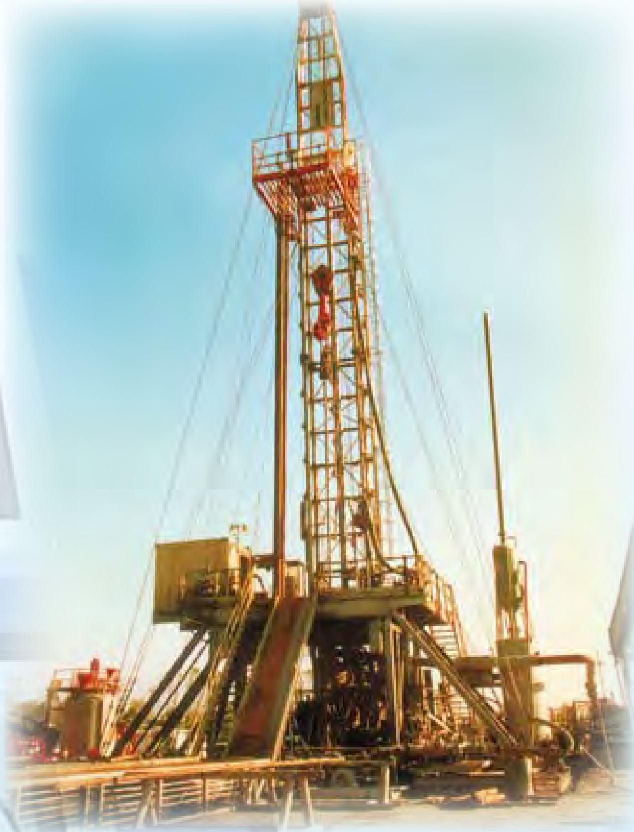
Appendix D

TYPICAL DRILLING OPERATION

MASSARENTI MR 7000

HYDRO DRILLING INTERNATIONAL S.p.A.



The “MR” series rigs, fully mechanically driven, are designed to ensure ease of operation in a wide variety of extreme terrain and climatic conditions and to enable the operator to work in areas requiring all-terrain vehicles such as in desert, swamp or jungle conditions and artic tundra. The drawworks, carrier and mast capacities are matched to provide good performances. The rig is manufactured from high strength material and equipped with heavy duty hydraulic systems capable of providing power for all the hydraulic services.

The rig is trailer mounted and is designed to satisfy the needs of quick rig-up and easily transportable unit

In order to guarantee operations on multi-well cluster, the rig is equipped with a skidding system so to reduce idle time between wells

The drilling control panel is placed in such a way to provide to the driller a complete vision of the drill floor area.

Moreover:

- All decks are checkered plate to ensure a safe walking surface in icy or wet conditions;
- All rig's components can be designed for operations ranging from - 45 °C up to + 50 °C;
- Weather protection on the drill floor area is available;
- Sound-proof shelter for engine is available.

MAIN RIG CHARACTERISTICS

DEPTH RATING
8800 Ft w/ 5“ DPs
12000 Ft w/ 3 1 /2“ DPs

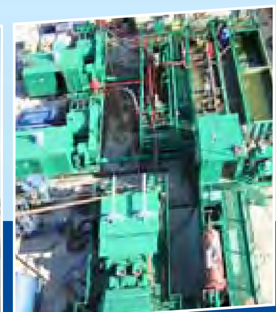
MAST SPECs: 117Ft - Telescopic type hydraulic raising w/Guy lines tied to substructure base beams
Gross Cap. 550.000 Lbs
Static hook load 350.000 Lbs = 160 T

SUBSTRUCTURE
Height 17 Ft = 5.20 m
Rotary cap. 400.000 Lbs = 180 T
Setback cap. 250.000 Lbs = 113 T

DRILLING
D-WORKS: Massarenti MAS 2500 TR
DRIVE COMPOUND: 2 Engines
GM12V-71 acoustic housing
ROTARY TABLE: Ideco 23“
TRAVELING BLOCK: Massarenti T 430-G 175
SWIVEL: Mass. I-200

TOP DRIVE
BOWEN 250 HTP HYDRAULIC Rated load capacity 225 Ton
Maximum continuous output torque 2.200 Kg-m
At rotating speed 75 RPM
Maximum rotating speed 200 RPM
Top Drive pipe handler w/ maximum output torque cap. 3.300 Ft-Lbs






MUD SYSTEM

MUD PUMPS
MUD PUMPS: 2 x MAS 1000 Hp
Drive engine GM 16V-149T/12V149T1100-1200 HP acoustic housed
CENTR. PUMPS: 3 each 5x 6R

MUD SYSTEM
MUD SYSTEM: Tanks cap. 1130 bls = 180mc. c/w 6 mud agitators
DRLG.WATER TANK: 250 bls = 40 mc and ground reserve pit

S/SHAKER
Triple Cobra Shaker Package

DESANDER
3 x 8" cones

MUD CLEANER
Swaco 6T4 12 x 4" cones

DEGASSER
Burgess Magnavac 1000
Drive eng. SAME 75 Hp for mud treatment and mixing

WELL CONTROL EQUIPMENT

CHOKE MANIFOLD
3 1/16" – 10000 3 chokes, 2 manual and remote control

BLOW OUT PREVENTERs
Hydril MSP 21 1/4 - 2000
Hydril 13 5/8 - 5000
CIW double 13 5/8 - 5000 U
CIW single 13 5/8 - 5000 U (shear rams)

BOP CONTROL
Koomey 120 Gls (22 x 11 gls bottles) - 8 control stations

OTHER EQUIPMENT

AC RIG GENS
SCANIA 400 KVA 380 V - 3 Ph - 50 Hz - Drive SCANIA DC12-54 + backup

FUEL TANKS
23 mc cap.

RIG SITE
Housing and auxiliary equipment to run operations Firefighting equipment and safety aids

RACKING IN DOUBLE
5" DPs 9360 Ft
3 1/2" DPs 13000 Ft

DRILLSTRING
5"-19.5 Grade G105 – S135
3 1/2-13.3 Grade G105
DCs 8" - 6 ½" - 4 3/4"

HYDRO DRILLING INTERNATIONAL S.p.A.

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EXPLORATION SITE

BDF

BRITISH DRILLING AND
FREEZING COMPANY LIMITED

RIG 28 – IDECO BIR 5625

RIG 28 - IDECO BIR 5625

Rig 28, a five axle self propelled Back in Rambler (BIR), purchased in 1991, is ideally suited for drilling wells to depths of 2250 metres, re-entry and workover operations.

Major rig features include:

- IDECO H37 (500 H.P) double drum drawworks, with DETROIT 12 V 71 power.
- IDECO KM 108 270 KH telescopic mast with an API static hookload of 270,000 lbs and 108ft clear height to permit mousehole connections.
- IDECO substructure with 12ft clear working height enabling use of 13⅝" double ram and annular B.O.P.S.
- IDECO 20½" rotary table.
- 2 No triplex mud pumps - 500HP, 600HP and 800HP pumps available.
- High specification ancillary equipment.
- All electrical equipment conforms to the latest I.P. Code of Practice and BASEEFA approval.
- Compact modular design of components ensures minimum site area is required and maximises efficiency of rig moves.
- Extensive acoustic enclosures to all prime movers ensures the rig can operate in environmentally sensitive locations.

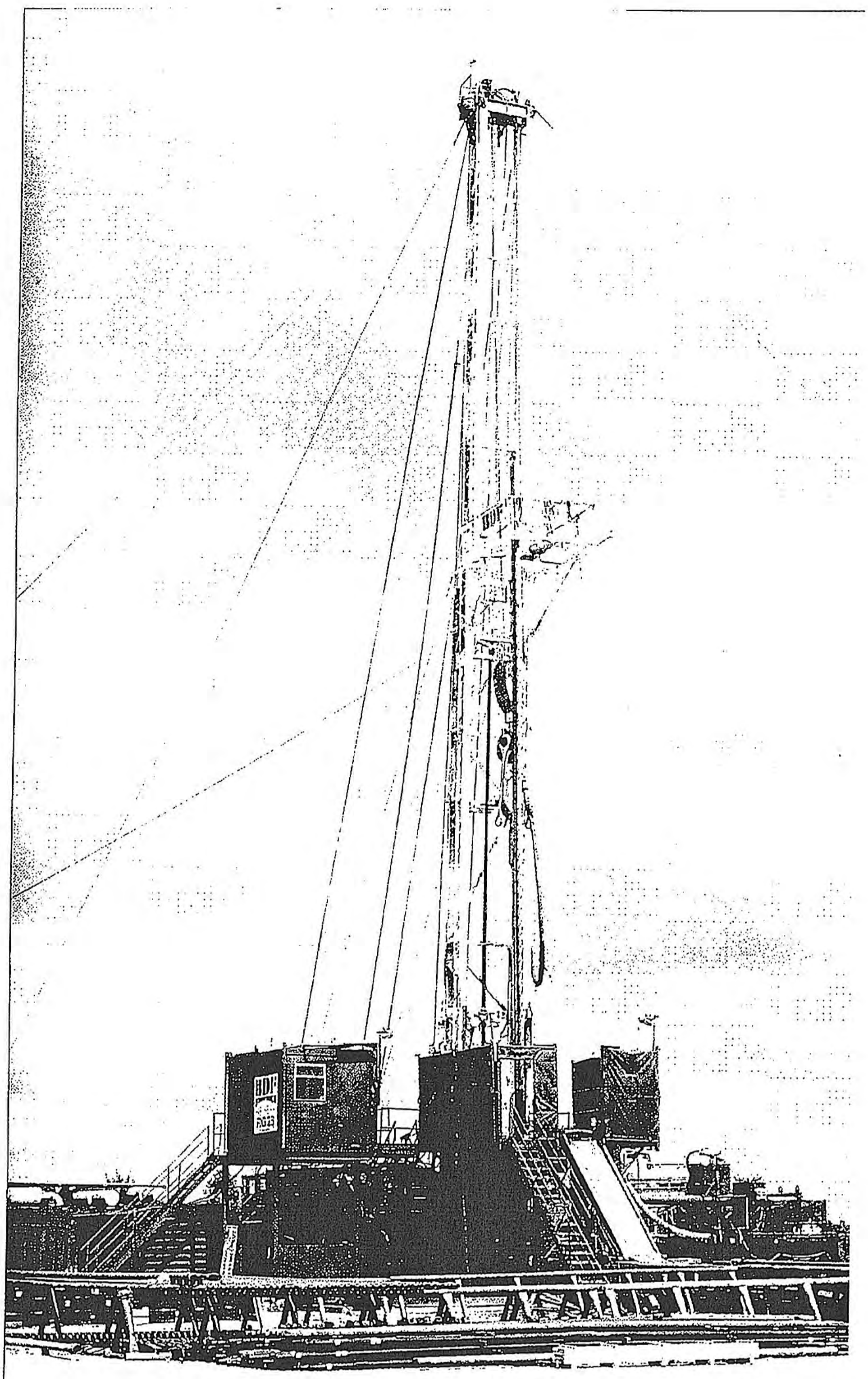


FIGURE 10a

EXPLORATION SITE

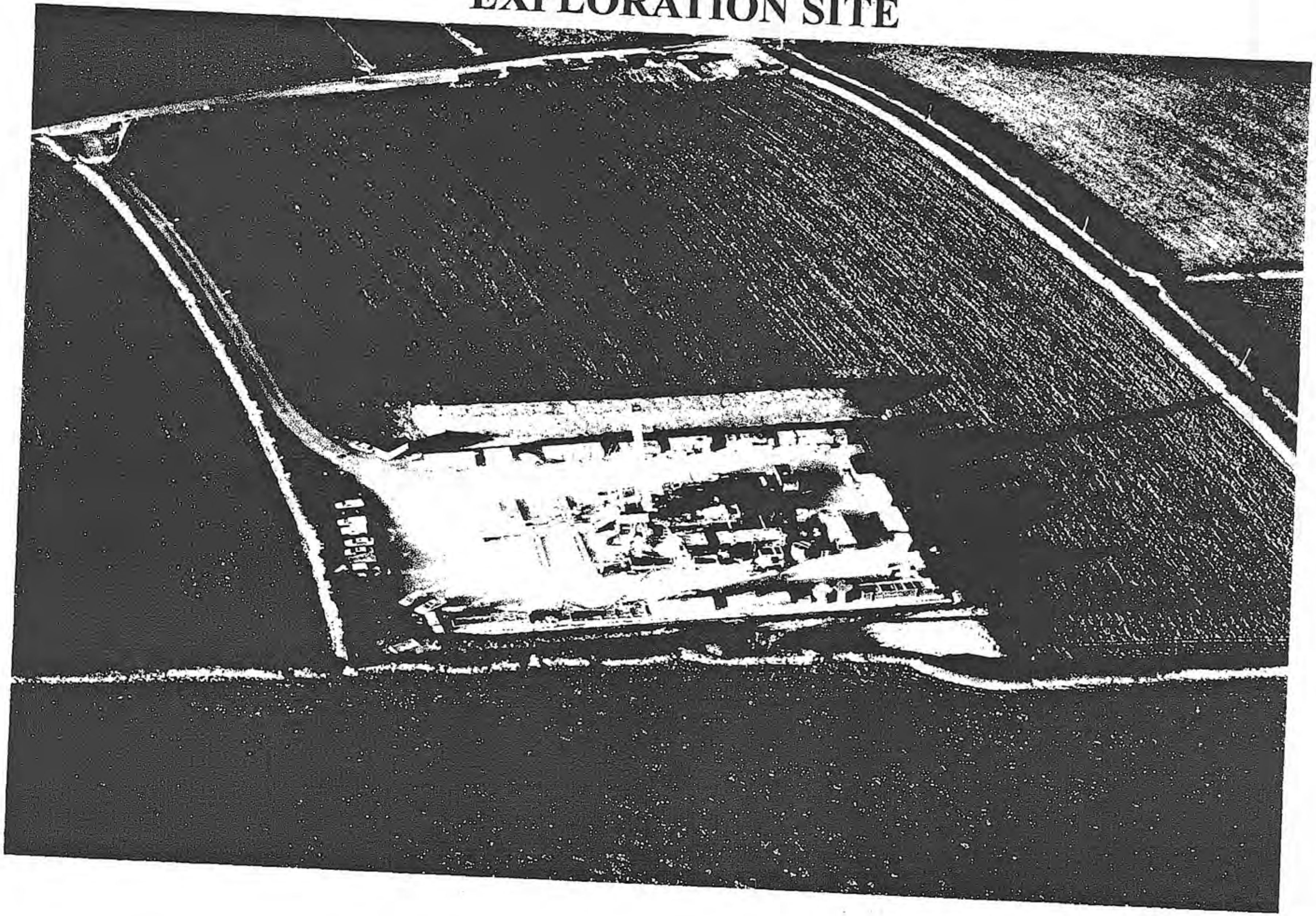


FIGURE 10

THE COMPONENTS OF A ROTARY DRILLING RIG

Circulating System
1. Mud Tanks
2. Mud Pumps (usually housed)
3. Rotary Hose
4. Mud Chemical Storage
5. Mud Return Line
6. Shale Shaker
7. Desilter
8. Desander
9. Degasser
10. Mud Pit or Slurry Pit

Rotating Equipment
11. Swivel
12. Kelly
13. Rotary Table and Kelly Housing

Hoisting System
14. Crown Block
15. Monkey Board
16. Mast or Derrick
17. Travelling Block
18. Hook
19. Elevators
20. Drawworks
21. Cathead
22. Driller's Console and Indicators
23. Substructure
24. Dog House

Well Control Equipment
25. Annular Blowout Preventer
26. Ram Blowout Preventers
27. Accumulator Unit (usually housed)
28. Choke Manifold
29. Gas Detector
30. Mud-Gas Separator
31. Mud Logging Unit

Power System
32. Power Generating Plant (housed)
33. Fuel Tanks

Down-hole Pipe and Equipment
34. Cellar
35. Conductor Pipe
36. Casing Head
37. Surface Casing
38. Cement
39. Drill Pipe
40. Drill Collars
41. Stabilisers
42. Drill Bit
43. Annulus
44. Pipe Racks
45. Catwalk
46. Pipe Ramp
47. Rathole
48. Mousehole
49. Tongs
50. Tong Counterweights

Site
51. Hard Core
52. Membrane
53. Soil Bund

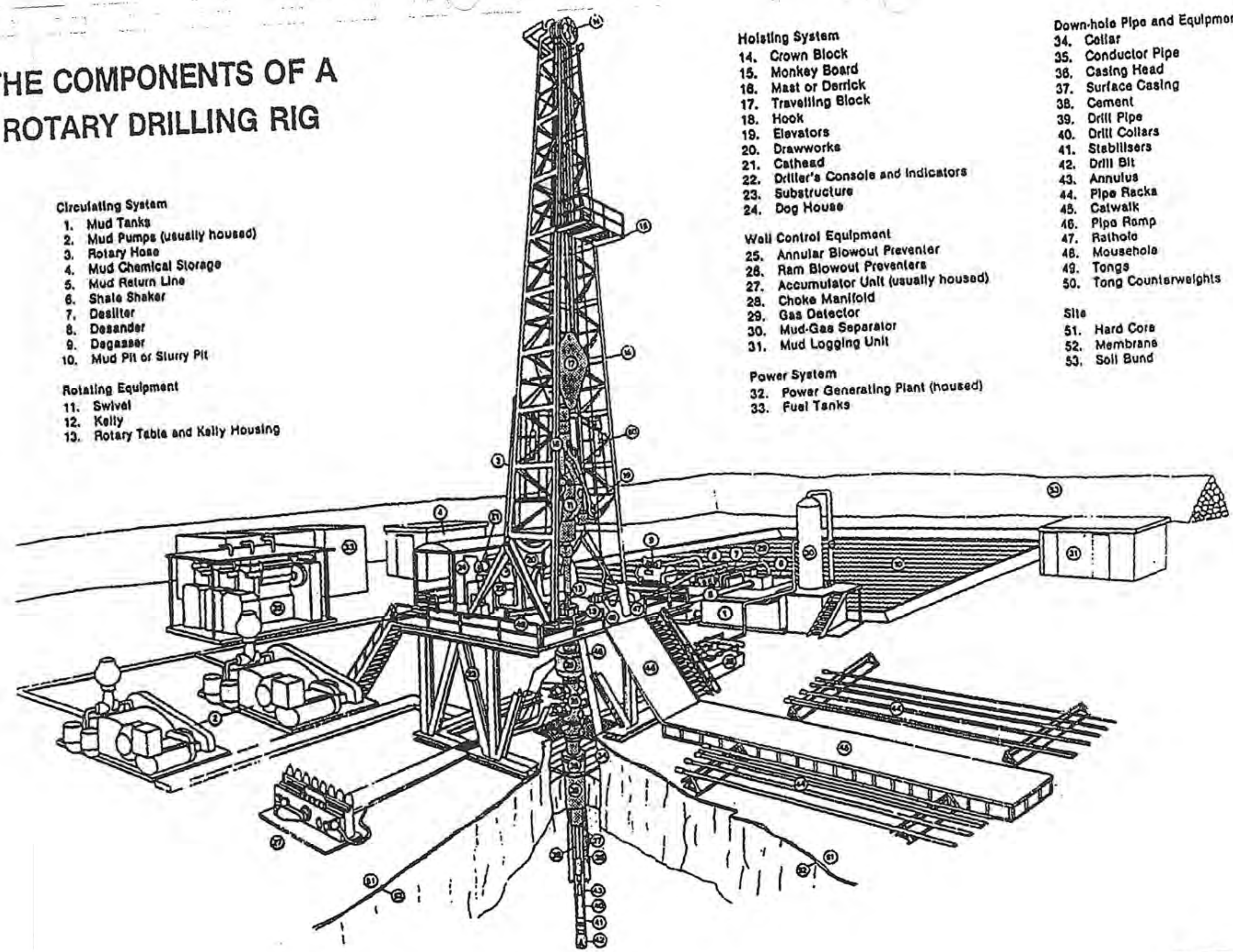


FIGURE (8)

THE DRILLING OPERATION

Wells for oil and gas are drilled using a rotary drilling rig, see diagram overleaf which illustrates the various components. This is a well tried and efficient method and employs a vertical "derrick", inside which is suspended a column of hollow steel pipe, known as a "drill string", with a drill bit fitted to its lower end. This "string" is rotated and the bit cuts downward through the rock strata.

During drilling, a dense fluid known as "mud" is pumped down the inside of the drill string. The mud lubricates the drill bit and brings to the surface fragments of rock which are analysed both to identify and correlate the strata through which the bit is passing, and for signs of any oil or gas within any reservoir rocks encountered. An aspect of safety is provided by the weight of the column of mud which exceeds any underground reservoir pressures and thereby contains them and therefore it is important in maintaining the safety of the drilling operation. The rig is fitted with valves known as "blow-out preventers" which can be closed immediately if an unexpected increase in pressure should occur.

As the depth of the well increases, drilling must stop periodically so that new lengths of pipe can be added to the drill string. When the drill bit becomes worn the whole string must be pulled out so that a new bit can be fitted. This is known as "round tripping", or "pulling out" and "running in".

At pre-determined stages in the drilling of such a well the walls of the borehole are supported by steel casing which is cemented into place, to provide additional safety measures by preventing the collapse of the borehole sides and the ingress of groundwater under pressure. It is essential that drilling continues throughout the day and night to keep the hole open and to maintain control for both safety and operational reasons. During the drilling of an exploration well, the progress of the operation is monitored constantly and a range of tests and analysis carried out.

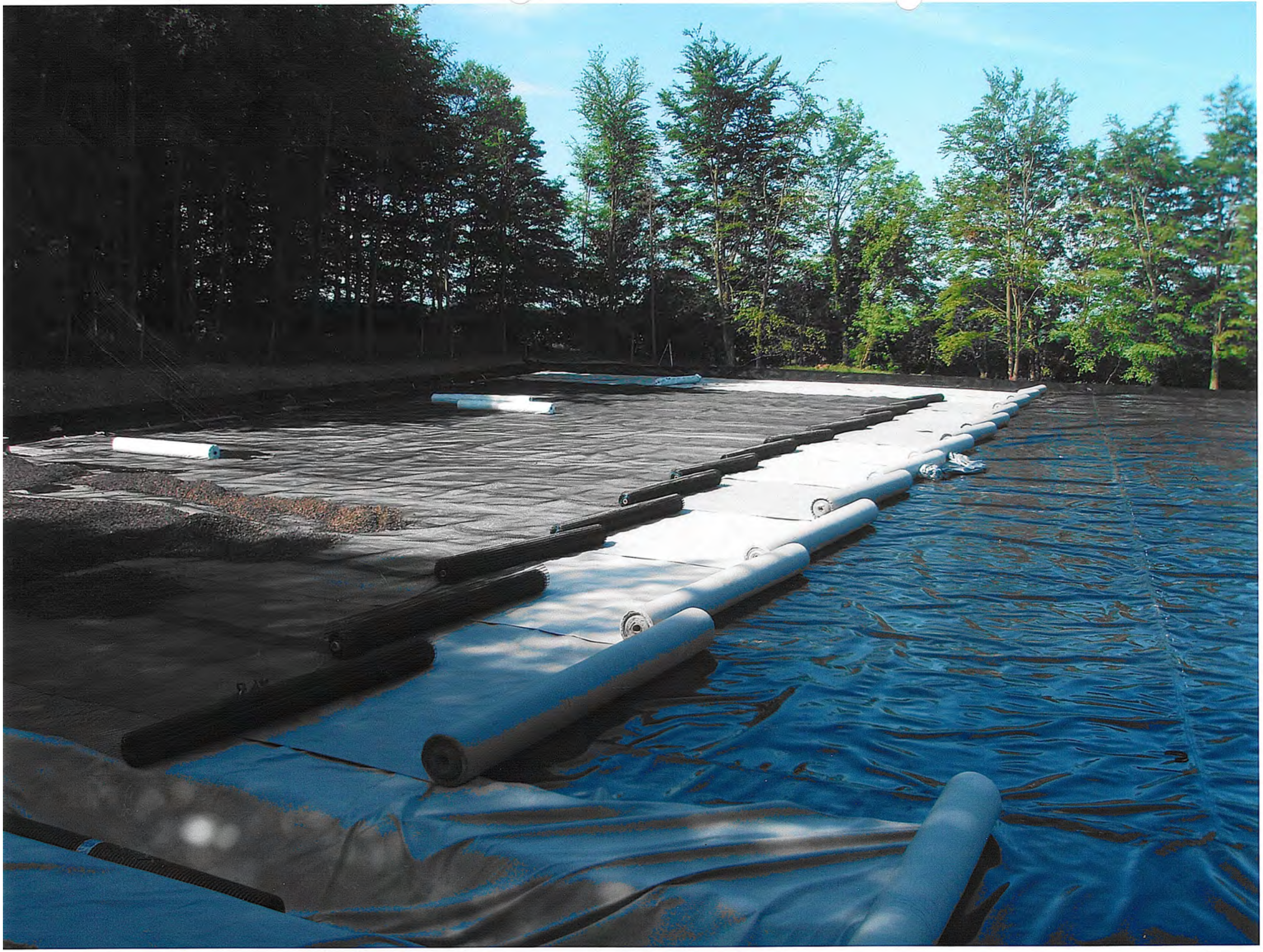
"Well logging" is used to obtain information both on the borehole itself (including its precise depth and direction at any time), and on the rock strata through which it passes. These tests can be either geophysical, using instruments lowered into the well as it is drilled, or can involve analysis of Chipping's brought to the surface in the mud stream. "Coring" is the recovery of sizeable rock samples which may be required from particular strata. This procedure involves the use of a special core bit to cut a cylindrical core of rock. The core is then brought to the surface for testing and analysis.

If, on reaching its target depth or before, the well reveals the presence of oil or gas, then testing is carried out to give a preliminary estimate of the extent and characteristics of the reservoir.

During testing operations any fluids flowing from the well are piped into a small storage tank and transported away by road. Gas is either vented to the atmosphere or burned in a flare. Following the final testing , the drilling rig will be dismantled and a well-head valve assembly, known as a "Christmas Tree" installed. Only small volumes of gas will be produced during such well testing. The data obtained are essential in enabling a decision to be taken on whether further appraisal is justified.

Appendix E

SITE PREPARATION DETAILS



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CAT
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Appendix F

DRY HOLE ABANDONMENT

SPE 54344

Society of Petroleum Engineers

Well Abandonment—A "Best Practices" Approach Can Reduce Environmental Risk

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This paper was prepared for presentation at the 1999 SPE Asia Pacific Oil and Gas Conference and Exhibition held in Jakarta, Apr. 20-22.

Abstract

Wells are drilled and completed for a typical production life of 15 to 20 years. After a well is depleted, it must be abandoned so that the permeable intervals penetrated by the wellbore are isolated. For an abandonment to be successful, it must stabilize the wellbore and its associated annuli until geologic forces can re-establish the natural barriers that existed before the well was drilled. The isolation of the hydrocarbon-bearing intervals, overpressured intervals, uncemented annuli, and any freshwater intervals penetrated by the wellbore is critical to successful abandonment. The abandonment plan must be based on the types of fluids contained in reservoirs and the well's mechanical condition at the time of abandonment. Government regulations for well abandonment are minimal guidelines for abandonment, and should not be considered finite answers to environmental safety issues.

This paper describes "best practices," concepts and techniques that operators should consider during abandonment planning, that will help ensure effective isolation within the wellbore.

Background

Wellbore abandonment is a natural consequence of the drilling operation. Wells have been drilled, completed, produced, and ultimately abandoned for more than 100 years. The techniques for drilling and completing wells have rapidly evolved as a result of new technology for drilling deeper and in more hostile environments, and a growing recognition of the importance of environmental safety during drilling and production.

The earth's natural resources were once believed to be endless. Today, environmental protection and safety are the two most important concerns during drilling and production operations. The main goals in developing new technology have been (1) maximizing the recovery of hydrocarbons and (2) reducing the risk for problems during a well's production life. Some of the choices that an operator can make to reduce risk during production, such as using mud as a completion fluid, can significantly increase the cost of an appropriate abandonment.

The evolution of abandonment techniques has been slower than well construction. Cost and government regulations have been the principal considerations in deciding when and how an abandonment should be done. Although most operators are required to meet government regulations for abandonment, they have generally been given little incentive to make well abandonment a high priority. Abandonment was perceived as a sunk cost. However, with widespread recognition that natural resources are dwindling, more emphasis is now being placed on abandonment techniques. Some government agencies have recognized the importance of keeping operators accountable, and have made them responsible for all future liability should the abandonment fail.

Choices made during drilling and production can mitigate or complicate an abandonment operation. Many factors influence how a well should be abandoned, including the following:

- the types of fluids left in each annulus
- the type and amount of cement used during drilling operations
- hole cleaning and cement placement techniques
- pressures applied to the casing strings during production operations
- obstructions left in the wellbore during its production life

The design of each well abandonment should be based on the individual well's mechanical history so that all abandonment issues are appropriately addressed.

Government Regulations

As concern for the environment has increased in countries around the world, the number of abandonment regulations has increased. Today, most countries have some form of regulation that addresses abandonment requirements. The regulations are neither uniform nor consistent between countries or between

References at the end of the paper.

agencies within a country. Therefore, they do not normally offer complete answers to abandonment issues. Instead, they provide a minimal standard for operating companies. For successful well abandonment, operators must understand that meeting required regulations does not alone ensure long-term protection of the environment.

Abandonment Objectives

The need for a "best practices" approach is best demonstrated by an examination of the following main well abandonment objectives:

- protecting the reserves remaining in the reservoir
- protecting freshwater sources penetrated by the wellbore
- preventing surface pollution
- meeting all regulatory requirements

A conflict can occur when operators try to meet these objectives while still controlling cost. Meeting specific regulatory requirements is often easier than developing an abandonment plan that will ensure isolation of the hydrocarbon-bearing formations and long-term protection of the environment.

Fluid Flow Control

Fluid flow must be controlled for abandonment objectives to be met. If a flowpath exists, fluid within the wellbore will flow from higher-pressured intervals to lower-pressured intervals. The abandonment operation must create barriers within the wellbore to prevent fluid movement. These barriers must remain in place until the natural balance that existed before the well was drilled can be re-established.

In addition to the abandonment operation, two other mechanisms are traditionally credited with helping eliminate fluid movement: 1) the installation and cementing of multiple casing strings during well construction, and 2) naturally occurring barriers.

Multiple casing strings are typically installed to control pressure during drilling, and later, during production operations. The requirements for abandoning a depleted well still depend on the original well-construction process. Typically, cementing programs and multiple casing strings should continue to control fluid movement during well abandonment. If they cannot control fluid movement during well abandonment, the abandonment process becomes more complicated. Whenever possible, the well-construction process should be designed to simplify well abandonment, and the abandonment process should be an extension of the original well-construction operation.

Natural barriers in the wellbore are created with time after the well is drilled. These barriers can be sloughing shales, collapsing formations, and the solids-laden mud that often remains in the annulus above the cement. Although these barriers are often present, they may not occur in every well, and not every naturally occurring barrier will effectively control fluid movement.[1]

The operator can control only two of the three fluid-control mechanisms. Therefore, abandonment planning is important from the beginning of well construction. For optimal results, the well-construction plan and the abandonment plan should complement each other. Operators must consider both the drilling requirements and any anticipated production operations that could affect the casing and cement integrity during the well's production life. If the casing program is compromised, or the primary cement fails before abandonment, the problems must be remedied during abandonment, which increases the cost.

Best Practices

The best practices included in this paper were developed from a review of literature[1-15] on abandonment practices and careful consideration of the primary objectives of well abandonment. This paper describes options that should be considered during well-abandonment planning. Ultimately, however, the operator must decide how a well will be abandoned and whether these practices will be beneficial in protecting the environment.

General Comments. The application of best practices depends on the mechanical condition of the well when the well is abandoned. Although the practices included in this paper are currently considered "best practices," they will likely change as technology becomes more advanced. Even today, operators must decide for themselves whether the cost associated with these recommendations is justified for an individual well. Specifically, they must determine how long the abandonment must be effective to allow nature to restore the pressure balance that existed before the well was drilled. Because nature moves at its own pace that is measured not in years, but in geologic time, abandonment must be effective indefinitely. Every well is unique; therefore, each well's abandonment should be individually designed.

The best practices outlined here address concerns that operators should consider during abandonment planning. An optimal well abandonment would include plugging the hydrocarbon-bearing formation matrix, and filling all casing strings from top to bottom with cement designed for the well conditions. The cement would be allowed to set in a clean, gas-free environment. Each annulus would be clean before the cement is placed. This kind of abandonment is often too expensive to be practical.

Two fundamental abandonment approaches exist. The traditional approach involves a rig for conducting operations, and it gives the operator the most flexibility, though at a higher cost. The second approach, which is used primarily offshore, is the rigless abandonment technique in which most of the tubulars are left in the well and a crane is used for pulling a minimal amount of pipe. When the rigless approach is used offshore, it is normally less expensive, and when properly planned, it can be as environmentally safe as the rig approach. Operators should select an approach only after reviewing the well's mechanical condition. The well's condition and environmental concerns will determine the steps required for a successful abandonment.

Cement Design. Cement plugs should be designed for the static bottomhole conditions at each plug's setting depth. The expected bottomhole pressure and temperature are the controlling factors in selecting a slurry. The slurry's density should be designed for the bottomhole pressure. Concentrations of additives such as retarders or accelerators should be based on the bottomhole temperature to ensure proper placement time and compressive-strength development. The bottomhole temperature also determines the need for special additives (such as silica) to control strength retrogression above 230°F.[9-12]

Gas Contamination. If gas contamination is a concern, a mechanical plug (cement retainer or bridge plug) should be used to ensure that the cement circulated above the plug sets in a gas-free environment.

Hole Cleaning. Ensuring that tubulars are clean before the cement is pumped will help minimize contamination risk and ensure a good bond to the pipe wall. The types of fluids in each annulus and the well-construction practices that were used in drilling the well determine whether the well requires cleaning and how it should be cleaned.

Cement Placement. Whenever possible, cement should be circulated in place, not bullheaded. Cement must be placed in a clean, known environment. When cement is bullheaded, especially down a casing annulus, the placement environment and the final placement depth cannot be controlled. Most annuli contain mud that was deposited when the well was drilled. Cement usually cannot displace this mud uniformly, and as a result, the pipe wall is not swept clean. While the operator assumes that the injection point down the annulus is below the casing shoe, injection may occur through a casing leak somewhere above it.

Production perforations are often bullhead-squeezed down the production tubing or a workstring. This technique can be an effective, inexpensive way to isolate the perforations, but it is not without risk. Bullheading does not ensure that the cement will be placed across the entire perforated interval. In a long interval with varied formation quality, bullheading could squeeze off only a portion of the interval, increasing the importance of both the casing's primary cement job and the other cement plugs placed in the well during the abandonment operation.

Amount of Cement. Many regulations specify a minimum cement-plug length of 50 to 200 ft. Though no specific length guarantees effectiveness, long cement plugs are more likely to create an effective barrier than short plugs.

Pressure Testing. Pressure testing, which is normally required during abandonment, helps confirm that pressure isolation has been achieved. When the hydrocarbon source has been isolated, additional testing (especially testing with excessive pressure) should be avoided. For successful abandonment, pressure integrity must be maintained for all primary cement jobs that were performed when the well was drilled, and for abandonment plugs that are bullheaded or circulated in place during abandonment. Excessive pressure testing during abandonment may break the cement bond with the pipe wall or create stress cracks in the brittle cement, providing a path for future hydrocarbon movement.[3]

Abandoning the Perforated Interval. Abandoning the production interval is the first step in successfully abandoning a well. Because the interval normally contains hydrocarbons, and the pressure within the interval probably has changed as a result of production activities, isolating the interval is critical. When an interval is first abandoned, the pressure within the interval is often lower than it was originally, and isolation is necessary to prevent contamination of any remaining reserves.

With time, nature tends to re-establish the pressure that originally existed in the interval. When this pressure change occurs, any remaining mobile hydrocarbons can migrate uphole because of the difference in fluid gravities.[1] Because the pressure within an interval will likely change with time, isolating the perforations is critical. Historically, perforated intervals have been isolated at the formation face with a cement plug that dehydrates against the permeable formation. For successful isolation, every perforation must be isolated, and an effective cement plug must be left in the production casing.

The best approach for isolating perforations is a set-through cement squeeze in which the cement is circulated across all perforations and pressure is applied from the surface to force the cement into the perforations (**Fig. 1, Page 6**). This approach ensures that cement is placed across all perforations, and it allows positive isolation of the entire interval.

A bullhead cement squeeze of the production interval is often performed through the production tubing after injectivity into the perforations has been established. This application is one of the few cases where bullheading can be an acceptable abandonment technique. If this technique is used, another cement plug may have to be circulated on top of the production packer in both the tubing and tubing/casing annulus. This additional plug helps isolate the interval should bullheading fail to fully isolate the perforations. Should this occur, the well will become more dependent on the production packer's seals for long-term isolation. An effective cement plug is necessary across both the tubing and the tubing/casing annulus opposite the cemented portion of the production casing. This plug minimizes the risk of future communication with the production interval for as long as the primary cement job's integrity is maintained.

Gravel-pack completions are a challenge during abandonment. Normal-grind cement will not penetrate the gravel pack, and attempting to squeeze off a gravel-pack completion with normal-grind cement will result in an unisolated formation. An ultrafine cement slurry will penetrate a sandpack, however. In gravel-pack completions, an ultra-fine cement can be pumped ahead of normal-grind cement to penetrate the sandpack and plug off the formation in the perforation tunnel.[15]

The use of a polymer during the perforation-isolation process should be considered. The polymer, which has a viscosity similar to water, is typically pumped into the formation matrix to displace the hydrocarbons. The cement is then pumped behind the polymer to penetrate the perforations and dehydrate against the formation. Isolating the hydrocarbons away from the wellbore with the polymer reduces the potential for migrating gas to contaminate the cement in the wellbore as it sets. The solidified polymer fills the formation matrix and reduces its permeability, thereby reducing the long-term environmental risk of hydrocarbon pollution from oil and gas remaining in the perforated reservoir.

Isolating Additional Hydrocarbon-Bearing Intervals. If the wellbore contains an additional hydrocarbon interval above the current perforated interval, it should also be isolated with a cement plug placed in both the tubing and tubing/casing annulus. Multiple cement plugs may be required if more than one hydrocarbon sand is present.

Plugs circulated into the annulus through the production tubing should be effective, provided that the tubing and annulus are clean and the annulus contains a clear packer fluid. If mud was used as the packer fluid, then the tubing should be pulled and the annulus should be scraped and circulated clean before a cement plug is circulated in place.

Isolating Overpressured Intervals. If the well contains intervals with abnormal pressures, at least one additional plug will be required to isolate the abnormally pressured section from the normally pressured section. The drill records should indicate where the pressure transition begins. Isolating the overpressured section is important because pressure differential is the main factor determining future fluid movement. The cement plug should be placed across the transition interval (**Fig. 2, Page 7**). The plug should be at least 200 ft long, and at least half of it should extend into the normal-pressure section of the casing.

Isolating Liner Tops and Other Potential Leak Paths. Each noncemented annulus that is open to the mudline must be isolated. The techniques used depend on individual circumstances. Liner tops that are not tied back to the surface should be isolated with cement at the liner-top depth (Fig. 2, Page 7). Noncemented casing annuli should be isolated as deeply as possible, but above the next casing shoe. Ensuring that the annulus is clean before the cement is pumped helps reduce the environmental risk. If the annulus contains mud, the most reliable way to ensure isolation is to cut and pull the casing so that the mud can be removed and the casing can be cleaned before the cement plug is placed. The best time to isolate an annulus is during the drilling phase, when the mud is in good condition. If isolation occurs during abandonment, then the abandonment operation will be more expensive and more complicated (Fig. 1, Page 6).[15]

If the operator chooses not to pull the casing, the most viable alternative is to cut the casing immediately above the next larger casing shoe. This approach relieves the tension that was left in the casing when the casing was originally set, and it provides a large circulation area for cleaning the annulus. After the circulation of the annulus is complete, the cement plug should be circulated in place across the casing cut. This technique is not as reliable as pulling the casing and circulating cement in a clean environment. However, it is preferred over bullheading cement down an annulus from the surface, when pulling the casing is not an option.

Isolating Freshwater Sections. To minimize the risk of contamination from saltwater or hydrocarbon intervals, operators must isolate all freshwater intervals. The most reliable approach is to cut and pull all noncemented casing strings that penetrate the freshwater section. Because most freshwater sections are relatively shallow in the wellbore, casing recovery is typically more cost-effective, even if more than one casing has to be pulled. See Fig. 1, Page 6.

Surface Isolation. The surface cement plug is the last plug to be placed in the well and the most critical for preventing surface pollution. Before this plug is circulated in place, all casing strings not cemented back to the surface should be cut and pulled. If possible, the casing strings should be cut at least 300 ft below the surface, or 300 ft below the mudline in offshore locations. A mechanical plug, such as a bridge plug or cement retainer, should be set in the smallest casing string that was cemented back to the surface. At least 200 ft of balanced cement should be placed on top of the mechanical plug. The surface plug is the last line of defense for preventing surface pollution. The mechanical plug provides a base that prevents the cement plug from falling and ensures that the surface plug will not be contaminated while it sets (Fig. 1, Page 6).[15]

Surface Cleanup and Removal of the Casing Strings. The final step in permanently abandoning a well is the removal of the wellhead and the recovery of the casing strings to a depth that will help ensure a safe environment for future activities. On land, casing strings are normally recovered from at least 3 to 5 ft below the plowline. Offshore, casings are normally recovered from at least 15 ft below the mudline to prevent current movements from exposing the casing stub. The recovery depth is fairly arbitrary and normally specified in the regulations governing a specific geographic area.

Well Construction Practices / Well Operation

The well-construction practices used in drilling and completing a well and the decisions the operator makes during the well's production life can affect the final abandonment requirements. If each annulus is properly isolated with noncontaminated cement during well construction so that no cleaning is needed during abandonment, and if the well is kept in good mechanical condition during its production life, the abandonment operation will be relatively simple and inexpensive.

Ideally, operators should consider abandonment requirements during well-construction planning. An abandonment plan should be developed before the well is drilled, and it should be updated during the well's production life whenever the well's mechanical configuration is changed. With this documentation, the operator can evaluate the impact of these changes on final abandonment and make an informed decision about whether the changes should be implemented.

Conclusions

1. Operators are responsible for developing an abandonment plan that meets regulatory requirements. They must also decide whether additional steps are required to ensure the environmental safety of the abandonment. For an abandonment operation to be considered successful, the abandoned wellbore must remain stable until the natural balance that existed before the well was drilled is re-established.
2. Each well is unique. Therefore, abandonment operations must be individually designed. By using a "best practices" approach in developing a plan, operators can choose abandonment techniques that are best suited to a well's mechanical condition. This approach involves isolating all leak sources and potential leak paths, including the following:
   - all perforations
   - all hydrocarbon-bearing intervals
   - all overpressured sections of the reservoir
   - all noncemented annuli
3. Sources of fresh water must be isolated from contamination from both below and above. The surface plug serves a dual purpose, It protects the freshwater sands from surface contamination and serves as the last line of defense against surface pollution.
4. The casing must be clean to ensure that each cement plug will bond to the pipe wall. Mechanical plugs should be used during abandonment to minimize the risk of gas contamination and to ensure that the cement plug remains in place while the cement sets.

Acknowledgments

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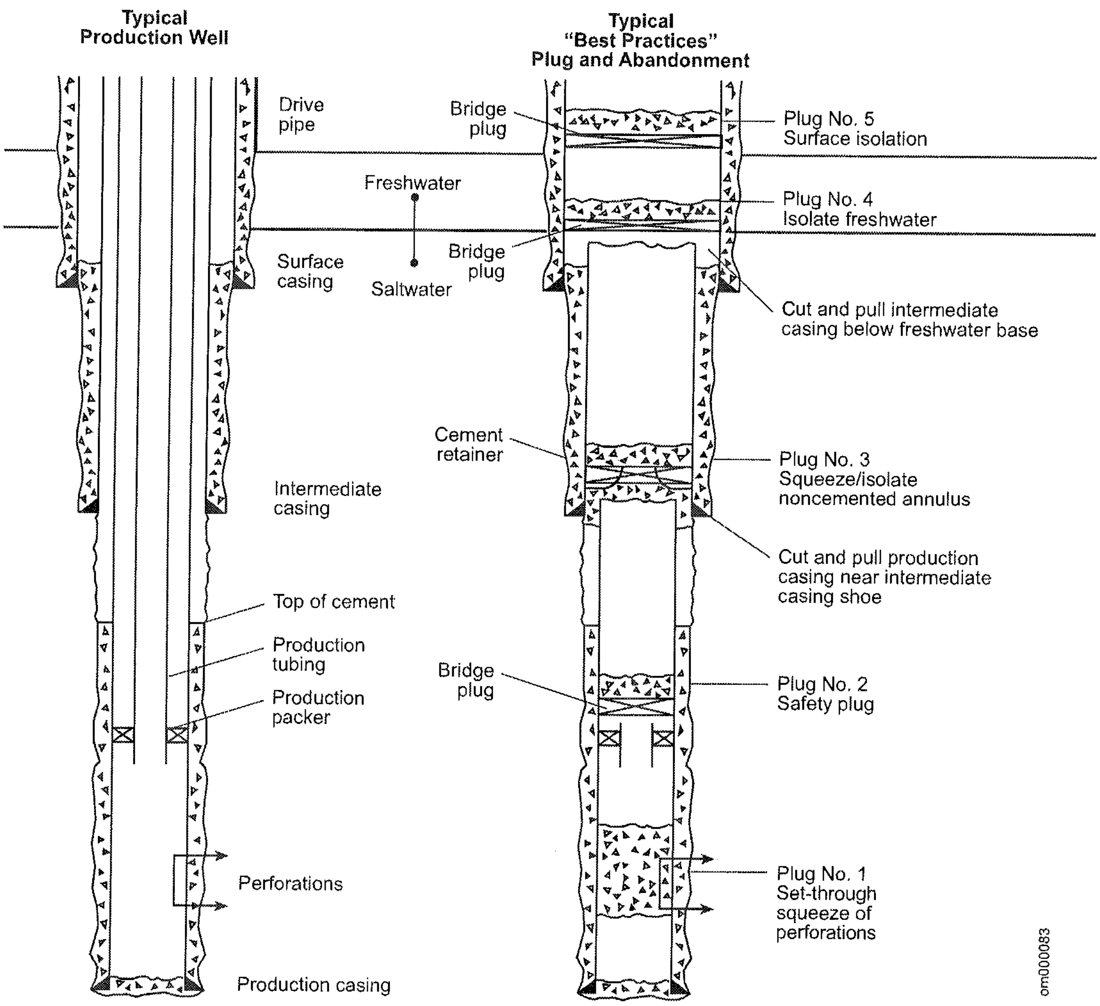


Fig. 1—A typical "best practices" abandonment.

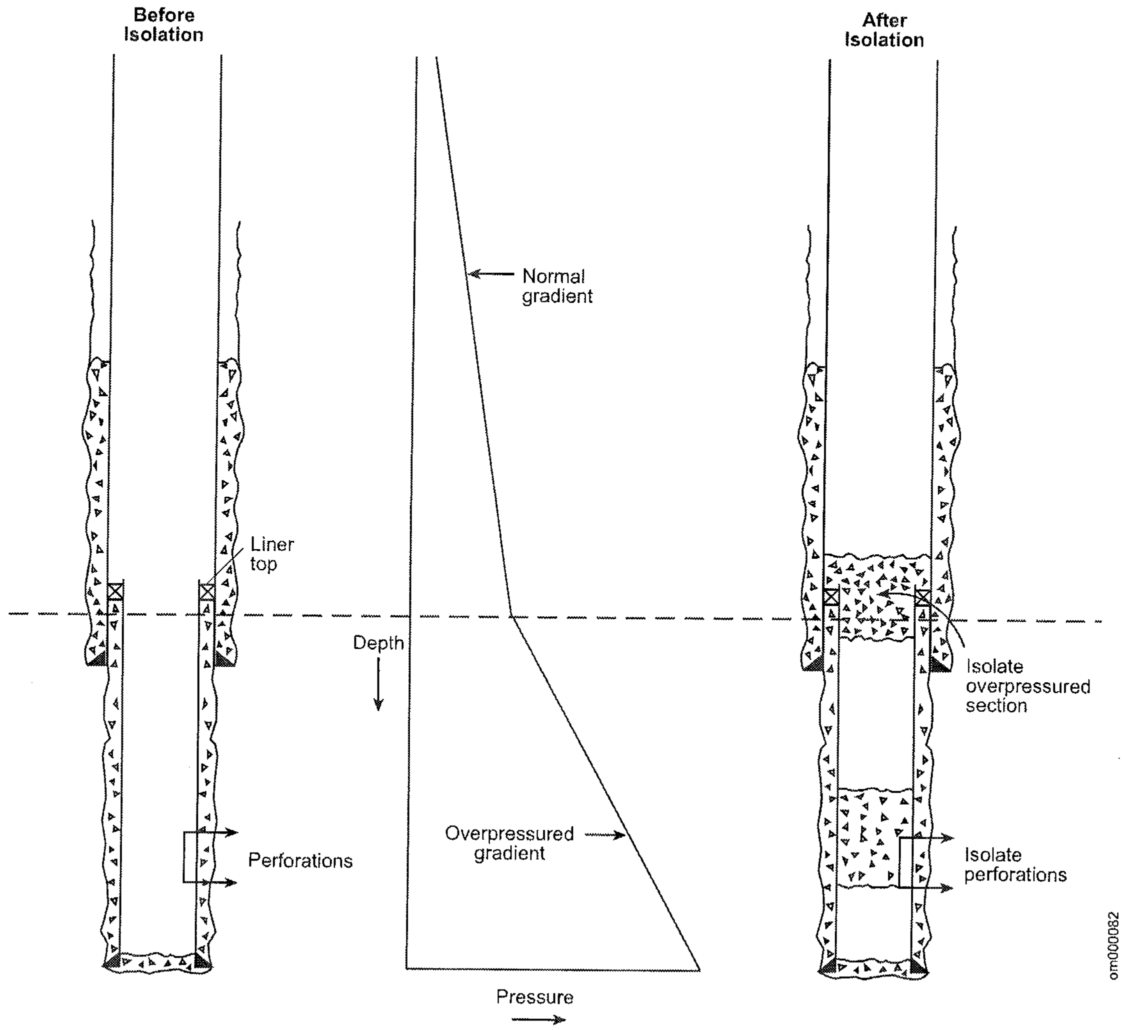
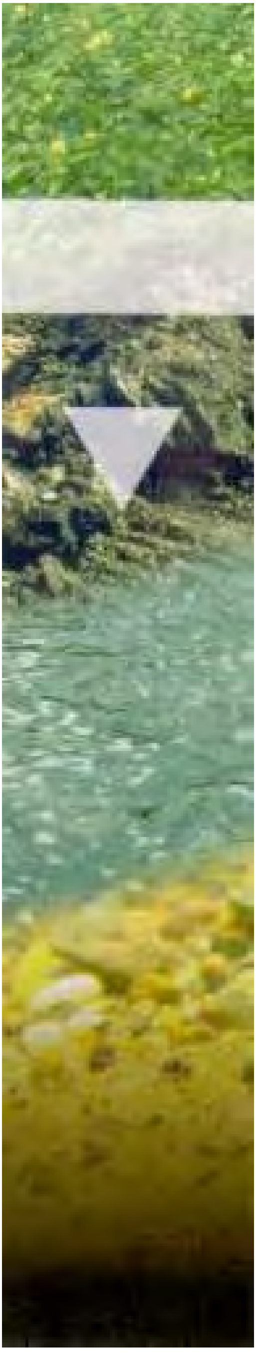


Fig. 2—Isolation of overpressured intervals.



National Groundwater and Contaminated Land Centre

Decommissioning Redundant Boreholes and Wells

ENVIRONMENT AGENCY

Decommissioning Redundant Boreholes and Wells in order to Protect Groundwater Resources.

1. Scope

This booklet is intended to assist with the decommissioning of redundant boreholes or wells in the context of protecting groundwater. It suggests a number of best practice options. It must be understood that other factors (for example ground and site conditions or health and safety issues) must be carefully considered before any final decisions are made and expert, site specific advice should always be sought. Boreholes near landfills or other sources of soil gas may also require venting to prevent the build-up of noxious or explosive gas.

2. Legal Framework

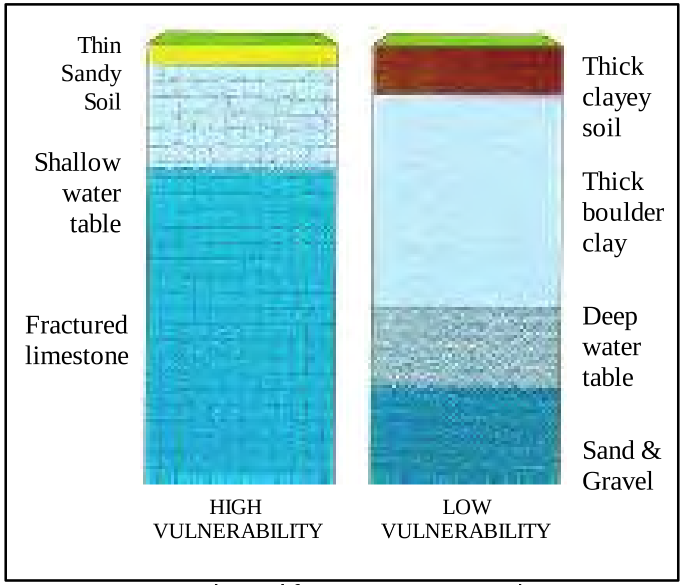
The Environment Agency is responsible for the protection of "controlled waters" from pollution under the Water Resources Act, 1991. Similar controls are in place in Scotland through the Control of Pollution Act, 1974 (as amended) and in Northern Ireland through the Water Act, 1972. It is an offence to cause pollution of controlled waters either

deliberately or accidentally. " Controlled waters" includes all watercourses and groundwater contained in underground strata (or aquifers).

The Agency also has a specific duty to prevent groundwater pollution by certain listed substances under the Groundwater Regulations, 1998. These regulations complete the transposition of the EC Groundwater Directive (80/68/EEC) into UK law. Discharge into groundwater of substances in List I of the directive is prohibited, and discharges of substances in List II must be minimised so as to prevent pollution.

The Environment Agency in England and Wales also has powers under Section 71 of the Water Industry Act, 1991 to prevent wastage of water resources from uncontrolled artesian overflows.

FIGURE 1
The factors controlling vulnerability of aquifers to pollution



3. Introduction

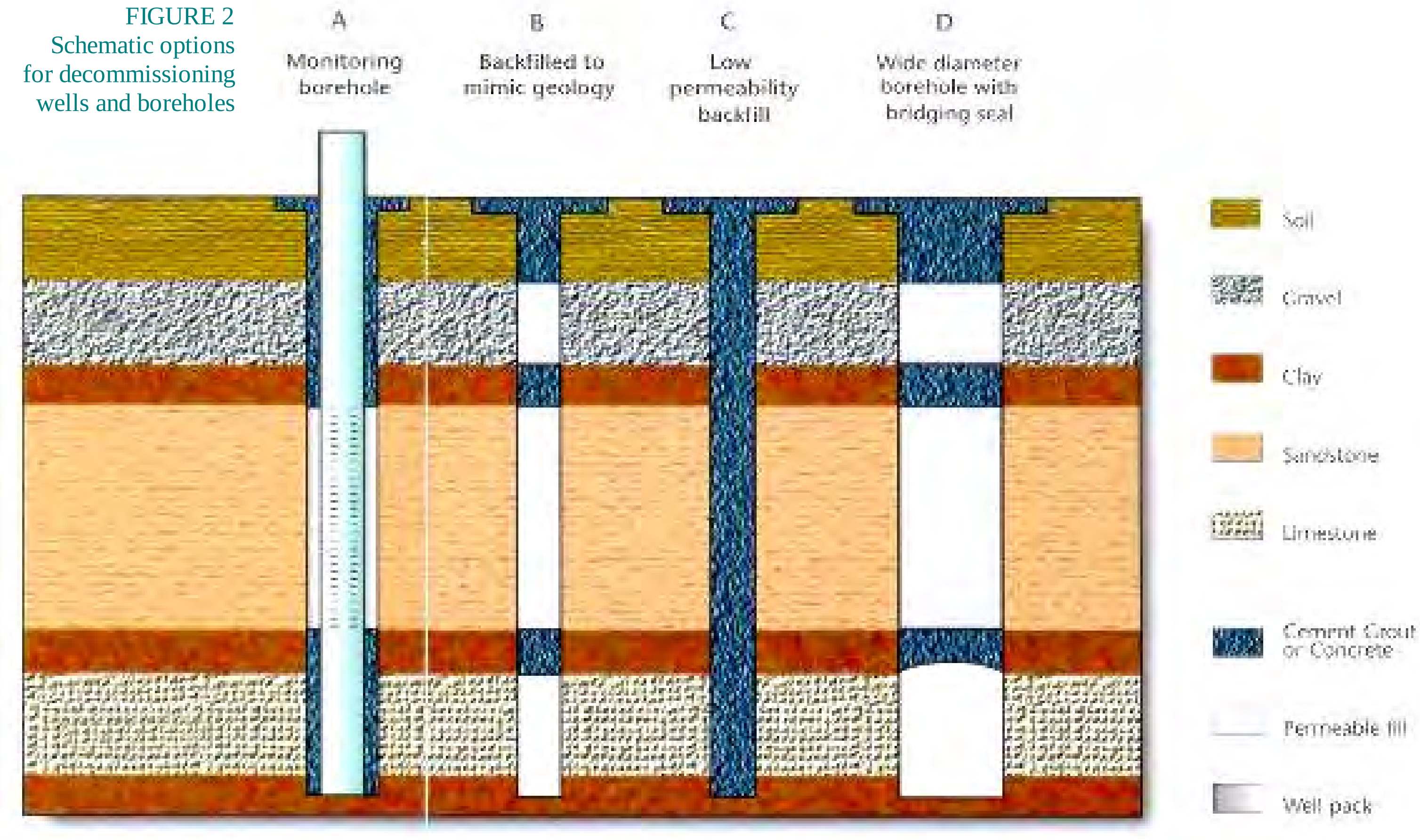
Boreholes and wells are constructed for a variety of purposes: to abstract water; to collect geological information; to investigate and sample soils and groundwater etc. Often, old wells are found on properties that are now connected to a mains water supply, and boreholes and wells may become redundant.

Improperly abandoned boreholes and wells may act as preferential pathways for contaminant movement, leading to the contamination of groundwater, or contributing to the loss of aquifer yield and potentiometric head (water pressure), or result in the mixing of groundwaters of variable quality from different aquifers. They may also present a physical hazard.

Boreholes and wells that are no longer required therefore need to be made safe, structurally stable and backfilled or sealed to prevent groundwater pollution and flow of water between different aquifer units. However, in certain circumstances they may be adapted for use as a groundwater monitoring facility, where this is appropriate. ***It is normally inappropriate and may be unacceptable to convert redundant wells and boreholes to soakaways for the disposal of foul or surface water due to the inherent risk of groundwater pollution.*** The advice of the Agency should always be sought in such cases.

Artesian boreholes (where groundwater in a confined aquifer is at sufficient pressure to cause water to discharge at the ground surface without any pumping) present different problems and warrant special attention to prevent wastage of groundwater resources either by the flow of water from one usable aquifer unit into another unusable unit, or mixing of clean and polluted groundwaters.

FIGURE 2
Schematic options
for decommissioning
wells and boreholes



4. Borehole of well construction

Before considering how best to backfill and seal a borehole or well, or whether it can be put to an alternative use, for example as a groundwater monitoring facility, it is necessary to obtain information on the geological strata encountered by the borehole and its completion details. These will include the depth of the borehole, its diameter(s) and construction details (casing, screen and pack). These details may be obtained from site records, the original driller's log(s), or the British Geological Survey. Once all available information has been collated and assessed, the most appropriate course of action can be determined.

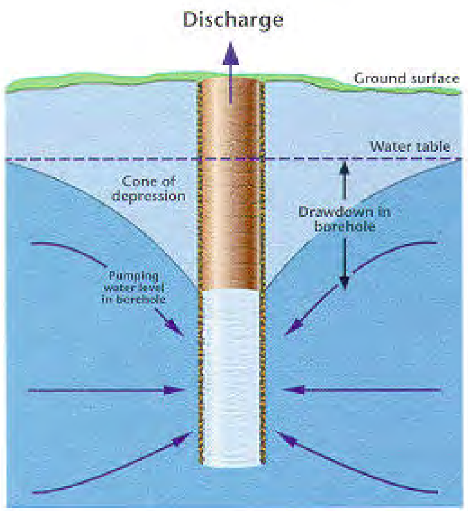
5. Conversion to groundwater monitoring points

Redundant boreholes have the potential for conversion into groundwater monitoring boreholes if the data collection exercise described in Section 4 (above) indicates that the boreholes intersect important aquifer units (in terms of resource and quality), and are constructed so that representative groundwater samples may be collected or water levels measured. The ideal borehole construction and completion is dictated by the geological strata encountered and its intended use. Boreholes which intersect a single aquifer unit may be cased through the unsaturated zone, but open hole (or screened) below the water table. Boreholes in complex geologies are likely to require casing over most of the depth of borehole with the exception of the aquifer unit(s) of interest **(*see Fig.2(A)*)**. These details must be established when considering conversion of the borehole to a monitoring point along with the ultimate purpose that the monitoring facility will serve.

a) Environment Agency strategic monitoring boreholes.

The Agency has a duty to monitor groundwater quality and water table elevation, and a network of Agency and privately owned boreholes and wells is used for this purpose. New monitoring points are often required to improve coverage or to replace boreholes which have been taken out of use.

FIGURE 3
The drawdown of the water table around a pumping borehole to form a cone of depression



When a borehole is constructed such that it allows a representative sample of groundwater to be collected or water levels to be measured, and is located in an area where additional monitoring points are required, consideration should be give to converting it to an Agency monitoring borehole. The Agency may be prepared to pay for the costs of the conversion, but in return will require access to the borehole and/or its long-term lease.

b) Contaminated land/landfill monitoring point

Site investigation boreholes which have been installed as part of ground engineering investigation, land contamination study or scientific investigation may lend themselves to adaptation to longer-term groundwater monitoring facilities.

The design of boreholes on or adjacent to sites which may be contaminated is particularly important because they will act as potential conduits for the vertical migration of contaminants within the soil or fill layers if incorrectly designed. Such boreholes should be cased through the unsaturated zone and the casing sealed with an impermeable cement or bentonite grout to prevent any movement of potentially contaminated water around the outside of the casing. The top of the borehole must also be suitably protected and fitted with a robust lockable cap to prevent the unauthorised entry of objects into the borehole. Where the top of the borehole casing is below ground level it must be surrounded by a suitably constructed, watertight housing.

Boreholes close to contaminated land, landfill sites or other sources of soil gas may also require a venting facility to prevent the build up of noxious gases within the borehole.

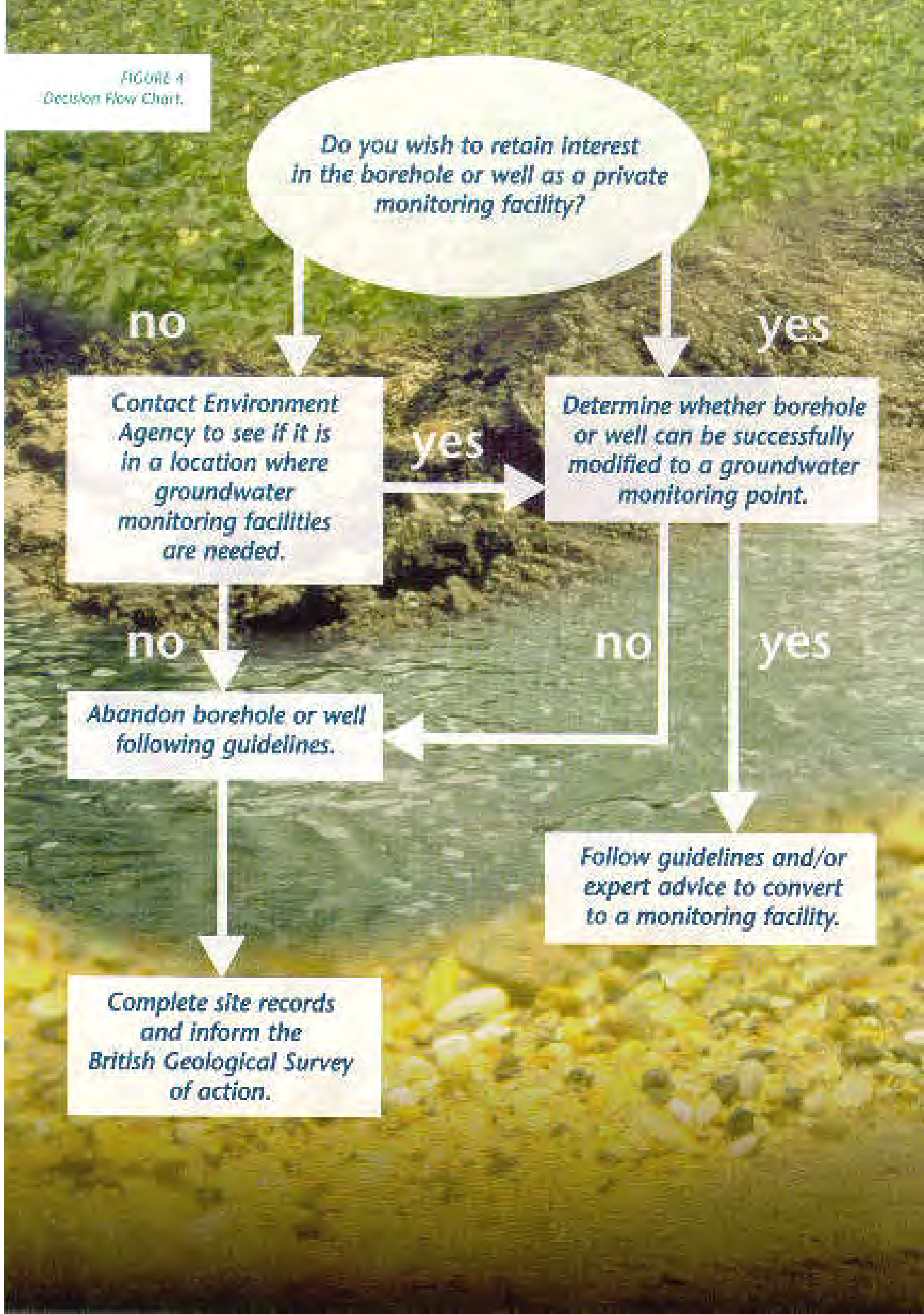


FIGURE 4
Decision Flow Chart.

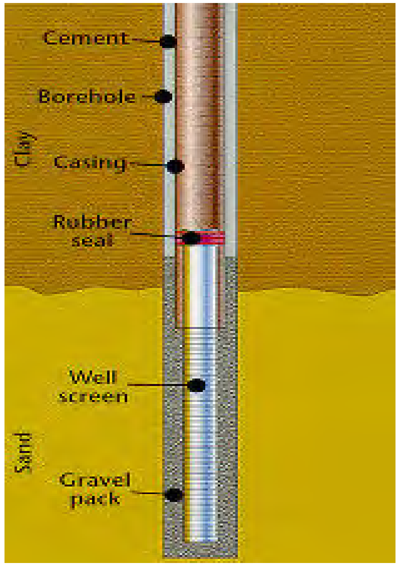


FIGURE 5
Section of a borehole showing a well screen and gravel pack (or filter) in unconsolidated sands.

c) Private monitoring boreholes.

A site owner may wish to convert a redundant abstraction borehole to a groundwater monitoring facility, particularly where the borehole is on or adjacent to contaminated land, or land where potentially polluting activities are being undertaken.

There are many good reasons for so doing including:

- To validate the success of any remedial works being undertaken on the site
- To demonstrate that activities are not causing pollution, hence prove regulatory compliance.
- As part of the " requisite surveillance" required under the Groundwater Regulations, 1998 or the Waste Management Licensing Regulations, 1994.
- To monitor water levels in an urban area where rising groundwater levels may threaten buried structures (tunnels, basements etc.).

6.Decommissioning redundant boreholes and wells

If conversion to a groundwater monitoring point is not possible or necessary, the following borehole abandonment procedures are recommended. However, every borehole and well is different and may require variation from the detail of the approach. For the best results, the employment of a proficient well contractor with a good knowledge of the local geology and well abandonment procedures is recommended.

a) Defining the objectives

Each site has its own particular characteristics that must be considered when planning how to decommission a borehole or well.

The following objectives may apply, although additional objectives may also be applicable;

- Remove the hazard of an open hole (safety issues).
- Prevent the borehole acting as a conduit for contamination to enter groundwater.
- Prevent the mixing of contaminated and uncontaminated groundwater from different aquifers.
- Prevent the flow of groundwater from one geological horizon to another.
- Prevent the wastage of groundwater from overflow to artesian boreholes.

The method of decommissioning should be capable of achieving each of the objectives that are applicable to a site.

b) Removing headworks and casing

Ensure that the borehole or well is free from all obstructions that may interfere with the sealing of the hole. In particular, the pump and pipework should be removed together with any other infrastructure (dip tubes etc.). The condition of any borehole casing and grout must be examined to ascertain whether its retention in the hole would prejudice any of the objectives of the abandonment. For many holes, examination of the casing from the ground surface will be adequate, however, deep boreholes may require the use of a down-hole Closed Circuit Television (CCTV) to examine the casing at depth.

Where casing has corroded or broken, or the grouting has failed, it may be necessary to remove those materials in order to prevent flow of groundwater around the outside of the borehole. Care should be taken, however, to ensure that removal of the well casing does not result in the collapse of the borehole walls (particularly in unconsolidated materials) and possible subsidence at the ground surface. The advice of a specialist well contractor should be sought over these issues. If it is decided that the well casing needs to be removed, various techniques are available to do this and the well contractor can advise on the most appropriate technique for a given site.

c) Backfilling the hole

For most purposes the ground should be restored as closely as possible to its pre-drilled condition. The borehole or well should be backfilled with clean (washed), uncontaminated, excavated materials such that the permeability of the selected materials are similar to the properties of the geological strata against which they are placed. The backfilled borehole will then mimic the surrounding natural strata and groundwater flow and quality will be protected.

Restoration will require a variety of materials to be used so that permeable aggregates (e.g. pea gravel, sand) are positioned adjacent to aquifer horizons, whilst low permeability materials (e.g. clay, bentonite or cement grout, concrete) are positioned adjacent to low permeability horizons ***(see Figure 2(B))***. Alternatively, the entire borehole or well can be backfilled with low permeability materials that will prevent significant vertical or horizontal movement of groundwater through or along the borehole ***(see Figure 2(C)).***

The materials used to backfill a borehole or well must be clean, inert and non-polluting. Suitable materials include pea-gravel, sand, shingle, concrete, bentonite or cement grout and uncontaminated rock. **UNDER NO CIRCUMSTANCES SHOULD POTENTIALLY POLLUTING MATERIALS BE USED AS INFILL.** Consideration should also be given to the geochemical environment into which these materials will be placed, as under different environmental conditions the behaviour of materials may change (e.g. phenol contamination may prevent bentonite grouts curing).

Aggregates (pea-gravel, shingle, sand etc.) should be selected such that they have a grain size that allows easy delivery into the borehole and should be introduced in a controlled manner to ensure that accidental “bridging” does not occur within the borehole. Concrete and grouts that are introduced in a liquid form should be introduced through an appropriate delivery pipe (e.g. tremmie pipe), to ensure that voids do not form. Boreholes that penetrate highly fissured aquifers, such as the Chalk and some limestones, present additional problems. Liquid grouts (particularly those injected under pressure), or fine-grained aggregates (e.g. fine sand) may be transported out of the borehole into the body of the aquifer through fissures. Careful monitoring of the process is required if these techniques are used, and in these cases it may be more appropriate to use coarser aggregate (e.g. gravel) as a backfill against fissured aquifers.

Where the site is in a very sensitive location (e.g. Inner Source Protection Zone (SPZI) **(*see figure 6*)** as defined in the Agency’s Groundwater Protection Policy, or within 50 metres of a potable abstraction) consideration should be given to disinfecting the materials prior to its use as infill. Care must be taken, however, to ensure that the disinfectant does not, in itself, present a groundwater pollution risk. Agency and disinfectant manufacturers advice should be sought in such instances.

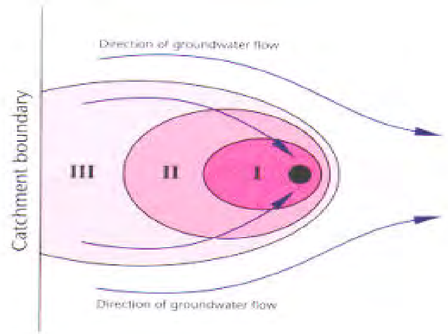


FIGURE 6
Source Protection Zones around a borehole.

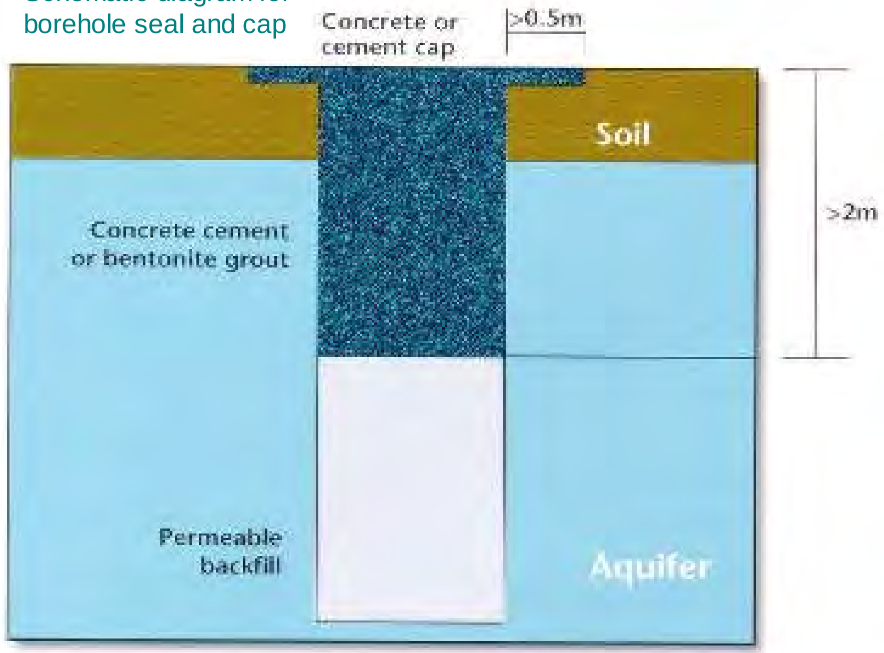
I - Inner Zone
II - Outer Zone
III - Total Catchment

d) Deep and wide boreholes/wells.

In the case of very deep boreholes and wells with wide diameters, the volume of material needed to backfill the hole may be very large. In such circumstances it may be appropriate to adopt an alternative strategy, as long as this will not prejudice any of the original objectives.

Provided that the long term structural stability of the borehole can be demonstrated, it is acceptable to place a permanent bridging seal, or plug, within the borehole and then to infill above this level using the approach given in Section 6c) **(*page 9*) (*see Figure 2(D)*).** The bridging seal should ideally be positioned below the lowest aquifer horizon. However, where this is not possible, it is important that the open borehole beneath the bridging seal penetrates no more than a single aquifer unit thereby preventing the flow of groundwater between different aquifers.

FIGURE 7
Schematic diagram for borehole seal and cap



The material commonly used as a bridging seal is cement, although a combination of a mechanical plug and cement is acceptable. Cement seals must be allowed to set (cure) in place before backfilling is continued and completed. The advice of a specialist well contractor should be sought for the most appropriate technique.

e) Sealing the top of the borehole.

In order to prevent potentially contaminated surface run-off or other liquids entering the backfilled borehole, it is necessary to complete the backfilling of all boreholes with an impermeable plug and cap. The final 2 metres (from ground level down) should be filled with cement, concrete or bentonite grout and a concrete or cement cap of suitable strength should then be installed over the top of the borehole and surrounding ground, such that its diameter is at least one metre greater than the diameter of the backfilled borehole ***(see Figure 7)*.**

f) Artesian boreholes.

For artesian boreholes, the de-commissioning process should aim to confine the groundwater to the aquifer from which it came in order to prevent loss of confining pressure, and the loss of water resources to the surface or other formations.

The first step is to control the artesian flow.

There are a number of ways to accomplish this depending, in part, on the water pressure in the confined aquifer and the depth to which the water level must be lowered, for instance;

- Pumping the borehole to produce the necessary drawdown.
- Pumping nearby boreholes.
- Extending the casing above ground level beyond the potentiometric surface.
- Introduce dense, non-polluting, fluids into the borehole.
- Introduce a pre-cast plug at an appropriate level within the hole.
- Using an inflatable packer, pressure grout the void space below the packer.

Decommissioning of artesian boreholes is likely to be easiest in late summer, when groundwater levels and artesian flows are at their lowest. Decommissioning artesian boreholes is a specialist job and requires expert advice.

g) Recording details on site plan

Complete and accurate records should be kept of the abandonment procedures for possible future reference.

These records should include the following;

- The reasons for abandonment (e.g. water quality problems).
- Measurement of groundwater level prior to backfilling.
- The depth and position of each layer of backfilling and sealing materials.
- The type and quantity of backfilling and sealing materials used.
- Any changes made to the borehole/well during the abandonment (e.g. casing removal).
- Any problems encountered during the abandonment procedure.

Abandoned borehole and well locations should be marked on site records and, if possible, on the ground. Details of any decommissioning or modifications to borehole construction should also be forwarded to the British Geological Survey.

7. Conversion to soakaways

Redundant wells and boreholes have historically been used for the disposal of surface water, foul effluent and other waste liquids. In many instances this practice has resulted in groundwater pollution. It is not considered acceptable practice to use redundant abstraction boreholes and wells for the disposal of surface or foul drainage, or any other potentially polluting matter.

It is a criminal offence under Section 85 of the Water Resources Act, 1991 to “cause or knowingly permit any poisonous, noxious or polluting matter or any solid waste matter to enter any controlled waters”. The definition of “controlled waters” includes all groundwater.

Where the on-site disposal of surface of foul drainage into land or groundwater is necessary then the effluent should normally be treated before its discharge into a shallow soakaway. An authorisation from the Environment Agency is normally required and a discharge may be illegal without one, regardless of whether pollution occurs.

In determining an application for an authorisation the Agency will assess the particular risks of pollution by taking into account the potential for attenuation of contaminants before they reach the water table.

8. Specialist Advice

It is recommended that the advice of a specialist well contractor and local Environment Agency staff should always be sought, and the site-specific characteristics of a site given full consideration when determining the best borehole abandonment solution. Details of specialist drilling contractors can be obtained from The British Drilling Association. Further advice can be obtained from the local Environment Agency office, or from the Agency’s National Groundwater & Contaminated Land Centre.

9. Further Guidance and References

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State Co-ordinating Committee on Groundwater, 1996. **State of Ohio Technical guidance for Sealing Unused Wells.**

The American Water Works Association, 1984. **AWWA Standards for Water Wells.** AWWA A100-84.

US Environmental Protection Agency, 1975. **Manual of Water Well Construction Practices.** EPA – 570/9-75-001.

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The Environment Agency delivers a service to its customers with the emphasis on authority and accountability at the most local level possible. It aims to be cost-effective and efficient and to offer the best service and value for money.

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