Carcass Disposal: A Comprehensive Review

National Agricultural Biosecurity Center Consortium
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Chapter 1

Burial

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Abbreviations

AI	avian influenza
APHIS	USDA Animal and Plant Health Inspection Service
BOD	biochemical oxygen demand
BSE	bovine spongiform encephalopathy
COD	chemical oxygen demand
CWD	chronic wasting disease
CAFO	confined animal feeding operation
CJD	Creutzfeldt-Jakob disease
DEFRA	UK Department for Environment Food and Rural Affairs (formerly MAFF, UK Ministry of Agriculture, Fisheries and Food)
EA	UK Environment Agency
END	exotic Newcastle disease
EPA	US Environmental Protection Agency
FMD	foot and mouth disease
MAFF	UK Ministry of Agriculture, Fisheries & Food
MSW	municipal solid waste
NAO	UK NAO
RHD	rabbit hemorrhagic disease
SEAC	Spongiform Encephalopathy Advisory Committee
TDS	total dissolved solids
TOC	total organic carbon
Ton	US ton (2,000 lbs)
Tonne	Metric ton (2,204 lbs)
TSE	transmissible spongiform encephalopathy
TVOC	total volatile organic compounds
UK	United Kingdom
US	United States
USDA	United States Department of Agriculture
VOC	volatile organic compounds
WHO	World Health Organization

Section 1 – Key Content

This report addresses three burial techniques, trench burial, landfill, and mass burial sites. For animal disease eradication efforts, trench burial traditionally has been a commonly used, and in some cases, even a preferred, disposal option (USDA, 1981; USDA, APHIS, 1978). In spite of potential logistical and economic advantages, concerns about possible effects on the environment and subsequently public health have resulted in a less favorable standing for this method. Landfills represent a significant means of waste disposal in the US and throughout the world, and have been used as a means of carcass disposal in several major disease eradication efforts, including the 1984 and 2002 avian influenza (AI) outbreaks in Virginia (Brglez, 2003), the 2001 outbreak of foot and mouth disease (FMD) in the United Kingdom (UK) (UK Environment Agency, 2001b), and the 2002 outbreak of exotic Newcastle disease (END) in southern California (Riverside County Waste Management Department, 2003). For purposes of this report, the term "mass burial site" is used to refer to a burial site in which large numbers of animal carcasses from multiple locations are disposed, and which may incorporate systems and controls to collect, treat, and/or dispose of leachate and gas. Mass burial sites played a key role in the disposal of carcasses resulting from the 2001 outbreak of FMD in the UK, and much of the information pertaining to this technique is garnered from this event.

1.1 – Burial Techniques

Trench burial

Disposal by trench burial involves excavating a trough into the earth, placing carcasses in the trench, and covering with the excavated material (backfill). Relatively little expertise is required to perform trench burial, and the required equipment is commonly used for other purposes. Large-capacity excavation equipment is commonly available from companies that either rent the equipment or operate for hire. The primary resources required for trench burial include excavation equipment and a source of cover material. Cover material is often obtained from the excavation process itself and reused as backfill.

Important characteristics in determining the suitability of a site for burial include soil properties; slope or topography; hydrological properties; proximity to water bodies, wells, public areas, roadways, dwellings, residences, municipalities, and property lines; accessibility; and the subsequent intended use of the site. Although many sources concur that these characteristics are important, the criteria for each that would render a site suitable or unsuitable vary considerably.

Estimates of the land area that may be required for disposal of mature cattle include 1.2 yd^3 (McDaniel, 1991; USDA, 2001a), 2 yd^3 (Agriculture and Resource Management Council of Australia and New Zealand, 1996), 3 yd^3 (Lund, Kruger, & Weldon), and 3.5 yd^3 (Ollis, 2002), with 1 adult bovine considered equivalent to 5 adult sheep or 5 mature hogs (McDaniel, 1991; Ollis, 2002; USDA, 1980). Excavation requirements in terms of the weight of mortality per volume were estimated as 40 lbs/ft^3 (1,080 lbs/yd^3) (Anonymous, 1973), and 62.4 lbs/ft^3 (1,680 lbs/yd^3) (USDA, Natural Resources Conservation Service, Texas, 2002). One source estimated that a volume of about 92,000 yd^3 would be required to bury 30,000 head of cattle (about 7 acres, assuming a trench depth of 8.5 ft) (Lund, Kruger, & Weldon).

Most cost estimates for trench burial refer only to the use of trench burial for disposal of daily mortality losses, which may be considerably different from those incurred during an emergency situation. Using information adapted from the Sparks Companies, Inc. (2002), costs for burial of daily mortalities were estimated to be about $15 per mature cattle carcass, and about $7-8 for smaller animals such as calves and hogs. Another source estimated about $198/100 head of hogs marketed (however, it is not clear how this estimate relates to actual cost per mortality) (Schwager, Baas, Glanville, Lorimor, & Lawrence). The cost of trench burial of poultry during the 1984 AI outbreak in Virginia was estimated to be approximately $25/ton (Brglez, 2003).

Advantages & disadvantages

Trench burial is cited as a relatively economical option for carcass disposal as compared to other available methods. It is also reported to be convenient, logistically simple, and relatively quick, especially for daily mortalities, as the equipment necessary is generally widely available and the technique is relatively straightforward. If performed on-farm or on-site, it eliminates the need for transportation of potentially infectious material. The technique is perhaps more discrete than other methods (e.g., open burning), especially when performed on-site (on-farm) and may be less likely to attract significant attention from the public.

Disadvantages of trench burial include the potential for detrimental environmental effects, specifically water quality issues, as well as the risk of disease agents persisting in the environment (e.g., anthrax, transmissible spongiform encephalopathy [TSE] agents, etc.). Trench burial serves as a means of placing carcasses "out of site, out of mind" while they decompose, but it does not represent a consistent, validated means of eliminating disease agents. Because the residue within a burial site has been shown to persist for many years, even decades, ultimate elimination of the carcass material represents a long-term process, and there is a considerable lack of knowledge regarding potential long-term impacts. Trench burial may be limited by regulatory constraints or exclusions, a lack of sites with suitable geological and/or hydrological properties, and the fact that burial may be prohibitively difficult when the ground is wet or frozen. In some cases, the presence of an animal carcass burial site may negatively impact land value or options for future use. Lastly, as compared to some other disposal options, burial of carcasses does not generate a useable by-product of any value.

Landfill

Modern Subtitle D landfills are highly regulated operations, engineered and built with technically complex systems specifically designed to protect the environment. Many older landfills in the US (sometimes called small arid landfills) were constructed before Subtitle D regulations were effective, and therefore were not constructed with sophisticated containment systems (US EPA). The environmental protection systems of a Subtitle D landfill are generally more robust than those of a small arid landfill, and would likely be less prone to failure following challenge by high organic loading (as would occur in disposal of large quantities of carcass material). An excellent overview of the design and operation of municipal solid waste (MSW) landfills is provided by O'Leary & Walsh (2002).

In many states, disposal of animal carcasses in landfills is an allowed option; however, it is not necessarily an available option, as individual landfill operators generally decide whether or not to accept carcass material (Wineland & Carter, 1997; Sander, Warbington, & Myers, 2002; Morrow & Ferket, 2001; Bagley, Kirk, & Farrell-Poe, 1999; Hermel, 1992, p. 36; Morrow & Ferket, 1993, p. 9; Kansas Department of Health and Environment, Bureau of Waste Management, 2001a; Kansas Department of Health and Environment, Bureau of Waste Management, 2001b; Fulhage, 1994; Britton; Talley, 2001; Ohio Environmental Protection Agency, 1997; Indiana State Board of Animal Health; Pope, 1991, p. 1124). Whether real or perceived, potential risks to public health from disposing of animal carcasses in landfills will likely be the most influential factor in the operator's decision to accept carcass material, as evidenced by the UK experience during the 2001 FMD outbreak (UK Environment Agency, 2002b; Hickman & Hughes, 2002), and by the Wisconsin experience in disposing of deer and elk carcasses stemming from the chronic wasting disease (CWD) eradication effort (Wisconsin Department of Natural Resources, 2003, p. 127). The US EPA recently outlined recommended interim practices for disposal of carcasses potentially contaminated with CWD agents (US EPA, Office of Solid Waste, 2004).

Because a landfill site is in existence prior to a time of emergency, set-up time would in theory be minimal. However, some time may be required to agree on the terms of use for the site if not arranged in advance (prior to time of emergency). The Riverside County California Waste Management Department developed an excellent training video to educate landfill operators and employees on appropriate biosecurity and operational procedures to prevent disease spread (Riverside County Waste Management Department, 2003). The primary by-products resulting from decomposition of wastes, including carcasses, in the landfill are leachate and landfill gas. As per Subtitle D regulations, systems are already in place to collect and treat these outputs and therefore additional systems would not likely be necessary. It is noteworthy that carcass material is likely of greater density and different composition than typical MSW, thus the disposal of significant quantities of carcass material could affect the quantity and composition of leachate and landfill gas generated.

Average fees charged by landfills for MSW in various regions of the US in 1999 ranged from about $21 to $58/ton, with the national average approximately $36/ton (Anonymous, 1999). Fees for disposal of animal carcasses at three different landfills in Colorado were reportedly $10 per animal, $4 per 50 pounds (approximately $160/ton), and $7.80 per yd^3 (Talley, 2001). As of 2003, fees for carcass disposal in Riverside County, CA, consisted of a $20 flat fee for quantities less than 1,000 lbs, and $40/ton for quantities greater than 1,000 lbs (Riverside County Waste Management Department). In Souix Falls, South Dakota, disposal fees for deer and elk carcasses at the city landfill were established as $50/ton for deer or elk carcasses originating within the state, and $500/ton for carcasses originating outside the state (Tucker, 2002). During the 2002 outbreak of AI in Virginia, fees at landfills for disposal of poultry carcasses were approximately $45/ton (Brglez, 2003). During the 2002 outbreak of END in southern California, fees were approximately $40/ton for disposing of poultry waste at landfills (Hickman, 2003).

Advantages & disadvantages

During an emergency or instance of catastrophic loss, time is often very limited, and therefore landfills offer the advantage of infrastructures for waste disposal that are pre-existing and immediately available. Furthermore, the quantity of carcass material that can be disposed of via landfills can be relatively large. Landfill sites, especially Subtitle D landfill sites, will have been previously approved, and the necessary environmental protection measures will be pre-existing; therefore, landfills represent a disposal option that would generally pose little risk to the environment. (Note that these advantages related to adequate containment systems may not apply to small arid landfills that rely on natural attenuation to manage waste by-products). Another advantage of landfills is their wide geographic dispersion. The cost to dispose of carcasses by landfill has been referred to as both an advantage and a disadvantage, and would likely depend on the situation.

Even though disposal by landfill may be an allowed option, and a suitable landfill site may be located in close proximity, landfill operators may not be willing to accept animal carcasses. Additionally, because approval and development of a landfill site is lengthy, difficult, and expensive, landfill owners and planning authorities may not want to sacrifice domestic waste capacity to accommodate carcass material. Those landfill sites that do accept animal carcasses may not be open for access when needed or when convenient. Landfilling of carcasses represents a means of containment rather than of elimination, and long-term management of the waste is required. Although several risk assessments conclude that disposal of potentially TSE-infected carcasses in an appropriately engineered landfill site represents very little risk to human or animal health, further research is warranted in this area as the mechanism and time required for degradation are not known. Another possible disadvantage associated with landfill disposal is the potential spread of disease agents during transport of infected material to the landfill (a potential concern for any off-site disposal method).

Mass burial

The scale of the 2001 UK FMD epidemic presented unprecedented challenges in terms of carcass disposal, prompting authorities to seek sites on which mass burials could be undertaken. A total of seven sites were identified as suitable and work began almost immediately to bring them into use (5 of the 7 sites were operational within 8 days of identification). In total, some 1.3 million carcasses (about 20% of the total 6 million) were disposed of in these mass burial sites (National Audit Office, or NAO, 2002, p. 74).

The disposal of carcasses in these mass burial sites was a hugely controversial issue and aroused significant public reaction, including frequent demonstrations and community action to limit their use (NAO, 2002, p. 77). Most of the negative reaction stemmed from the haste with which the sites were identified and developed (Scudamore, Trevelyan, Tas, Varley, & Hickman, 2002, p. 778), and the consequences of this haste (including damaged public relations as well as site management issues due to poor design) will undoubtedly be long-lasting and costly. Although UK authorities have indicated reluctance towards use of this disposal route in the future, the potential advantages of the method, when appropriate planning and site evaluation could be conducted prior to time of emergency, warrant further investigation.

As demonstrated by the UK experience, thorough site assessments prior to initiation of site development are critical for minimizing subsequent engineering and operational difficulties. The total amount of space required for a mass burial site would depend on the volume of carcass material to be disposed and the amount of space needed for operational activities. The total land area occupied by the seven mass burial sites in the UK ranged from 42 to 1,500 acres (NAO, 2002). In general, the resources and inputs required for a mass burial site would be similar in many respects, although likely not as complex, as those required for a landfill. However, whereas the infrastructure at an established landfill would be pre-existing, the resources for a mass burial site likely would not.

The estimated total capacity of the various UK mass burial sites ranged from 200,000 to 1,000,000 sheep carcasses (each approx. 50 kg [about 110 lbs]) (NAO, 2002). In terms of cattle carcasses (each approx. 500 kg [about 1,100 lbs]), these capacities would be reduced by a factor of 10. The sites generated tremendous volumes of leachate requiring management and disposal, the strategies for which in some cases were similar to those employed in MSW landfills, although some sites relied solely on natural attenuation. In many cases, leachate was taken off-site to a treatment facility.

Costs associated with the various UK mass burial sites ranged from £5 to £35 million, and the costs of all sites totaled nearly £114 million (NAO, 2002). Based on the estimated total number of carcasses buried at the sites, the approximate cost for this disposal option was about £90/carcass (ranged from approximately £20 to £337 at the various sites) (NAO, 2002). At the Throckmorton site, 13,572 tonnes of carcasses were disposed (Det Norske Veritas, 2003) at an estimated cost of £1,665/tonne.

Advantages & disadvantages

The most significant advantage of mass burial sites is the capacity to dispose of a tremendous number (volume) of carcasses. Assuming adequate site assessment, planning, and appropriate containment systems are employed, mass burial sites may be similar to landfills in terms of posing little risk to the environment. However, tremendous public opposition to the development and use of such sites during the UK experience caused officials to state that it is very unlikely that mass burial sites would be used as a method of disposal in the future (FMD Inquiry Secretariat, 2002). Other disadvantages included the significant costs involved, problems with site design leading to brief episodes of environmental contamination, and the need for continuous, long-term, costly monitoring and management of the facilities. Other potential disadvantages of mass burial sites would be similar to those outlined for landfills, namely serving as a means of containment rather than of elimination, lack of adequate research into long-term consequences associated with various disease agents (especially TSEs), presenting opportunities for spread of disease during transport from farm sites to the mass burial site, and not generating a usable by-product of any value. In spite of these potential disadvantages, mass burial sites could potentially serve as an effective means of carcass disposal in an emergency situation, although thorough site assessment, planning, and design would be required well in advance of the need.

1.2 – Disease Agent Considerations

In general, very little information is available regarding the length of time disease agents persist in the burial environment, or the potential for dissemination from the burial site. Concerns stem from the fact that burial, unlike some other disposal methods such as incineration or rendering, serves only as a means of ridding carcass material, but does not necessarily eliminate disease agents that may be present. The question arises as to the possibility of those disease agents disseminating from the burial site and posing a risk to either human or animal health. The most relevant hazards to human health resulting from burial identified by the UK Department of Health were bacteria pathogenic to humans, water-borne protozoa, and the bovine spongiform encephalopathy (BSE) agent (UK Department of Health, 2001c). Contaminated water supplies were identified as the main exposure route of concern, and the report generally concluded that an engineered licensed landfill would always be preferable to unlined burial.

Generally, the conditions of deep burial and associated pressures, oxygen levels, and temperatures are thought to limit the survival of the majority of bacterial and viral organisms (Gunn, 2001; Gale, 2002); however, precise survival times are unpredictable, and spore-forming organisms are known to survive in the environment for very long periods of time. Survival would be governed by conditions such as temperature, moisture content, organic content, and pH; transport of microbes within groundwater would be affected by the characteristics of the organism as well as the method of transport through the aquifer (UK Environment Agency, 2002a).

The FMD virus is generally rapidly inactivated in skeletal and heart muscle tissue of carcasses as a result of the drop in pH that accompanies rigor mortis (Gale, 2002, p. 102). However, it may survive at 4°C for approximately two months on wool, for two to three months in bovine feces or slurry, and has reportedly survived more than six months when located on the soil surface under snow (Bartley, Donnelly, & Anderson, 2002). Pre-treatment of leachate from the UK Throckmorton mass burial site with lime was discontinued 60 days after burial of the last carcass because FMD virus was reportedly unlikely to survive more than 40 days in a burial cell (Det Norske Veritas, 2003, p. II.21). However, no studies were cited to indicate from what data the 40-day estimate was derived. An evaluation was conducted in 1985 in Denmark to estimate whether burying animals infected with FMD would constitute a risk to groundwater (Lei, 1985). The authors concluded that the probability of groundwater contamination from burial of FMD-infected animals was very small, and that even if virus were able to reach groundwater sources, the concentration would likely be inadequate to present an animal-health risk.

The agents (known as prions) believed to be responsible for TSEs, such as BSE in cattle, scrapie in sheep, CWD in deer and elk, and Creutzfeldt-Jakob disease (CJD) in humans, have been demonstrated to be highly resistant to inactivation processes effective against bacterial and viral disease agents (Taylor, 1996; Taylor, 2000), and the scrapie agent has been demonstrated to retain at least a portion of its infectivity following burial for three years (Brown & Gajdusek, 1991).

Risk assessments conducted in the UK after the BSE epidemic, and after the 2001 FMD outbreak, addressed the issue of survival of the BSE agent in the environment as a result of disposal of infected or potentially infected carcasses (DNV Technica, 1997b; DNV Technica, 1997a; Comer & Spouge, 2001). Ultimately the risk assessments concluded that the risk to human health was very low (could be generally regarded as an acceptable level of risk). The Wisconsin Department of Natural Resources conducted a risk assessment to address the risks posed by disposal of deer and elk carcasses infected with CWD in landfills (Wisconsin Department of Natural Resources, 2002). The risk assessment concluded that the available knowledge about CWD and other TSEs suggested that landfilling CWD infected deer would not pose a significant risk to human health, and the risk of spreading CWD among the state's deer population by landfill disposal of infected carcasses would be small (Wisconsin Department of Natural Resources, 2002). Other sources have also reiterated this finding of very low levels of risk to human health from disposing of TSE-infected animal carcasses in landfill sites (Gunn, 2001; Gale, Young, Stanfield, & Oakes, 1998).

In spite of these risk assessment findings, additional research efforts are needed relative to TSE infectivity in the environment, including the communities of soil microorganisms and animals involved in carcass degradation, effect of anaerobic conditions and soil type on the degradation, persistence, and migration of TSEs in the soil environment, detection systems which can be used to identify infectivity in soil matrices, and a need to validate assumptions on the behavior of TSE agents which have been used in risk assessments (UK

DEFRA, 2002b). In a speech to the US Animal Health Association, Taylor (2001) indicated that "the present evidence suggests that TSE infectivity is capable of long-term survival in the general environment, but does not permit any conclusions to be drawn with regard to the maximum period that it might survive under landfill conditions." In 2003, the European Commission Scientific Steering Committee emphasized that the "extent to which [potential TSE] infectivity reduction can occur as a consequence of burial is poorly characterized" (European Commission Scientific Steering Committee, 2003). Based on this lack of understanding, along with concerns for groundwater contamination and dispersal or transmission by vectors, the committee indicated that burial of animal material which could possibly be contaminated with BSE/TSEs "poses a risk except under highly controlled conditions" (e.g., controlled landfill) (European Commission Scientific Steering Committee, 2003).

1.3 – Implications to the Environment

Animal carcass decomposition

From the point at which an animal (or human) succumbs to death, degradation of bodily tissues commences, the rate of which is strongly influenced by various endogenous and environmental factors (Pounder, 1995). Soft tissue is degraded by the postmortem processes of putrefaction (anaerobic degradation) and decay (aerobic degradation) (Micozzi, 1991, p. 37). Putrefaction results in the gradual dissolution of tissues into gases, liquids, and salts as a result of the actions of bacteria and enzymes (Pounder, 1995). A corpse or carcass is degraded by microorganisms both from within (within the gastrointestinal tract) and from without (from the surrounding atmosphere or soil) (Munro, 2001, p. 7; Micozzi, 1986). Generally body fluids and soft tissues other than fat (i.e., brain, liver, kidney, muscle and muscular organs) degrade first, followed by fats, then skin, cartilage, and hair or feathers, with bones, horns, and hooves degrading most slowly (McDaniel, 1991, p. 873; Munro, 2001, p. 7).

Relative to the quantity of leachate that may be expected, it has been estimated that about 50% of the total available fluid volume would "leak out" in the first week following death, and that nearly all of the immediately available fluid would have drained from the carcass within the first two months (Munro, 2001). For example, for each mature cattle carcass, it was estimated that approximately 80 L (~21 gal) of fluid would be released in the first week postmortem, and about 160 L (~42 gal) would be released in the first two months postmortem. However, the author noted that these estimates were based on the rates of decomposition established for single non-coffined human burials, which may not accurately reflect the conditions in mass burials of livestock (Munro, 2001). Another source estimated the volume of body fluids released within two months postmortem would be approximately 16 m^3 (16,000 L, or ~4,230 gallons) per 1000 adult sheep, and 17 m^3 (17,000 L, or ~4,500 gallons) per 100 adult cows (UK Environment Agency, 2001b, p. 11).

Regarding the gaseous by-products that may be observed from the decomposition of animal carcasses, one report estimated the composition would be approximately 45% carbon dioxide, 35% methane, 10% nitrogen, with the remainder comprised of traces of other gases such as hydrogen sulfide (Munro, 2001). Although this report suggested that the methane proportion would decrease over time, with very little methane being produced after two months, a report of monitoring activities at one of the UK mass burial sites suggests that gas production, including methane, increases over time, rather than decreases (Enviros Aspinwall, 2002b).

The amount of time required for buried animal carcasses (or human corpses) to decompose depends most importantly on temperature, moisture, and burial depth, but also on soil type and drainability, species and size of carcass, humidity/aridity, rainfall, and other factors (McDaniel, 1991; Pounder, 1995; Mann, Bass, & Meadows, 1990). A human corpse left exposed to the elements can become skeletonized in a matter of two to four weeks (Mann, Bass, & Meadows, 1990; Iserson, 2001, p. 384); however, an unembalmed adult human corpse buried six feet deep in ordinary soil without a coffin requires approximately ten to twelve years or more to skeletonize (UK Environment Agency, 2002a; Pounder, 1995; Munro, 2001; Iserson, 2001). In addition to actual carcass material in a burial site, leachates or other pollutants may also persist for an extended period. Although much of the pollutant load would likely be released during the earlier stages of decomposition (i.e., during the first 1-5 years) (UK Environment Agency, 2001b; McDaniel, 1991; UK Environment Agency, 2002a; Munro, 2001), several reports suggest that mass burial sites could continue to produce both leachate and gas for as long as 20 years (UK Environment Agency, 2001b; Det Norske Veritas, 2003).

Environmental impacts

Various works have estimated the potential environmental impacts and/or public health risks associated with animal carcass burial techniques. Several sources identify the primary environmental risk associated with burial to be the potential contamination of groundwater or surface waters with chemical products of carcass decay (McDaniel, 1991; Ryan, 1999; Crane, 1997). Freedman & Fleming (2003) stated that there "has been very little research done in the area of environmental impacts of livestock mortality burial," and concluded that there is little evidence to demonstrate that the majority of regulations and guidelines governing burial of dead stock have been based on any research findings directly related to the environmental impacts of livestock or human burials. They also conclude that further study of the environmental impacts of livestock burial is warranted.

During the 2001 outbreak of FMD in the UK, various agencies assessed the potential risks to human health associated with various methods of carcass disposal (UK Department of Health, 2001c; UK Environment Agency, 2001b). The identified potential hazards associated with burials included body fluids, chemical and biological leachate components, and hazardous gases. Further summaries of environmental impacts are outlined in investigations into the operation of various mass disposal sites (Det Norske Veritas, 2003; UK Environment Agency, 2001c).

Since precipitation amount and soil permeability are key to the rate at which contaminants are "flushed out" of burial sites, the natural attenuation properties of the surrounding soils are a primary factor determining the potential for these products of decomposition to reach groundwater sources (UK Environment Agency, 2002a). The most useful soil type for maximizing natural attenuation properties was reported to be a clay-sand mix of low porosity and small to fine grain texture (Ucisik & Rushbrook, 1998).

Glanville (1993 & 2000) evaluated the quantity and type of contaminants released from two shallow pits containing approximately 62,000 lbs of turkeys. High levels of ammonia, total dissolved solids (TDS), biochemical oxygen demand (BOD), and chloride in the monitoring well closest to the burial site (within 2 ft) were observed, and average ammonia and BOD concentrations were observed to be very high for 15 months. However, little evidence of contaminant migration was observed more than a few feet from the burial site.

The impact of dead bird disposal pits (old metal feed bins with the bottom removed, placed in the ground to serve as a disposal pit) on groundwater quality was evaluated by Ritter & Chirnside (1995 & 1990). Based on results obtained over a three-year monitoring period, they concluded that three of the six disposal pits evaluated had likely impacted groundwater quality (with nitrogen being more problematic than bacterial contamination) although probably no more so than an individual septic tank and soil absorption bed. However, they cautioned that serious groundwater contamination may occur if a large number of birds are disposed of in this manner.

In the aftermath of the 2001 UK FMD outbreak, the UK Environment Agency (2001b) published an interim assessment of the environmental impact of the outbreak. The most notable actual environmental pressures associated with burial included odor from mass burial sites and landfills, and burial of items such as machinery and building materials during the cleansing and disinfection process on farms. The interim environmental impact assessment concluded that no significant negative impacts to air quality, water quality, soil, or wildlife had occurred, nor was any evidence of harm to public health observed. Monitoring results of groundwater, leachate, and landfill gas at the mass disposal sites indicated no cause for concern (UK Public Health Laboratory Service, 2001c).

Monitoring programs

Following the disposal activities of the 2001 FMD outbreak, the UK Department of Health outlined environmental monitoring regimes focused on the key issues of human health, air quality, water supplies, and the food chain (UK Department of Health, 2001b; UK Public Health Laboratory Service); these programs might serve as models for monitoring programs in the aftermath of an animal disease eradication effort. The UK programs included monitoring of public drinking water supplies, private water supplies, leachate (levels, composition, and migration), and surveillance of human illness (such as gastrointestinal infections). Chemical parameters and indicators were reported to likely be better than microbiological parameters for demonstrating contamination of private water supplies with leachate from an animal burial pit, but testing for both was recommended. It was recommended that at-risk private water supplies should be tested for chloride, ammonium, nitrate, conductivity, coliforms, and *E. coli*. Because baseline data with which to compare would likely not exist, caution in interpretation of results was stressed (i.e., increased levels of an analyte may not necessarily indicate contamination by a disposal site; other sources may be involved) (UK Public Health Laboratory Service).

Section 2 – Historical Use

This chapter primarily addresses three burial techniques, namely trench burial, landfill, and mass burial sites. This section contains a brief overview of the historical use of these methods for disposal of animal carcasses.

One burial technique not addressed in this report is that of a “burial pit,” which consists of a hole dug into the earth, the sides of which may be lined with concrete, metal, or wood. The bottom of the pit is left exposed to the earth below, and the top is closed with a tight-fitting cover or lid. In the past, this technique was used extensively by the poultry industry as a convenient means of disposing of daily mortalities. However, this technique is not specifically addressed in this chapter, as it is not well-suited to the disposal of large quantities of material, and the use of such pits is generally being phased out due to environmental concerns.

The general frequency with which burial techniques, and other methods, are used by various livestock or food animal operations to dispose of daily mortalities is outlined in Table 1. The information contained in this table was summarized from various reports prepared under the National Animal Health Monitoring System of the Veterinary Services Division of the United States Department of Agriculture (USDA), Animal & Plant Health Inspection Service (APHIS). While these values may not reflect the situation that may occur during an animal health emergency, they provide some insight into the disposal methods used on an ongoing basis to dispose of daily production mortalities.

2.1 – Trench Burial

Background

Trench burial has been used throughout history as a method of carcass disposal. For animal disease eradication efforts in the US, trench burial has traditionally been a commonly used, and, in some cases even a preferred, disposal option (USDA, 1981; USDA, APHIS, 1978). In spite of its logistical and economic advantages, concerns about possible effects on the environment and subsequently public health have resulted in a less favorable standing for this method, especially when large numbers of carcasses may be involved.

TABLE 1. Percent of operations using (percent of mortalities disposed by) various disposal methods. Note values may not total 100% as operations may use more than one disposal method.

Disposal Method	Feedlot Cattle[a]	Dairy Cows[b]	Weaned Pigs[c]	Sheep[d]	Layer Hens[e]
Buried on operation	10.7 (5.3)	22.7	37.8 (11.5)	51.7 (27.1)	--
Landfill	1.6 (0.5)	1.9	--	7.5 (6.9)	--
Rendering	94.4 (94.1)	62.4	45.5 (68.0)	2.3 (4.2)	32.0 (41.4)
Incineration/Burn	--	2.2	11.6 (6.0)	12.9 (7.5)	9.0 (10.4)
Composting	--	6.9	18.0 (12.7)	6.9 (5.0)	15.0 (11.7)
Leave for scavengers	--	--	--	25.3 (47.4)	--
Covered deep pit	--	--	--	--	32.0 (17.9)
Other	0.4 (0.1)	3.9	2.5 (1.8)	2.6 (1.9)	16.1 (18.6)

[a] (USDA, 2000a)
[b] (USDA, 2002a)
[c] (USDA, 2001a)
[d] (USDA, 2002b)
[e] (USDA, 2000b)

Over time, views on the appropriateness of using trench burial for disposal have changed. For example, at the outset of the 2001 foot and mouth disease (FMD) outbreak in the United Kingdom (UK), on-farm burial was the first preferred means of carcass disposal. However, within a few weeks revised guidelines were issued placing on-farm burial as the least preferred of a list of five disposal options, largely due to concerns about environmental impacts and bovine spongiform encephalopathy (BSE) risks (UK Department of Health, 2001a; Northumberland FMD Inquiry Panel, 2002, p. 61). The panel of one inquiry conducted subsequent to the outbreak disagreed with this sweeping change, arguing that more effort should have gone into identifying suitable burial sites on or near farms (Northumberland FMD Inquiry Panel, 2002, p. 61). Not only in the UK, but within the US and throughout the world, large-scale burial remains a controversial technique during a situation of catastrophic loss.

Use of trench burial for carcass disposal

1984 avian influenza outbreak in Virginia

An outbreak of avian influenza (AI) in Virginia in 1984 resulted in the disposal of 5,700 tons of carcass material (Brglez, 2003). On-site burial was the primary means of disposal during this outbreak, accounting for approximately 85% of the carcasses disposed. Although a variety of trench designs and methods were used early in the outbreak, towards the end of the outbreak burial trenches were somewhat standardized using a width of 20 ft, a depth of 10 ft, with a length necessary to accommodate the quantity of carcasses. Based on the experience of this outbreak, approximately 20 ft^3 were required per 800 lbs of poultry carcasses.

2.2 – Landfill

Background

Landfills represent a significant means of waste disposal in the US and throughout the world. In 2000, approximately 232 million tons of municipal solid waste (MSW) was generated in the US—equivalent to approximately 4.5 pounds per person per day. Although source reduction, composting, and recycling are on the rise, landfills were still used to dispose of approximately 55% of the total MSW generated, or about 128 million tons. Over the past decade, the number of MSW landfills in the US has decreased dramatically from 8,000 in 1988 to 1,967 in 2000; however, average landfill size has increased (US EPA, Office of Solid Waste and Emergency Response, 2002).

The term landfill may conjure up images of what is more appropriately termed a "dump." Up until the 1950s, disposal of refuse in open pit dumps was common; these dumps were generally sited away from areas where people lived and worked and were havens for rats, flies, and other disease vectors. Fires sometimes arose spontaneously, but were also set intentionally to reduce the volume of waste and create more space in the dump. Garbage was generally left open to the elements, resulting in blowing garbage, vermin infestation, overpowering odors of decay, and contamination of streams and groundwater by runoff from rain water (McBean, Rovers, & Farquhar, 1995). The term "sanitary landfill" refers to improvements upon the open dump whereby refuse was covered at the end of each day to minimize these nuisance problems.

In stark contrast to the image of a "dump," the modern MSW landfill is a highly regulated operation, engineered and built with technically complex systems specifically designed to protect the environment. In 1991 the US Environmental Protection Agency (EPA) published the Resource Conservation and Recovery Act (RCRA; 40 CFR Parts 257 and 258). This regulation imposed a variety of requirements designed to protect the environment, including facility design and operating standards, groundwater monitoring programs, corrective action measures, as well as conditions for ultimately closing sites and conducting post-closure monitoring (US EPA, Office of Solid Waste and Emergency Response, 1995, p. 9-18). Sites operating under the design criteria outlined in this regulation are often referred to as "Subtitle D landfills." In addition to the federal Subtitle D regulations, states and local authorities may have additional, or even more stringent, regulatory criteria.

Some key design characteristics required by the Subtitle D regulations include (US EPA):

1. **Location.** Restricts proximity of landfills to floodplains, wetlands, fault areas, etc.
2. **Composite liners.** Upper component must consist of a flexible membrane liner (at least 30 mil thick; 60 mil thickness required if material is high density polyethylene, HDPE), lower component must consist of at least 2 ft of compacted soil with hydraulic conductivity no more than 1 x 10^{-7} cm/sec
3. **Leachate.** Restricts leachate to a depth of less than 30 cm over the liner
4. **Monitoring.** Requires groundwater monitoring systems
5. **Gases.** Requires a means of controlling explosive gases

Many landfills in the US were in existence long before Subtitle D regulations were effective, and therefore were not constructed with sophisticated containment systems (liners, leachate collection and treatment systems, etc). In some circumstances, small landfill facilities (those that accept less than 20 tons of MSW per day) located in arid regions (no more than 25 inches of precipitation annually) may be exempt from some aspects of the Subtitle D regulations, such as the requirement for composite liners. Such facilities may be referred to as "small arid landfills." These sites must demonstrate that the naturally occurring geological conditions provide sufficient protection against groundwater contamination and must verify this protection through groundwater monitoring programs (US EPA). This protection by natural geological conditions is known as "natural attenuation." Natural attenuation refers to the ability of soil to absorb (remove or reduce in concentration) and/or convert the chemical components in leachate (Figure 1). For example, as leachate moves through a clay soil, most of the heavy metals are retained by the soil. Natural attenuation is a variable and relatively unpredictable process, making it difficult to estimate the degree of protection afforded (US EPA, Office of Solid Waste and Emergency Response, 1995, pp. 9-41).

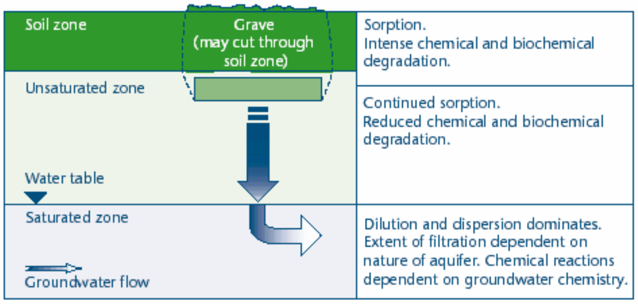

FIGURE 1. Representation of natural attenuation processes (UK Environment Agency, 2002a).

Use of landfills for carcass disposal

1984 and 2002 avian influenza outbreaks in Virginia

In 1984 an outbreak of AI in Virginia resulted in the disposal of approximately 5,700 tons of poultry carcass material. Approximately 15% of this total, or 655 tons, was disposed of in the Rockingham County sanitary landfill (Brglez, 2003, p. 26). From the standpoint of potential groundwater and surface water contamination, the geological and hydrological properties of the site, which was originally used as an unregulated dump, were not well-suited to the disposal of such carcass material. Although subsequent water quality tests from two domestic wells located in relatively close proximity to the site did not indicate groundwater contamination, a 240-fold increase in fecal coliform levels was observed in surface waters near the landfill (Brglez, 2003, p. 24). These environmental concerns resulted in limited use of the site for disposal purposes.

In 2002, this same region of Virginia experienced another, larger outbreak of AI. During this event, a total of approximately 16,900 tons of poultry carcass material was generated for disposal. In this outbreak, commercial landfills played a much more prominent role in the disposal process, as approximately 85% of this total, or about 14,500 tons, was disposed of in landfills (Brglez, 2003, p. 28-30). A summary of the quantity of carcass material disposed at various landfills, and the reported limitations of these landfill sites, is shown in Table 2.

TABLE 2. Carcass disposal by landfill during 2002 Virginia avian influenza outbreak (adapted from Brglez, 2003).

Landfill	Tons of poultry carcasses accepted	Distance from outbreak	Limitations/Problems
Rockingham County	3,400	Closest	Small capacity, odor concerns
Page County	951	40 miles	Small capacity
Frederick County	842		Inadequate capacity to handle leachate; ammonia levels in leachate tripled, and as of March 2003 remain too high for release into surface waters
Charles City	4,610	Over 160 miles	Transportation distance
Sussex County	4,625	Over 160 miles	Transportation distance

Note that the Charles City and Sussex County sites are very large landfills and were both prepared to accept up to 10,000 tons of poultry carcasses. Almost $1 million was paid for the use of both landfill sites. Although the fees charged by these larger landfills were similar to the closer, smaller landfills ($45/ton), significant additional cost was incurred due to the greatly increased transportation distance (Brglez, 2003, p. 30). Transportation proved to be a significant bottleneck, as a given truck could deliver only two loads per day (four-hour round trip) and only 14 appropriately-configured (sealed) trucks were available (Brglez, 2003, p. 30).

BSE epidemic in the UK

Between 1988 and 1991 (the early stages of the BSE epidemic) an estimated 6,000 carcasses infected with BSE were disposed of in 59 different landfill sites around the UK. Most of the landfill sites used for disposal were mature landfills (had been in operation for some time), and most did not have any engineered containment or leachate management systems but were operated as dilute and disperse sites. A risk assessment was undertaken to determine what, if any, hazard these carcasses posed to human health. After determining the most likely source of potential risk would result from possible contamination of leachate, the assessment concluded that the risk of infection was well below an individual risk of 1 in a million years (DNV Technica, 1997a, p. 3).

2001 FMD outbreak in the UK

During the 2001 outbreak of FMD in the UK, a total of approximately 6 million animal carcasses, totaling about 600,000 tonnes, were disposed. Estimates indicate that about 16% of this total (96,000 tons) was disposed of via licensed commercial landfills (UK Environment Agency, 2001b, p. 1). It is interesting to note that, in theory, the available capacity of the licensed commercial landfills could have easily accommodated all of the carcass material disposed during the outbreak. However, opposition by the local public, local authorities, pressure groups, and farmers near the sites was the primary reason for the limited use of this disposal route (Hickman & Hughes, 2002; Hamlen, 2002). Additional factors included BSE concerns, local opposition to heavy transport vehicle traffic carrying carcasses to the sites, operator opposition, cost, and significant transportation distances as large landfill sites were typically located near urban rather than rural centers (NAO, 2002, p. 74). During the outbreak, the UK Environment Agency (EA) (2002b) developed a best practice document for landfills disposing of animal carcasses. The document contains detailed instructions to landfill operators, with special emphasis on biosecurity measures.

During this outbreak, of the 111 landfill sites identified in England and Wales by the UK EA as suitable for carcass disposal, only 29 were used. A total of approximately 95,000 tonnes of carcasses were deposited in these sites, and the majority, 69,000 tonnes, was disposed of in three sites in Cumbria (UK Environment Agency, 2001b, p. 9; NAO, 2002, p. 74). Landfills were also used to dispose of approximately 100,000 tonnes of ash and associated material. Although seemingly significant quantities, these amounts actually represent only a small portion of the 280,000 tonnes of waste generally received at UK landfills on a daily basis (UK Environment Agency, 2001b, p. 9).

2002-03 exotic Newcastle disease outbreak in Southern California

An outbreak of exotic Newcastle disease (END) was confirmed on 1 October 2002 in a backyard farm in southern California. During the eradication effort, approximately 3,160,000 birds were depopulated from 2,148 premises. Landfilling was the primary route of disposal for poultry carcass waste from this eradication campaign. The fee charged by the landfills for accepting this waste was about $40/ton (Hickman, 2003). In the midst of this outbreak, the Riverside County Waste Management Division developed an outstanding training video for landfill operators on how to properly handle waste from this outbreak (Riverside County Waste Management Department, 2003).

2.3 –Mass Burial Site

Background

For purposes of this report, the term “mass burial site” will be used to refer to a burial site in which large numbers of animal carcasses from multiple locations are disposed. As discussed in the following sections, ideally a mass burial site would be engineered to incorporate systems and controls to collect, treat, and/or dispose of leachate and gas. Mass burial sites played a key role in the disposal of carcasses resulting from the 2001 outbreak of FMD in the UK, and much of the information pertaining to this technique is garnered from this event.

Use of mass burial sites for carcass disposal

2001 FMD outbreak in the UK

During the 2001 outbreak of FMD in the UK, approximately 6 million animal carcasses were disposed. The scale of this epidemic presented unprecedented challenges in terms of carcass disposal. As a matter of perspective, on the peak day of 5 April 2001, more than 100,000 animals were disposed of for disease-control purposes; in contrast, during the 1967-68 outbreak of FMD in the UK, the peak *weekly* disposal was 13,500 animals (NAO, 2002, p. 73). The need for rapid slaughter of infected or potentially infected animals, combined with the logistical challenges of carcass disposal, created a backlog of slaughtered animal carcasses awaiting disposal that peaked at over 200,000 in early April 2001 (NAO, 2002). Some estimates suggest that in the hardest-hit areas, over a third of farms experienced delays of more than a week from the time animals were slaughtered until they were disposed (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p. 44). This situation prompted the UK Department for Environment Food & Rural Affairs (DEFRA) to seek to identify sites on which mass burials could be undertaken, preferably sites with impermeable clay soils, far removed from residential properties, but accessible by large vehicles. After rapid assessment of several hundred possible locations, a total of seven sites were identified as suitable and work began almost immediately to bring them into use. In total, some 1.3 million carcasses (about 20% of the total 6 million) were disposed of at these mass burial sites (NAO, 2002, p. 74).

The disposal of carcasses in these mass burial sites was a hugely controversial issue and aroused significant public reaction, including frequent demonstrations and community action to limit their use. The extremely negative public opinion is at least one reason why DEFRA has indicated that this disposal method would not likely be used in the future (NAO, 2002, p. 77). Most of the negative public reaction stemmed from the fact that the sites were brought into use with very little planning or assessment (most pits took less than a week to bring into operation), and in most cases with no input from the surrounding communities. Risk assessments, groundwater authorizations, and planning consents were generally performed retrospectively (Scudamore, Trevelyan, Tas, Varley, & Hickman, 2002, p. 778). Although the use of these sites has been reported by one source to have "saved the campaign," by allowing the disposal rate to catch up to the slaughter rate, the consequences of the haste with which these sites were brought into use will undoubtedly be long-lasting and costly. Although DEFRA has indicated reluctance towards use of this disposal route in the future, the potential advantages of the method, when appropriate planning and site evaluation could be conducted prior to time of emergency, warrant further investigation. A detailed discussion of the technical aspects of the mass burial sites used in the UK is provided later in this report.

Section 3 – Principles of Operation

This section describes the principles of operation for trench burial, burial in landfills, and use of mass burial sites (sites designed and constructed specifically for the disposal of animal carcasses). As stated previously, the "burial pit" technique is not specifically addressed in this report as it is not well-suited to the disposal of large quantities of material, and the use of such pits is generally being phased out due to environmental concerns.

3.1 – Trench Burial

General overview

Disposal by trench burial involves excavating a trough into the earth, placing carcasses in the trench, and covering with the excavated material (backfill). Use of this method is widespread as it is relatively convenient and cheap. Regions where the water table is deep and the soil type is relatively impermeable are best suited to this disposal method. Although burial is generally allowed in most states that regulate carcass disposal, specific regulations differ in terms of burial depth, covering required, separation distances, etc. (Sander, Warbington, & Myers, 2002). Schematic examples of trench burial are provided in Figures 2 & 3 below.

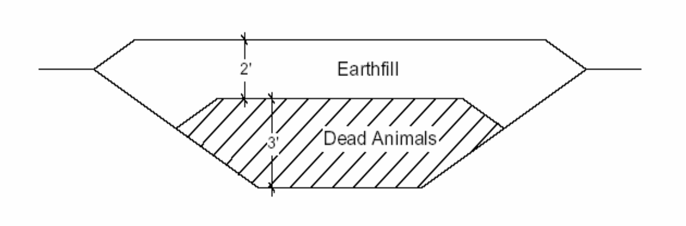

FIGURE 2. Cross section of trench burial (typical for deeper depth for larger animals) (USDA, Natural Resources Conservation Service, Texas, 2002).

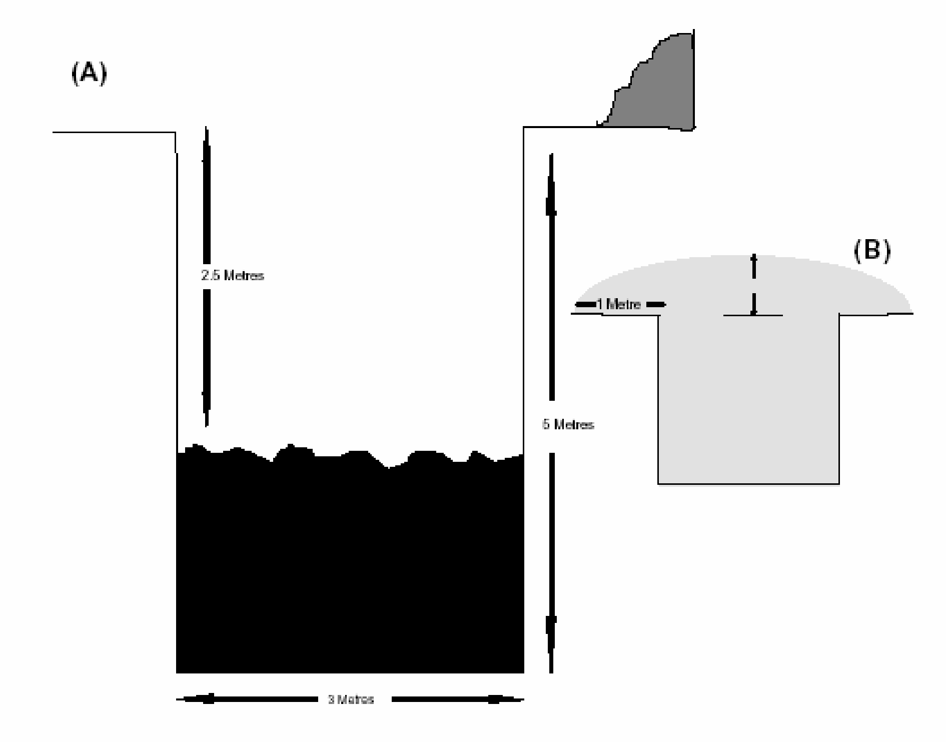

FIGURE 3. Disposal of carcasses by trench burial; (A) open pit; (B) freshly closed pit (Agriculture and Resource Management Council of Australia and New Zealand, 1996).

Expertise and/or personnel requirements

An advantage of trench burial, especially in instances where only small numbers of carcasses are involved, is that relatively little expertise is required and the equipment to perform the operation is commonly used for other purposes. Even in instances where large-capacity excavation equipment is required, companies that either rent the equipment, or operate for hire, are widely available in nearly all geographic areas.

Location considerations

Site selection criteria and regulatory considerations

Several characteristics should be evaluated when identifying a suitable site for the burial of animal carcasses; these characteristics include, but are not limited to the following:

- Soil properties (texture, permeability, surface fragments, depth to water table, depth to bedrock)
- Slope or topography
- Hydrological properties
- Proximity to water bodies, wells, public areas, roadways, dwellings, residences, municipalities, or property lines
- Accessibility
- Subsequent intended use of site

Although many sources concur that these characteristics are important, the criteria for each that would render a site suitable or unsuitable vary. As indicated previously, in states where carcass disposal is regulated, simple trench burial is frequently one of the options allowed. However, state regulations vary considerably in terms of specific criteria required for a suitable burial site. A summary of site selection guidelines, from both literature and regulatory sources, is shown in Table A1 (Appendix).

Space or land area required (footprint)

A variety of sources provide guidelines for the land area required for burial of animal carcasses. A summary of these guidelines is provided in Table A2 (Appendix).

Based on the information in Table A2, estimates of the required excavation volume to accommodate mature cattle carcasses include 1.2 yd^3 (McDaniel, 1991; USDA, 2001a), 2 yd^3 (Agriculture and Resource Management Council of Australia and New Zealand, 1996), 3 yd^3 (Lund, Kruger, & Weldon), and 3.5 yd^3 (Ollis, 2002). Several sources indicate that for purposes of determining necessary excavation volume, one adult bovine can be considered equivalent to five adult sheep or five mature hogs (McDaniel, 1991; Ollis, 2002; USDA, 1980). At least two sources provide estimates of excavation requirements in terms of the weight of mortality per volume. One source suggests approximately 40 lb/ft^3 (1,080 lbs/yd^3) (Anonymous, 1973), while another suggests 62.4 lbs/ft^3 (1,680 lbs/yd^3) (USDA, Natural Resources Conservation Service, Texas, 2002).

One source estimated that a volume of about 92,000 yd^3 (2,484,000 ft^3) would be required to bury 30,000 head of cattle (about 3 yd^3 per carcass) (Lund, Kruger, & Weldon). Based on the assumed trench depth of about 8.5 ft cited by the source, this would be equivalent to about 292,200 ft^2 of land surface, or about 6.7 acres (approximately 5 football fields).

Another source estimated that burial of 25,000 head of cattle would require a trench 13 ft deep (allowing for a cover depth of 6.5 ft), 6.5 ft wide, and 5 miles long (equivalent to about 3.3 yd^3 per carcass) (Ollis, 2002). This would be equivalent to a land surface of about 171,600 ft^2, or about 4 acres (approximately 3 football fields). This same source concluded that 189,852 head of cattle could be buried on a quarter section of land (160 acres), assuming trenches were 13 ft deep, 6.5 ft wide, and spaced about 30 feet apart.

Resource requirements

The primary resources required for trench burial include excavation equipment and a source of cover material. The cover material is often obtained from the excavation process itself and reused as backfill. Equipment needed for the operation is generally widely available either from rental companies or on a for-hire basis via contractors. In circumstances where the soil type is not necessarily conducive to minimizing potential environmental contamination, a source of clay may be needed to supplement the base (bottom layer) of the trench.

Pre-processing requirements

A pre-processing step prior to burial may or may not be warranted depending on the animal species involved. As a carcass decomposes, significant amounts of gas are produced and, when entrapped within the carcass, cause extensive bloating. As a result of bloating, buried carcasses can actually be displaced, shift, or even rise to the surface of a burial pit, similar to the way bodies of drowning victims rise to the surface of water (McDaniel, 1991). To prevent this phenomenon, some sources suggest puncturing or venting carcasses (especially those of large animals) to minimize gas entrapment (Agriculture and Resource Management Council of Australia and New Zealand, 1996). During the 2001 outbreak of FMD in the UK, guidance materials issued jointly by the UK EA and DEFRA included a requirement that all carcasses be ruptured via deep stab wound posterior to the ribs before burial in a landfill to help stabilize the mass (UK Environment Agency, 2002b, p. 9). United States Department of Agriculture (USDA) Animal & Plant Health Inspection Service (APHIS) guidelines for the eradication of FMD also recommend venting the thoracic and abdominal cavities of carcasses prior to burial (USDA, 1980). However, other sources suggest this process may be only minimally effective in preventing entrapment of gases in decaying tissues, and subsequently shifting within burial sites (McDaniel, 1991). It is likely that a venting step would not be practical or necessary for smaller carcasses, such as poultry.

Time considerations

The length of time required to establish a site for trench burial would depend on various factors, including the time required to identify an appropriate site, the time required to gain approval of the site by regulatory bodies (e.g., environmental regulatory agencies), as well as the type and quantity of excavation equipment available. Response time can likely be minimized if these issues are addressed prior to the time of need.

Throughput or capacity constraints

The length of time required to dispose of carcasses via trench burial will depend on (a) the species and total number of carcasses to be buried, since this determines the total excavation area required (refer to Table A2), and (b) the type and availability of excavation equipment, as this determines the time required to excavate the necessary area. An estimate of the typical capacity of excavator-type equipment (i.e., a backhoe) can be roughly equated to the bucket size. Approximately 100 yd^3/hr can be excavated for each yard of bucket size (Martin, 2003). Some general excavation capacities relative to CAT equipment are provided in Table 3.

Estimates of the time required to excavate burial trenches of various volumes using equipment of three different sizes were compiled by emergency planners in Ford County, Kansas. These estimates are summarized in Table 4. While these estimates are useful, it is important to note that the times shown are based on the use of a single piece of equipment; in reality, during an emergency situation it is likely that multiple pieces of equipment would be utilized simultaneously.

TABLE 3. Approximate excavation capacity for various types of CAT equipment (Martin, 2003).

Equipment	Approx. Bucket Size (yd)	Approx. Excavation Per Hour (yd^3)	Equipment Weight (lbs)	Transportability
CAT 320 hoe	1.5 – 2	150-200	45,000	Can haul on one trailer
CAT 322 hoe	1.5 – 2	150-200	52,000	Can haul on one trailer
CAT 325 hoe			60,000	Can haul on one trailer
CAT 330 hoe	3	300	65,000	Can haul on one trailer
CAT 345 hoe	4.5	450		Too large to haul in 1 pc. unless weight restrictions are waived

TABLE 4. Approximate time required to excavate burial trenches of various volume using three equipment types (adapted from Lane, 2003).

Carcass Units @ 1000 lbs ea	Approx. Excavation Volume Required[a]	Approx. Alternative Trench Dimensions (L x W x D)	Approximate Excavation Time (Hours)		
			13 yd scraper (78 cu yd/hr)	15 yd scraper (103.3 cu yd/hr)	27 yd scraper (162.03 cu yd/hr)
5,000	7,500 cu yd (202,500 cu ft)	450 ft. x 45 ft x 10 ft 250 ft x 81 ft x 10 ft	96.2	72.6	46.3
10,000	15,000 cu yd (405,000 cu ft)	450 ft x 90 ft x 10 ft 250 ft x 162 ft x 10 ft	192.3	145.2	92.6
25,000	37,500 cu yd (1,012,500 cu ft)	450 ft x 225ft x 10 ft 180 ft x 562 ft x 10 ft	480.8	363.1	231.5
50,000	75,000 cu yd (2,025,000 cu ft)	450 ft x 450 ft x 10 ft 180 ft x 1125 ft x 10 ft	961.5	726.2	462.9

[a] Assume 1.5 yd^3 of excavation area required per 1000 lb carcass unit.

Clean-up/remediation requirements

Output material generated and means of disposal

The principal by-products resulting from burial of carcasses are those that result from the decay process, namely leachate (liquid or fluid released from the decaying carcasses) and gases such as methane, carbon dioxide, hydrogen sulfide, and others. The quantity of these by-products produced will relate to the volume of carcass material buried. For the most part, these by-products simply represent additional waste streams which, if present in significant quantity, may themselves warrant containment or disposal strategies. Generally these by-products are of no commercial value (although methane generated in significant quantities may potentially be captured for subsequent energy recovery). Additional information regarding the generation of by-products and possible management strategies can be found in the landfill and mass burial sections of this report.

Site or facility remediation issues

As the carcass mass decomposes over time, settlement of the site will occur. Additional backfill may be required to prevent pooling of water at the site and to help restore the natural land surface. Depending on the volume of carcass material buried, some additional remediation steps to contain gas or leachate (similar to those described for landfill or mass burial) may be required.

Cost considerations

Many sources report that burial is a relatively low-cost means of carcass disposal; however, few provide estimates of the actual costs that may be involved. Cost estimates from some sources refer only to the use of trench burial for disposal of daily mortality losses, which may be considerably different from those incurred during an emergency situation.

Costs estimates for trench burial of daily mortalities

A report by Sparks Companies, Inc. (2002) prepared on behalf of the National Renderer's Association evaluated various methods of daily mortality disposal and their potential costs. Estimated costs of on-farm burial of daily mortalities (Table 5) were based on the following assumptions:

- All daily mortality losses are buried, with each mortality buried individually
- All environmental safeguards are followed (although the report does not provide any detail as to the nature of these safeguard procedures)
- All livestock operations could employ on-farm burial regardless of geographic region or climate

- The only direct costs associated with burial are labor (estimated at $10/hr) and machinery (rental or depreciation estimated at $35/hr)

Based on the costs of on-farm burial for all daily mortality losses estimated by Sparks Companies, Inc. (2002), the estimated cost per individual mortality can be calculated (this value is also shown in Table 5). These estimates are likely not representative of the costs that may be incurred during a catastrophic mortality loss, since multiple mortalities would be buried together, rather than individually as estimated here. Furthermore, actual hourly rates for labor and equipment may be significantly different during an emergency than estimated here.

TABLE 5. Costs associated with on-farm trench burial of daily mortalities (Adapted from Sparks Companies, Inc., 2002).

Species	Total Annual Mortalities	Labor Required for Burial per Mortality[a]	Total Hours Required for Burial	Estimated Costs			Estimated Cost Per Mortality[b]
				Total Labor Cost ($10/hr)	Equipment Cost ($35/hr)	Total Cost	
Cattle (over 500 lbs)	1,721,800	20 min ea	573,930	$5,739,300	$20,087,670	$25,827,000	$15.00
Calves	2,410,000	10 min ea	401,660	$4,016,600	$14,058,330	$18,075,000	$7.50
Weaned hogs	6,860,000	10 min ea	1,143,330	$11,433,330	$40,016,670	$51,450,000	$7.50
Pre-weaned hogs	11,067,700	10 min per group of 10	184,460	$1,844,610	$6,456,100	$8,300,780	$7.50 per group of 10
Other	832,700	10 min ea	138,780	$1,387,830	$4,857,300	$6,245,250	$7.50
TOTAL	22,892,200		2,442,160	$24,421,670	$85,476,070	$109,898,030	

[a] Labor = time in minutes to excavate trench, deposit carcass, and backfill trench.

[b] Estimated Cost per Mortality = Total Cost / Total Annual Mortality.

A survey of Iowa Pork Producers Association members was conducted in March 2001 to determine the disposal methods used for daily mortalities, as well as associated costs (Schwager, Baas, Glanville, Lorimor, & Lawrence). Of the 299 respondents, 94 reported using the burial method either alone or in conjunction with other disposal methods. Based on information from 69 respondents, average costs for machinery were estimated to be $50/hr for tractors, trenchers, and backhoes, and $40/hr for skid-loaders. The authors defined the total estimated cost for disposal by burial (including labor, machinery, contractors, and land) as a function of operation size, rather than as a function of the number of mortalities disposed. They estimated that the total cost for burial was approximately $198 per 100 head marketed. However, it is not clear how this estimate may relate to actual cost per mortality.

A report on various carcass disposal options available in Colorado identified the cost of renting excavation equipment as $50-75/hr (Talley, 2001). Based on this estimate, it was suggested that burial may represent a relatively costly option.

Doyle and Groves (1993) report the cost of on-farm burial of daily mortalities in Scotland to be £49-79/tonne. Based on the exchange rate as of 14 October 2003, this would equate to approximately $74-120/ton.

Costs estimates for trench burial of catastrophic mortalities

As stated previously, very little information is available regarding the costs associated with carcass burial during emergency situations. During the 1984 AI outbreak in Virginia, a total of 5,700 tons of poultry carcasses (about 1.4 million birds) were disposed. Approximately 85% of this total (about 4,845 tons) was disposed by trench burial at an estimated cost of approximately $25/ton. This was the same cost that was estimated for disposal in landfills during this outbreak (Brglez, 2003).

Other considerations

Alternate processes

Above-ground mounding is a variation of trench burial in which little or no excavation into the natural surface of the landform is used. Instead, carcasses are placed on top of the natural surface of the land and essentially "buried" within cover material obtained from another source. This technique could prove useful in areas where hydrology and geology are not well suited to trench burial. However, caution may be warranted as carcass material placed in these mounds will still generate leachate and gas and areas poorly suited to trench burial may also represent areas of poor natural attenuation. In the event that natural attenuation is insufficient to control these products of decomposition, environmental contamination may still occur.

Potential for use in combination with other disposal methods

In some situations trench burial may provide a good alternative for the disposal of outputs or by-products from other carcass disposal methods (e.g., ash from incineration processes, etc.).

Use of lime

Various sources discuss the use of lime during burial; however, there appears to be significant disagreement among the various sources as to the appropriateness, and even the intended purpose, of this practice. Some sources suggest that lime should be used to cover carcasses to discourage scavenging by predators, to prevent odors, to retard decomposition (and therefore limit leachate production), or even to hasten decomposition. However, other sources directly contradict these assertions and maintain that lime should not be used because it can slow the decomposition process, the products of which are critical in helping to inactivate disease agents. Following is a listing of selected excerpts from various sources regarding lime use:

- "Lime is not to be used on carcasses because it is believed to retard natural decay processes which in themselves bring about virus inactivation" (USDA, 1980, p. 33).
- Relative to the mass burial site at Throckmorton, "No lime was added to the burial cells because this would also kill the bacteria necessary for degrading the carcasses" (Det Norske Veritas, 2003, p. II.21).
- Lime may be added to prevent earthworms bringing contaminated material to the surface; however, do not place directly on carcasses because it slows and may prevent decomposition (Agriculture and Resource Management Council of Australia and New Zealand, 1996).
- "If quicklime is available, cover carcasses with it before filling. Quicklime will hasten decomposition" (Bilbo & Todd, 1994).
- "Sprinkle lime or fuel oil on carcasses to discourage uncovering by scavengers, and cover with at least 3-4 ft. of soil" (Friend & Franson, 1987).
- "Sprinkle a covering of lime over the carcasses sufficient to help limit liquid production" (California Water Resources Control Board and Regional Water Quality Control Boards, 2003).
- "Slaked lime may be added to the burial pit to break down the tissue of the carcasses, and, in effect, chemically sterilize the remains" (Wineland & Carter, 1997).

3.2 – Landfill

General overview

As discussed in section 2, modern landfills are required to meet design and operating standards outlined in the federal Subtitle D regulations. A schematic of a typical Subtitle D landfill is provided in Figure 4. Key features of the landfill design include composite liners, leachate containment systems, and gas collection systems. It is important to note that sites classified as "small arid landfills" may not include these design criteria, but instead rely on natural attenuation to adequately protect the surrounding environment. The environmental protection systems of a Subtitle D landfill are generally more robust than those of a small arid landfill, and would likely be less prone to failure following challenge by high organic loading (as would occur in disposal of large quantities of carcass material). An excellent overview of the design and operation of MSW landfills is provided by O'Leary & Walsh (2002).

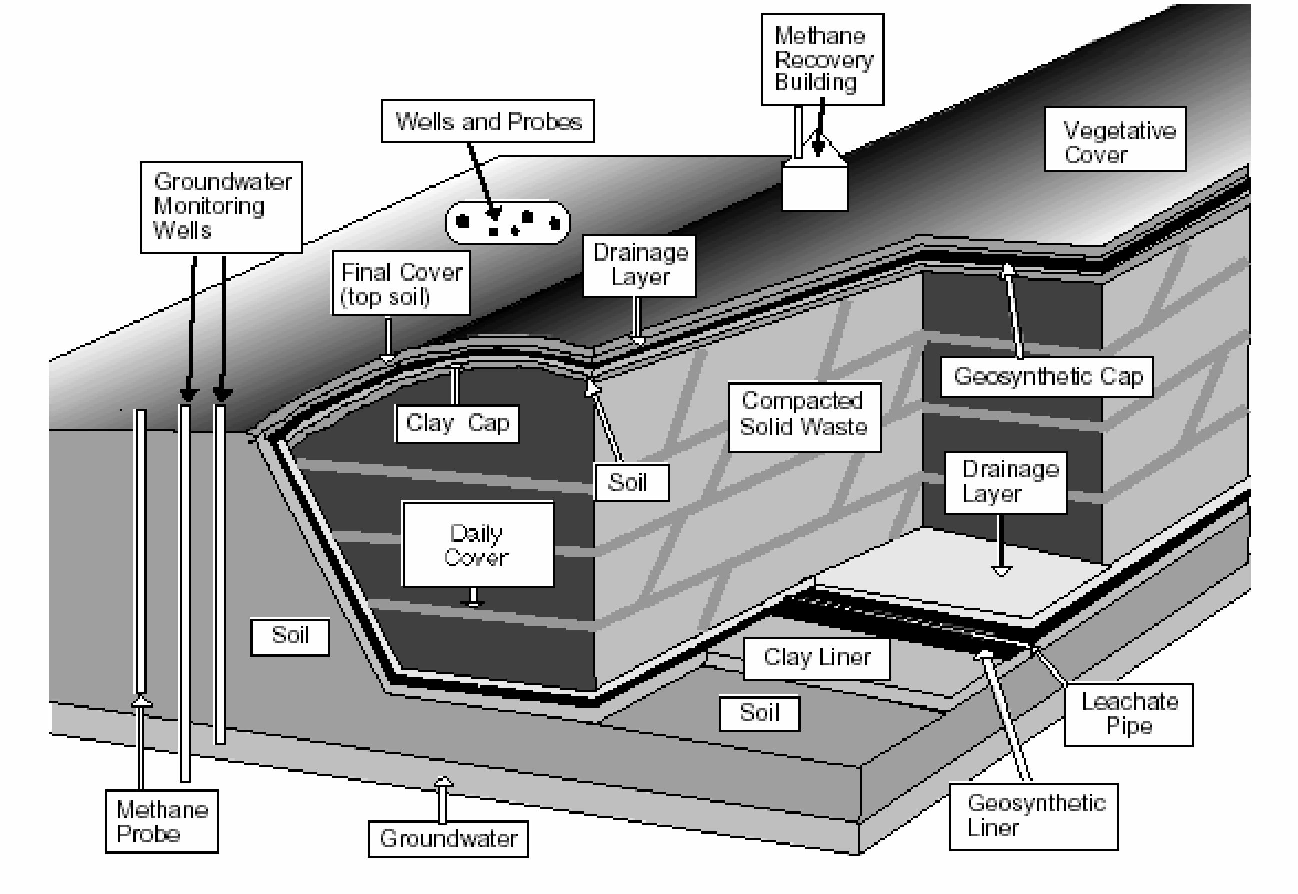

FIGURE 4. Schematic of a typical municipal solid waste (MSW) landfill (US EPA, Office of Solid Waste and Emergency Response, 1995; as reprinted from Waste Age, 1991-1992, P. O'Leary and P. Walsh, University of Wisconsin-Madison Solid and Hazardous Waste Education Center).

Regardless of whether classified as a Subtitle D or small arid site, the purpose of a landfill is to effectively contain waste such that the components of the waste and/or the by-products of decomposition do not escape into the environment. The environment within a landfill is such that degradation of waste is minimized. In fact, newspapers excavated from landfills after 15-20 years have been observed to be in relatively good condition–even readable (Loupe, 1990).

Various types of refuse contain decomposable matter in varying amounts. Decomposition of waste in a MSW landfill is complex, involving physical, chemical, and biological processes that ultimately result in solid, liquid, and gaseous by-products. These degradation processes fall into three categories:

1. **Physical.** Mechanical action of compaction and the rinsing/flushing action of water (McBean, Rovers, & Farquhar, 1995; The BioScan Group)
2. **Chemical.** Oxidation and acid-metal reactions (The BioScan Group)
3. **Biological.** Three stages: aerobic, acid-phase anaerobic, and anaerobic (methanogenic) (McBean, Rovers, & Farquhar, 1995)

The limiting factor controlling the amount of decomposition taking place in a MSW landfill is usually the availability of moisture (US EPA, Office of Solid Waste and Emergency Response, 1995, pp. 9-32). The primary by-products resulting from decomposition of wastes in the landfill are leachate and landfill gas.

Leachate. Leachate is defined as "a liquid that has passed through or emerged from solid waste and contains soluble, suspended, or miscible materials removed from such waste" (US EPA, 258.2). Leachate generation rates depend on the amount of liquid originally contained in the waste (primary leachate) and the quantity of precipitation that enters the landfill through the cover or falls directly on the waste (secondary leachate) (US EPA, Office of Solid Waste and Emergency Response, 1995, pp. 9-33). The composition of leachate changes as a landfill proceeds through various decomposition phases (acetic phase vs. methanogenic phase). If left unmanaged, leachate can be released from the landfill and pollute groundwaters or surface waters.

Subtitle D regulations require liners and leachate control systems to prevent migration of leachate from the site (see Figure 4). Liners provide a hydraulic barrier that impedes the flow of liquids, thus allowing leachate to be captured and removed from the site for treatment and controlled disposal (US EPA, Office of Solid Waste and Emergency Response, 1995, pp. 9-36).

Landfill gas. The anaerobic decomposition of organic materials in a landfill generates a combination of gases, collectively called landfill gas. Uncontrolled landfill gas migration can be a major problem; the gas must be controlled to avoid explosions and damage to vegetation in the vicinity of the landfill. The composition of gas produced is controlled primarily by microbial processes and reactions in the refuse; typically, landfill gas is composed of approximately 50% methane and 50% carbon dioxide (with trace amounts of other gases such as hydrogen, hydrogen sulfide, and carbon monoxide). Methane is typically the gas of concern as it can quickly asphyxiate a person and concentrations as low as 5% are explosive. Subtitle D standards limit the amount of methane present in the atmosphere of a building to 1.25% and in the atmosphere of the soil at the property line of the landfill to 5% (US EPA, Office of Solid Waste and Emergency Response, 1995, pp. 9-43 to 9-47). If left unmanaged, the gas generated in a landfill will either vent to the atmosphere or migrate underground (migration distances of greater than 1,000 feet have been observed). Passive gas control systems (relying on natural pressure and convection mechanisms to vent gas to the atmosphere) are becoming less common due to the unpredictable nature of gas movement in landfills. Active systems employ gas recovery wells or trenches and vacuum pumps to control the migration of landfill gas, and may even allow capture of the gas for energy recovery.

Expertise/personnel requirements

Service or equipment providers

Landfill sites may be privately owned or may be operated by municipalities. A listing of landfills located in various geographic areas can generally be obtained from the state agency which regulates the sites. For example, the Kansas Department of Health and Environment maintains a directory of MSW landfills, transfer stations, construction/demolition landfills, and composting operations located throughout the state. As of March 2003, 33 small arid landfills, 18 Subtitle D landfills, and 50 transfer stations were in operation in Kansas. However, it is important to note that not all landfills accept animal carcasses; this is generally left to the discretion of individual landfill operators.

Personnel requirements

One advantage of landfill disposal is that landfill sites are staffed and operated on an ongoing basis, regardless of the need for disposal of animal carcasses. In the event that a landfill is used to dispose of significant volumes of carcass material during a catastrophic event, it is possible that additional staff may be required as a result of extended hours of operation, additional security or traffic control, or additional biosecurity measures (e.g., cleaning and disinfecting of transport vehicles, etc.).

Regarding the need for education, additional training for landfill employees on the biosecurity measures necessary to prevent the spread of transmissible diseases may be warranted. For this very need, an excellent training video has been made available by the Riverside County California Waste Management Department to educate landfill operators and employees on appropriate biosecurity and operational procedures to prevent disease spread (Riverside County Waste Management Department, 2003).

Location considerations

Site selection criteria and regulatory considerations

Most states have regulations that define allowed carcass disposal options, and in many states disposal in landfills is allowed, although different options may be allowed under different circumstances (i.e., normal daily mortality vs. catastrophic mortality). However, the fact that landfilling may be an *allowed* option does not necessarily mean it will be an *available* option; it is generally up to the landfill operator's discretion as to whether or not carcass material will be accepted (Wineland & Carter, 1997; Sander, Warbington, & Myers, 2002; Morrow & Ferket, 2001; Bagley, Kirk, & Farrell-Poe, 1999; Hermel, 1992, p. 36; Morrow & Ferket, 1993, p. 9; Kansas Department of Health and Environment, Bureau of Waste Management, 2001a; Kansas Department of Health and Environment, Bureau of Waste Management, 2001b; Fulhage, 1994; Britton; Talley, 2001; Ohio Environmental Protection Agency, 1997; Indiana State Board of Animal Health; Pope, 1991, p. 1124).

Whether real or perceived, potential risks to public health from disposing of animal carcasses in landfills greatly influences the operator's decision to accept carcass material. For example, during the 2001 outbreak of FMD in the UK, the capacity available in suitably engineered landfill sites (those with adequate containment characteristics, leachate and gas collection and treatment systems, proximity to water protection zones, etc.) could have easily accommodated 100% of the carcasses material generated by the outbreak (approximately 600,000 tonnes). However, opposition by the local public near these sites resulted in only about 16% of the total carcass material (95,000 tonnes) being disposed of by this route (UK Environment Agency, 2002b; Hickman & Hughes, 2002). As a further example, after chronic wasting disease (CWD) was identified in deer in Wisconsin in 2002, the Wisconsin Department of Natural Resources conducted a risk assessment and concluded that disposal of infected deer in Subtitle D landfills did not pose a significant threat to human or animal health. Although landfill operators generally agreed with this conclusion, they were nonetheless unwilling to accept deer carcasses based on the fear of public opposition due to lingering perception of risk to human or animal health (Wisconsin Department of Natural Resources, 2003, p. 127).

Where disposal in landfills is an allowed option, state regulations generally do not impose limitations on which landfills (small arid landfills vs. Subtitle D landfills) may be used for disposal of animal carcasses. However, it would be prudent to evaluate both (a) the volume of mortality and (b) the circumstances by which the mortality arose to determine whether a particular site is suitable for carcass disposal. A qualitative representation of the relative potential risks associated with various disease agents and volumes of mortality are shown in Table 6. Generally, in most cases the more robust environmental protection systems afforded by Subtitle D landfills would make them preferable to small arid landfills.

TABLE 6. Relative potential risk (or degree of uncertainty regarding risk) to public health or the environment resulting from the disposal of carcasses in landfills under various circumstances.

	Mortality Volume	
Disease Agent	**LOW**	**HIGH**
None		░
Bacterial, viral	░	▒
TSE agent	▓	▓

Darker shading indicates greater potential risk and/or greater degree of uncertainty regarding risk.

During the 2001 outbreak of FMD, the UK EA identified minimum criteria for determining the suitability of a landfill for disposal of infected animal carcasses (UK Environment Agency, 2002b, Annex 2). The criteria were based on the assumptions that infectivity of material deposited in the landfill would be low and short-lived, and that the carcass material could generate organic loads for up to 20 years after disposal. Key criteria/site characteristics included the following:

1. **Location.** Prohibited use of some sites based on proximity to various source protection zones, aquifers, water tables, floodplains, etc.
2. **Liner.** Required that the base and sides be comprised of at least 1 m of a well engineered clay liner with a permeability of 10^{-9} m/s or less at a hydraulic gradient of 1. Prohibited use of sites that employed a flexible membrane liner alone.
3. **Leachate management.** Required an effective and robust leachate management system to ensure efficient collection of leachate for the next 20 years. Required contingency planning for treatment and disposal of leachate of very high organic loading for a period of at least 20 years.
4. **Gas management.** Required adequate gas management infrastructures to collect gas from the whole of the site.
5. **Monitoring.** Required a monitoring plan for groundwater, surface water, and leachate as well as an associated contingency plan in the event of an identified problem.
6. **Odor & vermin control.** Required effective odor and vermin control plans.
7. **Documentation.** Required documentation of the location, number, and extent of animal carcasses deposited within the site for future reference.

Space or land area required (footprint)

Total landfill space

The space or land area required for a landfill depends on the planned size of the facility, which will be influenced by factors such as the population it will serve, the length of time it will operate, the type of waste it will receive, and various operating parameters (i.e., compaction, etc). As an example of the area required for a landfill, the North Wake County Landfill in Raleigh, North Carolina occupies 230 acres of land, only 70 of which are dedicated to the actual landfill. The additional land is required for support areas such as runoff collection and leachate collection ponds, drop-off stations, buffer areas (50-100 ft), and areas for obtaining or “borrowing” cover soil (Freudenrich).

Landfills are comprised of various sections called “cells.” A cell typically contains waste from one day of operation which is covered by six inches of soil (daily cover) (Figure 5).

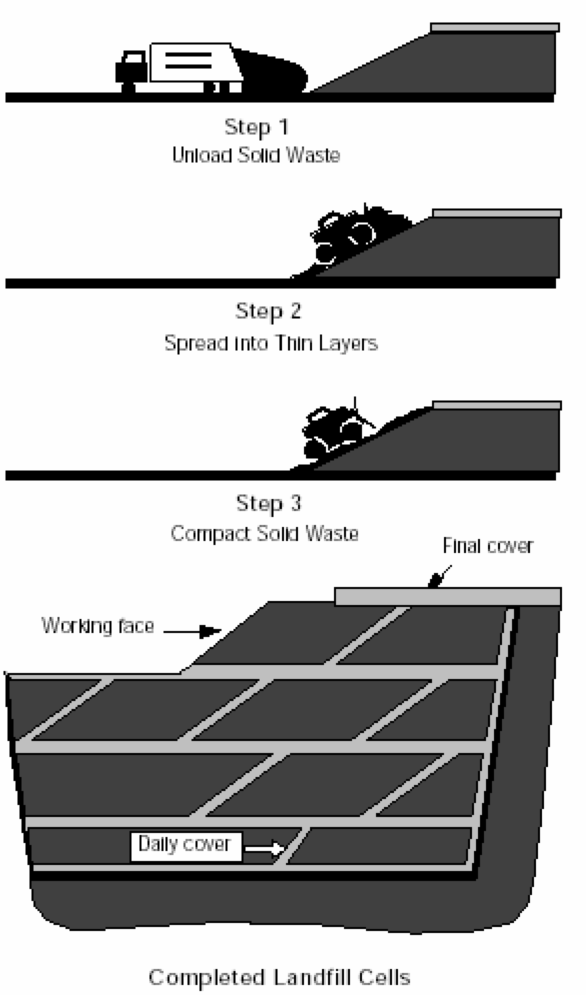

FIGURE 5. Solid waste placement and compaction (US EPA, Office of Solid Waste and Emergency Response, 1995, as reprinted from P. O’Leary and P. Walsh, University of Wisconsin-Madison Solid and Hazardous Waste Education Center, Waste Age Correspondence Course 1991-1992).

Cells are arranged in rows and layers of adjoining cells called "lifts." The amount of material that can be placed in a cell depends on the original density of the material and the amount of compaction achieved. For example, a typical cell in the North Wake County Landfill is approximately 50 feet long by 50 feet wide by 14 feet high and contains about 2,500 tons of waste compressed at 1,500 pounds per cubic yard (Freudenrich). Table 7 provides typical densities of various common waste materials.

For purposes of comparison, sources have estimated the density of carcass material to be approximately 1,080 lbs/yd^3 (Anonymous, 1973) to 1,680 lbs/yd^3 (USDA, Natural Resources Conservation Service, Texas, 2002). Furthermore, Brglez (2003) reported that 20 ft^3 (approximately 0.74 yd^3) was required to accommodate 800 lbs of poultry mortality. Therefore, the density of this poultry mortality can be assumed to be approximately 1,080 lb/yd^3. These estimates suggest that carcass material would be of greater density than the various types of non-compacted MSW typically received at landfills (Table 7).

TABLE 7. Typical density of various common municipal solid waste materials (adapted from Table 9-1, US EPA, Office of Solid Waste and Emergency Response, 1995).

Waste	Average Density (lbs/yd^3)
Residential (non-compacted)	
Cardboard	85
Plastics	110
Paper	150
Yard trimmings	170
Glass	330
Green grass – loose & moist	400
Food wastes	490
Commercial (non-compacted)	
Wooden crates	185
Food wastes	910
MSW – Compacted	
Compactor truck	500
Landfill – normally compacted	760
Landfill – well compacted	1010

Space required for carcasses

The space required to accommodate a given volume of animal carcass material would likely be similar to the estimates provided for trench burial. For illustration purposes, a typical cell in the North Wake County Landfill was reported to be approximately 50 ft. x 50 ft. x 14 ft (Freudenrich). This is equivalent to 1,296 yd^3. Based on the range of estimated volume of space required per cattle carcass from Table A2 (1.2 to 3.5 yd^3 per carcass), a cell of this size may be anticipated to accommodate from 370 to 1,080 mature cattle carcasses, or 1,850 to 5,400 mature hog carcasses. These wide ranges further highlight the significant variance among estimated burial volumes per carcass. These estimates may be further influenced by the fact that a significant amount of compaction is achieved in a landfill that may not be achieved by trench burial practices.

Resource requirements

In general, the resources and infrastructure necessary to dispose of animal carcasses at a landfill site are much the same as those required to operate the landfill on a daily basis. The purpose of a landfill is to provide a means of disposing of waste, and in some respects animal carcasses simply represent another form of waste. Because the infrastructure of a typical landfill site has already been discussed, it will not be repeated here. In some instances, such as the disposal of large volumes of carcass material resulting from a disease outbreak, resources unique to the disposal of animal carcass material may be required. Examples might include cleaning and disinfecting supplies and additional personal protective equipment.

Pre-processing requirements

As discussed previously for trench burial, puncturing or venting of carcasses (especially for large animals) to minimize gas entrapment may be warranted. During the 2001 outbreak of FMD in the UK, DEFRA required that all carcasses be ruptured before burial in a landfill to help stabilize the mass (UK Environment Agency, 2002b, p. 9). Again, the true benefit of this technique has been questioned.

Site security or biosecurity issues

A certain degree of site security would likely be inherent to a landfill site (e.g., fencing, central entrance, vermin/pest control, etc.). For instances of carcass disposal involving transmissible disease agents, some additional biosecurity measures would likely be warranted as illustrated by the guidelines issued to landfills receiving carcasses during the 2001 FMD outbreak (UK Environment Agency, 2002b), paraphrased as follows.

1. Carcasses shall be buried as soon as practicable following deposit, and must be buried prior to closure at day's end.
2. Carcasses shall not be buried within 2 metres of the final level of the landform.
3. Adequate controls must be in place for birds, vermin, and odor.
4. The area on site where animal carcasses are being deposited should be closed to all non-essential vehicles and personnel. All other vehicles should be kept clear of the area accepting animal carcasses.
5. Cover material should be stockpiled or available above the working face prior to the vehicle arriving at the tipping point.
6. Prepare trenches or pits in advance and tip the vehicle into the hollow under the working face. Where possible, the vehicle should be parallel to the face.
7. Drivers should remain in the cab of the transport vehicle; the tailgate should be opened by site operatives.
8. Backfill material should be placed and compacted into a manner to prevent or minimize contact of the excavator or compactor with carcasses. Compactors should not contact the carcass material until the backfill material is in place.
9. After deposit, the route taken by the transport vehicle on the site should be covered over with material to reduce potential contact with the virus by other vehicles.
10. All site machinery involved in the operation should be jet washed and subsequently disinfected after the carcasses are buried. Cleaning and disinfecting – clean the vehicle with water to remove all debris from the underside of the vehicle and wheels and wheel arches (top down). Clean the inside of the storage compartment. Disinfect vehicle when clean, including the underside, wheel arches, and wheels. All vehicles should then pass through a manual vehicle wheel wash before leaving the site.
11. Drivers and staff must wear personal protective equipment. Areas for showering and changing clothes are recommended when possible. Protective clothing such as overalls and gloves worn by operatives in the area of carcass disposal should be disposable and deposited and buried when the operative leaves the area. Work boots should be washed to remove any debris and operatives should pass through a footbath with disinfectant.

As mentioned previously, an excellent training video was developed by the Riverside County California Waste Management Department to educate landfill operators and employees on appropriate biosecurity and operational procedures to prevent disease spread (Riverside County Waste Management Department, 2003). This video highlights appropriate procedures for deterring scavengers, techniques to prevent contamination of equipment and personnel, and appropriate decontamination procedures.

In response to wildfires that occurred in California in late 2003, the agencies responsible for protecting water quality in the state developed recommendations for disposal of animals destroyed by the fires (California Water Resources Control Board and Regional Water Quality Control Boards, 2003). Included in those recommendations were guidelines for disposing of carcasses at MSW landfills. A variety of guidelines were outlined in order to avoid fluid-production-related problems, including the following:

- Limiting the thickness of each animal mortality layer to no more than two feet, or in the case of large animals such as cattle, to one animal thickness.
- Covering each layer of animal mortality with an even thicker layer of soil or other absorbent waste.
- If the landfill is composite-lined, depositing no more than two layers of mortality in any given area; if the landfill is not composite-lined,

depositing no more than one layer of mortality in any given area.

- Depositing animal mortality only to portions of the landfill underlain by a considerable thickness of other waste.
- If the mortality is mixed with material containing a significant percentage of water (such as saturated debris), mixing the waste with an absorbent material such as sawdust or soil prior to placement in the landfill.

Time considerations

Construction, set-up, or response time

Because the landfill site is in existence prior to a time of emergency, the set-up time would in theory be minimal. However, some time may be required to agree on the terms of use for the site. This time can be minimized by making arrangements with landfill sites for disposal of carcass material prior to a time of emergency.

Throughput or capacity constraints

The capacity of a landfill site to receive carcass material is dependent on the characteristics of the particular landfill site. Small arid landfill facilities would likely have less capacity than Subtitle D landfill sites. In some cases, restrictions on capacity may be imposed by local or state regulations. For example, during the 2001 FMD outbreak in the UK, government regulations limited the amount of carcass material that could be accepted at a landfill site to 5% of the total weekly waste inputs (UK Environment Agency, 2002b).

As an example of potential landfill capacity for disposal of animal carcass material, over three million birds were depopulated from 2,148 premises during the 2002 END outbreak in southern California, with landfills serving as a primary means of disposal. In addition to carcass material, other outbreak-associated materials, such as eggs and litter, were also disposed by landfill.

Species considerations

Clearly, significant differences exist in the size, weight, and volume of space occupied by carcasses of various animal species; significant differences even exist within a species for animals of various ages. For example, from Table A2, one mature bovine can reportedly be assumed equivalent to approximately five mature hogs, five mature sheep, or 40 market weight broiler chickens. Obviously, a significantly larger volume of space would be required to contain the same number of bovine vs. poultry carcasses.

Clean-up/remediation requirements

Output material generated and means of disposal

The output material resulting from the disposal of animal carcasses in landfills would be generally similar to that resulting from typical MSW: leachate and landfill gas. Because these are normal by-products of the landfill operation, systems are already in place to collect and treat these outputs and therefore no additional systems would likely be necessary. However, because the composition of animal carcasses differs from that of typical MSW, the disposal of significant quantities of carcass material in a landfill could affect the quantity and composition of leachate and landfill gas generated, and may warrant adjustments to the collection and/or treatment systems.

Site or facility remediation issues

Landfill sites are generally designed to be used over a period of decades, and part of the planning process for modern landfill sites includes identifying plans for final use of the site after closure. Therefore, ultimate remediation of a landfill site will have already been determined and would likely not change following use of the landfill to dispose of animal carcasses.

Cost considerations

The fee charged by a landfill for accepting waste is termed a “tipping” fee. For general waste disposal, these fees are based on either weight or volume, and may vary with the type of waste deposited. Average landfill tipping fees for MSW in various regions of the US are shown in Table 8.

TABLE 8. Average tipping fees in 1999 for typical municipal solid waste at US landfills by region (Anonymous, 1999).

Region	1999 ($/ton)
Northeast (CT, DE, ME, MD, MA, NH, NJ, NY, PA, RI, VT)	$57.68
Southern (AL, AR, FL, GA, KY, LA, MS, NC, SC, TN, VA, WV)	$34.36
Midwest (IL, IN, IA, KS, MI, MN, MO, NE, ND, OH, SD, WI)	$32.22
Western (AZ, CO, ID, MT, NV, NM, OK, TX, UT, WY)	$21.17
Pacific (AK, CA, HI, OR, WA)	$36.27
National	$36.26

For landfill disposal of small numbers of animal carcasses – such as companion animal remains, carcasses resulting from hunting activities (such as deer or elk), or small numbers of daily mortalities from livestock production facilities – fees may be based either on weight or on the number of carcasses. Fees at three landfills in Colorado were reportedly $10 per animal, $4 per 50 pounds (approximately $160/ton), and $7.80 per yd^3, respectively (Talley, 2001). As of 2003, tipping fees for carcass disposal in Riverside County, California consist of a $20 flat fee for quantities less than 1,000 lbs, and $40/ton for quantities greater than 1,000 lbs. These fees are slightly higher than those charged at the same facility for general MSW because animal carcasses are classified as "hard-to-handle" waste as they require immediate burial (immediate cover) (Riverside County Waste Management Department). Landfill costs for disposing of animal byproducts in European countries range from 30 to 80 Euros per tonne of material (Commission of the European Communities, 2001).

Following confirmation of two cases of CWD in South Dakota, the City Council of Souix Falls established disposal fees for deer and elk carcasses at the city landfill. A mono-fill area (mono-fill indicating waste of only one type) designed to accommodate 10,000 deer carcasses was developed in an unused expansion of the landfill at a reported cost of about $50,000. Fees of $50/ton were established for deer or elk carcasses originating within the state, and $500/ton for carcasses originating outside the state. However, private individuals are exempt from the ordinance and may dispose of up to 10 carcasses without charge (Tucker, 2002).

In situations involving significant volumes of carcass material (e.g., an animal disease outbreak), tipping fees would most likely be based on weight (i.e., per ton of carcass material). Tipping fees do not include costs associated with transportation of carcass material from the site of the outbreak to the landfill. In instances where this distance is great, transportation costs can be significant. Not unique to landfilling, transportation costs would be incurred for any off-site disposal method. During the 2002 outbreak of AI in Virginia, tipping fees were approximately $45/ton for disposing of poultry carcasses at landfills. However, significant additional cost was incurred due to lengthy transportation distance (Brglez, 2003, p. 30). During the 2002 outbreak of END in southern California, tipping fees were approximately $40/ton for disposing of poultry waste at landfills (Hickman, 2003).

Other considerations

Alternate processes

Bioreactors. In the field of MSW disposal, a process known as bioreactor technology is developing. Whereas a landfill is designed to minimize the degradation of waste material in order to lessen the formation of leachate and landfill gas, a bioreactor is designed to promote the degradation of waste through control of aeration and moisture contents. Reported benefits of bioreactor technology include a decreased concentration of most leachate constituents, removal of contaminants by recycling leachate, a reduction in the amount of leachate discharged to water treatment facilities, potential increased recovery of methane as a fuel source, and a reduction in post-closure care and maintenance (Walsh & O'Leary, 2002b; SCS Engineers). Detailed coverage of the history and background of landfill technology, research studies of actual bioreactor landfills, expected leachate and gas yields, specific design criteria, operation guidelines, and reuse of landfill sites to avoid having to establish new sites is provided by Reinhart & Townsend (Reinhart & Townsend, 1998).

Dedicated landfill sites. Several sources mention the creation of a designated landfill site specifically for the purpose of disposing of large quantities of carcasses in the event of an animal health emergency (Australian Department of Agriculture, 2002). This concept is not entirely different from pre-determining appropriate burial sites in advance of an emergency, and would be somewhat analogous to identifying, engineering, and approving mass burial sites in advance of an emergency. This approach has been suggested by several sources (The Royal Society of Edinburgh, 2002; Anonymous, 2002).

Potential for use in combination with other disposal methods

Landfills likely represent an attractive alternative for the disposal of outputs or by-products from other carcass disposal methods, such as ash from incineration processes, meat-and-bone meal or other products of rendering, or residues of alkaline hydrolysis treatments.

Public perception

Depending on the situation, the role of public perception and/or the degree of opposition to the use of a landfills for disposal of animal carcass material may be significant (e.g., 2001 UK FMD outbreak), or essentially negligible (e.g., 2002 California END outbreak). Although landfill capacity could have accommodated 100% of the carcass material requiring disposal during the UK FMD outbreak, only about 16% was disposed of via this route due primarily to significant local opposition (UK Environment Agency, 2001b, p. 1). Conversely, the vast majority of carcass material disposed during the 2002 California END outbreak was disposed of by landfill.

3.3 – Mass Burial Site

General overview

In this report, the term “mass burial site” is used to refer to a burial site in which large numbers of animal carcasses from multiple locations are disposed. As will be discussed in the following sections, ideally a mass burial site would be engineered to incorporate systems and controls to collect, treat, and/or dispose of leachate and gas.

Simple mass burial sites have likely been used numerous times during animal disease outbreaks. The most common situation would occur when sufficient land area, or appropriate geology, is lacking on one property but is available on a relatively nearby property. In this situation, animals from multiple holdings may be taken to a common burial site for disposal; this merely represents a form of trench burial. In fact the distinction between a large trench burial site and a mass burial site is not necessarily clear and may simply be a matter of opinion. A mass burial site that employs a more sophisticated approach and incorporates containment measures similar to a Subtitle D landfill would perhaps more appropriately be termed an “engineered mass burial site.” Mass burial sites played a key role in the disposal of carcasses resulting from the 2001 outbreak of FMD in the UK, and much of the following information pertaining to this technique is garnered from this event.

Table 9 summarizes various key characteristics of the seven mass burial sites developed during the 2001 UK outbreak of FMD. Note that one of the seven sites, Ash Moor, was ultimately never used for disposal.

Expertise and/or personnel requirements

Development of mass burial sites, especially engineered mass burial sites, would likely be best performed by companies with expertise in the design and construction of Subtitle D landfills. As evidenced by the UK experience, hastily planned or inadequately assessed sites can create significant operational and management problems.

TABLE 9. Mass burial sites created for carcass disposal during the 2001 FMD outbreak in the UK (adapted from NAO, 2002).

Site name & location	Former use	Approx. area (acres)	Potential capacity in sheep carcasses (avg sheep carcass = 50 kg)	Approx. actual number of carcasses buried
Great Orton (Watchtree), Cumbria	Airfield	516	750,000	460,000
Tow Law (Stonefoot Hill), County Durham	Former open cast coal working, used for heathland grazing	240	200,000	45,000
Widdrington (Seven Sisters), Northumberland	Open-cast coal working that had been used for landfill	62	200,000	134,000
Throckmorton, Worcestershire	Open farmland	1,549	750,000	133,000
Birkshaw Forest, Dumfries and Galloway, Scotland	Commercial forest	124	1,000,000	490,000
Eppynt (Sennybridge), Powys, Wales	Crown land adjacent to a clay quarry	42	300,000	0[a]
Ash Moor, Devon	Fields and clay pits	101	350,000	0[b]
TOTAL			3,550,000	1,262,000

[a] 18,000 carcasses originally buried, but were subsequently exhumed and burned due to groundwater contamination.
[b] By the time the site was completed, it was no longer needed; no carcasses were buried at the site.

Location considerations

Site selection criteria

Sites that would be appropriate for Subtitle D landfill construction would likely also be suitable for engineered mass burial sites. As demonstrated by the UK experience, thorough site assessments prior to initiation of site development are critical for minimizing subsequent engineering and operational difficulties.

As a result of wildfires in late 2003, the agencies governing water quality in the state of California developed recommendations for disposing of animal carcasses associated with the fires (California Water Resources Control Board and Regional Water Quality Control Boards, 2003). Included in those recommendations were guidelines for the creation of what was termed an "emergency landfill" for large quantities of carcasses (essentially analogous to a large trench burial site or mass burial site). They noted the difficulties associated with such sites used in the UK during the 2001 FMD outbreak, and recommended such sites (a) be located at least 500 feet from any surface water bodies and any wells, (b) have the base of the excavation at least 10 feet above the historical high groundwater level, and (c) not be located in highly permeable soils such as gravels, sands, loamy sands, old gravel quarries, etc. Recommendations were also made to include adequate containment and collection systems for leachate and gas by-products.

Space or land area required (footprint)

The total amount of space required for a mass burial site would depend on the volume of carcass material to be disposed and the amount of space needed for operational activities. The total land area occupied by the seven mass burial sites in the UK is shown in

Table 9 above. The specific excavation area required to accommodate carcasses would likely be similar to that described for trench burial or landfill (see Table A2). However, in the case of mass burial sites, additional land area beyond that required for actual burial may be required (i.e., for the North Wake County Landfill, only about 30% of the total land area is dedicated to burial of waste, with the remaining 70% required for support areas [Freudenrich]).

The land area required for an "emergency landfill" (analogous to a large trench burial site or mass burial site) was estimated by the California state water control boards in recommendations issued during the 2003 wildfires (California Water Resources Control Board and Regional Water Quality Control Boards, 2003). This estimate suggested that a one-acre area, constructed as described below, should accommodate over 1,500 tons of mortality. The following construction guidelines were used in the estimate:

- Excavating the area to a depth of 10 feet.
- Placing two layers of mortality (with 2 ft maximum thickness, or 1 animal thickness in the case of large animals) each covered by a layer of soil 3 feet deep.
- The completed site would have a soil mound about four feet above the original grade, with the top of the uppermost layer of mortality three feet below the original grade.

Resource requirements

In general, the resources and inputs required for a mass burial site would be similar in many respects, although likely not as complex, as those required for a landfill. However, whereas the infrastructure necessary to dispose of animal carcasses at an established landfill would be pre-existing, the resources for a mass burial site likely would not.

Site security or biosecurity issues

The site security and/or biosecurity requirements of a mass burial site would be expected to be similar to those outlined for landfill sites.

Time considerations

Construction, set-up, or response time

As used in the UK FMD outbreak of 2001, mass burial sites were brought online and into use very quickly (the time required to bring mass burial sites into operation is shown in Table 10). Of the six sites that were actually used to bury carcasses, five were receiving carcasses within eight days of being identified as suitable. It should be noted that the haste in which these sites were used caused significant subsequent problems, not only in terms of relations with the surrounding communities, but also in the operational aspects of the sites. Some sites required almost immediate remediation measures to contain leachate as the hastily-derived estimates regarding natural attenuation properties proved inaccurate.

Throughput or capacity constraints

The estimated total capacity of the various mass burial sites is shown above in Table 9. Note that these capacities were estimated based on the number of sheep carcasses that could be contained (one sheep carcass was estimated to weigh 50 kg [about 110 lbs]). These capacities would be reduced by a factor of 10 if reported in terms of the number of cattle carcasses that could be contained (assuming an average carcass weight of 500 kg [about 1,100 lbs]). Additional information for the Throckmorton site provides the estimated number of carcasses buried by species (Table 11). Note from the table that, in spite of the fact that the majority of carcasses buried in the site were sheep (83%), the majority of the mass (64%) was represented by cattle.

TABLE 10. Time required to bring mass burial sites into use, and total time of operation during the 2001 FMD outbreak in the UK (adapted from NAO, 2002).

Site Name & Location	Date in 2001			Days from site identification to operation (receipt of first carcasses)	Total days operational (days from receipt of first carcass to receipt of last carcass)
	Identified	Operational	Final Carcass		
Great Orton	23 March	26 March	7 May	3	42
Tow Law	5 April	3 May	28 October	28	178
Widdrington	30 March	3 April	28 May	4	55
Throckmorton	28 March	4 April	19 May	7	45
Birkshaw Forest	26 March	29 March	25 May	3	57
Eppynt	28 March	5 April	14 April	8	9[a]
Ash Moor	15 March	2 May	14 May (mothballed)	48	--[b]

[a] 18,000 carcasses were buried, but subsequently exhumed and burned due to groundwater contamination.
[b] By the time the site was completed, it was no longer needed; no carcasses were buried at the site.

TABLE 11. Estimated number of carcasses and approximate total carcass mass by species in Throckmorton mass burial site (adapted from Table VI.2.5, p. VI.10, Det Norske Veritas, 2003).

	Cattle	Sheep	Pigs	Deer	Total
Number of carcasses (% of total carcasses)	17,400 (13%)	111,200 (83%)	4,800 (3.5%)	400 (0.5%)	133,800
Typical carcass mass (kg)	500	40	80	100	
Estimated total mass in tonnes (% of total mass)	8,700 (64%)	4,448 (33%)	384 (2.8%)	40 (0.2%)	13,572

Clean-up/remediation requirements

Output material generated and site remediation issues

Burial of significant numbers of carcasses in mass burial sites, as during the UK FMD outbreak, will create tremendous volumes of leachate requiring management and disposal. Additionally, gaseous products may require management if produced in significant quantities. The strategies and means to contain these by-products may be similar to those employed in MSW landfills. Some examples of the quantities of leachate and/or gas by-products generated by the UK mass burial sites, as well as the containment or remediation systems implemented, follow.

Great Orton (Watchtree), Cumbria. The largest single burial site in the UK is at Watchtree near Great Orton. The facility was designed on a containment principle using the hydrogeology of the site as well as a system of barriers and drains to safeguard against seepage of effluent. The site was originally authorized to receive 500,000 carcasses and, upon completion of burial activities, the site had received a total of 466,312 carcasses, 96% of which were sheep (two-thirds of these sheep were slaughtered on-site) The site also received 12,085 cattle but was prohibited from receiving cattle born before 1 August

1996 (Cumbria Foot and Mouth Disease Inquiry Panel, 2002).

Leachate from the site was initially tankered off-site and discharged directly into the Irish Sea through a long outfall; however, later the material was, and continues to be, processed through wastewater treatment plants in Cumbria and elsewhere. The UK EA reports "some minor localized pollution incidents" due to works on the site, but these reportedly were rapidly brought under control (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p. 75). Information from the EA suggests that the site will require monitoring for at least 20 years. Reportedly a proposal exists to develop the site into nature reserve.

Tow Law (Stonefoot Hill), County Durham. The design of the site had to take into consideration the high water table in the area in order to contain the products of decomposition (required about four weeks to plan and construct the site). The site consisted of a number of trenches or cells each designed to hold approximately 30,000 carcasses. The cells were designed with sloping sides and were lined with 1-m thick compacted clay. They were then lined with a geo-clay liner to prevent seepage from the cells. Cells were installed with vents, to collect and burn off the gasses produced by decomposition, and with pumps, to remove leachate. The leachate removed from the cells was treated on site to remove FMD virus and then taken away by tanker to a treatment facility (Tow Law Council, 2002).

This site, one of the last to be opened and therefore benefiting from design and construction knowledge gained from the previous sites, was constructed more to landfill specifications with lined pits. Despite this, significant odor issues presented problems adjacent to the site and to surrounding communities, depending on wind direction. Following completion of burial activities, further engineering of the site was necessary to ensure the adequate handling of anticipated winter rainfall (Tow Law Council, 2002).

At the height of the decomposition of the animals in the trenches, 50-60 tankers per week were taking treated leachate from the site to a treatment facility, although leachate production subsequently stabilized at approximately 20 tankers per week (Tow Law Council, 2002).

Widdrington (Seven Sisters), Northumberland. According to the UK EA, the Widdrington mass burial site in Northumberland is located on low lying, level ground close to the sea and on old opencast coal workings (UK Environment Agency, 2001a, p. 10). It was determined that collection and treatment of leachate would not be necessary and therefore the site was constructed using a "dilute and disperse" concept – that is, no measures are in place to contain leachate from the site. Effluent from the burial pits soaks into permeable backfill, and there are no surface waters, streams, or springs which can be polluted by effluent from the burial pits. The fact that the groundwater at this site is below sea level means that surface outflows of groundwater contaminated with effluent could not occur. Natural attenuation during flow through the thick unsaturated backfill is expected to greatly assist in rendering less harmful the effluent from the burial. The groundwater below the burial pits is already contaminated by the old opencast and deep mining activities in the area and is, for all practical purposes, unusable. Minewater pumping to the sea will continue indefinitely to prevent the overflow of the minewater into streams and rivers in more sensitive locations (UK Environment Agency, 2001a, p. 10).

Throckmorton, Worcestershire. A comprehensive detailing of the design, construction, and operating aspects of the Throckmorton site are provided in Det Norske Veritas (2003). In this geographic region of the UK, the high water table and unsuitable soil conditions effectively ruled out on-site burial in the majority of cases. The Throckmorton site, an unused airfield owned by the UK Ministry of Defense, was chosen as likely to be most suitable for mass burial because it offered good access and, in terms of geology, the advantage of relatively impermeable layers of clay subsoil. The UK EA conducted a prior assessment of the site and concluded the risk to surface waters and groundwater was minimal (UK DEFRA, 2002a, p. 5).

Nine cells, each approximately 50 m in length, 25 m wide, and 5 m deep, were dug to contain the animal carcasses. The cells were not lined. Prior to placement of carcasses, drainage systems (consisting of basal drainage trenches and extraction wells) were installed to collect and remove leachate. Carcasses were buried over a period of about seven weeks (4 April to 19 May 2001). Six of the nine cells were ultimately used for burial of a total of 133,000 carcasses (similar in number, though a greater tonnage, than at Widdrington) (UK DEFRA, 2002a, pp. 8-9). In addition to carcasses which had been sprayed with disinfectant, plastic sheeting, straw and materials such as sawdust were buried in the cells. Estimates suggest that the decay should be substantially complete within 5 to 20 years (UK DEFRA, 2002a, p. 9).

After burial had commenced it was recognized that limestone bands, many times more permeable than clay, intersected the burial pits and represented a potential pathway for migration of leachate into the environment. As a remediation measure, an in-ground clay wall (barrier) 7-14 m deep was constructed in stages over an 18-month period to encircle the site (Det Norske Veritas, 2003, p. 3). The objective was to isolate the limestone bands in contact with the cells from the surrounding strata. During construction, leachate was observed seeping into portions of the excavation for the clay barrier, indicating leachate had escaped from the cells and entered groundwater (Det Norske Veritas, 2003, p. II.11). A schematic representation of a cell in the Throckmorton site is provided in Figure 6.

Risk assessments indicated that without the clay barrier, unacceptable levels of ammonia and dissolved organic carbon would have reached a nearby watercourse in about 80 days, and would have remained above the target concentration for over 100 years. In contrast, the time required for unacceptable levels of ammonia to cross the clay barrier was estimated to be 200 years; however, once past the clay barrier, only 42 additional days would be required to reach the nearby watercourse, demonstrating that the low permeability of the barrier was essential to containing leachate (Det Norske Veritas, 2003, p. II.36).

Leachate was pumped from the cells, held in storage tanks, and periodically tankered away by road to a licensed sewage treatment site (UK DEFRA, 2002a, p. 9). During the nine-month period from April 2001 to January 2002, the total quantity of leachate removed from the site was 7,651 tonnes, suggesting an annual quantity of about 10,000 tonnes (Det Norske Veritas, 2003, p. VI.11). The total quantity of leachate collected from the site between the beginning of February 2002 and end of February 2003 (393 day period) was 4,848 m^3 (4,848,000 L, or ~1,280,706 gallons), which is equivalent to about 12.3 m^3/day (12,300 L/day, or 3,249 gallons/day).

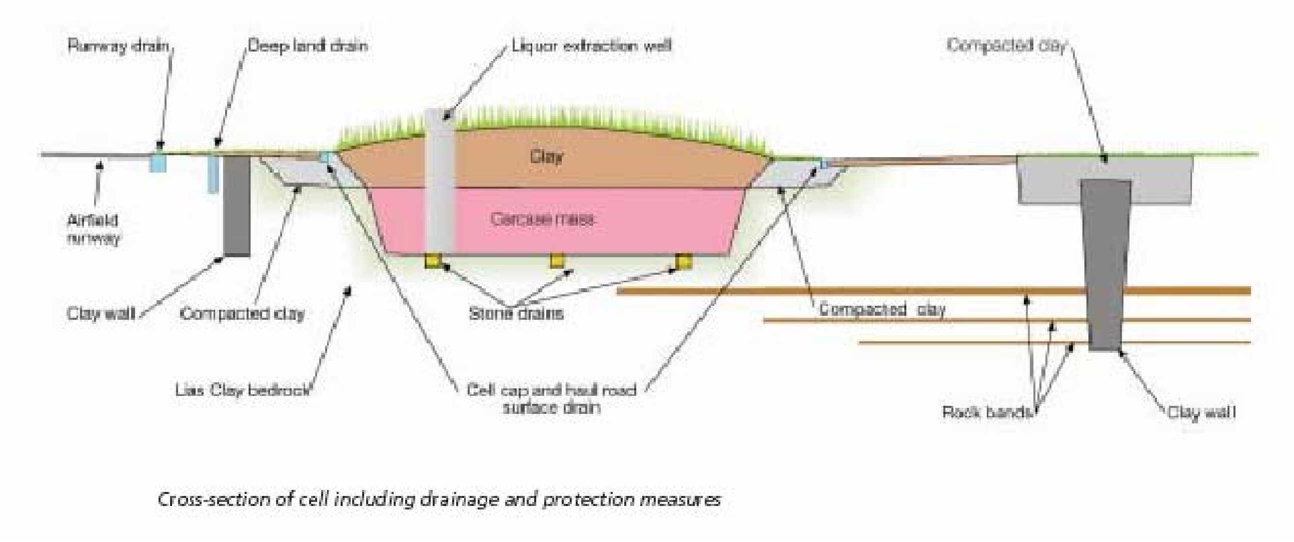

FIGURE 6. Schematic (cross-section) of cell at the Throckmorton mass burial site (UK DEFRA, 2002a).

A sample of leachate analyzed for suspended solids indicated a content of 2 g per liter of leachate, which would therefore give a suspended solids content of 25 kg/day, or 9 tonnes per year. Based on an estimated total carcass mass of 13,572 tonnes contained in the site, the annual fraction of suspended solids released is then estimated as 9/13600 = 6.6 x 10^{-4}. Assuming this flow remained constant for 20 years, this would result in the release of about 1.3% of the original disposed mass. Other estimates have indicated 0.7% for burial in shallow pits (DNV Technica, 1997b, App III.5.4) and 0.07% for burial in landfills (DNV Technica, 1997b, App III.6.3).

During operation, site gas was recorded as bubbling through ponded water on the site, although no damage to vegetation was recorded. No specific provision had been made for gas management other than gas vents from the deep ground drain. Subsequently, consideration has been given to the installation of a gas collection network as part of the final capping of the cells (Det Norske Veritas, 2003, p. II.12). No comprehensive measurements are available to estimate the quantity of site gas being generated. Although it is possible to estimate the quantity of gas generated at municipal waste sites, these methods may or may not be applicable for carcass burial sites. Based on estimates for MSW landfills, the quantity anticipated for the carcass disposal site was estimated to be about 2 kg of methane per tonne of waste per year. Based on a total of 13,600 tonnes of carcasses disposed in the site, this suggested a methane generation rate of 41,000 m^3 per year, or 27,000 kg per year (10^{-3} kg/s) from the site as a whole. This is reportedly an extremely low rate (Det Norske Veritas, 2003, p. VI.24).

Eppynt (Sennybridge), Powys, Wales. Preliminary hydrogeological investigations indicated that the geology of this site was of low permeability and published maps indicated the groundwater in this location was of "low vulnerable" status (UK Environment Agency, 2001c, p. 5). The site was adequately distant from licensed surface and groundwater abstractions, private water supplies, and surface water courses (500 m from the nearest surface water course) (UK Environment Agency, 2001c, p. 5). A quantitative risk assessment was performed using risk assessment software and a range of inputs for geological, hydrogeological, and geochemical parameters (described in detail in UK Environment Agency, 2001c, p. 9). The results of the computer modeling indicated the site would be suitable for mass burial. However, it was noted that further assessment and monitoring would be required to confirm the assumptions and conclusions from the modeling (UK Environment Agency, 2001c, p. 9).

A number of design measures were required for the site by the UK EA to ensure groundwater and surface water protection, including the following (UK Environment Agency, 2001c, p. 6):

- **Leachate collection systems.** Gravel drainage trenches running to collection sumps which were connected to leachate extraction wells.
- **Cover.** Replacement of soil removed during pit construction was required to encourage runoff.
- **Capping.** Placement of an impermeable membrane just under the topsoil layer to prevent surface water ingress into the pit.
- **Surface water diversion.** Construction of a cut-off ditch along the up gradient side of the pit was required to divert surface water.
- **Monitoring.** Boreholes were required for monitoring groundwater quality and levels.

In addition, a system of gas management was to be required. However, it was thought to be inappropriate to immediately construct a venting system for the gas due to the remote possibility that any virus in the carcasses could escape with the gas. Instead, the pit was to be sealed for a period of at least 40 days (the authority's estimation of the longevity of the virus) before venting the methane (UK Environment Agency, 2001c, p. 13).

Burial at the Sennybridge site commenced on 6 April 2001, but ceased just 5 days later due to significant escape of leachate from the site and the resulting threat to surface waters. In fact, all carcasses already buried at the site were exhumed and subsequently burned (UK Environment Agency, 2001d).

Ash Moor, Devon. The Ash Moor site, located adjacent to a clay quarry, was developed for use as a mass burial site but ultimately was never used for burial of carcasses. By the time the site was operational, the urgent need for disposal capacity had passed. Had the site been fully developed, it would have consisted of 15 lined cells which, once filled, would have been capped with additional liners followed by topsoil so that they would resemble raised barrows. Initially it was calculated that the site could accommodate 350,000 sheep carcasses. This figure was subsequently revised following experience at other sites, and was ultimately considered that it could take more than twice the original estimate. Three cells were excavated and lined; a fourth was excavated but not lined. The original intent was to have three cells in use at any one time – one being capped, one being filled, and one being excavated. This working procedure was designed to minimize odor and soil movements. The rest of the site was cleared in preparation for rapid excavation and use. The cells were lined with three liners using methodology employed in waste disposal sites. In addition, separate pipes were laid to extract leachate and methane. The leachate would have been disposed at an approved disposal site and the methane would have been burnt off by flare on-site (Workman, 2002).

Birkshaw Forest, Dumfries and Galloway, Scotland. During peak culling operations at the Birkshaw Forest mass disposal site (around the first week of May 2001), leachate disposal peaked at 400,000 liters per day. Leachate was pumped into static holding tanks which were treated with sodium hydroxide to raise the pH (Enviros Aspinwall, 2001c). As of October 2002, almost 18 months after burial operations ended, an estimated leachate production rate of 3.3 tonnes per day was observed (1-2 tankers per week). The leachate was reported to display characteristics of a high-strength, methanogenic leachate (Enviros Aspinwall, 2002b). Monitoring of gas at the Birkshaw Forest site demonstrated no measured methane at any boreholes in May 2001 (Enviros Aspinwall, 2001c), June 2001 (Enviros Aspinwall, 2001a), or August 2001 (Enviros Aspinwall, 2001b). Measured carbon dioxide levels were recorded as high as 4.2% in May 2001 (Enviros Aspinwall, 2001c), 2.5% in June 2001 (Enviros Aspinwall, 2001a), and near atmospheric levels in August 2001 (Enviros Aspinwall, 2001b). In December 2001, boreholes demonstrated sporadic instances of elevated methane and carbon dioxide levels; however, leachate extraction wells demonstrated methane levels occasionally as high as 38.5% (Enviros Aspinwall, 2002b). It was concluded that the marked increase in gas activity was consistent with maturing waste and did not represent a significant risk.

Cost considerations

The reported costs of mass burial sites used during the 2001 UK FMD outbreak are shown in Table 12. Based on the estimated number of carcasses buried at each site, the approximate cost per carcass has been calculated. Although cost per tonne would be a more preferred basis for comparison, for all sites except Throckmorton it was not possible to determine this value because few reports provided either the total weight of carcasses buried at each site, or the number of carcasses by species at each site (although reportedly the majority of carcasses were sheep). For the Throckmorton site, based on an estimated total weight buried in the site of 13,572 tonnes (see Table 11), the cost of using this site on a per-tonne basis is estimated to be £1,665/tonne.

Other considerations

Possible future technological improvements or alternate processes

The sites were constructed with varying complexities of environmental protection systems. Some sites were designed and constructed with sophisticated containment systems similar to those outlined in Subtitle D standards; however, some relied completely on natural attenuation to manage leachate (i.e., no engineered drainage, collection, or pumping system for leachate). In the future, sites such as these should all be planned, designed, and constructed in a manner similar to Subtitle D landfill requirements. This will likely not be possible if all planning and design takes place during the time of emergency, as was the case in the UK. If mass burial sites are to be a carcass disposal option, preliminary planning, assessment, and design work must be done in advance of the actual need.

TABLE 12. Estimated expenditures on mass burial sites resulting from the 2001 FMD outbreak in the UK (adapted from NAO, 2002).

Mass Burial Site	Cost in million £				Est. no. carcasses buried	Approx. cost (£) per carcass[a]
	Purchase (includes purchase and/or rent)	Initial construction, operation, & maintenance	Est long-term restoration and maintenance	Estimated total		
Great Orton	3.8	17.9	13.4	35.1	460,000	£76.30
Tow Law	0.5	7.6	7.1	15.2	45,000	£337.77
Widdrington	0.5	3.2	1.4	5.1	134,000	£38.06
Throckmorton	3.9	11.4	7.3	22.6	133,000	£169.92
Birkshaw Forest	0.5	5.0	4.5	10.0	490,000	£20.41
Eppynt	--	18.5	0.4	18.9	0[b]	--
Ash Moor	0.3	5.5	1.2	7.0	0[c]	--
TOTAL	9.5	69.1	35.3	113.9	1,262,000	£90.26

[a] Approx cost per carcass = Estimated total cost / Est. no. carcasses buried.
[b] 18,000 carcasses originally buried, but were subsequently exhumed and burned due to groundwater contamination.
[c] By the time the site was completed, it was no longer needed; no carcasses were buried at the site.

Public perception

As evidenced by the UK experience, there was tremendous public opposition to the use of mass burial sites, sometimes even escalating to the point of violence and vandalism. Because burial of such large numbers of animals in one site had not been done previously, the public viewed the operation as an experiment conducted at their expense. Much of the opposition was likely well-founded given that (a) thorough site assessments were not performed until after burial operations had commenced (in some cases until after burial operations were already completed), (b) surrounding communities, and even local regulatory bodies were not consulted prior to commencement of the operations, and (c) in one case the site chosen and approved by desktop analysis was subsequently proven to be unsuitable as evidenced by leachate escape, and the 18,000+ carcasses buried there had to be exhumed. Some additional examples of public opposition to various mass burial sites are provided below.

Great Orton (Watchtree), Cumbria. From its inception, disposal efforts at Watchtree were highly contentious. During construction and disposal, great disruption and distress was reported by the local communities; large numbers of heavy transport vehicles and the pervasive smell from the site were major problems until late 2001. Because the site is government owned, local planning approvals were not required, and the local authorities reported little or no pre-consultation. Concerns regarding long-term regulatory and enforcement issues continue to be expressed by the local authorities and the community (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p. 74). The way in which the Watchtree mass burial site was established left a legacy of resentment amongst the nearby local communities. The Cumbria inquiry panel recommended that the operators of the Watchtree mass burial site build on existing initiatives to ensure that complaints of smell or other environmental intrusions on the local community be fully addressed (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p. 81).

Tow Law (Stonefoot Hill), County Durham. Because the site was purchased by the government, use of the site was authorized without normal planning procedures, which caused great concern within the surrounding community. The former mining activities conducted on the site (resulting in numerous shafts on the site) caused the stability of the site to be of concern to local residents. A risk assessment was carried out concurrently with, rather than prior to, site construction (Tow Law Council, 2002). From the community standpoint, a major concern was the seemingly experimental nature of the site in that carcasses had never been buried on such a scale before, and, therefore, no models existed on which to base safety conclusions (Tow Law Council, 2002).

Widdrington (Seven Sisters), Northumberland. As with other mass burial sites, the local community expressed significant opposition to the site, to the extent that protests were staged. A local liaison committee was formed and detailed many of the community issues in a submission to the Anderson inquiry (Widdrington FMD Liaison Committee).

Ash Moor, Devon. Although this site was engineered to the highest standards, there remained significant active opposition to the site. Due to the urgent nature of the disposal problem, normal planning and consultation processes were not followed, planning applications were filed retrospectively, and environmental impact assessments were not completed prior to development. Opposition was most vocal from the non-farming community whose concerns included accidental leakages from the pits and from transport to and from the site (Workman, 2002). The site was purchased at a cost of £295,000, and construction of the site cost more than £5 million. Local opinion is that the site should be restored to its former condition, though restoration would be costly. Another alternative would be to mothboll the site, perhaps by making ponds out of the cells but retaining the ability to convert the site back to its original purpose in the event of a subsequent outbreak (Workman, 2002).

Section 4 – Disease Agent Considerations

This section includes information on the fate of selected disease agents (bacterial, viral, and prion) as a result of burial of infected animal carcasses. In many cases, very little information is available regarding (a) the length of time disease agents persist in the burial environment, or (b) the potential for dissemination from the burial site.

Concerns relative to disease agents stem from the fact that burial in and of itself is not a decontamination technique. That is, unlike some other disposal methods such as incineration or rendering, burial serves only as a means of ridding carcass material, but does not necessarily eliminate disease agents that may be present. The question arises as to the possibility of those disease agents to disseminate from the burial site and represent a risk to either human or animal health.

During the 2001 outbreak of FMD in the UK, the Department of Health prepared a rapid qualitative assessment of the potential risks to human health associated with various methods of carcass disposal (UK Department of Health, 2001c). The most relevant hazards to human health resulting from burial were identified as bacteria pathogenic to humans, water-borne protozoa, and BSE. The main potential route identified was contaminated water supplies, and the report generally concluded that an engineered licensed landfill would always be preferable to unlined burial. In general terms, the findings of the qualitative assessment relative to biological agents are summarized in Table 13.

4.1 – Bacterial Agents

Non-spore-forming organisms

Little information is available specifically concerning the survival of non-spore-forming bacteria and subsequent dissemination from actual carcass burial sites. Generally, the conditions of deep burial and associated pressures, oxygen levels, and temperatures are thought to limit the survival of the majority of such organisms (Gunn, 2001).

TABLE 13. Potential health hazards and associated pathways of exposure resulting from landfill or burial of animal carcasses (adapted from UK Department of Health, 2001c).

Potential public health hazard	Pathway of agent to humans	Potential exposure of humans to hazard	
		Landfill	Burial
Campylobacter, E. coli (VTEC), Listeria, Salmonella, Bacillus anthracis, C. botulinum, Leptospira, Mycobacterium tuberculosis var bovis, Yersinia	Private water supplies, Direct contact, Recreational water use, (possibly also shellfish)	Some	Greater
Cryptosporidium, Giardia	Water supplies (mains and private) Crops, shellfish, Direct contact, Recreational water use	Some	Greater
Clostridium tetani	Contact with contaminated soil	Some	Greater
Prions for BSE, scrapie	Water supplies via leachate, runoff, ash burial	Some	Greater

A study was undertaken in 1996 to ascertain the dissemination and persistence of *Salmonella typhimurium*, *Salmonella enteritidis*, *Bacillus cereus*, and *Clostridium perfringens*, in the environment after disposal of contaminated calf carcasses by deep burial (Davies & Wray, 1996). Calves were anaesthetized and inoculated intravenously with a solution containing 10^{12} of an equal combination of the four organisms. The calves were then killed and placed in a conventional grave dug to a depth of 2.5 m (about 8 ft). The authors report that within one week of placing the calves, extensive contamination of the soil surrounding the grave occurred, and there was an unexpected rapid passage of Salmonellae through the soil to a drainage ditch. Salmonellae were isolated from the soil around the burial site for 15 weeks, and reappeared in soil samples during cold winter weather after an apparent 68-week absence from the burial site (total of 88 weeks after the start of the experiment). *B. cereus* was also increasingly isolated during colder winter months. *C. perfringens* was more prevalent in samples during spring. However, the authors do not state how, or if, the isolates obtained from the environmental samples were confirmed as having originated from the inoculated calf carcasses.

As a result of land application of sewage sludge, considerable research has evaluated the potential for bacterial agents to survive in soil following such application. Although likely not entirely representative of the potential survival of bacterial agents in a burial environment (as it does not take into account several factors, including the potential bactericidal compounds produced by the decay process), such data could serve as approximations. Table 14 summarizes the estimates outlined by Gale (2002).

TABLE 14. Decay of bacterial pathogens in soil following application of sewage sludge (adapted from Gale, 2002).

Pathogen	Decay in soil as $\log_{10}$ units	Time frame and experimental conditions
Salmonellae	2.0	5 weeks; winter
Campylobacter spp.	2.0	16 days
E. coli O157:H7	1.0	49 days; 18°C

The potential for bacterial pathogens to disseminate and survive within the environment surrounding human cemeteries was evaluated (UK Environment Agency, 2002a). The authors indicated that although pathogens may be present, they will likely die off naturally and rapidly reduce in concentration with increasing distance from the grave site. Survival would be governed by physical conditions, such as temperature, moisture content, organic content, and pH (UK Environment Agency, 2002a, p. 7). The transport of microbes/pathogens within groundwater would be affected by the characteristics of the organism (size, shape, activity) as well as the method of transport through the aquifer. Water extracted from shallow depth with a shorter travel-time since recharge would have a higher pollution risk than an extraction drawing on water with a long residence time. Therefore, spring systems and shallow wells would be more vulnerable to microbial pollution problems than deep wells or boreholes (UK Environment Agency, 2002a, p. 8). The potential for an aquifer matrix to remove pathogens by filtration would depend on the nature of the matrix. Where the major route of groundwater flow is through porous intergranular matrix (intergranular flow), such as sandstone aquifers, there would be higher filtration potential. Conversely, in aquifers where fractures provide the predominant flow route, such as chalk aquifers, the potential for filtration of microbes would be limited.

Spore-forming organisms

In general, spore-forming organisms are known to survive in the environment for very long periods of time. Therefore, it is expected that spore-forming organisms within the burial environment will persist, perhaps indefinitely. Dissemination of such organisms would be dependent on many characteristics unique to the burial site, such as hydrological and geological properties.

Sporulation of *Bacillus anthracis* requires oxygen and does not occur inside an intact carcass. Consequently, regulations in most countries forbid postmortem examination of animals when anthrax is suspected (Turnbull, 2001). Most, if not all, vegetative *B. anthracis* cells in the carcass are killed by putrefactive processes in a few days, although the exact length of time required is unpredictable and greatly depends on climatic conditions such as temperature. *B. anthracis* organisms may escape from the carcass via exudates from the nose, mouth, and anus, and may lead to environmental contamination.

In most countries, the preferred method of disposal of an anthrax contaminated carcass is incineration, although some countries also consider rendering an effective approach (Turnbull, 2001). Where neither of these options is possible or practical, burial is the remaining best alternative. Burial is relatively unreliable for long term control of anthrax; this is reaffirmed by periodic reports of viable anthrax spores at burial sites of animals which died many years previously. Disturbances (e.g., ploughing, laying drainage, or scavenging of wildlife) at such burial sites can bring spores to the surface. Spores can sometimes migrate to the soil surface even in the absence of mechanical disturbances (Turnbull, 2001).

The prevalence of anthrax spores from the environment (soil) in the area of sites previously used to dispose of anthrax-infected bison carcasses was investigated (Dragon, Rennie, & Elkin, 2001). No anthrax spores were detected from the environment of burial sites 14-30 years old at the time of sampling; however, anthrax spores were detected from burial sites that were less than two years old at the time of sampling. Anthrax spores were isolated from the bone beds of cremation sites, especially those which contained residual mats of bison hair. The authors concluded that both incineration and deep burial appear to be equally effective at removing anthrax spores from the immediate environment.

4.2 – Viral Agents

As stated for bacterial agents, little published information is available specifically concerning the survival of viruses and subsequent dissemination from actual carcass burial sites. Again, the pressures, oxygen levels, and temperatures associated with deep burial, combined with the antimicrobial products generated by decaying processes, are thought to limit survival (Gunn, 2001; Gale, 2002).

Foot and mouth disease virus

Bartley, Donnelly, & Anderson published a review of the survival of FMD virus in animal excretions and on fomites (2002). The virus can survive in the absence of animal hosts, with potential reservoirs including the excretions and secretions of infected livestock as well as contaminated inanimate objects or fomites. The virus may survive at 4°C (39°F) for approximately two months on wool, and for two to three months in bovine feces or slurry. The virus has reportedly survived more than 6 months when located on the soil surface under snow (temperature range of -17.7 to 5.1°C [0 to 41°F]). In general, at ambient temperatures survival was longer when the virus was located beneath the soil surface or under leaves (>19 days) than when it was situated on the soil surface or on plant stems (<5 days). Results also generally showed decreasing survival with increasing temperature. The authors highlight the insufficiency of available data for evaluating disease control strategies (appropriate timeframe for movement and restocking restrictions, declaration of disease-free status, etc.), and identify a need for further evaluation of virus survival using large-scale, long-term field studies conducted in FMD endemic areas (Bartley, Donnelly, & Anderson, 2002).

In the carcasses of animals infected with FMD, the virus is rapidly inactivated in skeletal and heart muscle tissue as a result of the drop in pH that accompanies rigor mortis (Gale, 2002, p. 102). The virus may persist for longer periods in blood clots, bone marrow, lymph nodes, and offals (e.g., kidney and liver) because these tissues are protected from the pH changes that accompany rigor mortis. Liver, kidney, rumen, lymph node, and blood from diseased cattle have all been shown to be highly infective and to remain so if stored frozen. Acid formation in these tissues and in blood is not on the same scale as in muscle, and prolonged survival of virus is more likely. This remains true of lymph node and of residual blood in vessels of a carcass in which the development of rigor mortis is complete. In the absence of specific data for soil, Gale (2002) assumed decay in soil to be similar to that of decay in bovine fecal slurry (at 4°C [39°F], a 5-log reduction [99.999% reduction] was predicted after 103 days).

Information about the operation of the Throckmorton mass burial site in the UK indicated that initially leachate extracted from the site was treated with lime in order to adjust the pH to kill FMD virus prior to disposal at an off-site sewage treatment works. However, pre-treatment of leachate with lime was discontinued 60 days after burial of the last carcass because the FMD virus was reportedly unlikely to survive more than 40 days in a burial cell. (Det Norske Veritas, 2003, p. II.21). Unfortunately, no details are provided to indicate from what data the 40-day estimate was derived.

An evaluation was conducted in 1985 in Denmark to estimate whether burying animals infected with FMD would constitute a risk to groundwater (Lei, 1985). The evaluation considered characteristics of the virus, survival within various tissues, likely disposition within the grave, adsorption to and transport within soil, soil characteristics, influence of leachate and precipitation, and the characteristics of local geography and hydrology. Although not specifically indicated, the evaluation appeared not to address the issue of burial of significant numbers of carcasses in a given site, but rather was related to burial of small numbers of animals. The authors ultimately concluded that the probability of groundwater contamination from burial of FMD-infected animals was very small, although in situations of atypical or unfavorable circumstances the possibility could exist. They further suggested that even if viruses were able to reach groundwater sources, the concentration would likely be inadequate to present an animal-health risk.

Classical swine fever virus

Classical swine fever (CSF) virus is stable in the pH range of 5-10, but inactivated below pH 3 or above pH 10. Unlike FMD virus, little to no destruction of CSF virus would occur solely as a result of a drop in pH levels due to rigor mortis in the muscle of an infected animal (Gale, 2002, p. 117). In the absence of data for soil, Gale (2002) assumed decay in soil to be similar to that of decay in pig fecal slurry (at 4°C [39°F], a 5-log reduction [99.999% reduction] after 92 days). Survival of the virus in water ranged from 6-24 days at 20°C (68°F).

Other viral agents

The persistence of rabbit hemorrhagic disease (RHD) virus in decomposing rabbit carcasses was evaluated by McColl, Morrissy, Collins, & Westbury (2002). This study is discussed here because it represents one of the few that actually measured, under controlled conditions, the survival of a disease agent within decomposing carcasses. In laboratory experiments, rabbits were infected with RHD virus and all died within 36 hours. Carcasses were allowed to decompose in cages for 30 days at about 20°C (68°F). Liver samples were obtained and tested weekly for the presence of viral antigen, as well as for the presence of infectious RHD virus (by inoculation into healthy rabbits). Results indicated that infectious RHD virus survived in the liver tissue of rabbit carcasses for 20-26 days. These results suggest that, in addition to direct rabbit-to-rabbit transmission of the virus and the possibility of vector-borne transmission, the persistence of viruses in infected carcasses may be an important factor in the epidemiology of RHD.

4.3 – TSE Agents

The agents (known as prions) thought to be responsible for transmissible spongiform encephalopathies (TSEs), such as BSE in cattle, scrapie in sheep, CWD in deer and elk, and Creutzfeldt-Jakob disease (CJD) in humans, are highly resistant to inactivation processes effective against bacterial and viral disease agents. Prions have been demonstrated to be highly resistant to inactivation by chemical means, thermal means, as well as ionizing, ultraviolet, and microwave irradiation processes (Taylor, 1996; Taylor, 2000). Additionally, the scrapie agent has been demonstrated to retain at least a portion of its infectivity following burial for three years (Brown & Gajdusek, 1991). In a speech to the US Animal Health Association, Taylor (2001) indicated that "the present evidence suggests that TSE infectivity is capable of long-term survival in the general environment, but does not permit any conclusions to be drawn with regard to the maximum period that it might survive under landfill conditions. Experiments on the longterm survival of the BSE agent after burial are about to be initiated at the Neuropathogenesis Unit in Edinburgh, UK, but it will take up to ten years to gather results from these experiments."

As a result of the BSE epidemic in the UK, resources were increasingly focused on determining the potential for TSE agents to survive in the environment as a result of disposing of infected animal carcasses. In 1997, a series of risk assessments were conducted in the UK to specifically address the issue of survival of the BSE agent in the environment as a result of disposal of infected or potentially infected carcasses (DNV Technica, 1997b; DNV Technica, 1997a). These assessments estimated that some 6,000 carcasses were disposed of in 59 different landfill sites around the UK in the early stages of the epidemic (from 1988 to 1991). Possible routes of human infection from BSE-infected carcasses disposed in a landfill include landfill gas, which is not thought to contain any infectivity, and leachate. The possible contamination of leachate, which might then possibly contaminate water supplies, was determined to be the most likely source of risk. Ultimately the risk assessments concluded that the risk of infection was well below an individual risk of one in a million years, which would be generally regarded as an acceptable level of risk. It is interesting to note that this low level of risk was identified even though most of the landfill sites were generally mature operations employing only natural attenuation (no engineered leachate containment systems) (DNV Technica, 1997a, p. 3). Other sources have reiterated this finding of very low levels of risk to human health from disposing of TSE-infected animal carcasses in landfill sites (Gunn, 2001; Gale, Young, Stanfield, & Oakes, 1998).

Following the 2001 FMD epidemic in the UK, the Ministry of Agriculture, Fisheries and Food (MAFF; subsequently DEFRA) asked DNV to assess the risk of BSE from disposal of carcasses resulting from the FMD epidemic. DNV used the modeling approach and assumptions from the 1997 risk assessments (DNV Technica, 1997b; DNV Technica, 1997a) and concluded that the risk of exposure to humans would be entirely due to contamination of groundwater, and that these risks were again very low (dose received by any one person would be extremely small) (Comer & Spouge, 2001). In a note issued on 24 May 2001, the UK Spongiform Encephalopathy Advisory Committee (SEAC) Working Group indicated that although considerable uncertainty existed as to exact location and number, as many as 10,000 cattle over five years of age may have been buried in the early period of the FMD outbreak (prior to EA guidance) (UK SEAC, 2001). With an assumed prevalence of 0.4%, it would be possible that about 40 carcasses with late-stage BSE may have been buried. The SEAC Working Group had discussed potential risks associated with various courses of action. Although the potential for release of BSE agent into the environment existed from these burials, exhuming these sites to remove the carcasses may result in even higher risks than leaving the burial site undisturbed. The group concluded that there was a need for site-specific risk assessments, with the number of older animals buried at any one site being of central importance (UK SEAC, 2001).

The increasing emergence of CWD in deer and elk populations in various regions of the US has also resulted in assessment of risk relative to disposal of carcasses potentially infected with a TSE agent. The Wisconsin Department of Natural Resources also conducted a risk assessment to address the risks posed by disposal of such carcasses in landfills (Wisconsin Department of Natural Resources, 2002). As was the case in other risk assessments, the risk assessment supported the following:

1. The disease specific agent is hydrophobic and is expected to adhere to organic materials present in landfills,
2. It is likely to take the CWD agent several months to move through a landfill, during which time the agent will be subjected to biodegradation and is likely to lose a significant amount of its infectivity,
3. Any infectivity that exits the landfill will be captured in the effluent and transferred to a wastewater treatment plant or re-circulated within the landfill,
4. CWD prions present in wastewater are expected to partition with the sludge fraction, and
5. Land-applied sludge will be greatly diluted by surface soils and incorporated with soil at a depth of 9 inches.

Based on these findings, the risk assessment concluded that the available knowledge about CWD and other TSEs suggested that landfilling CWD infected deer would not pose a significant risk to human health, and the risk of spreading CWD among the state's deer population by landfill disposal of infected carcasses would be quite small (Wisconsin Department of Natural Resources, 2002).

In 2002, a meeting was convened to identify the research required to address possible contamination of the soil and water environment by TSE agents as a result of agricultural practices (UK DEFRA, 2002b). Burial of animal carcasses infected with a TSE agent was identified as a significant potential source of environmental contamination. Results of the meeting highlighted several areas in which additional research efforts are needed relative to TSE infectivity in the environment, including the communities of soil microorganisms and animals involved in carcass degradation; the effect of anaerobic conditions and soil type on the degradation, persistence, and migration of TSEs in the soil environment; detection systems which can be used to identify infectivity in soil matrices; and a need to validate assumptions on the behavior of TSE agents which have been used in risk assessments (UK DEFRA, 2002b).

An opinion published in 2003 by the European Commission Scientific Steering Committee addressed the use of burial to dispose of carcasses potentially infected with TSE agents. This opinion emphasized the fact that the "extent to which infectivity reduction can occur as a consequence of burial is poorly characterized" (European Commission Scientific Steering Committee, 2003). Based on this lack of understanding, along with concerns for groundwater contamination and dispersal or transmission by vectors, the committee indicated that burial of animal material which could possibly be contaminated with BSE/TSEs "poses a risk except under highly controlled conditions" (e.g., controlled landfill) (European Commission Scientific Steering Committee, 2003).

In 2004 the US EPA outlined recommended interim practices for landfill disposal of materials potentially contaminated with CWD (US EPA, Office of Solid Waste, 2004). These practices, intended to minimize the potential for release of infectious agents, included the recommendation that only those sites compliant with Subtitle D regulations and having no uncontrolled release from disposal cells be used.

Section 5 – Implications to the Environment

5.1 – Animal Carcass Decomposition

Biodegradation of organic matter

Based on the concept of waste degradation within a landfill, degradation of material within a burial site generally proceeds in three stages: aerobic decomposition, acid-phase anaerobic decomposition (non-methanogenic), and anaerobic decomposition (methanogenic) (McBean, Rovers, & Farquhar, 1995). During the aerobic stage of decomposition, aerobic microorganisms degrade organic materials to carbon dioxide, water, partially degraded residual organics, and heat. Compared to the subsequent anaerobic stages, this aerobic decomposition stage is relatively rapid (McBean, Rovers, & Farquhar, 1995, p. 61).

Ultimately, aerobic decomposition is responsible for only a small proportion of the total degradation that occurs. As oxygen levels decrease, the process transitions to the second stage of decomposition, acid-phase anaerobic decomposition in which facultative organisms are dominant and high concentrations of organic acids, ammonia, hydrogen, and carbon dioxide are produced. Acid fermentation prevails, with characteristic end products being high levels of carbon dioxide, partially degraded organics (especially organic acids) and some heat. As oxygen is depleted, activity becomes dominated by anaerobic organisms that generate methane as a primary by-product. This stage of decomposition can continue for many years (McBean, Rovers, & Farquhar, 1995, p. 62).

Process and products of carcass decomposition

From the point at which an animal (or human) dies, degradation of bodily tissues commences. However, the rate at which decay proceeds is strongly influenced by various endogenous and environmental factors (Pounder, 1995). Because of the relevance to human forensic science (specifically pertaining to time of death determinations), much is known about the processes and rates of decay of human corpses in various environments. In contrast, relatively little research has been conducted specifically regarding the decomposition processes of animal corpses, except in those instances where animal corpses have been used as surrogates for human subjects, for example (Micozzi, 1986; Hewadikaram & Goff, 1991; Turner & Wiltshire, 1999; Payne & King, 1972). Additionally, research often focuses on the decay rates that occur when human or animal remains are left exposed to the elements, rather than buried. Various human forensic studies may have reasonable application to animal carcass burial, such as (Mann, Bass, & Meadows, 1990; Hopkins, Wiltshire, & Turner, 2000; Rodriguez & Bass, 1985; Spennemann & Franke, 1995; Galloway, Birkby, Jones, Henry, & Parks, 1989).

In spite of the shallow pool of direct experimental evidence, some generalizations regarding the degradation of animal carcasses are possible. Soft tissue, in the absence of any means of preservation, is degraded by the postmortem processes of putrefaction (anaerobic degradation) and decay (aerobic degradation) (Micozzi, 1991, p. 37). Putrefaction results in the gradual dissolution of tissues into gases, liquids, and salts as a result of the actions of bacteria and enzymes. Key indicators of putrefaction include changes in tissue color (especially notable in human corpses), evolution of gases, liquefaction of tissues, and development of a putrid odor (Pounder, 1995). Color changes and development of foul odors occur as a result of the sulfur-containing gas produced by intestinal or rumen bacteria. Accumulation of this gas can then result in physical distortions such as bloating of the body, protrusion of the tongue and eyes, expulsion of the intestines through the vagina or rectum, and discharge of large amounts of foul-smelling fluid from the nose, mouth, and other orifices (Iserson, 2001, p. 50).

A corpse or carcass is degraded by microorganisms both from within (from the gastrointestinal tract) and from without (from the surrounding atmosphere or soil) (Munro, 2001, p. 7; Micozzi, 1986), and these organisms may include both aerobes and anaerobes.

The component tissues of a carcass degrade at varying rates, the order of which is generally (1) body fluids and soft tissues other than fat (brain, epithelial, liver, and kidney tissues decompose fairly early, followed by muscle and muscular organs), (2) fats, (3) skin, cartilage, and hair or feathers, and (4) bones, horns, and hooves (McDaniel, 1991, p. 873; Munro, 2001, p. 7). A report on the proportions of degradable matter in a coffined human corpse indicates 60% to be readily degradable, 15% to be moderately degradable, 20% to be slowly degradable, and 5% to be inert or non-degradable (UK Environment Agency, 2002a, Table 3).

Some of the best information available on the decomposition of animal carcasses in burial sites stems from the 2001 outbreak of FMD in the UK. Although a devastating event, this incident provides unique and valuable information relative to decomposition of mass quantities of animal carcasses. A report commissioned at the very early stages of the outbreak as a result of problems related to the use of mass burial sites attempted to estimate the volume of fluid leachate which could be expected to originate from cattle, sheep, and pig carcasses. It was estimated that about 50% of the total available fluid volume would "leak out" in the first week following death, and that nearly all of the immediately available fluid would have drained from the carcass within the first 2 months (Table 15).

TABLE 15. Estimated volume of leachate released per animal following death (adapted from Munro, 2001).

Species	Est. volume of fluid released per animal, in L	
	First week postmortem	First 2 months postmortem
Cattle – Adult (500-600 kg; 1100-1300 lbs)	80	160
Cattle – Calf	10	20
Sheep – Adult (50 kg; 110 lbs)	7-8	14-16
Sheep – Lamb	1	2
Pig – Adult	6	12
Pig – Grower/finisher	3	6
Pig – Piglets	0.4	0.8

The author of this report highlighted the fact that much of the information used to generate the estimates was obtained from the rates of decomposition established for single non-coffined human burials, and these estimates may not accurately reflect the conditions in mass burials of livestock (Munro, 2001).

A UK EA report which assessed the environmental impact of the 2001 FMD outbreak suggests that the estimated volume of body fluids released within two months postmortem would be approximately 16 m^3 (16,000 L, or ~4,230 gallons) per 1000 adult sheep, and 17 m^3 (17,000 L, or ~4,500 gallons) per 100 adult cows (UK Environment Agency, 2001b, p. 11).

In addition to leachate, gaseous products will also be generated from the decomposition of animal carcasses. Munro (2001) estimated that the composition of the gas produced would be approximately 45% carbon dioxide, 35% methane, 10% nitrogen, with the remainder comprised of traces of other gases such as hydrogen sulfide. This report suggested that the methane proportion would decrease over time, with very little methane being produced after 2 months. A drop in methane production would reportedly result from decreased pH within the burial environment which would be detrimental to methane-producing bacteria. As was reported for leachate, it was estimated that the majority of the gas would be released immediately after burial, with decreasing amounts thereafter (Munro, 2001). However, this estimation of decreasing amounts of gas over time seems to contradict, somewhat, the conventional knowledge that gas production in MSW landfills generally increases over time as the waste matures. Additionally, a report of monitoring activities at one of the UK mass burial sites also suggests that gas production increases over time, rather than decreases (Enviros Aspinwall, 2002b).

Time required

The amount of time required for buried animal carcasses (or human corpses) to decompose depends on many factors including temperature, moisture, burial depth, soil type and drainability, species and size of carcass, humidity/aridity, rainfall, and possibly other factors (McDaniel, 1991). The factors of most significance will likely be temperature, moisture level, and burial depth. Warm temperatures hasten decomposition by the body's natural enzymes found in many of the body's cells and in the digestive juices (Iserson, 2001, p. 384).

A carcass left on the surface of the ground generally decays much more quickly than a buried carcass due in large part to destruction of much of the soft tissue by insects, carnivores, and rodents (Micozzi, 1991; Mann, Bass, & Meadows, 1990; Iserson, 2001; Rodriguez & Bass, 1985). In ideal conditions (warm to hot weather), a human corpse left exposed to the elements can become skeletonized in a matter of two to four weeks (Mann, Bass, & Meadows, 1990; Iserson, 2001, p. 384). However, an unembalmed adult human corpse buried six feet deep in ordinary soil without a coffin requires approximately 10 to 12 years to skeletonize (UK Environment Agency, 2002a; Pounder, 1995; Munro, 2001; Iserson, 2001). Other sources indicate that even longer may be required:

> Scottish lore held that a grave was 'ripe' for twenty years after burial, meaning that it was likely more than bones would turn up if the grave was reopened before twenty years had passed. Since the Scots frequently reused gravesites, this maxim was well founded.
>
> (Iserson, 2001, p. 391)

Given relatively equal factors (temperature, body size, etc.), a corpse placed in water (with no fish or reptiles present) will generally decompose about four times faster than a corpse that is buried (Iserson, 2001, p. 390). One source indicates that a buried whale carcass remained largely intact and putrid after 10-20 years (Gaudet, 1998).

In addition to the lengthy persistence of actual carcass material in a burial site, leachates or other pollutants may also be long-lived. Although much of the pollutant load would likely be released during the earlier stages of decomposition (i.e., during the first 1-5 years) (UK Environment Agency, 2001b; McDaniel, 1991; UK Environment Agency, 2002a; Munro, 2001), several reports suggest that mass burial sites could continue to produce both leachate and gas for as long as 20 years (UK Environment Agency, 2001b; Det Norske Veritas, 2003).

Some insight into the possible longevity of material within mass animal burial sites can be gathered from research into the environmental impacts of human cemeteries. The UK Environment Agency (2002a), in a study of the potential of human cemeteries to pollute groundwater, identified the primary factors affecting the decay rate of human remains to be those that affect microbial activity, as this is the primary means of decay. Factors listed as important included the following:

- availability of nutrients (carbon, nitrogen, phosphorus, and sulfur) and moisture
- pH, with neutral conditions being most favorable to decay
- climate, with warm temperatures accelerating decay
- soil lithology (well drained soil accelerates decomposition whereas poorly drained soil has the reverse effect)
- burial practice (depth of burial, use of a coffin, etc.)

In addition to these extrinsic factors, characteristics of the carcass material can also affect decay rates. One study evaluated the effect of freezing, thawing, or mechanical injury of carcasses on the time required for decomposition. The study found that rat carcasses which were frozen and then thawed were more susceptible to invasion by insects and microorganisms from the outside than were fresh-killed carcasses (Micozzi, 1986). These results may have relevance for situations such as the frozen storage of deer carcasses suspected of harboring CWD. In some cases carcasses may be held in frozen storage until results of testing are complete.

5.2 – Environmental Impacts

The potential exists for the decay products of buried animal carcasses to be released into the surrounding environment, with subsequent negative environmental and/or public health consequences resulting from chemical or biological pollutants. The potential effects arising from burial will be similar regardless of the technique used (e.g., trench burial vs. landfill); however, the likelihood and scale of the effects may differ. Another important consideration is the total volume of material buried; the impacts resulting from burial of 30 carcasses would likely be of an entirely different magnitude than those resulting from burial of 30,000 carcasses.

Estimating potential impacts

Various works have attempted to estimate the potential environmental impacts and/or public health risks associated with animal carcass burial techniques. Several sources identify the primary environmental risk associated with burial to be the potential contamination of groundwater or surface waters with chemical products of carcass decay (McDaniel, 1991; Ryan, 1999; Crane, 1997). See Figure 7.

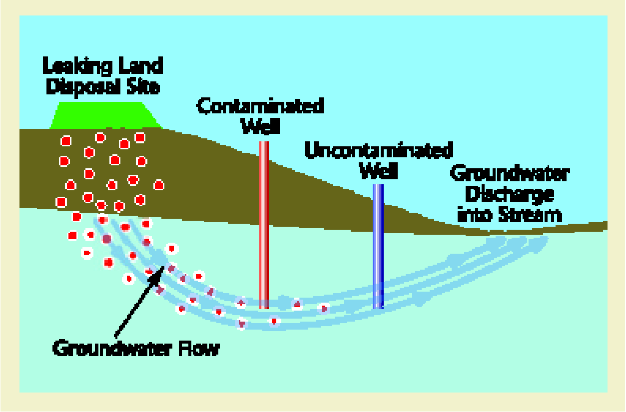

FIGURE 7. Contamination of groundwater by leachate leaking from a land disposal site (Walsh & O'Leary, 2002a).

Freedman & Fleming (2003) sought to evaluate the scientific basis for, as well as the appropriateness and adequacy of, regulations governing the burial of dead stock. They state in their report there "has been very little research done in the area of environmental impacts of livestock mortality burial." Due to this information void, they conclude that there is little evidence to demonstrate that the majority of regulations and guidelines governing burial of dead stock have been based on any research findings directly related to the environmental impacts of livestock or human burials. They also conclude that further study of the environmental impacts of livestock burial is warranted.

During the 2001 outbreak of FMD in the UK, a significant volume of information was generated by various agencies with the intent of attempting to assess the risks involved in disposing of carcasses by various means. A particular challenge faced by these agencies was the need to generate information in a very rapid timeframe. As in the case of other previous assessments, leaching of decay products into water courses was identified as a significant potential environmental impact (UK Environment Agency, 2001b; UK Department of Health, 2001c; Munro, 2001).

The UK Department of Health (2001c) prepared a rapid qualitative assessment of the potential risks to human health associated with various methods of carcass disposal. Annex C of this qualitative risk assessment provides an exhaustive summary of the potential hazards associated with the various carcass disposal options, including biological, chemical, and other types of hazards (UK Department of Health, 2001c, Annex C). Each hazard is characterized as to the following:

- **Release.** Source, mechanism of release, and timescale of release.
- **Exposure pathway.** Likely location of contaminant (soil, air, or water), and pathway to human exposure.
- **Public health consequences.** Likelihood of exposure, population exposed (at-risk groups), leading indicators, individual outcomes, as well as existing preventive measures.

The UK EA conducted an interim assessment of the environmental impacts of FMD carcass disposal (UK Environment Agency, 2001b). In that assessment, hazards which may potentially be associated with on-farm burial, landfilling, or mass burial included:

- **Body fluids.**
- **Leachate components.** Including high concentrations of ammonia (up to 2,000 mg/L) and high chemical oxygen demand (COD; up to 100,000 mg/L, about 100 times that of raw sewage).
- **Pathogens in the leachate.** Including *E. coli* O157:H7, *Campylobacter*, *Salmonella*, *Leptospira*, *Cryptosporidium*, *Giardia,* and BSE prions.

- **Release of gases.** Including carbon dioxide, methane, or other foul-smelling gases.

Following the FMD epidemic, inquiries were conducted by several bodies at both the national and regional levels. In many of the submissions to these inquiries, potential environmental impacts are outlined (Aldridge, Pratt, Dawson, & Skinner, 2001; Natural Environment Research Council, 2001). Additionally, investigations into the operation of various mass disposal sites include a summary of potential environmental impacts (Det Norske Veritas, 2003; UK Environment Agency, 2001c). Relative to BSE risks in particular, because as many as 10,000 cattle over five years of age may have been buried in the early period of the FMD outbreak, a study was also conducted to specifically assess the risk due to BSE from disposal of carcasses resulting from the FMD epidemic (Comer & Spouge, 2001).

Human cemeteries

Although perhaps not entirely representative of burial of animal carcasses, some information on potential environmental impacts can be inferred from the potential effects that may arise from human cemeteries. Because little published information was available on the potential sources of pollutants from cemeteries, an assessment was conducted in 1998 to evaluate the potential impact on the environment and to public health (Ucisik & Rushbrook, 1998). This assessment also identified products arising from decay of corpses as a risk to water courses, with possible contaminants including bacteria, viruses, and organic and inorganic chemical decomposition products. Soil type was identified as a significant factor in movement of bacteria and viruses as an unsaturated soil layer acts as a filter and an adsorbent. Most microorganisms were reportedly filtered out on or near the soil surface (however, adsorption was reported to decrease with increasing water velocity). The most useful soil type for maximizing natural attenuation properties was reported to be a clay-sand mix of low porosity and small- to fine-grain texture (Ucisik & Rushbrook, 1998).

A 2002 report by the UK EA provided a review of the published literature relating to the potential environmental threat posed by cemeteries to identify and quantify the risks of pollution (UK Environment Agency, 2002a). This report identified the primary pollutants derived from human corpses as dissolved and gaseous organic compounds and dissolved nitrogenous forms (particularly ammonia nitrogen). One of the most important factors governing the rate of release of these contaminants was reported to be the rate of microbial decay. This report estimated that over half of the pollutant load leaches from a corpse within the first year, and halves year-on-year thereafter. That is, less than 0.1% of the original loading may remain after 10 years (see Table 16).

TABLE 16. Potential contaminant release (kg) from a single 70 kg human burial (adapted from UK Environment Agency, 2002a).

Year	TOC[a]	NH_4	Ca	Mg	Na	K	P	SO_4	Cl	Fe
1	6.00	0.87	0.56	0.010	0.050	0.070	0.250	0.210	0.048	0.020
2	3.00	0.44	0.28	0.005	0.025	0.035	0.125	0.110	0.024	0.010
3	1.50	0.22	0.14	0.003	0.013	0.018	0.063	0.054	0.012	0.005
4	0.75	0.11	0.07	0.001	0.006	0.009	0.032	0.027	0.006	0.003
5	0.37	0.05	0.03	<0.001	0.003	0.004	0.016	0.012	0.003	0.001
6	0.19	0.03	0.02	<0.001	0.002	0.002	0.008	0.006	0.002	<0.001
7	0.10	0.01	0.01	<0.001	0.001	0.001	0.004	0.003	<0.001	<0.001
8	0.05	<0.01	<0.01	<0.001	<0.001	<0.001	0.002	0.001	<0.001	<0.001
9	0.02	<0.01	<0.01	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
10	0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[a] TOC = Total organic carbon.

Since precipitation amount and soil permeability are key to the rate at which contaminants are "flushed out" of burial sites, the natural attenuation properties of the surrounding soils would be a primary factor determining the potential for these products of decomposition to reach groundwater sources (UK Environment Agency, 2002a). Several other works have also attempted to determine the environmental impacts of human burials (cemeteries) (Spongberg & Becks, 1999; Spongberg & Becks, 2000; Pacheco, Mendes, Martins, Hassuda, & Kimmelmann, 1991).

Trench burial

Contaminants released from Iowa burial sites

In 1990 the Iowa Department of Natural Resources developed rules for on-farm burial which established maximum loading rates, minimum burial depths, and separation distances. During the rulemaking process, questions arose regarding the likely rate of carcass decay, the quantity and type of contaminants released, and the potential effects on groundwater. To attempt to gain insight into these questions, a study was initiated to monitor two animal burial sites (Glanville, 1993).

On "Site #1" (a small research plot with well drained soils), approximately 165 lbs of 25- to 30-lb pigs were buried in each of two 20-foot-long trenches. The bottom and sides of one trench were lined to permit capture and analysis of decay products; the second trench was unlined. To evaluate groundwater effects of leachate from the unlined trench, eight shallow wells located immediately down-gradient were monitored. During the 19-month period after leachate production began, mean biochemical oxygen demand (BOD) concentrations in the leachate collected from the lined trench exceeded 4,000 mg/L, ammonia nitrogen averaged 740 mg/L, average total dissolved solids (TDS) were nearly 1600 mg/L, and chloride averaged 120 mg/L (Glanville, 1993).

The total mass of BOD recovered in the trench leachate during the 21-month period following burial would have been sufficient to contaminate more than 36,000 L of water at a concentration of 200 mg/L (strength of typical untreated municipal sewage). Similarly, the total mass of ammonia nitrogen recovered (if oxidized to nitrate) would be sufficient to raise the nitrate concentration in more than 85,000 L of water above the drinking water standard of 10 mg/L. Furthermore, large scale burial at the same area loading rate would be equivalent to applying 510 lbs of nitrogen per acre. Since much of the nitrogen released from the burial site occurred during late fall and winter, a time when crop uptake would be negligible, continuous large-scale on-farm burial has considerable potential to cause excess nitrogen loading (Glanville, 1993).

"Site #2" in this study was established on a commercial turkey farm in northwest Iowa following a catastrophic ventilation failure that killed 2,500 birds. Approval was given to bury approximately 62,000 lbs of turkeys in two shallow pits. Soils in the site were wet, and the water table fluctuated between depths of one to five feet. Monitoring results demonstrated high levels of ammonia, TDS, BOD, and chloride in the monitoring well closest (within two ft) to the burial site. Average ammonia and BOD concentrations (monthly sampling during 15 months) exceeded 300 mg/L, and average TDS reached nearly 2,000 mg/L. Nitrate levels were very low, indicating an anaerobic environment. However, little evidence of contaminant migration was observed in wells located more than a few feet from the burial site (Glanville, 1993; Glanville, 2000).

One of the monitoring wells used during this same study was inadvertently located within or near an older burial site. Although the exact age of the older burial pit was unknown, it was believed to have been constructed at least nine years prior to the time of the study. Despite its advanced age, drill cuttings at the old site revealed very dark colored, odorous material at a depth of approximately two to six feet. Monthly groundwater sampling at this location showed average ammonia nitrogen concentrations of nearly 200 mg/L, TDS levels of about 1300 mg/L were twice the background levels, and BOD levels of 25 mg/L were two to three times apparent background levels (Glanville, 1993).

Groundwater quality impacts of disposal pits

The impact of dead bird disposal pits (old metal feed bins with the bottom removed placed in the ground to serve as a disposal pit) on groundwater quality was evaluated by Ritter & Chirnside (1995 & 1990). Disposal pits represent a slightly different technique than trench burial (a disposal pit generally consists of a hole dug into the earth, the sides of which may be lined with concrete, metal, or wood. The bottom of the pit is left exposed to the earth below, and the top is closed with a tight-fitting cover or lid). However, the data provides some insight as to the pollution potential associated with trench burial. In the past, the use of disposal pits was relatively common for poultry operations as a means of disposing of daily mortalities. Because of the high water table on the Delmarva Peninsula, the bottoms of many of the disposal pits are located in the groundwater during part or most of the year (Ritter & Chirnside, 1995).

In this study a total of six existing disposal pits were evaluated by means of monitoring wells placed around each pit at distances of 3 and 6 m. Wells were sampled every four to eight weeks for approximately three years (from March 1987 to March 1990). Although no EPA drinking-water standard exists for ammonia, it is undesirable to have ammonia present in drinking-water supplies at any level. Around several of the disposal pits the ammonia levels were much higher than 10 mg/L (the EPA standard for nitrate), and one ammonia concentration of 366 mg/L was observed. Most samples around the disposal pits had concentrations of nitrate, chloride, and fecal coliforms which were below EPA drinking-water standards. The researchers concluded that three of the six disposal pits evaluated had likely impacted groundwater quality (with nitrogen being more problematic than bacterial contamination) although probably no more so than an individual septic tank and soil absorption bed. However, they cautioned that serious groundwater contamination may occur if a large number of birds are disposed of in this manner (Ritter & Chirnside, 1995).

Impacts of poultry disposal pits in Georgia

Myers (1998) evaluated the environmental impacts of poultry disposal pits in Georgia. Four counties representing long-term concentrated poultry production, as well as four major soil provinces were selected for study. Electromagnetic conductivity surveys were conducted to determine local groundwater flow and the relationships to disposal pits and domestic wells. Domestic wells were monitored for a variety of chemical and microbiological contaminants. At the time of publication (1998), data were still being collected and therefore no conclusions were presented. A 2003 personal communication from the author cited by Freedman & Fleming (2003) suggests that the final report of these studies should be available soon.

Findings following the 2001 UK FMD outbreak

In the aftermath of the 2001 UK FMD outbreak, considerable monitoring of various disposal sites has been conducted, and is ongoing. As a result of the outbreak, monitoring and surveillance programs were established jointly by various UK agencies to evaluate public health impacts, as well as environmental impacts, resulting from the handling and culling of animals and disposal of carcasses (UK Public Health Laboratory Service, 2001c). Results of this monitoring program were published periodically during the outbreak, namely in July 2001 (UK Public Health Laboratory Service, 2001a), August 2001 (UK Public Health Laboratory Service, 2001b), and November 2001 (UK Public Health Laboratory Service, 2001c).

In December 2001, the UK EA published an interim assessment of the environmental impact of the outbreak (UK Environment Agency, 2001b). The most notable actual environmental pressures that were identified included the following:

- Emissions to air from pyres.
- The delay in the disposal of carcasses early in the outbreak.
- The storage of slurry on farms for longer periods than normal.
- The inappropriate disposal of some carcasses and ash early on in the outbreak.
- Odor from mass burials and landfill sites.
- The burial of items such as machinery and building materials during the cleansing and disinfection process on farms.

The primary conclusions of the interim environmental impact assessment identified in this report are summarized in Table 17. In general, the report concluded that no significant negative impacts to air quality, water quality, soil, or wildlife had occurred. Additionally, no evidence of harm to public health was observed.

TABLE 17. Summary of negative environmental impacts following the 2001 UK FMD outbreak (UK Environment Agency, 2001b).

Impact	Short-term effects (during the outbreak)	Medium-term effects (within a year)	Long-term effects (more than a year)
Air pollution	Pyre emissions elevated local concentrations of some pollutants but did not breach air quality standards. The fumes and odor caused public concern. Odor from some of the landfills caused public concern.		Possible soil contamination from emissions of dioxins, PCBs, and PAHs.
Groundwater pollution	Seepage from burials and pits under pyres has contaminated a small number of groundwaters.	Seepage will continue and could contaminate groundwater.	Seepage to groundwater could occur over 20 years.
Surface water pollution	212 reported pollution incidents, 14 causing significant harm, mainly from disinfection, carcass fluids and slurry. Unable to access farmland to maintain small sewage works or to attend pollution incidents.	Seepage from burial and pits under pyres could reach surface waters.	
Soils	Increased local soil erosion where animals could not be moved. Pyre emissions led to small risk of local soil and food contamination by dioxins, PCBs, and PAHs.		Any significant dioxin, PCB, or PAH contamination could persist for several years.
Wildlife and fisheries	Rat poison could be picked up by birds of prey. Three large fish kills reported; unrecorded disinfectant pollution could cause local harm to fish populations.	Local changes in grazing pressure would benefit some habitats and degrade others.	Changes depend on the response of the farming industry and any changes to agricultural policy.
Landscape	Pyre smoke, loss of farm stock, footpath restrictions.	Lack of farm stock in some areas and changes in vegetation will affect the landscape.	Changes depend on the response of the farming industry and any changes to agricultural policy.

Although the report identified only minor overall impacts on the environment, it was acknowledged that many instances of local nuisance occurred. For example, runoff of blood and body fluids from slaughtered animals awaiting disposal occurred on many sites, especially during the early months of the crisis when disposal operations were outpaced by slaughter rates. As a result the public reported many pollution incidents, although the report states that relatively few cases of significant water pollution actually occurred. It is noted, however, that these exposed carcasses caused an increased risk of pathogen or disease agent transmission by pests or wildlife (e.g., rats, crows, and gulls), and created a local odor nuisance.

Mass burial

Monitoring of groundwater, leachate, and landfill gas has been conducted at UK FMD mass burial sites by both the operators of the sites and by the UK EA. Surface waters, groundwaters, and leachates were tested for BOD, ammonia, and suspended solids as well as chloride and potassium levels. Microbiological testing of water supplies conducted around two mass burial sites demonstrated no deterioration in microbiological quality of any private water supplies nor of waters around the sites. The EA reported that the monitoring results from the mass disposal sites indicated no cause for concern (UK Public Health Laboratory Service, 2001c).

All seven mass burial sites intended for disposal of carcasses were met with significant opposition from local communities located near them. Although the

UK EA assessment indicated that at all sites consideration was given to minimizing the risk of surface and groundwater pollution, it also noted that, at the time of publication, some site management controls were still in development. At all the mass burial sites except for Widdrington, leachate was collected/contained, and in some cases taken off-site for disposal. For example, at the Throckmorton site by September 2001 some 74,000 m^3 (74,000,000 L) of leachate had been collected and removed by tanker for treatment and disposal at sewage treatment plants. Significant findings resulting from monitoring efforts through December 2001 at mass burial sites included the following (UK Environment Agency, 2001b):

- **Great Orton.** Small quantities of carbon monoxide, methane, and hydrogen sulfide were detected via monitoring at 71 boreholes and manholes.
- **Great Orton.** Monitoring of 20 surface water sites since April 2001 resulted in the observance of one incident; the incident was caused by leachate and was quickly stopped.
- **Tow Law and Widdrington.** No impact on surface waters.
- **Throckmorton.** Airfield drains showed some contamination with leachate and disinfectant, but no effect on downstream watercourses either chemically or biologically.
- **Sennybridge.** Stream showed some contamination.

Additional details regarding key findings of environmental monitoring efforts at some of the mass burial sites are outlined below.

Eppynt (Sennybridge, Wales)

Key monitoring results from the Eppynt burial site as of August 2002 indicate that some residual environmental issues remain. For example, at the head of a small stream downhill from the burial site, dissolved oxygen levels continue to be reduced, suggesting some residual contamination with localized impact. Furthermore, groundwater in a borehole 12 m deep located at the southwest end of the burial pit still shows slight contamination, although concentrations of all chemical contaminants are approaching background levels. Table 18 provides key monitoring data from the Eppynt burial site (UK Environment Agency, 2001d; UK Environment Agency, 2002c).

TABLE 18. Key results of water quality monitoring conducted at the Eppynt (Sennybridge) mass burial site, Powys, Wales (adapted from UK Environment Agency, 2001d; UK Environment Agency, 2002c).

Contaminant	Date – Level	
	Borehole 12 meters deep, southwest end of burial site (ID = Borehole 2)	Stream head downhill from burial site (ID = Sample Point #1)
Biochemical Oxygen Demand (BOD)	April 2001 – 7400 mg/L July 2001 - >100 mg/L October 2001 – below 10 mg/L August 2002 – Below 4 mg/L	April 2001 – Rose from 0.7 to 70 mg/L August 2002 – at background (1 mg/L)
Chemical Oxygen Demand (COD)	April 2001 – 13,000 mg/L July 2001 - >200 mg/L October 2001 - >100 mg/L August 2002 - ~30 mg/L	April 2001 – Rose from 12 to 90 mg/L July 2001 – At background
Dissolved oxygen	N/A	April 2001 – Fell from 80% to 30% saturation August 2002 – Variable, occasionally below RE1
Ammonia	April 2001 – 340 mg/L October 2001 – 10-20 mg/L August 2002 - <5 mg/L	April 2001 – 0.5 mg/L August 2002 – Around DL of 0.01 mg/L
Chloride	April 2001 – 360 mg/L August 2002 – at background	April 2001 – Rose from 7 to 14 mg/L August 2002 – Less than 5 mg/L

Throckmorton

Monitoring results demonstrated that the leachate from the Throckmorton site had the following characteristics (Det Norske Veritas, 2003, p. II.25):

- **BOD.** Very high in all cells initially (360,000 mg/l); steadying to below 50,000 mg/l within 4 months; typically below 5,000 mg/l within 6 months; and typically below 3,000 mg/l within 13 months.
- **Ammonia as nitrogen.** Initially 2,000 – 10,000 mg/l; reducing to less than 3,000 mg/l within 6 months; thereafter fluctuating below this level.
- **Chloride.** Fluctuated greatly up to 1,400 mg/l during the first 9 months; thereafter generally less than 350 mg/l, although some cells fluctuated up to 550 mg/l.

Birkshaw Forest, Lockerbie, Scotland

In May 2001, as a result of complaints regarding the odors emanating from the mass burial site at Birkshaw Forest, monitoring of the air quality near the site was performed to determine the presence of compounds that may be injurious to human health (Glasgow Scientific Services Colston Laboratory, 2001). The monitoring regime included total volatile organic compounds (TVOC), flammable and other bulk gases, individual volatile organic compounds (VOC), and hydrogen sulfide. It was concluded that although odor causing compounds were identified, the concentration of contaminants were within air quality guidelines and, although a source of annoyance, were not expected to result in adverse health affects.

A monitoring program (for groundwater, leachate, and gas) was undertaken at the Birkshaw Forest site by Enviros Aspinwall on behalf of the Scottish Executive. A series of reports provide the results of this monitoring program (Enviros Aspinwall, 2001c; Enviros Aspinwall, 2001a; Enviros Aspinwall, 2001b; Enviros Aspinwall, 2001d; Enviros Aspinwall, 2002a). These reports, in conjunction with quarterly site management reports (Enviros Aspinwall, 2002b; Enviros Aspinwall, 2003), provide operational details for the site. Key observations from these monitoring reports are summarized in Table 19. It is noteworthy that the February 2003 report (Enviros Aspinwall, 2003) indicated that the leachate produced continued to be of very high strength, even $1\frac{1}{2}$ years after burial operations ended. In spite of the potent nature of the leachate, monitoring results provided no evidence of widespread groundwater contamination, confirming the effectiveness (and necessity) of the sophisticated containment systems and operational procedures implemented (Enviros Aspinwall, 2003).

5.3 – Monitoring Requirements

Following the disposal activities of the 2001 FMD outbreak, the UK Department of Health (2001b) outlined environmental monitoring regimes focused upon the key issues of human health, air quality, water supplies, and the food chain. The methods of surveillance employed in these programs include the following:

- **Public drinking water supplies.** Water companies carry out routine monitoring of microbiological and chemical quality of their supplies.
- **Private water supplies.** Guidance for monitoring included testing for both chemical and microbiological parameters (although chemical parameters were reported to be better indicators of contamination) (UK Public Health Laboratory Service).
- **Leachate.** At landfill and mass burial sites, leachate is managed as well as monitored for both composition and migration. Groundwater and surface water sources are tested in the vicinity of these sites.
- **Surveillance of human illness.** Illnesses, such as gastrointestinal infections, that might arise in connection with FMD carcass disposal is monitored.

It was noted that, although baseline data with which to compare would be useful, for most private water supplies such baseline data would not exist. Therefore, caution in interpretation of results was stressed (i.e., increased levels of an analyte may not necessarily indicate contamination by a disposal site, other sources may be involved) (UK Public Health Laboratory Service).

TABLE 19. Key results and conclusions from the monitoring program of the Birkshaw Forest (Lockerbie) mass burial site.

Reporting Period	Key Observations/Conclusions	Significant Monitoring Results
May 2001 (Enviros Aspinwall, 2001c)	Of 8 boreholes, 2 demonstrated evidence of contamination (located to the east of the site). Likely sources of contamination included a leachate spill and runoff from decontamination stations.	Borehole east of site COD[a] 5,270 mg/l; TOC[b] 1,280 mg/l; Leachate COD 74,200 mg/l; BOD[c] 47,550 mg/l; pH 6.6
June 2001 (Enviros Aspinwall, 2001a)	The majority of sample locations continued to demonstrate no groundwater contamination. Of the two boreholes previously identified as contaminated, measured parameters showed improvement.	Borehole east of site COD 1,200 mg/l; pH 8.6
August 2001 (Enviros Aspinwall, 2001b)	Monitoring results indicate no widespread leachate release, although limited release from one unlined pit. Monitoring results from the spill-contaminated borehole showed a continued trend toward improvement. No risk from gas identified.	Borehole east of site COD 1,000 mg/l; pH below 7
October 2001 (Enviros Aspinwall, 2001d)	Monitoring results continued to show no evidence of groundwater contamination. Levels in the spill-contaminated borehole reduced considerably.	--
December 2001 (Enviros Aspinwall, 2002a)	Monitoring results continued to show no evidence of widespread groundwater contamination, although one borehole east of the site showed some signs of leachate contamination. Levels in the spill-contaminated borehole continued to decline.	--
July-Sep 2002 (Enviros Aspinwall, 2002b) Oct-Dec 2002 (Enviros Aspinwall, 2003)	No evidence of significant surface water or groundwater pollution. Gas monitoring suggests the pits are methanogenic and producing gas at low levels. Leachate of very high strength continues to be produced (COD in the thousands of mg/l).	--

[a] COD: chemical oxygen demand.

[b] TOC: total organic carbon.

[c] BOD: biochemical oxygen demand.

Section 6 – Advantages & Disadvantages

6.1 – Trench Burial

The advantages and disadvantages associated with trench burial, as reported by a wide variety of sources, are summarized below. The advantages have been summarized from sources including Agriculture and Resource Management Council of Australia and New Zealand (1996), Sander, Warbington, & Myers (2002), Morrow & Ferket (2001), Ryan (1999), Blake & Donald (1992), Damron (2002), and Minnesota Board of Animal Health (2003).

Sources reporting disadvantages include Sander, Warbington, & Myers (2002), Morrow & Ferket (2001), Hermel (1992), Pope (1991), UK DEFRA (2002b), Ryan (1999), Ritter & Chirnside (1995), Doyle & Groves (1993), Myers (1998), Blake & Donald (1992), Minnesota Board of Animal Health (2003), Alberta Agriculture, Food and Rural

Development (2002c), Minnesota Board of Animal Health (1996), Franco (2002), and Moorhouse (1992). In some cases, certain advantages or disadvantages may have varying degrees of relevance depending on whether viewed in the context of disposal of daily mortalities or disposal of mortalities from an emergency situation (e.g., natural disaster or animal disease).

Advantages

Several sources report trench burial to be a relatively economical option for carcass disposal as compared to other available methods. However, a variety of factors would likely impact the cost effectiveness of trench burial, including the circumstances under which it is used (i.e., whether used for an emergency situation or for disposal of daily mortalities), whether equipment is owned or rented, and whether any environmental protection measures are necessary. Trench burial is reported to be convenient and logistically simple, especially for daily mortalities, as the equipment necessary is generally widely available and the technique is relatively straightforward. This also allows trench burial to be performed relatively quickly. If performed on-farm or on-site, it eliminates the need for transportation of potentially infectious material, reducing the potential for disease spread or breaches in biosecurity. The technique is perhaps more discrete than other methods (e.g., open burning), especially when performed on-site (on-farm) and may therefore be less likely to attract significant attention from the public. Furthermore, bacteria and viruses reportedly seem not to move very far from the burial site, although this would be highly dependent on the specific individual circumstances (e.g., volume of mortality buried, geological and hydrological properties of the site, disease agent of concern, etc.). These attributes, particularly those of convenience, logistical simplicity, and rapid completion, have resulted in trench burial being a traditionally favored option for carcass disposal.

Disadvantages

Conversely, there are also a wide variety of disadvantages associated with trench burial. Perhaps most significant among them is the potential for detrimental environmental effects, specifically water quality issues. Again, the effects that may arise would depend on the specific circumstances, such as volume of mortality buried, geological and hydrological properties of the site, etc. Additionally, the risk of disease agents persisting in the environment may be of concern (e.g., anthrax and TSE agents). Trench burial, in effect, serves as a means of placing carcasses “out of site, out of mind” while they decompose, but does not represent a consistent, validated means of eliminating disease agents. Because the residue within a burial site has been shown to persist for many years, even decades, although the actual placement of carcasses within a trench can be completed relatively rapidly, ultimate elimination of the carcass material represents a long-term process. Furthermore, there is a considerable lack of knowledge and research regarding the potential long-term impacts of trench burial. From a practical standpoint, the use of trench burial may be limited by several factors, including a lack of sites with suitable geological and/or hydrological properties in some regions, regulatory constraints or exclusions relative to suitable locations, and the fact that burial may be prohibitively difficult in winter or when the ground is wet or frozen. In some cases, the presence of an animal carcass burial site may negatively impact land value or options for future use. Lastly, as compared to other disposal options, burial of carcasses does not generate a useable by-product of any value.

6.2 – Landfill

Advantages

The following advantages associated with landfill disposal of animal carcasses have been summarized from the following sources: Brglez (2003), Wisconsin Department of Natural Resources (2003, p. 128), Gunn (2001), DNV Technica (1997a), Wisconsin Department of Natural Resources (2002), Gale, Young, Stanfield, & Oakes (1998), and Ryan (1999).

Perhaps the most significant advantages of landfill disposal are the fact that the infrastructure for disposing of waste already exists, and capacity can be relatively large. Landfill sites, especially Subtitle D landfill sites, will have been previously evaluated for suitability, and the necessary environmental protection measures will already have been designed and implemented. During an emergency or instance of catastrophic loss, time is often very limited, and therefore landfills offer the advantage of pre-existing and immediately-available infrastructures for waste disposal (including equipment, personnel, procedures, and importantly, containment systems). Because landfill sites are already equipped with the necessary engineered containment systems for handling waste by-products such as leachate and gas, landfills represent a disposal option that would generally pose little risk to the environment. (Note that these advantages related to adequate containment systems may not apply to small arid landfills that rely on natural attenuation to manage waste by-products.) As an example of the significant capacity potentially available in landfill sites, approximately 95,000 tonnes of carcass material was deposited in landfills during the 2001 UK FMD outbreak (UK Environment Agency, 2001b, p. 9; NAO, 2002, p. 74), in addition to approximately 100,000 tonnes of ash and associated material (UK Environment Agency, 2001b, p. 9). Furthermore, during the 2002 END outbreak in southern California over three million birds were depopulated, with landfills serving as a primary route of disposal.

Another advantage of landfills is their wide geographic dispersion. Many, although certainly not all, geographic areas would have a landfill site in relatively close proximity. However, as will be discussed below, not all landfills that can accept carcasses will do so. The cost to dispose of carcasses by landfill has been referred to as both as an advantage and a disadvantage, and would likely depend on the situation. For purposes of disposing of daily mortalities, costs to dispose via landfill may be higher than for alternative methods. However, costs in an emergency situation or for certain disease agents may be comparable or favorable for landfills versus alternative methods.

Disadvantages

The following disadvantages associated with landfill disposal of animal carcasses have been summarized from sources including Sander, Warbington, & Myers (2002), Morrow & Ferket (2001), Bagley, Kirk, & Farrell-Poe (1999), UK Environment Agency (2002b), Hickman & Hughes (2002), Wisconsin Department of Natural Resources (2003, p. 128), UK DEFRA (2002b), and Ryan (1999).

Even though disposal by landfill may be an allowed option, and a suitable landfill site may be located in close proximity, landfill operators may not be willing to accept animal carcasses. A commonly cited reason for this is the fear of public opposition (as occurred during the 2001 UK FMD outbreak, and during the management of CWD deer in Wisconsin). Additionally, because the development of a landfill site is an extremely lengthy, difficult, and expensive process, landfill owners and planning authorities may not want to sacrifice domestic waste capacity to accommodate carcass material. Those landfill sites that do accept animal carcasses may not be open for access when needed or when convenient.

As was described for trench burial, landfilling of carcasses represents a means of containment rather than of elimination, and long-term management of the waste is required. However, this long-term commitment will be in effect for landfill sites regardless of whether or not carcass material is accepted. Relative to disease agent concerns, and TSEs in particular, several risk assessments conclude that disposal in an appropriately engineered landfill site represents very little risk to human or animal health due to robust containment systems and some degree of anticipated degradation of prions over time. However, further research is warranted in this area as the mechanism and time required for degradation are not known. An additional possible disadvantage associated with landfill disposal is that of potential spread of disease agents during transport of infected material from the site of origin to the landfill. It should be noted that this potential for disease spread would be equally associated with other off-site disposal methods. Although the potential exists for disease spread, rigorous biosecurity efforts have allowed landfill disposal to be successfully used in several infectious disease eradication efforts (such as the 2002 outbreak of END in southern California).

Compared to some other disposal options, a disadvantage of all burial techniques including landfill is the fact that they do not generate a useable by-product of value. As previously stated, the costs associated with landfill disposal have been cited as a disadvantage, and in some cases are even termed "prohibitive." Again, depending on the circumstances, the cost of landfill disposal may be higher than, or comparable to, other disposal alternatives.

6.3 – Mass burial

The most significant advantage of mass burial sites is the capacity to dispose of a tremendous number (volume) of carcasses. For mass burial sites created in the midst of an emergency, this may perhaps be one of the only advantages. Assuming appropriate containment systems are employed in the design, mass burial sites may be similar to landfills in terms of posing little risk to the environment. However, the significant disadvantages associated with mass burial sites, as used during the 2001 UK FMD outbreak, caused UK officials to state that it is very unlikely that mass burial sites would be used as a method of disposal in the future (FMD Inquiry Secretariat, 2002). One of the most significant disadvantages from the UK experience was the massive public opposition to the development and use of such sites. From a practical standpoint, other disadvantages included the significant costs involved, problems with site design leading to brief episodes of environmental contamination, and the need for continuous, long-term, costly monitoring and management of the facilities. From a theoretical standpoint, other potential disadvantages of mass burial sites would be similar to those outlined for landfills, namely serving as a means of containment rather than of elimination, lack of adequate research into long-term consequences associated with various disease agents (especially TSEs), presenting opportunities for spread of disease during transport from farm sites to the mass burial site, and not generating a usable by-product of any value.

In spite of these potential disadvantages, mass burial sites may have the potential to serve as an effective means of carcass disposal in an emergency situation. However, this would require thorough site assessment, planning, and design well in advance of the need.

Section 7 – Critical Research Needs

7.1 – Relevant Research In-Progress

1. A study to retrospectively evaluate burial sites used in the UK during the 1967-68 FMD outbreak is in progress by the UK EA. The EA website indicates the study, titled "Sampling of 1967 FMD Remains" is in progress, but the report is not yet available. The reported purpose of the project is "to gather analytical data on the degraded remains of animals culled during the 1967 FMD outbreak." Additional details are available at http://www.environment-agency.gov.uk/science/scienceprojects/304016/334745/.
2. In a speech at the 2001 US Animal Health Association meeting, Taylor (2001) reported,

   > Experiments on the longterm survival of the BSE agent after burial are about to be initiated at the Neuropathogenesis Unit in Edinburgh, UK, but it will take up to ten years to gather results from these experiments. However, burial is not the same as landfill because the latter process usually involves an enhanced degree of microbiological activity because of the variety of waste materials that are present. As far as the author is aware, there are no experiments in progress to study the degradation effects on TSE agents when they are land-filled.
3. Extensive research on the transport and fate of prions in the environment, particularly in landfill environments, is currently in progress at the University of Wisconsin, Madison. Objectives of the research include:

- Investigation of the processes affecting the preservation of prions in soils (including evaluation of the extent to which prions associate with various soil constituents, whether association with soil constituents protects prions from degradation, and the extent to which infectivity is retained by particle-associated prions).
- Investigation of the factors influencing the mobility of prions in soils and landfills, including the infectivity of leached prion proteins.
- Investigation of the fate of prions in wastewater treatment plants, including sorption to sludge and sedimentation, and degradation by sludge microbial populations.

7.2 – Research Needed

1. Investigate means to make on-farm burial more environmentally sound.

   Explore potential design and construction techniques that may improve the environmental soundness of on-farm burial sites, especially for those sites in locations with marginally acceptable geology. Some design aspects used in Subtitle D landfills may be relevant. Also evaluate pre-planning steps that can facilitate the rapid use of on-farm burial sites in an environmentally sound manner at time of emergency.

2. Thoroughly evaluate the design, construction, operation, management, and environmental impacts of mass burial sites used in the UK during the 2001 FMD outbreak and use this information to establish best practice guidelines for similar sites that may be used in the US.

   Because burial is included as a disposal option in many states' contingency plans, burial sites in livestock-dense areas may contain significant numbers (or volumes) of carcasses. These sites could be similar in scope to the mass burial sites used in the UK during the 2001 FMD outbreak. The UK sites provide a unique opportunity to learn from the experiences of others in order to establish suggested guidelines for such sites in advance of a need for them.

3. Retrospectively evaluate burial sites used in the past to better understand the decomposition processes that occur, as well as the possible environmental impacts of the sites.

   Few if any investigations of the nature and dynamics of decomposition within mass burial sites of cattle, sheep or pigs have been conducted (Munro, 2001). As mentioned in section 7.1, a study of burial sites used in the UK during the 1967-68 FMD outbreak is in progress. In addition to the insights from the UK work, previous burial sites used in the US should be identified for evaluation. Potential candidates might include burial sites from the 1984 AI outbreak in Virginia, as well as burial sites used during Hurricane Floyd in North Carolina.

4. Conduct controlled studies to gain a better understanding of the potential environmental impacts associated with various burial techniques. Use this information as a basis for developing scientifically valid burial regulations and guidelines.

   A recent evaluation of the water quality impacts of burying livestock mortalities concluded that the majority of regulations and guidelines governing burial are not based on scientific information regarding the potential environmental impacts of such operations, largely due to the fact that critical information in the following areas is lacking (Freedman & Fleming, 2003):

   - Measurement of the relative impacts of different types of contaminants, including nutrients, pathogens, antibiotics, etc.
   - Movement of contaminants from buried large animals (e.g., cattle)
   - Movement of contaminants through different types and textures of soils.

In their interim environmental impact assessment, the UK EA identified a need for a decision-making framework for management including a review of the "best practicable environmental options" for the disposal of carcasses to protect human health and the environment (UK Environment Agency, 2001b, p. 27).

A briefing by the World Health Organization (WHO) on the impact of human cemeteries on the environment and public health identified the following areas of needed research (Ucisik & Rushbrook, 1998), which are analogous to areas of study needed relative to animal burials:

- Identify safe distances between aquifers and cemeteries in various geological and hydrogeological situations.
- Investigate why and how most microorganisms arising during the putrefaction process do not appear in the groundwaters beneath cemeteries.
- Determine the desirable minimum thickness of the unsaturated zone beneath cemeteries.
- Collect together existing regulations on cemetery siting and design from various countries and prepare, with the latest scientific findings, a set of common practices.

5. Conduct studies to better understand the survival and potential migration of various disease agents within burial systems.

   In an interim environmental impact assessment following the 2001 FMD outbreak, the UK EA identified a need for improved technical information on pollutant sources, pathways, and impacts of various disposal options including burial (UK Environment Agency, 2001b, p. 27). For example, a specific need for information on the microbiological contaminants in groundwaters from the burial of carcasses and other materials was identified.

6. Pre-identify and assess the carcass disposal options available, including potential burial (or mass burial) sites, particularly in regions densely populated with confined animal feeding operations (CAFOs).

   The strategic assessment of options for the disposal of infected wastes in the event of a disease outbreak in the poultry industry conducted by the Department of Agriculture in Western Australia is an excellent model that could be used by various geographic regions or by states (e.g., by state within the US) as a tool for developing contingency plans and disposal hierarchies appropriate to the unique circumstances of each region (Australian Department of Agriculture, 2002). The approach used in this strategic assessment ensures that all available options are investigated and would help to maximize the number of available options in an emergency.

   As demonstrated unequivocally by the experiences of the UK during the 2001 FMD outbreak, it is not possible to adequately plan for and design mass burial sites during the time constraints of an emergency situation. It would be wise to identify CAFO-dense areas (e.g., the southwestern areas of Kansas) and conduct preliminary assessments of possible mass burial sites.

7. Evaluate the potential for designing carcass burial sites as "bioreactors" or for using existing bioreactors for carcass disposal.

   Bioreactors are generally a type of landfill that, unlike traditional landfills, are designed to promote the degradation of material rather than minimize it. The advantage of promoting degradation is the reduced long-term maintenance of the site. Several sources suggest advantages associated with such a design (Det Norske Veritas, 2003, p. II.7; Munro, 2001); however, additional research is needed to better understand the design and operating parameters of such a site.

8. Investigate the survival of TSE agents, specifically those related to BSE and CWD, in the

environment of carcass burial sites, including landfills.

This research area includes questions related to the management of burial sites: How do anaerobic conditions affect the degradation, persistence, and migration of TSEs in the soil environment? What detection systems can be used to identify TSE infectivity in soil systems? Can earthworms be used as an effective "sampling tool?" How does the TSE agent partition between solid and liquid fractions in burial environments?

In an opinion published in 2003 addressing the issue of TSEs, the European Commission Scientific Steering Committee (2003) emphasized the fact that the "extent to which infectivity reduction can occur as a consequence of burial is poorly characterized;" a fact reiterated by Taylor (2001).

References

Agriculture and Resource Management Council of Australia and New Zealand. (1996). AUSVET Disposal operational procedures manual. http://www.aahc.com.au/ausvetplan/disfnl2.pdf

Alberta Agriculture, Food and Rural Development. (2002a). Livestock burial. http://www.agric.gov.ab.ca/engineer/livestock_burial.html

Alberta Agriculture, Food and Rural Development. (2002b). *Livestock diseases act - destruction and disposal of dead animals regulation.* Retrieved January 15, 2004, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/acts299?OpenDocument

Alberta Agriculture, Food and Rural Development. (2002c). Livestock mortality management (disposal). http://www.agric.gov.ab.ca/engineer/livestock_mortality.html

Aldridge, B., Pratt, J.C., Dawson, R.A., & Skinner, J.L. (2001). A report on the concept, construction & effect of Ash Moor Barrows at Meeth and Petrockstow Devon 2001. http://www.royalsoc.ac.uk/inquiry/204.pdf

Anonymous. (1973). Dead bird disposal by burial. *Poultry Digest, 32,* 316-317.

Anonymous. (1999). Solid waste price index. *Solid Waste Digest, 9* (3), i-xi.

Anonymous. (2002). Agency seeking potential burial grounds for carcasses. http://131.104.232.9/animalnet/2002/8-2002/animalnet_august_12.htm

Arkansas Livestock and Poultry Commission. (1993). Regulations for the disposal of large animal carcasses, excluding dogs and cats. http://www.biosecuritycenter.org/arkdead.htm

Atkins, J.W., & Brightling, A. (1985). The management of sheep burial pits. *Australian Veterinary Journal, 62* (10), 347-348.

Australian Department of Agriculture. (2002). Stockguard Avian - Strategic assessment - Disposal of infected wastes in the event of an outbreak of an exotic disease in the poultry industry in Western Australia. http://agspsrv34.agric.wa.gov.au/programs/app/industry/StockGuard/avian/disposal.pdf

Bagley, C.V., Kirk, J.H., & Farrell-Poe, K. (1999). *Cow mortality disposal.* Logan, UT: Cooperative Extension Service, Utah State University. http://extension.usu.edu/publica/agpubs/ag507.pdf

Bartley, L.M., Donnelly, C.A., & Anderson, R.M. (2002). Review of foot-and-mouth disease virus survival in animal excretions and on fomites. *Veterinary Record, 151* (22), 667-669.

Bilbo, D.L., & Todd, J. (1994). The extension agent's handbook for emergency preparation and response. http://www.fema.gov/txt/library/eprhb.txt

Blake, J.P., & Donald, J.O. (1992). Alternatives for the disposal of poultry carcasses. *Poultry Science, 71* (7), 1130-1135.

Brglez, B. (2003). Disposal of poultry carcasses in catastrophic avian influenza outbreaks: A comparison of methods (technical report for Master of Public Health). Chapel Hill: University of North Carolina.

Britton, J. C*atastrophic poultry mortality loss: handling and disposal alternatives.* Oklahoma Cooperative Extension Service, Oklahoma State University. http://www.ansi.okstate.edu/exten/poultry/f-8216/f-8216.pdf

Brown, P., & Gajdusek, D.C. (1991). Survival of scrapie virus after three years internment. *The Lancet, 337* (8736), 269-270.

California Water Resources Control Board and Regional Water Quality Control Boards. (2003). State Water Resources Control Board's and Regional Water Quality Control Boards' interim recommendations for disposal of animal carcasses associated with fires. http://www.swrcb.ca.gov/rwqcb9/misc/wildfires/FireMort.pdf

Comer, P., & Spouge, J. (2001). *Assessment of risk due to BSE infectivity from disposal of cattle due to FMD* (No. 716018). London: DNV Consulting for UK Ministry of Agriculture Fisheries and Food.

Commission of the European Communities. (2001). C*ommission staff working paper on the processing, disposal, and uses of animal by-products in Member States* (No. SEC (2001) 1889). Europe: Commission of the European Communities.

Crane, N. (1997). Animal disposal and the environment. *State Veterinary Journal, 7* (3), 3-5.

Cumbria Foot and Mouth Disease Inquiry Panel. (2002). C*umbria foot and mouth disease inquiry report.* Cumbria, UK: Cumbria County Council.

Damron, B.L. (2002). Options for dead bird disposal: Fact Sheet AN-126. http://edis.ifas.ufl.edu/BODY_AN126. University of Florida: Animal Sciences Department and Florida Cooperative Extension Service.

Davies, R.H., & Wray, C. (1996). Seasonal variations in the isolation of Salmonella typhimurium, Salmonella enteritidis, Bacillus cereus and Clostridium perfringens from environmental samples. *Journal of Veterinary Medicine (Series B), 43* (2), 119-127.

Det Norske Veritas. (2003). *Independent environmental and public health risk assessment of DEFRA Foot and Mouth Disease disposal site* (No. 20073900).

DNV Technica. (1997a). *Assessment of risk from BSE carcases in landfills, report prepared for the UK Environment Agency* (No. 7243/1). London: DNV Technica.

DNV Technica. (1997b). O*verview of risks from BSE via environmental pathways, report prepared for the UK Environment Agency* (No. C7243). London: DNV Technica.

Doyle, C.J., & Groves, C.R. (1993). Fallen stock disposal: a case for public intervention. *Scottish Agricultural Economics Review, 7,* 51-62.

Dragon, D.C., Rennie, R.P., & Elkin, B.T. (2001). Detection of anthrax spores in endemic regions of northern Canada. *Journal of Applied Microbiology, 91,* 435-441.

Enviros Aspinwall. (2001a). *Birkshaw Forest Lockerbie - groundwater monitoring briefing 2* (No. SC0690011C).

Enviros Aspinwall. (2001b). *Birkshaw Forest Lockerbie - groundwater monitoring briefing 3* (No. SC0690011C).

Enviros Aspinwall. (2001c). *Birkshaw Forest Lockerbie - groundwater monitoring report - end May 2001 (briefing 1)* (No. SC0690011C).

Enviros Aspinwall. (2001d). *Birkshaw Forest, Lockerbie - groundwater monitoring report briefing note 4* (No. SC0690011C).

Enviros Aspinwall. (2002a). *Birkshaw Forest, Lockerbie - groundwater monitoring report briefing note 5* (No. SC0690011c).

Enviros Aspinwall. (2002b). *Birkshaw Forest, Lockerbie, quarterly monitoring report no. 1.*

Enviros Aspinwall. (2003). *Birkshaw Forest, Lockerbie: quarterly monitoring report no. 2.*

European Commission Scientific Steering Committee. (2003). Opinion on the use of burial for dealing with animal carcasses and other animal materials that might contain BSE/TSE. European Commission Health & Consumer Protection Directorate-General. http://europa.eu.int/comm/food/fs/sc/ssc/out309_en.pdf

European Parliament. (2002). Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules concerning animal by-products not intended for human consumption. *Official Journal of the European Communities,* L 273/1.

FMD Inquiry Secretariat. (2002). Foot and mouth lessons learned inquiry: Environment Agency notes of meeting.

Franco, D.A. (2002). Animal disposal – the environmental, animal disease, and public health implications: an assessment of options. Proceedings of California Department of Food and Agriculture Symposium, Sacramento, California.

Freedman, R., & Fleming, R. (2003). *Water quality impacts of burying livestock mortalities*.

Freudenrich, C.C. *How landfills work.* Retrieved September 8, 2003, from http://www.howstuffworks.com/landfill.htm/

Friend, M., & Franson, J. C. (1987). Disease control operations. In *Field Guide to Wildlife Diseases* (pp. 21-58). Washington, DC: US Fish & Wildlife Service.

Fulhage, C.D. (1994). *Dead animal disposal laws in Missouri.* Missouri: University of Missouri-Columbia, Cooperative Extension Service. http://www.muextension.missouri.edu/xplor/envqual/wq0216.htm

Gale, P. (2002). *Risk assessment: use of composting and biogas treatment to dispose of catering waste containing meat: Final report to the Department for Environment, Food and Rural Affairs.*

Gale, P., Young, C., Stanfield, G., & Oakes, D. (1998). Development of a risk assessment for BSE in the aquatic environment – a review. *Journal of Applied Microbiology, 84* (4), 467-477.

Galloway, A., Birkby, W.H., Jones, A.H., Henry, T.E., & Parks, B.O. (1989). Decay patterns of human remains in an arid environment. *Journal of Forensic Sciences, 34* (3), 607-616.

Gaudet, D. (1998, September). A whale of a burial. S*urveyor.*

Georgia Department of Agriculture. Chapter 40-13-5 Dead Animal Disposal. http://www.agr.state.ga.us/assets/applets/Proposed_Rules_40-13-5_Dead_Animals_12-4-02.pdf

Glanville, T.D. (1993). Groundwater impacts of on-farm livestock burial. *Iowa Groundwater Quarterly, 4*, 21-22.

Glanville, T.D. (2000). Impact of livestock burial on shallow groundwater quality. Paper presented at ASAE Mid-Central Meeting, St. Joseph, Missouri (No. MC00-116).

Glasgow Scientific Services Colston Laboratory. (2001). *Analyses of ambient air from Birkshaw Forest landfill site and its environs*. Glasgow, UK: Glasgow Scientific Services Colston Laboratory.

Government of British Columbia, Ministry of Agriculture, Food & Fisheries. *Environmental guidelines for beef producers – 11: dead animal disposal.* Retrieved December 11, 2002, from http://www.agf.gov.bc.ca/resmgmt/fppa/environ/beef/beef11.htm

Gunn, M. (2001). Observations on disposal of BSE-infected carcasses. *Irish Veterinary Journal, 54* (4), 192-193.

Hamlen, H.J. (2002, April). Preparing for Disaster. *Render*, 18-20.

Henry, C., Wills, R., & Bitney, L. (2001). *Disposal methods of livestock mortality.* Nebraska: University of Nebraska-Lincoln, Cooperative Extension, Institute of Agriculture and Natural Resources. http://www.ianr.unl.edu/pubs/animals/g1421.htm#target1

Hermel, S.R. (1992). Now what? *National Hog Farmer, 37* (4), 34-40.

Hewadikaram, K.A., & Goff, M.L. (1991). Effect of carcass size on rate of decomposition and arthropod succession patterns. *American Journal of Forensic Medicine and Pathology, 12* (3), 235-240.

Hickman, G., & Hughes, N. (2002). Carcase disposal: a major problem of the 2001 FMD outbreak. *State Veterinary Journal, 12* (1), 27-32.

Hickman, M. (2003). Disposal of END waste in southern California by landfill. Kansas City, Missouri: Midwest Regional Carcass Disposal Conference.

Hopkins, D.W., Wiltshire, P.E.J., & Turner, B.D. (2000). Microbial characteristics of soils from graves: an investigation at the interface of soil microbiology and forensic science. *Applied Soil Ecology, 14* (3), 283-288.

Horney, M.R. (2002). *Livestock carcass disposal: More than you ever wanted to know.* California: University of California Cooperative Extension. http://ucce.ucdavis.edu/counties/ceglenn/newsletterfiles/Land_and_Livestock_News956.pdf

Indiana State Board of Animal Health. Dead animal disposal. http://www.in.gov/boah/includes/disposal.html

Iowa Farm-A-Syst. Assessing your dead animal management practices. http://www.ifbf.org/farmasyst/pdf/compost.pdf

Iserson, K.V. (2001). In *Death to dust: what happens to dead bodies?* (2nd ed.). Tucson, Arizona: Galen Press, Ltd.

Kansas Department of Health and Environment, Bureau of Waste Management. (2001a). *Disposal options for large quantities of dead animals.* Topeka, Kansas: KDHE. http://www.kdhe.state.ks.us/waste/guidance/sw01-01.pdf

Kansas Department of Health and Environment, Bureau of Waste Management. (2001b). *Disposal options for small quantities of dead animals.* Topeka, Kansas: KDHE. http://www.kdhe.state.ks.us/waste/guidance/sw94-01.pdf

Kay, R.M. (2000). Practical problems of carcass disposal. *The Pig Journal, 46,* 95-103.

Lane, J. (2003). Carcass disposal emergency planning. Kansas City, Missouri: Midwest Regional Carcass Disposal Conference.

Lei, J.C. (1985). Can virus from buried animals with foot and mouth disease constitute a pollution hazard in ground water? An evaluation. *Dansk Veterinaertidsskrift, 68* (24), 1263-1274.

Loupe, D.E. (1990). To rot or not. *Science News, 138* (14), 218-219, 223.

Lund, R.D., Kruger, I., & Weldon, P. Options for the mechanised slaughter and disposal of contagious diseased animals - a discussion paper. Proceedings from Conference on Agricultural Engineering, Adelaide.

Mann, R.W., Bass, W.M., & Meadows, L. (1990). Time since death and decomposition of the human body: variables and observations in case and experimental field studies. *Journal of forensic sciences, 35* (1), 103-111.

Martin, E. (2003). Personal communication to A. Nutsch: E. Martin (Glover Construction, Pleasant Hill, NC).

McBean, E.A., Rovers, F.A., & Farquhar, G.J. (1995). *Solid waste landfill engineering and design.* New Jersey, USA: Prentice Hall.

McColl, K.A., Morrissy, C.J., Collins, B.J., & Westbury, H.A. (2002). Persistence of rabbit haemorrhagic disease virus in decomposing rabbit carcasses. *Australian Veterinary Journal, 80* (5), 298-299.

McDaniel, H.A. (1991). Environmental protection during animal disease eradication programmes. *Revue scientifique et technique Office international des Épizooties, 10* (3), 867-884.

Michigan Department of Agriculture, Animal Industry Division. Bodies of dead animals; R 287.652 Disposal of animal carcasses and disposal of residue from burning process of carcasses. http://www.biosecuritycenter.org/midead.htm

Micozzi, M.S. (1986). Experimental study of postmortem change under field conditions: effects of freezing, thawing, and mechanical injury. *Journal of Forensic Sciences, 31* (3), 953-961.

Micozzi, M.S. (1991). *Postmortem change in human and animal remains: a systematic approach.* Springfield, Illinois: Charles C Thomas.

Minnesota Board of Animal Health. (1996). *Best management practices – carcass disposal.* Retrieved December 10, 2002, from http://www.extension.umn.edu/administrative/disasterresponse/bmp96.html

Minnesota Board of Animal Health. (2003). *Carcass disposal.* Retrieved February 21, 2003, from http://www.bah.state.mn.us/animals/carcass%20disposal/carcass_disposal.htm

Mississippi Board of Animal Health. Disposition of carcasses of dead livestock. http://www.biosecuritycenter.org/msdead.htm

Moorhouse, D.G. (1992). On-farm carcase disposal means and methods. *Pig Veterinary Journal, 28,* 84-94.

Morrow, W.M., & Ferket, P.R. (1993). The disposal of dead pigs: a review. *Swine Health and Production, 1* (3), 7-13.

Morrow, W.E.M., & Ferket, P.R. (2001). *Alternative methods for the disposal of swine carcasses* (No. ANS 01-815S). Raleigh, NC: North Carolina State University.

Munro, R. (2001). *Decomposition of farm animals corpses in mass burial sites.*

Myers, L.M. (1998). Impact of poultry mortality pits on ground water quality in Georgia. Proceedings of the One Hundred and Second Annual Meeting of the United States Animal Health Association, Minneapolis, Minnesota (pages 555-562).

NAO. (2002). *The 2001 outbreak of foot and mouth disease.* London: UK National Audit Office.

National Association of State Departments of Agriculture Research Foundation. State environmental laws affecting Kentucky agriculture. http://www.nasda-hq.org/nasda/nasda/Foundation/state/Kentucky.pdf

Natural Environment Research Council. (2001). *Comments on the Royal Society Inquiry into infectious diseases of livestock: call for detailed evidence.*

Nevada Division of Environmental Protection. NRS 571.200 Disposal of carcasses of diseased livestock. http://www.biosecuritycenter.org/nvdead.htm

New Hampshire Department of Environmental Services. (2001). Solid waste environmental fact sheet: Disposal of dead animals. http://www.des.state.nh.us/factsheets/sw/sw-20.htm

North Carolina Department of Agriculture & Consumer Services. *Proper disposal of poultry mortality in North Carolina.* Retrieved January 28, 2003, from http://www.ncagr.com/vet/poultrydisposal.htm

North Carolina Department of Health and Human Services. (2000). *Animal burial guidelines during a declared emergency.* Retrieved November 19, 2002 from http://www.ncagr.com/sart/burial.asp

Northumberland FMD Inquiry Panel. (2002). *Report of the Northumberland foot and mouth inquiry panel.*

Ohio Environmental Protection Agency. (1997). Ohio EPA News Release - carcass disposal. http://www.epa.state.oh.us/pic/nr/1997/septem/anmlcar.html

O'Leary, P., & Walsh, P. (2002). *Landfill continuing education course.* Retrieved January 13, 2004, from http://landfill-ed.wasteage.com/

Ollis, G. (2002). Pre-selecting mass carcass disposal sites. http://www.agric.gov.ab.ca/agdex/400/400_29-3.pdf

Pacheco, A., Mendes, J.M.B., Martins, T., Hassuda, S., & Kimmelmann, A.A. (1991). Cemeteries - A potential risk to groundwater. *Water Science & Technology, 24* (11), 97-104.

Payne, J.A., & King, E.W. (1972). Insect succession and decomposition of pig carcasses in water. *Journal of the Georgia Entomological Society, 7* (3), 153-162.

Pope, C.W. (1991). Poultry production's environmental impact on water quality. *Poultry Science, 70* (5), 1123-1125.

Pounder, D.J. (1995). *Postmortem changes and time of death.* Retrieved August 11, 2003, from http://www.dundee.ac.uk/forensicmedicine/llb/timedeath.htm

Province of Manitoba. (1998). *The environment act: Livestock manure and mortalities management regulation. Section 15: Disposal of mortalities.* Canada: The Queen's Printer for the Province of Manitoba. http://web2.gov.mb.ca/laws/regs/pdf/e125-042.98.pdf

Reinhart, D.R., & Townsend, T.G. (1998). *Landfill bioreactor design and operation.* Boca Raton, Florida: Lewis Publishers.

Ritter, W.F., & Chirnside, A.E.M. (1990). Dead bird disposal and ground-water quality. Proceedings of the 6th International Symposium on Agricultural and Food Processing Wastes, Chicago, Illinois (pages 414-423).

Ritter, W.F., & Chirnside, A.E.M. (1995). Impact of dead bird disposal pits on ground-water quality on the Delmarva Peninsula. *Bioresource Technology, 53,* 105-111.

Riverside County Waste Management Department. (2003, March). Exotic Newcastle Disease 2003 [DVD]. Riverside County, CA.

Riverside County Waste Management Department. *Landfill fees.* Retrieved September 10, 2003, from http://www.rivcowm.org/landfill_fees_02.htm

Rodriguez, W.C. III, & Bass, W.M. (1985). Decomposition of buried bodies and methods that may aid in their location. *Journal of Forensic Sciences, 30* (3), 836-852.

Ryan, J. (1999). Appendix 23 - deciding how to dispose of large numbers of animal carcasses in an environmentally-friendly manner. Research Group of the Standing Technical Committee of EUFMD.

Sander, J.E., Warbington, M.C., & Myers, L.M. (2002). Selected methods of animal carcass disposal. *Journal of the American Veterinary Medical Association, 220* (7), 1003-1005.

Schwager, M., Baas, T.J., Glanville, T.D., Lorimor, J., & Lawrence, J. *Mortality disposal analysis.* Iowa: Iowa State University, Management/Economics. http://www.extension.iastate.edu/ipic/reports/01swinereports/asl-1788.pdf

SCS Engineers. *Bioreactor landfills: An alternative to "dry tombs."* Retrieved January 13, 2004, from http://www.scseng.com/bioreactor.html

Scudamore, J.M., Trevelyan, G.M., Tas, M.V., Varley, E.M., & Hickman, G.A.W. (2002). Carcass disposal: lessons from Great Britain following the foot and mouth disease outbreaks of 2001. *Revue scientifique et technique Office international des Épizooties, 21* (3), 775-787.

Sparks Companies, Inc. (2002). *Livestock mortalities: methods of disposal and their potential costs.* McLean, Virginia: Sparks Companies, Inc.

Spennemann, D.H.R., & Franke, B. (1995). Decomposition of buried human bodies and associated death scene materials on coral atolls in the tropical pacific. *Journal of Forensic Sciences, 40* (3), 356-367.

Spongberg, A.L., & Becks, P.M. (1999). Inorganic soil contamination from cemetery leachate. *Water, Air, and Soil Pollution (2000), 117,* 313-327.

Spongberg, A.L., & Becks, P.M. (2000). Organic contamination in soils associated with cemeteries. *Journal of Soil Contamination, 17,* 313-327.

State of Idaho. *IDAPA 02.04.17 Rules governing dead animal movement and disposal.* Idaho: Idaho Department of Agriculture. http://www2.state.id.us/adm/adminrules/rules/idapa02/0417.pdf

State of Kansas. *K.S.A. 47-1219 (Dead animals) Unlawful disposal; penalty.* Topeka, Kansas: Kansas Animal Health Department. http://www.accesskansas.org/kahd/disposal.html

State of West Virginia. § 19-9-34. Disposal of carcass of diseased animal. http://www.biosecuritycenter.org/wvadead.htm

Talley, B. (2001). Options for carcass disposal in Colorado. http://www.thefencepost.com/article.php?sid=556

Taylor, D.M. (1996). Inactivation studies on BSE agent. *British Food Journal, 98* (11), 36-39.

Taylor, D.M. (2000). Inactivation of transmissible degenerative encephalopathy agents: A review. *The Veterinary Journal, 159* (1), 10-17.

Taylor, D.M. (2001). Issues involving the disposal of TSE infected animals. US Animal Health Association 2001 Proceedings.

The BioScan Group. *Municipal landfills - sources of contamination.* Retrieved September 9, 2003, from http://www.bioscan.ca/water2f.htm

The Royal Society of Edinburgh. (2002). *Inquiry into foot and mouth disease in Scotland.*

Tow Law Council. (2002). Tow Law burial site submission.

Tucker, D.D. (2002). Individuals are exempt from carcass-disposal fees. http://www.pheasantcountry.com/news/Story.cfm?ID=74

Turnbull, P. (2001). Guidelines for the surveillance and control of anthrax in humans and animals, 3rd Edition (Rep. No. WHO/EMC/ZDI/98.6). World Health Organization.

Turner, B., & Wiltshire, P. (1999). Experimental validation of forensic evidence: a study of the decomposition of buried pigs in a heavy clay soil. *Forensic Science International, 101* (2), 113-122.

Ucisik, A.S., & Rushbrook, P. (1998). The impact of cemeteries on the environment and public health, an introductory briefing (Rep. No. EUR/ICP/EHNA 01 04 01(A)). World Health Organization, Regional Office for Europe.

UK DEFRA. (2002a). DEFRA's operations in Throckmorton, 2001.

UK DEFRA. (2002b). Workshop on TSEs in the environment, Nobel House, DEFRA,

UK Department of Health. (2001a). Foot and mouth disease - measures to minimise risk to public health from slaughter and disposal of animals - further guidance.

UK Department of Health. (2001b). Foot and mouth disease: disposal of carcasses. Programme of monitoring for the protection of public health.

UK Department of Health. (2001c). A rapid qualitative assessment of possible risks to public health from current foot & mouth disposal options - main report and annexes.

UK Environment Agency. (2001a). Environment Agency: Submission to Northumberland County Council's Foot and Mouth Disease Inquiry.

UK Environment Agency. (2001b). The environmental impact of the foot and mouth disease outbreak: an interim assessment.

UK Environment Agency. (2001c). Preliminary assessment of carcass disposal sites at Mynydd Eppynt.

UK Environment Agency. (2001d). Summary of the water quality monitoring undertaken at the Epynt burial and burn sites from 1st April to 31st August 2001.

UK Environment Agency. (2002a). Assessing the groundwater pollution potential of cemetery developments.

UK Environment Agency. (2002b). Protocol for the use of licensed landfills for the disposal of animal carcasses during the foot and mouth outbreak. http://www.environment-agency.gov.uk/commondata/105385/126564

UK Environment Agency. (2002c). Summary of the water quality monitoring undertaken at the Epynt burial and burn sites from 1st July 2001 to 31st August 2002.

UK Public Health Laboratory Service. (2001a). Foot and mouth disease: disposal of carcasses. First report on results of monitoring public health.

UK Public Health Laboratory Service. (2001b). Foot and mouth disease: disposal of carcasses. Second report on results of monitoring public health.

UK Public Health Laboratory Service. (2001c). Foot and mouth disease: disposal of carcasses. Third report on results of monitoring public health.

UK Public Health Laboratory Service. Guidance on the monitoring of private water supplies (PWS) that may have been affected by animal burial pits or those potentially affected.

UK SEAC. (2001). *Note of SEAC Working Group on disposal of carcasses of cattle culled for Foot and Mouth Disease (FMD) control (24 May 2001).*

Retrieved December 3, 2002, from http://www.seac.gov.uk/summ_0601a.htm

US EPA. 40 CFR Part 258 – Criteria for municipal solid waste landfills.

US EPA, Office of Solid Waste. (2004). *Recommended interim practices for disposal of potentially contaminated chronic wasting disease carcasses and wastes.* http://www.epa.gov/epaoswer/non-hw/muncpl/land-prac.pdf

US EPA, Office of Solid Waste and Emergency Response. (1995). *Decision-makers' guide to solid waste management* (Vol. 2). Washington, DC: US EPA. http://www.epa.gov/epaoswer/non-hw/muncpl/dmg2/chapter9.pdf; http://www.epa.gov/epaoswer/non-hw/muncpl/dmg2.htm

US EPA, Office of Solid Waste and Emergency Response. (2002). Municipal solid waste in the United States: 2000 facts and figures executive summary (No. EPA530-S-02-001).

USDA, APHIS. (1978). *Eradication of exotic Newcastle disease in southern California 1971-74* (No. APHIS-91-34). USA: United States Department of Agriculture, Animal and Plant Health Inspection Service.

USDA, APHIS. (1980). *Foot and mouth disease – guidelines for eradication*. Hyattsville, MD: United States Department of Agriculture, Animal and Plant Health Inspection Service, Veterinary Services.

USDA, APHIS. (1981). *Hog cholera and its eradication, a review of U.S. experience* (No. APHIS 91-55). USA: United States Department of Agriculture, Animal and Plant Health Inspection Service.

USDA. (2000a). *Part I: Baseline reference of feedlot management practices, 1999* (No. #N327.0500). Fort Collins, Colorado: USDA, APHIS, VS, CEAH, National Animal Health Monitoring System.

USDA. (2000b). *Part II: Reference of 1999 table egg layer management in the US.* Fort Collins, Colorado: USDA, APHIS, VS, CEAH, National Animal Health Monitoring System.

USDA. (2001a). *Part I: Reference of swine health and management in the United States, 2000* (No. #N338.0801). Fort Collins, Colorado: USDA, APHIS, VS, CEAH, National Animal Health Monitoring System.

USDA. (2001b). National emergency response to a highly contagious animal disease: executive summary. http://www.ifbf.org/commodity/New%20Folder/20020327_natlfootandmouthplan.pdf

USDA. (2002a). *Part I: Reference of dairy health and management in the United States, 2002* (No. #N377.1202). Fort Collins, Colorado: USDA, APHIS, VS, CEAH, National Animal Health Monitoring System.

USDA. (2002b). *Part I: Reference of sheep management in the United States, 2001*. Fort Collins, Colorado: USDA, APHIS, VS, CEAH, National Animal Health Monitoring System.

USDA, Natural Resource Conservation Service, Alabama. Emergency disposal of dead animals. http://efotg.nrcs.usda.gov/references/public/AL/al317b.pdf

USDA, Natural Resources Conservation Service, Texas. (2002). *Catastrophic animal mortality management (burial method) technical guidance.* Texas: Texas State Soil and Water Conservation Board. http://tammi.tamu.edu/burialguidance.pdf

Walsh, P., & O'Leary, P. (2002a). Lesson 2: Land disposal of municipal solid waste: protecting health & environment. *Waste Age.*

Walsh, P., & O'Leary, P. (2002b). Lesson 6: Bioreactor landfill design and operation. *Waste Age.*

Widdrington FMD Liaison Committee. Submission to FMD public inquiry.

Winchell, W. (2001). Proper disposal of dead poultry. Canada Plan Service. http://www.cps.gov.on.ca/english/plans/E5000/5702/M-5702L.pdf

Wineland, M.J., & Carter, T.A. (1997). *Proper disposal of dead poultry.* Retrieved November 19, 2002, from http://www.ces.ncsu.edu/depts/poulsci/techinfo/4Pst19.htm

Wisconsin Department of Natural Resources. (2002). An analysis of risks associated with the disposal of deer from Wisconsin in municipal solid waste landfills. http://www.whitetailsunlimited.com/pages/cwd/risk_analysis.pdf

Wisconsin Department of Natural Resources. (2003). *Environmental impact statement on rules to eradicate chronic wasting disease from Wisconsin's free-ranging white-tailed deer herd.* Wisconsin: Wisconsin Department of Natural Resources.

Workman, R. (2002). Ash Moor - briefing; submission to Anderson Inquiry.

Appendix

TABLE A1. Summary of reported criteria for burial site selection.

Jurisdiction/Source	Minimum cover (distance between carcass and natural surface of the ground)	Separation Distances: Between bottom of trench and water table	Separation Distances: From wells, surface water intake structures, public/private drinking water supplies	Separation Distances: From bodies of surface water (i.e. lakes, streams, rivers, etc.)	Separation Distances: Other	Other notes
Recommended guidelines for burial site selection (literature)						
AL (USDA, Natural Resource Conservation Service, Alabama)	2 ft		300 ft up-gradient/ 150 ft down-gradient from any potable source	100 ft		Should be located in suitable soils; soils suitable for sanitary landfill are also suitable for this purpose
CA (Horney, 2002)	4-6 ft	5 ft	100 ft	100 ft	Property Lines: 25 ft Residences: 100 ft Roads, highways, parks, 0.25 mi.	Burial site should be in an area not likely to be disturbed in the near future. Recommend locating on a site of 5-10 acres minimum to allow for proper setbacks and other restrictions.
NE (Henry, Wills, & Bitney, 2001)	4 ft				Production facilities: 100 ft	Discourage use of burial for daily mortalities; consider primarily for occasional or catastrophic losses. Site should consist of deep, fine-textured soils (such as clay and silt) with underlying geology that poses little risk to groundwater.
TX (USDA, Natural Resources Conservation Service, Texas, 2002)	2 ft	2 ft	150 ft private 500 ft public	150 ft	Residences and Property Lines: 50 ft min 200 ft recom.	Do not locate where surface runoff could enter pit Extensive information on soil properties/classes
Canada (Winchell, 2001)	0.6 m (2 ft) min	1 m				Must be in low permeability soils (less than 10-7 cm/sec) Lime may be added to the layer of carcasses before being covered

Alberta, Can (Alberta Agriculture, Food and Rural Development, 2002a)						Extensive information on appropriate soil types. Should not bury on hilly land to reduce surface water contamination potential (slope should be less than 2% [2 m drop for every 100 m]) Difficult to bury in frozen ground – difficult to excavate and to cover mortalities Should not be less than 70-100 m apart Should not use more than ~10% of total land owned for burial per year. Therefore, only use a burial site once every 10 years.
British Columbia, Can (Government of British Columbia, Ministry of Agriculture, Food & Fisheries)	1 m (3 ft)	1.2 m (4 ft)	120 m (400 ft)	30 m (100 ft)		Burial pits should be sized for a max of 700 kg (1,500 lbs) of animals Sites should be staggered throughout the operation
UK/EU (Kay, 2000)	1 m (3 ft)	1 m (3 ft)	250 m (820 ft)	30 m (100 ft) from spring or watercourse	Field drain: 10 m (30 ft)	When first dug, must be free of standing water NOTE: Burial of animal carcasses, except in extraordinary circumstances, has effectively been banned in the EU as of May 2003 (European Parliament, 2002).
Regulatory requirements for burial site selection						
AR (Arkansas Livestock and Poultry Commission, 1993)	2 ft		300 ft from well			Carcasses are not to be buried in a landfill Anthrax carcasses must be covered with 1 inch of lime
GA (Georgia Department of Agriculture)	3 ft	1 ft Max pit depth is 8 ft	100 ft	100 ft		At least 15 ft from edge of any embankment. Must be in soil with moderate or slow permeability. Must not be located in areas with gullies, ravines, dry stream beds, natural/man-made drainage ways, sink holes, etc. Criteria outlined for disposal pits
ID (State of Idaho)	3 ft		300 ft	200 ft	Residences: 300 ft Property Lines: 50 ft Roadways: 100 ft	Sites shall not be located in low-lying areas subject to flooding, or in areas with high water table where seasonal high water level may contact burial pit
IA (Iowa Farm-A-	6 inches immediate;	Can not bury in flood	100 ft private; 200 ft public	100 ft		Soils must be classified as moderately well, well, somewhat excessively, or excessively drained.

Syst)	30 inches final	plains, wetlands, or on shore lines				Max/acre/year: 7 cattle, 44 swine, 73 sheep, 400 poultry, all others 2 animals
KS (State of Kansas)	3 ft					On-site burial of 6 or more animal units requires written approval of landowner and local gov't or zoning authority; approval must be submitted to Kansas Department of Health & Environment.
KY (National Association of State Departments of Agriculture Research Foundation)	4 ft		100 ft	100 ft	Residences & Highways: 100 ft	Burial site must be in a location that does not flood
MI (Michigan Department of Agriculture, Animal Industry Division)	2 ft final		200 ft			Individual graves: Max individual graves/acre = 100 (min 2-1/2 ft apart); total carcass weight/acre = 5 tons Common graves: min 100 ft apart; max carcass weight = 5,000 lbs/acre
MN (Minnesota Board of Animal Health, 2003; Minnesota Board of Animal Health, 1996)	3 ft	5 ft	Do not place near	Do not place near		Most suitable for small amounts of material (e.g. less than 2000-lb./burial pit/acre) Burial not recommended for catastrophic losses due to potential for groundwater pollution Cannot bury where water table is within 10 ft of surface Do not bury in "karst" or sandy areas; do not bury in areas subject to flooding
MS (Mississippi Board of Animal Health)	2 ft				Residences: 300 ft Property Lines: 150 ft	Trench/pit constructed so as not to allow rain water to drain. For large numbers of carcasses, contact Miss DNR for approval
MO (Fulhage, 1994)	6 inches immediate 30 inches final	Lowest elevation of burial pit 6 ft or less below surface of the ground	300 ft	100 ft	Residences: 300 ft Property Lines: 50 ft	Can bury animals on no more than 1 acre or 10% of total property owned (whichever is greater) per year Max loading rates/acre/year: High groundwater risk = 1 bovine, 6 swine, 7 sheep, 70 turkey, 300 poultry Low groundwater risk = 7 cattle, 44 swine, 47 sheep, 400 turkey, 2,000 poultry
NV	3 ft	5 ft (increase	200 ft	300 ft	Dwellings: 200 ft	Must be buried at least 3 ft underground

(Nevada Division of Environmental Protection)		distance in areas w/highly permeable soils)			Neighboring residences: 500 ft Property Lines: 50 ft	Consider covering animals with quicklime to control odors and promote decomposition
NH (New Hampshire Department of Environmental Services, 2001)		4 ft	75 ft	75 ft		Recommended that “quick lime” be applied during burial to reduce odors and promote decomposition
NC (North Carolina Department of Health and Human Services, 2000; North Carolina Department of Agriculture & Consumer Services)	3 ft	3 ft when possible; at least 12 inches	300 ft public well 100 ft other well	300 ft		Burial site cannot include any portion of a waste lagoon or lagoon wall. If burial in a waste disposal spray field, burial site not avail for waste spraying until new crop established Primarily for emergency situations. Not recommended for daily mortalities
OK (Britton)	2.5 ft					Site must have the type of soil that allows for proper drainage.
WV (State of West Virginia)	2 ft		100 ft	100 ft	Residences: 100 ft Roadways: 100 ft	Burial site shall not be subjected to overflow from ponds or streams Carcass shall be covered with quicklime to a depth not less than three inches
Alberta, Can (Alberta Agriculture, Food and Rural Development, 2002b)	1 m (3 ft) compacted soil	1 m (3 ft)	100 m (333 ft)	100 m (333 ft)	Residences: 100 m (333 ft) Livestock facilities: 100 m (333 ft) Primary highway: 300 m (1,000 ft); secondary highway: 100 m (333 ft); any other road: 50 m (150 ft)	Weight of dead animals in a trench may not exceed 2,500 kg (~5,500 lb)
Manitoba, Can (Province of Manitoba, 1998)	1 m (3 ft)		100 m (333 ft)	100 m (333 ft)		Site must be constructed so as to prevent the escape of any decomposition products of the mortalities that cause or may cause pollution of surface water, groundwater, or soil

TABLE A2. Land area or excavation volume required for trench burial.

Jurisdiction/ Source	Total Trench Depth (D)	Carcass Depth	Cover Depth	Trench Width (W)	Trench Length (L)	Est. Area or Volume Required	Carcass Equivalents	Other Notes
Literature								
NC (Wineland & Carter, 1997)						50-55 ft^3 (~2.0 yd^3) per 1,000 broilers or commercial layers 100 ft^3 (3.7 yd^3) per 1,000 turkeys		Note that the volume estimates were based on a disposal pit design, rather than trench burial.
Australia (Atkins & Brightling, 1985)	~3.5 m (11.5 ft)	1.5 m (5 ft)	2.0 m (6.5 ft) to ground level	3-5 m (10-16.5 ft) determined by equipment used	--	1 m^3 (~35 ft^3 or 1.3 yd^3) per 8-10 mature sheep (off-shears)	--	To calculate the necessary pit volume, including an allowance for cover, a value of 0.3 m^3 of excavation per sheep was used.
Australia (Lund, Kruger, & Weldon)	2.6 m (8.5 ft)	--	1 m (3.3 ft)	4 m (13 ft)	6.7 km (~4.2 mi) for 30,000 cattle	30,000 head of cattle requires trench of 70,000 m^3 (2.5 million ft^3, or 92,000 yd^3)	--	Equates to excavation volume of 2.3 m^3 (82 ft^3 or 3 yd^3) per cattle carcass.
N/A (McDaniel, 1991)	9 ft	3 ft	6 ft	7 ft	--	14 ft^2 at bottom of pit for each adult bovine (assuming 3 ft depth, equates to ~42 ft^3 or ~1.2 yd^3 per adult bovine)	1 adult bovine = 5 mature sheep or hogs	For every additional 3 ft of trench depth, the number of carcasses per 14 ft^2 can be doubled. Due to bulky feathers, poultry require more burial space per unit of weight than cattle, hogs, or sheep. Estimate space required for poultry by counting carcasses that fill a space of known volume (i.e. truck).
N/A (Sander, Warbington, & Myers, 2002)	9 ft	--	3-4 ft	7 ft	--	14 ft^2 per mature cow	--	
N/A (Anonymous, 1973)	--	--	--	--	--	Assume 40 lbs of poultry carcasses per 1 ft^3	--	Equates to approximately 1,080 lbs/yd^3.

Regulatory Agencies								
AL (USDA, Natural Resource Conservation Service, Alabama)	8 ft (for deep soils where bedrock not a concern)	1 ft max small animals 1 carcass max large animals	2 ft mounded	--	--	--	--	Max size of burial excavation should be 0.1 acre (~4,400 ft^2) Excavations over 3.5 ft deep should be sloped on sides at least 1.5 (horiz) to 1 (vert)
TX (USDA, Natural Resources Conservation Service, Texas, 2002)	3 ft min 8 ft max	1 ft small animals 1 carcass large animals	2 ft	4 ft	Adequate for mortality	Total mortality weight ÷ 62.4 lb/ft^3 = ~volume of mortality in ft^3 Pit excavation = 2-4 times the mortality volume to allow for voids and fill soil Spreadsheet avail on request	--	Pits 6 ft or greater in depth – perform soil tests to a depth two ft below lowest planned excavation Multiple pits – separate by 3 ft of undisturbed or compacted soil For deep soils, carcasses and soil can be placed in multiple layers up to a total depth of 8 ft 62.4 lb/ft^3 suggests a density of approximately 1,680 lbs/yd^3
APHIS (USDA, 1980)	9 ft or greater	--	--	7 ft or greater	--	14 ft^2 at bottom of pit for each adult bovine	1 adult bovine = 5 mature sheep or hogs	For every additional 3 ft of trench depth, the number of carcasses per 14 ft^2 can be doubled. Trench site should be mounded over and neatly graded. Do not pack the trench – decomposition and gas formation will crack a tightly packed trench causing it to bubble and leak fluids.
APHIS (USDA, 2001a)	--	--	--	--	--	42 ft^3 (~1.2 yd^3) required to bury 1 bovine, 5 pigs, or 5 sheep	--	
Australia (Agriculture and Resource Management Council of Australia and New Zealand, 1996)	~5 m (~16.5 ft)	--	2 m (6.5 ft)	~3 m (~10 ft)	--	1.5 m^3 (~53 ft^3 or ~2 yd^3) per each adult beast or 5 adult sheep	--	Example: Trench 5 m deep x 3 m wide filled with carcasses to within 2.5 m of ground level will accommodate 5 cattle or 25 sheep per linear meter (2.5 x 3 x 1 = 7.5 m^3; 7.5/1.5 = 5 cattle or 25 sheep)
Alberta, Canada (Ollis, 2002)	4-5 m (13-16.5 ft)	--	2 m (6.5 ft)	2 m (6.5 ft)	10 m (33 ft)	31 adult cattle carcasses require trench 4 x 2 x 10 m (DxWxL) (80m^3, 2,800	1 bovine = 5 adult hogs or sheep 1 bovine = 40	

	ft^3, or 105 yd^3 per 31 adult cattle) (~2.6 m^3, 92 ft^3, or 3.5 yd^3 per carcass) 46 adult cattle carcasses require trench 5 x 2 x 10 m (DxWxL)	broiler chickens (market-ready weight)	