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Feasibility Study Report: Management of Swine Lagoons Following African Swine Fever Outbreak

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Disclaimer

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Executive Summary

A particular concern for disease outbreaks at swine operations is the management of waste lagoons that may be acres in size and many feet deep. For example, weather and other occurrences (e.g., natural disasters) have the potential to cause lagoons to overflow and release untreated material to the environment. As a product of collaborative research between the U.S. Environmental Protection Agency's (USEPA's) Office of Research and Development and the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS), this report evaluates options to prevent the spread of African Swine Fever Virus (ASFv) from swine lagoons in the event of a potential outbreak of the disease in the United States.

The information in this report is based on an extensive review of available literature, followed by a meeting with subject matter experts from government, academia, and the pork industry. Potential lagoon management options are evaluated based on potential effectiveness, technical feasibility, environmental and health concerns, and cost considerations. This report also offers recommendations for further research to reduce uncertainties associated with some of the options.

Background

EPA and USDA are working to prepare for a possible ASFv outbreak in the United States. Research efforts include all aspects of preparedness planning and critical response activities including quarantine, depopulation, decontamination, and carcass management. One important aspect of disease response is to prevent the spread of the virus from solid and liquid manure storage infrastructure. The potential for spread of ASFv is high for the large, uncovered manure storage lagoons predominantly used in the southeastern and western states which, because of their large volume and earthen construction, are vulnerable to extreme weather events or other natural disasters. Therefore, this report focuses on lagoon management following an outbreak of ASFv, but several of the biosecurity practices and waste management methods described could apply to other types of manure storage structures.

This report presents a summary of the currently available information on lagoon management practices that could be implemented in response to an ASFv outbreak to prevent the spread of virus. At present, the available literature includes very limited research on methods that could be used during a response to prevent ASFv spread from swine lagoons. Because few relevant field studies are available, there is a limited basis to describe and evaluate how technologies such as thermal and chemical treatment would best be implemented at field scale. However, information is available to describe the potential advantages of various methods that make them worthy of consideration and the limitations that could impede or negate their performance and implementation. While actual cost information is unavailable or uncertain, the types of costs entailed with each method can be characterized for comparison among the methods. In addition, information is provided to aid site-specific planning and decision making, because the best course of action in the event of an outbreak will depend upon factors that may vary by site.

ASFv Persistence in Swine Waste Lagoons

The persistence of ASFv in swine waste lagoons is not reported in the literature, which presents a challenge to the study of the risk of transmission from swine lagoons and effectiveness of potential control measures. Based on the available information, conclusions about ASFv persistence relevant to swine waste lagoon management include the following:

- The persistence of ASFv in swine lagoons is likely to vary substantially between different operations based on several factors, including size of the farm, number of infected animals, type and depth of lagoon, climate, and season.
- Some information on ASFv survival in manure slurry is available from secondary sources, but there is uncertainty involved in applying this limited information to swine lagoons.
- At present, the available scientific information is insufficient to support defensible estimation of how long ASFv will remain infectious in swine lagoons. Thus, onsite monitoring of the viral load, preferably in the different layers of the swine lagoon, would be required to ascertain the initial infectious potential, rate of natural inactivation, and the effectiveness of lagoon management options.
- For this report, a conservative general assumption was used regarding how long ASFv will remain viable in swine lagoons, based on the longest reported survival of ASFv in slurry (i.e., 160 days or 6 months). Survivability of the virus will likely be shorter (around 3 months) if an outbreak occurs during warm months and temperatures measured in the lagoon are regularly >17°C (62.6°F).

Identification and Screening of Management Methods

- The lagoon management methods evaluated in this report were identified from a review of peer-review and grey literature. For example, several government agencies and other researchers have published guidance, recommendations, or reviews of manure management practices relevant to an ASFv outbreak. A meeting with subject matter experts provided further insights, particularly regarding the availability, use, and practicality of potential methods to contain or disinfect ASFv in liquid manure. A brief literature summary is presented for each management method, including available information on its documented use and effectiveness, implementability, and other relevant research. Long-term storage, chemical disinfection, and thermal treatment are the methods recommended most often for inactivation of ASFv in liquid manure. However, the recommendations are not based on documented experience during past outbreaks or comparative field experiments.
- The literature identifies UV treatment and biological treatments as other potential methods for inactivation of viruses in liquid manure or lagoon effluent.
- This report also considered the installation of lagoon covers and raising the height of berms as potential methods to prevent spread of ASFv from lagoons.

Feasibility Analysis of Lagoon Management Methods to Prevent the Spread of ASFv

The report uses information available for each of the management methods to select those for further consideration in the feasibility analysis. Selections were based on screening criteria that address technical effectiveness, implementability, environmental and health concerns, and cost considerations.

- **Long-term storage.** Storage in the lagoon for up to 6 months is likely to be effective and technically feasible for most farms in the event of an ASFv outbreak. However, additional measures may be needed for lagoons that are near their maximum storage capacity when an outbreak occurs. If precipitation or extreme weather events cause a lagoon to reach capacity during long-term storage, excess liquid would need to be pumped out and stored in alternative tanks until the end of the fallow period or disinfected prior to land application.
- **Batch chemical disinfection.** Batch chemical disinfection of lagoon effluent using calcium hydroxide (hydrated lime) would be effective and technically feasible for some farms following an outbreak of ASFv, depending on the volume of effluent that needs to be treated. Treating many batches of effluent may become cost prohibitive for some farms. In addition, there is a need for an alternative storage vessel and mixing equipment to carry out treatment which will be another added expense. The literature reports an effective concentration of hydrated lime to disinfect ASFv in effluent is 1% (w/v) (10 kg/m^3 or 83.4 pounds per 1,000 gallons). Sources generally recommend an exposure period of 4 to 7 days for disinfecting liquid manure through addition of an alkaline reagent, with daily stirring for at least one hour during the exposure period to bring the pH above 11. The use of sodium hydroxide (caustic soda) for disinfection of effluent is less preferable due to its highly corrosive and irritant properties. Potential technical issues with this method include difficulty mixing the chemical into the effluent, long treatment period, formation of solid precipitate and potential for clogging of valves and nozzles, and potential damage to equipment from corrosivity of treated effluent.
- **Thermal treatment.** Experimental data suggest that raising the temperature of lagoon effluent to 65°C [149°F] for 5 minutes would be effective for inactivating ASFv. However, batch heat disinfection is likely to be impractical for most farms during an ASFv outbreak. Use of this method would require high energy or fuel costs to heat batches of liquid waste, as well as the acquisition, installation, and testing of a heating system.
- **UV treatment.** UV treatment of lagoon effluent would likely be an impractical disinfection method for most farms during an ASFv outbreak due to the specialized equipment that would be needed, high energy requirements, and high costs involved. In addition, no experimental information is available to determine the effective dose and length of exposure required for sufficient inactivation of ASFv in lagoon effluent. The effectiveness would be limited by the quantity and size of suspended solids, and a pre-clarification step may be needed prior to treatment.
- **Thermophilic anaerobic digestion (AD).** The limited data suggest that, in an outbreak situation, AD is an effective and feasible method to inactivate ASFv in liquid manure, but this method is feasible only for farms that already have an AD system in place.

- **Aeration.** There are insufficient data available to estimate how long aerobic lagoons will remain infectious following an ASFv outbreak. It would not be technically feasible for most farms to begin aerating an anaerobic lagoon after an outbreak due to how strongly anaerobic those lagoons are. There would be a very high energy requirement to supply the required amount of oxygen. Furthermore, relatively shallow depths and large surface areas are required to maintain aerobic conditions in lagoons.
- **Supplemental structural containment.** Structural containment methods evaluated for this report include lagoon covers and fortified berms. Installing a lagoon cover as a means of diverting precipitation and containing infected waste would not be feasible for most farms in an outbreak situation. In addition, building up the earthen berm of a lagoon could damage the berm and result in berm failure; therefore, this method is also not feasible for most farms in an outbreak situation.
- **Emerging technologies.** Emerging technologies for disinfection of lagoon effluent, such as ozone and cavitation, have insufficient data available to support their use against ASFv as an outbreak response action.

Conclusions and Research Needs

Natural inactivation processes would begin to reduce ASFv levels in swine waste lagoons as soon as infected waste is no longer added. The implementation of management methods other than long-term storage alone would be delayed until required equipment is acquired and installed. Therefore, site-specific project timelines and virus testing data should be used to evaluate the incremental benefit of supplemental storage or treatment options.

To aid site-specific decision-making in the event of an ASFv outbreak, the feasibility study concludes with a detailed table that provides useful information for each management method. Specifically, the table provides important facts about the use and performance of each method (e.g., minimal temperature and time requirements for effective thermal treatment), technical advantages and disadvantages, feasibility findings, and selection factors.

There are several uncertainties associated with the lagoon management methods described in this feasibility study report. Further research on the methods would help reduce uncertainties and could substantially increase the feasibility of different methods for individual farms. Topics that would benefit from further research include:

- Identification of countermeasures to inactivate ASFv in waste prior to reaching lagoons to further minimize risk, including evaluation of effectiveness and potential long-term effects on the lagoon.
- ASFv survival and inactivation rates in different layers of typical swine lagoons.
- How ASFv inactivation rates are affected by waste characteristics including pH, dissolved oxygen, and solids content, as well as ambient temperature and lagoon design (e.g., depth, surface area).
- The performance of chemical disinfection using hydrated lime to treat lagoon effluent and slurry with higher solids content. This research will help to determine how the effective chemical

concentration and exposure period to treat effluent compares to the values reported for slurry treatment.

- The effectiveness of UVC treatment for inactivating ASFv in lagoon effluent with varying levels of turbidity.
- How the proposed management strategies impact the production of biogas at operations designed capture biogas.

1. Introduction and Background

As a product of the collaborative research between the U.S. Environmental Protection Agency's (USEPA's) Office of Research and Development and the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS), this report evaluates options to prevent the spread of African Swine Fever Virus (ASFv) from swine lagoons in the event of a potential outbreak of the disease in the United States. Outbreak response actions at contaminated animal operations include depopulation, decontamination, and other measures to prevent transmission of the disease to unaffected operations. A particular concern for disease outbreaks at swine operations is the management of waste lagoons that may be acres in size and many feet deep. For example, weather and other occurrences (e.g., natural disasters) have the potential to cause lagoons to overflow and release untreated material into the environment.

1.1. Background

African swine fever is a contagious hemorrhagic viral disease that affects domestic and wild members of the pig (Suidae) family. It is one of the most serious threats to pork production systems around the world due to its high lethality, devastating economic consequences, and the lack of available vaccines or effective treatments (USDA, 2020; FAO, 2017). The causative agent, African swine fever virus (ASFv), is an enveloped nucleocytoplasmic large DNA virus (NCLDV) and only member of the *Asfarviridae* family (Mönttinen et al., 2021). It shares similar structural features and genomic replication strategy with other NCLDV's including *Poxviridae*, *Iridoviridae*, and *Phycodnaviridae* (GARA, 2018). African wild suid species, including warthogs, bushpigs, and the giant forest hog, are the natural hosts for ASFv, and soft ticks of the genus *Ornithodoros* are the only known natural arthropod hosts of the virus and enable the persistence of ASFv transmission within a sylvatic cycle among these suid species. *Ornithodoros* spp. may serve as a source of infection in domestic pigs in Africa and Southern Europe (OIE, 2019). Domestic pigs, feral pigs, and wild boar are all susceptible to the virus, but there is no evidence that ASFv infects humans (Spickler, 2019).

ASFv can be transmitted by direct or indirect contact with infected animals, their wastes, or other bodily fluids, by ingestion of contaminated feed, pork, or pork by-products, through the bites of soft ticks (*Ornithodoros* spp.) that act as reservoirs and vectors of the disease, or by contact with contaminated fomites (e.g., clothing, footwear, vehicles, equipment, bedding) (USDA, 2020). In addition, it is possible that ASFv could be spread mechanically by hard ticks, mosquitoes, or blood-feeding flies (Mazur-Panasiuk et al., 2019; Olesen et al., 2018a). Moreover, a recent study demonstrated infection of pigs following ingestion of stable flies that were fed ASFv-infected blood (Olesen et al., 2018b). Clinical presentation of the disease varies by viral strain, ranging from peracute death, characterized by high fever and hemorrhagic signs, including subclinical or low-level disease, to chronic disease characterized by emaciation (Gaudreault et al., 2020; Spickler, 2019). Some exposed animals may produce antibodies (i.e., seroconvert) without showing symptoms (Spickler, 2019). Infected animals will shed ASFv in oronasal fluids, urine, feces, and blood just before and throughout the period of clinical signs (Neumann et al., 2021). Davies et al. (2017) detected ASFv DNA in urine the day before onset of fever and infectious ASFv in feces and urine from the first day of fever. Experimental studies have demonstrated a very low infectious dose of ASFv via the oro-nasal route, especially among young pigs (Wales and Davies, 2021).

Today, ASFv is endemic in sub-Saharan Africa, parts of west Africa, and Sardinia. It is currently spreading in parts of Southern and Eastern Europe, Russia, China, and Southeast Asia (SHIC, 2022), and has recently been detected in the Dominican Republic and Haiti (USDA, 2021b). ASFv has never been reported in the United States, but international trade and illegal entry of swine products and by-products pose a potential threat of ASFv entry into the United States (USDA, 2020).

EPA and USDA are working to prepare for a possible ASFv outbreak in the United States. Research efforts include all aspects of preparedness planning and critical response activities including quarantine, depopulation, decontamination, and carcass management. One important aspect of disease response is to prevent the spread of the virus from solid and liquid manure storage infrastructure. The potential for spread of ASFv from these structures is high for the large, uncovered lagoons predominantly used in the southeastern and western states which, because of their large volume and earthen construction, are vulnerable to extreme weather events or other natural disasters. Therefore, this report focuses on lagoon management following an outbreak of ASFv, but several of the biosecurity practices and waste management methods described in this report could apply to other types of manure storage structures.

This report presents a summary of the currently available information on lagoon management practices that could be implemented in response to an ASFv outbreak to prevent the spread of the virus. It provides information to inform decisions for selecting site-specific management practices, because the best course of action will depend upon several factors that may vary by site. Additionally, this report offers recommendations for further research to reduce uncertainties associated with some of the options.

1.2. Liquid Manure Storage Systems

Liquid animal manure is a mixture of feces, urine, feed and supplements, wash water, and rainwater. Manure in liquid form is commonly stored in under-floor storage pits, above-ground tanks, settling basins, holding ponds, or lagoons before being applied to agricultural land (USEPA, 2013; VanDevender, 2003). In-house pits and above-ground tanks are often constructed of concrete while settling basins, holding ponds, and lagoons are earthen structures that may be lined with clay, geosynthetic plastic, or concrete (Chastain and Henry, 2002). Liquid manure stored in pits and tanks is commonly referred to as slurry, and it has a thick consistency with solids content ranging between 2 and 15 percent. Liquid manure stored in ponds or lagoons is more dilute than slurry, with much lower solids content at the surface (0.3 to 0.6 percent) and sludge accumulation at the bottom (Sharara, 2020).

Liquid manure storage structures are designed and managed to allow operators to store manure during times when land application is not possible and to ensure there is adequate capacity available to prevent spills and over-topping during times of heavy precipitation (USEPA, 2013). The size and type of liquid manure storage structure at a farm will depend on many factors including the climate, type of animal production system, area limitations, local and state regulations, and costs (USEPA, 2013). The storage period for liquid manure varies at different operations based upon the type of structure and the utilization schedule. Manure storage structures in warm climates are often designed to store from 120 to 180 days worth of liquid manure, while those in cold climates are more commonly designed for a 1-year capacity (USDA, 2019b). Treatment lagoons have both a liquid storage volume and a solids storage volume, with solids being removed much less frequently (VanDevender, 2003).

Animal manure contains three types of bacteria: aerobic, anaerobic, and facultative (which can survive in both aerobic and anaerobic conditions). All three types can decompose the organic matter in manure (Chastain and Henry, 2002). Most operations in the U.S. store liquid manure in oxygen-free conditions, which encourages the growth of anaerobic bacteria; however, some lagoons are aerated to encourage the growth of aerobic bacteria (LPELC, 2019; Chastain and Henry, 2002). Treatment lagoons are designed and managed to maximize the digestion of organic matter into smaller components (VanDevender, 2003).

Anaerobic lagoons receive urine, manure, flush water, rainwater and other waste from the barns (VanDevender, 2003). They are separated into two distinct zones: the sludge accumulation zone at the bottom, and the liquid zone above the sludge (Sharara, 2020). Manure and other substances are digested by microorganisms in the liquid layer and the treated solids accumulate at the bottom in a layer called sludge. The sludge contains settled manure solids, nonorganic material from manure, microbial cells, and other debris that entered the manure collection system (Sharara, 2020). Lagoon management includes monitoring the depth of the sludge layer, and when it becomes too deep, sludge must be removed (Sharara, 2020). This is accomplished either by dredging or by agitating the bottom of the lagoon and pumping out the suspended sludge mixture.

The liquid zone of an anaerobic lagoon separates into two layers. The layer near the surface is referred to as the temporary liquid storage zone. The liquid in this zone is low in solids (typically 0.3 to 0.6 percent solids) and is called supernatant or effluent (Sharara, 2020). This liquid is easily pumped out and is typically applied to agricultural land. The layer below the storage zone is referred to as the permanent liquid treatment zone. This is a transitional zone (typically 5 to 10 percent solids) where most of the digestion occurs (Sharara, 2020). This liquid is typically not pumped out but may be disturbed during sludge removal.

Anaerobic treatment lagoons can substantially reduce pathogenic bacteria and virus concentrations in liquid manure, but the rate of reduction is inconsistent and varies depending on climate and temperature (Sobsey, 2006). Furthermore, the bottom sludge layer can serve as a reservoir for pathogens (USEPA, 2013).

1.3. Persistence of ASFv in the Environment

ASFv is stable under a wide range of environmental conditions, which contributes to its spread and transmission (Gaudreault et al., 2020). Cool, moist, and protein-rich environments enable survival of the virus, while exposure to heat, ultraviolent (UV) radiation from sunlight, and drying reduce its survival

(Blome et al., 2020; Bellini et al., 2016). It can survive many freeze-thaw cycles but is rapidly inactivated at high temperatures (>56˚C [132.8˚F]) (Mazur-Panasiuk et al., 2019; OIE, 2019). The virus is stable over a pH range of 4 to 10 (Penrith et al., 2009), and is generally rapidly inactivated at pH <4 or >11.5 in serum-free medium; however, in the presence of serum, it can survive below pH 4 for hours and at pH 13.4 for days (Wales and Davies, 2021).

ASFv remains viable for long periods of time in blood, tissues, and feces (USDA, 2020; Mazur-Panasiuk et al., 2019). In experimental studies, ASFv DNA was detected for up to 98 days in feces and 126 days in urine at various temperatures even though infectious ASFv was only detected for up to 5 days (Davies et al., 2017). Based on half-life calculations, the authors estimated that feces will remain infectious for 3.7 days at 37°C (98.6°F) to 8.5 days at 4°C (39.2°F), and urine will remain infectious for 2.9 days at 37°C (98.6°F) to 15.3 days at 4°C (39.2°F).

In soil, pH, organic matter, and temperature contribute to wide variability in how long ASFv will remain viable (Wales and Davies, 2021). Carlson et al. (2020) investigated different soil matrices spiked with ASFv-positive blood from wild boar and stored at 25˚C (77°F) up to three weeks and found that infectious ASFv was detected for 3 weeks in sterile sand, two weeks in beach sand, one week in yard soil (pH 6.7 at 4˚C [39.2°F] or 25˚C [77°F]), and three days in swamp mud. Meanwhile, no infectious virus was detected in acidic forest soils (pH 3.2 or 4.1) at any time point. Despite the decline in infectious ASFv that was observed in all soils, ASFv DNA was still detectable, with no clear decline in all soil types throughout the observation period.

No studies were identified that measured persistence of ASFv in soil after application of infected slurry or lagoon effluent onto agricultural land.

1.4. Persistence of ASFv in Swine Waste Lagoons

The persistence of ASFv in swine waste lagoons is not reported in the literature. No on-farm studies were identified through a comprehensive literature search; however, some information on ASFv survival in manure slurry is available from secondary sources.

Haas et al. (1995) reported unpublished findings by Eizenberger et al., who assessed persistence of ASFv in pig slurry (solids content not reported) and found that infectious virus was detected for up to 84 days at 17°C (62.6°F) and 112 days at 4°C (39.2°F) under simulated field conditions. Several other sources report that ASFv may remain infectious in pig slurry for up to 60-100 days (Haas et al., 1995) or 60-160 days (Marszałek et al., 2019; EFSA AHAW Panel, 2014; Strauch, 1991). Unfortunately, none of these sources provide details on the experimental conditions (e.g., temperature, pH, solids content) that were used to derive these estimates.

The limited information available on ASFv survival in lagoons and liquid manure in general presents a challenge to the study of the risk of transmission from swine lagoons and effectiveness of potential control measures. In general, the length of time that swine lagoons will remain infectious after a viral disease outbreak is highly variable and will depend on many different factors, but it should be considered on the scale of days to months (Tun et al., 2016265). Ramirez and Zaabel (2012) report that porcine reproductive and respiratory syndrome virus (PRRSv) can survive in swine lagoons for up to 14 days at 4˚C (39.2°F), while influenza A virus (IAv) can survive at similar temperatures for up to nine weeks. A recent study in Canada found that porcine epidemic diarrhea virus (PEDv) could survive for up to 9 months in two earthen manure storage structures with ambient temperatures ranging between -30 to 23˚C (-22 to 73.4°F) (Tun et al., 2016265). The results showed that viral load was higher in the top layer during the first 3 weeks after an outbreak, but the trend was reversed toward the end of the 9-month sampling period when viral load was higher in the bottom layer. At that time, viral load in the top layer of the lagoon was very low. To help understand whether PEDv remained infectious in the lagoons, the authors also measured viral replicability in cell culture, which reflects the infectivity. In one lagoon, PEDv was detected in the top, middle, and bottom layers after 5 to 7 weeks, but infectivity was only detected in the middle and bottom layers. No other timepoints were studied. In the other lagoon, PEDv in the top and bottom layers remained potentially infective after 2 to 4 weeks, but only the bottom layer remained potentially infective after 7 to 9 months with a low viral titer observed.

In general, the survival of viruses in liquid manure is dependent on many factors including the initial viral burden, physical condition of the virus (e.g., encapsulation, aggregation, association with suspended solids), temperature, pH, microbial activity, free ammonia concentration, UV radiation, and possibly added detergents and disinfectants (Štukelj et al., 2021; Sobsey, 2006; Haas et al., 1995; Pesaro et al., 1995). For example, non-enveloped viruses are typically more persistent in the environment than enveloped viruses because the viral envelope's lipid membrane is susceptible to environmental stresses (Silverman and Boehm, 2021). Furthermore, viral particles that are adsorbed or embedded within suspended solids in liquid manure may be protected from inactivation (Sobsey, 2006; Pesaro et al., 1995). Virus survival in liquid manure is substantially longer at colder temperatures (Haas et al., 1995), and higher pH is strongly linked with the rate of viral inactivation (Pesaro et al., 1995). A possible explanation is that ammonium (NH_4^+) is converted to virucidal ammonia (NH_3) at pH >8 (Sobsey, 2006; Pesaro et al., 1995). Importantly, the rate of inactivation of viruses in liquid manure may not necessarily follow first order kinetics (Haas et al., 1995).

At present, the available scientific information is insufficient to support defensible estimation of how long ASFv will remain infectious in swine lagoons. Thus, onsite monitoring of the viral load, preferably in the different layers of the swine lagoon, would be required to ascertain the initial infectious potential, rate of natural inactivation (which may not remain constant), and the effectiveness of lagoon management options. In the absence of on-site testing, decisions about when a lagoon may be returned to service should be made with the support of the authorities involved in disease response. These decisions should be compatible with the overall disease response plan for the site and site-specific factors (e.g., region, season, berm integrity, capacity level, proximity to surface waters or neighboring farms) that may affect viral survival or the potential for the spread in the event of a release. In addition, a conservative general assumption can be based on the longest reported survival of ASFv in slurry (i.e., 160 days or 6 months). Survivability of the virus will likely be shorter (around 3 months) if an outbreak occurs during warm months and temperatures measured in the lagoon are regularly >17°C (62.6°F). These estimates are most appropriate for the upper layer of a lagoon as even less is known about how long ASFv will persist in the middle and bottom layers.

1.5. Biosecurity Considerations for Manure Storages and Lagoons

ASFv is shed in feces and urine beginning from the onset of disease symptoms (Davies et al., 2017). Therefore, all forms of manure are potentially infectious. Because the ASFv load and persistence may be different in the forms of manure, decisions regarding manure management should consider the forms of the waste present. In addition, decisions regarding manure management will need to be made during and after an ASFv outbreak. Solid manure that is infected with ASFv may be composted, burned, or buried (USDA, 2018). However, most U.S. swine operations store manure in a liquid form (USDA, 2011). In regions where wild boar and feral pigs are present, land application of contaminated manure, effluent, or slurry could spread the disease to these animals who in turn may spread the disease to domesticated pigs in the area (Bellini et al., 2016). In addition, liquid manure pumping services could accidentally spread the virus to other operations (USDA, 2011).

Once an ASFv outbreak is identified, it will be necessary to isolate the liquid manure storage structure or lagoon to prevent spread of the disease. For areas of with known wild boar population, this may include installation of adequate boar-proof fencing around the entire lagoon or manure storage structure. The lagoon will be fallowed, and no material should be removed until authorities determine it is safe to resume normal operation. The length of the fallow period may vary from farm to farm and will overlap with the carcass composting period that must occur following an ASFv outbreak.

The persistence of ASFv in a liquid manure storage structure or lagoon is likely to vary substantially between different operations based on several factors including size of the farm, number of infected animals, type and depth of storage structure, climate, and season. Frequent sampling and testing of material from different depths of the storage structure or lagoon is ideal but may not always be possible. Polymerase chain reaction (PCR) analysis detects genetic material of a virus but does not measure the ability of the material to infect cells (viability). Therefore, a sample that is PCR positive for ASFv may or may not cause infection in animals. On the other hand, viral titer measured in cell culture is a direct measure of infectivity of a sample.

As soon as an outbreak occurs, there may be an opportunity to reduce the amount of virus that is transferred to the storage structure or lagoon by stopping the flow of waste and disinfecting the waste prior to transfer. In addition, disinfection procedures in the barn may introduce chemicals, such as lime or formalin, into waste stored beneath the barn, which could provide some disinfection and opportunistically reduce the amount of virus that ultimately reaches the storage structure or lagoon. However, the incidental addition of chemicals into a treatment lagoon may also reduce the population of beneficial microorganisms that digest organic waste. This could have negative long-term consequences for the lagoon.

If an infected manure storage structure or lagoon is covered with an impermeable cover, precipitation would be excluded during a fallow period, and there should be no danger of overflow. However, if the structure is uncovered, there is a possibility that precipitation during the fallow period may result in a release from the storage structure. If an uncovered and fallowed lagoon is nearing capacity and at risk of overflow (e.g., due to precipitation), it may be necessary to remove effluent to provide adequate capacity. For example, effluent can be pumped into an alternative storage structure. In those cases, good biosecurity practices will help prevent spreading the virus, such as disinfection of all manure handling equipment, clothing, and footwear worn by farm personnel involved in transferring the waste. The material could either be stored until destruction of the virus occurs through natural processes or decontamination before it is spread on agricultural land. These methods are discussed further in Section 3.

2. Research Methods

Information for this feasibility study was gathered through two processes: a systematic literature review and a meeting with industry experts. A detailed description of the literature review and search strategy can be found in Appendix A. In short, the literature review consisted of targeted searches designed to capture the latest scientific information on ASFv and management of swine waste lagoons during and after a viral disease outbreak from both peer-reviewed and gray literature sources, followed by a screening process to identify the key sources and tag them to several topic areas (e.g., ASFv persistence) and categories of interest (e.g., field research studies). Literature database searches captured publications through February 2021, and additional sources were identified from citations in key sources and the expert meeting. For the full list of databases searched and further information on the screening procedures, see Appendix A.

The expert meeting was conducted to supplement the information gathered during the literature review and specifically aimed to gain expert opinions on the operational and practical aspects of various lagoon management options. The interview was held virtually on February 10th, 2022, with nine participants representing academia, farming, agricultural operations consulting, trade associations, and state agricultural, environmental, and biodefense agencies. Experts were asked a series of questions regarding the feasibility of various swine lagoon management practices, which were provided before the meeting. There were five general questions about swine lagoon management measures overall and their use and practicality, followed by a series of questions for each of five potential management categories: lagoon covers, raising the berm height, chemical treatment, thermal treatment, and "other" methods. The experts were asked to discuss the extent to which each option is used and any operational, financial, or permitting considerations that would be relevant to their potential use to prevent the spread of ASFv in the event of an outbreak.

3. Description of Lagoon Management Methods and Screening their Potential use following ASFv Outbreak

This section describes the lagoon management methods that were identified from the literature search and expert meeting and describes the screening of different options based on feasibility criteria. As discussed in Section 1.1., concern for spread of ASFv is especially high for the large, uncovered swine lagoons predominantly used in the southeastern and western states. Therefore, the information presented in this section focuses on the management of these lagoons following an outbreak of ASFv. However, several of the management methods described in this section could apply to liquid manure stored in other ways, such as slurry stored in above-ground tanks or deep pits.

The literature search identified publications by several government agencies and other authors that provided guidance or reviews of manure management and other practices relevant to an ASFv outbreak (Iacolina et al., 2021; De Lorenzi et al., 2020; Juszkiewicz et al., 2019; USDA, 2019; GARA, 2018; Council of the European Union, 2002; FAO, 2001); however, none of these publications contain guidance specific to swine waste lagoons. Instead, methods are reported for solid manure, liquid manure in general, and slurry stored in tanks or pits. Long-term storage, chemical disinfection, and thermal treatment are the methods recommended most often for inactivation of ASFv in liquid manure or slurry. These recommendations tend to be based on few, if any, cited sources and generally do not address the range of environmental and other conditions that may be present at actual farms affected by an outbreak. A 2002 EU Council Directive states that slurry infected with ASFv must be stored for at least 60 days after the last addition of infective material, unless authorities authorize a reduced storage period for slurry that has been effectively treated to ensure destruction of the virus (Council of the European Union, 2002). Although not specific to ASFv, USDA's Foreign Animal Disease Preparedness and Response Plan (USDA, 2018) states that slurry should generally be stored for at least 60 days in summer or 90 days in winter before being spread on a pasture to render pathogens inactive.

The literature search also found several reviews that discuss the stability of animal viruses in liquid manure in general and the effects of various management methods on the inactivation of viruses (Bilotta and Kunz, 2013; Martens and Böhm, 2009; Sobsey, 2006; Bicudo and Goyal, 2003; Turner and Burton, 1997; Haas et al., 1995). The methods reported as effective for virus inactivation in liquid manure include long-term storage, chemical methods, physical methods (e.g., UV irradiation, heat), and biological methods (e.g., anaerobic digestion, aerobic treatment). All of these methods were investigated further to determine their effectiveness at inactivating ASFv and technical feasibility during an outbreak situation. Supplemental structural containment methods, including installing a cover or building up the earthen berm, were also considered as potential lagoon management methods for farms dealing with an ASFv outbreak.

The following sections summarize the information obtained from the literature search and expert interviews for each of the options identified. In addition, each of the options is screened using the feasibility criteria listed below.

1. Availability of technical data that support the effectiveness of the option at preventing the spread of ASFv from swine waste lagoons.
2. Technical feasibility of the option, such that the option can be implemented at a typical U.S. swine operation.
3. The option does not raise serious environmental or public health concerns.
4. The option does not impose prohibitive costs or costs that are not justified by superior environmental or public health benefits or reliability.

As discussed, some options were screened from further consideration based on these criteria.

3.1. Long-Term Storage

Outside of host cells, viruses are inactivated over time due to exposure to unfavorable environmental conditions (e.g., heat, extreme pH, enzymes, microbial predation) (Sobsey, 2006). For this reason, storage of animal wastes is considered one approach capable of reducing virus levels (Sobsey and Hill, 2008). In the event of an ASFv outbreak, long-term storage would be implemented by simply discontinuing the addition or removal of waste to or from the lagoon for a period of time until the waste becomes non-infectious. Removing a lagoon from use for such a period is sometimes referred to as fallowing the lagoon.

Effectiveness

As discussed in Section 1.2, reductions of virus levels in anaerobic lagoons can be substantial, but the rate of inactivation is not consistent (Sobsey, 2006). Inactivation of viruses in liquid manure is highly dependent on factors such as temperature, pH, ammonia concentration, initial concentration of virus, physical conditions of the virus, and microbial activity (Haas et al., 1995). Additionally, rate of inactivation of viruses in liquid manure may not necessarily follow first order kinetics (Haas et al., 1995).

Data on ASFv persistence in pig slurry at typical ambient temperatures support the idea that long-term storage in the lagoon will reduce the level of infectious ASFv (Haas et al., 1995). However, as described in Section 1.4, currently available data are insufficient to predict with certainty how long ASFv will persist and remain infectious in different layers of a swine lagoon. No on-farm studies were identified that evaluated the persistence of ASFv in swine lagoons. A conservative general assumption can be based on the longest reported survival of ASFv in slurry (i.e., 160 days or 6 months). Survivability of the virus will likely be shorter (around 3 months) if an outbreak occurs during warm months and temperatures measured in the lagoon are regularly >17°C (62.6°F). These estimates are most appropriate for the upper layer of a lagoon as even less is known about how long ASFv will persist in the middle and bottom layers.

Technical Feasibility

Long-term storage would be technically feasible for most farms except in situations when the lagoon is near capacity when an outbreak occurs, and normal precipitation or extreme weather events may cause a lagoon to overflow during the fallow period. In those cases, some other action would be required to prevent overflow and the release of infectious material to the environment. One possible action would be to pump out excess liquid as needed to maintain storage capacity and store the liquid in tanks (e.g., Baker Tanks) until the end of the fallow period. The feasibility of that action will depend on the availability and cost of renting tanks or other storage vessels.

The advantages of using long-term storage for inactivation of ASFv over other possible methods include that it requires no additional inputs, equipment, or other expenses to implement (unless alternative storage tanks are needed). If a farm has the capability to test for ASFv levels in the lagoon (in particular, the amount of infectious ASFv present), testing can be performed at several timepoints to determine when liquid can be safely removed from the lagoon.

The variability and uncertainty in the rate of virus inactivation in the lagoon and the threat of overflow are the main problems associated with this management method. Other problems associated with fallowing a lagoon include decreased levels of beneficial bacteria, rate of decomposition, and nutrient content. Importantly, the farm cannot be repopulated while the lagoon is fallowed, which may result in more economic hardship for a farm after an outbreak.

Environmental and Health Concerns

There are no significant environmental or health concerns associated with long-term storage.

Cost Considerations

For farms that do not need to remove excess liquid during the fallow period, the most substantial costs involved with long-term storage would be loss of revenue because the farm cannot be repopulated while the lagoon is fallowed. However, for farms that must pump out excess liquid during the fallow period to prevent overflow, expenses will also include renting alternative storage tanks for up to 6 months.

Summary

Long-term storage in the lagoon for up to 6 months is likely to be feasible for most farms in the event of an ASFv outbreak. However, for lagoons that are near capacity when an outbreak occurs, there would be more expenses involved as excess liquid would need to be pumped out and stored in alternative tanks until the end of the fallow period or disinfected prior to land application. The length of time that a lagoon will remain infectious is unknown due to lack of scientific data on the topic, and it will likely vary substantially for different farms based on local climate and many other factors. Six months is a conservative general assumption based on data reported for slurry. Frequent testing of samples from the lagoon to determine the amount of infectious ASFv that is present will provide a more accurate determination for when liquid can safely be removed from the lagoon for disposal or land application.

3.2. Batch Chemical Disinfection of Lagoon Effluent

Agricultural animal wastes are not usually treated by chemical disinfection in the United States (Sobsey and Hill, 2008). Furthermore, disinfection of an entire lagoon is typically not a practical option due to technical difficulties and health concerns. For example, the addition of chemicals to large open surfaces such as lagoons might result in hazardous gaseous emissions (Turner and Burton, 1997). However, there is evidence from the literature that chemical treatment of lagoon effluent or slurry is a recommended option in the event of an animal disease outbreak. For example, the Nebraska Department of Agriculture's Livestock Disease Emergency Monograph No. 2 states that chemical treatment in a lagoon or other liquid manure storage structure is generally not a practical option, and the recommended course of action is to isolate the lagoon, allowing for the destruction of the pathogen over time; however, if liquid or slurry is pumped into an alternative storage structure to prevent overflow, it may be treated with an organic acid or alkaline reagent to adjust the pH to less than 3 or greater than 11 (NDA, 2013).

Effectiveness

A couple of laboratory studies were identified that evaluated the effectiveness of chemical disinfection of ASFv in slurry, but no studies were identified specifically for lagoon effluent. Turner et al. (1999) performed a series of experiments to determine the effectiveness of sodium and calcium hydroxide at disinfecting pig slurry (with 2.3% solids content) that was seeded with ASFv. The authors found that 1.0% weight/volume (w/v) of either chemical resulted in inactivation of the virus to below detectable levels within 150 seconds at 4°C (39.2°F). Lower concentrations were tested for longer exposure durations, and 0.5% (w/v) of either chemical was effective at inactivating ASFv within 30 minutes at 4°C (39.2°F) and 22°C (71.6°F). The Russian Academy of Agricultural Sciences tested the effectiveness of four different disinfectants in pig slurry and found that 2% solutions of Triosept-Endo (Russia), Biodez Extra DVU (Russia), Teotropine-P (Russian National Research Institute of Veterinary Virology and Microbiology) and Chloramine B (Russia) inactivated ASFv in slurry (with 1.9% solids content) within 6 hours at 18°C (64.4°F) (RAAS, 2014).

Chemical treatments recommended most frequently in reviews and guidance documents for inactivation of ASFv in effluent or slurry are alkalis, including sodium hydroxide (caustic soda), calcium hydroxide (hydrated lime), and sodium carbonate (washing soda) (Štukelj et al., 2021; De Lorenzi et al., 2020; USDA, 2019; GARA, 2018; AHA, 2008; FAO, 2001). A final concentration of 1% sodium or calcium hydroxide in liquid manure is commonly recommended for rapid inactivation of ASFv, based on the results of Turner and Williams (1999). The effective concentration of sodium carbonate in liquid manure was not identified. One review by the Global African Swine Fever Research Alliance reports that 1% sulfuric acid, 4% formic acid, 1% formaldehyde, 3% sodium dodecyl sulfate, or 1% glutaraldehyde could be used to inactive ASFv in liquid manure, with a recommended exposure time of 1 week (GARA, 2018). However, in general, inorganic acids are rarely used for treatment of liquid manure because of their corrosivity, and the protein content of liquid manure greatly reduces the effectiveness of organic acids (Haas et al., 1995). Aldehydes are less corrosive than acids, but their effectiveness in liquid manure is dependent on temperature (Haas et al., 1995). In addition, the use of formaldehyde is limited by its toxicity (Štukelj et al., 2021).

The limited available information indicates that chemical treatments can be considered an effective option for inactivating ASFv in batches of effluent or slurry; however, the data come from laboratory studies conducted using very small volumes of slurry that were artificially seeded with the virus. No studies were identified that evaluated the effectiveness of chemical disinfection of lagoon effluent during an ASFv outbreak. Several different chemicals may be effective against ASFv in effluent; however, calcium and sodium hydroxide are recommended most frequently in the literature for inactivation of ASFv in liquid manure and have published data on their effectiveness.

Technical feasibility

If infectious effluent needs to be removed from a lagoon, disinfection with an appropriate chemical would be technically feasible for some farms if the necessary equipment is available. Treatment is recommended to take place in an alternative storage tank or a slurry tank spreader (Stevens et al., 2018), and equipment for mixing will be needed because effectiveness depends on chemical disinfectants being thoroughly dissolved and evenly distributed in the effluent (Turner and Burton, 1997; Haas et al., 1995). The best chemical for treatment may vary by farm, but will be based on proven effectiveness against ASFv, availability, and safety concerns. Hydrated lime is commonly used on farms to modify soil pH and stabilize biosolids, and has been shown to be effective against ASFv and other swine viruses in pig slurry (Stevens et al., 2018; Turner and Williams, 1999). Since it is readily available to agricultural operations, it may be the best option for disinfecting lagoon effluent on most farms experiencing an outbreak of ASFv. Sodium hydroxide (caustic soda) has also been shown to be effective (Turner and Williams, 1999), and some sources report it is the strongest virucidal agent for inactivating ASFv in liquid manure (Štukelj et al., 2021; De Lorenzi et al., 2020); however, it is highly corrosive and poses a significant safety concern for workers (see below).

Technical considerations that may need to be addressed for chemical treatment of lagoon effluent include determining the proper dose and length of exposure needed, ensuring adequate distribution and mixing of the chemical in the effluent, managing precipitation of solids, and the potential for readjusting pH closer to neutral once treatment is complete.

Turner and Williams (1999) found that the effective dose of sodium or calcium hydroxide for inactivation of ASFv in pig slurry (with 2.3% solids) was 1% (w/v) (10 kg/m^3) within 5 minutes at 4°C (39.2°F). That dosing rate corresponds to 83.4 pounds of chemical per 1,000 gallons of effluent or slurry. The laboratory experiments demonstrated that inactivation of ASFv occurred when the pH of slurry was raised above 10.6 (Turner and Williams, 1999). Other sources generally recommend that addition of alkaline agents should raise the pH of liquid manure above 11 to inactivate most viruses (Sobsey, 2006). Rapid inactivation (within 5 minutes) was demonstrated in small volumes of slurry in the laboratory; however, there is some uncertainty regarding the recommended exposure period for liming large volumes of effluent. Sources generally recommend an exposure period of 4 to 7 days for disinfecting liquid manure through addition of an alkaline reagent, with daily stirring for at least one hour during the exposure period (USDA, 2018; Martens and Böhm, 2009; FAO, 2001); however, the time needed to achieve complete disinfection of lagoon effluent may be much less than what is needed for slurry due to the lower solids content of effluent (typically 0.5% solids compared to 6-8% solids in slurry). Material with lower solids content will be easier to mix and distribute the chemical throughout.

One potential issue with chemical disinfection is that adding lime to liquid manure results in formation of carbonates (e.g., $CaCO_3$) that precipitate and form a thick sludge (Schmidt, 2016; Albihn et al., 2012). Any precipitate that forms will need to be removed from the treatment vessel. If treatment occurs in the tank spreader, precipitate might cause clogging (e.g., of valves or nozzles). In addition, treated effluent with high pH has the potential to be corrosive to land application equipment if the pH is not readjusted first.

Increasing the pH of liquid manure through the addition of alkalis increases volatilization of ammonia, which can create significant odors and potentially harmful levels of ammonia gas (Schmidt, 2016). The loss of ammonia also reduces the end product's value as a fertilizer (Stevens et al., 2018). Other gases that can be released during agitation of effluent or slurry include carbon monoxide, carbon dioxide, hydrogen sulfide, and methane (AHA, 2008).

Disposal or land application of large volumes of treated effluent may pose logistical difficulties for farms. If the pH of treated effluent is above 12.5, it would require management as a hazardous waste unless the material is neutralized using an appropriate acidic agent (USDA, 2018).

Another potential limitation to implementing this treatment method is that any unapproved product intended for emergency use against ASFv would require emergency authorization under Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) section 18 before it could be used to disinfect effluent. Several disinfectants approved by EPA may be used against ASFv on farm premises and related structures and equipment; however, none of the approved products are specifically registered for use with effluent (USDA, 2021a). In the event of an ASFv outbreak, it would be necessary for state or federal agencies to apply for a FIFRA section 18 emergency exemption to have a chemical disinfectant approved for emergency use with lagoon effluent.

Environmental and Health Concerns

If not properly planned and implemented, chemical treatment to disinfect lagoon effluent could pose potential environmental and health concerns. As discussed above, raising the pH of liquid manure will release ammonia gas because ammonium will be converted to ammonia, which is more easily lost through volatilization (Boyles, 2018). Raising the pH to 11-12 will release a substantial amount of ammonia gas that may pose a health concern to workers. Addition of hydrated lime to a tank while effluent is being added is not recommended, because the concentration of ammonia gas coming from the tank could be a health concern for workers adding the lime (Stevens et al., 2018). Instead, hydrated lime should be added to the treatment vessel prior to adding effluent. This will help with mixing and reduce worker exposure to hazardous gases (Stevens et al., 2018). In addition, treatment should take place in small batches, when possible, to lessen the amount of gas that is released per batch.

"Lime" is a commonly used term to refer to many different calcium-containing inorganic materials. The term "quicklime" refers to calcium oxide (CaO), which is highly reactive with water (Stevens et al., 2018). When quicklime is added to water, an exothermic reaction occurs that may be dangerous for people nearby. Calcium hydroxide ($Ca(OH)_2$, or hydrated lime) is much less reactive, and is commonly used in barns or other areas of the farm during the disinfection phase after a livestock disease outbreak (Stevens et al., 2018). Even though hydrated lime is safer to handle than quicklime, it is still corrosive and may be dangerous to those handling it. Inhalation and contact with eyes and skin should be avoided (Stevens et al., 2018).

Sodium hydroxide (caustic soda) is highly corrosive and irritating to skin, eyes, and mucous membranes, and may produce severe burns (Iacolina et al., 2021). This presents substantial worker safety concerns. It may also damage farm equipment due to its highly corrosive properties.

No long-lasting negative effects to soil are expected if effluent treated with lime is applied to agricultural land (Martens and Böhm, 2009). Lime, in various forms, is commonly applied to agricultural soils, mainly to address soil acidity and increase productivity (Holland et al., 2018). There has been substantial research on the beneficial impacts of lime application to agricultural soils including improved nutrient availability, soil processes, soil structure, microbial biomass, and microbial activity (Holland et al., 2018). However, lime may have both positive and negative impacts on soil biodiversity (Holland et al., 2018). Lime application to soil increases phosphorus availability to plants, but excessive application of lime could result in reduced availability of phosphorus and micronutrients, such as manganese, to plants (Crozier and Hardy, 2018).

Because soil pH varies in different areas, individual farmers will need to consider the pH of the receiving soil and sensitivity of the receiving crop before applying effluent treated with lime. There may be negative effects on the receiving crop from application of treated effluent if the pH is too high or too low, particularly for young crops. Consultation with appropriate local, state, and federal agricultural authorities is recommended before undertaking land application of effluent treated to inactivate ASFv. Also, treated effluent should be applied to soil at a rate consistent with the farm's Nutrient Management Plan, if applicable.

Cost Considerations

Expenses associated with implementing this method include purchasing a sufficient amount of chemical needed for treatment (which may be quite large), possibly renting or purchasing a tank to serve as the treatment vessel and mixing equipment, and possibly purchasing a sufficient amount of acidic agent to readjust the pH of effluent after treatment. At a dosing rate of 1% w/v (Turner and Williams, 1999), which is equivalent to 83.4 pounds per 1,000 gallons of effluent, treatment of a full 10,000-gallon tank spreader would require 834 pounds of hydrated lime. At a cost of around 40 dollars per 50-pound bag, the total cost would be approximately $670. For a lagoon 3 acres in size, a one-inch rainfall event would add around 81,463 gallons of liquid. To treat that volume in batches would require around 6,794 pounds of hydrated lime costing approximately $5,435.

Summary

Chemical disinfection of lagoon effluent using calcium hydroxide (hydrated lime) would be technically feasible for most farms following an outbreak of ASFv; however, additional equipment (e.g., storage tanks, stirring equipment) may be needed to carry out treatment, and care should be taken to prevent harm to people, damage to equipment, or impacts on soil. The literature reports an effective concentration of hydrated lime to disinfect ASFv in effluent is 1% w/v (10 kg/m^3 or 83.4 pounds per 1,000 gallons). Sources generally recommend an exposure period of 4 to 7 days for disinfecting liquid manure through addition of an alkaline reagent, with daily stirring for at least one hour during the exposure period to bring the pH >11. The use of sodium hydroxide (caustic soda) for disinfection of effluent is less preferable than calcium hydroxide due to its highly corrosive and irritant properties.

3.3. Batch Thermal Treatment of Lagoon Effluent

The use of heat to disinfect liquid manure is possible, but uncommon (Martens and Böhm, 2009). In some countries, this treatment method may be used in response to outbreaks of notifiable animal diseases(Martens and Böhm, 2009). The methods involve either direct or indirect heating of small batches of material or microwave treatment of material with a continuous flow mode (Martens and Böhm, 2009).

Effectiveness

One study was identified that evaluated the effectiveness of thermal treatment for inactivation of ASFv in pig slurry with varying concentrations of total solids (0.5 to 5 percent [%]) (Turner et al., 1999). The experiments were performed in a laboratory with slurry in small glass bottles placed in a heated water bath prior to inoculation with the virus. Many different temperatures and time combinations were tested, and viral inactivation in Eagle's Minimal Essential Medium (EMEM) was also evaluated for comparison to slurry. The authors determined that the critical temperature for inactivation of ASFv in slurry was between 56˚C (132.8°F) and 65˚C (149°F), and inactivation occurred more slowly in EMEM than in slurry. Rapid inactivation tests showed that slurries from different sources and slurries with different concentrations of solids required different lengths of time for virus inactivation; however, all slurry samples were below the limit of detection within 5 minutes at 60˚C (140°F). Experiments with EMEM showed that no virus was detected after 15 minutes at 60˚C (140°F).

No experiments specifically evaluating thermal treatment of lagoon effluent were identified; however, slurry with 0.5 % total solids tested by Turner and Williams (1999) is comparable to the solids content of typical lagoon effluent. Turner and Burton (1997) hypothesized that the presence of solids may improve heat retention in slurry thus leading to quicker inactivation of viruses in slurries with higher solids content. The results from Turner and Williams (1999) generally support that hypothesis, with inactivation taking the longest in laboratory medium and slurry with only 0.5 % total solids.

The limited information available indicates that thermal treatment can be considered an effective option for inactivating ASFv in batches of effluent; however, the efficacy data come from laboratory studies conducted with very small volumes of slurry, and no field studies were identified. A conservative general assumption can be made that batches of effluent with low solids content would need to be heated to 65°C (149˚F) for a minimum of 5 minutes to ensure destruction of ASFv. This assumption was recommended by Turner et al. (1999) for for large-quantity treatment of hog slurry and it includes a "reasonable margin of safety" to account for differences in slurry characteristics that may have and effect on virus inactivation.

Feasibility

In the event of an ASFv outbreak, thermal treatment of lagoon effluent is expected to be technically infeasible for most farms for several reasons. For example, it may be necessary to acquire and install specialized treatment equipment in a timely manner. Even if equipment is available, it would be difficult to ensure the necessary temperature is reached throughout the effluent for the duration of time needed for destruction of the virus. In addition, the costs associated with the high amount of energy required would likely be prohibitive for most farms experiencing an outbreak.

Safety and Environmental Concerns

This method presents a safety risk of workers being burned. A severe burn can occur after only 5 seconds of exposure to liquid that is 60°C (140°F). Heated effluent should return to normal temperature before being moved or land applied to prevent burns and damage (e.g., to receiving vegetation or soil microbe communities).

Cost Considerations

Expenses associated with thermal treatment include purchasing or renting the specialized equipment (e.g., heat exchangers, fuel, and treatment vessels) that would be needed to heat effluent in batches. Also, the energy requirements and associated costs would be high. For example, to heat a 10,000-gallon batch of effluent would require around 6.6 million British thermal units (BTUs) to raise the temperature from 70 to 149˚F (21.1 to 65°C).[1] For a lagoon 3 acres in size, a one-inch rainfall event would add around 81,463 gallons of liquid. To pump out and treat that volume in batches would require around 54 million BTUs using the same temperature assumptions.

Summary

Although high temperatures can inactivate ASFv effectively, thermal treatment of lagoon effluent is likely an impractical method for most farms during an ASFv outbreak due to the high energy consumption required.

[1] One BTU is the amount of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit; BTU calculation assumes 1 gallon of water at room temperature weighs around 8.33 pounds.

3.4. Batch UV Treatment of Lagoon Effluent

Ultraviolet-C (UVC) light is commonly used for decontamination by many industries, including municipal wastewater treatment. This treatment method is not commonly used for disinfection of swine wastewater, but sources suggest it could be effective at reducing virus and other pathogen levels if the material is pre-clarified or a high dose is applied (Macauley et al., 2006; Turner and Burton, 1997).

The ultraviolet (UV) band of the electromagnetic spectrum includes wavelengths from 100 to 400 nanometers (nm). Disinfection applications typically utilize the range called UVC (200 to 280 nm) (Ruston C, 2022). Experimental studies have shown that UVC is effective at inactivating enveloped and non-enveloped swine viruses in liquid porcine and bovine plasma (Blázquez et al., 2021). The virucidal effects of UVC may be related to several modes of action including damage of the virus genome, cross-linking of nucleocapsid proteins (i.e., the shell that that encloses the genetic material), and damage of the outer envelope through lipid peroxidation (in the case of enveloped viruses such as ASFv) (Blázquez et al., 2021). Viruses are more resistant to UV disinfection than other types of pathogens (Sobsey, 2006) and may need three to four times greater UV doses than bacteria to achieve decontamination (Turner and Burton, 1997); however, unlike bacteria, viruses are unable to repair the nucleic acid damage caused by UV light outside of host cells (Turner and Burton, 1997).

Effectiveness

Two studies were identified that investigated the effectiveness of UV treatment for disinfecting bacterial pathogens in swine lagoon effluent (Bilotta et al., 2017; Macauley et al., 2006), but no studies in effluent were identified for ASFv or any other swine viruses. Xu et al. (2020) investigated the effects of UVC radiation on ASFv in water and found that ASFv was inactivated within 30 minutes when exposed to UVC lamps at an intensity of 110–120 $\mu W/cm^2$ and within just 3 seconds at 3,600 $\mu W/cm^2$.

While the effectiveness of UVC disinfection of wastewater, such as lagoon effluent, depends on many factors, the most important are the presence of suspended solids and turbidity of the water, the wavelength and intensity of light, the duration of exposure, and the configuration of the UV reactor (USEPA, 1999). The success of disinfection by UVC radiation is much higher when total suspended solids (TSS) is low and percent transmissibility is high (Turner and Burton, 1997). The disinfection effectiveness of low-pressure UV lamps declines when TSS levels in wastewater are above 30 mg/L (equivalent to 0.003 %) (USEPA, 1999).

Research on the use of UVC for disinfection of ASFv specifically in lagoon effluent is currently unavailable. Therefore, no conclusions can be drawn about the effective dose and length of exposure that would be needed for adequate disinfection.

Feasibility

The available literature indicates that, while UV disinfection appears to be effective against ASFv in clear drinking water (Xu et al., 2020), it may not be technically feasible to use with lagoon effluent. The effectiveness of UV treatment is limited by the quantity and size of suspended solids in the material, and this method may require a pre-clarification step for removal of suspended solids prior to disinfection

(Bilotta et al., 2017; Bilotta and Kunz, 2013). Because UV treatment is commonly used for wastewater disinfection, the treatment of lagoon effluent is not limited by the availability of equipment and expertise. However, it might be difficult to acquire and install a treatment system in the necessary timeframe of an ASFv outbreak response. Operating costs would include energy for the UV treatment system and a pre-clarification system, if required.

For farms that do have the capability for UV treatment, there are several advantages to this method over other methods for effluent disinfection. Firstly, with intense radiation, pathogens can become inactivated in a very short period of time. This method does not require chemical disinfectants, which eliminates the need to handle potentially hazardous chemicals, and there are no residual chemicals in the treated effluent. Furthermore, this treatment technique will retain the nutrient content of the effluent for land application (Sobsey, 2006). In addition, its effectiveness is not sensitive to temperature (Xu et al., 2020; Turner and Burton, 1997).

Safety and Environmental Concerns

UVC light is mutagenic and carcinogenic. Therefore, the UVC treatment chamber should be completely enclosed and exposure to any part of a person's skin or eyes should be avoided (Ruston C, 2022).

No potential impacts of land application of UV-treated effluent on soil or crops were identified in the literature.

Cost Considerations

Small, inline UV systems for wastewater disinfection are available for purchase from a variety of manufacturers. Costs and energy use will vary based on the size and operating parameters of the unit.

Summary

Available information indicates that the effectiveness of UV disinfection would be low because of the quantity and size of suspended solids in the lagoon effluent. Importantly, no experimental information is available to determine the effective dose and length of exposure required for sufficient inactivation of ASFv in lagoon effluent. In addition, treating lagoon effluent with UV radiation in the event of an ASFv outbreak would require timely installation of the UV system and pre-clarification of the effluent may be necessary for effective treatment.

3.5. Biotechnological Treatments

Storage of liquid manure in anaerobic treatment lagoons is a form of biological treatment that leads to the inactivation of pathogens over time. Storage as a management method is discussed in Section 3.1. Anaerobic treatment lagoons can substantially reduce pathogenic bacteria and virus concentrations, but the rate of reduction is inconsistent and varies depending on climate and temperature (Sobsey, 2006). Other biotechnological treatments that may be used for treatment of liquid manure include anaerobic digesters (e.g., covered lagoons, plug flow digesters, and complete mix systems) and aerobic treatment systems. These two types of treatment systems are discussed separately below.

Anaerobic Digesters

Anaerobic digestion (AD) systems are used on farms primarily for manure stabilization, odor control, and biogas production. However, these systems are uncommon at hog operations in the United States due to their high capital and operating costs (e.g., heating and electricity) (Smith Jr et al., 2005).

Effectiveness

Temperature is thought to be the main factor that inactivates pathogens during the anaerobic digestion process (Buchanan et al., 2013). Turner et al. (1998) found that thermal treatment of pig slurry inactivated ASFv within four hours at 40°C (104°F), 30 minutes at 50°C (122°F), and rapidly at temperatures greater than 56°C (132.8°F). There are two types of anaerobic digesters that differ between their operation temperature: mesophilic (30–37°C [86-98.6°F]) and thermophilic (50–60°C [122-140°F]). Based on temperature alone, it could be predicted that a thermophilic system would effectively inactivate ASFv; however, a similar prediction cannot be made for a mesophilic system (Franke-Whittle and Insam, 2013).

There is limited information available on the inactivation of ASFv in AD systems. One experimental study was identified, a PhD thesis in German (Moss, 2001) as cited in (Blome et al., 2020). This study found that ASFv was inactivated within hours in a correctly operated thermophilic AD biogas plant and within days in a mesophilic plant.

Technical Feasibility

The limited data suggests that, in an outbreak situation, thermophilic AD is an effective and feasible method to inactivate ASFv in liquid manure, but only for farms that already have a system in place.

Aerobic treatment

Aeration involves exposing manure to oxygen or air and it can substantially increase the rate of treatment with fewer odors compared to anaerobic systems (LPELC, 2019; Sobsey, 2006).

Effectiveness

Experimental studies have shown that aeration of slurry may reduce the persistence of viruses and bacterial pathogens in swine manures (Bauza-Kaszewska et al., 2015; Grewal et al., 2007; Lund and Nissen, 1983; Derbyshire and Brown, 1979). No experimental data were identified for ASFv specifically on this topic.

As discussed in Section 1.2, most hog operations in the U.S. store liquid manure in oxygen-free conditions, which encourages the growth of anaerobic bacteria; however, some swine lagoons are aerated to encourage the growth of aerobic bacteria (LPELC, 2019; Chastain and Henry, 2002). At this time, there is insufficient data to estimate how long ASFv will persist in aerobic treatment lagoons, but the available information suggests it may be shorter than the estimated survival time for anaerobic treatment lagoons.

Technical Feasibility

In the event of an ASFv outbreak, it would not be technically feasible for most farms to begin aerating an anaerobic lagoon due to how anaerobic those lagoons are. There would be a very high energy requirement to supply the required amount of oxygen. Furthermore, aerobic lagoons are typically very shallow (3 to 4 feet deep), with a much larger surface area than anaerobic lagoons (Chastain and Henry, 2002).

3.6. Supplemental Structural Containment Methods

The structural containment methods that were considered to prevent the spread of ASFv from lagoons in the event of an outbreak are installing a cover for exclusion of precipitation and building up the earthen berm to prevent overflow.

Technical Feasibility

The experts interviewed for this project agreed that installing a cover as part of an ASFv response action would be infeasible. Covers are used at some farms to divert precipitation and to collect biogas. Where covers have already been installed, their use to divert precipitation could help to prevent lagoons from exceeding capacity during fallowing. Installing a new cover during fallowing would be impractical due to the time required for design and installation, and in some cases, structures needed to retrofit a cover might threaten the integrity of existing earthen berms. Moreover, there would be substantial costs involved with installing and maintaining a cover that might be prohibitive for some farms or impractical as a short-term disease response. Therefore, this option is considered infeasible in an outbreak situation. The experts also warned against building up the earthen berm to prevent overflow. This action could damage the berm and result in berm failure. Therefore, this option is also considered infeasible in an outbreak situation.

3.7. Emerging Technologies

A number of other potential methods were mentioned in one or more of the publications in the relevant literature (e.g., chlorination, ozone, and cavitation). These methods were discussed briefly as hypothetical solutions or as emerging technologies with little or no experimental documentation of effectiveness for inactivation of viruses in lagoon effluent, and they were not evaluated further for this report.

4. Summary of Feasibility Analysis

In the event of an ASFv outbreak, federal and state authorities led by USDA APHIS would implement strategies to control and eradicate the disease in the domestic swine population. As described in the USDA African Swine Fever Response Plan (USDA, 2020), these actions include isolating, depopulating, and disinfecting farms where ASFv has been detected. Large swine waste lagoons pose a unique challenge for response planning because of the large amount of potentially infected waste they may contain and their open contact with the environment.

As described in Section 3, very limited research is available on methods that could be used during a response to prevent ASFv spread from swine lagoons. Because few relevant field studies are available, there is a limited basis to describe and evaluate how technologies such as thermal and chemical treatment would best be implemented at field scale. However, information is available to describe the potential advantages of the various methods that make them worthy of consideration and the limitations that could impede or negate their performance and implementation. While actual cost information is unavailable or uncertain, the types of costs entailed with each method can be characterized for comparison among the methods. In addition, information from the literature, and supplemented expert knowledge, identify factors that can be considered when making site-specific response action decisions. This information is summarized in Table 1.

The findings summarized in Table 1, indicate that a few of the lagoon management methods reviewed here would be technically feasible for most hog operations in the U.S. in the event of an ASFv outbreak, namely long-term storage in the lagoon, long-term storage in the lagoon and supplemental tanks, and, potentially, batch chemical disinfection of lagoon effluent. There is no known use of batch thermal treatment or UV treatment to inactivate ASFv or other viruses in liquid from swine waste lagoons and both methods are expected to be technically impractical, involve large energy costs, and may be difficult to set up before natural decay processes have already reduced the viral load in the lagoon. Limited evidence suggests that biological treatments (i.e., anaerobic digesters, aerobic treatment systems) would be effective at inactivating ASFv. However, these treatments would be available only at farms that already have systems in place at the time of the outbreak.

Table 1. Summary of Feasibility Findings and Factors for Site-specific Decision-making

Lagoon Management Method to Prevent Spread of ASFv	Advantages	Disadvantages	Feasibility Findings and Factors for Site-specific Decision making
1. Long-term storage in the lagoon for up to 6 months ▪ Lagoon is fallowed with no waste additions or effluent removal until natural decay inactivates ASFv. ▪ Storage time is variable and depends on initial load and various site-specific factors such as ambient temperature. ▪ Conservative estimate of a 6 month infectious period based on limited information available for ASFv and swine lagoons. ▪ Potential for reduced storage time to 3 months when lagoon temperatures are consistently >17°C (62.6°F).	▪ Technically feasible for any farm with a lagoon or other storage with available excess capacity. ▪ Requires no additional equipment or operating costs. ▪ Reliable and effective given sufficient time.	▪ Farm revenue is lost during storage because the farm cannot be repopulated while lagoon is fallowed. ▪ Additional methods will be needed if precipitation during long-term storage will cause the level in the lagoon to exceed the maximum storage capacity. ▪ The extended duration of this option increases the risk of releases from the lagoon due to extreme weather events (e.g., hurricanes) or animal vectors.	▪ Long-term storage is the most technically feasible option and has little or no implementation cost. ▪ The required storage time is uncertain and affected by initial virus load and various factors (e.g., season and temperature, pH, oxygenation) that affect the rate of virus degradation. Testing will be needed to monitor infectious ASFv. ▪ The risk of releases during storage due to hurricanes or other extreme events or animal vectors may be affected by farm location, berm condition, proximity to surface water bodies, or other site factors.

Lagoon Management Method to Prevent Spread of ASFv	Advantages	Disadvantages	Feasibility Findings and Factors for Site-specific Decision making
2. Long-term storage in the lagoon and supplemental storage ▪ Equivalent to long-term storage in the lagoon plus the addition of external storage capacity. ▪ If the lagoon reaches maximum storage capacity, the excess effluent is pumped to tanks or similar storage vessels.	▪ Obtaining additional storage can be planned as a contingency that will be needed only if the lagoon reaches maximum capacity. ▪ Technically feasible for most farms. ▪ Low operating cost.	▪ The need for and volume of additional storage capacity may be difficult to anticipate. ▪ Dependent on the availability and cost of storage tanks. ▪ If the volume of excess storage needed is very large, costs and technical factors may reduce the feasibility of this option.	▪ Like long-term storage in the lagoon only, this option is feasible for most farms. ▪ Deciding whether supplemental storage may be needed will depend on the excess capacity available in the lagoon, the expected duration of storage, and the expected amount of precipitation during the storage period. Testing of infectious ASFv will be needed to confirm effective treatment.

Lagoon Management Method to Prevent Spread of ASFv	Advantages	Disadvantages	Feasibility Findings and Factors for Site-specific Decision making
3. Batch Chemical Disinfection of Lagoon Effluent ▪ If the lagoon reaches maximum storage capacity during the fallow period, the excess effluent is drawn off in batches, treated with a chemical disinfectant (e.g., alkaline agent), possibly treated with an acidic agent to readjust the pH of the treated effluent, and then land applied. ▪ To be used supplementally with long-term storage in the lagoon. ▪ Only liquid effluent would be treated; sludge would not be removed during the fallow period. ▪ The effective dosing rate (1% w/v calcium or sodium hydroxide for 4-7 days, pH >11) is based on experimental data in slurry; no experimental data are available for ASFv in lagoon effluent. ▪ The concentration and treatment time required for disinfection of effluent may be less than what is required for slurry due to lower solids content.	▪ Can be planned as a contingency that will be needed only if the lagoon reaches maximum capacity. ▪ Long-term storage of the treated effluent is not required.	▪ Potential technical issues include ensuring adequate mixing of the chemical in the effluent, precipitation of solids and clogging of land application equipment, potential damage to equipment due to corrosivity, and readjustment to neutral pH after treatment is complete. ▪ Costs include purchasing large amount of chemicals, possibly renting or purchasing a treatment vessel and mixing equipment, and possibly purchasing acidic agent to readjust pH. ▪ Care is needed to protect the health/safety of workers who handle corrosive and irritating chemicals and exposure to ammonia gas during treatment.	▪ Disinfection with calcium hydroxide (hydrated lime) may be feasible for some farms; disinfection with sodium hydroxide (caustic soda) is less preferable due to its highly corrosive and irritant properties. ▪ The rate of batch chemical treatment depends on the capacity and availability of treatment vessels, the rate of disinfection after the addition of chemicals, and the rate at which treated batches can be land applied (e.g., due to the available area of treatable land). ▪ Implementation is affected by the local availability and cost of chemicals and equipment. ▪ There is uncertainty about the necessary chemical dosing rate and treatment time because very little supporting research is available. Testing will be needed to monitor infectious ASFv. ▪ Chemical precipitates and corrosivity should be managed to avoid damaging equipment or harming workers.

Lagoon Management Method to Prevent Spread of ASFv	Advantages	Disadvantages	Feasibility Findings and Factors for Site-specific Decision making
4. Batch Thermal Treatment of Lagoon Effluent ▪ If the lagoon reaches maximum storage capacity, the excess liquid waste is drawn off in batches, heated using specialized equipment (e.g., heat exchangers), and then land applied. ▪ To be used supplementally with long-term storage in the lagoon because only the liquid component of the waste would be treated. The bottom sludge would not be treated. ▪ Effective temperature (65°C [149°F] for 5 minutes) is based on experimental data in slurry; no experimental data available for ASFv in lagoon effluent.	▪ Can be planned as a contingency that will be needed only if the lagoon reaches maximum capacity. ▪ Long-term storage of the treated effluent is not required.	▪ Requires specialized equipment that may not be readily available in a timely manner. ▪ Thermal treatment is energy intensive and energy costs may be prohibitive for some farms. ▪ Additional expenses include renting or purchasing treatment vessels and equipment (e.g., heat exchangers).	▪ Batch thermal treatment is not likely feasible for most farms due to the availability of equipment and high energy requirements. ▪ The rate of batch thermal treatment depends on the capacity and availability of treatment vessels and equipment and the time required for heating, disinfection, and sufficient cooling before land application. The availability of treatable land area also may also affect the rate of treatment. ▪ Testing of infectious ASFv will be needed to confirm effective treatment. ▪ Treatment cost will depend on the number and size of the batches, the manner of heating, and unit energy costs (e.g., price per kWh of electricity).

Lagoon Management Method to Prevent Spread of ASFv	Advantages	Disadvantages	Feasibility Findings and Factors for Site-specific Decision making
5. Batch UV Treatment of Lagoon Effluent ▪ If the lagoon reaches maximum storage capacity, the excess liquid waste is drawn off in batches, treated with UV lamps and then land applied. ▪ To be used supplementally with long-term storage in the lagoon because only the liquid component of the waste would be treated. ▪ No information is available on the effective UV dose to inactivate ASFv in lagoon effluent.	▪ Equipment commonly used for UV treatment of wastewater could be repurposed for this use. ▪ UV leaves no chemical residue and treatment is completed in a relatively short period of time.	▪ Turbidity of lagoon effluent would interfere with the effectiveness of this method. Pre-clarification may be needed for effective treatment. ▪ Energy requirements are very uncertain because the treatment dose and treatment capacity are unknown. ▪ Additional costs include purchasing or renting UV treatment equipment and any other equipment (e.g., for pre-clarification) required for the treatment system. ▪ Care is needed to protect workers from UV exposure.	▪ UV treatment is not likely feasible for most farms and the effectiveness is uncertain due to turbidity in the effluent (if not pre-clarified) and the lack of information on the effective dose.

Lagoon Management Method to Prevent Spread of ASFv	Advantages	Disadvantages	Feasibility Findings and Factors for Site-specific Decision making
6. Biotechnological Treatments (Anaerobic Digestion and Aerobic Treatment) ▪ Available only to farms that already have anaerobic digestion or aerobic treatment systems in place. Most do not. ▪ Limited information available for ASFv suggests that inactivation should occur within hours in a correctly operated thermophilic anaerobic digester. ▪ Insufficient data are available to estimate how long ASFv will persist in aerobic treatment systems (e.g., aerobic lagoons), but the available information suggests it may be shorter than the estimated survival time for anaerobic lagoons.	▪ Limited information indicates that biological treatment systems are effective at inactivating ASFv. ▪ No additional costs for farms that already have these treatment systems in place.	▪ Not an option for most farms because they do not have the necessary systems already in place. ▪ There is a potential for wastewater from the disinfection of farm facilities to interfere with biological treatment.	▪ Feasible for farms that have thermophilic anaerobic digestion systems or aerobic treatment systems already in place. ▪ Testing of infectious ASFv will be needed to monitor effective treatment. ▪ Not feasible for farms to convert to these systems in an outbreak situation.
7. Supplemental Structural Containment ▪ Examples include the use of lagoon covers to divert precipitation and augmenting existing lagoon berms. ▪ These methods are intended to prevent lagoons from exceeding maximum capacity during long-term storage.	▪ These methods involve technologies that are commonly available to hog operations.	▪ Installing a cover often requires a long lag period, high installation cost, and future maintenance expenses. ▪ Building up the earthen berm to prevent overflow could damage the berm and result in berm failure. ▪ These methods do not benefit farms that have sufficient capacity for long-term storage.	▪ Timely implementation of covering a lagoon is not likely to be feasible for any farms during the long-term storage period and will incur future expenses for a farm. ▪ Building up the earthen berm is not recommended due to the potential to damage the berm.

Long-term storage is a passive management method that requires no additional equipment, resources, or operating costs. Fallowing lagoons with ASFv-infected wastes allows natural degradation to progress while also minimizing the movement and potential accidental release of waste. Therefore, fallowing infected waste lagoons until the virus is reduced to safe levels is advisable as the primary response action regardless of other methods that may be employed. Long-term storage can be considered a baseline lagoon management method that would be supplemented with, but not replaced by, other methods.

Reasons to supplement long-term storage include the risk of accidental releases of infected waste during the fallow period if precipitation or extreme weather events cause the maximum storage capacity to be exceeded or damage the structural integrity of the berm. In addition, long-term storage can add to the economic impact of an outbreak if it further delays repopulation and return to operation, and odor is an ongoing issue that may present challenges. The issues must be weighed for each farm affected by an outbreak based on, but not limited to:

- The initial level of ASFv contamination in the lagoon;
- Available excess storage capacity in the lagoon when fallowing begins;
- The expected duration of fallowing (e.g., based on the initial virus level and ambient temperature);
- The potential for exceeding available capacity, based on the expected duration of fallowing, estimated precipitation for the location and season, and the surface area of the lagoon;
- The potential for hurricanes or other natural disasters during the fallow period;
- Any known defects to the structural integrity of the lagoon that might contribute to the risk of accidental release (e.g., in the event of extreme weather);
- The context of all other response activities at the farm;
- Proximity to neighboring uninfected farms, surface water bodies, feral pig and wild boar populations, other location factors that might raise the potential for the infection to spread if an accidental release were to occur; and
- The direction of federal and state authorities leading the outbreak response plan.

After considering these factors, long-term storage alone is likely to be the preferred method for managing ASFv-infected lagoons at most farms, especially those with lagoons expected to have excess storage capacity throughout a fallow period of up to six months. Farms with lagoons that are close to capacity when an outbreak occurs or have an elevated risk of releasing waste for any reason may need additional intervention to mitigate the potential spread of ASFv. In those cases, there may be a need to use supplemental storage vessel(s) and possibly to disinfect the excess effluent. The research reviewed for this report suggests that treating the effluent volumes in batches with hydrated lime (calcium hydroxide) can be effective at inactivating ASFv and is the disinfection method most easily and affordably implemented at most farms. However, decisions about managing infected lagoons should be made separately for each farm considering site-specific factors and in the context of the site's overall ASFv response plan.

If it is necessary to remove excess effluent from an ASFv-infected lagoon, using supplemental long-term storage would involve less equipment, materials, and labor than chemical disinfection. However, chemical disinfection provides more flexibility than supplemental long-term storage to manage very large or uncertain volumes of effluent. For example, the feasibility of using supplemental long-term storage might be limited by the capacity of available storage vessels. If the amount of effluent that must be removed to prevent the lagoon from exceeding its maximum capacity is greater than the capacity of available storage vessels, then it may be advisable to use a disinfection method that is not limited by a maximum volume.

For farms that are not able to store or disinfect effluent that must be removed from a lagoon, the only feasible option may be land application of potentially infectious material. In those cases, the risk of spreading the disease can be mitigated using one or more techniques. Direct injection into soil or spray application only on days with very low wind can prevent spread to nearby areas through aerial drift. Establishment of a dedicated spray field will help contain infectious material in one area. Furthermore, installation of boar-proof fencing around the dedicated spray field will help prevent spread to wild boar and feral pig populations.

Supplemental long-term storage and any of the batch disinfection methods discussed in this report are intended for managing the liquid effluent layer of the lagoon. The sludge layer does not need to be removed and can stay in the lagoon during the period of long-term storage. If it is necessary to remove infectious sludge, composting may be a viable option for managing the sludge on-site. Composting has not been tested for ASFv (Costa and Akdeniz, 2019), but it can achieve temperatures that have been reported as effective at inactivating ASFv in swine slurry (Turner et al., 1998).

5. Conclusions and Research Needs

This report summarizes the currently available information on practices that could be implemented following an ASFv outbreak to prevent the spread of ASFv from on-site waste lagoons. The potential spread of ASFv from lagoons is a concern, particularly for the large, uncovered earthen lagoons prevalent in the Southeast United States, because of their large size, the large volumes of infected wastes they may hold, and their open contact with the environment and vulnerability to extreme weather events. The available scientific literature includes very limited information on the levels and persistence of ASFv in swine waste lagoons, the potential for ASFv releases from lagoons, and management methods to control releases or disinfect the lagoon liquid. Using the available information, supplemented with expert interviews, potential lagoon management options are evaluated based on potential effectiveness, technical feasibility, environmental and health concerns, and cost considerations. In addition, information is provided to aid site-specific planning and decision making, because the best course of action in the event of an outbreak will depend upon several factors that may vary by site.

Conclusions from the feasibility study include the following:

ASFv Persistence in Swine Waste Lagoons

- The persistence of ASFv in swine lagoons is not reported in the available literature and is likely to vary substantially between different operations based on several factors including size of the farm, number of infected animals, type and depth of lagoon, climate, and season.
- Some information on ASFv survival in manure slurry is available from secondary sources, but there is uncertainty involved in applying this limited information to swine lagoons.
- At present, the available scientific information is insufficient to support defensible estimation of how long ASFv will remain infectious in swine lagoons. Thus, onsite monitoring of the viral load, preferably in the different layers of the swine lagoon, would be required to ascertain the initial infectious potential, rate of natural inactivation, and the effectiveness of lagoon management options.
- A conservative general assumption about how long ASFv will remain viable in swine lagoons can be based on the longest reported survival of ASFv in slurry (i.e., 160 days or 6 months). Survivability of the virus will likely be shorter (around 3 months) if an outbreak occurs during warm months and temperatures measured in the lagoon are regularly >17°C (62.6°F).

Identification of Management Methods

- Several government agencies and other researchers have published guidance, recommendations, or reviews of manure management practices relevant to an ASFv outbreak. Long-term storage, chemical disinfection, and thermal treatment are the methods recommended most often for inactivation of ASFv in liquid manure. However, the recommendations are not based on documented experience during past outbreaks or comparative field experiments.
- The literature identifies UV treatment and biological treatments as other potential methods for inactivation of viruses in liquid manure or lagoon effluent.
- This report also considered the installation of lagoon covers and raising the height of berms as potential methods to prevent the spread of ASFv from lagoons.

Screening of Lagoon Management Methods to Prevent the Spread of ASFv

- Long-term storage in the lagoon for up to 6 months is likely to be effective and technically feasible for most farms in the event of an ASFv outbreak. However, additional measures may be needed for lagoons that are near their maximum storage capacity when an outbreak occurs. If precipitation or extreme weather events cause a lagoon to reach capacity during long-term storage, excess liquid would need to be pumped out and stored in alternative tanks until the end of the fallow period or disinfected prior to land application.
- Batch chemical disinfection of lagoon effluent using calcium hydroxide (hydrated lime) would be effective and technically feasible for some farms following an outbreak of ASFv, depending on the volume of effluent that needs to be treated. Treating many batches of effluent may become cost prohibitive for some farms. In addition, there is a need for an alternative storage vessel and mixing equipment to carry out treatment which will be another added expense. The literature

reports an effective concentration of hydrated lime to disinfect ASFv in effluent is 1% w/v (10 kg/m^3 or 83.4 pounds per 1,000 gallons). Sources generally recommend an exposure period of 4 to 7 days for disinfecting liquid manure through addition of an alkaline reagent, with daily stirring for at least one hour during the exposure period to bring the pH above 11. The use of sodium hydroxide (caustic soda) for disinfection of effluent is less preferable due to its highly corrosive and irritant properties. Potential technical issues with this method include difficulty mixing the chemical into the effluent, long treatment period, formation of solid precipitate and potential for clogging of valves and nozzles, and potential damage to equipment from corrosivity of treated effluent.

- Experimental data suggest that raising the temperature of lagoon effluent to 65°C [149°F] for 5 minutes would be effective for inactivating ASFv. However, batch heat disinfection is likely to be impractical for most farms during an ASFv outbreak. Use of this method would require high energy or fuel costs to heat batches of liquid waste, as well as the acquisition, installation, and testing of a heating system. Farms with existing and operational biodigesters may be able to utilize waste heat to aid batch thermal treatment.
- UV treatment of lagoon effluent would likely be an impractical disinfection method for most farms during an ASFv outbreak due to the specialized equipment that would be needed, high energy requirements, and high costs involved. In addition, no experimental information is available to determine the effective dose and length of exposure required for sufficient inactivation of ASFv in lagoon effluent. The effectiveness would be limited by the quantity and size of suspended solids, and a pre-clarification step may be needed prior to treatment.
- The limited data suggest that, in an outbreak situation, thermophilic AD is an effective and feasible method to inactivate ASFv in liquid manure, but this method is feasible only for farms that already have an AD system in place.
- There is insufficient data available to estimate how long aerobic lagoons will remain infectious following an ASFv outbreak. It would not be technically feasible for most farms to begin aerating an anaerobic lagoon after an outbreak due to how strongly anaerobic those lagoons are. There would be a very high energy requirement to supply the required amount of oxygen. Furthermore, relatively shallow depths and large surface areas are required to maintain aerobic conditions in lagoons.
- Structural containment methods evaluated for this report include lagoon covers and fortified berms. Installing a lagoon cover as a means of diverting precipitation and containing infected waste would not be feasible for most farms in an outbreak situation. In addition, building up the earthen berm of a lagoon could damage the berm and result in berm failure; therefore, this method is also not feasible for most farms in an outbreak situation.
- Emerging technologies for disinfection of lagoon effluent, such as ozone and cavitation, have insufficient data available to support their use against ASFv as an outbreak response action.

Natural inactivation processes would begin to reduce ASFv levels in swine waste lagoons as soon as infected waste is no longer added. The implementation of management methods other than long-term storage alone would be delayed until required equipment is acquired and installed. Therefore, site-specific project timelines and virus testing data should be used to evaluate the incremental benefit of supplemental storage or treatment options. There are several uncertainties associated with the lagoon management methods described in this feasibility study report. Further research on the methods would help reduce uncertainties and could substantially increase the feasibility of different methods for individual farms. Topics that would benefit from further research include:

- Identification of countermeasures to inactivate ASFv in waste prior to reaching lagoons to further minimize risk, including evaluation of effectiveness and potential long-term effects on the lagoon.
- ASFv survival and inactivation rates in different layers of typical swine lagoons.
- How ASFv inactivation rates are affected by waste characteristics including pH, dissolved oxygen, and solids content, as well as ambient temperature and lagoon design (e.g., depth, surface area).
- The performance of chemical disinfection using hydrated lime to treat lagoon effluent and slurry with higher solids content. This research will help to determine how the effective chemical concentration and exposure period to treat effluent compares to the values reported for slurry treatment.
- The effectiveness of UVC treatment for inactivating ASFv in lagoon effluent with varying levels of turbidity.
- How the proposed management strategies impact the production of biogas at operations designed capture biogas.

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Appendix A: Literature Search and Screening Procedures

Methodology for Peer-Reviewed Literature

The review methodology for peer-reviewed literature began with a search of selected publication databases using keywords and Boolean logic. Titles and abstracts of the publications returned by the literature search were processed to eliminate duplicates and then screened to identify a subset of "key" sources that met criteria for relevance and usefulness for the Feasibility Study Report. Key sources were then "tagged" to pre-defined topics to help staff easily identify the most relevant sources for topics covered in the report.

Peer-Reviewed Literature Search Strategy

The search of peer-reviewed literature focused on references relevant to the scope of the Feasibility Study Report as defined in the Task Order 0039 Work Plan dated October 26, 2020. The search identified references from 2010–February 2021 with special priority given to publications dated 2015 and later. Relevant review articles summarizing previously published information were of particular interest, and the search methods were designed to capture such articles. During development of the Feasibility Study Report, additional targeted literature searches were made as needed and as permitted by available resources to complement the initial literature search (e.g., to fill data gaps identified after the initial search).

The search of peer-reviewed literature utilized the following sources:

- **AGRICOLA (AGRICultural OnLine Access):** AGRICOLA records describe publications and resources encompassing all aspects of agriculture and allied disciplines, including animal and veterinary sciences, entomology, plant sciences, forestry, aquaculture and fisheries, farming and farming systems, agricultural economics, extension and education, food and human nutrition, and earth and environmental sciences. Produced by the National Agricultural Library (NAL), U.S. Department of Agriculture.
- **AGRIS:** AGRIS facilitates access to publications, journal articles, monographs, book chapters, and gray literature — including unpublished science and technical reports, theses, dissertations, and conference papers in the area of agriculture and related sciences. Maintained by the Food and Agriculture Organization of the United Nations (FAO).
- **PubMed:** U.S. National Library of Medicine National Institutes of Health.
- **Web of Science:** Web of Science Core Collection, refined by Research Area. Clarivate Analytics.
- **Google Scholar**

Different sets of keywords were developed to capture references with relevance to swine waste lagoons. Sets were combined using Boolean logic to identify relevant references for screening and evaluation. Search results were limited to publications written in English.

For each search, all references were downloaded into EndNote and then DeDuper was used to remove duplicate references (i.e., references that appeared in more than one of the databases searched). DeDuper is a tool that uses a two-phase approach to identify and resolve duplicates: (1) it locates duplicates using automated logic, and (2) it employs machine learning to predict likely duplicates which are then verified manually.

Peer-Reviewed Literature Screening and Tagging

The sources returned by the literature search were screened to identify those that were considered "key" sources for this report. Key sources are publications relevant to the project scope that exhibit at least most of the general attributes provided in EPA's Quality Assurance Instructions for Contractors Citing Secondary Data.

Relevance to the project scope was evaluated against specific topics and criteria, including:

- Practices currently in use or under development to contain viruses in swine waste lagoons.
- Lagoon treatments and best practices for managing an outbreak of ASFv.
- Recommendations from government agencies or research institutions for handling an outbreak of ASFv.
- Activities concerning securing lagoons in preparation for natural disasters.
- Strategies for management of lagoons and effluent, including:
    - Temporary storage,
    - Lagoon covers,
    - Chemical disinfection of effluent before discharge,
    - Heat treating effluent before discharge, and
    - Other means of overflow management.
- Performance of the identified swine waste management methods.
- Feasibility of the methods.
- Economic effectiveness of the methods.
- Operational biosecurity of the methods.

Screening was performed by reviewing titles and abstracts or executive summaries, as applicable, to sort each publication against the screening criteria. In addition to screening the literature for relevance, relevant publications were tagged to major topics, including, but not limited to: feasibility, economic effectiveness, and operational biosecurity, as well as types of best practices.

To ensure internal consistency and accuracy, each reviewer completed a pilot review of 5-10 references for evaluation and feedback from a senior reviewer. In addition, 10 percent of each reviewer's assigned citations were reviewed by a second reviewer. Discrepancies between the primary and secondary reviews were resolved by discussions between the reviewers.

Methodology for Gray Literature

The literature review identified relevant sources in the "gray literature" to ensure a comprehensive review and synthesis of available literature. The review methodology for gray literature included a search strategy, and approaches for screening and tagging key sources.

Gray Literature Search Strategy

The peer-reviewed literature search was supplemented with a search and retrieval of relevant gray literature from the sources listed below:

- Internet domain searches of websites of selected governmental (e.g., EPA, USDA) or non-governmental (e.g., National Pork Board, NPPC, AASV) organizations that provide downloading of relevant publications, using keywords identified for the bibliographic database searches (see Table A-1); and

- Additional sources recommended by EPA or USDA through future technical direction.

Google was used to search for publications within the domains of the selected governmental and non-governmental organizations. A Google search can be limited to a specific website (i.e., domain) by adding "site: [domain]" at the end of the search string. These searches used Boolean keywords strings similar to those identified for the peer-reviewed literature search. The search focused on .gov, .edu, and .org websites, with particular interest in .edu references from agricultural institutions and .gov references from state and federal agencies with relevant jurisdiction (e.g., over hog farm infrastructure, environmental releases from hog farms, or foreign animal disease outbreaks).

The titles and URLs of potential sources identified by the searches were compiled in an Excel file referred to as the gray literature database and used for subsequent screening.

Gray Literature Screening and Tagging

Gray literature was screened using the key source criteria defined for peer-reviewed literature. The screeners applied the criteria to each of the potential sources in the database file described above (i.e., titles and URLs identified from searches). For each URL, the screeners evaluated the sources by reviewing abstracts, executive summaries, forewords, keyword lists, or tables of contents (whichever was available). When a screener identified a key source, they recorded additional information including publishing organization, author names, and year published in the gray literature database. They also downloaded or created a PDF for each key source.

Tagging applied only to the gray literature identified as key sources, and the same tags as used for peer-reviewed literature were used for gray literature. The screeners applied the tags in columns included in the gray literature database.

Table A-1. Websites for Gray Literature Searches

Organization	Domain
Governmental Organizations	
USDA (United States Department of Food and Agriculture)	usda.gov
Global African Swine Fever Research Alliance	ars.usda.gov/GARA
EPA (U.S. Environmental Protection Agency)	epa.gov
National Pork Board	pork.org
National Academies (The National Academies of Sciences, Engineering, Medicine)	nationalacademies.org
NSF (National Science Foundation)	nsf.gov
Department of Agriculture and Agri-Food Canada	agr.gc.ca

Organization	Domain
UN FAO (Food and Agriculture Organization of the United Nations)	fao.org/home/en
Non-Governmental Organizations	
North Carolina State University College of Agriculture and Life Sciences	cals.ncsu.edu
The Center for Food Security and Public Health at Iowa State	cfsph.iastate.edu
Morrison Swine Health Monitoring Program	vetmed.umn.edu
North Carolina Pork Council	ncpork.org
Swine Health Information Center	swinehealth.org
National Pork Producers Council	nppc.org
American Association of Swine Veterinarians	aasv.org
Pork Center of Excellence	porkgateway.org
The North American Meat Institute	www.meatinstitute.org
The Pig Site	thepigsite.com
National Hog Farmer	nationalhogfarmer.com

SCIENCE

United States
Environmental Protection
Agency

PRESORTED STANDARD
POSTAGE & FEES PAID
EPA
PERMIT NO. G-35

Office of Research and
Development (8101R)
Washington, DC 20460

Official Business Penalty
for Private Use
$300