vegetation damage from overland vehicles.	Temporary noise due to transportation, and aircraft.		
Seismic Survey								
• Nonexplosive	Compaction and vegetation damage from heavy vehicles, possible cut and fill in steep terrain, and test procedures. Vegetation removal and alteration for seismic lines. Erosion due to cut and fill or overland vehicle travel.	Sedimentation due to rutting from overland heavy vehicles.	Degradation of habitat due to impacts to soil, vegetation, water quality or noise. Reduced populations due to disturbance of habitat.	Criteria pollutant emissions from combustion engines.	Scenic quality degradation due to the presence of heavy equipment, and temporary trails. Ruts and vegetation damage from preparation of seismic lines.	Temporary noise from heavy vehicles and test equipment.	Damage to delicate formations from ground vibrations due to heavy equipment traffic and test procedures.	Damage from surface disturbance and trail construction. Damage from ground vibrations due to heavy equipment traffic and test procedures.
• Explosive	Compaction and vegetation damage from heavy vehicles, and possible cut and fill in steep terrain. Vegetation removal and alteration for seismic lines. Erosion due to cut and fill activities and shothole preparation.	Sedimentation due to rutting from off road heavy vehicle travel. Groundwater contamination due to flow from formations.	Degradation of habitat due to impacts to soil, vegetation, water quality or noise. Reduced populations due to disturbance of habitat. Fish kills from the use of uncontained explosives in aquatic surveys.	Criteria pollutant emissions from combustion engines.	Scenic quality degradation due to the presence of heavy equipment and temporary trails. Ruts and vegetation damage from preparation of seismic lines.	Temporary noise from heavy vehicles. Vibrations due to blasting.	Damage to delicate formations from ground vibrations due to heavy equipment traffic and explosives.	Damage from surface disturbance and trail construction. Damage from ground vibrations due to heavy equipment traffic and explosions.

Table II-2
Mitigations for Potential Environmental Impacts
Associated with Exploratory Operations

Operation	Soil and Vegetation	Water Quality	Fish and Wildlife	Air Quality	Visual Quality	Noise	Geological Features	Cultural Resources
<u>Geological Exploration</u>								
Mapping	Route travel on firm soil. Limit access on fragile soil and vegetation types. Avoid running lines during spring thaw or times when the soil will be easily compacted and rutted.				Fill in ruts. Limit travel through fragile, highly visible terrain.			
Geochemical	Same as above.				Same as above.			
<u>Geophysical Exploration</u>								
Gravitational Survey	Same as above.				Same as above.			
Magnetic Survey	Same as above.				Same as above.			
<u>Seismic Survey</u>								
• Nonexplosive	Limit travel across fragile soil or vegetation types. Alter routes to avoid steep slopes. Re-contour rutted areas.	Avoid travel on steep slopes. Avoid routes through or near stream channels.			Same as above. Minimize vegetation damage. Drive around trees. Use existing roads and trails if possible. Hand-carry geophones.		Limit access near delicate formations. Move lines away from sensitive formations.	Limit access in areas of cultural resources. Move lines away from cultural sites.
• Explosive	Same as above. Use backpack drills when environment is easily damaged by vehicle traffic. Cut plug of vegetation from top of shot hole. Replace drill cuttings and plug in hole when shooting is complete.	Avoid travel on steep slopes. Avoid routes through or near stream channels. Grout or cement shot holes closed if formation water flows are a problem.			Same as above. Minimize size of drill trucks. Avoid cutting large trees. Hand-carry geophones.		Limit access near delicate formations. Minimize size of charges. Move lines away from sensitive formations.	Limit access in areas of cultural resources. Minimize size of charges. Stop or reroute lines if new sites are discovered.

III. DRILLING OPERATIONS

Stratigraphic test drilling often supplements a detailed geophysical exploration program and is used to further define and confirm seismic data. Once the surface and subsurface geological and geophysical data are interpreted and a potential hydrocarbon trap is located, exploratory holes are drilled to search for actual deposits of crude oil and natural gas. This form of drilling goes beyond that encompassed by stratigraphic test drilling and is known as "wildcatting."

When a wildcat well discovers an oil or gas deposit, additional wells are drilled to establish the extent and commercial viability of the field. Wells are tested for productivity, then either completed for production or plugged and abandoned. If a good producing zone is found, then support facilities are brought in to allow production. Development of a field may take many years, continuing on through the beginning stages of production. The following discussion addresses stratigraphic test (core) and wildcat drilling, oil and gas field development, potential environmental effects of these activities and suggested mitigation measures.

A. Stratigraphic Tests

"Strat" or core tests involve drilling relatively shallow holes to supplement seismic data. These tests aid in revealing the nature of near-surface structural features. The holes are usually from 100 to several thousand feet deep, and are drilled primarily by truck-mounted drill rigs. As the rock is drilled, the resulting rock chips are brought to the surface by a high-pressure airflow or circulating drilling mud. Samples of these chips are collected, bagged and identified as to depth of origin. They are then studied by a geologist to determine composition, age and possible formation. The geologist looks for a geological marker zone or formation to correlate this geological and geophysical data to other known subsurface structure in order to prepare a subsurface geological map.

Truck-mounted drilling equipment for strat tests is fairly mobile and does not require any more than reasonably level solid ground for access to the drill site. In rugged or wet terrain, some clearing, grading and other road construction may be required to gain access.

A space of about one-half acre or less is leveled and cleared of vegetation for the average strat test drill site. If air drilling is employed, drill cuttings are blown into a reserve pit next to the drill truck through what is known as a blooey line. If mud is used as a drilling fluid, mud pits may be dug; more commonly, portable mud tanks are used. Usually 1 to 3 days are required to drill the strat test holes, depending on the well depth and the hardness of the bedrock. In areas with shallow, high-pressure, waterbearing zones, casing may be required to keep water out of the hole.

B. Wildcat and Development Well Drilling

1. Road and Drill Pad Location

The characteristics of the potential hydrocarbon trap and other geological considerations determine the desired bottom hole location, or target zone. The bottom hole location is defined by both surface location and depth. The industry prefers to drill vertically and usually chooses a drill site directly above the bottom hole location. Topographical, geological or environmental constraints may prevent a drill site from being located directly above the bottom hole location, necessitating the use of directional drilling.

Directional drilling involves directing a wellbore from the vertical below the surface along a predetermined course to a target zone located a given distance away. It is a common practice in the industry today with a number of uses. Directional drilling techniques can be applied if the target zone lies underneath an inaccessible location such as a heavily urbanized area, mountain or water body, and the drill rig must be located elsewhere. The technique is most often used in offshore applications to allow many wells to be drilled from one location. It can be used to drill around or through fault planes, salt domes or obstructions in the hole, and to provide relief to a nearby well which has blown out. Finally, as will be discussed in Section F of this chapter, directional drilling can be a useful tool in mitigating a large number of environmental impacts.

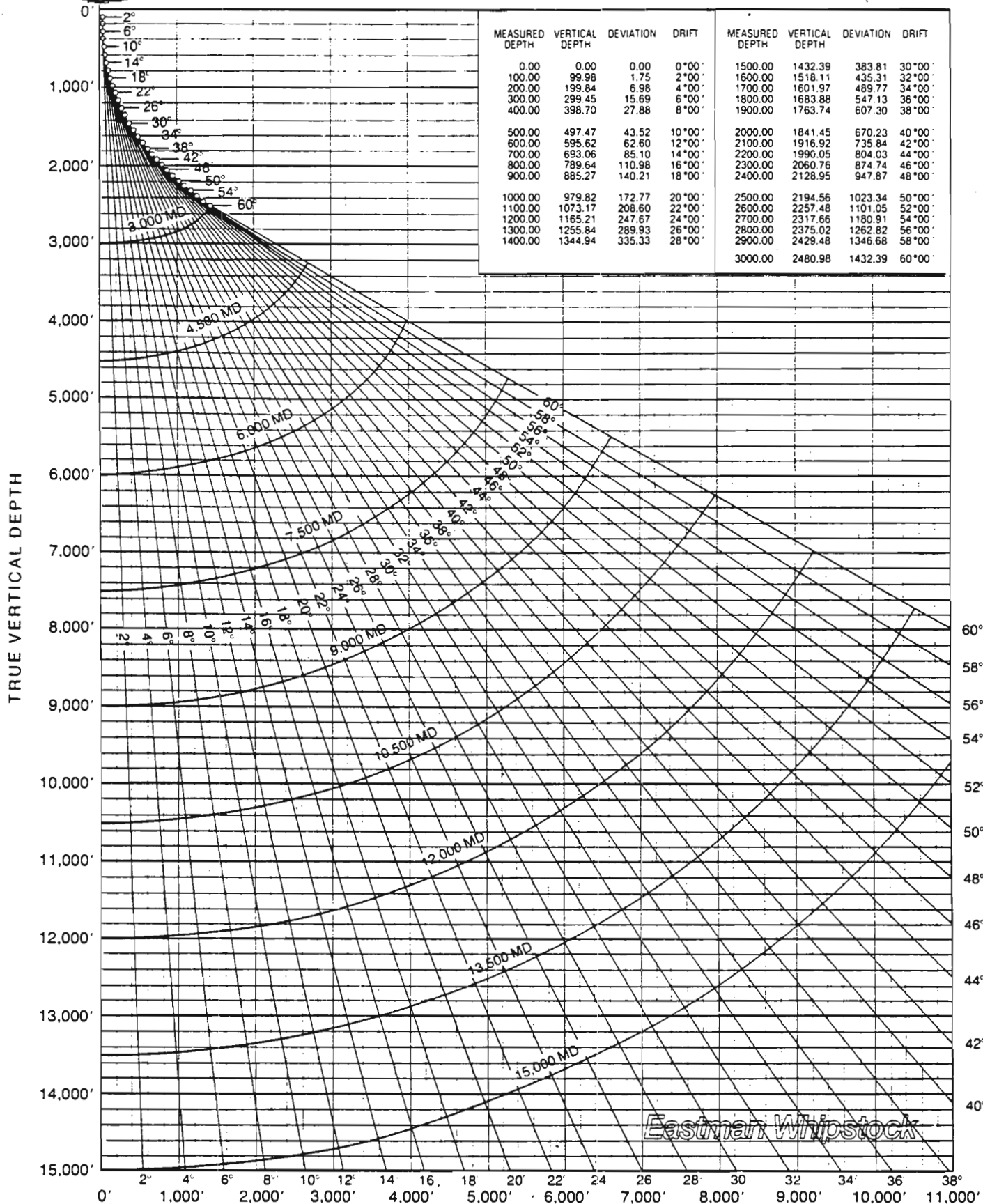
While directional drilling allows flexibility in the selection of the drill site, there are numerous technical, physical and economic constraints on its use. For example, accurately monitoring the orientation of the drill and the resultant hole is technically very difficult. A mathematical procedure using what the industry calls "standard build up" charts can be used to calculate the lateral displacement possible for inclinations of up to 60° from the vertical (Introduction to Directional Drilling). An example chart is provided as Figure III-1. Geological characteristics such as formation stability, type and dip angle physically complicate and restrict the opportunities for using directional drilling. The cost of using this technique averages substantially more (50 percent) than vertical drilling and it is financially riskier. A more complete discussion of the applications and limitations of directional drilling can be found in "A Procedural Guide for Oil and Gas Administration."

Once a drill site has been selected, it may be necessary to construct access roads. Although long-term drilling efforts in remote areas may establish living quarters onsite, usually a substantial work force must commute to the site. There will also be considerable large truck and specialized heavy equipment traffic, especially if a well is completed and brought into production.

Wildcat drilling often takes place in remote areas. Preliminary exploration work will not have contributed any new roads to an area, although there may be some cross-country trails. Temporary access roads will have



UNIFORM 2°00' INCREASE IN DRIFT PER 100 FT OF HOLE DRILLED



SOURCE: Eastman - Christensen. Reprinted with permission.
FIGURE III-1 BUILD UP CHART

to be constructed and if they exist, low standard roads may require upgrading to accommodate the heavier loads associated with truck traffic. One lane is usually adequate. Installation of culverts or other engineering structures will be necessary in steep terrain or when crossing stream channels. Access roads may be surfaced with material such as gravel, oyster shells, caliche or ground limestone. In marshy areas, a roadbed may be laid with heavy boards.

If the well discovers a commercial quantity of oil or gas and further development of a field takes place, additional roads will be constructed. The National Park Service may or may not wish roads constructed by the oil and gas industry for long-term use in a producing field to become permanent.

Site preparation may include extensive clearing, grading, cutting, filling and leveling of the drill pad using heavy construction equipment. The drill pad typically occupies 3 to 5 acres. Directional drilling may require a larger sized rig or additional facilities which increase the pad size. For inland water sites, drilling barges that sit on the bottom may be used as a foundation for the drill rig. Some dredging may be done on these sites to create a "slip," and protective "skirts" or pilings may be installed around the barge to prevent erosion by currents and tidal flow. In deeper water, jack-up, submersible and semisubmersible rigs and drill ships may be used to drill wildcat wells. An offshore platform is required to drill development wells in deep water.

2. The Drilling Operation

A drilling operation usually involves the following items (see Figure III-2):

- o An access road to the drill site as previously discussed
- o A drilling pad, reserve pits to capture drill cuttings or produced fluids, burn pits, and sumps to capture rig wash water or pad runoff [in units of the National Park System, drill cutting pits and sumps will be contained in metal tanks]
- o The drilling rig and associated tanks, motors, generators and storage facilities
- o Pipe and casing racks
- o Living quarters and sanitary facilities for the drilling crew
- o A source for water used in drilling (e.g., water wells, water lines and pumps or trucking in water)
- o Numerous support vehicles used for construction and transportation of men and equipment to the site

The actual drilling equipment is collectively known as a drilling rig. Rigs may be of any of several types, but all include the following basic components: the derrick or mast; the hoisting equipment, including the

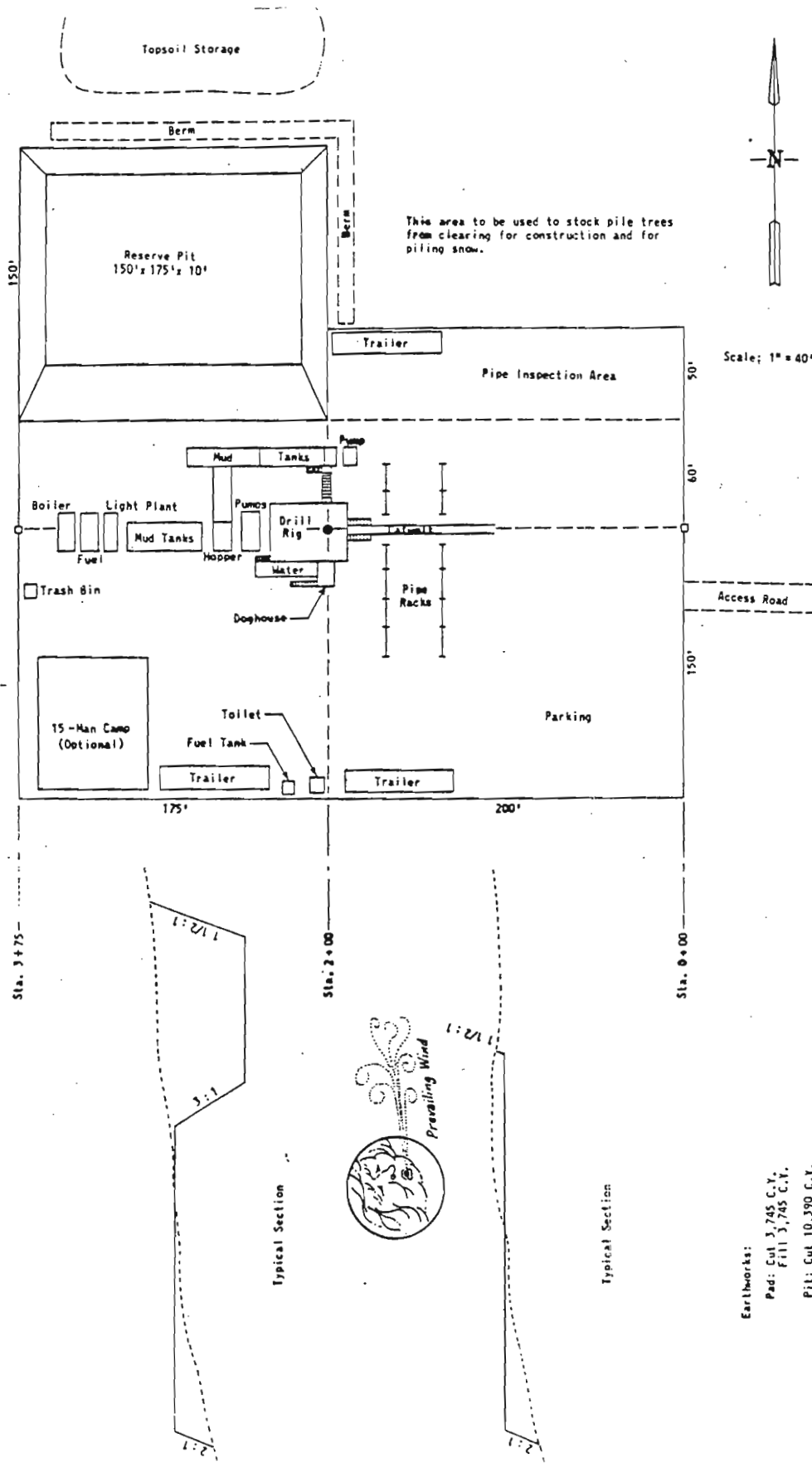


Figure III-2 Typical Drilling Equipment Layout

Source: USDA Forest Service

draw works, crown and travelling blocks and hook; the rotating equipment, including a swivel, kelly, drillpipe, drill collars and bit; the mud system and finally, the prime movers or engines and other auxiliary equipment (Figure III-3).

Drilling rigs may be either standard or portable. Standard derricks are usually trucked in modules and assembled on the site. However, if moving distances are short, the derrick may be skidded from one site to the next on the same pad. Portable truck-mounted masts are usually smaller and cannot be used for wells deeper than 2,000 to 3,000 feet. Their use saves on costs for erection, teardown and transport.

While on location for a drilling operation, most rigs run 24 hours a day with a crew of 4 or 5 men in attendance. Drilling times may run anywhere from 2 weeks to 6 months or longer either to bring a well into production or to determine that it is dry. The depth of a well depends upon the geology of the area. Some wells may run only a thousand feet deep, but depths of over 10,000 feet are common. The deepest wildcat well reached 31,000 feet and took almost 17 months to drill.

Power must be provided to the rig in order to operate the mud circulation system, the rotation of the bit, the hoist and the operating lights. Most rotary rigs are powered by internal combustion engines that burn diesel, natural gas, butane or gasoline. Power can also be provided by steam engines, diesel electric generators or alternating current. Most rigs have two or more engines with horsepower ranges from 1,000 to 3,000 hp. Auxiliary power for lighting is usually provided by smaller (100 to 150 hp) units.

Wells are drilled by a rotary drilling method, a technique which has all but replaced the older cable-tool method. In the rotary method, a rotating drill bit is connected to and rotated by a drill string or pipe added in sections as drilling depth increases. Cuttings from the drilling process are removed by a drilling fluid either "mud," air, or foam, which is continuously circulated through the drill string, out nozzles in the bit and back up to the surface in the annular space between the drill string and the walls of the borehole. Once back to the surface, the returned fluid is diverted through a series of tanks (mud and reserve pits) that remove the drill cuttings and keep the fluid well mixed. In the last of these tanks, the fluid is picked up by a pump and the whole cycle is repeated (Figure III-4).

This system is perhaps the most important component of the rotary drilling method. In addition to removing cuttings, the mud helps to maintain hydrostatic pressure in the hole and thus prevents any uncontrolled flow from penetrated formations. When uncontrolled flow advances to the surface, the result, called a "blowout," is one of the most damaging of all oil field accidents. Other functions of the drilling mud are to cool the bit, to seal the walls of the hole preventing loss of fluids into permeable formations and to protect against corrosion of the drill string and other components.

Drilling mud may be pumped at rates up to 12 barrels per minute and under surface pressures as high as 3,000 pounds per square inch. Because all

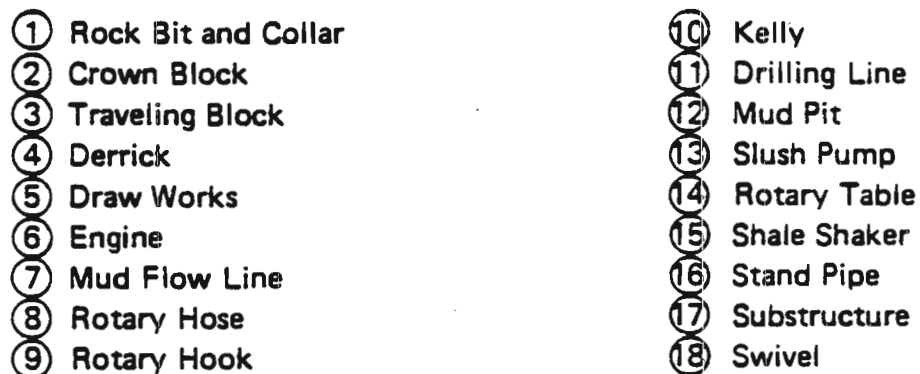
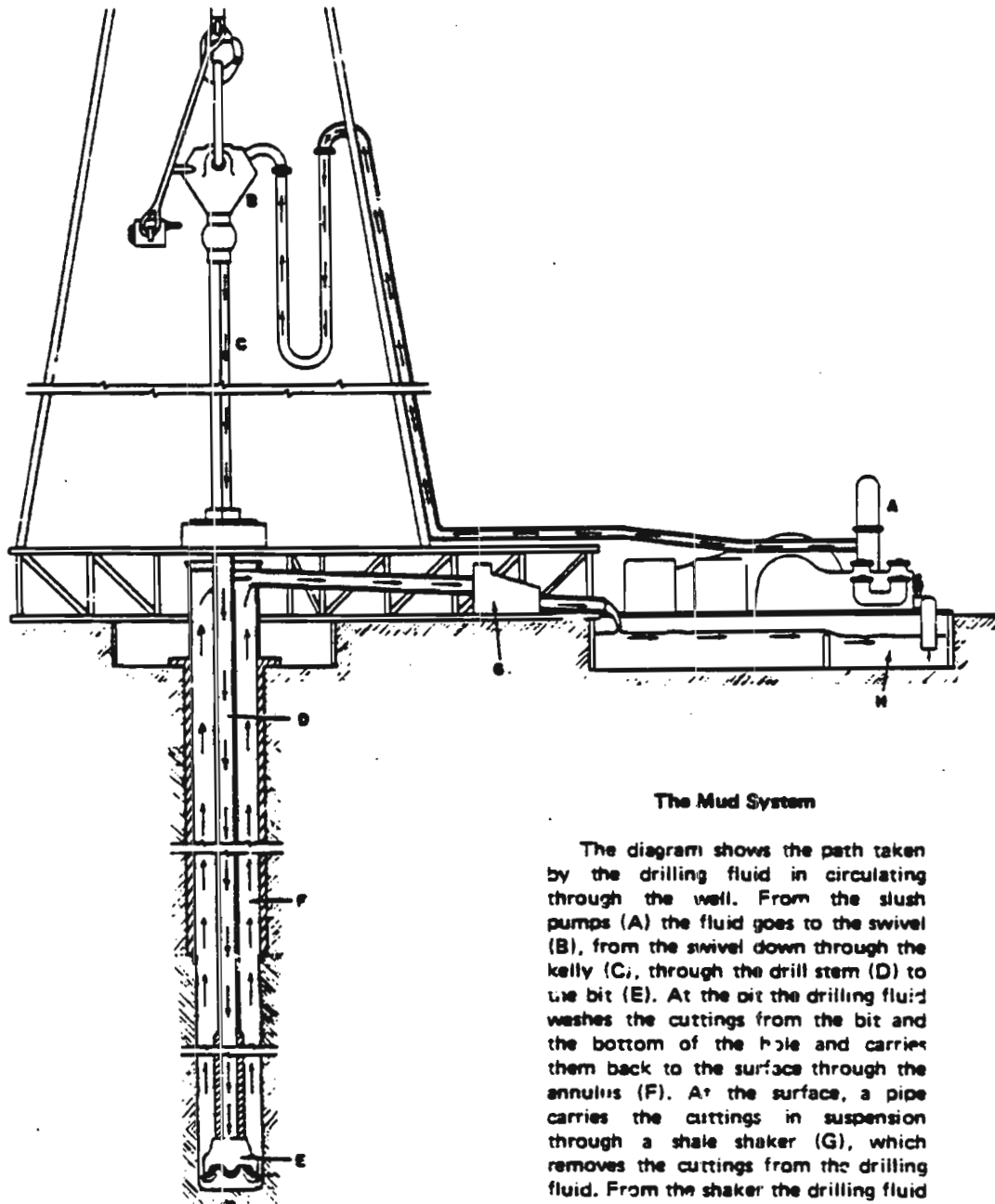


Figure III-3



The Mud System

The diagram shows the path taken by the drilling fluid in circulating through the well. From the slush pumps (A) the fluid goes to the swivel (B), from the swivel down through the kelly (C), through the drill stem (D) to the bit (E). At the bit the drilling fluid washes the cuttings from the bit and the bottom of the hole and carries them back to the surface through the annulus (F). At the surface, a pipe carries the cuttings in suspension through a shale shaker (G), which removes the cuttings from the drilling fluid. From the shaker the drilling fluid goes to the mud pit (H) and the whole cycle is begun again.

DRILLING AND MUD SYSTEM (from University of Oklahoma, 1975)

Figure III-4

of its functions are important, the drilling fluid system constitutes a major portion of the equipment and cost in drilling a deep well. Most mud operations are controlled by a mud contractor. Drilling muds will be discussed in more detail in Section 3 entitled Drilling Fluids.

Another very important component of any drilling operation is the pressure control equipment, which is usually mounted directly beneath the rig floor in an 8 to 10 foot deep cellar. This component, which is called a blowout preventer stack, consists of several different large valves that are intricately connected with the mud circulation system. These valves are designed to shut in the wellbore should the drilling encounter high pressures or flows of fluids or gas. The blowout preventers should be sized according to the highest potential pressure for the area. Normal sizes will contain 2,000, 3,000 or 5,000 psi pressures.

As part of the safety equipment, returning mud comes back through the blowout preventer stack, out through a choking device that is designed to relieve borehole pressures, and into a mud-gas separator. This device, sometimes called a "vacuum degasser," separates usable mud from entrained combustible gas, which is then piped a safe distance from the rig and either flared or bubbled through water. Many states forbid flaring of well gas; in these areas it may be contained and piped from the site.

During most drilling operations, casing is run into the hole and cemented in place. This is a costly but important function for the successful drilling of any well. Many major oil field accidents have resulted from improper casing programs. Casing requirements call for the setting a number of casing strings (Figure III-5).

- o Large diameter conductor pipe is installed during site preparation. It allows drilling through weak or sticky surface material.
- o The surface casing provides for attachment of the blowout preventers and protection of fresh or treatable water aquifers
- o The protection or intermediate casing string is set primarily to prevent a blowout through weaker, intermediate formations. It also protects against possible contamination of freshwater aquifers by brines. Intermediate casing is primarily used in deep wells, over 5000 feet deep.
- o A production casing string is set at the bottom of the well opposite the producing formation where maximum well pressures are expected. If a well is dry and abandoned, production casing is not installed.

Casing a well has seven important functions:

- o To prevent caving of the hole
- o To prevent contamination of freshwater aquifers

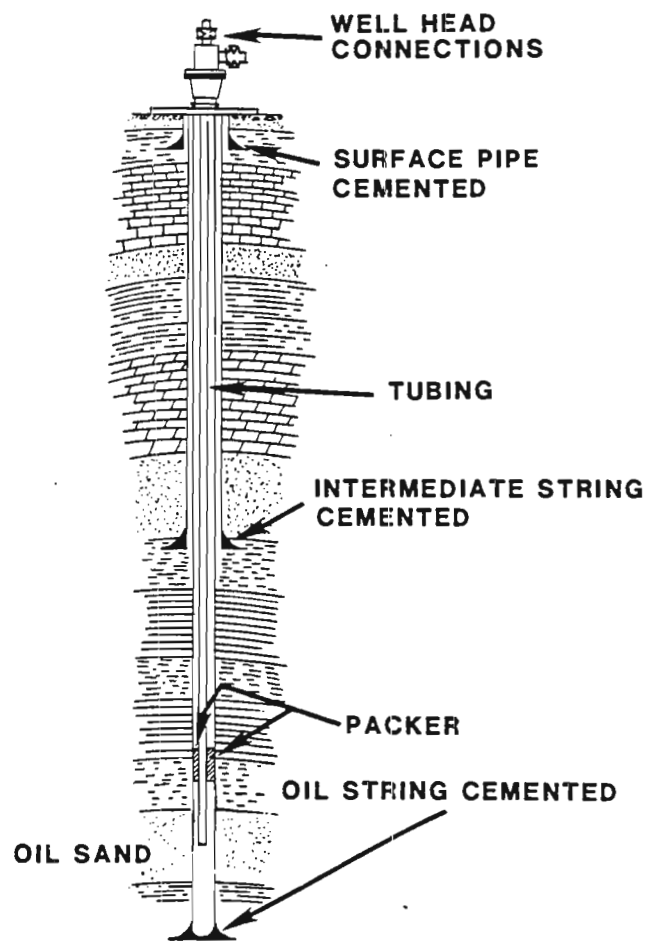


FIGURE III-5 WELL CASINGS

Source: Introduction to Oil and Gas Production, 1983,
American Petroleum Institute

- o To exclude water and drilling fluids from producing formations
- o To exclude formation waters or brines from entering the wellbore
- o To confine production to the borehole
- o To provide a way of controlling formation pressures
- o To permit installation of artificial lift equipment for producing the well

Casing programs are based on geophysical information and developed from recommendations by the geologist and the drilling engineers. Further discussion on casing programs and cementing will follow under Section C of this chapter.

Water wells may be drilled onsite, or pumps and water lines may be installed to bring water to the site for use in drilling operations. Up to 350 barrels of water per day may be needed for mixing drilling mud, cleaning equipment, cooling engines, etc. Water may be trucked in to the drill site if surface or shallow groundwater is not locally available.

3. Drilling Fluids

The importance of the drilling fluids or muds is described in the previous section. Because they are such a vital component of a drilling operation, it is important to understand the character and constituents of drilling fluids as well as the importance of maintaining good quality mud.

The drilling fluid has a number of primary characteristics: viscosity, gel strength, density and colloidity. The mud can be either water-based or oil-based. Water-based muds, which include fresh water-based and salt water-based, are most commonly used. Typical compositions include water, clay, weighting materials (barite is popular), and chemical additives. Table III-1 illustrates major drilling fluid components. Mud composition is varied to respond to changes in the drilling environment.

Mud program planning is critical for deep drilling operations. Down-hole conditions must be consistently monitored for temperature and pressure in order to provide the proper mud characteristics. It requires considerable skill to balance the weight of the drilling mud against the pressure of formation fluids. It is necessary to secure a weight sufficient to prevent a blowout and yet light enough so that fluid will not enter a formation, causing lost circulation. In order to accomplish this, a number of additives are used in drilling fluids.

Fluid densities for muds may range from 9 pounds per gallon (67 lbs. per cu. ft.) to 20 pounds per gallon (150 lbs. per cu. ft.). For comparison, fresh water is 8.33 pounds per gallon (62.3 lbs. per cu. ft.). In very deep wells where down-hole temperatures can reach 500° F, serious problems can develop with the drilling fluids. At temperatures above

Table III-1
Major Drilling Fluid Components Used at the Six API Mud Pit Sites

Component	Site Code					
	DND	EWY-1	EWY-2	CIX	KIX	ILA
(Percent of Total Dry Weight of Solid Components)						
Weighting Agents and Viscosifiers						
Barite (BaSO ₄)	-	18.9	29.6	57.3	71.4	49.6
Bentonite Clay	-	62.4	33.8	20.1	3.0	45.7
Attapulgitte Clay	21.2	10.6	10.6	-	-	-
Asbestos Fiber	0.84	-	-	-	-	0.07
Fluid Loss Reducers						
Sodium Carboxymethylcellulose	-	-	-	-	-	0.6
Polyanionic Cellulose	-	-	2.44	-	-	-
Sodium Polyacrylate	-	0.46	-	-	-	-
Corn Starch	9.0	-	-	-	-	-
Organic Polymer	-	0.02	2.41	-	-	0.36
Dispersants and Thinners						
Ferrochrome Lignosulfonate	-	-	-	6.9	-	-
Chrome Lignosulfonate	-	-	2.22	-	3.9	0.60
Lignite	-	-	-	1.0	2.3	0.80
Sodium Acid Pyrophosphate	-	-	-	-	-	0.36
Lost Circulation Materials						
Fiber Blends	-	0.04	0.17	-	-	-
Cedar Fiber	1.6	-	-	-	-	-
Sugar Cane	0.6	-	-	-	-	-
Nut Shells	-	0.39	-	-	-	0.93
Mica	1.2	-	-	4.7	0.01	0.26
Chip Plug	-	-	0.70	-	-	-
Sawdust	-	0.25	10.35	-	-	-
Lubricants, Detergents, Emulsifiers, Defoamers, and Flocculating Agents						
Aluminum Stearate	-	0.02	0.06	-	0.03	0.01
Surfactants	-	0.05	-	1.3	-	-
Bentonite Extender	-	0.14	0.08	-	-	-
Sulfonated Asphaltene	-	-	-	1.5	-	-
Bituminous Asphalt	-	-	-	-	0.34	-
Sodium Polyacrylate Polymer	-	0.10	0.01	-	-	-
Diesel Fuel Oil	*	-	-	-	-	-
Chemical Additives						
Caustic Soda (NaOH)	-	1.49	2.49	6.5	1.3	0.76
Soda Ash	-	3.04	2.62	-	0.4	-
Sodium Dichromate	-	0.55	-	-	-	-
Sodium Bicarbonate (Na ₂ CO ₃)	-	0.43	1.28	-	0.05	0.03
Salt (NaCl)	66.1	-	0.44	-	-	-
Lime (CaOH or CaO)	0.1	0.08	0.15	0.2	-	0.06
Gypsum	0.06	-	-	-	-	-
Sodium Pentachlorophenate	0.08	-	-	-	-	-
Ammonium Nitrate	-	0.13	0.57	-	-	-
Corrosion Inhibitors						
Ammonium Bisulfite	-	0.02	-	-	-	0.06

* Used during drilling operation in ranges up to 8 percent by volume; the exact quantity or interval of use are not recorded on mud logs and are, therefore, not quantified in this table.

Source: Hydrologic and Environmental Effects of Drilling Mud Pit and Produced Water Impoundments, Bost, 1982.

300° F, most muds begin to break down. Special precautions must then be taken to prevent uncontrolled fluid loss or a blowout condition.

During any drilling operation, the drilling mud in use may be exchanged for a different type, depending upon the down-hole environment. Therefore, onsite storage of prepared dry muds is necessary. Proper handling and storage techniques are important for mud operations in order to prevent accidental spillage or breakage. Also, dust hazards are created by muds with high silica and asbestos fiber contents.

Most mud circulation systems are now contained in metal tanks. Earthen pits are used to dispose of excess or unused muds and drill cuttings. The industry prefers to dispose of drill cuttings and waste fluids extracted from the mud in the earthen reserve pit before it recirculates the mud. The pit may be lined with plastic or bentonite to prevent fluid loss. It is possible to dispose of these waste materials in metal tanks and periodically haul used mud and cuttings to an appropriate disposal site outside the park. Tanks should be used as the preferred alternative to reserve pits to prevent the possibility of leaching contaminants into the soil.

Where certain conditions exist, wells may be drilled using air, gas or foam in lieu of drilling fluid. This method may be used when the following circumstances are present:

- o Formations are not excessively water-bearing or high-pressure
- o Producing formations can be easily injured by drilling fluids
- o Highly fractured or porous zones allow lost circulation of drilling fluids
- o Well depth is relatively shallow

Air, gas or foam drilling hazards include the possibility of explosion and an inability to control down-hole pressures. To help prevent these hazards, gas drilling operations have exhaust vents downwind from the rigs to disperse excess gas to the air. Also, mud is usually kept on hand to enable workers to "kill" the well in the event of a potential blowout.

C. Testing, Dry Hole Abandonment and Cementing

1. Testing for Productivity

Once a well has been drilled to the desired depth, the drilling or lease operator must decide whether to complete the well or abandon it. Several tests are available to help make this decision. They include analysis of drill cuttings, corings, well logs and drill stem tests.

Cuttings carried to the surface by the drilling fluid and separated out in the shale shaker (see Figures III-3 and III-4) are analyzed to see if any oil or gas is in the rock formation being drilled. Or a core can be

taken by lowering a core barrel into the hole to cut a cylindrical sample of rock, which is then brought to the surface for analysis.

Well logging can be performed any time the drill string is out of the hole. Logging tools, lowered on a wireline into the hole, measure properties of the formations they pass. Electric logs are a measure of the electrical properties of the formations and are commonly done in all wells; acoustic, radioactivity and other logs are also possible.

While core analysis and well logs provide useful information, they can be inconclusive as to the true potential of the hole. Drill stem tests offer more definitive information. They may be run several times during the drilling of a single hole, perhaps as many as 20 to 30 times. A drill stem test uses a tool lowered into the hole on the drill string to isolate the formation of interest. The hydrostatic pressure of the mud is relieved to allow formation fluids to flow into the drill pipe. The pressure in the hole is recorded and a sample of the formation fluid is brought to the surface for analysis. Because this test is a temporary completion of the well, care must be taken by the operator to prevent a blowout and to properly dispose of any gases, oil or brine brought to the surface as the drill pipe is removed.

If evidence of a good producing zone is not found from the tests, no production casing is run, and the well is plugged and abandoned.

2. Dry Hole Abandonment

If the hole is determined to be dry, it is then plugged and abandoned. Procedures for well abandonment are usually outlined by state regulatory authorities or the Bureau of Land Management and may vary from state to state. If future contamination of subsurface aquifers is to be prevented, at a minimum, zonal plugs of cement should be placed opposite production zones, freshwater-bearing strata and at the surface. Intervals between each plug should then be filled with a heavy mud. Actual requirements are dependent upon the physical characteristics of the penetrated formations, such as permeability, porosity and thickness. Plugging requirements are described in more detail in Chapter V-C.

3. Cementing Operations

If the well is determined to be a producer, then the production casing is run and cemented in place. The surface and intermediate casings are also sealed with cement when they are run.

Well cementing is usually a contracting service. It requires a great amount of specialized heavy equipment travel to the drill site. Cement either can be prepared offsite and trucked in slurry form to the drill site, or can be stored at the site in bulk dry form and mixed during the cementing operation. In either case heavy-duty pumping vehicles are usually required.

Each casing string is cemented in place by the slurry, which is pumped down the drill pipe and up the annulus between the casing and the borehole walls. This operation is critical and, if not properly done,

can result in a future blowout or contamination between formations. Conductor pipe and surface casing should be cemented from bottom to surface. Some contractors do not cement their intermediate or production casings all the way to the surface; others do. The amount of cement depends on the depth of the well and number of producing zones, and depths and number of freshwater or corrosive water zones. Cementing is also important to retard corrosion of the casing by minimizing contact with corrosive formation brines. Production casing should be cemented so that the pipe is bonded to the formation to a height of 50 feet above the highest potential producing zone.

Well cements are varieties of regular cements used in construction work. Common portland cement is used, for instance, with various chemical additives for down-hole conditions. Some specific additives are as follows:

- o Bentonite
- o Diatomaceous earth
- o Volcanic ash
- o Diesel oil, kerosene
- o Barite
- o Calcium chloride
- o Sodium chloride
- o Sodium silicate
- o Carboxymethyl hydroxyethyl cellulose
- o Calcium lignosulfonates

Special cements also can be used. One of the more important of these is pozzolan cement. Pozzolan cements, both natural and synthetic, are siliceous cements that react with lime. Fly ash is a common source of pozzolan.

During operations, liquid components of the cement are often returned to the surface. These liquids should be stored in lined pits or agitated tanks and not allowed to come in contact with soil, surface or subsurface fresh waters.

After the cement has set the required time and tests have been made to determine that it has set up properly, the well is ready to be completed. There are four different types of completions. Well completion techniques will be covered in Chapter IV, Production Operations.

The cost involved in drilling wells may range from \$50,000 to \$2.5 million per well depending upon depth of the well, down-hole environment and remoteness of location. Completion costs for wells (for production) may range from \$70,000 to \$3.5 million.

D. Hazards Associated with Drilling

1. High Fluid Flows

Drilling operations sometimes encounter high pressures and fluid flows of gas, oil, brine or fresh water from the hole. High pressures in the well are usually indicated by a rise in the level of mud in the tank or by mud

being returned to the surface cut with gas, oil, brine, or fresh water. High pressures and fluid flows are controlled by the mud system. The weight of the mud is increased until it balances with the formation pressure. Additives are introduced to the drilling mud to increase its density (see Table III-1). High pressures and flows of well fluids are kept under control not only to protect the environment but to save the well from blowing out.

Excess mud or waste fluids are disposed of in the reserve pit or tank along with the drill cuttings. Gas is removed by a degasser and may be routed to a flare for disposal. If the gas contains a significant fraction of hydrogen sulfide (H_2S) it is controlled by special mud additives which scavenge or neutralize the H_2S . The drilling crew will also take special precautions to protect themselves from exposure to H_2S ; these are discussed in Section D.4 of this chapter entitled Hydrogen Sulfide.

2. Blowouts

High pressures and fluid flows of gas, oil, brine or fresh water can result in a loss of control and subsequent blowout. Drilling crews attempt to avoid blowouts at all costs because of the severe damage to the environment, loss of recoverable oil or gas, possible loss of the well, damage to and possible loss of the drill rig and the potential loss of life. Next to a well fire, blowouts are the most serious drilling accidents.

Blowout preventers equipment (BOP) are used to control well fluids in the event of a sudden increase in their pressure called a kick. Blowout prevention systems include the preventers, both annular and ram-type; the actuating system: accumulator units, emergency backup systems, control manifolds, remote stations, hydraulic control lines and hydraulic fluid; auxiliary equipment: fill-up lines, kill lines, choke lines, standpipes, kelly cocks, internal preventers and pipe safety valves and hole fluid monitoring equipment.

The drilling crew must be thoroughly trained in the use of BOP's, and regular tests and inspections made to assure that a kick can be controlled when it occurs. Operators in units of the National Park System should be required to test the blowout prevention equipment weekly during drilling and after running a string of casing.

3. Fires and Explosions

Drill rig accidents, especially high pressure gas blowouts, may lead to fires and explosions. Air drilling is inherently more dangerous in terms of fire or explosion than drilling with a mud system because hydrocarbons may be returned to the surface mixed with air. Drilling operators have contingency plans in place to better cope with accidents when they occur, and the drilling crew is trained to respond to potential blowout conditions to prevent fires and explosions. Should a fire or explosion get out of control, specialists are brought in to deal with the situation.

Safety equipment, in addition to BOP's, should be installed on the drill rig. The equipment should include circuit breakers, fire extinguishers, and explosion-proof lighting and ventilation systems. Also, if there is the potential for gas or hydrogen sulfide to accumulate around or under the rig or mud tanks, fans with explosion proof motors should be installed to keep the areas ventilated. Personnel and visitors on the rig should not smoke unless they are in a designated smoking area.

4. Hydrogen Sulfide

Drilling operations may encounter hydrogen sulfide, H_2S , along with oil or gas deposits. H_2S is a poisonous, highly corrosive gas which can be deadly at relatively low concentrations in air. It is colorless, heavier than air and soluble in both oil and water. H_2S smells like rotten eggs at very low concentrations (2-20 ppm). At 100 ppm H_2S kills the sense of smell. Physical effects and toxicity comparisons are shown on Table III-2.

Drilling operators must be prepared to control releases of H_2S because of its extreme danger to both the drilling crew and the local population. Certain special practices are required if there is a potential for an atmospheric concentration of greater than 20 ppm. The potential well toxicity area (radius of exposure) is calculated and contingency plans drawn up. The drill pad is planned to safeguard the drilling crew and provide for the control and safe disposal of H_2S . The placement of access roads, passageways, drilling rig ventilation, wind streamers, fans and blowers, well site buildings, briefing areas, logging units, electrical generators, flare areas and lines, emergency relief valves and vent lines and miscellaneous equipment takes into consideration the possibility of H_2S gas releases and the prevailing wind directions.

Safety practices should begin and special equipment installed when the hole approaches within 1,000 feet of a known H_2S bearing formation, or whenever it is unexpectedly encountered in the hole. Emergency equipment such as H_2S detectors, respirators or outside air lines, a communication system and warning signs should be installed. As with other critical areas such as blowout and fire prevention, the drilling crew must be thoroughly trained in understanding the dangers of H_2S and controlling a release of H_2S . On federal leases, rig crews are required to run through a weekly training drill to ensure they can rapidly and correctly respond to a release of hydrogen sulfide.

In addition to protecting the health of the drilling crew and the public, it is necessary to prevent corrosion and sulfide stress cracking (embrittlement) of equipment in contact with H_2S such as the drill string, casing, wellhead, blowout preventers and pressure control equipment. This is done by adding lime or other caustics to the mud to raise the pH and neutralize the H_2S (heavy metal compounds can also be added to the mud to scavenge H_2S), and by choosing materials for the casing or drill string with metallurgical properties resistant to H_2S attack.

Unauthorized personnel, both park visitors or staff, should not be allowed on the drill pad in areas where hydrogen sulfide may be

Table III-2
Toxicity of H₂S Gas for Humans

H ₂ S ppm	0-2 Min.	2-15 Min.	15-30 Min.	30 Min. - 1 Hr.	1-4 Hrs.	4-8 Hrs.	Over 8 Hrs.
50- 100				Mild, conjunctivitis, respiratory tract irritation			
100- 150		Coughing, irritation of eyes, loss of sense of smell	Disturbed respiration; pain in eyes; sleepiness	Throat irritation	Salivation and mucous discharge; sharp pain in eyes; coughing	Increased symptoms*	Hemorrhage and death
150- 200		Loss of sense of smell	Throat and eye irritation	Throat and eye irritation	Difficult breathing; blurred vision; light shy	Serious irritating effect*	Hemorrhage and death*
250- 350		Irritation of eyes; loss of sense of smell	Irritation of eyes	Painful secretion of tears; weariness	Light shy; nasal catarrh; pain in eyes; difficult breathing; conjunctivitis	Hemorrhage and death	
350- 450		Irritation of eyes; loss of sense of smell	Difficult respiration; coughing; irritation of eyes	Increased irritation of eyes and nasal tract; dull pain in head; weariness; light shy	Dizziness; weakness; increased irritation; death	Death*	
500- 600	Coughing; collapse and unconsciousness*	Respiratory disturbances; irritation of eyes; collapse*	Serious eye irritation; light shy; palpitation of heart; a few cases of death	Severe pain in eyes and head; dizziness; trembling of extremities; great weakness and death*			
600-1,500	Collapse, unconsciousness; death*	Collapse; unconsciousness; death*					

* Data secured from experiments on dogs, which have a susceptibility similar to men.

Source: National Safety Council data sheet D-chem. 16.

encountered. Personnel who do require access for inspections or monitoring should receive the appropriate training from the operator in how to use the breathing equipment and how to behave in emergency situations.

E. Field Development

If the wildcat well produces oil or gas in commercial quantities, additional wells are drilled to develop the field. The procedures for drilling development wells are about the same as for wildcats, except there is usually less subsurface sampling, testing and evaluation. More detailed seismic work may be performed to aid in the location of these wells.

Well locations are surveyed and a spacing pattern is established by the State Oil and Gas Commission, the Bureau of Land Management and possibly other jurisdictional agencies. Physical properties of the hydrocarbons, geological considerations and well production rates determine the best spacing pattern. Typical spacings are 10, 20, 40, 160, 320 or 640 acres per well. However, if a field is producing from more than one formation, the surface location of the wells may be much closer, since each formation will have its own optimum spacing. In practice, spacing patterns can be highly variable. Oil wells, for example, are distributed using between 10 and 160 acres per well. Spacing as close as 4 acres per well can be allowed during enhanced oil recovery operations. Figure III-6 illustrates an 80 acre per oil well spacing. Gas wells are spaced further apart, up to 1 square mile per well.

Access roads to development wells are usually better planned and constructed than those for wildcat wells because these wells tend to have a longer life. Typically a lease area will have one main route, with side roads to each well or multiwell pad location. Development from temporary to permanent roads does not take place until a well has been established as capable of production. The amount of roadway required per square mile of field is 4 miles, based upon a spacing pattern of 40 acres and a separate pad for each well.

Other surface equipment and support facilities are brought in or constructed during field development. For example, a battery of storage tanks or a pipeline may be required to handle oil or gas brought to the surface during drilling and productivity testing activities. Separation and treatment facilities are required to separate gas and water from oil. Storage pits or tanks are required to hold brines produced during oil extraction, and a proper disposal capability, most typically reinjection, must be developed for the quantities of brine generated. Natural gas must be properly disposed or treated to remove impurities if it is to be kept. These subjects will be addressed more thoroughly in Chapter IV, Production Operations.

F. Possible Effects and Mitigations

This section provides a general discussion of environmental impacts from and available mitigation measures for oil and gas drilling operations in NPS areas. Each park is unique, and drilling projects are varied. A

multidisciplinary team of specialists should review each Application for Permit to Drill and Plan of Operations to ascertain specific impacts and mitigations on a case-by-case basis.

Oil and gas activity on NPS lands will affect the environmental resource values identified in this chapter. Drilling operations can affect several resource areas, and impacts are strongly interrelated with each other. Those values with the most potential for significant impacts are addressed first.

Impacts to the environment from stratigraphic test drilling are similar to those from wildcat or development well drilling. They will generally be lesser, however, because of the lesser intensity, duration and land/water area requirements of the operation. Truck and other vehicle traffic will be lighter and less frequent because of the sparser equipment, material and personnel involved. In addition, the possibility of an oil spill from a blowout will not be present. Limiting travel in roadless areas, during wet seasons and in areas of unique natural and cultural resources such as are commonly found in national parks can mitigate impacts to the environment from stratigraphic tests.

One of the most important mitigation measures is the use of directional drilling. It allows the drill site to be alternatively located and still reach the same bottom hole location.

1. Surface Disturbance (Soil and Vegetation)

Soil and vegetation impacts can be separated into four categories. Drilling operations can cause soil compaction and associated damage to vegetation, removal or alteration of topsoil and vegetation, erosion and contamination.

a. Soil Compaction/Vegetation Damage

Soil compaction occurs when pressure on the surface causes pore spaces in the soil to collapse. Compacted soils often do not support vegetation because of reduced water-holding capacity and an inability of roots to gain adequate penetration. Compacted soils also have a lower infiltration capacity, resulting in greater runoff of precipitation and subsequent downslope erosion. Compaction impacts are most severe during spring or the wet season when soil moisture is at or near field capacity.

For wildcat wells, the industry normally constructs a temporary road. For a developing field, more permanent roads are constructed because of the expected longer term use, but they still are not usually paved. Vehicular traffic will cause compaction and rutting of soil on unpaved roads. Table III-3 gives the expected number of vehicle trips, excluding road construction and maintenance, required for a representative well 10,000 feet deep taking 4 to 6 months to drill and an additional 1 month to complete. During cross-country travel, vehicles will leave behind tracks of disrupted low-lying vegetation. These impacts will be most intense at the drill site, where activity is concentrated and at stream crossings where soil moisture is high.

Table III-3

Expected Vehicle Trips *
(Excluding road construction and maintenance)

<u>Trips</u>	<u>Weight (lb)</u>
<u>Move rig in or out</u>	
14	<80,000
4	80,000 to 110,000
<u>Drilling</u>	
1261	4,000 to 10,000
99	18,000
120	35,000
2	40,000
3	46,000
19	80,000
6	90,000
<u>Completion</u>	
147	4,000 to 10,000
15	10,000 to 20,000
33	35,000
3	40,000 to 46,000
4	60,000
12	70,000 to 80,000
2	90,000

* Data for a Representative Well 10,000 Feet Deep Which Takes 5 to 7 Months to Drill and Complete

Limiting travel in roadless areas to a minimum length of new roadway, following the natural contour of the land during construction and avoiding areas of unique natural resources such as are commonly found in national parks can mitigate many impacts from road construction and vehicle traffic. The length of roads necessary to develop a field can be minimized by grouping several wells on a single pad and directionally drilling to reach the desired bottom hole locations. Pipeline and utility corridors which may exist in the area usually have service roads which may be available for use to access drill sites. The use of existing disturbed areas can reduce the cumulative impact of the roads and well locations. At the drill site, laying of heavy boards or gravelling areas receiving a high volume of traffic or other activity can mitigate impacts to the soil. As an alternative to surface access through sensitive areas, helicopter access may be an alternative but there are very few rigs that have been built in modules that are transportable by helicopter. Significant drawbacks such as greatly increased cost (adding 15 to 50 percent to the total costs of a wildcat well) and impacts from noise also have to be dealt with.

b. Topsoil/Vegetation Removal and Alteration

Clearing, grading and cut-and-fill activities associated with road construction and site preparation will result in loss of topsoil and vegetated area. Construction of a new 14-foot wide, single lane, all-weather road will impact 4.0 acres of land per mile of road, including shoulders and turnouts. Vegetation will also be cleared at the drill site. The exposed soil is then devoid of vegetative cover. Revegetation and general adherence to good civil engineering practice can mitigate impacts from these effects. Stockpiling and reusing the topsoil can help revegetate areas with thin layers of topsoil and poor growing conditions.

The invasion of nonnative species introduced by people or equipment, especially in disrupted (cleared) areas, can also impact the ecology of a native forest or other ecosystem. Native species should be planted to reduce the chance of exotics.

Borrowing of fill and aggregate materials used for road construction and site preparation involves excavation which will leave behind an open pit. Excavations have to be outside of NPS boundaries to mitigate impacts to the natural contours of the land as well as vegetation, visual quality and the noise environment.

Drilling operations in an aquatic, brackish or marine environment are much the same as for terrestrial drilling, except for the mode of access and site preparation. In deeper water, barges and drilling ships provide the mode of access and a foundation for drilling activities. In shallower water, it is often neither deep enough to float a vessel nor dry enough to allow overland travel. Then either a channel is cleared or dredged to accommodate a drilling barge, an area is filled to form an access road and drilling pad, or an alternative drilling location is chosen. Vegetation directly in the path of the channel or roadway and drill site will be disrupted or destroyed. The channel or roadway should be constructed to allow the natural waterflow pattern to continue.

Roadways should have appropriately placed culverts. Channels should not have cut material piled to one side creating a dam or diverting the waterflow. Maintaining the natural waterflow will help maintain the natural environment around the access route and drill pad.

c. Surface Erosion and Instability

Disturbances which leave the ground barren of natural vegetation render the productive surface soil horizons susceptible to removal by the erosive forces of gravity, wind and water. The erosion potential of a soil increases geometrically with slope. Less productive and excessively drained soils are more susceptible to long-term erosion than more fertile soils because the former do not have the ability to revegetate as rapidly. The USDA Soil Conservation Service publishes Soil Surveys for many areas which can be consulted to help identify areas susceptible to impact by erosion.

Clearing, grading and cut-and-fill activities associated with road construction and site preparation will result in increased erosion and instability. Vehicular traffic will also increase erosion of soil on unpaved roads. Rutting from vehicle traffic and other erosional impacts will be greatest during wet weather or spring thaw. Loads can be limited and number of vehicle trips can be reduced during these periods to reduce road damage. Paving a road will mitigate rutting and erosion of the road surface but makes rehabilitation more difficult when activity in an area is abandoned. Runoff control structures such as culverts and bridges may be necessary to mitigate erosional impacts at stream crossings. Culverts should be constructed of corrosion resistant metal, be adequately sized and be kept free of debris.

Earthmoving activities or significantly altered surface runoff patterns may exacerbate preexisting geological hazards or create wholly new ones. Mass movement resulting from destabilization of the soil, such as soil creep, mud flows, rockfalls, landslides or avalanches, can contribute to downstream sedimentation and pose problems for engineering and structural developments. Streambanks are particularly critical because they are easily destabilized, resulting in a small-scale landslide of material into the stream. Avoiding areas of preexisting hazards (especially on steep terrain and in stream channels), providing for adequate drainage, revegetation of cut-and-fill slopes and general adherence to good civil engineering practice can mitigate impacts from instability.

In units of the National Park System, reserve tanks should be used to eliminate the opportunity for leaking fluids to destabilize the berms around the reserve pits. Outside units, reserve pits should be constructed in the cut portion of the drill pad. Pits should not be constructed in filled areas to lower the possibility of collapse or failure.

d. Soil Contamination and Vegetation Damage

Soil contamination and vegetation damage result from liquids and solids that contain toxic compounds making contact with soil and vegetation. Drilling muds may contain hazardous substances such as heavy metal ions,

chromium, zinc or asbestos. Refer to Table III-1 for types of potentially toxic compounds. Contamination may happen gradually through percolation and improper disposal practices, or it may occur suddenly in a spill or a blowout.

A loss of drilling mud and well fluids from the mud tanks or reserve pit could result in localized contamination of soil. Reserve pits can overflow from a kick or high rainfall, and can suffer failure of a containment wall, resulting in a loss of the contents. The magnitude of such an impact on the soil depends upon the volume of fluids lost, the topography and the composition of the drilling fluid. Vegetation may be killed or damaged where the soil has been contaminated. If reserve pits are used, the pit should be sized to hold double the expected volume of mud changes and fluid flows. The level in pits and tanks should be frequently monitored and excess fluid hauled to an appropriate disposal site. The level in the tanks or pits should be kept low enough that the entire contents of the wellbore and the mud-mixing tanks can be dumped into the pit without the danger of an overflow. The level should be kept even lower if there could be substantial rainfall.

Building berms around the reserve pit contains spills. Their proper design, construction and maintenance can mitigate large-scale losses of drilling muds. Using pit liners also mitigates fluid losses and is discussed in Section 2 entitled Water Quality.

Drilling mud and well fluids may remain behind in the reserve pit when activity ceases. Chemical additives or other contaminants in the mud can percolate into the soil, impacting vegetation or water quality. Removing the drilling mud from the pit by vacuum truck, when drilling is complete or suspended for long periods, can mitigate this impact.

The disposal of drill cuttings can impact the soil and vegetation. The cuttings themselves are not toxic but they are rock chips which will not support healthy, strong vegetation. Also, the cuttings may contaminate the soil because of the residual drilling mud or well fluid clinging to the cuttings. The volume of drill cuttings can be substantial; for example, an 8-inch hole will generate 12.9 cubic yards of material for every 1,000 feet of depth. Normally they will be contained in the reserve pit of the mud system. In park units the cuttings should be hauled to an appropriate disposal site outside the park. In areas adjacent to park units where the cuttings are not removed from the drill site, the topsoil excavated from the pit during construction should be stockpiled and used to cover and rehabilitate the mud pit and cuttings when drilling is complete. As an alternative, a totally containerized mud system can be used, and drill cuttings removed from the site by truck with the rest of the equipment and material (Figure III-7). For barge mounted drill rigs, there will be no reserve pit. Drill cuttings should be placed on a barge, removed from the site and disposed of in a permitted manner and location.

The use of air drilling can mitigate impacts from the loss of drilling fluids because no muds are used. This technique has limited applicability because it is not feasible when drilling in wetland, floodplain or shoreline areas. It cannot be used when high-pressure

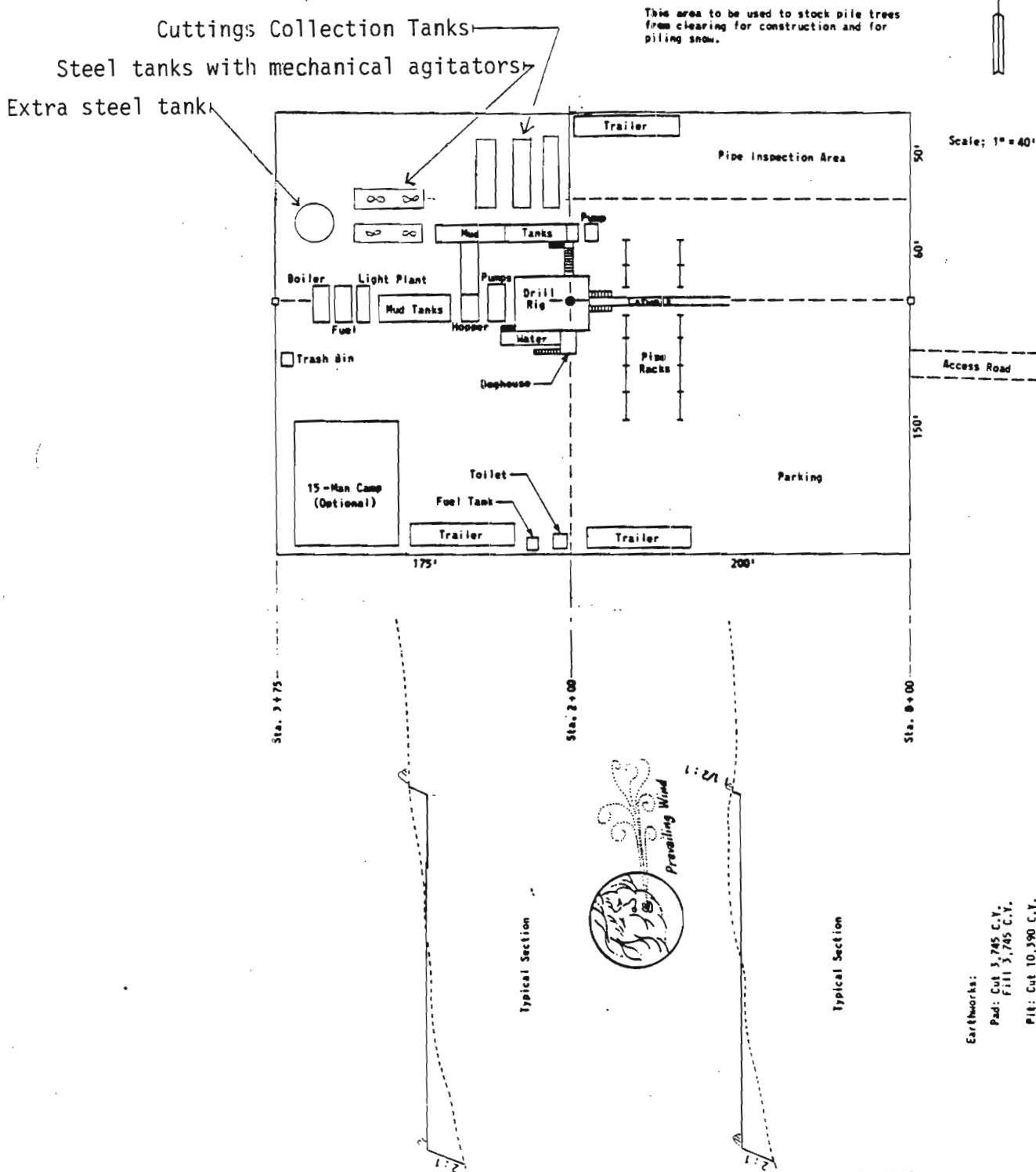


FIGURE III-7 DRILL PAD LAYOUT WITH FULLY CONTAINERIZED MUD SYSTEM

formations exist or if the walls of the hole tend to collapse around the drill stem. Also, air drilling is not without its own drawbacks such as an increased possibility of fire, which is a potentially serious impact in a heavily forested area. If air drilling is employed, drill cuttings are blown into a reserve pit to the side of the drill rig. The pit should be rehabilitated just as if a mud system were employed.

Potentially one of the most severe impacts associated with drilling operations is an oil spill. Oil spills generally occur when petroleum is being transferred from one place to another, but may also occur if the well blows out while being drilled. Since oil spills are more likely to occur during the production phase of a well's life, oil spills are discussed in Section IV-J-1-d.

Brine spills can kill vegetation and resulting soil contamination will hinder regrowth. Like oil, brines are more commonly spilled during transport or storage, but can also be lost in a blowout or through a leaking pit wall. The subject of brine disposal is discussed in Chapter IV entitled Production Operations. Brine is usually highly saline water, as measured by the total dissolved solids content. The major constituents of brine include the ions sodium (Na^+), calcium (Ca^{++}), magnesium (Mg^{++}), sulfate (SO_4^{-2}), bicarbonate (HCO_3) and chloride (Cl^-). The impacts of a brine spill on the soil can be very long term or permanent in an arid environment because of the lack of water to leach the salts out of the root zone. In addition, brine high in exchangeable sodium (Na^+) can reduce the water infiltration capacity of the soil. The actual composition of brine varies widely and needs to be determined to ascertain the potential impact from a spill. The impacts of a brine spill due to its toxicity are also discussed in Section 2 entitled Water Quality.

Having an adequate blowout preventer (BOP) and maintaining an up-to-date Spill Prevention, Control and Countermeasure (SPCC) plan can mitigate the impacts of oil or brine spills from a blowout. Wells should be adequately and properly cased and cemented to reduce the possibility of blowouts. This topic is discussed more thoroughly in Section 2 entitled Water Quality. Careful conduction of drill stem tests can also help to prevent blowouts. Maintenance of deep test pits, multiple mud tanks or high berms provides adequate capacity to control the spread of well fluids in the event of a kick.

Limiting the aerial extent of the spill once it occurs is the most important step in controlling environmental impacts. The drilling company should have access to equipment capable of vacuuming up the spilled material, booms for containing oil spills onto water and absorbant material for soaking up oil or brine. The location of emergency equipment and materials should be identified in the SPCC plan. The SPCC should also identify the cleanup procedures and the people who need to be contacted, and the order of contacting them, and who will supply the labor for cleaning up a spill. Operators can start or join cooperatives which provide for pooling the resources necessary to effectively respond to and clean up major spills.

Removing contaminated soils can prevent the spread of the contaminants. Diluting brine with fresh water can reduce the impacts of a brine spill. Restoration of impacted areas can also help mitigate oil or brine spills. Spreading topsoil over lightly contaminated or bare soil, fertilizing it and revegetating it will enhance bacterial degradation of oil, aid in infiltration of water in areas of spilled brine and restore vegetation to protect the soil from erosion. If drilling operations are completed during a season when an appropriate perennial wildlife food or ground cover cannot be established, or if drilling activities are suspended pending completion at a later time, temporary revegetation measures can be employed. They include mulching and seeding with an annual ground cover. Tree planting, seed mixtures and rates and fertilizer requirements can be specified.

Cementing operations can also contaminate soil and kill or damage vegetation. Truck accidents can spill cement and additives, which should be promptly cleaned up. The cementing process can generate wastewaters which sometimes include brine. These should be properly handled and disposed of in a permitted manner and location. Lined pits or agitated tanks can contain the wastes when they are generated to prevent percolation into the soil.

2. Water Quality

Drilling operations may cause sedimentation and contamination of surface and groundwater.

a. Sedimentation

Increases in sedimentation may occur due to clearing, grading and cut-and-fill activities associated with road construction and site preparation. The procedures involved increase erosion and surface instability. Eroded soils will eventually enter streams and increase their sediment loads. Excess sediment loads can reduce water clarity, degrading its ability to support fish and its value for drinking. Also, increased sedimentation can alter streambed profiles, which may impact fish populations. Impacts can be mitigated by any of the suggested mitigation measures for the conservation of soil and the protection of vegetation, fish and wildlife. Local water districts may be consulted for information on turbidity standards and whether particular impacted streams serve as a supply of drinking water.

Sedimentation also takes place at points of stream discharge such as lakes, wetlands, floodplains and near-shore areas. These water bodies often lack a brisk flow, and entrained sediments fall out. Bottom-dwelling organisms can be smothered, and flora and fauna requiring clear water can be adversely affected, to the detriment of the ecosystem. These impacts are mitigated by protecting upstream points from sedimentation effects.

The bentonite or other weighting material in mud and the drill cuttings can enter the nearest stream channel, increase its sediment load, reduce water clarity and impact water quality if the reserve pit wall is breached, gives way or if the pit is inadequately rehabilitated upon

completion of drilling. A metal tank mud system can prevent the impacts from mud and drill cuttings entering waterways. As an alternative, for wells drilled outside park units, the cuttings and mud can be removed from the site and disposed of in a permitted manner and location.

b. Surface Water Contamination

Well fluids lost to the environment from leaks, spills or blowouts will impact surface water quality. Oil, brine and drilling mud are of concern. Their volume can range from a few barrels during a kick or from a small leak, to hundreds of thousands of barrels if they escape around the outside of the casing or if the blowout prevention equipment fails in a full-scale loss of control. Blowouts are less likely for development wells than for wildcat wells because formation pressures are better known.

A loss of drilling mud and well fluids from the mud tanks or reserve pit is the most common cause of surface water contamination. Reserve pits can overflow from a kick or high rainfall and can suffer a containment wall failure, resulting in a loss of the contents. The magnitude of surface water contamination depends upon the volume of fluids lost, the local topography and the composition of the drilling fluid.

Drilling fluids are often highly caustic. Many additives can be hazardous to the environment, including alkalies, bactericides, soluble chromates and corrosion inhibitors. When diluted to the degree of normal use in drilling mud, however, their toxicity is greatly reduced.

It is necessary to consider the chemical form of the constituents of a mud additive when determining its toxicity. Substances that are usually nontoxic may be dangerous in certain combinations. For example, barium sulfate, a common weighting agent, is nontoxic, while barium carbonate used on rare occasions in mud, is toxic. Similarly, chrome lignosulfonate, a dispersant and thinner, is chemically stable and nontoxic, but sodium chromate is soluble and toxic under some exposure conditions. Detailed information on the toxicity of particular compounds can be found in a reference volume such as "Dangerous Properties of Industrial Materials" by Sax (1984).

Since the toxicity of additives varies widely, knowledge of the chemical compounds present at the drill site will expedite cleanup procedures in the event of surface water contamination. Records of dry muds and additives used in drilling or stored onsite will be required. This inventory could help mitigate impacts in the event of a fluid loss.

Drilling operations in wetlands, floodplains and near-shore areas can impact water quality from the loss of drilling mud or well fluids into the immediate water environment. Impacts to these areas can also occur from drilling operations upstream which suffer an accident like a blowout.

In the event of an oil spill, oil floating on the surface will continue downstream until checked by containment booms or other spill cleanup equipment. Some of the oil may emulsify and fall to the bottom of the

stream or other water body. Oil which is not cleaned up will eventually biodegrade; the factors governing this process are not fully understood and are highly variable. Thus, the time frame for biodegradation is not easily predictable.

The effects of the oil will be physical, chemical and biological in nature. The primary toxic agents in crude oil are the low-boiling aromatic hydrocarbons such as benzene, toluene and xylenes. Cycloparaffins, olefins and straight-chain paraffins are gradually less toxic. Dissolved oxygen is depleted by bacterial degradation of crude oil and chemical oxidation of dissolved gases such as hydrogen sulfide (H_2S). Crude oils also contain naphthenic acids and phenols.

The properties and composition of crude oil varies from place to place. Attention should be paid to the character of oils, e.g., diesel fuel, light crude, or heavy viscous crude, likely to be involved in a spill in a given area. This can materially aid in predicting the extent of damage and also may accelerate the cleanup and restoration operation. A full discussion of the environmental consequences of oil spills, including impacts to vegetation, fish and wildlife, as well as water quality, can be found in some of the publications listed in the bibliography.

Brine spills can also impact surface water quality. Brine is usually highly saline water, as measured by the total dissolved solids content. Table III-4 gives a comparison of oilfield brines, seawater and the Secondary Maximum Contaminant Level (federal drinking water standard):

Table III-4
Brine Components Versus Seawater
and Drinking Water Standards

<u>Component</u>	<u>Oilfield-Brine-(mg/l)</u>	<u>Seawater-(mg/l)</u>	<u>Secondary MCL-(mg/l)</u>
Na^+	12,000-150,000	10,600	-
K^+	30- 4,000	380	-
Ca^{+2}	1,000-120,000	400	-
Mg^{+2}	500- 25,000	1,270	-
Cl^-	20,000-250,000	19,000	250
Br^-	50- 5,000	65	-
I^-	1- 300	0.05	-
HCO_3^-	0- 1,200	142	-
SO_4^{-2}	0- 3,600	2,560	250
Total dissolved solids highly variable		34,400	500

It can be readily seen from the information in Table III-4 that brine can be substantially more saline than seawater, and that it has tremendous potential for contamination of freshwater resources. One barrel of brine can contaminate up to 1,000 barrels of freshwater, based upon the chloride (Cl⁻) content. Brine usually contains a small percentage of oil (0.10 to 0.33 percent by volume), dissolved gases such as H₂S and possibly trace elements which can also impact water quality. The actual composition of brine varies widely and needs to be determined to ascertain the potential impact of a spill.

BOP's and a SPCC plan will help mitigate the impacts from a blowout. SPCC plans are required in EPA regulations for all nontransportation related oil facilities which have or could reasonably be expected to discharge oil into navigable waters of the United States.

Holes should be adequately and properly cased and cemented to reduce the possibility of blowouts. Installation of conductor pipe, surface casing and intermediate casing facilitate the drilling operation and are routinely performed for all holes. Their functions include allowing for the blowout preventer stack to be attached at the surface, preventing a blowout through weak surface or intermediate depth formations. Production casing must withstand the potentially high pressures of the producing formations and should be made up with special care in order to guard against leaks.

Spill booms limit the aerial extent of the spread of oil and have been designed for both quiet waters and the open ocean. Portable skimmers are used to draw the oil off the water surface so that vacuum trucks can remove it from the environment. The recovered oil can usually be saved by treating it with existing separation equipment found in a producing field. Periods of high stream flow will make the containment of oil spills more difficult. Straw and other absorbing fibrous materials have proven useful when booms have failed. Chemical dispersants are an effective means of removing an oil slick from sight and enhancing the natural degradation of the oil, but may be more toxic than the oil itself and should only be used if recovery is not possible. The dispersed oil forms an emulsion with the water, which may then sink to the bottom. Regardless of the efforts to cleanup an oil spill, recovery or dispersion is never 100 percent efficient, and surface water sheens will be apparent downstream from the spill control area.

c. Groundwater Contamination

Groundwater contamination, like surface water contamination, results from leaks, spills and blowouts of drilling mud and well fluids. They may escape through the wellbore virtually unnoticed into the environment, potentially polluting freshwater aquifers. Fluids from the mud tanks or reserve pit if left on the ground can percolate into the soil and the groundwater. They may also seep through the bottom of an earthen reserve pit.

Though earthen pits should no longer be used in park units, special precautions should be taken if earthen pits are used adjacent to a unit. Application of recently derived technology developed for land disposal of

hazardous waste can help reduce the possibility of drilling fluid losses through percolation. This application includes compacted clay pit liners and seam-sealed synthetic double liners.

Prediction of the impact of drilling mud or well fluids on groundwater resources requires a hydrogeological investigation which encompasses site-specific characteristics. In general, areas of high rainfall, shallow groundwater, porous alluvium or highly fractured formations or dependence upon groundwater for domestic supply will be more susceptible to the impact of contamination. The mitigation measures suggested for the protection of surface water and soil and vegetation, including air drilling, berms, and removing the drilling mud by vacuum truck, also apply to water quality.

Brine spills can impact groundwater quality. Freshwater aquifers can be impacted by brine even when no spills are apparent on the surface. An improperly abandoned hole will act as a conduit and allow formation fluids to mix with freshwater aquifers. As detailed in Section b. entitled Surface Water Contamination, brine has tremendous potential for contamination of freshwater resources.

The mitigation measures suggested for protecting surface water, soil and vegetation from brine also apply to groundwater quality. Adequate and proper casing and cementing are especially important groundwater containment mitigation measures. One of their functions is protecting freshwater aquifers from oil, brine or drilling fluid contamination. Freshwater aquifers can be protected by running surface casing strings at least 50 to 100 feet beyond the depths of the deepest usable water as a safety margin. Running cement all the way to the surface for each casing string, if possible, is another method of protecting freshwater zones. The conductor and surface casings should always be cemented to surface. Production casing must withstand the potentially high pressures of the producing formations and should be made up with special care in order to guard against leaks. As wells go deeper, formation pressures go higher (greater than 20,000 psi has been encountered).

3. Fish and Wildlife

The effects of drilling operations on fish and wildlife vary immensely because of the diversity of animal species and their unique habitat needs. Alterations in and loss of habitat may impact their populations. Virtually any of the impacts to soil and vegetation, water quality or noise will also impact fish and wildlife habitat. Some of the more common effects are discussed below.

Habitat loss or damage can result from any phase of drilling operations. Clearing, grading and cut-and-fill activities associated with road construction and site preparation will result in a temporary, if not permanent, loss of habitat. Increased sediment loads from eroded soil alter streambed profiles which will impact fish resident and spawning habitats, and indirectly affect fish populations from impacts to aquatic insect producing areas. Drilling operations can also impact fish and wildlife habitats in other ways. Noise from traffic or drilling activity, as well as the presence of people, will frighten wildlife. The

industry tends to conduct drilling operations around the clock, which requires the use of night lights which can disrupt wildlife behavior.

Any of the mitigation measures for soil and vegetation, water quality or noise will also mitigate impacts to fish and wildlife. In addition, impacts can be mitigated by limiting travel and drilling. This could protect habitats of rare and endangered species, riparian zones and wetlands that are critical fish and wildlife feeding, migration and breeding areas. Travel and drilling limitations can also be used to mitigate habitat disruptions during critical seasons such as migration, breeding/ spawning and winter stress periods. Limiting drilling activity to daylight hours in addition to the mitigation measures previously listed may be necessary.

Drilling accidents can adversely affect fish and wildlife either directly or by damaging habitats. For example, additional roads and vehicle travel will not only increase harassment of animals, but it may also result in accidental deaths and injuries due to collisions. Well fluids accidentally lost to the environment can impact fish and wildlife. Spilled oil will coat birds, potentially destroying the insulating and waterproofing qualities of the feathers of waterfowl or seabirds. Oil and brine can spoil the drinking water source of wildlife and are toxic to fish. Aquatic life is affected by components which are relatively water soluble. Ecosystems dependent upon surface waters will be overwhelmed with even a small quantity of oil or brine contamination. Severe impacts to microorganisms, fish and wildlife are possible. For small streams, this may be as little as one gallon. For large streams and rivers, a barrel or more may go unnoticed.

The construction of roads in areas previously difficult to reach may also impact fish and wildlife by allowing easy access to hunters and fishermen. The areas affected would be more susceptible to increases in both hunting and poaching. Rare and endangered species may be affected, both directly and by changes in their prey or predator populations. Installation of lockable gates on newly constructed access roads may help mitigate these impacts.

4. Air Quality

National Ambient Air Quality Standards and any state or local standards which exist apply to drilling operations. It is the responsibility of the applicant to determine if an area is in attainment for the criteria pollutants (oxides of nitrogen, sulfur dioxide, particulate matter, carbon monoxide, nonmethane hydrocarbons, ozone and lead) and whether the activity is subject to regulation by Prevention of Significant Deterioration or New Source Review requirements of the Clean Air Act. The NPS will need to know the existing air quality in the area proposed for drilling in order to determine if additional emissions will be a significant impact.

Air pollutants generated during the drilling and development stage include particulate dust from vehicles traveling on unpaved access roads and around the drilling site. Particulate dust introduced into the atmosphere from unsurfaced roadways and work areas can be limited by

controlling the number and sizes of vehicles allowed, closing and rehabilitating unneeded roads and drill sites, placing speed limits on the roads and periodically watering the roads and drill sites. Construction of roads and drill sites during especially dry and windy conditions can also be curtailed.

Criteria pollutant emissions are generated by vehicle and stationary engines used in drilling operations. Emission factors found in EPA publications (AP-42 or AEROS Manual Series, Volume V) can be used in conjunction with the expected number of vehicle trips, Table III-3, to estimate emissions once project specifics are known. To find appropriate emission factors, it is necessary to determine the number, type and size of the engines to be used on the drill rig and the type(s) of fuel required. The size of the work force and the number of miles of paved or unpaved roads they travel from living and supply areas to the site must be known. The estimated duration of drilling activity, and whether oil or gas is the anticipated product are also factors. Table III-5 illustrates typical levels for pollutant emissions for vehicular activities associated with oil and gas in the Mobile Delta area of the United States. Maintenance and use of all applicable pollution control devices on internal combustion engines and fuel storage tanks will minimize environmental effects.

In the event deposits of oil or gas are struck, well fluids returned to the surface during normal drilling activity or well testing can result in light end (natural gas) and volatile hydrocarbon emissions. These emissions can be largely controlled by the use of mud degassers and flares. The degassers remove gases from the drilling fluid, and route them to a flare. Flares reduce the amount of hydrocarbon emissions, but are themselves a source of combustion products which can include oxides of nitrogen and sulfur. Smokeless flares use steam or air injection to create turbulence in the combustion zone, increasing combustion efficiency and reducing emissions.

Emissions of H_2S can endanger the health and lives of the drilling crew and nearby population. Table III-2 shows the toxicity of H_2S gas for various concentrations and lengths of exposure. A time weighted average of 10 ppm over an 8-hour workday is considered a safe level for personnel working onsite. H_2S concentrations of 1,000 to 10,000 ppm in oil or gas are not uncommon, and up to 270,000 ppm are known. Since a well may be capable of producing 100,000 ft³ or more of gas per day, then it is easily seen that large quantities of H_2S are potentially available for release. The Pasquill-Gifford equation² is used to determine the radius of exposure of a given concentration for individual well flow rates and H_2S concentrations (see "Drilling and Operating Oil, Gas, and Geothermal Wells in an H_2S Environment" for nomographs used to calculate these values). H_2S is heavier than air and it will accumulate in low areas such as well cellars and ditches. These low areas should be approached with caution during H_2S excursions.

H_2S emissions can be the result of well fluids returned to the surface during normal drilling activity, well testing and blowouts. The use of mud additives, wet gas-gathering systems and flares can mitigate the impact of emissions in controlled situations. The planned design and

Table III-5

Typical Vehicle Emissions Associated With
Oil and Gas Activities in the Mobile Delta

Vehicle Type	Units for Emission Measurement	Emission (Tons Per Year)				
		Carbon Monoxide (CO)	Hydrocarbons (HC)	Nitrogen Oxides (NO _x)	Sulfur Dioxide (SO ₂)	Total Suspended Particulates (TSP)
Bulldozer	grams/hour	335	106	2290	158	75.8
Light Boat	grams/hour	1.69	.117	.179	.008	-
Light Truck (gasoline)	grams/mile	43.8	3.48	5.38	.118	.548
Heavy Truck (diesel)	grams/mile	30	5	21	3	1.5

Assumed 120 KM travel per day per vehicle = 74.56 mi

Assumed drilling period 180 days

equipping of the drill rig for H₂S occurrences will mitigate impacts under most circumstances. A contingency plan will help protect the crew as well as the public in case an evacuation is required in an uncontrolled situation such as a blowout.

Blowouts will also result in considerable hydrocarbon emissions. Prompt containment and cleanup of spilled oil can reduce emissions resulting from weathering of the oil.

In the event of a blowout, it is possible that a well fire will generate large volumes of thick, black smoke. Well fires can be mitigated by any of the mitigation measures for the prevention of a blowout, plus additional safety equipment maintained on the drill rig. A contingency plan should be in place to allow drilling operators to cope with accidents when they occur.

5. Aesthetic Quality

Disruption of surface vegetation for roads and the drill site is a source of visual impact. Unsurfaced roadways and pad areas will turn into a muddy quagmire during spring thaw or in wet weather from the heavy traffic. Areas of severely compacted soil often will not revegetate. Roads and drill sites should be restricted to areas which are not highly visible to mitigate the impact.

Drilling activities will cause visual impacts in otherwise nonindustrial areas. Drilling rig derricks and masts are tall, up to 200 feet. They could be visible for miles, and will contrast with the natural surroundings. Many visitors will view a drilling rig unfavorably in a park setting. Impacts to crucial scenic vistas can be mitigated by the use of directional drilling to allow the drill site to be alternatively located. Suggested drill site locations may be in areas of parks receiving little use by the public, and in favorable topographical locations (in canyons as opposed to hilltops or ridgelines). Also, directional drilling can be used to group several wells on a single pad as opposed to multiple pads which may be more visible to more people.

Drilling fluid reserve pits, which can take up a substantial proportion of the area cleared for the drill site, are unsightly. Flaring of waste gases is also a source of visual impact. Mitigation measures can include the construction of vegetated berms around the drill site to obscure the site and any flares from view. The berms can be constructed using topsoil moved during site preparation.

Truck traffic associated with drilling will be a source of visual impact in a setting such as a national park. Restricting deliveries of equipment and supplies during heavy visitation periods can mitigate this impact.

Refuse and other debris such as survey stakes, packaging, broken or unusable materials or equipment, personal litter, etc., generally accumulates at drill sites. Requiring good housekeeping both during drilling operations and when activities are completed can mitigate this impact.

Mitigating measures in practice are quite variable because of the diversity of oil and gas activities and the assortment of visual management objectives. Examples of different possible visual management objectives for an area are presented in Chapter IV, Section J.5.

6. Noise

Construction of roads to the drill site usually requires heavy equipment such as bulldozers and graders, which are sources of noise. Thus, road building activities will contribute to the overall noise impact. Table III-5 illustrates representative noise levels in decibels from road construction activities. The use of mufflers on engines will contribute substantially to reducing noise.

Car and truck traffic associated with drilling activities will also be a source of noise. Cars will carry the work crews, and supply vehicles will usually be large trucks. Vehicle traffic associated with the drilling will be intermittent. The actual number of vehicle trips depends upon many factors and will be quite variable. Roads are a linear source of noise, as opposed to drill sites, which are a point source.

Drilling operations are a noisy activity. Drill rigs generate noise from several sources, including main and auxiliary engines, pumps and supply handling. Stratigraphic test drilling usually requires a truck-mounted drill rig which is much smaller than required for wildcat or development well drilling, and thus quieter. The duration of core drilling will also be much shorter than for wildcat or development well drilling because of the shallower depths involved.

A drill rig has both large main and smaller auxiliary engines which will be a continuous source of mid to low frequency noise. Pumps and other mechanical equipment which are also a part of the drill rig will generate a variety of noises. Handling of materials such as drill pipe or well casing can be a source of sharp, high frequency noises as metal bangs against metal.

Table III-5 illustrates representative noise levels in decibels from motor vehicle and routine operations associated with drilling. With multiple drilling rigs, cumulative noise impact is involved. Table III-6 presents estimated cumulative levels for construction and operation in a coastal environment. Further information on noise levels associated with drilling operations is presented in an Environmental Impact Statement on exploration and production in coastal Alabama and Mississippi (U.S. Army Corps of Engineers 1984).

Blanketing of the drill rig derrick, construction of wood fencing around a drill site and use of mufflers on engines will all contribute substantially to reducing noise. Possible use of electric cranes and restriction of some equipment use to daylight hours will also minimize noise impacts. These practices are quite common in urban areas, and may be desirable in important recreational and wilderness areas such as national parks as well.

Table III-6

Representative Noise Levels
Associated with Drilling Operations

<u>Equipment</u>	<u>Decibels (dBA)</u>	<u>Distance from Source</u>
Dozer	80	50 ft
Chain saw	83	50 ft
Truck	72 - 95	50 ft
Motorboat	80	50 ft
Helicopter	70 - 90	1,000 ft
Generic drill rig	85	100 ft

Table III-7

Cumulative Noise Levels Associated with Drilling
Rig Construction and Normal Operation

<u>Number of Rigs</u>	<u>Attenuated Cumulative Noise Levels (dBA)</u>			
	<u>Construction</u>		<u>Normal Operation</u>	
	<u>Dredging</u>	<u>Piledriving</u>	<u>Drilling</u>	
	<u>(85 dBA)*</u>	<u>(90 dBA)*</u>	<u>(95 dBA)*</u>	<u>(85 dBA)*</u>
1	54	59	64	54
2	57	62	67	57
3	58	63	68	58
4	58	63	68	58

* Operation noise at 100 feet.

7. Geological Features

Impacts on geological features by oil and gas drilling operations can be similar to disturbances caused by seismic operations. But many of the impacts associated with drilling may be more severe or of longer duration as shown below.

Delicate formations, such as balanced rocks, natural arches or spires can be weakened by the ground vibrations generated by the earthmoving or blasting during the construction of an access road or pad. During the drilling operation, large trucks move on and off the pad regularly to deliver the rig, fuel, casing or services. The trucking will create vibrations near the access roads. Any operations such as pile-driving the surface casing are a source of ground tremors. Hard, rocky ground will transmit more vibrations than sandy or soft soils.

The access road and pad should be located as far away as possible from rock formations or other geological resources that may be sensitive to damage from ground tremors. Directional drilling may allow the same bottom hole location to be reached. A quarter to a half mile buffer should be adequate. Also, blasting and use of explosives should be prohibited or limited.

Deposits of collectable minerals and rocks and petrified wood can be destroyed or damaged if the deposits lie within the proposed disturbance zone. Additionally, the road to a well pad can allow drilling personnel and park visitors access to resources that were not easily reached prior to the building of the road. NPS base maps and data should be reviewed to identify the areas where these resources exist. Reconnaissance of the area should identify deposits and possible protection measures. The best protection is avoiding the resources by relocating the road and pad. If proximity to the resources cannot be avoided, access can be limited by locking or by guarding the entrance to the road. If the outcrop or occurrence is small, fencing the resource or posting may educate the prospective collector to leave the resources in place.

The disposal of drill cuttings in a reserve pit can impact geological features if significant disruption of soil and vegetation, erosion and downslope sedimentation occur. Impacts can be mitigated by any of the mitigation measures for the conservation of soil or protection of vegetation.

8. Cultural Resources

Cultural resources are sites, structures, objects and districts significant in history, architecture, archaeology or culture. Impacts on them by oil and gas drilling operations can be similar to disturbances on geological features. Any surface disturbing activity such as access road construction, site preparation or drill cutting disposal may impact nearby cultural resources through disruption of soil and vegetation, increased erosion, sedimentation, surface instability and ground vibrations. Impacts can be mitigated by any of the mitigation measures for the conservation of soil and protection of vegetation.

Known artifacts can also be destroyed or damaged if they lie within the proposed disturbance zone. The road to a well pad can allow drilling personnel and park visitors access to resources that were not easily reached prior to the building of the road. Once again, the best protection is avoiding the resources by relocating access roads and the drill pad. Directional drilling will allow the same bottom hole location to be reached in most circumstances. If proximity to the resources cannot be avoided, access can be limited by locking or guarding the entrance to the road. If the area is small, fencing the resource or posting may educate the prospective collector to leave the resources in place.

If cultural resource sites are discovered that will be impacted, mitigative measures specific to the project/cultural resource site should be designed in cooperation with the State Historic Preservation Office, Advisory Council on Historic Preservation and NPS Historical Specialists. Such measures might involve modification of the project, recovery of the cultural resource by excavation or other means, or a combination of these.

K. Summary

Table III-8 presents the major activities associated with drilling operations and the potential impact on each environmental resource value. Table III-9 presents possible mitigation measures for the potential impacts.

IV. PRODUCTION OPERATIONS

Once a well has been drilled and cased, it is completed, and if necessary, stimulated into production using a variety of methods. Production levels increase as an oil or gas field is developed with additional wells and production equipment. Reservoir limits are determined and temporary facilities give way to permanent installations. Production facilities usually include road systems, wellhead and pumping equipment, storage tanks, oil and water separation equipment, natural gas processing equipment, water disposal equipment and pipelines. Production of gas may not begin for an extended period after discovery. A pipeline must first be economically justified and constructed.

The following discussion addresses well completions, production methods and equipment, well stimulation, onsite separation, treatment and storage, disposal of produced water, methods of transportation, hazards associated with production, methods of increasing recovery, potential environmental impacts and suggested mitigation measures.

A. Well Completion

After a well has been drilled to the necessary depth and determined to be productive, it is prepared for production. Production casing is installed and the well is completed. Well completions may be one of four following different types:

- o Perforated casing, where the production casing is perforated using bullets or jets from an explosive charge in the producing zone
- o Multizone completion, where several producing zones or strata are produced simultaneously through the same borehole
- o Open-hole completion, where the casing is set above the producing zone
- o Liner completion, where a screen is set opposite the producing zone to prevent sloughing

Production casing is almost always installed in a well in order to control down-hole pressures and fluids. Ninety-five percent of all completions use perforated casing. The production casing can be perforated using special tools lowered into the well which either fire a bullet or use a jet from an explosive charge to penetrate the casing, cement and surrounding formation. The oil then enters the wellbore through the hole left behind. Multizone completions use one or more strings of production tubing in the same well to allow production from more than one productive zone. Open-hole completions are generally restricted to limestone reservoirs with a single productive zone and low pressure, and thus are rare. Liner completions are used when the productive zone is a loose, soft sand which could enter the wellbore and clog it or become entrained in the oil.

B. Natural Production Methods and Equipment

The oil is produced most often through another string of pipe called tubing. Tubing is necessary because casing is usually too large in diameter to maintain continuous, efficient flow and because casing must remain intact for a long time, and its repair or replacement is costly. Tubing packers are used to seal off the space between the tubing and the casing. By sealing off this space, the casing is not exposed to potentially corrosive well fluids or high pressures, and the chances of casing failure is reduced. Some shallow and low pressure or pumping wells may only have a single casing string or use tubing as the well casing.

Wells often flow from natural reservoir pressure when first put into production. Safety valves can be installed to provide protection against accidents resulting from high pressures. One type of subsurface valve shuts in the well if a predetermined rate of flow is exceeded. Another type is controlled by an external hydraulic pressure system actuated on the surface. Failsafe valves on the wellhead close if there is a loss of pressure somewhere in the line.

The wellhead is the equipment used to maintain surface control of the well. It is designed to support the weight of the tubing and often has many heavy fittings to withstand high pressures and direct flow. The estimated down-hole pressures determine the type and pressure of the rating wellhead required. Parts called the casinghead, tubinghead, Christmas tree, stuffing box, and pressure gages are all part of the wellhead.

C. Well Stimulation

A swab and flow operation is sometimes conducted to initiate production. This operation lowers the hydrostatic head of the fluid in the tubing so that oil or gas will start flowing immediately after the perforations are made. If the swab and flow operation is successful, additional storage tanks and separation and treatment equipment will be needed to contain the production fluids.

Wells often must be treated to improve the recovery from a reservoir, or to remove barriers within the producing formation which prevent easy passage of the fluid into the wellbore. Well stimulation treatments include fracturing, acidizing and other chemical treatments. Explosives were popular for stimulation long ago, but have now been largely supplanted by newer methods.

Fracturing involves the injection of a fracturing fluid and propping agent into the formation under extremely high pressures, literally cracking open existing fractures to enlarge them or creating new ones. The technique is most commonly used on sandstone producing formations with low permeability. Fracturing operations use a number of base fluids to which chemicals are added to improve their physical and chemical properties as a hydraulic fracturing medium. Base fluids can be crude or refined oil, fresh water, brine and acid. Chemical additives are used to

- o Increase the viscosity of the fluid
- o Reduce friction pressure in the pipe
- o Control fluid loss in the rock matrix
- o Improve compatability with the formation fluid and rocks
- o Divert fluid movement

For oil based fracturing fluids, additives include fatty acid and caustic combinations, phosphate esters, organic polymers, organic acids containing inorganic solids, oil-soluble surfactants, and organic particulates such as wax pellets and naphthalene granules. Water based fluids additives include natural or synthetic polymers such as gums and cellulosic or acrylic polymers, natural gums and starches, finely divided inert materials such as silica flour, potassium chloride, demulsifying and wetting agents and particulates such as granular salt, carbohydrates and proteins.

Propping agents are inert granular substances used to keep fractures open after treatment and commonly include silica sand, nutshells, glass beads, sinter bauxite, aluminum pellets and steel shot. They are required because the fractures close and tend to heal without them when the pumping pressure is relieved.

Field procedures for fracturing require the use of specialized heavy pumping equipment (ten or more pumping trucks may be needed), mixing equipment and storage space for the 3,000 to 10,000 gallons or more of fracture fluid that will be injected. Following the fracturing operation, spent fluid is produced out of the well into tanks or lined pits.

Acid stimulation is used if the producing formation is composed of carbonate rocks (limestone or dolomite) or calcareous sandstones with low permeability. Between 100 and 5,000 gallons of hydrochloric acid pumped into the well dissolves the rock to enlarge existing channels and open new ones. The acid strength may range from 3 to 28 percent, but is normally 15 percent. Propping agents are not required as with fracturing. The acid can contain numerous additives such as corrosion inhibitors to protect the casing, and demulsifying, sequestering and wetting agents. Inhibitors may typically include inorganic arsenic compounds, organic nitrogen compounds and alcohols. Surfactants prevent emulsions from forming and make the acid easier to pump.

Other acids may also be used alone or in combination with hydrochloric acid for other types of producing formations. The type of acid is chosen on the basis of the solubility of the reaction products so that precipitates which will plug the pore spaces in the producing formation are not formed. Hydrofluoric acid in concentrations ranging from 3 to 20 percent is used if the rock is high in silica content. Acetic acid or formic acid is also used occasionally.

Field procedures for an acid job are similar to a fracture treatment. The treatment requires the same heavy pumping equipment, mixing equipment, tanks for storing the "live" acid and tank or lined pits for the spent acid produced from the well.

Chemical treatment involves the use of chemicals other than fracturing or acidizing agents. Many of them are commonly used as additives in the above processes. They may include, for example, corrosion control treatments or applications of demulsifying and wetting agents.

D. Artificial Production Methods and Equipment

When pressures in the oil reservoir have fallen to the point where a well will not produce at its most economical rate by natural energy, some method of artificial lift is introduced. The most common methods of artificial lift are

- o Sucker rod pumping
- o Gas lift
- o Subsurface electrical pumping
- o Subsurface hydraulic pumping

Sucker rod pumps are by far the most widely used method. Commonly known as rod pumping, or beam pumping, this method uses a pumping unit on the surface to impart an up-and-down motion to a sucker rod string that is attached to a piston pump at the bottom of the well (see Figure IV-1). The power to run the beam pumping unit comes from a prime mover. The prime mover is usually an electric motor, or an internal combustion engines where electric power is not available. Operators prefer electric motors because they are more easily automated, more dependable, require less maintenance, involve less fire hazard and make less noise. The size and speed of the pumping unit is selected to match the production rate of the well.

Gas lifting is a method of producing oil in which gas under pressure is used to lift the well fluids. In this process, either natural gas (from a nearby well or pipeline) or another high pressure gas is injected into the fluid column of a well to lighten and raise the fluid by expansion of the gas. Gas may be injected continuously or intermittently, depending upon the producing characteristics of the well. This method will be used less in the future as supplies of high pressure natural gas decline. It is still the most popular method for production operations offshore because it requires a minimum of surface equipment and high pressure gas is usually available.

Subsurface electrical pumps are centrifugal pumps sized to fit in the well and are submerged in the well fluids. Current is supplied through a heavy-duty insulated cable extending from transformers on the surface through a control box to the pump in the bottom of the well.

Subsurface hydraulic pumps are direct coupled positive displacement pumps placed at the bottom of the well, powered by a hydraulic pump on the surface. The hydraulic fluid is usually crude oil taken from a storage tank. A single surface pumping system may be used to pump several wells.

Most gas wells produce by normal flow and do not require pumping. Surface use at a flowing well is usually limited to a fenced area 20 feet square containing a gas well Christmas tree. If water enters a gas well and chokes off the gas flow, a pump may be installed to pump off the

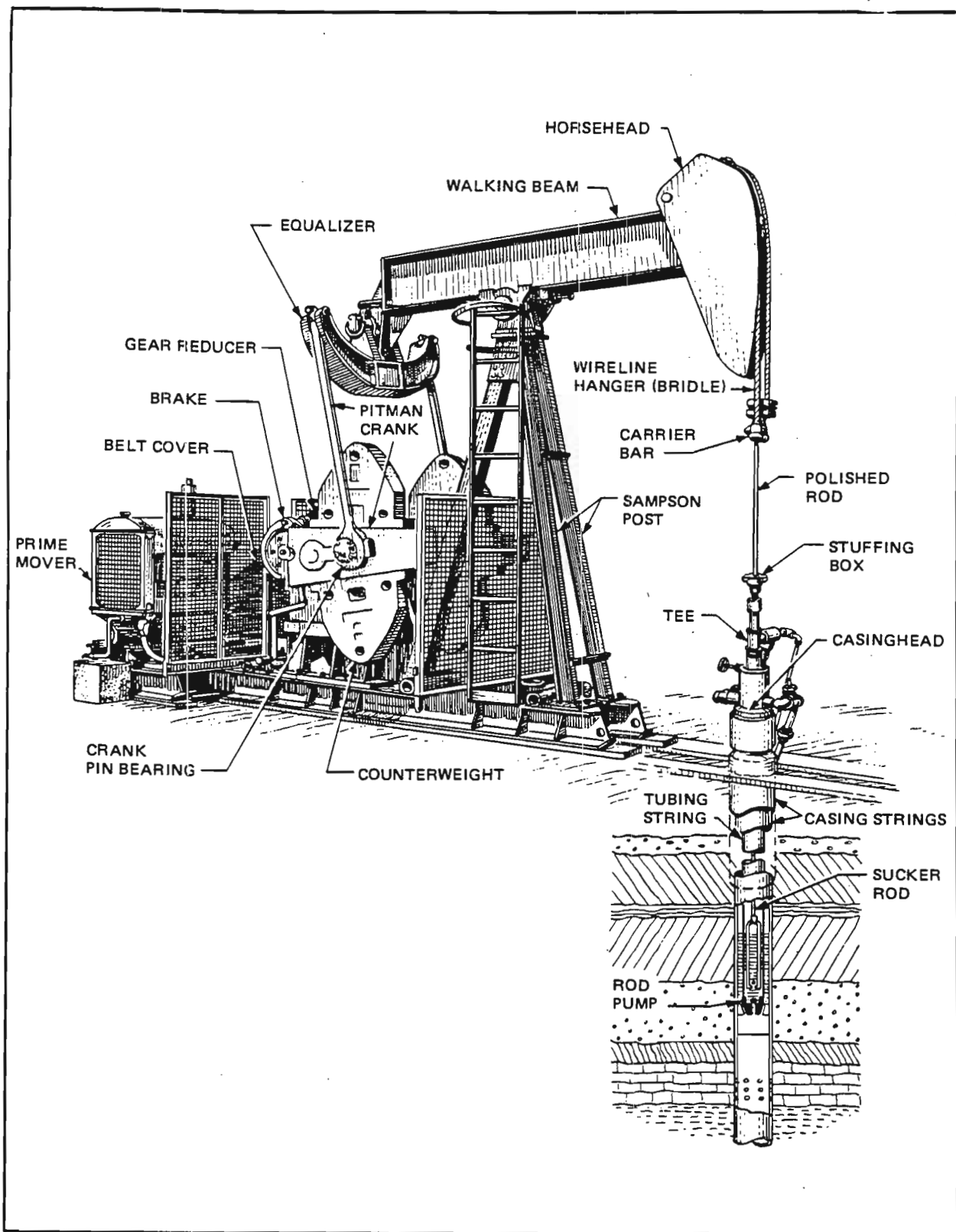


FIGURE IV-1 ROD PUMPING COMPONENTS

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column of water. After the water is removed, the gas flows to the surface until water again chokes it off. Some gas wells may require almost continual water pumping.

Most wells will require servicing or a workover sometime during their productive lives. The most common well servicing operations are those related to artificial lift installations, tubing string repairs, and repair of other down-hole equipment that may malfunction. Workovers include more extensive repairs. They require the use of a rig which in many respects resembles a scaled down drilling rig. Workover operations include sand removal, liner removal, casing repair, cementing and refracturing or reacidizing the well.

Oil and gas production operations include a variety of tests to determine the performance and optimum production rate of a well. They are performed not only to maximize production efficiency and profits, but also to comply with regulatory requirements. Potential tests are a measurement of the oil, water, and gas that a well will produce in a 24-hour period under certain fixed conditions. Storage tanks and treatment equipment normally present in a producing field are required to receive the flow from the well. Information from these tests is used to establish the production rate for the well. Bottomhole pressure tests may be conducted either in a flowing or shut-in condition. When performed with potential tests, they are known as productivity tests. Other tests include bottomhole temperature determination, sonic fluid level determination, water analysis, and routine production volume tests. They allow for the continued production of oil and gas at the most efficient rate and identification of equipment problems.

E. Onsite Separation, Treatment and Storage

Well fluids are often a complex mixture of oil, gas, water and impurities. It is necessary to separate these components, treat the valuable oil and gas and dispose of wastes before the product can be transported and sold. Impurities may include hydrogen sulfide, carbon dioxide, free water, water vapor, mercaptans, nitrogen, helium and a variety of solids such as wax or sediment.

Separation of well-stream gas from free liquids is the most common and simplest form of field processing. A separator uses gravity and cyclonic flow to separate the gas and liquid. Separators are built in various designs; vertical and horizontal types are both common. Often a number of separators are operated in series at successively lower pressures to achieve greater separation efficiency. Although natural gas leaving the separator no longer contains free liquids, it may be saturated with water vapor or contain other gaseous impurities. And although the liquid leaving the separator does not contain any gas, it too may contain substantial impurities such as water or sediment.

High pressure gas usually requires dehydration before it can be transported from the field. Gas which cools or undergoes a pressure drop will often condense free water. Free water in the gas line has a tendency to cause corrosion, reduce flow rates and promote the formation of gas hydrates. Most pipeline companies will not accept gas with more

than 7 pounds of water per million cubic feet of gas. Several methods are available to prevent condensation in a gas line as follows:

- o Heating the gas stream to maintain a temperature at which condensate or hydrates will not form
- o Adding an anti-freeze such as methanol or glycol
- o Removing the water vapor by use of a glycol dehydrator
- o Dehydrating the gas stream by use of solid dessicants
- o Dehydrating the gas stream by use of expansion refrigeration

Other impurities such as hydrogen sulfide or carbon dioxide can be removed by a variety of chemical or physical processes. They may include the alkanolamine process, iron sponge process, glycol-amine process, sulfinol process and molecular sieve removal. Condensable hydrocarbons such as propane and butane are also removed from natural gas and sold separately.

Crude oil requires treatment to remove basic sediment and water (BS+W). The water in the oil may occur either as free water or in an emulsion. Free water can be easily separated from oil by gravity in a free water knockout, which is little more than a retention vessel which allows water to settle out and the oil to float to the top. Emulsions are more complex. The treatment required depends upon the tightness of the emulsion, properties of the oil and water, the percentage of water present and the type of emulsifying agent in the liquid. Heater-treater uses thermal, gravity, mechanical and sometimes chemical or electrical methods to break emulsions (see Figure IV-2). The properties of the emulsifying agent are neutralized or destroyed so water droplets can coalesce and settle out. Relatively unstable emulsions may not require elaborate heater-treater and can instead be separated in a specially designed settling vessel called a gun barrel or wash tank. In general, production from high pressure wells requires more treatment than production from wells under low pressure or wells being pumped.

After treatment, oil that meets pipeline specifications is held in storage tanks pending transportation offsite. The number and size of storage, or stock, tanks depends upon the production rate of the wells and the transportation means employed. The size of the tanks may range from less than 100 barrels to several thousand barrels of oil. Multiple tanks are required so that production can continue while a delivery is being made. Vapors evaporating from the oil in the tanks can be recovered by a vapor recovery unit to conserve valuable resources and reduce air pollution. The separating, treating and storage facilities are collectively known as a tank battery (see Figure IV-3). One tank battery may serve several wells from a convenient location.

Gaging and metering the production of oil and gas is one of the most important functions of the lease operator. Oil or gas may be produced at the maximum rate a well will yield, or at some "allowable" level set by a state regulatory agency. Tank volumes are determined (strapped) and tank

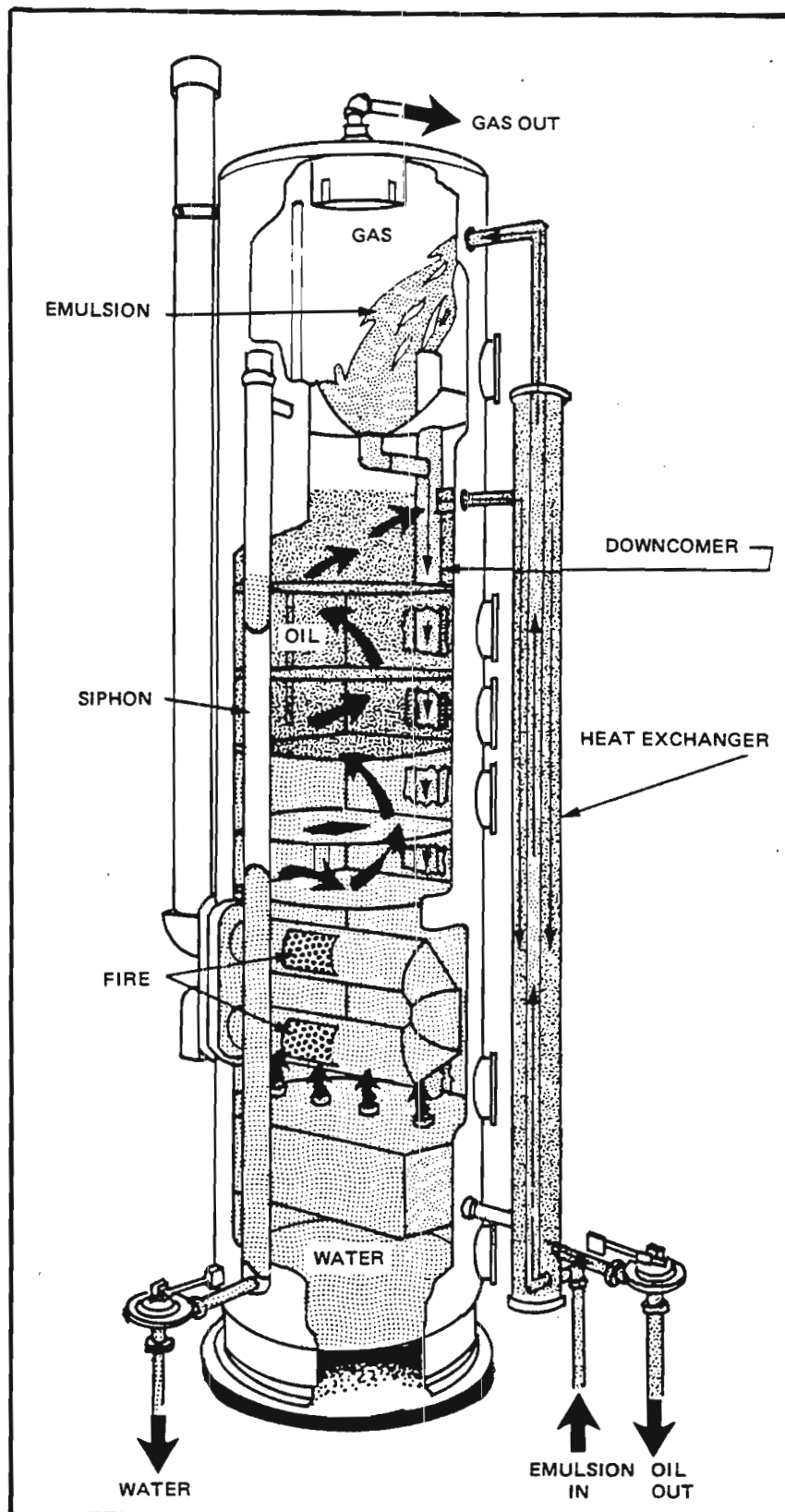
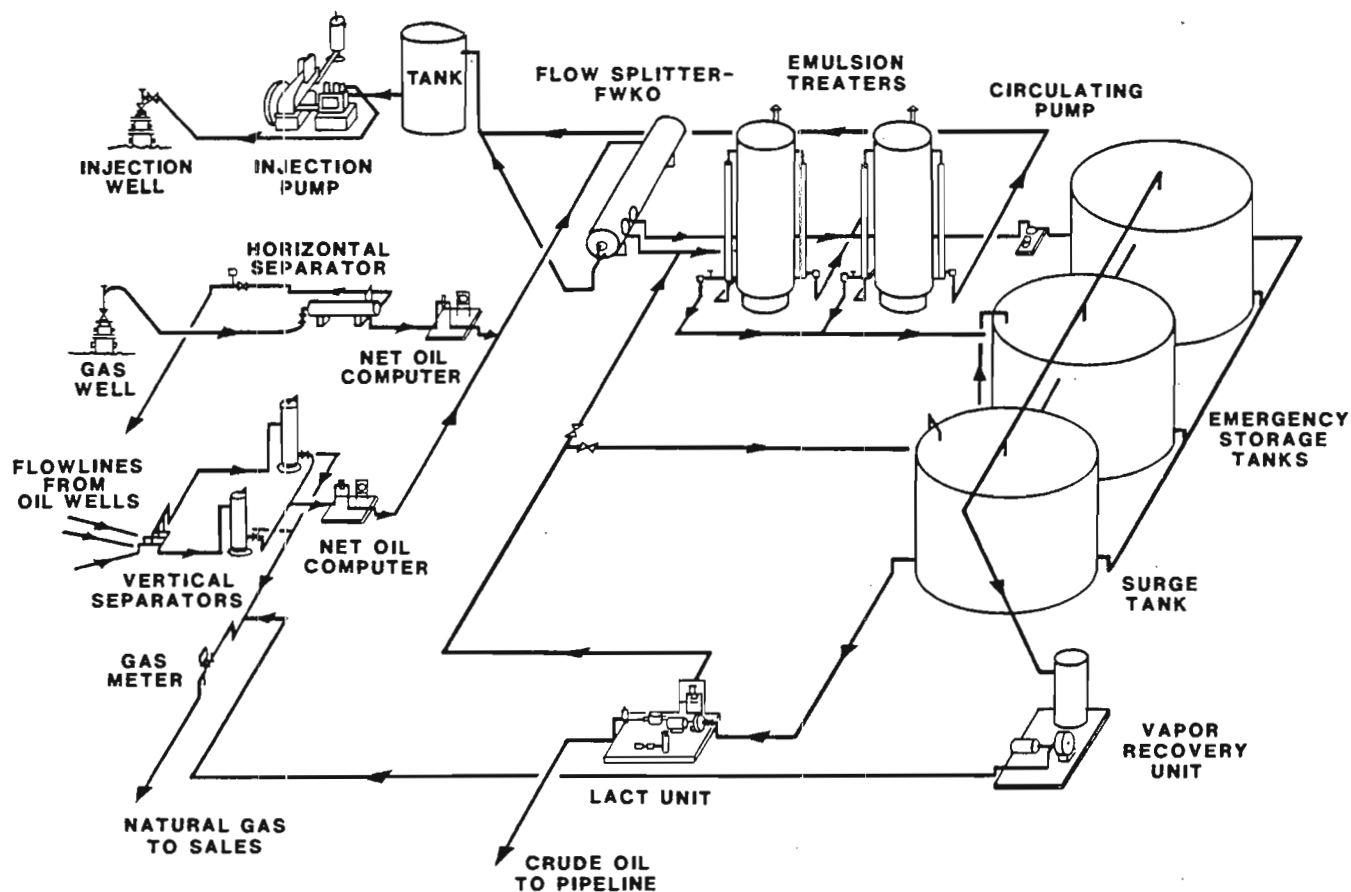


FIGURE IV-2 VERTICAL HEATER-TREATER

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SOURCE: American Petroleum Institute. Reprinted with permission.
 FIGURE IV-3 TANK BATTERY

tables are constructed which show the contents of the tank in barrels for a given fluid height. Fluid heights are typically recorded every 24 hours. They may be taken manually with a plumb bob or with an automatic tank gauge using a float indicator. The gravity, temperature and basic sediment and water content of the oil is determined from samples every time a delivery is made from a tank so that the exact volume, quality and identifying properties of the oil are known.

A lease automatic custody transfer unit (LACT unit) provides for the unattended transfer of oil or gas from the lease to a pipeline. It saves considerable labor by taking samples, recording temperatures, determining quality and net volume, eliminating gas if necessary, recirculating bad oil for additional treatment, recording information and shutting down equipment and sounding an alarm if something goes wrong. Additional advantages include increased operating efficiency and control, and possibly a reduction in required storage tank volume and associated evaporative losses.

Natural gas is typically metered using an orifice meter. Samples of the gas are taken in the field before delivery to a pipeline to determine quality.

F. Disposal of Produced Water

Most oil and gas wells produce some water. The amount of water produced varies considerably and depends upon the producing formation and the location, construction and age of the well. Some wells produce little or no water at first, but gradually produce more as time goes by. Many older wells with marginal production produce 100 barrels or more of water per barrel of oil. Some of the produced waters are fresh, while others are highly saline, as measured by the total dissolved solids content. The water is treated before release or disposal. Treatment includes removing suspended solids with a filter and coalescing oil particles until the water is clean enough either for release into surface waters or reinjection into the hydrocarbon reservoir or saline aquifer. Corrosion inhibitors may also be added.

Disposal into surface waters used for drinking water or onto the land surface is strictly regulated by most states and rarely practiced any more. The water is usually too saline to serve a beneficial use, and in fact will contaminate otherwise high quality water or productive soil. Produced water from offshore platforms is commonly released into the ocean after treatment.

Reinjection is the most widely used method to handle produced waters. The aquifer used for reinjection must contain water of equal or poorer quality than the produced water. The proper location, pumping pressure and construction of a disposal well is critical to avoid contamination of usable water supplies. A typical water disposal system consists of a treatment vessel, an accumulation or storage tank, reinjection pump, controls and a disposal well. One disposal well may serve several production wells and may be jointly owned and operated by several production companies.

Problems can beset reinjection of oilfield brines. For example, incompatible brines may react to form precipitates on the wellbore and in the formation. Precipitates such as carbonates and sulfates of calcium, barium, iron and strontium restrict flow and increase the pump pressure needed to inject the water into the formation. Therefore, it is necessary to ascertain the chemical composition and compatibility of both the wastewater and the reinjection zone water. Other problems include leakage of brines through holes in the casing or cement of the disposal well, or migration of brines to the surface through improperly abandoned wells which are nearby and through subsurface faults and fractures.

Reinjection of water may enhance the recovery of oil. Fluid injection, or water flooding, is a secondary recovery method which helps restore reservoir pressure. The technique is more thoroughly discussed in Section G of this chapter entitled "Methods of Increasing Recovery."

G. Methods of Transportation

The cost of transportation of domestic crude oil from the field to refineries may amount to as much as 50 to 60 percent of the delivered cost of the oil. The mode of transportation thus becomes a critical economic decision for most operators. There are four methods of transportation available today: pipelines, tank trucks, tank railroad cars and barges or ocean-going tankers. The choice among these methods depends upon whether oil or gas or both is produced, the distance covered, the produced quantities of the field and the availability of the different methods of transportation.

1. Pipelines

Pipelines are the most efficient form of domestic transport over long distances, but they require substantial production rates in order to justify the high cost of installation. Field gathering lines are used to transport production from the wellhead to a tank battery or treating facility. Separate lines are used for fluids and for gas. Field gathering lines are normally 2 to 4 inches in diameter. When pipelines are used for offsite transportation, oil is then pumped from the tank battery in the field through lines (usually 2 to 6 inches in diameter) to a gathering station. The gathering station collects oil from many tank batteries and need not be located in the producing field. Oil is then routed to the nearest trunkline for delivery to a refinery or shipping terminal. Trunklines may be 4 to 16 inches in diameter and several hundred miles or more in length. They require a large pumping station and booster stations along the way to send the up to 1,000,000 barrels per day of oil through the pipeline. Centrifugal pumps, driven by electric motors, are used to pump the oil. Storage tank farms serve as receiving and holding stations at both gathering and trunkline stations. They are necessary to temporarily hold the oil for sorting, measuring and rerouting, or during pipeline and pumping station repair operations.

The movement of oil through pipelines is controlled by an elaborate scheduling and dispatching system which ships oil in distinct batches. The various owners of the oil which is shipped through a pipeline prefer to keep their oil separate from other oil because of the variations in

quality. Manifolds at tank farms allow different batches of oil to be segregated into different tanks and stored separately until the oil is ready for shipment. "Pigs" (usually an inflatable sphere) can be inserted in the pipeline to differentiate batches of oil. Scheduling and dispatching operations are aided by computer. A detailed discussion of pipeline operations can be found in "Introduction to the Pipeline Industry" (1978).

Natural gas is always transported by pipeline. Oil and gas cannot be transported in the same pipeline because their divergent physical characteristics require different operating procedures, as well as different engineering specifications for the pipelines and pumping or compressor stations.

After treatment in the field to remove water vapor, impurities and other condensables, the gas is compressed to provide the energy required to send it through the pipeline. Compressors may be driven by electric motors, gas turbines or internal combustion engines, often using natural gas from the pipeline as the fuel. Compressor stations send the gas through field gathering lines to a centralized terminal for transmission to market through a trunkline. The trunkline requires a large compressor station assisted by booster stations along the way to send the large volumes of gas the great distances it must cover to market. Pipeline operations require that the volume, density, dew point, temperature and pressure of the gas be measured, recorded and controlled to maintain efficient flow. A computer system can provide automation of most normal operations of the pipeline. Construction techniques for gas pipelines are similar to those used for oil pipelines, although the attendant terminal and intermediate facilities are different.

If natural gas is bound for domestic or most industrial use, mercaptan odorants are added to the gas to aid in the detection of leaks. They allow the otherwise odorless gas to be smelled at low concentrations, so that leaks can be repaired before a fire hazard develops. Odorants are not introduced to gas bound for petrochemical plants where it is used as a feedstock for commodities such as plastics, because they would contaminate the gas.

Hydrocarbon products, such as propane and butane which have been condensed out of gas in the field, are usually transported by truck in liquified form (under pressure).

Field gathering lines and trunklines are usually buried, but may also be on the surface or elevated. Buried pipelines are the safest in terms of accidental rupture from activities on the surface. Leaks, however, are not as easy to detect or repair. Buried lines also are insulated from the cold, possibly alleviating the need for oil heaters along the pipeline route in cold climate areas.

The actual construction of an underground pipeline requires a strip of vegetation to be cleared from 50 to 75 feet wide. Then a ditch of at least 12 inches wider than the pipe diameter and at least 3 feet deep is cut. The pipe is coated, bent to conform to the shape of the ditch, welded together, inspected, coated again and lowered into the ditch.

Backfilling the ditch completes the installation. The pipe must be buried deep enough to allow normal surface activities such as farming or road construction above it without disruption. Once the pipeline is buried, the right-of-way is usually kept clear of shrub or tree growth so that periodic inspections can be made. Often the inspections are done from low flying aircraft. Pipelines laid offshore require the use of special barges to construct the line and lower it to the bottom. A more complete discussion of pipeline construction can be found in "A Primer of Pipeline Construction" (1966).

2. Tank Trucks

Tank trucks may be used to transport oil. They pick up oil from the tank battery in the field and deliver it to a pipeline gathering or trunk station, shipping terminal or directly to a refinery. Trucking is a popular method of transport in marginal, low volume fields or from wildcat wells, because it does not necessitate the construction of an expensive pipeline. Existing roads are used with little additional expense.

3. Railroad Tank Cars

Railroad tank cars may also be used to transport oil. The use of this method is limited to areas with existing railroad tracks and without an available pipeline. The method is much more suited to delivering refined petroleum products to market.

4. Barges and Ocean-going Tankers

Barges and ocean-going tankers are a very efficient method of transporting oil where navigable waterways are available. Shipment by this method requires a loading terminal and tank farm to transfer the oil from the lease to the ship. Oil is often transported to a loading terminal by truck.

H. Hazards Associated with Production

1. Hydrogen Sulfide

Production operations may produce hydrogen sulfide (H_2S) along with oil or gas. As detailed in the drilling chapter H_2S is a toxic, highly corrosive gas which can be deadly at relatively low concentrations (100 ppm in air). Production crews must be thoroughly trained regarding the dangers of H_2S and how to prevent exposure both to themselves and the surrounding population. NPS personnel who may have to inspect the well or facility should be thoroughly trained regarding the dangers of hydrogen sulfide. Any site with hydrogen sulfide should be securely fenced to prevent admission of visitors or other uninformed people.

Storage tanks with oil containing H_2S are a potential source of exposure to production crews. Dissolved H_2S will enter the headspace of the tank and accumulate at concentrations of 40 to 100 times the concentration in the oil. Thief hatches used for obtaining oil samples are labelled to warn of H_2S if the potential concentration exceeds safe levels. Tank

hatch seals, vent lines, and relief valves are inspected for leaks which could release H_2S . Emergency equipment such as H_2S detectors and respirators should be onsite when an inspection is performed.

Special precautions are taken with production vessels if they have contained H_2S . When opened to the atmosphere, flammable vapors in the tank can explode from heat supplied by the reaction of iron sulfide on the vessel wall with air to form iron oxide. The container surfaces or bottom sulfide sludge is kept wet until flammable vapors can be purged.

Corrosion and sulfide stress cracking (embrittlement) of equipment in contact with H_2S can occur. For this reason, H_2S is removed from the oil or gas as soon as possible after production. The H_2S is absorbed into an aqueous, regenerative sorbent or processed in a sulfur recovery plant to obtain elemental sulfur, which may then be sold. If no recovery plant is available, the H_2S is flared to produce less toxic sulfur dioxide. A variety of special alloy metals, protective coatings and inhibitors may be used to prevent damage to wells or other production equipment exposed to H_2S .

2. Fires and Explosions

The danger of fires or explosions is present with any equipment containing hydrocarbons. If a spill or a leak should occur, vapors are easily ignited. For this reason, venting of gases and fugitive emissions of hydrocarbon vapors are kept to a minimum. Gases which are released are routed to a flare for safe disposal. Production equipment is inspected and repaired or replaced if necessary to prevent spills or leaks. Safety equipment including circuit breakers and fire extinguishers is made a part of tank battery installations.

3. Pipeline Rupture

Buried oil or gas pipelines run the risk of leaking or being ruptured. There are a variety of causes, both natural and man-made. Corrosion of the pipe or failure of a flange, valve or seal is one of the most common causes. Construction and excavation activity is another leading cause; the powerful hydraulics on heavy equipment can easily rupture a pipeline. Movement of the earth, such as an earthquake, erosion or landslide, can also induce pipeline failure.

A leaking or ruptured pipeline can lead to an oil spill or fire. Pipeline companies maintain shut-off valves easily available in emergencies at many points along a pipeline. Catastrophic failures will be evidenced by a sudden loss of pipeline pressure. Slow leaks or failures in remote areas are spotted by periodic inspections or flyovers by pipeline company inspectors. Work crews employed by the pipeline company can respond to spills or fires reported by authorities.

Once a leaking or ruptured pipeline has been shut off, it is repaired as quickly as possible in order to restore pipeline operation. Then work begins to clean up spilled oil. Since oil spills and fires are hazardous, represent an economic loss to the company and are bad for the

industry public image, pipelines are periodically tested and regularly maintained to prevent as many accidents as possible.

I. Methods of Increasing Recovery

Underground oil is under pressure in practically all reservoirs. This pressure is usually transmitted to the oil through gas or water in the reservoir with the oil. When oil is pumped out of the well, pressure is reduced in the reservoir around the drillhole. This allows the gas or water in the reservoir to expand, pushing more oil into the space next to the well and retarding the decline in pressure. A reservoir that has mostly gas pushing the oil is called "gas drive," and one that has mostly water pushing the oil is called "water drive." Gas drive wells, also known as depletion drive wells, may be of either the solution-gas or gas-cap type depending upon whether the gas is in solution in the oil or in a free state above it. Oil that is recovered under these natural pressures is considered primary production. Primary production accounts for about 10 to 15 percent of the oil in a reservoir. Substantial quantities of oil will normally remain behind in the reservoir when natural pressure is depleted without some form of enhanced oil recovery (EOR).

Methods of increasing recovery from reservoirs generally involve pumping additional water or gas into the reservoir to maintain or increase the reservoir pressure. This process is called secondary recovery. Recently, the trend has been to institute secondary recovery processes very early in the development of a field.

Secondary recovery is currently used in about 50 percent of the oil fields. Waterflooding is the method used in about 90 percent of these secondary recovery efforts. Water is injected into the reservoir to increase reservoir pressure and drive additional oil to the surface. The water supply is usually a brine obtained from wells in or near the waterflood area. Fresh water is not desirable for waterflood purposes because it may cause clays found in some reservoir rocks to swell and thus reduce the permeability of that reservoir. The amount used for injection is normally in the range of 100 to 2,000 barrels per day per well.

Other secondary recovery methods include high pressure gas drive, enriched gas drive and carbon dioxide flooding. These methods involve the reinjection of light end hydrocarbons which dissolve the oil to reduce its viscosity and allow it to flow to a well, increasing the overall recovery rate.

Tertiary recovery methods are the third phase of recovery. Tertiary projects normally increase recovery rates by chemically complex or expensive methods including lowering the viscosity of oil through thermal processes, miscible flooding or injection of polymers. Tertiary recovery is not yet widely used in this country. By the year 2000, the ultimate recovery rate from an oil reservoir is expected to reach an average of 40 percent nationally through use of enhanced recovery techniques.

Figure IV-4 shows how primary, secondary and tertiary methods of oil recovery work.

J. Possible Effects and Mitigations

This section provides a general discussion of environmental impacts from and available mitigation measures for oil and gas production operations in NPS areas. Each park is unique, and production operations are varied. A multidisciplinary team of specialists should review each Plan of Operations to ascertain specific impacts and mitigations on a case-by-case basis.

Oil and gas activity on NPS lands will affect the environmental resource values identified in this chapter. Production operations can affect several resource areas, and impacts are strongly interrelated with each other. Those values with the most potential for significant impacts are addressed first.

1. Surface Disturbance (Soil and Vegetation)

Soil and vegetation impacts can be separated into four categories. Production operations can cause soil compaction and associated damage to vegetation, removal or alteration of topsoil and vegetation, erosion and contamination.

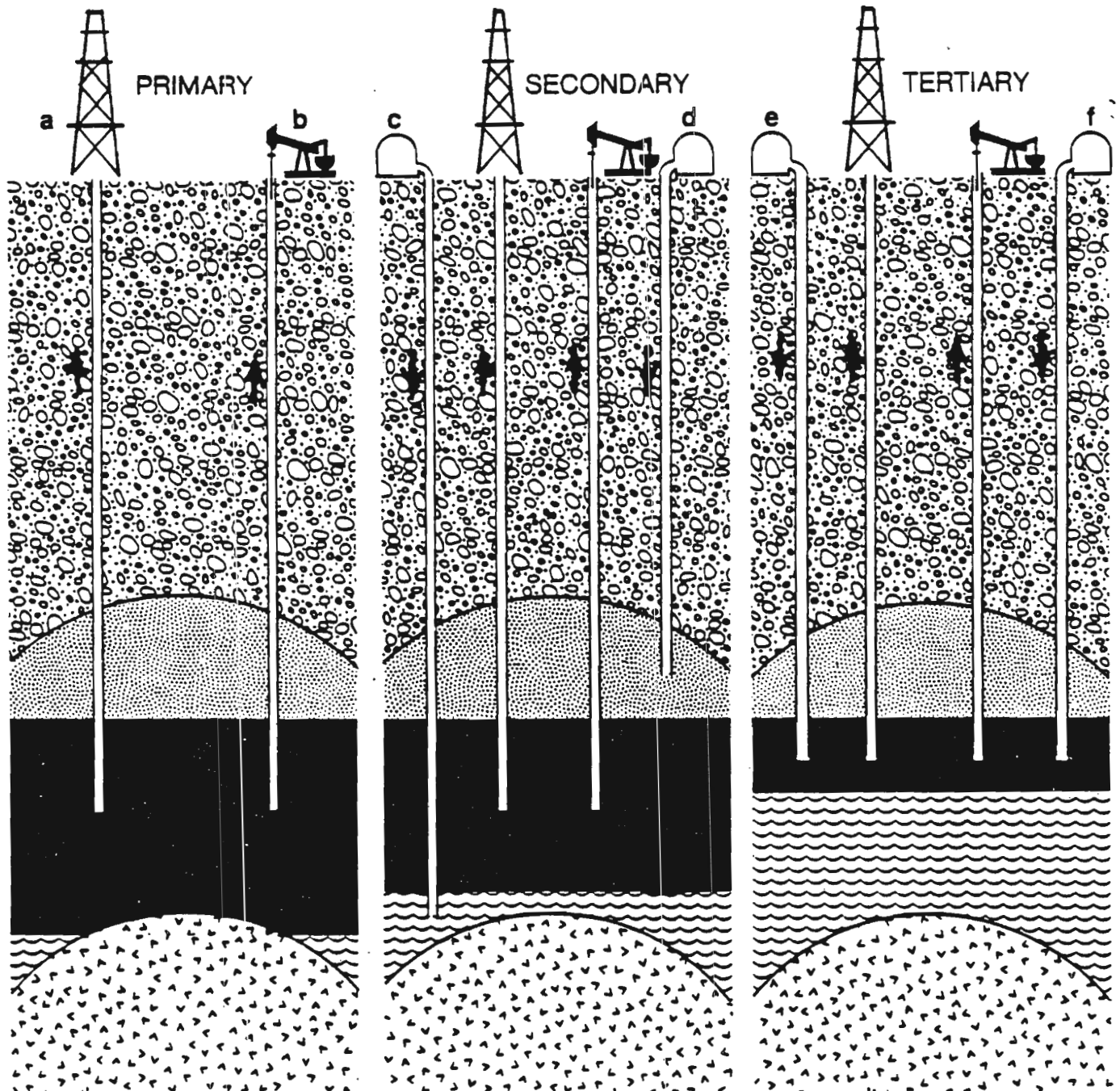
a. Soil Compaction/Vegetation Damage

Roads established during development of a producing field will become more permanent. Vehicular traffic associated with installation and maintenance of production equipment and trucking of produced oil will cause further compaction and rutting of soil on unpaved roads. An estimate of the volume of traffic or vehicle weight associated with production operations depends on the type of production, rate of production, method of transportation used for the oil and water, amount of storage capacity and access to water disposal systems. If oil and gas pipelines are installed and water is piped to a disposal well, then traffic to the oil field will be predominantly pickup truck maintenance vehicles. If both oil and water have to be trucked, then several large tanker trucks will need to be scheduled per day.

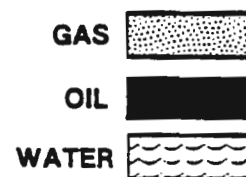
Soil compaction and vegetation damage from construction and traffic will also occur at sites developed for production facilities. Compaction caused by construction and grading equipment on and around a production pad occurs when pressure on the surface causes pore spaces in the soil to collapse. Compacted soils have a lower infiltration capacity, resulting in greater runoff of precipitation and subsequent downslope erosion.

Limiting travel to established roads and pads can mitigate impacts of soil compaction and vegetation damage to a minimum. Using existing pipelines or railways for transport of oil can reduce truck traffic. Pipeline and utility corridors which already exist in the area usually have service roads which may be available for use to access production facilities, reducing the need for new roads.

METHODS OF OIL RECOVERY



Oil is generally found under pressure in porous rock, often in a geological structure such as the one shown here. Drilling a well into the oil-bearing stratum releases the pressure, and in primary production the oil flows to the surface (a) or is pumped out (b). When the natural pressure is too low to bring the oil to the well, secondary recovery may be achieved by pumping water (c) or gas (d) into the field to increase the pressure. In tertiary recovery the oil's viscosity is lowered by injecting steam, which heats it (e), or by injecting a chemical (f).



SOURCE: Scientific American, vol. 238, no. 38, March 1978.

Figure IV-4 Methods of Oil Recovery

b. Topsoil/Vegetation Removal and Alteration

Clearing, grading and cut-and-fill activities associated with site preparation for production facilities can result in loss of topsoil and vegetated area. Pipeline routes particularly contribute to this impact. Revegetation and general adherence to good civil engineering practices can mitigate impacts from these effects. Pipelines should be installed adjacent to roads to minimize the area of disturbance. Topsoil excavated during construction activities should be stockpiled and used to rehabilitate the area.

Borrowing of fill and aggregate materials used in site preparation involves excavation which will leave behind an open pit. Excavations have to be outside of NPS boundaries to mitigate impacts to the natural contours of the land as well as vegetation, visual quality and the noise environment.

The invasion of nonnative species introduced by people or equipment, especially in disrupted (cleared) areas, can impact the ecology of a native forest or other ecosystem. If there is a potential for nonnative species growth, the cleared areas not actually used for production activities should be reseeded with native species as quickly as possible to reduce the space for exotics.

c. Surface Erosion and Instability

Clearing, grading and cut-and-fill activities associated with site preparation and pipeline construction will result in increased erosion and instability since disturbances which leave the ground barren of natural vegetation render the productive surface soil horizons susceptible to removal by the erosive forces of gravity, wind and water. Vehicular traffic will also increase erosion of soil on unpaved or ungravelled roads especially during wet weather or spring thaw.

Paving a road will mitigate rutting and erosion of the road surface but makes rehabilitation more difficult when activity in an area is abandoned. Runoff control structures such as culverts and bridges may be necessary to mitigate erosional impacts at stream crossings. Culverts should be constructed of corrosion resistant metal, be adequately sized and be kept free of debris.

Rutting and erosion result in a loss of the valuable top horizon of the soil, which is necessary for revegetation of impacted areas. The erosional loss of soil increases geometrically with slope. Revegetation and possibly tilling of impacted areas may be required for the soil to completely recover to its original state.

Earthmoving activities or significantly altered surface runoff patterns may exacerbate preexisting geological hazards or create wholly new ones. Streambanks are particularly critical because they are easily destabilized, resulting in a small-scale landslide of material into the stream. Avoiding areas of preexisting hazards (especially on steep terrain and in stream channels), providing for adequate drainage,

revegetating of cut-and-fill slopes, and adhering to good civil engineering practices can mitigate impacts from instability.

d. Soil Contamination/Vegetation Damage

Soil contamination and vegetation damage result from liquids and solids that contain toxic compounds making contact with soil and vegetation. This may occur suddenly in a spill or gradually through percolation through the soil.

Oil spills generally occur when petroleum is being transferred from one place to another, whether the transportation method is a pipeline, railcar, tank truck or ship. Spills can also occur if a storage or treating vessel ruptures or if a wellhead blows out. Percolation through the soil of brine or oil can occur because of a slow leak in the treating or storage vessels, leaks in the well casings near the surface or improper disposal practices. Transportation equipment and associated facilities, such as pipelines and tank farms, are also susceptible to leaks.

A spill will flow overland, both coating the soil surface and infiltrating the ground. It will inundate the low lying vegetation. If it flows to surface water bodies or is spilled into them, streambanks or shorelines and associated vegetation will be coated with oil. The most immediate risk of large oil spills is the possibility of fire in a heavily vegetated area. In the event that plant life is killed either in aquatic or land environments from an oil spill, regrowth begins after a few days when the oil has been removed and any residue has weathered. Species diversity, however, may be reduced. Oil spills will not lead to permanent damage to the productivity of the land, but impacts can last for several years. The oil will eventually volatilize, be naturally degraded by bacteria, and physically flushed from water bodies. The impacts of an oil spill due to its toxicity are discussed further in Section 2 entitled Water Quality.

Surface disposal and spills of brine can kill vegetation, and resulting soil contamination will hinder regrowth. Like oil, brines are more commonly spilled during transport or storage. Brine is usually highly saline water, as measured by the total dissolved solids content. The major constituents of brine include the ions Na^+ , Ca^{+2} , Mg^{+2} , SO_4^{-2} , HCO_3^- and Cl^- . The impacts of a brine spill on the soil can be very long-term or permanent in an arid environment because of the lack of water to leach the salts out of the root zone. In addition, brine high in exchangeable sodium (Na^+) can reduce the water infiltration capacity of the soil. The actual composition of brine varies widely and needs to be determined to ascertain the potential impact from a spill. The impacts of improper disposal of brine are also discussed in Section 2 of this chapter entitled Water Quality.

Production facilities can be periodically inspected and regularly maintained to prevent as many accidents as possible. Both production and water injection wells should be adequately and properly cased and cemented to reduce the possibility of blowouts or leaks.

Maintaining an up-to-date Spill Prevention, Control, and Countermeasure (SPCC) plan can mitigate the impacts of oil spills shortening response time needed to control and clean up a spill. Steps included in controlling and cleaning oil and brine spills include the following:

- 1) Limiting the aerial extent of the spill once it occurs is the most important step in controlling environmental impacts. Shutting off the source of the spill, booms, earthen dikes and diversion ponds can be used to limit the aerial extent of the spill.
- 2) Vacuum trucks should pick up as much oil or brine as possible as quickly as possible.
- 3) Digging up and replacing contaminated soil should be evaluated.
- 4) Flushing or diluting brines with fresh water should be evaluated.

A SPCC plan should include names and phone numbers of the operator's representative, it should designate who is responsible for cleaning up the spill and the source of the manpower needed to clean up the site and it should identify where any special equipment such as booms, vacuum trucks or absorbant pads can be found. The plan should also include the composition of the brine, oil or chemicals that have the potential to be spilled.

Restoration of impacted areas can help mitigate the impacts of oil or brine spills. Spreading topsoil over contaminated or bare soil, fertilizing it and revegetating it will enhance bacterial degradation of any residual oil, aid in infiltration of water in areas of spilled brine and restore vegetation to protect the soil from erosion.

Temporary revegetation measures can be employed if surface disruptive activities are completed during a season when appropriate perennial wildlife food or groundcover cannot be established. They include mulching and seeding with an annual groundcover. Tree planting, seed mixtures and rates and fertilizer requirements can be specified in the SPCC plan.

2. Water Quality

Production operations may cause sedimentation and contamination of surface and groundwater.

a. Sedimentation

Increases in sedimentation may occur due to clearing, grading and cut-and-fill activities associated with site preparation for production facilities. Pipeline river crossings will increase sedimentation as they are buried beneath the streambed. Construction of the pipeline could alter the stream channel profile, creating a logjam effect. Elevation of the pipeline (use of a suspension bridge or similar design) can mitigate

this impact but causes a visual problem. The impacts of sedimentation and mitigations are covered in the Water Quality section of Chapter III.

b. Surface Water Contamination

Fluids lost to the environment from leaks or spills during production operations will impact surface water quality. Oil, brine, treating chemicals and acidizing or fracturing fluids are of concern. The magnitude of water contamination depends upon the volume of fluids lost, the local geography and the composition of the fluid.

The impacts from oil and brine spills, and measures used for cleanup and restoration, are discussed in the Water Quality section of Chapter III. Leaks and spills can occur from equipment and facilities used to produce and transport oil and dispose of brine. For example, field gathering lines, separation and treatment equipment, tank batteries and pipelines are all susceptible to leaks. Railcars, tank trucks and barges or tankers may be involved in a collision or other accident, resulting in a spilled load. Pipelines and storage tanks used for the disposal of brine in reinjection wells can leak.

Corrosion is a leading cause of equipment failure. Production equipment which is in contact with production fluids before treatment is particularly susceptible to corrosion. Hydrogen sulfide and brine are corrosive and attack equipment from the inside. Some areas have naturally corrosive soils, which will attack pipelines from the outside. The use of protective measures such as special alloy metals and protective coatings on production equipment, and the addition of corrosion inhibitors to production fluids when necessary, can mitigate impacts from corrosion induced leaks.

Periodic inspections and regular maintenance of production equipment can help to prevent as many accidents as possible. The use of secondary containment, berms, around tank batteries can help to contain spills should they occur from storage tanks. Storage tanks used for oil and brine can have automatic flow shut-off valves to prevent overfilling. Safety valves can be installed in the well or on the wellhead to provide protection against accidents resulting from high pressure. And most important, an up-to-date SPCC plan should be in place.

Transport of oil by tank truck is inherently much riskier than transport by pipeline. The probability of accidents occurring which result in a spilled load are much higher. To mitigate impacts from spills during transport, methods other than trucking should be encouraged whenever available or practical.

Shipping of oil will result in surface water contamination in the ocean, rivers and harbors. Spills can occur at shipping terminals during loading or fueling operations. Wetland areas are particularly vulnerable because of their important ecological role, the tendency for oil to accumulate and the high traffic level in rivers just upstream or near the coast. The greatest volume of oil lost in the ocean which may wash ashore is not a result of accidents, but of the routine tanker operation seawater deballasting. A number of mitigation measures are available to

prevent discharge of oily water ballast which can impact wetland or shore areas in parks, including cleaning of tanks at the unloading terminal, retaining ballast onboard for onshore treatment and refinements to the technique of loading oil on top of slop oil remaining in the tank after ballast handling or tank cleaning have been completed.

Disposal of brine in evaporation or percolation ponds or in surface waters such as lakes or rivers can impact surface water quality. Ponds can overflow from excess pumping or high rainfall and can suffer failure of a containment wall, resulting in a loss of the contents. The brine will impact the water quality until the water body is physically flushed of the contaminated water by new influent. Drinking water supplies can potentially be interrupted. Open evaporation ponds should not be allowed in units of the National Park System. Brines should be stored in tanks until it can be transported out of the park for disposal or reinjected into a nearby disposal well. ReInjection of brine can mitigate impacts from disposal on the surface. This topic is discussed in the next section on groundwater quality.

Fracturing fluids may be composed of a base fluid, such as crude or refined oil, freshwater, brine or acid, to which chemical additives are introduced at the well site. Cleanup of fracturing fluid spilled during transport to the site will be concerned with the problems of handling the base fluid rather than the chemically treated fluid. Base fluid spills can be handled in the same manner as any other oil or brine spill. Spills of undiluted additives can contaminate surface waters in two ways. Additives which are inherently toxic will directly impact water quality. Many of the additives, however, are nontoxic but add to the biological/chemical oxygen demand of surface waters as they naturally biodegrade. Detailed information on the toxicity of particular compounds can be found in a reference volume such as "Dangerous Properties of Industrial Materials."

Oil based fracturing fluids are returned to the surface with crude oil when production begins. Their strength will be depleted due to dilution or from chemical changes. Since the oil is collected and sold, there will be no disposal problem. Water based fracturing fluids are also returned to the surface with crude oil when production begins, but are separated from the oil for recycle or disposal. Proper containment and disposal are required to mitigate impacts to surface waters. The fluids may be directed to the storage tanks and held until they are injected into a disposal well. As an alternative the fluids can be trucked offsite for treatment in a wastewater treatment system. Treatment methods include skimming of oil and activated sludge biodegradation (methods used by a typical municipal wastewater treatment system performing primary and secondary treatment).

Acids used for well treatment can be spilled during transport to the site or delivery into the well. Addition of lime or other caustic material (NaOH) and dilution with fresh water can mitigate the impacts of acid spills. The addition of caustic may be required to raise the pH to a neutral level, and the dilution with water is required to lower the total dissolved solids content to acceptable water quality levels. As much of the neutralized acid as possible should be vacuumed up before dilution

water is added. Particular care should be taken with formic acid (a commonly used preservative) because of its strong biological effects.

Following an acid workover, spent acids are produced at the surface. The fluids will be high in dissolved solids, somewhat similar to brine. Spent hydrochloric acid will have a high chloride content. The reaction products of hydrofluoric acid are various forms of fluorosilicates. Residual fluorides in spent hydrofluoric acid fluids have the potential to seriously contaminate surface waters due to the very low limits allowed in drinking water (the Maximum Contaminant Level is between 1.4 and 2.4 mg/l, depending upon the temperature). Acetic acid yields acetates of calcium, sodium or aluminum, and formic acid yields formate compounds. Acetate salts and degradation products of formate compounds are relatively innocuous. Fluids produced following an acid workover should be held in storage tanks until they can be disposed of in an acceptable disposal well or trucked offsite for treatment in a wastewater system to mitigate impacts to surface waters. Treatment methods may include pH adjustment, flocculation, clarification of residual acid and evaporation or reverse osmosis for dissolved solids such as chloride.

Acid inhibitors may be organic or inorganic compounds. Organic inhibitors are largely adsorbed by the formation rock and not returned to the surface. Those which are returned can be treated as any other organic material in wastewater. Inorganic inhibitors are arsenic compounds and may be used in concentrations up to 20,000 ppm. Arsenic is persistent in the environment, bioaccumulative and highly toxic to life forms dependent upon the surface water. The arsenic will be present in the spent acid at the same concentration as in the raw acid. For these reasons, both raw acids and spent acids containing arsenic inhibitors should be handled and disposed of with environmental concern in mind. They require removal from the environment and treatment if spilled to mitigate impacts to surface waters.

Demulsifying and wetting agents are organic compounds. As with other organic materials, they are nontoxic and will impact surface waters by raising the biological/chemical oxygen demand as they naturally degrade.

Production chemicals include corrosion inhibitors, scale preventers, paraffin solvents and oil treating compounds, all of varying degrees to toxicity. Since the toxicity of production chemical and stimulation additives varies widely, knowledge of the chemical compounds present at the well site will expedite cleanup procedures in the event of surface water contamination. Records of chemicals and additives used in production or stored onsite should be required in the SPCC plan. This inventory could help mitigate impacts in the event of a fluid loss.

In addition to losses of crude oil, fuel oil used to power engines can also leak or be spilled. Residual oils (No. 6), often used on tankers, and distillate oils (No. 2), often used for large stationary engines, are increasingly more toxic than crude oil.

c. Groundwater Contamination

Groundwater contamination, like surface water contamination, results from leaks or spills of well fluids. They may escape through the wellbore virtually unnoticed into the environment, potentially polluting freshwater aquifers. Or they may percolate through the soil from spills or improper disposal on the surface.

Proper well casing, cementing and completion techniques can help mitigate impacts of fluid loss through the production wellbore. It is important to isolate freshwater aquifers from brine or petroleum bearing strata when the well is completed for production. Casing and cementing of wells is discussed in Chapter III. Periodic pressure testing of the well can identify problems with the casing and cement which may develop during the productive life of the well. Well servicing or workover operations including recementing the casing can correct problems identified by the pressure testing.

Disposal of brine in evaporation or percolation ponds can impact freshwater aquifers. Leaching of soluble salts through the soil into drinking water supplies can contaminate the water, spoiling it for use. Because of the extremely slow movement of groundwater and the high cost of treatment once it has become contaminated, the impact will be more or less permanent. Prohibiting the disposal of brine in ponds can mitigate this impact.

Pipelines and surface structures used to convey and store brine for disposal can leak, with the subsequent leaching of soluble salts contaminating groundwater. Periodic inspection and maintenance of the disposal equipment can identify corroded or leaking parts and allow for repair before leaks become serious.

The use of injection wells for the disposal of brine, while the best alternative available, can impact freshwater aquifers if operations are conducted carelessly. The reinjected water can contaminate groundwater supplies in several different ways. The formation selected for disposal should not contain usable water or lie above fresh or treatable water aquifers. The formation should be separated from usable groundwater by a sufficiently impermeable and thick sealing formation to prevent brine migration through natural faults and fractures in the rock. Disposal wells themselves can allow brine to escape from the proper formation if poorly designed or constructed. Brine can possibly leak through the casing if it has become corroded, or up through the wellbore alongside the casing if cementing was inadequate. Improperly abandoned wells in the area can also serve as a conduit, allowing formation fluids to mix or allowing brine to escape on the surface.

In order to prevent contamination from leaking wells, the disposal and overlying formations should be thoroughly evaluated for their suitability to accept and contain the injected brine. The well should be constructed with sufficient casing and cement. The casing should be protected against corrosion so that the injected brine does not leak out through the wellbore. If abandoned oil wells are proposed for use in the

disposal of brine, it is necessary to determine their suitability before use.

Acidizing or fracturing fluids which are spilled on the surface and inadequately cleaned up may impact groundwater by percolating through the soil. Mitigation measures for the protection of surface water quality will also protect groundwater quality.

3. Fish and Wildlife

The effects of drilling operations on fish and wildlife vary immensely because of the diversity of animal species and their unique habitat needs. Alterations in and loss of habitat may impact their populations. Virtually any of the impacts to soil and vegetation, water quality or noise will also impact fish and wildlife habitat. There are some common effects, and they are discussed below.

Habitat loss or damage can result from any aspect of production operations. Clearing, grading and cut-and-fill activities associated with site preparation and pipeline construction will result in a long-term, if not permanent, loss of habitat. Increased sediment loads from eroded soil alter streambed profiles which will impact fish resident and spawning habitats, and indirectly affect fish populations from impacts to aquatic insect producing areas. Production operations can also impact fish and wildlife habitats in other ways. Noise from traffic, worker activity or pipeline pumping/compressor stations, as well as the presence of people, will frighten wildlife. Night lights used during emergency maintenance and spill response activity taking place after dark can disrupt wildlife behavior. Aboveground pipelines can interfere with migratory or other behavior habits of wildlife.

Any of the mitigation measures for soil and vegetation, water quality or noise will also mitigate impacts to fish and wildlife. In addition, pipeline routes and tank battery locations can be specified. This could protect habitats of rare and endangered species, riparian zones and wetlands that are critical fish and wildlife feeding, migration and breeding areas. Limitations on nonemergency maintenance can also be used to mitigate habitat disruptions during critical seasons such as migration, breeding/spawning and winter stress periods, and after dark.

Accidents occurring in a producing field can adversely affect fish and wildlife either directly or by damaging habitats. For example, additional roads and vehicle travel will not only increase harassment of animals, but it may also result in accidental deaths and injuries due to collisions. Well fluids accidentally lost to the environment can impact fish and wildlife. Spilled oil will coat birds, killing them. Oil and brine can spoil the drinking water source of wildlife and are toxic to fish. Aquatic life is affected by components which are relatively water soluble, and by the tendency of oil to destroy the insulating and waterproofing qualities of the feathers of waterfowl or seabirds. Ecosystems dependent upon surface waters will be overwhelmed with even a small quantity of oil reaching them. Severe impacts to microorganisms, fish and wildlife are possible. For small streams, this may be as little

as one gallon. For large streams and rivers, a barrel or more may go unnoticed.

The construction of roads in areas previously difficult to reach may also impact fish and wildlife by allowing easy access to visitors or hunters in those units where hunting is allowed. Rare and endangered species may be affected, both directly and by changes in their prey or predator populations. Installation of lockable gates on newly constructed access roads may help mitigate these impacts.

4. Air Quality

National Ambient Air Quality Standards and any state or local standards which exist apply to production operations. It is the responsibility of the applicant to determine if an area is in attainment for the criteria pollutants (oxides of nitrogen, sulfur dioxide, particulate matter, carbon monoxide, nonmethane hydrocarbons, ozone and lead) and whether the activity is subject to regulation by Prevention of Significant Deterioration or New Source Review requirements of the Clean Air Act. The NPS will need to know the existing air quality in the area proposed for production in order to determine if additional emissions will be a significant impact.

Production equipment will be a source of fugitive light end and volatile hydrocarbon emissions. Odors, especially if the oil or gas is sour (high in sulfur), may be present. Wellheads, field gathering lines, separation and treatment equipment, tank batteries, pipelines, pumping/compressor stations and enhanced recovery equipment can all leak hydrocarbons. Flanges, valves and seals of all kinds are susceptible to leaks. While each individual leak may be almost imperceptible, together they all add up. Periodic inspection and regular maintenance can mitigate hydrocarbon emissions from chronic leaks and large spills.

In addition, all of the above equipment has the potential for being a point source of emissions, i.e., light end and volatile hydrocarbons separating from oil during handling which is released as a waste. Providing for collection of these gases can not only mitigate a significant quantity of hydrocarbon emissions, but conserve a valuable energy resource as well. The gases can be condensed or reintroduced to the headspace of a storage tank by a vapor recovery system, or routed to a natural gas field gathering line.

Often in the early stages of a producing field, a natural gas pipeline will not have been developed. Hydrocarbon emissions may be released as a waste gas, as previously described. One alternative available to mitigate this impact is to route these gases to a flare. Flares will reduce the amount of hydrocarbon emissions, but are themselves a source of combustion products including oxides of nitrogen and sulfur. Smokeless flares use steam or air injection to create turbulence in the combustion zone, increasing combustion efficiency and reducing emissions. Another, better alternative is to reinject natural gas and other volatile hydrocarbons back into the producing formation. This will eliminate emissions and help to maintain reservoir pressure, which will enhance the

production of oil. The gas will still be available for production if a gas pipeline is constructed at a later time.

Air pollutants generated during production include particulate dust from vehicles traveling on unpaved access roads and around production facilities. Particulate dust introduced into the atmosphere from unsurfaced roadways and work areas can be limited by closing and rehabilitating unneeded roads and production facilities, placing speed limits on the roads and paving or graveling the roads and production facility sites. Site preparation and pipeline construction during especially dry and windy conditions can also be curtailed.

Criteria pollutant emissions are generated by vehicle and stationary engines used in production operations. Emission factors found in EPA publications (AP-42 or AEROS Manual Series, Volume V) can be used in conjunction with the expected number of vehicle trips to estimate emissions once project specifics are known. To find appropriate emission factors, it is necessary to determine the number, type and size of the engines to be used in the various production facilities and the type(s) of fuel required. The size of the work force and the number of miles of paved or unpaved road they travel from living and supply areas to the field must be known. The estimated duration of production activity and whether oil or gas is being produced are also factors. Maintenance and use of all applicable pollution control devices on internal combustion engines and fuel storage tanks will minimize environmental effects.

Emissions of H_2S can endanger the health and lives of the production crew and nearby population. Table III-4 in the previous chapter shows the toxicity of H_2S gas for various concentrations and lengths of exposure. A time weighted average of 10 ppm over an 8-hour workday is considered a safe level for personnel working onsite. H_2S concentrations of 1,000 to 10,000 ppm in oil or gas are not uncommon, and up to 270,000 ppm are known. Since a well may be capable of producing 100,000 ft³ or more of gas per day, then it is easily seen that large quantities of H_2S are potentially available for release. The Pasquill-Gifford equation is used to determine the radius of exposure of a given concentration for individual well flow rates and H_2S concentrations (see "Drilling and Operating Oil, Gas, and Geothermal Wells in an H_2S Environment" for nomographs used to calculate these values). H_2S will volatilize from oil and accumulate in the headspace of storage tanks. The use of floating roof tanks or vapor recovery systems can keep the H_2S dissolved in the oil, preventing emissions and exposures to production personnel. The H_2S can then be safely removed and handled in the refinery.

Steam generators burning crude oil enhanced during recovery of heavy oil are a significant source of criteria emissions, particularly oxides of nitrogen. The use of selective noncatalytic reduction (ammonia injection) is an emerging technology which may prove effective in mitigating NO_x emissions from steam generators and other stationary sources involving fuel combustion.

Fires and accidents occasionally occur in a producing field, causing smoke and ash generation. Contingency planning and preparedness can help mitigate impacts from fires.

5. Aesthetic Quality

Disruption of surface vegetation for roads, the well site and pipeline routes is a source of visual impact. Unsurfaced roadways and tank battery areas will turn into a muddy quagmire during spring thaw or in wet weather from the heavy traffic. Areas of severely compacted soil often will not revegetate. Roads, tank batteries and pipeline routes should be restricted to areas which are not highly visible to mitigate the impact.

Production equipment and activities will cause visual impacts in otherwise nonindustrial areas. These include wellhead equipment, pumping equipment, workover rigs, separation and treatment equipment, storage tank batteries, areas of disrupted vegetation from oil and brine spills, pipelines, electrical transmission lines, waste gas flares and enhanced recovery equipment such as steam generators. They could be visible for miles and will contrast with the natural surroundings. Suggested tank battery site and pipeline route locations may be in areas of parks receiving little use by the public, and in favorable topographical locations (in canyons as opposed to hilltops or ridgelines). Mitigation measures can include the construction of vegetated berms around production facilities to obscure them from view using topsoil moved during site preparation. Also, facilities can be screened with trees and shrubs.

Refuse and other debris such as survey stakes, packaging, broken or unusable materials or equipment, personal litter, etc., can accumulate in producing fields. Requiring good housekeeping throughout the life of a producing field can mitigate this impact.

Mitigating measures in practice are quite variable because of the diversity of oil and gas activities and the assortment of visual management objectives. The following are several examples of different possible visual management objectives for an area, and how the visual effects of oil and gas production activities could be mitigated to comply with each particular objective.

- o The retention management objective limits activities to those that are not visually evident. One way to accomplish this (and mitigate the effects) might be to create visual screens around oil and gas production facilities so that these points are not evident.
- o The partial retention objective requires that all facilities be visually subordinate to the characteristic landscape. This might be accomplished by specifically designed roads, temporary roads, etc., that do not visually dominate the landscape.
- o The modification objective allows production facilities to visually dominate the original characteristic landscape, but their visual characteristics must blend with the landscape. This could be accomplished through use of appropriate equipment such as horizontal treaters as opposed to verticle

treaters, structures and colors that are in harmony with the landscape.

- o The maximum modification objective allows production facilities to visually dominate the landscape but requires that they conform to the background scenery. This may require limitations on the size and contrast of activity effects.

6. Noise

Production operations contribute noise from a variety of sources. Noise from well completion activities includes truck traffic and the pumps and engines required for acidizing or fracturing. Beam pumps used to produce oil will generate noise; the level is dependent upon the type of prime mover used. Although noise levels from internal combustion engines are highly variable, electric motors are generally quieter (approximately 75 to 80 dBA). Workover rigs can be as noisy as a drill rig, about 85 dBA at a distance of 100 feet.

Considerable traffic will be associated with installation, operation and maintenance of production equipment. For example, gas treatment facilities can be quite noisy, generating levels between 110 and 120 dBA. Large equipment will require large trucks for delivery, which are inherently noisier than smaller trucks or passenger vehicles. Construction of oil and gas pipelines will be noisy due to the use of heavy equipment and associated truck traffic. Bulldozers used for pipeline construction and other site preparation work generate approximately 80 dBA at a distance of 50 feet. Pipeline pumping/compressor stations generate a substantial amount of noise from the large engines and pumps.

The transportation of oil by truck or rail generates noise. At a distance of 100 feet, a locomotive will generate approximately 100 dBA, with the rest of the train generating 76 dBA. Spill response activities include vehicle traffic and possibly heavy equipment use, which are additional sources of noise. Equipment used for enhanced recovery, such as a pump used for waterflooding, or a steam generator, will generate noise. Roads and railways are linear sources of noise, as opposed to production facilities, which are point sources.

Many of the above sources of noise are intermittent and sometimes rarely generated. Others, however, are continuous. Beam pumps, pipeline pumping/compressor stations and field treatment equipment and engines all run continuously. Vehicle traffic, while occurring on a continuing basis throughout a producing field, will be intermittent at any one place. And pipeline construction activity, although intense, lasts only for a short period at any one place and occurs only once for each line.

Construction of wood fencing or planting of vegetation around production facilities can prevent many sources of noise from being heard. All engines should be muffled to reduce noise levels. Small motors or pumps can be fully enclosed. Restriction of noncontinuous sources of noise such as pipeline construction or installation of production equipment during heavy park visitation periods can mitigate noise impacts.

Suggested tank battery site and pipeline route locations may be in areas of parks receiving little use by the public. These practices are quite common in urban areas, and may be desirable in many areas of the national parks as well.

7. Geological Features

Impacts on geological features by oil and gas production operations can be similar to disturbances caused by seismic or drilling operations. But many of the impacts associated with production may be more severe or of longer duration as shown below.

Delicate formations, such as balanced rocks, natural arches or spires can be weakened by the ground vibrations generated by the earthmoving or blasting during the construction of a tank battery site or pipeline. Trucks will move throughout the production field to deliver equipment, perform maintenance, respond to spills and haul oil. The trucking will create vibrations near the access roads. Hard, rocky ground will transmit more vibrations than sandy or soft soils.

Roads and facilities should be located as far away as possible from rock formations or other geological resources that may be sensitive to damage from ground tremors. A quarter to a half mile buffer should be adequate. Also, blasting and use of explosives should be prohibited or limited.

Deposits of collectable minerals and rocks and petrified wood can be destroyed or damaged if the deposits lie within the proposed disturbance zone. Additionally, the road to a well site can allow production personnel and park visitors access to resources that were not easily reached prior to the building of the road. NPS base maps and data should be reviewed to identify the areas where these resources exist. Reconnaissance of the area should identify deposits and possible protection measures. Once again, the best protection is avoiding the resources by relocating the road, tank batteries and pipelines.

If proximity to the resources cannot be avoided, access can be limited by locking or guarding the entrance to the road. If the outcrop or occurrence is small, fencing the resource or posting may educate the prospective collector to leave the resources in place.

8. Cultural Resources

Cultural resources are sites, structures, objects and districts significant in history, architecture, archaeology or culture. Impacts on them by oil and gas production operations can be similar to disturbances on geological features. Any surface disturbing activity such as site preparation or pipeline construction may impact nearby cultural resources through disruption of soil and vegetation, increased erosion, sedimentation, surface instability and ground vibrations. Impacts can be mitigated by any of the mitigation measures for the conservation of soil and protection of vegetation.

Known artifacts can also be destroyed or damaged if they lie within the proposed disturbance zone. The road to a well pad can allow production

personnel and park visitors access to resources that were not easily reached prior to the building of the road. Once again, the best protection is avoiding the resources by relocating access roads, tank batteries and pipelines. If proximity to the resources cannot be avoided, access can be limited by locking or guarding the entrance to the road. If the area is small, fencing the resource or posting may educate the prospective collector to leave the resources in place.

If cultural resource sites are discovered that will be impacted, mitigative measures specific to the project/cultural resource site should be designed in cooperation with the State Historic Preservation Office, Advisory Council on Historic Preservation and NPS Historical Specialists. Such measures might involve modification of the project, recovery of the cultural resource by excavation or other means or a combination of these.

K. Summary Tables

Table IV-1 presents the major activities associated with production operations and the potential impact on each environmental resource value. Table IV-2 presents possible mitigation measures for the potential impacts.

T₂ 2
Mitigations for Potential Environmental Impacts
Associated with Production Operations

	Soil and Vegetation	Water Quality	Fish and Wildlife	Air Quality	Visual Quality	Noise	Geological Features	Cultural Resources
Well Completion and Treatment	Grade and rip compacted soils. Use lined pits or tanks to contain treating fluids.	Design pad without steep erodible banks. Build berms and containment dikes. Use lined pits or tanks.	Reclaim as much pad and road as possible. Limit access to area.	Water down roads in dry seasons. Contain well gases.			Do not allow heavy equipment near delicate features.	Do not allow heavy equipment near sensitive resources.
Production Facility Preparation	Design cut and fill with low slopes. Save and use topsoil on edges of pads or roads. Reseed.	Do not allow construction next to streams. Use settling ponds. Design berms with low slopes	Limit work during critical breeding periods. Limit size of pad. Limit access.	Water down pad during dry season.	Hide production site behind hills or vegetation. Maintain clean, small sites.		Do not allow heavy equipment near delicate features. Limit access to area.	Do not allow heavy equipment near sensitive cultural resources. Limit access.
On-Site Separation, Treatment, and Storage	Design adequate berms. Monitor equipment frequently. Repair drips immediately.	Frequent monitoring and repairs of leaking equipment.	Frequent monitoring and repairs of leaking equipment.	Limit emissions from tank batteries by not venting. Repair any gas leaks.	Hide production site behind hills or vegetation. Camouflage site with neutral paint.	Muffle engines. Use insulated buildings. Use noise barrier fences.		
Disposal of Produced Water	Proper completion of injection well. Use of corrosion prevention. Frequent monitoring.	Use corrosion control techniques on pipelines. Frequent monitoring. Repair of pipelines.	Prevent leaks by frequent monitoring and replacement. Revegetate area.		Hide or camouflage.	Muffle pump engines. House equipment.		
Transportation	Grade and revegetate ROW with appropriate grasses or vegetation. Build runoff control ridges on steep slopes.	Proper road maintenance. Proper road installation. Frequent monitoring of pipelines. Replacement of old or leaking lines.	Speed limits. Screen truck drivers to ensure reliability.	Speed limits.	Hide or camouflage. Build roads or ROW's with bends to limit line of sight.	Muffle pump engines.	Do not allow roads or pad near delicate features.	Do not allow heavy equipment near sensitive resources.
Hazards								
Blowouts	Collect and properly dispose of brine or oil. Prevent blowouts with proper casing and cementing design and blowout preventers.	Prevent blowouts with adequate casing and cement and BOP. Contain fluids to tanks.	Prevent blowouts. Limit spread of well fluids or gas. Contain fluids to tanks. Flare gas. Immediate cleanup.		Prevent blowouts. Immediate cleanup.			
Fires	Contain gas and flammable liquids. Don't smoke near equipment.	Minimize erosion by replanting vegetation.	Contain and control gas and flammable liquids. Build berms around flare pits.	Prevent fires.	Prevent fires. Replant burned area.			
Hydrogen Sulfide	Properly case and cement well. Use H ₂ S resistant metal for pipes and well.		Flare or pipe gas containing H ₂ S off location to treatment facility. Fence and lock to prevent unauthorized access to equipment.	Pipe gas containing H ₂ S off location to treatment facility.				
Increased Recovery								

V. ABANDONMENT AND RECLAMATION OPERATIONS

The lifespans of oil and gas fields vary because each given field has unique characteristics. Such factors as reserves, reservoir characteristics, the nature of the petroleum, subsurface geology, and political, economic and environmental constraints all affect a field's lifespan from discovery to abandonment. The average life of a "typical" field is estimated to be 15 to 25 years. Abandonment of individual wells may start early in a field's life and reach a maximum when the field is depleted. Reclamation operations generally involve the filling of any pits, ditches and other excavations, the removing or covering of all debris and the restoring of the surface of the land and the access road to their former condition.

The following discussion addresses abandonment and reclamation planning, intermediate rehabilitation, abandonment operations, reclamation operations, and their potential environmental impacts and suggested mitigation measures.

A. Planning

Abandonment and reclamation planning begin with the access road and well site construction phase and last throughout the life of the well. The initial survey, design and development of proposed access roads, well locations and production pads affect the effectiveness of reclamation efforts. A planner must consider the following to design a reclaimable road or pad:

- o Minimizing steep hillside locations
- o Designing well pad axes or dimensions to best fit the topography
- o Minimizing special or unique erosion features
- o Returning aspect, slope, soil type, and depth of topsoil to the original conditions
- o Minimizing disturbance to natural drainage channels
- o Protecting watershed needs by special engineering requiring large drainage structures, bridges, etc.
- o Returning the vegetative cover to the original mix
- o Preserving sensitive habitat situations and ecogroups
- o Avoiding or preserving cultural and geologic sites

B. Intermediate Rehabilitation

Rehabilitation practices are employed in the transition from the drilling phase to production activities to protect the surface and enhance the general appearance of the producing site during the life of the well.

After the drilling phase is completed, the surface, including the reserve mud pit, is restored to the requirements of the surface management agency. The reserve pit (the part of the mud pits in which the excess drilling fluids, water or drill cuttings is stored) should be pumped dry and filled with soil material stockpiled when the site was prepared. Usually two weeks is allowed for drill cuttings and residual drilling muds to settle out of the liquid before the pit is pumped dry. All drilling fluids are pumped out and hauled to a disposal facility. Residual cuttings and sludge are allowed to dry out and firm up before backfilling. A minimum of 4 feet of fill material is placed over the entombed reserve pit and compacted to at least 90 percent. Stockpiled topsoil is spread over the pit area. Drainage control is incorporated in the final landscape design to control runoff water over the reclaimed pit surface.

In park units, the reserve pit should be in metal tanks. The well operator should pump out the pits, allow the cuttings to dry and take both the fluids and the cuttings and residual drilling muds to an approved disposal facility.

The backslope is reduced to create a more desirable and compatible topographic configuration. Fill slopes are reduced to at least 2.5:1 (horizontal:vertical).

The pad dimensions required for drilling operations are reduced to a minimum size required for production. The minimum size is determined by what type of wellhead and production equipment is needed on the pad. A site with a simple pumping unit for oil or Christmas tree for gas will need an area only large enough for a pickup truck to turn around the wellhead. If future workovers are projected for the well, an area at least 60 feet by 40 feet may be needed. If treating, metering or storing equipment will be on the pad, the minimum spacing between the wellhead and treating vessels and treating vessels and storage tanks is based on state and Occupational Safety and Health Administration (OSHA) requirements. These requirements minimize the potential for fire spreading from one piece of equipment to another.

Once the production equipment has been set up and any pits reclaimed, a portion of the stored topsoil is spread over pad areas not needed for production. The remaining top soil is stored with a layer of vegetation to help resist wind and water erosion.

Spillage and containment dikes are constructed around the wellhead and around the production facility, including the heater/treater, and the tank battery. The dikes should be constructed with an impervious clay-type material and covered with a layer of pea gravel or scoria. The volume inside the dike area should be large enough to contain two times the volume of the storage tanks. All discharge valves or truck loading valves should be located inside the dike area.

Various maintenance and routine operations are also involved. Drainage channels should not be plugged with road fills or with side cast materials. Culverts and other drainage structures should also be maintained and kept free of debris. Pipeline trenches and corridors should be maintained to prevent settlement and erosion. Flow lines to the heater/treater should be monitored frequently (monthly) to ensure that no leakage occurs.

C. Shut-in and Abandonment

When a well no longer produces an economic quantity of oil and the operator has no use for it, for example, conversion to a water injection well, it is plugged and abandoned. If the poor economic conditions are temporary, the well can be shut-in. The length of time a well can be shut-in before it is properly plugged varies from state to state. Some states mandate periods as short as three months, others have no time limit on how long a well can be shut-in. The NPS can limit the amount of time a well is shut-in with stipulation in the plan of operations.

Well plugging and abandonment requirements vary with the rock formations, subsurface water, well site, the well and the state regulatory authorities. The objectives of plugging a well are to: (1) seal any brine water zones, producing zones and lost circulation zones; (2) protect any minerals besides the oil and gas in the well; (3) stop fluid migration from one zone to another and (4) protect freshwater aquifers.

Generally, in a shallow (less than 2,500 feet) well, the hole should be plugged by filling it from top to bottom with cement. Different states have established widely different regulations for plugging. The Bureau of Land Management has established federal standards for plugging that are as strict or stricter than most states. Operators in park units should meet the BLM standards. Figure V-1 shows the following minimum locations of plugs:

Plug #1 - 50 feet cement at the surface, including the annulus area

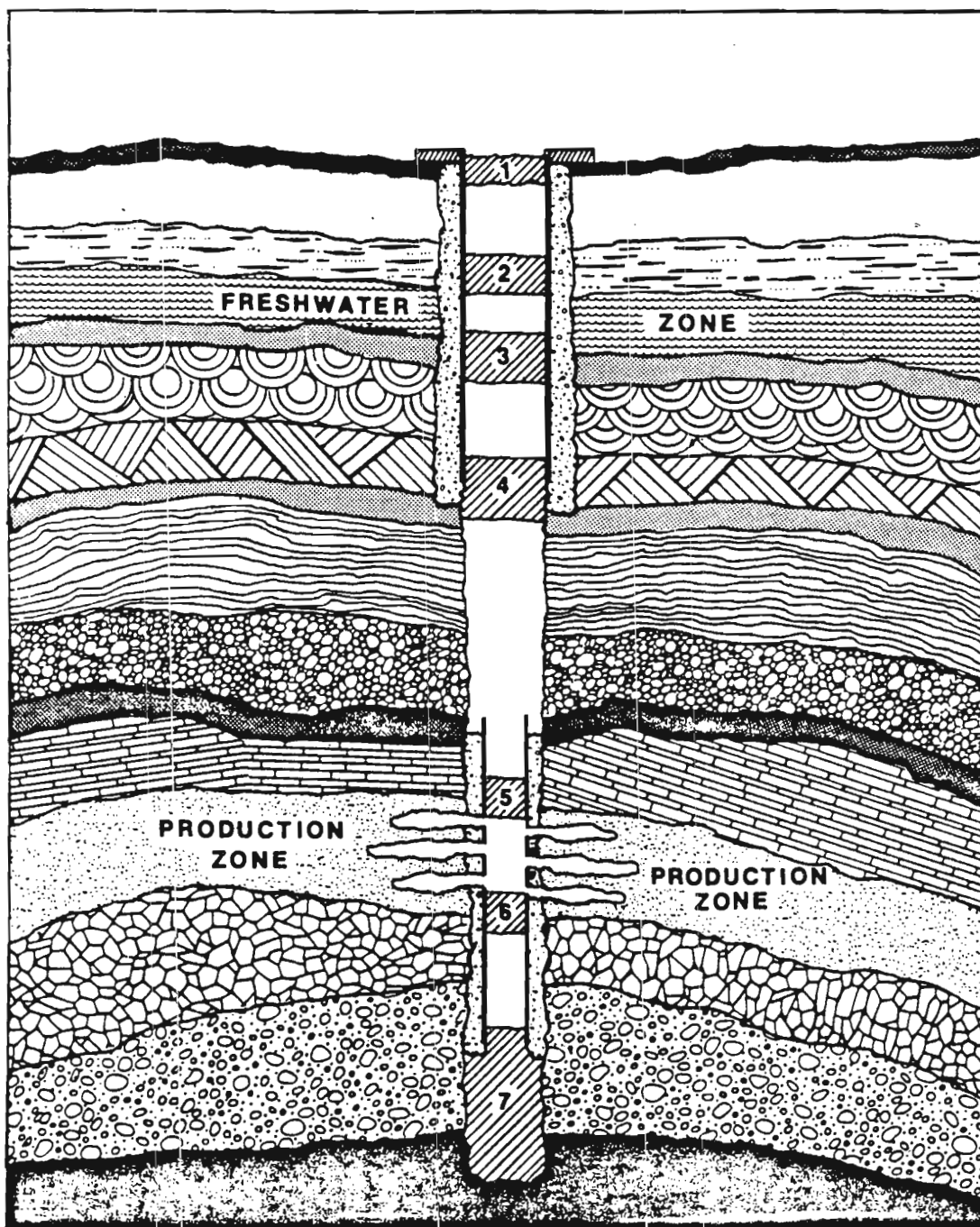
Plug #2 and #3 - One cement plug that extends from 50 feet above any fresh or treatable water zone through the zone to 50 feet below it or if the water zone is extremely thick two 100 feet plugs, one that extends 50 above and one that extends 50 feet below the zone

Plug #4 - A plug that extends 50 feet above and below (100 feet total plug) the base of the surface casing in a well where there is no production or intermediate casing

Plug #5 and #6 - A plug that extends from 50 feet above a productive zone, a lost circulation zone or an other mineral zone to 50 feet below the zone or if the zone is extremely thick two 100 feet plugs one of which extends 50 feet above the zone and one that extends 50 feet below the zone

Plug #7 - The bottom plug below a productive zone or zone of interest should extend to the bottom of the well

Diagram



SOURCE: Bureau of Land Management

Figure V-1 Cement Plug Locations in Abandoned Wells

Plug #8 - A cement plug every 3,000 feet

#9 - The space between the plugs should be filled with mud weighing a minimum of 9 pound per gallon

A pipe monument giving the location and name of the well is required unless waived by the surface managing agency. If waived, the casing may be cut off and capped below ground level.

Depleted producing wells are plugged in a manner similar to the procedures outlined above. Once the well is plugged, surface flow or injection lines are removed but buried pipelines are usually left in place and plugged at intervals as a safety measure. All wellhead, treating or storage equipment should be removed from the site. Foundations for equipment should be broken up and removed.

D. Reclamation

Several steps are involved in site reclamation, including site preparation, seedbed preparation, drainage and erosion control, erosion control treatment and access road rehabilitation. Appendix 1 presents key elements of a sample reclamation plan. Figures A-1 through A-3 in Appendix 1 illustrate typical reclamation site maps for a general situation, an abandoned well and a production facility.

Dozers and graders are used to landscape the several acres associated with each drill pad. The area should be reshaped to the original contours. If the site cannot be returned to the original contours, then a layout that will allow revegetation to take place and minimize erosion should be used. After grading the subsoil, the stockpiled topsoil will be spread. A complete discussion of soils management addressing soils analysis, materials handling, treatment and land surfacing can be found in "User Guide to Soils, Mining and Reclamation in the West", 1979. A detailed discussion of erosion control and watershed protection can be found in "A Procedural Guide for Oil and Gas Administration", 1983.

How the natural vegetation is grown on the site depends on the area. Some areas will naturally revegetate if left alone. In other areas, the land is mulched and seeded with a grass mixture to establish good growth. Usually a fence is erected to protect the site until revegetation is complete, particularly in range areas if clover is part of the seed mixture. A detailed discussion on revegetation addressing species selection, plant materials, planting methods, cultural treatments and monitoring can be found in "User Guide to Vegetation, Mining and Reclamation in the West", 1979.

E. Possible Effects and Mitigations

1. Surface Disturbance (Soil and Vegetation)

Compaction can occur from heavy equipment and vehicular activity in the abandonment phase. Damaging effects may be especially noticeable when they occur on surfaces where the topsoils are left intact.

Compaction impacts can be minimized by limiting the use of heavy equipment on easily compacted soils according to the season, weight and type of equipment, and duration of use. Compacted soil horizons can be ripped and revegetated as a rehabilitation measure.

Erosion will have the greatest effects with steep slopes. These will accelerate runoff and create severe erosion hazard zones. Vegetation may be unable to become established or to maintain a significant cover on slopes that approach the angle of repose of that site. Mitigation measures involve the reduction of backslope to between 1:1 to 2:1 (horizontal:vertical) and the reduction of fill slopes to at least 2.5:1. Also small terraces or elongated water barriers can be installed on all slopes after reduction. In addition, erosion control material, such as excelsior blanket, netting, straw or burlap, can be applied in critical areas.

Erosion will also have significant effects where mechanized equipment has disturbed the surface. These surface disturbance areas can include unpaved roadways and recontoured topsoil. Disturbed areas can be rehabilitated through mulching, surface manipulation, proper timing of topsoil placement and immediate establishment of vegetation.

Stability problems may occur during or as a result of surface recontouring. Impacts of surface hazards can be minimized by restricting developments to gentle slopes, or stabilizing the developments through topsoil compaction, surfacing, adequate drainage and revegetation of cut-and-fill slopes.

2. Water Quality

Exposed soil areas during reclamation involving grading and recontouring may contribute to erosion and increased stream sedimentation. Reduced water quality from sedimentation may be minimized by requiring construction of berms during reclamation to control erosion.

Possible sources of surface water contamination are leaks from mud pits and evaporation pits. Impacts from oil dumping may occur during the abandonment phase when all equipment is removed from the well site. Effects may be minimized by using a totally containerized mud system, or proper evaporation, and disposal of earthen mud pit contents. Impacts from oil dumping can be minimized by cleaning out the tanks or treating vessels before removal and properly disposing of the tank bottoms.

Groundwater contamination may occur from surface leaching and from the introduction of well fluids into deep groundwater aquifers. Near-surface contamination may occur during the abandonment phase at locations where mud pits and evaporation pits are closed. Improperly cemented or abandoned wells can allow hydrocarbons or brines to enter the well and get into freshwater formations, contaminating them. Near-surface contamination may be minimized by proper evaporation and pumping out of earthen evaporation and mud pits or the use of metal mud tanks. Deep groundwater contamination may be prevented through the proper design and placement of cement plugs for abandoned wells.

3. Fish and Wildlife

Some common effects for all fish and wildlife species may result from abandonment and reclamation activities. Contamination of surface waters entering riparian zones would have serious adverse effects on many wildlife species. These effects may be minimized by requiring the proper closure of evaporation and mud pits to prevent contamination of waters.

Noise associated with dozers and graders could disturb wildlife activities. Fatalities of wildlife could occur in rare instances due to accidents involving heavy equipment. Alteration of wildlife activities could occur with fencing of areas undergoing revegetation. Conflicts between wildlife and oil and gas operations may be minimized by ensuring rapid reclamation and revegetation of pad areas and temporary roads for wildlife use.

4. Air Quality

Heavy equipment and vehicles will continue to emit combustion related pollutants during abandonment and reclamation. Continued use of unpaved or unsurfaced roads and trails by the public will produce particulate dust in the area for years.

National ambient air quality standards as well as any state standards which may exist will apply to minimize effects. To mitigate the amount of particulates introduced into the atmosphere from access roads, the unneeded roads could be closed and revegetated.

5. Aesthetic Quality

As wells are abandoned and production facilities are removed, visual discord can be essentially eliminated. Some surface scars from roads and well pads may remain until revegetation occurs.

6. Noise

Abandonment and reclamation operations contribute noise from several sources, including well plugging, earthmoving and transportation. The various types of pumps used in well plugging can affect the noise environment. Pumps are usually powered by internal combustion engines. Earthmoving activities can involve grading and recontouring. Heavy dozers and graders can cause noise levels from approximately 80 to 90 dBA.

Car and truck traffic associated with abandonment and reclamation activities are also a source of noise. Cars will carry the work crews, and large trucks will carry well plugging equipment and supplies and earthmoving equipment and reclamation materials. Use of mufflers on engines will mitigate noise levels.

7. Geological Values

As wells are abandoned, production facilities are removed and access roads are less used, the potential damage associated with ground

vibration from large equipment and truck movement will decrease. Any additional construction during this phase that occurs outside previously disturbed areas, such as digging borrow pits for reclamation fill dirt, would have the potential for impacting geological values. The best protection is to avoid the resources by relocating the new construction area.

8. Cultural Values

No cultural resource sites should be discovered or impacted if the equipment used for abandonment and reclamation is confined to the previously disturbed area. As with drilling and production activities, cultural resources unearthed during the reclamation phase should be protected by stopping the work until mitigation measures specific to the site can be designed. Measures should be designed in cooperation with NPS Historical Specialists and State Historic Preservation Office. These might involve redesign of the recontouring plan or recovery of the cultural resource.

K. Summary Tables

Table V-1 presents the major activities associated with reclamation and abandonment operations and the potential impact on each environmental resource value. Table V-2 presents possible mitigation measures for the potential impacts.

Table V-1
Potential Environmental Impacts Associated with
Abandonment and Reclamation Operations

Environmental/Resource Value								
Operation	Soil and Vegetation	Water Quality	Fish and Wildlife	Air Quality	Visual Quality	Noise	Geological Features	Cultural Resources
Abandonment	Compaction and vegetation damage from heavy equipment. Erosion due to surface disturbance.	Contamination from mud and evaporation pits. Aquifer contamination from cross-formation flows.	Damage to habitat due to contamination, noise, and heavy equipment.	Increased particulates due to trail use. Criteria pollutant emissions from combustion engines.		Noise from heavy equipment and transportation vehicles.		
Reclamation	Compaction and vegetation damage from heavy equipment. Erosion due to steep slopes and surface disturbance. Instability from recontouring.	Increased sedimentation due to grading and recontouring.	Damage to habitat due to sedimentation, noise, heavy equipment and fencing.	Increased particulates due to trail use. Criteria pollutant emissions from combustion engines.		Noise from heavy equipment and transportation vehicles.	Disturbance while obtaining fill dirt.	Damage while obtaining fill dirt.

Table V-2
Mitigations for Potential
Environmental Impacts Associated with Abandonment and Reclamation Operations

	Soil and Vegetation	Water Quality	Fish and Wildlife	Air Quality	Visual Quality	Noise	Geological Features	Cultural Resources
Abandonment:	Limit equipment to previously disturbed areas. Scarify compacted soils. Limit steepness of slopes. Compact subsoils and fill material.	Do not allow pits in NPS units. Ask for lined pits or containers in areas adjacent to units. Properly dispose of muds and cuttings. Properly plug wells.	Properly dispose of fluids and tank bottoms. Muffle equipment. Limit equipment to established pads.	Establish lower speed limits to reduce dust.		Temporary situation. Have mufflers on equipment.		
Reclamation	Limit equipment to previously disturbed areas. Limit steepness of slopes. Minimize new cut and fill areas. Re-vegetate as quickly as possible.	Build temporary berms or settling ponds on edge of disturbance to collect sedimentation.	Use correct slope design and civil engineering principles to minimize sedimentation.	Establish lower speed limits to reduce dust.		Temporary situation. Have mufflers on equipment.	Obtain fill dirt outside NPS unit.	Obtain fill dirt outside NPS unit.

Appendix 1

Sample Reclamation Plan Elements Source - US Forest Service

o SITE-PREPARATION

REGRAIDING, SHAPING AND BACKFILLING

The work shall consist of regrading, shaping, and backfilling designated areas to stabilize the soil, reduce damage from sediment and runoff to downstream areas, enhance the visual quality, and improve wildlife habitat.

- . Regrading - Will be done with the final objective to return the disturbed area to a near original or normal contour.
- . Shaping,-discing,-scarification - The objective is to blend disturbed material to native material and to prepare site for topsoil replacement. The work is to be accomplished in a manner acceptable to the NPS representative in charge of the project.
- . Backfills-and-fill-construction - The work shall consist of constructing earthen embankments and other structures to protect disturbed area from potential erosion. Fill construction shall be done with horizontal lifts of not more than 6". Each lift will be compacted. The final layer will be smoothed to the satisfaction of the NPS representative.

Topsoil will be spread evenly over the entire disturbed area and shall be free of hard lumps, debris, or compacted material. The final objective is to have an acceptable surface for a seedbed.

Production Facilities: Site preparation will be required on all designated non-use areas and shall be so indicated on the reclamation site map.

Plug and Abandon Site: The entire disturbed area will be reclaimed to near original contours or as indicated on the plug and abandon reclamation site map.

SLOPE REDUCTION

The objective of slope reduction is to maintain a final slope gradient of at least 2.5:1 (preferred is 3:1) (horizontal:vertical).

o SEEDBED-PREPARATION

Primary objective is to restore disturbed surfaced left bare by construction projects, provide for the safe disposal of runoff water, and stabilize critical areas.

SOIL PLACEMENT

Use stockpiled topsoil only. No salt contaminated soil will be used in the final treatment.

All topsoil shall be replaced. Depth of topsoil will vary according to aspect. Recommended depth is:

South and west aspect - 4-6 inches
North and east aspect - 3-4 inches

SCARIFICATION

Replaced topsoil will be smooth and scarified to permit a planting depth of 1/4 to 1/2 inch. As a minimum, the depth of scarification should not exceed the depth of the topsoil.

PLANTING DEPTH

Planting depth will not be over 10 times the diameter of the seed. Normal depth will average 1/4 to 1/2 inch. Areas where mechanical seed equipment cannot be used will be raked in by hand.

SEED APPLICATION

All seeding will be with the contour to avoid vertical rills.

REPEAT APPLICATION

Areas where seeding was done after the recommended cutoff or areas that do not have adequate vegetation (stocking standards and sample conducted by range conservation specialists) near the end of the first growing season will be re-treated with a second application.

SEED MIXTURE

A site-specific list of seed mixtures will be identified. All seed is to be certified.

o DRAINAGE-AND-EROSION-CONTROL

SLOPE PROTECTION

Runoff berm or ditch should be constructed across the top of slope above the entombed reserve pit. Flow direction should be away from all disturbed areas. Do not allow runoff from diversion ditch to flow onto disturbed area.

WORKING SURFACE PROTECTION

Provide for a diversion channel or ditch to intercept surface runoff. Do not allow surface water to accumulate on the working surface. Provide some type of catch basin where intercept ditch

exits the working surface. Catch basin should be designed to hold oil and saltwater residue which might escape from containment dikes.

Install containment dikes around the tank batteries, treater, and production pipes from treater to tanks. Containment dikes should be sized to hold double the volume in the tanks or treaters. Install containment dike or berm around perimeter of pad.

CULVERTS AND DRAINAGE STRUCTURES

Protect inlets and outlets. Use riprap, erosion control blanket, plastic mesh, or other treatment.

o EROSION-CONTROL-TREATMENT

Primary objective: A temporary means to stabilize disturbed soil surface and aid revegetation until established to hold grass seed and soil in place until adequate cover is apparent.

EXCELSIOR BLANKET

Use on south and west aspects and severe slopes. Normally not required on slopes less than 3:1. Steeper slopes with fine sandy soil should be treated with excelsior blanket.

Blanket should be installed with the contour, starting at the bottom and working towards the top of the slope. Each blanket should overlap the previous blanket and staked firmly in place. Care should be used to ensure that the biodegradable plastic netting remains intact after installation.

DITCH MATTING

Install in ditch if gradient is two percent or more. Use in combination with hay bales. Set perpendicular to centerline of ditch.

HYDROMULCH/SEED MIXTURE

Use on roadside cut and fill slopes and in conjunction with excelsior blanket on extremely difficult steep slopes. Normally good success occurs on relatively cool and moist sites. Should not be applied on directly south or west facing aspects.

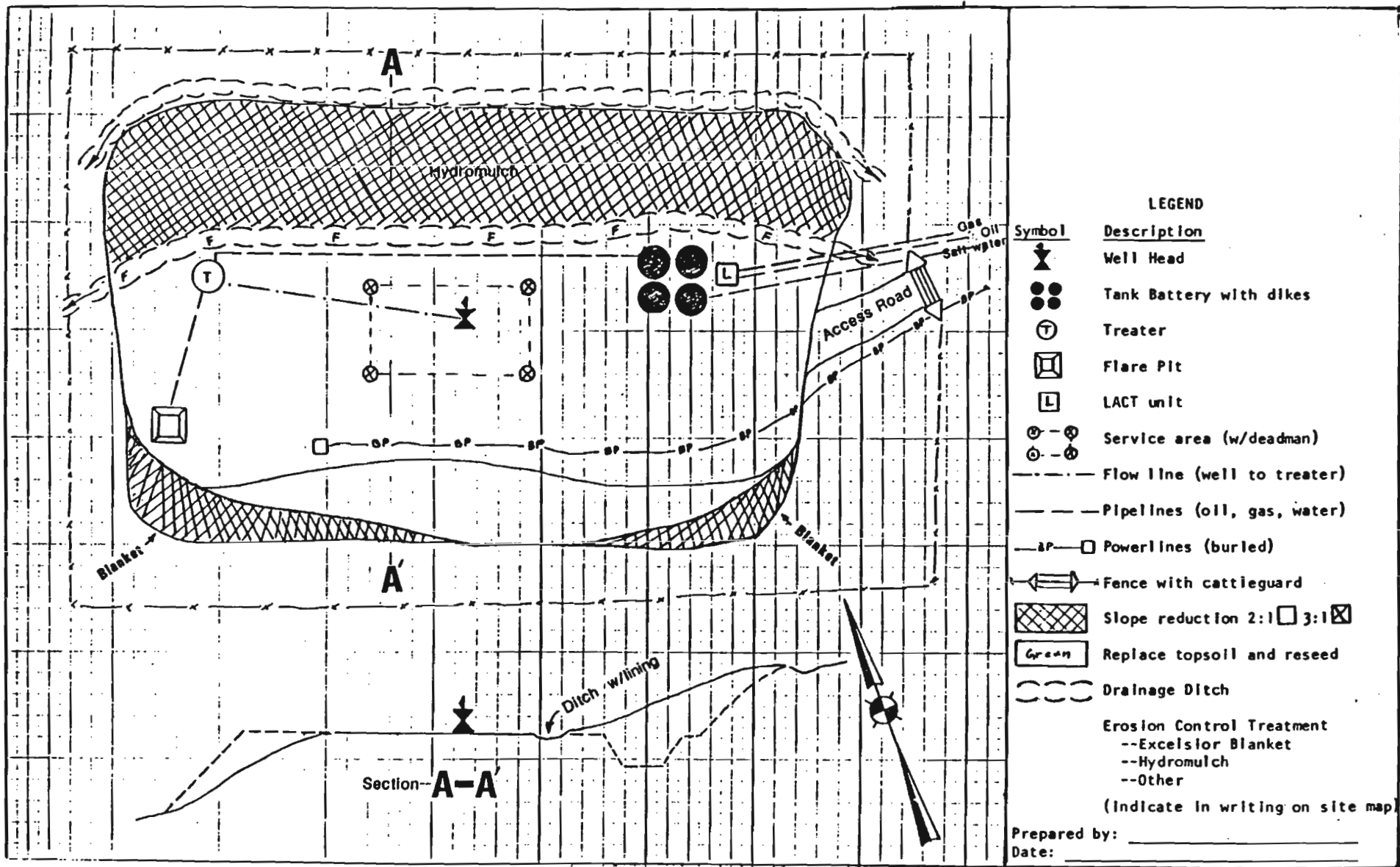


FIGURE A-1 TYPICAL RECLAMATION SITE MAP

SOURCE: USDA Forest Service. Reprinted with permission.

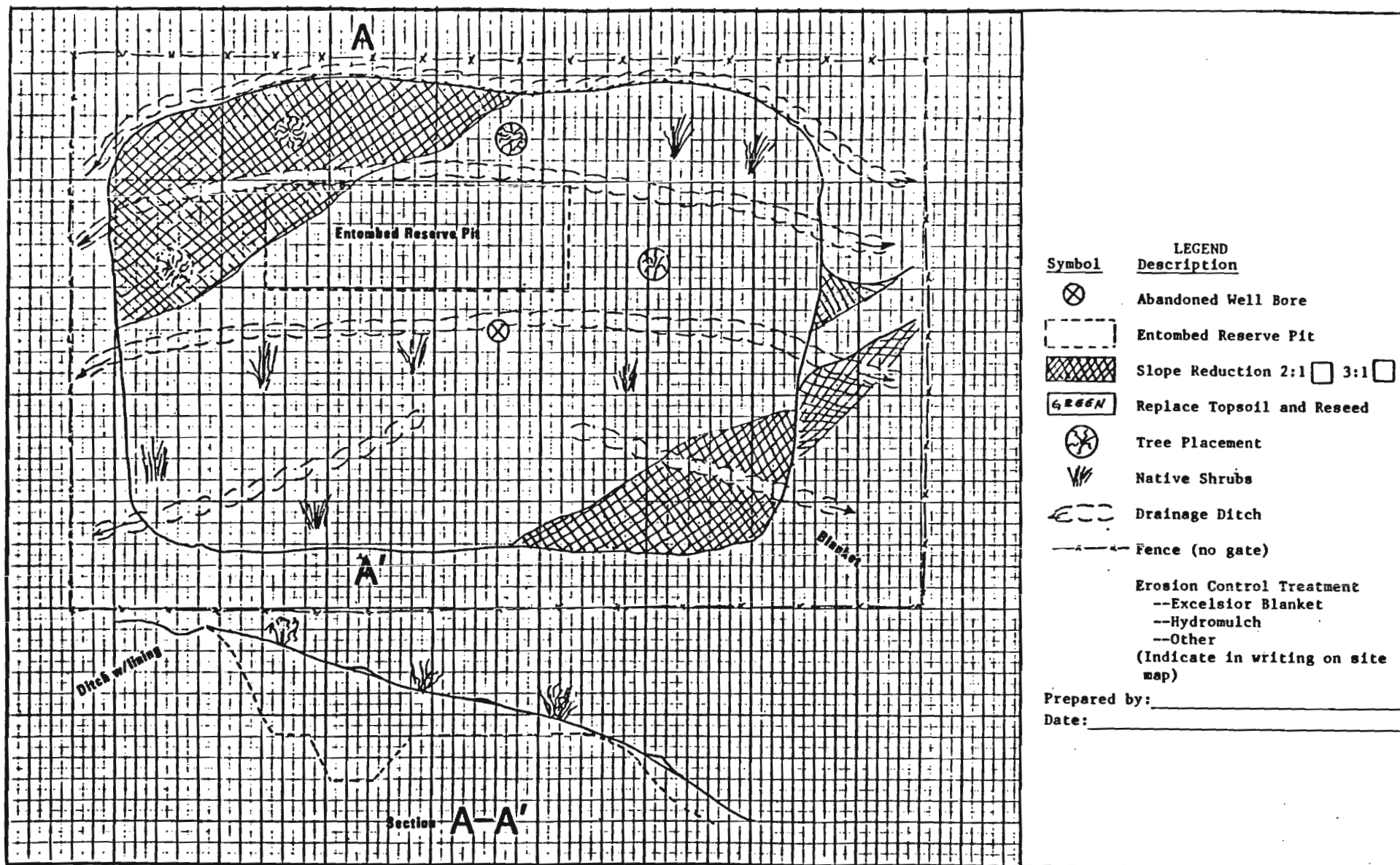


FIGURE A-2 TYPICAL RECLAMATION SITE MAP FOR AN ABANDONED WELL

SOURCE: USDA Forest Service. Reprinted with permission.

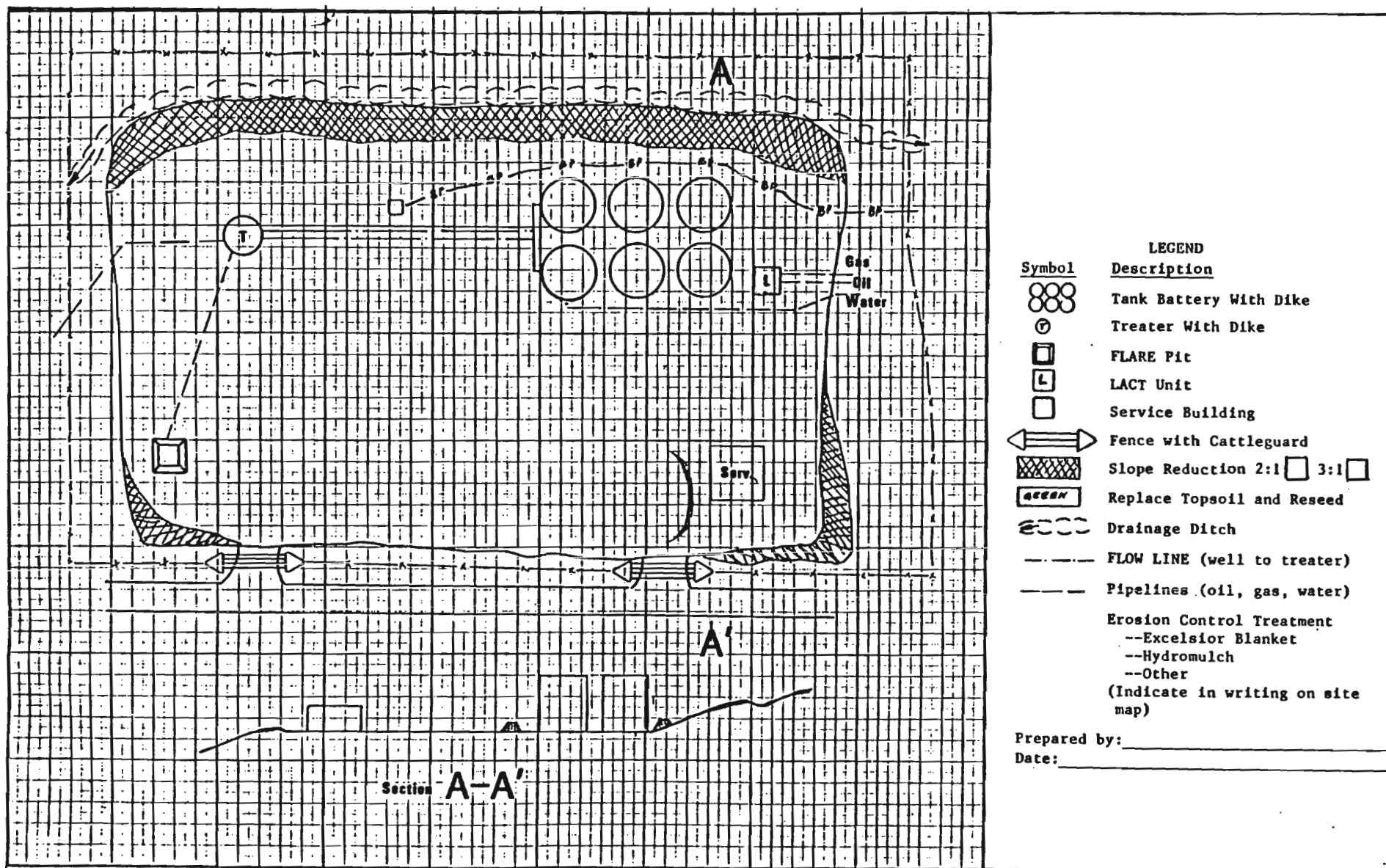


FIGURE A-3 TYPICAL RECLAMATION SITE MAP FOR A PRODUCTION FACILITY

SOURCE: USDA Forest Service. Reprinted with permission.

GLOSSARY

A

ABANDON. To cease producing oil and gas from a well when it becomes unprofitable. A wildcat well may also be abandoned after it has proven nonproductive. Several steps are involved in abandoning a well: part of the casing is removed and salvaged; one or more cement plugs are placed in the borehole to prevent migration of fluids between the different formations penetrated by the borehole and the equipment is removed.

ACIDIZING. The treatment of formations with hydrochloric or other type acids in order to increase production.

ANGLE OF DEFLECTION. In directional drilling, the angle, expressed in degrees, at which a well is deflected from the vertical.

ANNULAR BLOWOUT PREVENTER. A large valve, usually installed at the top of the blowout prevention stack, which seals the annular space between the pipe and wellbore or, if no pipe is present, seals the wellbore itself.

ANNULAR SPACE. (1) The space surrounding a cylindrical object within a cylinder. (2) The space around a pipe suspended in a wellbore, the outer wall of which may be the wall of either the borehole or the casing; sometimes termed the annulus.

B

BARITE. Barium sulfate, BaSO_4 ; a mineral used to increase the weight of drilling mud. Its specific gravity is 4.2 (i.e., it is 4.2 times heavier than water).

BARREL. A measure of volume, equal to 42 U.S. gallons.

BIT. The cutting or boring tool used in drilling oil and gas wells. Most bits used in rotary drilling are roller-cone bits. The bit consists of the cutting element and the circulating element. The cutting element consists of the cones and teeth which cut or chip away the formation rock. The circulating element permits the passage of drilling fluid, uses the hydraulic force of the fluid stream to improve drilling rates and cleans the bit of drill cuttings. In rotary drilling several drill collars are joined to the bottom end of the drill pipe column. The bit is attached to the end of the drill collar.

BLOWOUT. An uncontrolled flow of gas, oil or other well fluids into the wellbore. A surface blowout, or gusher, can occur when formation fluids enter the wellbore and steps are not taken to stop the entry of fluids and the fluid or gas escapes to the surface.

BLOWOUT PREVENTER (BOP). Equipment installed on the wellhead at surface level on land rigs and on the seafloor of floating offshore rigs to prevent the escape of pressure either in the annular space between the casing and drill pipe or in an openhole during drilling and completion operations. (See annular blowout preventer.)

BOREHOLE. The wellbore; the hole made by drilling or boring.

BOTTOMHOLE. Pertaining to the lowest or deepest part of a well.

BOTTOMHOLE PRESSURE. The pressure in a well measured at or near the bottom of the hole.

BRINE. Highly saline water often found in deep aquifers.

C

CASED HOLE. A wellbore in which casing has been run.

CASING. Steel pipe placed in an oil or gas well as drilling progresses to prevent the wall of the hole from caving during drilling, it prevents fluid migration from one zone to another and provides a means of extracting petroleum if the well is productive.

CASING HEAD GAS. Dissolved gas produced with crude oil; oil well gas.

CEMENT CASING. To fill the annulus between the casing and hole with cement to support the casing and prevent fluid migration between permeable zones.

CEMENTING. The application of a liquid slurry of cement and water to various points inside or outside the casing. (See primary cementing and secondary cementing.)

COASTAL WETLANDS. Forested and nonforested habitats, mangroves, and all marsh islands which are exposed to coastal waters. Included in forested wetlands are hardwood hammocks, cypress-tupelogum swamps, and fluvial vegetation/bottomland hardwoods. Nonforested wetlands include fresh, brackish and salt marshes. These areas directly contribute to the high biological productivity of coastal water by input of detritus and nutrients, by providing nursery and feeding areas for shellfish and finfish, by serving as habitat for many birds and other animals.

COMINGLING. Bringing together the production from wells, leases, pools and fields with production of other operators.

COMPLETE A WELL. To finish work on a well and put it on productive status. (See well completion.)

CONDENSATE. Hydrocarbons which are in the gaseous state under reservoir conditions but which become liquid either in passage up the hole or in the surface equipment.

CORE. A cylindrical sample taken from a formation for geological analysis. Usually a conventional core barrel is substituted for the bit and procures a sample as it penetrates the formation. To obtain a formation sample for analysis.

CORE ANALYSIS. Laboratory analysis of a core sample to determine porosity; permeability, type of rock, fluid content, angle of dip, geological age and probable productivity of the formation.

CRITICAL HABITAT. An area that is essential to the conservation of a species.

CRUDE OIL. A mixture of hydrocarbons that exists in the liquid phase in the underground reservoir and remains liquid at atmospheric pressure after passing through surface separating facilities.

CUTTINGS. Fragments of rock dislodged by the bit and brought to the surface in the drilling mud. Washed and dried cuttings are analyzed by geologists to obtain information about the formations drilled.

D

DEGASSER. The equipment used to remove undesired gas from a drilling fluid.

DELINEATION WELL. An exploratory well drilled to define the aerial extent of a field. Also referred to as an "expendable well."

DEMULSIFIER. A chemical used to "breakdown" crude oil/water emulsions so the water may be removed from the oil.

DERRICK. A large load-bearing structure, usually of bolted construction. In drilling, the standard derrick has four legs standing at the corners of the substructure and reaching to the crown block. The substructure is an assembly of heavy beams used to elevate the derrick and provide space to install blowout preventers, casingheads, and so forth. Because the standard derrick must be assembled piece by piece, it has largely been replaced by the mast, which can be lowered and raised without disassembly.

DEVELOPMENT WELL. (1) A well drilled into a proven producing field to enable complete drainage of the reservoir. (2) An exploitation well.

DIRECTIONAL DRILLING. Intentional deviation of a wellbore from the vertical. Although wellbores are normally drilled as vertically as possible, it is sometimes necessary or advantageous to drill at an angle from the vertical. Controlled directional drilling makes it possible to reach subsurface areas laterally remote from the point where the bit enters the earth.

DISCOVERY WELL. The first oil or gas well drilled in a new field; the well that reveals the presence of a petroleum bearing reservoir. Subsequent wells are development wells.

DISPLACEMENT FLUID. In oil well cementing, the fluid, usually drilling mud or saltwater, that is pumped into the well after the cement to force the cement out of the casing and into the annulus.

DISSOLVED GAS. Natural gas which is in solution with crude oil in the reservoir.

DRILLING FLUID. The circulating fluid, one function of which is to force cuttings out of the wellbore to the surface. (See mud.)

DRILLING RIG. (See rig.)

DRILL PIPE. The heavy, seamless pipe used to rotate the bit and circulate the drilling fluid. Sections of pipe 30 feet long are screwed together to form the desired length of pipe.

DRILL STEM. The entire length of tubular pipes, composed of the kelly, drill pipe and drill collars, that make up the drilling assembly from the surface to the bottom of the hole.

DRILL-STEM TEST. A type of formation testing which removes the weight of drill mud from the formation and allows reservoir fluids to be temporarily produced.

DRILL STRING. The column, or string, of drill pipe, not including the drill collars or kelly. Often, however, the term is loosely applied to include both the drill pipe and drill collars.

DRY GAS. Natural gas that is produced without liquid hydrocarbons. Also gas that has been dehydrated to remove water (pipeline gas).

E

EMULSION. A mixture of crude oil and formation water.

ESTUARY. Semienclosed coastal body of water which has a free connection with the open sea and within which seawater is measurably diluted with fresh water.

EXPLOITATION WELL. A well drilled to permit more effective extraction of oil from a reservoir. It is sometimes called a development well.

EXPLORATORY WELL. A well drilled in unproven or semiproven territory for the purpose of ascertaining the presence underground of a commercial petroleum or natural gas deposit.

F

FIELD. A geographical area in which a number of oil or gas wells produce from a continuous reservoir; may refer to surface area only or to underground productive formations as well. In a single field, there may be several separate reservoirs at varying depths.

FORMATION TESTING. The gathering of data on a formation to determine its potential productivity before installing casing in a well. The conventional method is the drill stem test.

G

GAS-CUT MUD. A drilling mud that has entrained formation gas giving the mud a characteristically fluffy texture. When entrained gas is not released before the fluid returns to the well, the weight or density of the fluid column is reduced. Because a large amount of gas in mud lowers its density, gas-cut mud must often be treated to lessen the chance of a blowout.

I

INLAND BARGE RIG. A drilling structure consisting of a barge upon which the drilling equipment is constructed. When moved from one location to another, the barge floats, but when stationed on the drill site, the barge is submerged to rest on bottom.

INTERMEDIATE CASING STRING. The string of casing set in a well after the surface casing to keep the hole from caving and to seal off troublesome formations. The string is sometimes called protective casing.

K

KICK. The intrusion of formation liquids or gas that results in an increased volume of mud returned to the pit. Without corrective measures, this can result in a blowout.

L

LAY BARGE. A shallow draft, barge-like vessel used in the construction and laying of underwater pipelines in swampy areas.

M

MARSHES. Persistent emergent nonforested wetlands characterized by vegetation consisting predominantly of cordgrasses, rushes and cattails.

MARSH BUGGY. A tractor-like vehicle whose wheels are fitted with extra large rubber tires for use in swamps.

MIX MUD. To prepare drilling fluids from a mixture of water or other liquids and one or more of the various dry mud-making materials (such as clay, weighting material, chemicals, etc.).

MUD. The liquid circulated through the wellbore during rotary drilling. In addition to its function of bringing cuttings to the surface, drilling mud cools and lubricates the bit and drill stem, protects against blowouts by holding back subsurface pressures, and deposits a mud cake on the wall of the borehole to prevent loss of fluids to the formation.

MUD PIT. A reservoir or tank usually made of steel plates, through which the drilling mud is cycled to allow sand and fine sediments to settle out. Additives are mixed with mud in the pit, and the fluid is temporarily stored there before being pumped back into the well. Mud pits are also called shaker pits, settling pits and suction pits, depending on their main purpose.

N

NATURAL GAS. A mixture of hydrocarbons and varying quantities of nonhydrocarbons that exists either in the gaseous phase or in solution with crude oil in natural underground reservoirs.

NATURAL GAS LIQUIDS. Those portions of reservoir gas which are liquefied at the surface in separators, field facilities, or gas processing plants.

O

OIL FIELD. The surface area overlying an oil reservoir or reservoirs. Commonly, the term includes not only the surface area but may include the wells and production equipment as well.

OIL AND GAS SEPARATOR. Production equipment used to separate the liquid components of the well stream from the gaseous components.

P

PERMEABILITY. A measure of the ease with which a fluid flows through the interconnected pores of a rock. A measure of the relative size and number of interconnecting passages in a porous medium.

PIPELINE GAS. Gas which meets gas pipeline purchaser specifications.

PIPELINE OIL. Clean oil. Crude oil whose basic sediment and water content is low enough for transport or pipeline shipment.

PLUG AND ABANDON (P&A). To place cement plugs into a dry hole and abandon it.

POROSITY. The amount of void space or openings within the mass of a rock.

PRIMARY CEMENTING. The cementing operation that takes place immediately after the casing has been run into the hole; used to provide a protective sheath around the casing, to segregate the producing formation and to prevent the migration of undesirable fluids. (See secondary cementing.)

PRODUCTION CASING. The last string of casing set in a well; the casing string set to the top or through the producing formation. The tubing string is usually suspended inside the production casing.

R

RAM-TYPE BLOWOUT PREVENTER. A device that seals the open space in the wellbore by forcing two horizontal sliding gates (rams) against one another.

RESERVE PIT. (1) (obsolete) a pit in which a supply of drilling fluid is stored. (2) A waste pit, usually an excavated earthen pit, sometimes lined with plastic, or a metal tank used to dump cuttings, catch overflow and dump muds when changing.

RESERVOIR. A subsurface, porous, permeable rock body in which oil or gas is found. Most reservoir rocks are limestones, dolomites, sandstones, or a combination of these. The three basic types of hydrocarbons contained in reservoirs are oil, gas and condensate. An oil reservoir generally contains three fluids, gas, oil and water, with oil the dominant product. In the typical oil reservoir, these fluids occur in different phases because of the variance in their gravities. Gas, the lightest, occupies the upper part of the reservoir rocks; water, the lower part and oil, the intermediate section. In addition to occurring as a cap or in solution, gas may accumulate independently of the oil; if so, the reservoir is called a gas reservoir. Associated with the gas, in most instances, are saltwater and some oil. In a condensate reservoir, the hydrocarbons may exist as a gas, but, when brought to the surface, some of the heavier ones condense to a liquid or condensate.

RIG. The derrick, drawworks and attendant surface equipment of a drilling unit.

RIPARIAN ZONE. Area located on the bank of a natural water course (as a river, a lake or a tidewater).

ROTARY DRILLING. A drilling method in which a hole is drilled by a rotating bit to which downward force is applied. The bit is fastened to and rotated by the drill stem, which also provides a passageway through which the drilling fluid is circulated. Additional joints of drill pipe are added as drilling progresses.

S

SECONDARY CEMENTING. Any cementing operation after the primary cementing operation. Secondary cementing includes a plug-back job, in which a plug of cement is positioned at a specific point in the well and allowed to set. Wells are plugged to shut off bottom water, or to reduce the depth of the well for other reasons.

SEDIMENT. Material deposited as by water, wind or glacier.

SEPARATOR. A pressure vessel used for the purpose of separating gas from crude oil and water.

SOUR GAS. Natural gas contaminated with chemical impurities, notably hydrogen sulfide or other sulfur compounds, which impart to the gas a foul odor. Such compounds must be removed before the gas can be used for commercial and domestic purposes.

SOUR OIL. Crude oil containing significant quantities of hydrogen sulfide gas.

SPILL. A sudden, unintentional or accidental unplanned release of oil.

SUBSIDENCE. A sinking of a large part of the earth's crust.

W

WELL COMPLETION. The activities and methods necessary to prepare a well for the production of oil and gas; the method by which a flow line for hydrocarbons is established between the reservoir and the surface.

WELLHEAD. The equipment installed at the surface of the wellbore. A wellhead includes such equipment as the casinghead, tubing head and Christmas tree. Pertaining to the wellhead (as wellhead pressure).

WETLANDS. Areas periodically inundated or saturated by surface or groundwater and supporting predominantly vegetation typically adapted for life in saturated soil conditions.

WILDCAT. A well drilled in an area where no oil or gas production exists. With present-day exploration methods and equipment, about one wildcat out of every six proves to be productive, although not necessarily profitable.

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