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ARTIFICIAL POTHoles--
BLASTING TECHNIQUES

Section 5.5.4, US ARMY CORPS OF ENGINEERS
WILDLIFE RESOURCES MANAGEMENT MANUAL

by

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A management techniques report on blasting artificial potholes is provided as Section 5.5.4 of the US Army Corps of Engineers Wildlife Resources Management Manual. The report was prepared as a guide to assist biologists and resource managers in developing habitat management programs for project lands. Topics covered for artificial potholes include management objectives, cautions and limitations, wildlife use, site selection and preparation, blasting methods, maintenance, evaluation, and personnel and costs. Blasting potholes is a practice employed to improve waterfowl habitat by creating open-water areas in an otherwise monotypic stand of emergent wetland vegetation. The procedure has been most widely used in the prairie pothole region of the northern United States and southern Canada but has also been applied successfully in other areas. Potholes are most (Continued)					
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often used by dabbling ducks and may also attract other wetland-dependent wildlife species. Details are provided on selection of sites appropriate for blasting, development of design criteria, and implementation of blasting techniques. The uses of dynamite, ammonium nitrate/fuel oil mixtures, and waterproof gels as blasting agents are described, and safety precautions are discussed for all techniques. The pros and cons of blasting methods are examined, and comparative cost information is given.

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PREFACE

This work was sponsored by the Department of Defense (DOD) military branches under the DOD Natural Resources Program. Technical Monitors for the study were representatives of the Fish and Wildlife Committee of the Defense Natural Resources Council, DOD. The report serves as a section of the US Army Corps of Engineers Wildlife Resources Management Manual, as developed by the Headquarters, US Army Corps of Engineers, under the Environmental Impact Research Program.

This report was prepared by Mr. Chester O. Martin, Resource Analysis Group (RAG), Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), and Mr. Larry E. Marcy, who was employed by WES under an Intergovernmental Personnel Act contract with Texas A&M University. Mr. Marcy is currently employed by the US Army Engineer District, Vicksburg, Vicksburg, Miss. Mr. Martin, Team Leader, Wildlife Resources Team, RAG, was principal investigator for the work unit.

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NOTE TO READER

This report is designated as Section 5.5.4 in Chapter 5 -- MANAGEMENT PRACTICES AND TECHNIQUES, Part 5.5 -- WETLAND HABITAT MANAGEMENT, of the US ARMY CORPS OF ENGINEERS WILDLIFE RESOURCES MANAGEMENT MANUAL. Each section of the manual is published as a separate Technical Report but is designed for use as a unit of the manual. For best retrieval, this report should be filed according to section number within Chapter 5.

ARTIFICIAL POTHOLES--BLASTING TECHNIQUES

Section 5.5.4, US ARMY CORPS OF ENGINEERS
WILDLIFE RESOURCES MANAGEMENT MANUAL

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Potholes are defined as shallow open-water retention areas or basins with surface areas of usually less than 4 acres (Atlantic Waterfowl Council 1972, Yoakum et al. 1980). Artificial potholes are smaller, usually 1/10 to 1/2 acre in size, and are most often created by bulldozers, draglines, and blasting with explosives (Schnick et al. 1982). This report discusses the use of blasting methods to create artificial potholes. Its purpose is not necessarily to promote blasting as a preferred management practice, but rather to provide technical information that will help the biologist make sound management decisions regarding the use of blasting techniques. Additional strategies for managing waterfowl habitat are described in other sections of this manual.

MANAGEMENT OBJECTIVES

The primary objective for pothole blasting is to improve sites as waterfowl habitat by creating open-water areas in an otherwise monotypic stand of

emergent wetland vegetation (Fig. 1). Well-placed and properly blasted potholes can be especially beneficial to wildlife by increasing the interspersed vegetative cover and aquatic habitats (Strohmeyer and Fredrickson 1967, Hopper 1972). Other potential benefits include provision of (1) open-water areas to attract waterfowl for courtship activities and brood-rearing, (2) additional aquatic areas to help disperse waterfowl throughout a marsh, (3) improved loafing or feeding areas, and (4) dependable water sources during dry periods for wetland-dependent wildlife species (Atlantic Waterfowl Council 1972, Schnick et al. 1982).

Pothole blasting has been most widely used in the prairie pothole region of the northern United States and southern Canada to restore or create waterfowl habitat (Provost 1948, Mathiak 1965, Strohmeyer and Fredrickson 1967, Hoffman 1970). However, the practice has also been used successfully in other regions. In the Chesapeake Bay area of Maryland, Warren and Bandel (1968) found blasting to be an appropriate management technique in both fresh and salt marshes. Blasting was used to reclaim small woodland potholes on the Chippewa National Forest in Minnesota (Mathisen et al. 1964), and it has been applied to improve marsh sites in Colorado (Hopper 1972), New Mexico (Stahlecker and Skinner 1980, Skinner 1982), and other western states. In Missouri, potholes have been blasted to create open-water areas for attracting waterfowl to managed moist-soil units (George Seek, Missouri Department of Conservation, pers. commun., 1987).

Blasting should be considered for pothole construction only when the manipulation of water levels by other means proves impractical for obtaining the desired relationship of open water to suitable cover (Provost 1948). It is most appropriate where site conditions limit the use of heavy equipment (dredges, dozers, and draglines) for pond creation (Mathisen et al. 1964). The project manager should carefully consider site characteristics, safety factors, adjacent land uses, the proximity of structures and human activities, and alternative methods to wetland development before embarking on a pothole blasting program.

CAUTIONS AND LIMITATIONS

Although blasting potholes has been used successfully to create wetland diversity and attract waterfowl in several regions, the resource manager



Figure 1. Artificial potholes created by blasting in marsh habitats in northern Iowa (courtesy Guy Zenner, Iowa Department of Natural Resources)

should be aware of some serious limitations to the technique. It became a popular management practice in the 1960s when the development of ammonium nitrate and fuel oil (AN/FO) mixtures provided a cost-effective blasting agent, and numerous openings were blasted in public and private wetlands. However, later studies showed that many of these potholes provided only limited nesting and brood-rearing habitat and had no apparent effect on waterfowl production (Burger 1973). Artificial techniques such as blasting may also be less aesthetically pleasing than more natural approaches to wetland management and are less likely to produce the zonation typical of natural plant communities (Weller 1978, 1981).

A disadvantage of using explosives to create potholes is the extremely steep and sometimes almost perpendicular sides that often result from the blast (Fig. 2). This condition creates habitats that are less attractive to waterfowl than basins with gradual slopes (Linde 1969; Weller 1981; Guy Zenner, Iowa Department of Natural Resources, pers. commun., 1987). The steep sides resulting from explosives is also a concern in areas where livestock may become entrapped. Thus, consideration should be given to using blasting patterns that result in more gradual slopes, especially on rangelands (Don Childress, Montana Department of Fish, Wildlife and Parks, pers. commun., 1988). The application of various patterns and charge sizes to achieve desired slopes is discussed later under the topic Blasting Methods.

Opinion apparently differs as to the suitability of pothole shorelines for waterfowl. The banks of potholes blasted in Manitoba were used primarily as loafing sites; ducks spent 86% of their time on top of elevated banks, which provided a good vantage point or lookout (Hoffman 1970). However, blasting does not always leave exposed soil banks suitable for loafing and nesting (Burger 1973). Factors that apparently affect the characteristics of banks resulting from pothole blasting include soil type, hydrologic conditions, type and amount of explosive charge used, and reinvasion potential of surrounding plant communities. Periodic maintenance and site manipulation may be needed to ensure a diversity of exposed and vegetated areas to satisfy waterfowl loafing, nesting, and cover requirements.

Even though blasting is considered cost effective (see section on Personnel and Costs), draglines or bulldozer ditching and dredging have certain advantages over using explosives (Burger 1973). The use of low-level dams to slightly raise water levels may be less expensive and more effective than

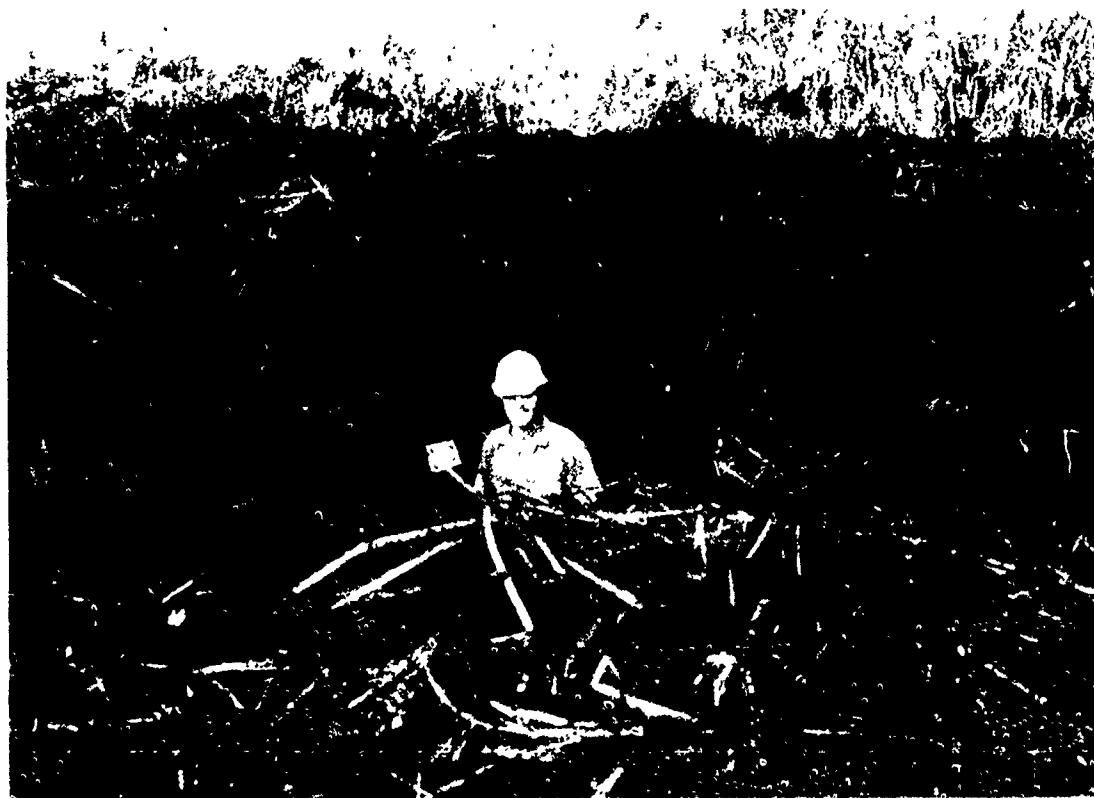


Figure 2. Blasted potholes showing steep sides and blown out material
(courtesy Guy Zenner, Iowa Department of Natural Resources)

blasting in some areas (Strohmeyer and Fredrickson 1967). Guy Zenner (pers. commun., 1987) recommended that better alternatives to blasting (although probably more expensive) might consist of (1) building a water control structure at a wetland's outlet and regulating the water level or (2) selectively removing soil from the basin with a dragline or bulldozer. It should be noted that blasting or ditching in wetland areas may require a permit under Section 404 of the Clean Water Act (Public Law 92-500).

The State of Minnesota no longer recommends pothole creation using either blasting or dragline methods because of past damages to wetland habitats resulting from the improper application of these techniques, especially on private lands (Richard A. Carlson, Minnesota Department of Natural Resources, pers. commun., 1987). Large open-water areas are occasionally created with dozers in dry weather periods or during wetland drawdowns; however, this is usually not recommended unless a vegetation-choked wetland is at least 80 acres in size and there is a natural open-water wetland nearby.

A critical concern regarding pothole blasting is the potential safety hazard inherent with the use of explosives. Basic precautions for handling and applying explosives are provided in Appendix A. Safety procedures are also emphasized in the text under Preparation for Blasting and Blasting Methods.

WILDLIFE USE

Habitat created by pothole blasting is considered most beneficial to migrating and breeding waterfowl (primarily dabbling ducks) by providing seclusion, feeding, nesting, and loafing sites (Provost 1948, Strohmeyer and Fredrickson 1967, Hoffman 1970). Artificial potholes in Iowa were most attractive to blue-winged teal (*Anas discors*) on spring migration, and greatest use occurred when excavations were new (Provost 1948). In Colorado, 95.4% of pothole use by waterfowl was in the spring; mallards (*A. platyrhynchos*) and blue-winged teal composed 61.7% and 10.4%, respectively, of ducks using the potholes (Hopper 1972). Hoffman (1970) reported that 66% of all waterfowl use of potholes in Manitoba was by breeding pairs of dabbling ducks, primarily blue-winged teal (56.4%). Other dabbling ducks that use blasted potholes are northern pintail (*Anas acuta*), gadwall (*A. strepera*), American wigeon (*A. americana*), northern shoveler (*A. clypeata*), green-winged teal

(*A. crecca*), and American black duck (*A. rubripes*) (Provost 1948, Hoffman 1970, Hopper 1972).

Use of artificial potholes by diving ducks is limited; species occasionally reported are lesser scaup (*Aythya affinis*), ring-necked duck (*A. collaris*), redhead (*A. americana*), and canvasback (*A. valisineria*). Hopper (1972) counted only 4 instances of use by Canada geese (*Branta canadensis*) during a 3-year study of potholes in eastern Colorado. Other species of birds reported to occur in pothole habitats include pied-billed grebe (*Podilymbus podiceps*), American coot (*Fulica americana*), American bittern (*Botaurus lentiginosus*), king rail (*Rallus elegans*), Virginia rail (*R. limicola*), sora (*Porzana carolina*), red-winged blackbird (*Agelaius phoeniceus*), yellow-headed blackbird (*Xanthocephalus xanthocephalus*), swamp sparrow (*Melospiza georgiana*), and common yellowthroat (*Geothlypis trichas*) (Provost 1948). Ring-necked pheasants (*Phasianus colchicus*) were attracted to the edge of newly blasted potholes in Michigan and Wisconsin (Mathiak 1965).

Mammals reported to use habitats associated with potholes are muskrat (*Ondatra zibethica*), mink (*Mustela vison*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), ground squirrels (*Spermophilus* spp.), meadow jumping mouse (*Zapus hudsonius*), long-tailed shrew (*Sorex dispar*), white-tailed deer (*Odocoileus virginianus*), and cottontails (*Sylvilagus* spp.) (Provost 1948, Mathiak 1965). Reptiles that frequent potholes include the common snapping turtle (*Chelydra serpentina*), painted turtles (*Chrysemys* spp.), garter snakes (*Thamnophis* spp.), cricket frogs (*Acris* spp.), and leopard frogs (*Rana* spp.) (Provost 1948). Many other nongame species potentially use pothole habitat.

SITE SELECTION AND PLACEMENT

Site Considerations

Soil type and level of the water table are the most important site location factors for blasting potholes. Soils that are greater than 6 ft deep or without a hardpan (a cemented layer of coarse mineral soil or compacted clayey layer impenetrable to plant roots) are not conducive to blasting (Scott and Dever 1940, Provost 1948). Blasting should not be attempted in peat soils unless a mineral soil is within 3 to 4 ft of the surface (Mathisen et al. 1964, Bedish 1972). In deep peat soils, the bottom of the hole is loosened by

the blast, and material may float up and fill the pothole within a year. Coarse mineral soils and clays are more conducive to blasting than are sands, sandy-clays, silts, or peat soils (Strohmeyer and Fredrickson 1967).

The depth of the water table is also important in preserving size and shape of the hole (Provost 1948). Inundation of the hole immediately after blasting helps preserve its volume and depth, whereas exposure to air hastens the loss of both. Soils exposed to alternate periods of drying and wetting will fragment more quickly than soils that are continually wet or dry. Greatest initial depth is attained when the water table is at or less than 4 in. below the surface at the time of blasting. The higher the water table, the less depth is needed to preclude plant regrowth and maintain the clearing (Provost 1948).

Location and orientation of excavations should be planned with consideration given to potential impacts from wave action on the completed basin or ditch (Scott and Dever 1940). Loss in depth and volume result primarily through erosion of the sides by wave action. Therefore, the long dimension of a ditch should be oriented with the prevailing winds. If possible, potholes should be located where surrounding vegetation will provide a windbreak.

The vegetation existing on a site can sometimes be used as a guide to help determine if it is suitable for pothole development. Provost (1948) found that if sedges (*Carex* spp.) dominated a marsh, the water table was generally inadequate to maintain potholes throughout the waterfowl nesting season because such areas usually dried up in the summer. However, sedge-dominated marshes are often underlain by a considerable amount of water that can be easily exposed by blasting. The major drawback is that the holes will likely change shape and may become covered with floating sections of sedge mat (Guy Zenner, pers. commun., 1987).

Location

Artificial potholes are of greatest value to waterfowl where dabbling ducks are abundant and where open-water habitats are limiting. Potholes located near good waterfowl areas or along flight lanes can be expected to receive greater use in a shorter period of time than those located far from duck concentrations (Mathiak 1965). Although potholes have primarily been created in marsh habitats, Strohmeyer and Fredrickson (1967) suggested that isolated bogs, shallow and continuously vegetated ponds, and wet meadows may

be better suited to blasting. Extensive mud flats in reservoir drawdown zones and along riparian corridors may also be potential sites for pothole blasting. However, the longevity of potholes in drawdown zones may be severely reduced due to bank erosion caused by wave action during both drawdown and filling (Don Childress, pers. commun., 1988).

Provost (1948) recommended that potholes blasted for dabbling ducks be located as close as possible to good upland nesting cover. In areas where marshes are subject to severe summer drought, potholes should be located within 0.5 mile of suitable brood-rearing habitat (Atlantic Waterfowl Council 1972). However, blasted potholes in Manitoba did not function as brood habitat, and there was little direct relationship between nest location and pothole use when adequate nesting cover was available (Hoffman 1970). Similar conclusions were reached by Evans et al. (1952) and Evans and Black (1956) in Manitoba and South Dakota, respectively.

Spacing and Dimensions

The number of potholes desired and their spacing will depend on the existing cover-to-water ratio and interspersions of cover types in the management area. Linde (1969) recommended that pothole arrangements be in block form, but patterns and sizes may have many variations based on site characteristics and management objectives. Hammond and Lacy (1959) suggested spacing potholes 150 to 200 ft apart, and Mathiak (1965) recommended one hole every 200 to 300 ft. Warren and Bandel (1968) suggested blasting potholes in groups of 5 to 15 within a radius of 200 ft, with similar clusters arranged at intervals of 500 to 1000 ft. Another strategy for pothole placement is the saturation method in which a marsh area is covered with ponds of various sizes (Warren and Bandel 1968). Emergent cover well interspersed with open water in a 1:1 ratio has been shown to support the greatest diversity and density of breeding waterbirds, including dabbling ducks, in inland fresh marshes (Weller and Spatcher 1965, Weller and Fredrickson 1974, Kaminski and Prince 1981, Murkin et al. 1982). This relationship may generally be used as a guide to determine how many potholes are needed and where they should be placed. However, limitations to project funds and available personnel will seldom allow the manager to achieve an ideal cover-to-water ratio using pothole blasting methods.

A variety of blasting strategies can be used to create ditches or oval to round potholes (Fig. 3). Hammond and Lacy (1959) found the optimum size of potholes to be 20 to 25 ft wide and 40 to 75 ft long, with a surface area of 500 to 2000 sq ft and a preferred depth of 4 ft. Potholes blasted in Manitoba averaged 26 ft wide, 55 ft long, and 5 ft deep (Hoffman 1970). Best results were obtained in Maryland freshwater marshes with potholes 30 to 35 ft in diameter (Warren and Bandel 1968); a hole 5 to 6 ft deep when blown was still 4 to 5 ft deep after some filling occurred. Hopper (1972) examined 84 potholes blasted using several AN/FO charge sizes and found that potholes averaging approximately 570 and 850 sq ft received significantly more duck use than those averaging 200 and 290 sq ft.

It is strongly recommended that the manager experiment with various-sized charges to determine the optimum amount of explosive needed to give best results in the project area (Linde 1969). Additional information on blasting patterns and results is provided in the descriptions of blasting methods.

PREPARATION FOR BLASTING

The use of explosives to create potholes should be strictly supervised by qualified, experienced personnel. Although basic safety requirements are discussed in this report, the information presented is intended to provide a description of techniques and not a detailed guide to the use and care of explosives and blasting agents. Project personnel must not attempt blasting unless they have received proper training, and the appropriate clearances and permits must be obtained. The manager must always consider the potential impacts of concussions on surrounding property to avoid damages to structures and injury to humans and livestock.

For maximum efficiency, blasting should be done when climatological records indicate a probable rise in the water table (Provost 1948). Blasting must occur when wind conditions are favorable. A moderate to strong wind blowing away from the axis of the charge will prevent debris from falling back into the excavation (Fig. 4); this is especially true for holes with large diameters (Scott and Dever 1940, Provost 1948, Mathisen et al. 1964). Strong winds are an important safety factor because blasting personnel can station themselves upwind to avoid the effects of fallout (Mathiak 1965). Additionally, blasting on windy days makes the concussion much less noticeable and rapidly dissipates gases produced by the blast.



Figure 3. Examples of blasting used to create a ditch (top) and a series of small oval potholes (bottom). (Courtesy Guy Zenner, Iowa Department of Natural Resources)



Figure 4. Potholes should be blasted when there is a moderate to strong wind to keep debris from falling back into the excavation (courtesy George Seek, Missouri Department of Conservation)

Blasting must never be attempted during an electrical storm or when one is impending. A lightning strike or nearby miss is almost certain to initiate both electric and nonelectric blasting caps and other sensitive explosive elements, such as caps in delay detonators. Even at remote locations, lightning strikes can cause extremely high local earth currents that may initiate electrical firing circuits. The effects of remote lightning strikes are amplified by proximity to conducting elements, such as those found in buildings, fences, railroads, bridges, streams, and underground cables or conduit. The only safe procedure is to immediately suspend all blasting activities when climatic conditions favor electrical storms (US Army 1986; George Seek, pers. commun., 1988).

Even though soils may appear suitable for blasting, preliminary soil borings should always be made to ascertain the underlying substrate. Don Childress (pers. commun., 1988) stated that heavy soils blasted along old river oxbows in Montana were often found to overlay gravel beds at varying depths. Blasting under these conditions can result in the shock wave being

dissipated into the gravel, and rocks blown from the hole can create a very hazardous situation unless precautions are taken.

The blast site should be cleared of rank vegetation to facilitate work by the charge-loading crew. Planks can be used as walkways on wet sites to aid crew mobility (Scott and Dever 1940). Charge lines should be marked and staked off (Provost 1948), and warning signs should be placed around the perimeter of the marsh site. Unauthorized persons must be prevented from entering the blast area, and personnel should be positioned along roads to delay traffic until blasting is completed. A discussion of distances at which personnel are relatively safe from the effects of blasting is provided in Appendix A. Test shots (i.e., preliminary blasts to test the effect of charges and response of the substrate) should always be made to determine the best charges for a particular area (Warren and Bandel 1968).

BLASTING METHODS

Dynamite was the first type of explosive used to blast potholes for waterfowl management (Scott and Dever 1940, Provost 1948, Dries 1963). The most prevalent blasting agent today is AN/FO, which has been widely used since the mid-1960s (Mathiak 1963, 1965; Mathisen et al. 1964; Miller and Stricker 1965; Bandel et al. 1967; Hoffman 1967, 1970; Linde 1969; Warren and Bandel 1968; Bedish 1972). However, dynamite is still preferred in some cases because it offers greater flexibility in the placement of small charges (Strohmeyer and Fredrickson 1967). An explosive waterproof gel has recently been tested by the USDA Forest Service (Stahlecker and Skinner 1980, Skinner 1982) and shows promise for future use.

Although a detailed description of explosives and blasting agents is beyond the scope of this report, a general discussion of firing systems and their components is needed to understand procedures outlined under each blasting technique. This information, including an explanation of commonly used blasting terms, is provided in Appendix B. The manager should refer to State and Federal guidelines and manuals (e.g., US Army 1986) and consult a certified blasting advisor for more detailed information. Safety precautions applicable to all techniques are provided in Appendix A. Basic procedures for using explosives to blast potholes are described below.

Dynamite

Dynamite has been successfully used to create artificial potholes, but the manager must use extreme care in its application and be aware of the different types of dynamites and their characteristics. Most dynamites, with the notable exception of military dynamite, contain nitroglycerin plus various combinations of absorbents, oxidizers, antacids, and freezing depressants. Dynamites vary greatly in strength and sensitivity depending upon, among other factors, the percentage of nitroglycerin they contain. Uses and characteristics of military and commercial dynamites are shown in Table 1. Military dynamite is equivalent in strength to 60% commercial dynamite and is more stable and safer to store, handle, and transport. However, it is reliable underwater only up to 24 hours. Because of its low sensitivity, sticks of military dynamite must be well compacted to ensure complete detonation of the entire charge (US Army 1986).

Scott and Dever (1940) and Provost (1948) described the use of dynamite to create ditches and basins to open up stands of marsh vegetation. Provost conducted experimental blasts at 21 sites in northwest Iowa using 4 blasting patterns (1-, 2-, and 3-line charges and posthole charges). The application of procedures will vary according to site conditions and management objectives. Test shots should always be fired before blasting on a larger scale.

Line charges. Line charges consist of a series of charges placed approximately 2 ft apart in a straight line. The propagation method, in which the detonation of a single charge explodes all the others, is preferred for line charging; the method is most reliable when the ground is saturated (Scott and Dever 1940, Provost 1948). Multiple rows of line charges may be used to create deeper, wider ditches. Figure 5 shows recommended placement of 1- and 2-line dynamite charges (after Provost 1948). Several line charges may be crisscrossed to produce an oval or round hole. Instructions for charge placement and preparation for blasting are as follows:

- (1) Clear the site of rank vegetation and debris, and stake out a line along which the charges will be placed.
- (2) Use a broom handle or other suitable probe, marked in inches to indicate depth, to punch holes in the wet soils. Scott and Dever (1940) suggested that holes be 2-1/2 to 4-1/2 ft deep located at 18- to 24-in. intervals along the line. For 2-line charges, Provost (1948) recommended 4 sticks of dynamite or less every 2 ft along lines spaced 2 to 4 ft apart. Where individual charges are of 2 sticks, spacing should be reduced to 18 in., and where they are

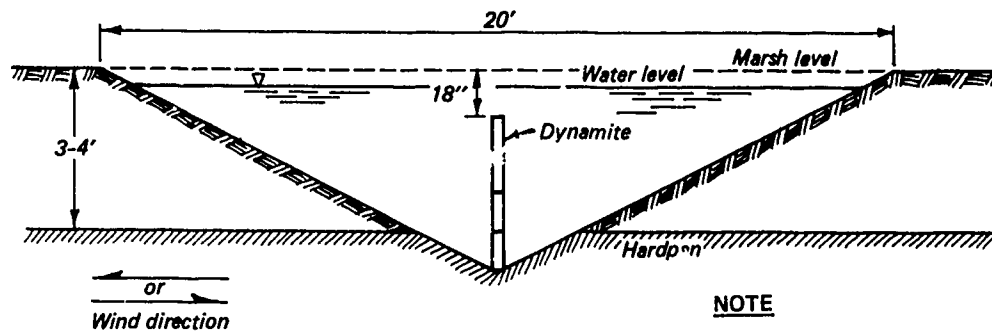
Table 1. Types of dynamites and selected characteristics
(after US Army 1986)

Type of Dynamite	Velocity of Detonation ft/sec (m/sec)	Intensity of Poisonous Fumes	Water Resistance
Military dynamite, M1	20,000 (6,100)	Dangerous	Good*
Straight dynamite 40%	15,000 (4,600)	↓	Good*
(commercial) 50%	18,000 (5,500)		Good
60%	19,000 (5,800)		Good
Ammonia dynamite 40%	8,900 (2,700)		Poor
(commercial) 50%	11,000 (3,400)		Poor
60%	12,000 (3,700)		Poor
Gelatin dynamite 40%	7,900 (2,400)		Good
(commercial) 50%	8,900 (2,700)		Good
60%	16,000 (4,900)		Good
Ammonia-gelatin 40%	16,000 (4,900)	↓	Excellent
dynamite 60%	18,700 (5,700)		Excellent
(commercial)			

* Good only if fired within 24 hours.

4 sticks, spacing may be increased to 30 in. However, a spacing of 2 ft for ordinary loads results in maximum efficiency for propagation and excavation (Provost 1948).

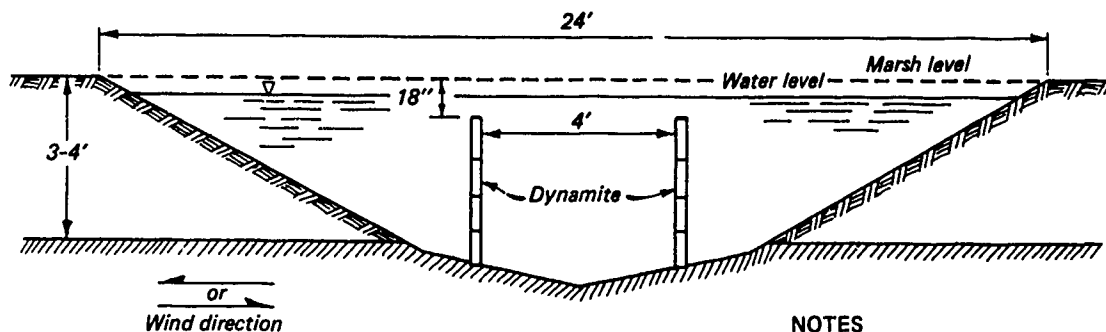
- (3) The size of the charge is governed by the depth of the soil and water above the surface of the hardpan; use one stick of dynamite for 2-1/2 ft, two to three sticks for 3-1/2 ft, and three to four sticks for 4-1/2 ft of soil and water, respectively (Scott and Dever 1940, Provost 1948). The bottom charge should rest on the hardpan, and the top edge of the upper charge should be approximately 18 in. below the soil surface (Fig. 5). The load side should then be tamped down firmly.
- (4) Prime the end stick(s) in a line charge with det-cord (50 grains per foot). Prime the det-cord using an electric or nonelectric firing system, as described in Appendix B. One cap usually suffices for each line loading; where spacing of the charges approaches 2 to 4 ft, as in multiple lines, the use of a det-cord ring main will prevent partial detonation, especially in drier soils that prohibit sympathetic propagation of charges.
- (5) If a nonelectric system is used, blasting caps should be primed by trimming the end of the fuse at a right angle to the long axis of the fuse to expose a fresh, clean, and dry surface to the cap. Insert the trimmed end of the fuse into the cap until it makes contact with the charge in the cap (Mathiak 1965). Special care



NOTE

Use 16 sticks of dynamite, 4 per hole,
each hole spaced 2 ft apart.

POTHOLE PROFILE WITH 1-LINE CHARGE



NOTES

Use a total of 40 sticks of dynamite in 2
lines, spaced 4 ft apart.

Use 4 sticks per hole, each hole spaced
2 ft apart.

POTHOLE PROFILE WITH 2-LINE CHARGES

Figure 5. Recommended line charges for creating ditches or potholes by blasting with dynamite (after Provost 1948)

should be taken to avoid twisting or pushing the cap firmly against the fuse, as blasting caps are pressure sensitive and will explode if handled carelessly. A cap crimper, specifically designed for the job, should be used to tighten the cap around the fuse about 1/8 in. from the open end of the cap.

Posthole charges. Posthole charging is used to produce round or oval-shaped basins by placing primed bundles of dynamite (20 to 35 sticks each) in 4-ft-deep, 10-in.-diam holes dug with a posthole digger or auger (Fig. 6). Priming the charges is the same as described for line charges. Figure 7 shows a design for placing posthole charges 10 ft apart along crisscrossed line charges; this technique is recommended for opening up centers of shallow ponds and marshes. A cross-shaped clearing composed of 5 deep potholes in the center of a 5- to 20-acre marsh will give maximum edge and interspersion (Provost 1948). Posthole charges scattered throughout a marsh can be detonated to create deeper reservoirs of water during times of drought (Provost 1948).



Figure 6. A posthole auger can be effectively used to dig holes for charge placement (courtesy George Seek, Missouri Department of Conservation)

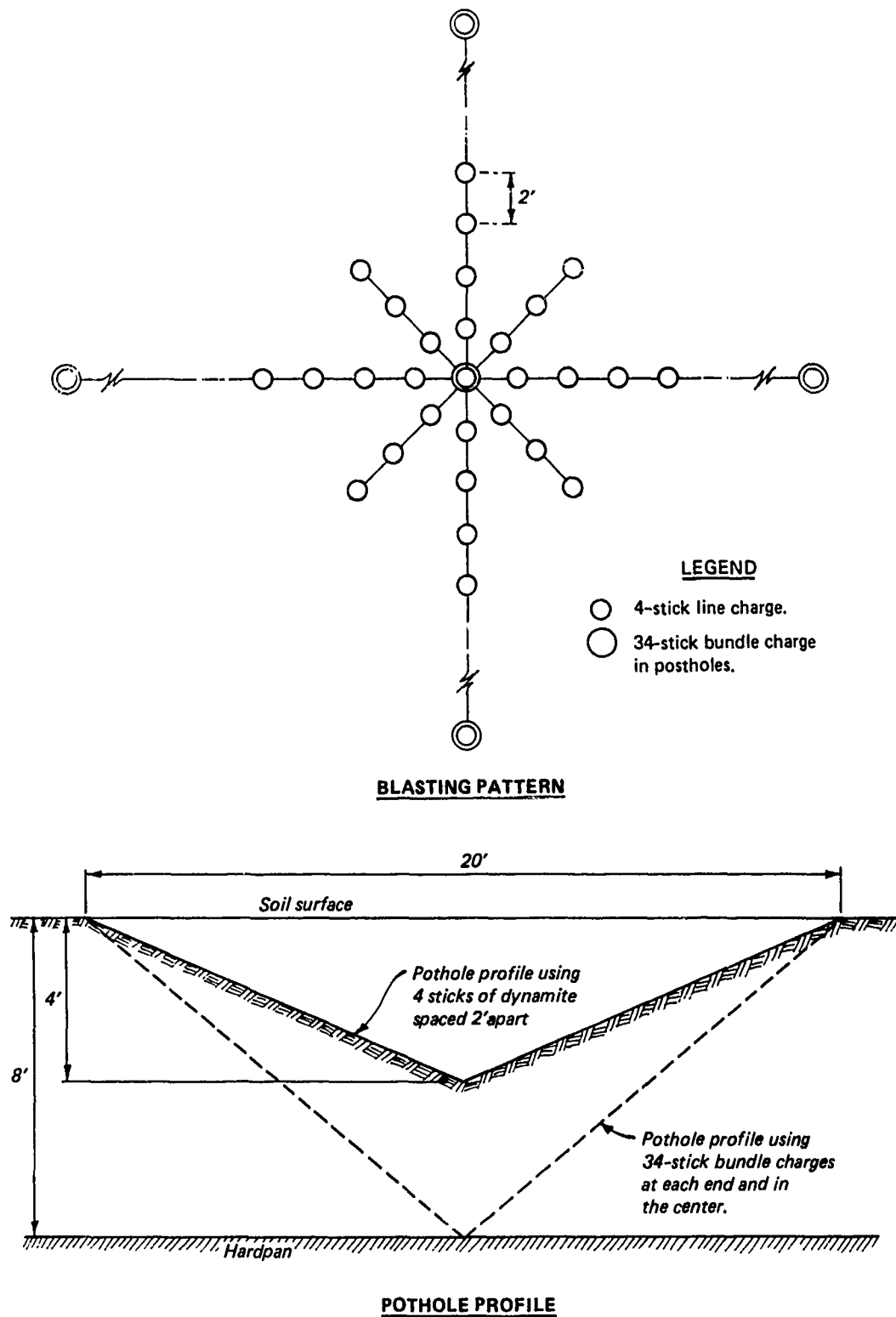


Figure 7. Recommended charge placement for opening up the center of shallow ponds or marshes using posthole charges positioned along crisscrossed line charges (after Provost 1948)

Ammonium Nitrate

Ammonium nitrate is a common commercial fertilizer that can be used to blast potholes. The prilled form (spherical pellets) mixed with No. 2 fuel oil is the most satisfactory type and is classed as a blasting agent (Mathisen et al. 1964). The product is relatively inexpensive and is safer to use than dynamite. However, ammonium nitrate is extremely hygroscopic and is not suitable for underwater use unless packaged in a waterproof container or detonated immediately after placement. The poisonous fumes of ammonium nitrate are considered dangerous (US Army 1986). The AN/FO mixture is insensitive to shock and must be detonated by means of a dynamite primer rather than a blasting cap. It can be purchased in premixed quantities, but onsite field-mixing is possible. The field mix usually recommended is 1 gal of No. 2 fuel oil to 100 lb ammonium nitrate (Mathisen et al. 1964). However, Mathiak (1965) found that a mix of 5 to 6 qt of fuel oil to 100 lb of AN produced the best results. Warren and Bandel (1968) substituted diesel fuel for No. 2 fuel oil because it was readily available at their site. Thorough mixing and a soaking time of at least 45 minutes is recommended (Mathisen et al. 1964); soaking the mixture for 24 hours prior to blasting will result in maximum effectiveness of the product.

Blasting procedure. The basic procedure for using AN/FO to blast potholes is as follows:

- (1) Clear the site of debris and unwanted vegetation, and dig the charge holes. Holes can be dug with sharp shovels, posthole diggers, hand augers, or power augers, but excessive diameters should be avoided. The use of a backhoe is not recommended because loosening the ground reduces the efficiency of the explosion. The charge hole should usually be dug 3 to 5 ft deep (Mathiak 1965).
- (2) A medium-strength dynamite primer (50% to 60% nitroglycerin) is necessary to initiate detonation of the AN/FO (Mathisen et al. 1964). Use a full stick (1/2 lb) for 40- to 50-lb charges; one-half stick may be used for smaller quantities of AN/FO.
- (3) A det-cord ring main (see Appendix B) should be used if simultaneous detonations of multiple charges are desired. However, a delay of 50 to 100 milliseconds between explosions will distribute the shock wave over a longer period of time and result in less disturbance to nearby inhabited areas (Warren and Bandel 1968). Several methods are available for achieving delay detonation of the individual charges; a blasting advisor should be consulted for the best technique for a specific situation.
- (4) Attach a suitable length of det-cord to the dynamite primer and insert the primer into the center of the AN/FO charge (Fig. 8).

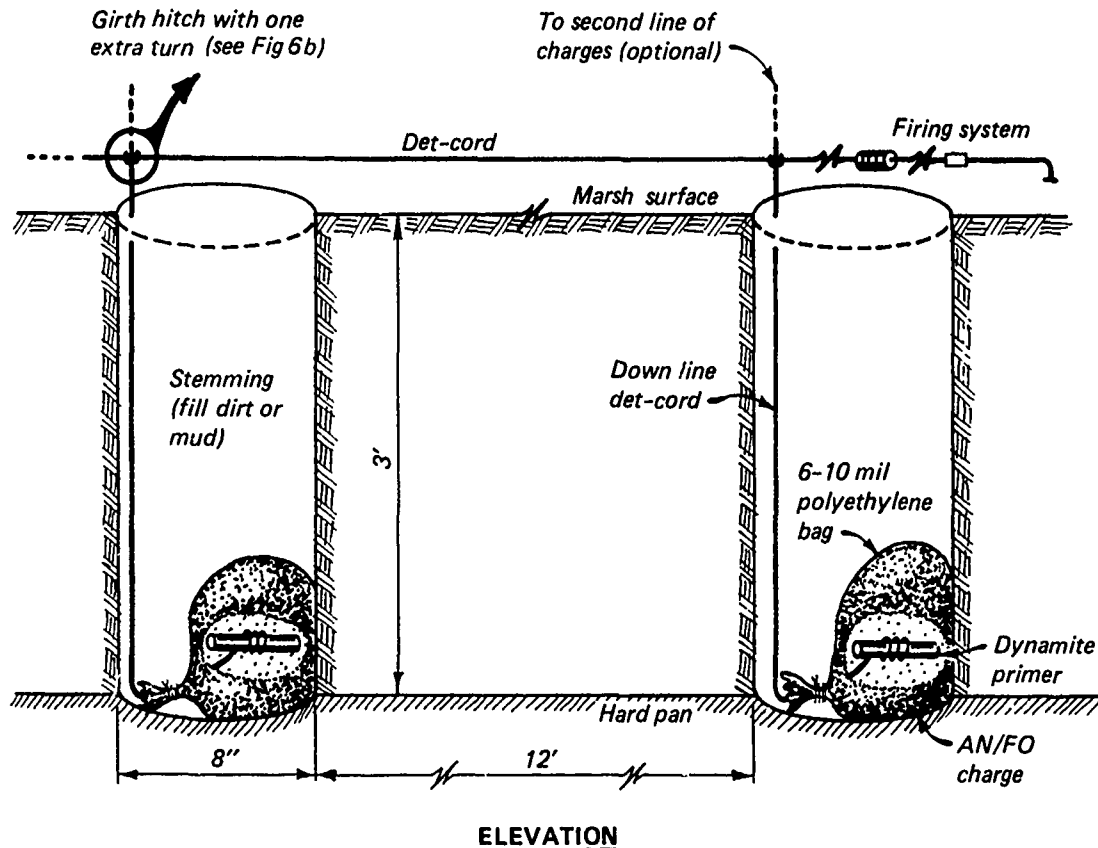


Figure 8. Recommended placement of AN/FO charges and fuse connections for blasting potholes or ditches (modified from Mathisen et al. 1964, Mathiak 1965). Electric or nonelectric firing systems may be used for detonation

Each charge must be placed in a 6- or 10-mil plastic bag and the top of the bag sealed with tape or string to prevent water from entering the bag. This is critical! AN/FO charges must be kept watertight to avoid misfires. When sealing the bag, remove as much air as possible. Leave enough det-cord out of the bag for connection to a det-cord ring main or to prime with a blasting cap.

- (5) Place charges in the hole and make sure each charge is secured at the bottom, as AN/FO will float if water is present in the hole. Fill the hole with dirt, mud, or sandbags. Preloaded sandbags work very well and help expedite the job. To facilitate placement of charges, special blasting sleeves are available in various sizes that are conducive to holes dug by an auger or posthole digger.
- (6) Connect the det-cord from each charge to a main line det-cord. Tie the det-cord leads from individual charges securely to the main line with a girth hitch with one extra turn tied at right angles to each other and in close contact with the main line (Appendix B).

- (7) Attach a blasting cap to the main line det-cord to initiate the blast. Blasting caps can be attached to the det-cord with rubber or plastic electrician's tape. Prime the det-cord using either an electric or nonelectric firing system.

Blasting patterns. A variety of blasting patterns and charge sizes can be used to create potholes with AN/FO charges (Fig. 9). Mathisen et al. (1964) blasted potholes in heavy clay soils using two 50-lb charges placed 12 ft apart and 3 to 4 ft deep; these blasts created holes 35 ft long $\times$ 25 ft wide $\times$ 7 ft deep. Six 50-lb charges placed in 2 rows on 10-ft centers produced a hole 40 $\times$ 30 $\times$ 6 ft. In peat marshes, two 8-lb charges created a pothole 19 $\times$ 14 $\times$ 4 ft, and one 50-lb charge produced a hole 25 ft in diameter and 7 ft deep. The average depth of charges tested by Mathisen et al. (1964) was 3 to 4 ft. Increasing the depth resulted in deeper but narrower holes. Blasting at depths of 2 to 3 ft produced shallower and wider holes, particularly in heavy clay soils. The poorest results occurred when the depth of the charge was less than 2 ft.

Warren and Bandel (1968) used 20-, 25-, and 50-lb charges of AN/FO in freshwater marshes, with 2 to 8 charges per pothole; the total weight of charges per pothole ranged from 80 to 160 lb. In saline marshes the total amount of AN/FO per pothole ranged from one 20-lb charge to fifteen 27-lb charges. Charge holes were dug 8 to 12 in. deep in fresh marsh and 24 to 36 in. deep in brackish marsh. Best results were obtained with charges placed in a straight-line or square pattern. Hopper (1972) used a triangular pattern for AN/FO charge placement in Colorado. Results of these studies are further discussed under Evaluation.

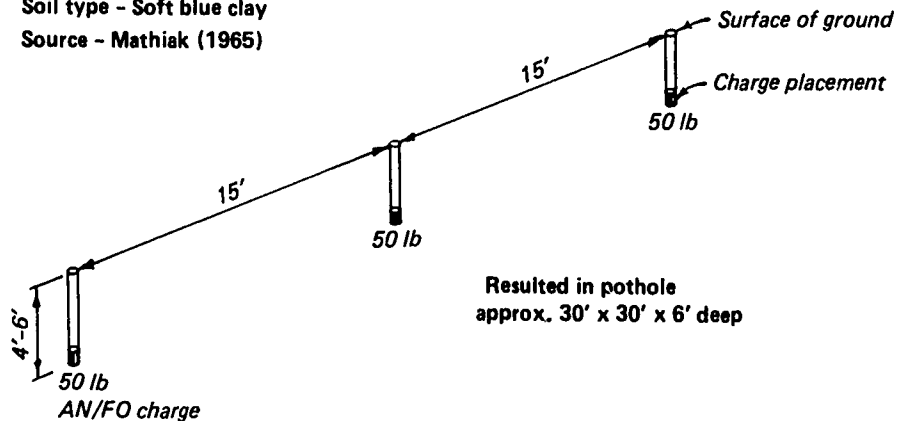
Two sets of charges hooked up in a series and arranged in pentagon-shaped patterns were used by the Indiana Division of Fish and Wildlife in 1969 to blast large potholes along the Wabash River (Vic Heshner, Indiana Division of Fish and Wildlife, pers. commun., 1988). Sites were composed of deep muck soils in floodplain areas, with the water table 6 to 8 ft below the surface at the time of blasting. The design consisted of five 30-lb interior charges spaced approximately 20 ft apart and five 15-lb exterior charges spaced 30 ft apart (Fig. 10). The larger charges were set 6 ft deep and the smaller charges 3 ft deep. Charges were detonated using a time-delay system between the interior and exterior charges, with the larger charges blown first to create a deep hole; the exterior charges were blown approximately 15 seconds after the initial blast and provided a sloping effect to the sides. The

STRAIGHT - LINE PATTERN

Location - Wisconsin

Soil type - Soft blue clay

Source - Mathiak (1965)

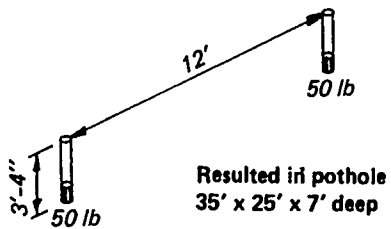


STRAIGHT - LINE PATTERN

Location - Minnesota

Soil type - Heavy clays

Source - Mathisen et al. (1964)

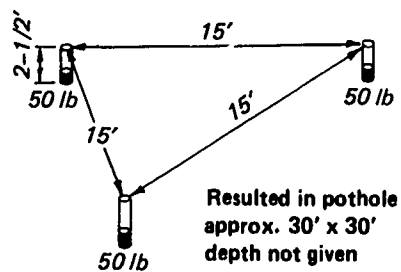


TRIANGULAR PATTERN

Location - Eastern Colorado

Soil type - Sandy suburface,
some heavy clays

Source - Hopper (1972)



SQUARE PATTERN

Location - Chesapeake Bay, Maryland

Soil type - Organic soils in fresh
tidal marsh

Source - Warren and Bandel (1968)

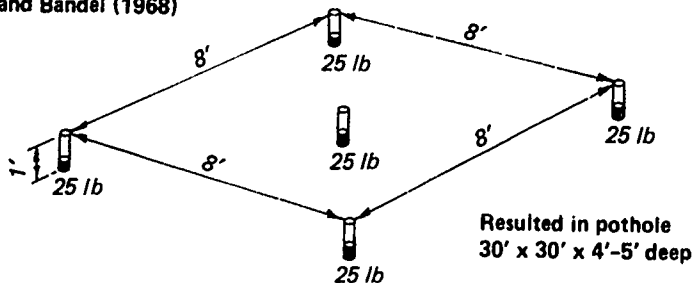
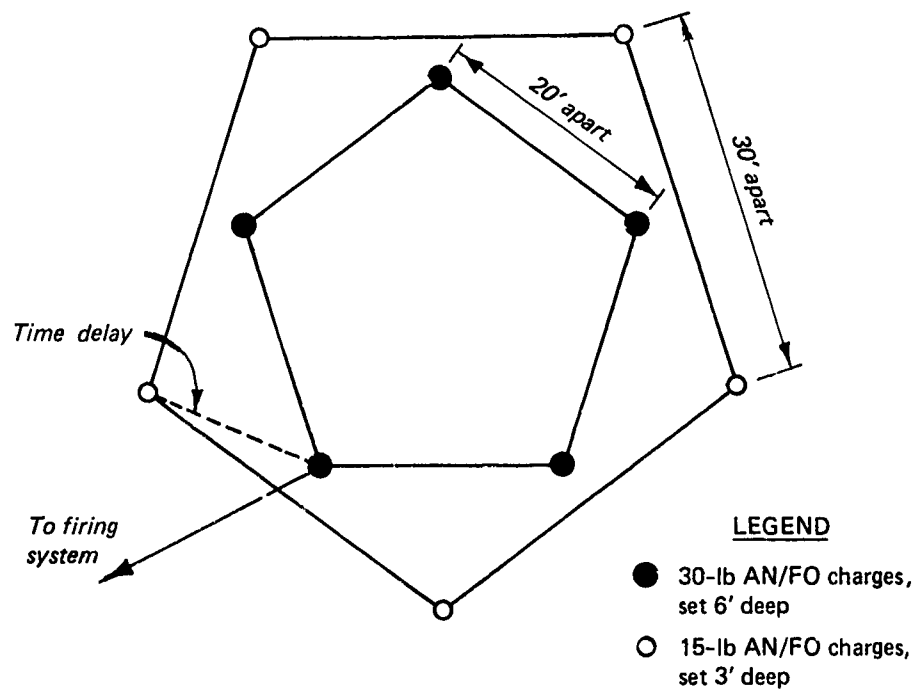
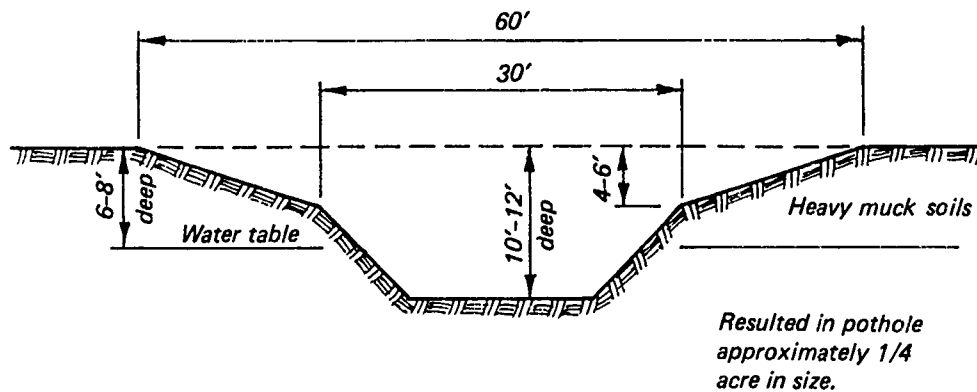


Figure 9. Examples of blasting patterns and charge sizes used to create potholes with AN/FO mixtures



BLASTING PATTERN



POTHOLE PROFILE

Figure 10. Blasting pattern and charge sizes used to create large potholes with AN/FO charges along the Wabash River, Indiana (as described by Vic Heshner, Indiana Division of Fish and Wildlife, pers. commun.)

resulting potholes were slightly less than 1/4 acre in size and 10 to 12 ft deep at the center.

Waterproof Gel

Explosive waterproof gels were used to blast potholes in deteriorating waterfowl habitats at Cebolla Marsh and Lake Fork Canyon on USDA Forest Service land in northern New Mexico (Stahlecker and Skinner 1980, Skinner 1982). Commercial gels were selected over AN/FO because they are safer, waterproof, and the fumes produced by blasting are nontoxic. The high specific gravity of the gel (1.20 g/cc) allows it to sink in water, thus keeping it at the bottom of holes. A blasting cap is required for detonation.

Seven potholes were blasted at the New Mexico sites in late September 1980 (Stahlecker and Skinner 1980). The gel used was DuPont Tovex 800 water gelatin, which is packaged in 3-3/4 x 16-in. plastic cartridges weighing 7 lb each. The blasting design consisted of 3 holes dug 10 ft apart in a triangular pattern. The holes were dug 4 ft deep with an 8-in.-diam hand auger. Thirty-five pounds of explosive per hole (105 lb/pothole) was used where the water table was more than 4 ft below the soil surface. Where the water table was at or near the surface, 42 lb/hole (126 lb/pothole) was used. Cartridges were wrapped in det-cord and placed in the holes. Holes were then filled with mud. Det-cords from all 3 holes were connected to a ring main and primed with an electric blasting cap, which was connected to the electric firing wire located a safe distance from the charge site.

All potholes created using the above blasting pattern and charge sizes were approximately 30 ft in diameter. Blasts made in drier canyon sites resulted in holes 7 ft deep, whereas holes created at the Cebolla Marsh site, which had a high fall water table, were only 3-1/2 ft deep (Stahlecker and Skinner 1980). The sites blasted in 1980 were evaluated by the USDA Forest Service, and additional potholes were created in 1981 using improvements to the basic technique. Changes have included circular design patterns, blasting in clusters, creating larger potholes, adding ditches, and increasing the delay between explosions (Gilbert Sandoval, USDA Forest Service, pers. commun., 1987).

The blasting design used at Cebolla Marsh in 1981 consisted of a cluster of 3 potholes connected with trenches; this pattern resulted in larger amounts of open water and an island in the center of the basins (Skinner 1982). For

each pothole, 3 holes (10 ft apart and 4 ft deep) were dug in a triangular pattern using a 4-in.-diam power auger and an 8-in. hand auger (Fig. 11). The center of each pothole was estimated to be 50 ft from the center of each of the other potholes in the cluster, and the radius of each pothole was estimated as 15 ft (based on charge size to be used and results of previous blasting efforts). To form the trenches, two 4-ft-deep holes were dug 19 ft from the centers of each pothole along an imaginary straight line connecting the basins.

Explosive gels used for the new design were Gulf Detagel and Iremite 60, since DuPont Tovex 800 was not available at the time of blasting (Skinner 1982). Charge sizes for the potholes consisted of 25 lb of explosive placed in the hole to form the apex of the triangle farthest from the other potholes and 33 lb each in the other holes of the triangle (Fig. 11). Each trench hole contained 17 lb of explosive. Cartridges were taped together and wrapped in det-cord before being placed in the holes; each hole was then filled with mud and tamped. Det-cords from all holes at each site were connected to a ring main and primed as previously described.

All new potholes blasted using the improved design were approximately 30 ft in diameter and 4 to 5 ft deep. The island created in the middle of the potholes was triangular in shape and was approximately 15 ft long on each side. The trenches were 6 ft wide and approximately 3 ft deep. The potholes began to fill with water immediately and were completely impounded about 4 days after blasting (Skinner 1982).

MAINTENANCE

The primary objectives of pothole maintenance are to (1) control vegetation that reestablishes on the site and (2) control erosion of the banks and subsequent sedimentation in the hole. Provost (1948) reported that from 25% to 45% of a pothole could be expected to be lost the first few years after blasting but, following this period, there is a subsequent decline in the sedimentation process. The pothole will become shallower through erosion of the banks and slipping of the sides. This frequently causes an increase in surface area, which may compensate for the decrease in depth. However, depth of the hole is more important than volume because depth is the factor that primarily determines the rate of revegetation. Holes less than 12 in. deep are quickly revegetated (Provost 1948).

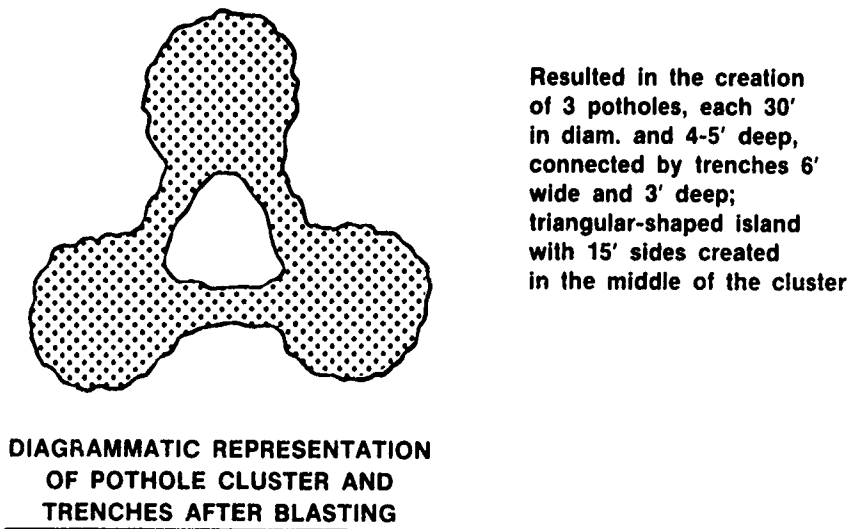
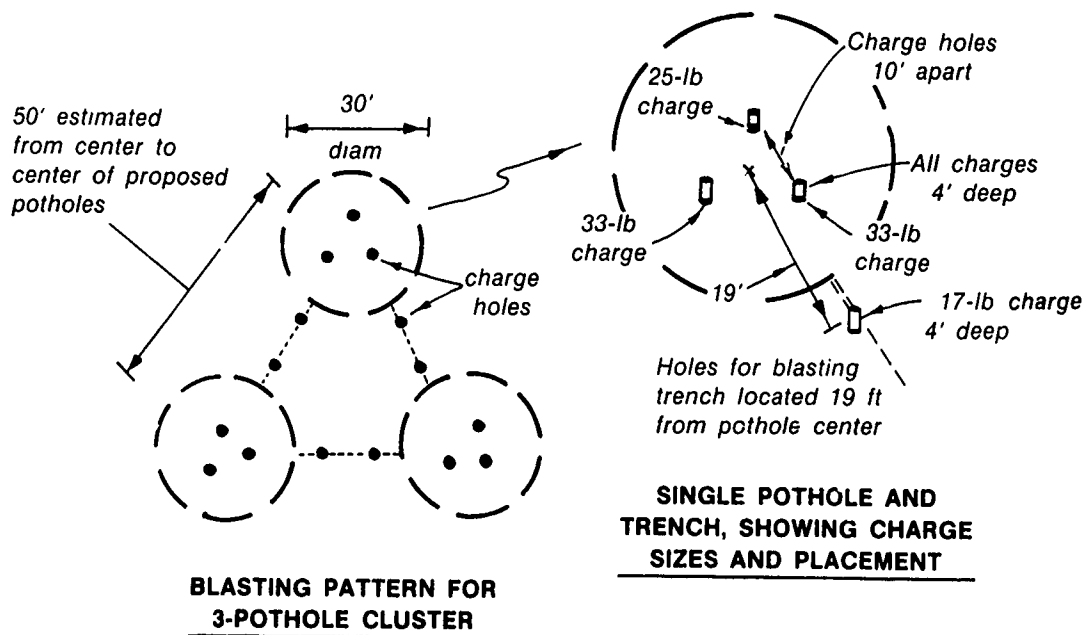


Figure 11. Design specifications for using waterproof gel to create 3-pothole clusters at Cebolla Marsh, New Mexico (after Skinner 1982)

Potholes that are continually full of water have longer functional life spans than those subjected to alternate drying and wetting of the soil caused by fluctuations in the water level (Provost 1948). Reblasting after 5 years may be necessary for a hole created by a single-line or pothole charge; reblasting potholes created by double-line charging after 10 years will give the hole a longer life and probably some degree of permanency (Provost 1948). Strohmeier and Fredrickson (1967) determined that potholes blasted in Iowa continued to provide some open-water habitat after 20+ years, but the holes had lost most of their depth (refer to Evaluation section).

Native plant species that invade the denuded blast site may either enhance or reduce the value of the pothole and may require control measures (Provost 1948). Provost suggested that the shoulders of banks be reseeded after blasting and that emergent vegetation in the holes be controlled to maintain open-water area; however, some exposed areas should be left along the banks to provide loafing sites. A sod-forming grass that will tolerate periodic inundation is recommended to control bank erosion. Mathiak (1965) recommended planting submersed aquatics, such as coontail (*Ceratophyllum* spp.) and pondweed (*Potamogeton* spp.), to make potholes more attractive to waterfowl, but recent studies of plant succession in freshwater marshes have shown that many wetland species will germinate naturally from residual seed sources (van der Valk and Davis 1978, van der Valk 1981).

Grit stations, supplied with fine gravel or cracked oyster shells, can be located at convenient points near potholes to enhance their value to wildlife (Uhler 1956). Wooden rafts anchored to the bottom of potholes are attractive to waterfowl as well as to turtles, frogs, and muskrats (Mathiak 1965). Provost (1948) suggested establishing and maintaining a population of muskrats in the pothole management area. Muskrats are capable of controlling emergent vegetation, which can decrease the usable life of a pothole, but their populations must be managed to prevent degradation of the habitat.

PERSONNEL AND COSTS

Pothole blasting as a waterfowl management technique was once limited by the cost of dynamite, but the development and improvement of AN/FO charges has increased the applicability and cost-effectiveness of blasting (Burger and Webster 1964, Schnick et al. 1982). Using AN/FO is considered the quickest

and most economical method for constructing most types of small potholes, but dynamite may still be used where precision blasting is required (Schnick et al. 1982). Stahlecker and Skinner (1980) reported that waterproof gels were much safer to use than other explosives.

The cost of AN/FO is about 1/10 that of dynamite (Linde 1969, 1985). Cost comparisons given in 1969 were \$0.42/lb for dynamite and \$0.04/lb for AN/FO; the cost of a 50-lb charge of AN/FO was approximately \$3.00, complete with detonating charge, fuse, and cap. However, studies by Burger and Webster (1964) showed that costs of blasting with AN/FO were 1/5 to 1/3 those of dynamite. Costs for detonating 1 ton of AN/FO at several sites in Maryland were \$460 for saline marshes (\$160 for materials and \$300 for labor) and \$436 for fresh marshes (\$231 for materials and \$205 for labor); the amount of earth moved per ton of AN/FO averaged approximately 1530 cu yd, at a cost of \$0.30 per cubic yard (Warren and Bandel 1968).

Cost data for potholes blasted with AN/FO charges in Wisconsin (Mathisen et al. 1964) and Colorado (Hopper 1972) are shown in Tables 2 and 3. In terms of surface area resulting per pound of explosive, 25 lb of AN/FO per charge appeared more efficient than 50 lb per charge when placed either singly or in multiples of three (Hopper 1972). With the same amount of AN/FO per charge, multiple charges were slightly less efficient than single charges; this was largely due to the overlapping effect of spaced multiple charges. Total costs did not double with an increase in size from 25 lb to 50 lb or from 75 lb to 150 lb because the amounts of dynamite and caps used were the same in each case. Labor costs exceeded material costs for the two smallest charge sizes, but the reverse was the case for the 75- and 150-lb charges.

Linde (1969) compared costs for creating potholes using blasting (with AN/FO), draglines, and bulldozers. Bulldozing was least expensive based on cost per acre-foot, but blasting was far more economical based on cost per pothole. If only limited funds are available for a project, blasting may be the only technique feasible for providing open water on an area (Linde 1969). However, on larger projects, draglining may actually be cheaper than blasting, even with AN/FO (Burger 1973).

Project costs were developed by the USDA Forest Service Jemez Ranger District for using commercial gels to blast potholes in New Mexico (Stahlecker and Skinner 1980, Skinner 1982). The planning process for the original potholes blasted in 1980 required approximately 8 man-days of staff time, which

Table 2. Volume and costs of experimental potholes blasted with charges of AN/FO (after Mathisen et al. 1964; table modified from Schnick et al. 1982)

Size of Charge	Soil Type	Pothole Size, ft			Cost (Including Labor)
		Width	Length	Depth	
100 lb (2 charges, 50 lb ea, 12 ft apart)	Clay	25	35	7	\$11.00
16 lb (2 charges, 8 lb ea)	Peat	14	19	4	\$4.00
50 lb (1 charge)	Peat	25	25	7	\$5.60
972 lb (3 rows, 12 charges long, on 10-ft centers; each with 27 lb AN/FO)	Not given	60	120	8-10	\$50.00

Table 3. Relation of cost and surface area of 84 potholes according to AN/FO charge size (from Hopper 1972)*

Size of Charge lb	Average Cost per Pothole			Average Cost per 100 sq ft
	Materials	Labor	Total	
25	\$2.12	\$2.75	\$4.87	\$2.42
50	\$3.49	\$3.62	\$7.11	\$2.42
75	\$6.35	\$5.12	\$11.47	\$2.01
150	\$10.49	\$8.32	\$18.81	\$2.21

* Materials included AN/FO, plastic bags, dynamite, and electric caps; labor was charged at \$2.50 per man-hour.

included preparation of an environmental assessment. Material costs were 750 lb of Tovex 800 gel (\$613.13), 7 detonators (\$40.00), and 200 ft of det-cord (\$12.00) for a total materials cost of \$665.13, or approximately \$95 per pothole. Youth Conservation Corps (YCC) crews were used to dig holes and work at road blocks, which substantially reduced labor costs. Charge holes were dug a week before blasting to expedite movement from site to site during blasting; this allowed 7 potholes to be blasted in 6 hours. The total cost of materials and labor for the project was approximately \$1000, or \$145 per pothole. Future pothole blasting in the area was projected to be less expensive since planning activities would not be as extensive as required for the original effort (Stahlecker and Skinner 1980).

Material costs for blasting pothole clusters at Cebolla Marsh, New Mexico, in 1981 were as follows: 1511 lb of Gulf Detagel and Iremite 60 explosive gel (\$1511), 1000 ft of det-cord (\$88), and 5 detonators at approximately \$6 each (\$30). Site preparation, including layout and digging holes (primarily by YCC crews), required approximately 55 man-hours at a cost of \$250. Labor costs for blasting, including the use of YCC personnel, was approximately \$170; the blaster's time was donated. The total cost of creating 11 potholes with connecting trenches was \$2049. This consisted of blasting one new cluster of 3 potholes and adding 2 potholes each to 4 previously blasted basins, resulting in a total of five 3-pothole clusters connected by ditches. The estimated cost per cluster of 3 new potholes was \$500 (Skinner 1982).

EVALUATION

Dynamite

Provost (1948) evaluated the results of potholes created by line charges and posthole charges 5 years after blasting. The 1-line pattern was most successful in terms of ditch volume per unit cost. When only depth of the ditch was considered, the posthole charge was initially most efficient; the 2-line charge ranked second, and the 1-line charge was least effective. However, after 5 years, potholes created with 2-line charges were deepest, and posthole charges ranked second. All potholes lost depth as the soil banks eroded, and each showed a tendency toward increasing in width.

A further evaluation of these potholes after two decades was conducted by Strohmeyer and Fredrickson (1967). Of 21 potholes originally blasted, 19 were found and their dimensions measured (Table 4). The holes had lost 71% of their depth over the 21- to 22-year period, and all potholes had become nearly equal in depth regardless of their original dimensions. The potholes were evaluated as remaining effective in restricting emergent vegetation in standing water areas. However, natural changes in water levels and muskrat populations were of greater influence on the interspersions of cover and water. The value of the potholes for marsh birds was restricted to dry years when vegetation was dense, but the potholes appeared to be important to overwintering muskrats in shallow marshes (Strohmeyer and Fredrickson 1967).

AN/FO

Mathiak (1965) presented data on potholes blasted in different soil types using 50-, 75-, and 100-lb AN/FO charges (Table 5). Results showed considerable variation in depth, diameter, and contour of the bottom, and an increase in charge size did not always produce a larger pothole. Potholes blasted in wet marl had minimal depth but large diameters, whereas those blasted in hard clay were often conical in shape with greater depth and less diameter. Larger charges were recommended by Mathiak (1965), who hypothesized that increased depth and diameter should increase the longevity of the potholes. Mathiak also suggested that much larger holes could be made with multiple charges and that a few large basins may be desirable if there are no other natural waters nearby; otherwise, it would be better to use a larger number of single charges. A spacing of 15 ft was best for multiple charges of 50 lb each (Mathiak 1965).

The best results in freshwater marshes of Maryland seemed to occur when a square pattern was used with charges at each corner (Warren and Bandel 1968); charges spaced 8 ft apart, with one charge in the center, worked best when either 20- or 25-lb charges were used. This design produced a pothole 30 to 35 ft in diameter and 4 to 5 ft deep and was most efficient in terms of water surface created and material removed. In the saltwater marsh, several attempts were made to create potholes with 10-ft spacings using square and triangular blasting patterns, but these designs did not result in basins with clean and reasonably flat bottoms. Rather, 8-ft spacings arranged in either a square or straight line produced the best potholes (Warren and Bandel 1968).

Table 4. Blasting pattern, physical attributes at time of blasting, and measurements of dynamited potholes in northern Iowa in 1941, 1946, and 1962 (after Strohmeier and Fredrickson 1967)

Pothole Number*	Blasting Pattern	Soil Type	Soil Saturation**	Length, ft		Width, ft		Maximum Depth, in.		
				1941	1962	1941	1946	1941	1946	1962
1	1-line	Peat	Above	99.0	67.0	11.1	12.9	32.0	17.5	12.7
2	1-line	Peat	Above	105.9	103.0	12.9	14.4	26.8	18.0	12.0
3				125.1	122.0	12.0	14.1	29.8	15.7	14.8
4				114.0	106.5	12.0	12.0	33.9	14.6	13.8
5				126.9	97.0	14.4	18.0	30.5	15.9	9.8
6				147.0	142.0	12.0	13.0	28.7	13.5	12.1
8				75.0	74.0	8.1	12.0	32.4	15.0	12.3
10	3-line	Clay	Below	117.0	118.5	19.2	24.0	42.0	17.2	14.7
11				116.1	116.5	18.0	21.0	45.0	20.8	9.0
12				123.9	127.5	27.0	29.1	42.0	19.8	12.2
13	2-line	Peat	At	120.0	116.0	21.9	24.9	46.0	19.6	14.3
14	Posthole	Clay	Below	31.2	34.0	31.2	28.8	57.0	14.1	11.5
15	Posthole	Peat	Above	37.8	33.3	37.8	40.8	46.0	18.2	17.2
16	1-line	Sandy-clay		104.1	103.0	17.1	17.1	46.0	19.5	16.6
17	2-line	Clay		120.0	139.0	21.3	22.2	56.0	36.1	11.2
18	1-line			108.9	113.0	20.1	20.1	54.0	34.0	17.9
19	Posthole	Clay	At	31.8	66.5	31.8	36.0	60.0	21.6	2.2
20	Posthole		Below	33.0	35.0	33.0	34.2	102.0	32.2	16.7
21	1-line		Above	378.6	404.0	20.1	24.6	48.0	20.1	4.9

* Sites 7 and 9 could not be located.

** Water level above, below, or at the surface.

Table 5. Summary of dimensions of potholes blasted with
AN/FO charges (modified from Mathiak 1965
and Schnick et al. 1982)

Weight of AN/FO Charge and Soil Type	Number of Potholes Measured	Pothole Size	
		Depth in.	Diameter ft
Heavy (150 lb)			
Wet peat	1	48	39
Dry peat	1	96	33
Soft blue clay	1	72	29
Unweighted average		72	34
Moderately heavy (100 lb)			
Wet peat	4	48	26
Dry peat	5	57	32
Soft blue clay	4	76	24
Hard clay	14	69	22
Wet marl	1	36	41
Dry marl	1	84	24
Dry sand	2	49	23
Wet sand	3	45	25
Unweighted average		58	27
Intermediate (75 lb)			
Wet peat	9	52	25
Hard clay	6	58	21
Unweighted average		55	23
Light (50 lb)			
Wet peat	6	45	27
Dry peat	1	48	23
Hard clay	9	52	21
Wet marl	1	30	35
Dry marl	1	72	21
Dry sand	11	40	19
Wet sand	1	50	19
Unweighted average		48	24

Hopper (1972) analyzed 84 potholes blasted in eastern Colorado using single charges of 25 and 50 lb each and multiple charges of 75 and 150 lb each. The 75-lb charges consisted of three 25-lb charges placed 11 ft apart in a triangular pattern, and the 150-lb charges were composed of three 50-lb charges set 15 ft apart. Holes for 25- and 50-lb charges (both single and multiple) were made 10 and 15 in. in diameter, respectively. All charge holes were dug 30 in. deep, and the tops of charges were consistently 15 in. below the surface of the ground when set in place. The 4 sizes of charges produced potholes with the following average surface areas for all blocks combined (with 19 to 21 potholes per block): 25 lb--201 sq ft; 50 lb--293 sq ft; 75 lb--570 sq ft; and 150 lb--851 sq ft. The 25- and 75-lb charges created more average surface area per pound (8.0 and 7.6 sq ft) than the 50- or 150-lb charges (5.9 and 5.7 sq ft), thus indicating a greater efficiency for the 25-lb charges. However, in terms of both cost and duck use, 75-lb charges produced the most effective potholes, followed by the 150-lb size (Hopper 1972).

Based on the above studies, there is apparently considerable flexibility in the choice of patterns and amount of AN/FO charge that can be used to blast potholes. However, most authors recommended a total charge size of 75 to 150 lb per pothole for producing the best results. A charge size of 100 to 125 lb appeared to be maximum for a single blast without causing disturbance to property owners within approximately 1 mile of the blast sites in Maryland (Warren and Bandel 1968). A 150-lb charge was generally the upper limit advisable in Wisconsin wetlands, with many areas restricted to smaller charges due to the proximity of houses (Mathiak 1965).

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APPENDIX A: SAFETY PRECAUTIONS*

The use of explosives to create potholes is considered a hazardous operation, and all safety precautions must be strictly enforced. State and local authorities should be notified of the intent to use explosives, and the necessary permits must be obtained. Prior to blasting, all unauthorized persons must be prevented from entering the blast area. General safety precautions are summarized below; detailed guidelines are available in safety manuals and may be obtained from blasting advisors.

Misfires

a. A misfire is a complete failure to function. Working on or near a misfire is the most hazardous of all blasting operations. Investigation and correction should be undertaken only by the person who placed the charge. Make one individual responsible for all electrical wiring in a demolition circuit.

b. A misfire cannot be immediately distinguished from a delay in function. Do not handle suspected misfires until after the required waiting period has elapsed and other safety precautions have been accomplished.

c. Digging into a charge may initiate the charge. Check on depth and direction of the borehole during digging to minimize the danger of striking a charge or placing the new charge too far away to induce detonation.

d. Wait 1/2 hour before approaching any misfire unless it can be positively ascertained that failure is strictly electrical. If this is the case, corrective action may be taken immediately.

e. Contact between the cap end of a time fuse and moist finger or other damp objects can cause a misfire.

Blasting Caps/Firing Systems

a. Blasting caps are a unique hazard because they are easier to initiate than other demolition materials. Both electric and nonelectric caps can be initiated by impact; the open end of nonelectric caps contains an especially sensitive material.

b. Electric caps can be initiated by static electricity or induced current from radio frequency transmissions. If electric blasting caps are to be transported near operating transmitters or in vehicles (including helicopters) where a transmitter is used, place the caps in a metal can with a snug-fitting cover with a half-inch or more overlap. Do not remove caps from containers near an operating transmitter.

c. A rough, jagged cut fuse inserted into a blasting cap can cause a misfire. If the rough cut is due to an unserviceable crimper and no others are available, use a sharp knife to cut the fuse. To ensure that the fuse is cut square when using a knife, cut it against a solid surface such as wood.

d. Foreign matter in a blasting cap may cause a misfire. If foreign matter is to be removed from a nonelectric blasting cap, do not tap the cap

* Summarized from Field Manual 5-25 (US Army 1986).

with a hard object or against a hard object. Never blow into a blasting cap. Do not insert anything into a cap to remove dirt or other foreign material.

e. Do not force a time fuse into a blasting cap. Forcing a time fuse into a blasting cap by twisting or other means may cause the cap to explode.

f. A crimp too near the explosive in a blasting cap can cause detonation. Do not crimp the cap more than 1/4 in. from the open end.

g. The blasting machine for an electric firing system must not be connected to firing wires until completion of prefiring tests and until ready for firing.

h. Face away from blasting caps when the circuit is completed to minimize face injuries resulting from accidental initiation. If at all possible, maintain cover between blasting caps and testing personnel.

i. Lightning is a hazard to both electric and nonelectric blasting caps. A strike or near miss is almost certain to initiate either type of cap and other sensitive explosive elements such as caps in delay detonators. Lightning strikes, even at remote locations, may cause extremely high local earth currents that may initiate electrical firing circuits.

Poisonous Fumes

a. The detonation or burning of all explosives produces poisonous fumes. The chemicals used in explosives are poisonous, and personnel should be cautioned against inhaling fumes or ingesting explosives. When explosives are used in closed areas or underground, adequate time must be allowed for the fumes to dissipate before investigation.

b. Since explosives contain their own oxidizers, burning explosives cannot be extinguished by smothering. Whenever explosives burn, there is a hazard of possible detonation. Personnel should not attempt to extinguish burning explosives without professional advice and assistance and should keep their distance because of toxic fumes.

Safe Distances

a. The greatest danger to personnel is generally from missiles thrown by an explosion. Blast effect (the increase in air pressure) is a hazard even when special protective features are used.

b. Explosives can propel lethal missiles great distances. How far an explosion-propelled missile will travel in air depends primarily upon relations between weight, shape, density, initial angle of projection, and initial speed.

c. The distance (in meters) at which personnel in the open are relatively safe from missiles can be calculated using the formula below. The formula applies to charges ranging from 27 to 425 lb placed in or on the ground, regardless of type or condition of the soil.

$$D = 100 \sqrt[3]{P}$$

where

D = safe distance, meters

P = pounds of explosive

For example, the approximate minimum safe distance for 30 lb of explosives is 311 m (1020 ft); the safe distance for a 125-lb charge is 500 m (1640 ft).

Care and Handling

a. Explosive demolition materials must be handled with appropriate care at all times. The explosive elements in primers, blasting caps, and fuses are particularly sensitive to shock and high temperatures.

b. Personnel should be trained to handle all demolition items and components, including practice and training items, as potentially dangerous.

c. Store explosive demolition materials in the original containers in a dry, well-ventilated place protected from the direct rays of the sun and other sources of intensive heat.

d. Keep sensitive initiators such as primers, blasting caps, fuses, and igniters separate from other explosives.

e. Keep all demolition materials and containers clean, dry, and protected from possible damage.

f. Disassembly of explosive components, without specific authorization, is strictly prohibited.

g. Do not open sealed containers or remove protective safety devices until just before use.

h. All demolition material prepared for firing but not fired must have protective safety devices installed before returning to original packing. Packing must be marked appropriately.

APPENDIX B: FIRING SYSTEMS

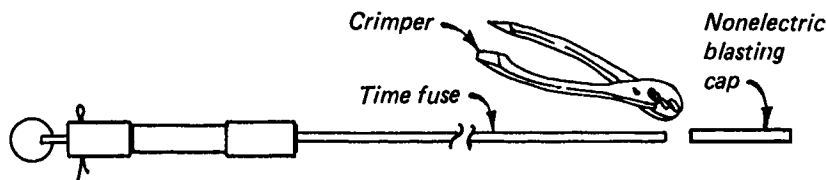
The two basic types of firing systems are "electric" and "nonelectric." These systems and the "detonation cord" (det-cord) firing system, which can be initiated either electrically or nonelectrically, are described below (summarized from Field Manual 5-25, US Army 1986).

Nonelectric Firing System

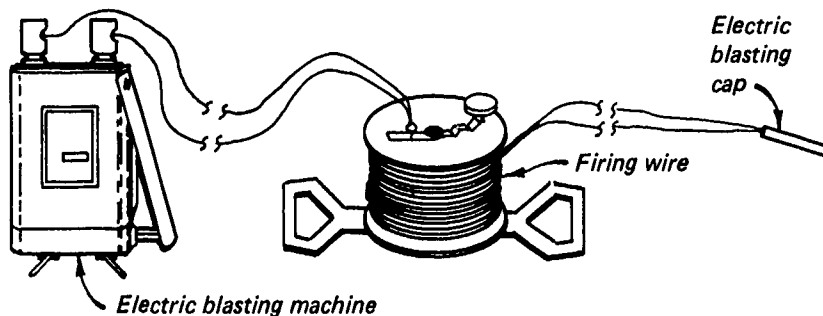
A nonelectric system is one in which an explosive charge is prepared for detonation by means of a nonelectric blasting cap. The basic materials consist of (1) a nonelectric blasting cap, which provides a shock adequate to detonate the explosive; (2) the time blasting fuse, which transmits the flame that fires the blasting cap; and (3) a means of igniting the time fuse (Fig. 12a). A proper crimper is needed to cut and discard a 6-in. length from the free end of the time blasting fuse to prevent a misfire caused by the exposed powder absorbing moisture from the air. If more than one charge must be detonated simultaneously, the nonelectric system must be combined with a det-cord to ensure simultaneous firing (described later).

Electric Firing System

An electric firing system is one in which electricity is used to fire the primary initiating element (Fig. 12b). The chief components of the system are



a. NONELECTRIC FIRING SYSTEM



b. ELECTRIC FIRING SYSTEM

Figure 12. Diagram of major components of (a) nonelectric and (b) electric firing systems (from US Army 1986)

the electric blasting cap, firing wire, and the blasting machine. An electric impulse supplied from a power source, usually an electric blasting machine, travels through the firing wire and cap lead wires to fire an electric blasting cap. The preparation of the explosive charge for detonation by electric means is called electric priming. Electric blasting caps can be detonated by radio frequency; therefore, minimal safe distances (see Appendix A) must be strictly observed.

Detonation Cord Firing System

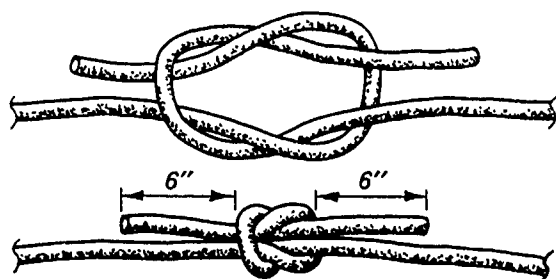
Of all the firing systems, a det-cord system is the most versatile and easily installed. The system is especially suitable for underwater and underground blasting because the blasting cap of the initiating device may remain above the water or ground. A det-cord system employs the use of the det-cord as a relay element between the initiator and the main explosive charge. It has the following advantages over other systems:

- a. It allows a long distance between the sensitive initiator element (blasting cap or delay detonator) and the main charge.
- b. It allows simultaneous detonation of a number of charges with a single initiator.
- c. The det-cord itself is waterproof and thus can be used to run the priming system into damp areas or even underwater.
- d. Since most charges can be primed with det-cord, its lack of sensitivity to accidental initiation reduces the danger associated with investigation of misfires (i.e., digging into a misfired det-cord primed charge is less dangerous than digging into a blasting cap primed charge).

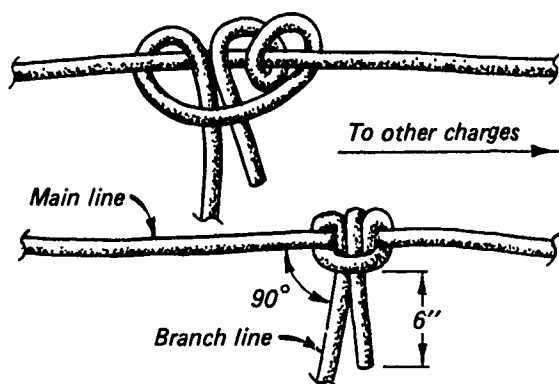
Priming the charge. The explosive charge may be primed with encircling loops of det-cord or knots of it within plastic explosive, or by means of a nonelectric blasting cap crimped onto the end of the detonating cord. The det-cord may be initiated by an electric or nonelectric blasting cap or a delay detonator. A firing device or time fuse may be used to initiate a nonelectric cap; a standard blasting machine will be used to initiate electric caps.

Use of connections. The proper use of connections is extremely important for det-cord assembly. A det-cord clip or square knot pulled tight is used to splice the ends of the det-cord (Fig. 13a). To ensure detonation from a dry portion of the cord, at least a 6-in. length should be left free at both sides of the knot. When fabric-coated cord is used, the fabric must not be removed. The knot may be placed in water or in the ground, but the cord must be detonated from a dry end. A branch line is fastened to a main line by means of a det-cord clip or a girth hitch with one extra turn (Fig. 13b). The angle formed by the branch line and the cap end of the main line should not be less than 90 deg. At a smaller angle, the branch line may be blown off the main line without being detonated. To ensure positive detonation from the dry end of the line, at least 6 in. of the running end of the branch line should be left free beyond the tie.

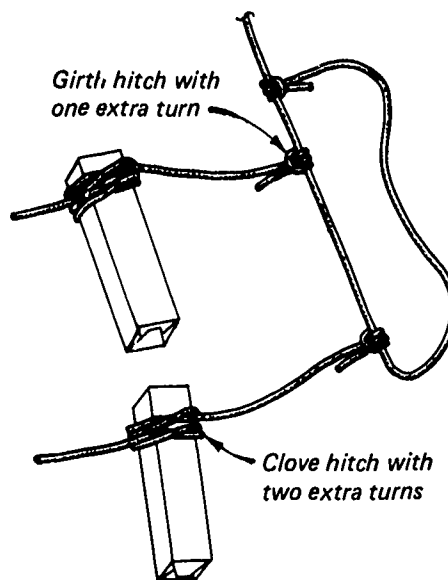
Use of a ring main. A "ring main" may be constructed to detonate an almost unlimited number of charges. It is made by bringing the main line back in the form of a loop and attaching it to itself with a girth hitch with one extra turn (Fig. 13c) or a det-cord clip. The ring main makes the detonation



a. SQUARE KNOT CONNECTION



b. GIRTH HITCH WITH EXTRA TURN



c. RING MAIN WITH BRANCH LINES

Figure 13. Det-cord connections and ring main: (a) square knot used to splice the ends of a det-cord; (b) girth hitch used to fasten a branch line to a main line; and (c) ring main with branch lines for detonating multiple charges (US Army 1986)

of all charges more positive because the detonating wave approaches the branch lines from both directions, and charges will be detonated even when there is one break in the ring main. Branch line connections should be made perpendicular to the ring main. Kinks in lines should be avoided, and changes in direction should not be sharp. Any number of branch lines may be connected to the ring main, but a branch line is never connected at a point where the ring main is spliced. In making det-cord branch line connections, avoid crossing lines. However, if this is necessary, be sure to have at least 1 ft of clearance at all points between detonating cords; otherwise, cords will cut each other and destroy the firing system.