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An Evaluation of the Economics and Logistics of Animal Mortality Composting for the Virginia Department of Transportation

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16. Abstract:

Many maintenance facilities of the Virginia Department of Transportation (VDOT) face a decreasing availability of the conventional methods of animal mortality disposal (i.e., landfills and burial of individual mortalities) and have a need for a viable alternative. Others are interested in an alternative means of managing mortality that will save time and labor. Recent studies found that static windrow composting and in-vessel forced aeration composting systems are useful and effective means of managing animal mortality for VDOT, but more information is needed with regard to their cost and feasibility.

The purpose of this study was to determine the economic value of implementing a composting program for VDOT. A survey was used to gather general information on animal mortality management from VDOT's area headquarters (AHQs). Weekly diaries were also collected from eight AHQs and two VDOT residencies over an 8-month period to gather more detailed information regarding their means of mortality management. With the use of these maintenance areas as case studies, cost models were developed that determined the costs or savings incurred from replacing the maintenance area's current means of disposal with one of three composting methods: static windrows, a rotary drum, or a forced aeration composting system.

The study found that even the most expensive composting option currently available to VDOT, the forced air system, is cost-effective when there is sufficient mortality volume. Under the assumptions of the cost models, with regard to the AHQs evaluated, purchasing and operating the current forced air system and rotary drum can save VDOT up to $54,000 and $36,500, respectively, within the lifetime of the vessels. Static windrows are always cost-effective when a free carbon source (i.e., woodchips from vegetative debris removal) is available. As a general rule with regard to the cost-effectiveness of composting, the start-up costs of the current forced aeration composting system should not exceed 22 times the operational savings from composting in the first year and the start-up costs of rotary drum composting should not exceed 14 times the operational savings from composting in the first year.

To maximize the cost-effectiveness of composting, maintenance area superintendents who plan to use composting for animal mortality management should try to identify a no-cost carbon source; use finished compost for transportation project applications in place of purchasing comparable material; seek other maintenance areas with which to share composting facilities; and consider using static windrows whenever possible, including to supplement vessel composting during periods of high mortality. In addition, the Virginia Center for Transportation Innovation and Research should pursue the design of a forced air system with a smaller capacity and lower construction costs than the one presently in use. This would increase the cost-effectiveness of composting for AHQs that do not have a readily available no-cost carbon source; that have smaller mortality volumes; and/or for which pooling of mortality with other AHQs is infeasible. VDOT can save costs by replacing current mortality management methods with a composting alternative and adopting supportive business practices.

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In Cooperation with the U.S. Department of Transportation
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ABSTRACT

Many maintenance facilities of the Virginia Department of Transportation (VDOT) face a decreasing availability of the conventional methods of animal mortality disposal (i.e., landfills and burial of individual mortalities) and have a need for a viable alternative. Others are interested in an alternative means of managing mortality that will save time and labor. Recent studies found that static windrow composting and in-vessel forced aeration composting systems are useful and effective means of managing animal mortality for VDOT, but more information is needed with regard to their cost and feasibility.

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INTRODUCTION

Background

The number of deer-vehicle collisions in Virginia each year is consistently among the highest in the United States, with nearly 57,000 collisions reported from July 2012 through June 2013 (M. Miles, personal communication). Virginia's Loudoun and Prince William counties have the 7th and 12th highest claim frequencies in the United States, respectively, according to an analysis of nationwide animal strikes in November during the 6-year study period (2006 through 2011) (Highway Loss Data Institute, 2012). Removing animal mortalities from Virginia roads and properly disposing of them is an important service conducted by the Virginia Department of Transportation (VDOT). However, many VDOT maintenance facilities face a decreasing availability of landfills and viable burial areas, VDOT's predominant means of managing wildlife mortalities.

Recent studies conducted at the Virginia Center for Transportation Innovation and Research (VCTIR) found that composting animal mortality is a useful and effective waste management strategy (Donaldson and White, 2013; Donaldson et al., 2012). Composting also has numerous environmental benefits (Composting Council Research and Education Foundation [CCREF] and the United States Composting Council [USCC], 2008). Composting animal mortalities rather than disposing of them at a landfill not only saves valuable landfill space but also can decrease the volume of organic byproducts, which are known sources of methane production. In addition, the use of compost itself can sequester carbon within the soil (CCREF and USCC, 2008). For these reasons, the U.S. Environmental Protection Agency promotes composting and lists the following benefits of its use in state and local roadside applications:

- prevents or reduces erosion
- retains water and reduces runoff rates
- assists in establishing vegetation with vigorous root growth

- improves soil structure and porosity, buffers pH, and provides beneficial microorganisms

- retains sediment while allowing clear water to pass through

- retains pollutants such as heavy metals, oil, fuel, and pesticides

- bioremediates trapped nitrogen, phosphorus nutrients, oil fuel, and some pesticides (cited in CCREF and USCC, 2008).

Composting studies conducted at VCTIR found that static windrows (passively aerated piles of compost material) (hereinafter windrows), a forced aeration system (hereinafter forced air system), and a rotary drum are useful and effective methods of composting animal mortality for VDOT. The temperatures achieved with these methods result in the destruction of target pathogens, and the methods perform well from an operational standpoint. Table 1 provides information about each evaluated composting method that is currently available to VDOT.

Table 1. Comparison of Three Composting Methods Available to VDOT Maintenance Facilities

Category	Windrows	Forced Air System	Rotary Drum
Description	Piles of mortality and a carbon source constructed on slightly sloped ground or pavement. Animal mortality is placed side by side in layers between layers of a carbon source.	Four concrete containers (with pipes along bottom that force air upward) and a storage area. Animal mortality is placed side by side in layers between layers of a carbon source (i.e., sawdust). Leachate drains into underground tank and is cycled back onto material.	Automatically rotating drum. Animal mortality is loaded into drum with a dry carbon source (i.e., sawdust or woodchips) in a ratio of 1:1 to 1:1½ by volume.
Carbon source	Woodchips (generated from tree debris in right of way) or sawdust	Sawdust or woodchips	Sawdust or woodchips (must be dry)
Method of aeration	Passive aeration through sides of windrow. Turning windrows aerates material and speeds composting process.	Pipes incorporated at bottom of each container force air upward through material.	Each rotation of drum (1-3 times per day) turns and aerates material.
Space requirement	Dependent on number of mortalities (24 deer per 40 ft x 8-ft windrow)	Approximately 1,730 ft^2	Approximately 240 ft^2
Setback requirement[a]	Greater than 50 ft from property or right-of-way boundary and surface waters[b]	Greater than 25 ft from property right-of-way boundary and surface waters	Greater than 25 ft from property right-of-way boundary and surface waters
Capacity (deer)	Limited only by space (8 deer per 100 ft^2)	600 deer (can be loaded at one time)	3-5 deer per day
Composting duration	10-11 months if not turned, faster if turned	Minimum of 6 weeks in containers and 9 weeks in windrow	Up to 2 weeks in drum and minimum of 8 weeks in windrow

VDOT = Virginia Department of Transportation.
[a] The setback requirement for all composting methods also includes a setback distance greater than 200 ft from any residence, health care facility, school, recreational park area, or similar public institution.
[b] The setback requirement for windrows also includes a setback distance greater than 50 ft from caves and sinkholes, rock outcrops, and intermittently flowing drainage swales and 200 ft from any well or spring currently used as a drinking water source.

Given the continued success of the composting methods currently in use at three VDOT maintenance facilities, numerous VDOT maintenance personnel have expressed interest in composting as their primary means of mortality management. In addition, a recently executed memorandum of understanding (MOU) between VDOT and the Virginia Department of Environmental Quality (DEQ) regarding animal mortality composting is expected to increase composting implementation prospects for VDOT (DEQ and VDOT, 2015).

For maintenance facilities that face challenges with their current means of mortality management (i.e., disposal facilities that are distant, costly, or no longer accepting animals), adopting a composting program may be an obvious favorable option. For other maintenance areas, the choice may depend on comparative cost and the feasibility for their region. Now that research studies have determined that windrows and certain compost vessels can be effective and environmentally compliant means of mortality management, the final leg of determining the feasibility of their use by VDOT requires analyses of more specific and representative data from a variety of maintenance areas in order to develop cost guidance that is both relevant to and sufficient for the wide variety of VDOT maintenance areas. Such information can facilitate mortality management decisions for transportation maintenance areas interested in considering an alternative management method.

PURPOSE AND SCOPE

The purpose of this study was two-fold: (1) to document current VDOT animal mortality management methods and gauge interest in composting at VDOT maintenance areas, and (2) to determine the cost-effectiveness of various composting scenarios for VDOT maintenance areas. To achieve this purpose, documented mortality management experiences of VDOT AHQs and residencies were used as the basis for case studies with which to develop cost models. The models were designed to reflect the variety in mortality volumes, current mortality management methods, and local costs among VDOT maintenance areas.

One of the primary values of animal mortality composting for VDOT is that, regardless of the costs, it provides an alternative for maintenance areas that currently have limited burial and landfill options. Another value is its numerous environmental benefits over burial or landfill disposal (CCREF and USCC, 2008). These values, however, are difficult to monetize and were beyond the scope of this study.

METHODS

Four tasks were performed to achieve the study objectives.

1. Collect data from VDOT area headquarters (AHQs).
2. Gather information on costs of composting methods.
3. Create cost models using case studies.
4. Develop a general rule for determining the cost-effectiveness of vessel composting.

Collect Data From VDOT AHQs

VDOT AHQ Superintendents Survey

A survey was used to gather information on animal mortality management from VDOT AHQs. The Internet-based program SurveyMonkey was used to create the survey. An e-mail containing a link to the survey was distributed to all VDOT district residency administrators with a request that they forward the survey link to their maintenance area superintendents (the e-mail and the survey are provided in Appendix A).

In addition to collecting readily available data from maintenance area superintendents (e.g., disposal methods used, numbers of mortalities, distances from mortalities to the maintenance facility), the survey was designed to collect more detailed local information on current mortality management practices, including any local maintenance routines adopted to reduce the cost of mortality management. For example, task-chaining (the performance of unrelated maintenance duties en route to or from landfill sites) and shared mortality management agreements between AHQs are local arrangements perceived in some locations to be more efficient than former stand-alone mortality management practices. It is important to note that relatively few AHQs log their mortality numbers, so survey responses were based on survey respondents' best estimates from recall. Responses that required such recall were not used to create the model or estimate costs but rather were used by researchers to understand the general scale of mortality numbers perceived among AHQs and to select AHQs to contact for more information.

The survey also ascertained AHQs' interest in composting and potential compost end use options that would benefit the maintenance area (e.g., erosion control and grass establishment). Another set of questions was aimed at determining whether the maintenance facility lot met composting space and setback requirements applicable at the time of survey distribution.

Weekly Maintenance Area Diaries

Weekly diary forms were also used to collect mortality management information from VDOT maintenance areas. The purpose of the diaries was to collect more detailed information than solicited in the survey; to reduce the chance of recall-associated errors; and to provide local data for the development of cost models. Each form comprised a set of questions designed to gather information similar to that gathered by the survey, but the questions were to be answered on a weekly basis by a subset of maintenance area superintendents.

Given the commitment required by AHQ superintendents for this task, some of those selected to participate included those who had participated in previous projects. Others were selected in order to ensure that the group represented a range of mortality management methods (i.e., burial, landfill, contractor, or composting) across several VDOT districts. Seventeen superintendents were called to solicit their participation. Eight AHQs (two of which shared mortality management responsibilities) and two residencies (one comprising four AHQs and the other comprising eight AHQs) ultimately participated (Figure 1). Ten of these AHQs had also responded to the survey.

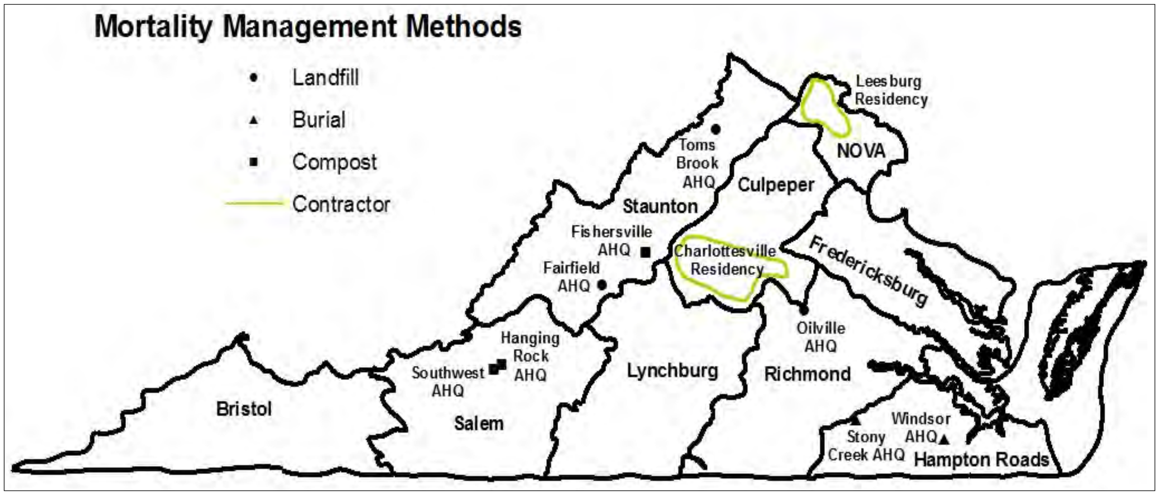

Figure 1. VDOT Area Headquarters (AHQ) and Residency Participants in Weekly Diaries and Their Current Method of Deer Mortality Management

The researchers asked the participating AHQ superintendents an initial set of questions related to the management of the animal mortality in their maintenance area (see Appendix B). Topics included how and where the maintenance crew learns of mortality that requires removal; how the crew disposes of mortality; and whether any task-chaining is conducted during removal and disposal. The form comprising the weekly set of questions was e-mailed to each superintendent (see Appendix B). Topics included number of mortalities; proportion of mortalities located on the primary and secondary systems (i.e., VDOT-maintained roads); and distance of each mortality from the residency headquarters or AHQ. The questions were to be answered for each day of the workweek (Monday through Friday). Superintendents (or their employees) returned the completed form to the researchers by e-mail at the beginning of each week during the diary collection period. If the completed form was not received by mid-week, researchers called or e-mailed the superintendent to obtain the information.

The weekly diaries for AHQs that managed their own mortalities (rather than using a contractor) were collected from October 2013 through April 2014. This span included the late fall season when deer mortality on roads is highest. For the two residencies (Charlottesville and Leesburg) that used a contractor to remove and dispose of mortalities, contractor invoices and data from VDOT's financial database were provided by residency staff for the entire fiscal year 2014 (FY14). Invoices included the date and number of deer mortalities removed from the road and the fee charged by the contractor.

Gather Information on Costs of Composting Methods

The specific costs of the three composting methods (windrows, forced air system, and rotary drum) available to VDOT maintenance staff were determined. Since VDOT's costs as specified in its financial management database do not itemize mortality removal and disposal work (Donaldson and Moruza, 2010), costs were determined through (1) inspection of operation manuals; (2) discussions with those involved with the coordination and purchase of compost vessels and associated equipment and staging materials; and (3) observations of VDOT composting site practices. The costs were grouped in broad categories including composting equipment; site preparation and operations; carbon source (i.e., vegetative material such as sawdust or woodchips that serves as the source of energy for organisms that decompose organic matter) and end product valuation; mortality characteristics; and VDOT equipment and labor rates. Discussions were frequently held with the VDOT superintendents overseeing the composting budget and operations and the VCTIR implementation coordinator, who had been coordinating compost vessel installations.

Create Cost Models Using Case Studies

As mentioned previously, the AHQs and residencies that provided weekly diary data represented the full range of mortality management methods conducted across Virginia (Figure 1). These AHQs also varied widely with respect to the number of animal mortalities removed from roads and distances driven for removal and disposal work. These AHQs and residencies were therefore used as case studies on which to base the cost models. The cost models were developed with the information obtained from the weekly diaries and contractor invoices and the costs of each composting method (windrows, forced air system, and rotary drum) described previously.

The case study areas (hereinafter study areas) were grouped according to their method of animal mortality management: by full service contractor (FSC) and landfill or transfer station disposal; by AHQ pickup of mortality and disposal by burial, landfill, or transfer station; and by AHQ pickup of mortality and composting at the AHQ. For simplicity, the method in effect at the close of the weekly diary period was compared with the alternatives in a cost model.

The cost models compared current practice with each of the alternative composting options (or with the landfill option if the current practice was composting) on the basis of total costs over the service life of the composting equipment (i.e., the period of operation until the composting equipment would need to be replaced). For example, to compare the costs of FSC mortality management and forced air system composting, the total cost of FSC mortality management at current relative costs was compared with that of forced air system composting over the period of the service life of the system to determine which method, after it was discounted to its present value (PV), entailed lower costs. The relative cost of FSC management, or any other current practice, was analogously compared with that of rotary drum composting and of windrow composting.

A composting method was considered cost-effective if the PV of its lifetime cost was equal to or less than the cost of the non-composting mortality management method within the service life of the composting equipment. Alternatively, the composting method was not considered to be cost-effective if the original management method was less costly than the composting alternative within the lifetime of the compost vessel. (The service life of windrows has no limit.)

The cost model employed the standard formula for PV discounting of a regular annual stream of expenses in continuous time:

PV (Annual costs) = ∫Annual cost $_t$*$e^{-(r*t)}$

which simplifies to

PV (Annual costs) = Annual cost*(1 − $e^{(r*t)}$)/r

or

PV (Annual costs) = Annual cost*(PVD)

where

PVD = present value discounting factor.

The PVD, i.e., (1 − $e^{(r*t)}$)/r, performs the function of condensing a stream of regular annual costs that continues t years into the future into a single PV cost in the current period. It allows the comparison of two different streams of costs over the same period of time, in this study the service life of the composting equipment. The PVD takes on values corresponding to the service life t of the composting equipment under evaluation and r, the discount rate, as shown in Table 2, where probable equipment service life is noted for each composting method. The role of the discount rate is to reflect uncertainty in future costs: the higher the discount rate, the greater the uncertainty.

Table 2. PVDs Given Discount Rate and Equipment Service Life

Discount Rate, r	**PVD (Forced Air System) (50-yr SL)**	**PVD (Rotary Drum) (20-yr SL)**	**PVD (Windrows) (No Limit SL)**
0.02	31.60	16.48	43.23
0.04	21.62	13.77	24.54
0.06	15.84	11.65	16.63

PVD = present value discounting factor; SL = service life.

Equations 1 and 2a provide the basic cost equations used for each case study.

PV (Cost of current mortality management practice over service life of composting method (i)) = PVD(i)*(Annual cost of current practice) [Eq. 1]

where

PVDs for each composting method (i) are as shown in Table 2.

PV (Cost of composting method (i) over service life of composting method equipment) = Start-up costs + PVD(i)*(Annual costs of composting method (i)) [Eq. 2a]

The PV of lifetime costs of each composting method is calculated by specifying a composting method in Equation 2a as shown in Equations 2b through 2d.

PV (Cost of forced air system disposal over service life of system) = Construction cost of forced air system + Start-up medium + PVD (Forced air system)*(Annual costs of forced air system composting method) [Eq. 2b]

PV (Cost of rotary drum disposal over service life of drum) = Construction cost of drum + Start-up medium + PVD (Drum)*(Annual costs of drum composting method) [Eq. 2c]

PV (Cost of windrow disposal over service life of windrows) = Construction cost of windrows + Start-up medium + PVD (Windrows)*(Annual costs of windrows composting method) [Eq. 2d]

Working with these equations, the researchers developed and examined three cost comparisons to determine the relative cost-effectiveness of alternative methods of mortality management. The three metrics support and are consistent with each other, but they provide different information and detail.

First, the PV of the lifetime cost of current practice was compared with the PV of the lifetime cost for each composting alternative over the respective service life of the alternative. If a study area was already composting animal mortality, the PV of the lifetime cost of composting over the service life of the equipment was compared with the cost of other options evaluated over the same period. The objective was to determine how the costs of the current practice compared with those of the alternatives. This calculation involved solving Equations 1 through 2d using the local costs of the study areas.

Second, the time N to reach cost parity between the current method and each alternative (i.e., the "breakeven" cost point) was calculated. The value of N was determined by setting equal the PV of the lifetime costs of the current practice and the PV of the lifetime costs of a given alternative method and then solving for time (i.e., N) in the PVD term in the resulting equation. The time that equates the two cost functions is the number of years at which the PV of their lifetime costs reaches parity. If no such point exists prior to the equipment expiring (i.e., reaching the end of its service life), N either exceeds the service life or has no solution and the composting method is not cost-effective. This calculation involved the simultaneous solution of Equation 1 and each of Equations 2b, 2c, and 2d separately. It should be noted that for a single study area the composting methods differed in initial equipment costs, energy use, and PVD (a function of equipment service life), but the equations otherwise feature the same local costs.

As an example of solving for N, Equation 3 provides the initial equality between the no-cost landfill option and a forced air system, and Equation 4 provides the final derivation following from Equation 3 that solves for N in this comparison:

PVD(i)*(Annual cost of current practice over service life of composting method (i)) = Construction cost of a forced air system + Start-up carbon source + PVD (Forced air system)*(Annual costs of forced air system composting method) [Eq. 3]

$$N(i) = \ln(1 - (r*A(i)/B(i)))*(-1/r) \quad \text{[Eq. 4]}$$

where

A(i) = Construction cost (Forced air system) + Start-up carbon source (Forced air system)
B(i) = Cost *savings* of forced air system composting over current practice in the first year.

Third, required annual mortality D was determined for each study area. The value of D would represent the mortality needed for parity in PV of lifetime costs between composting and an alternative management method during the service life of the composting equipment. In general, if D exceeds actual FY14 mortality (and if FY14 mortality is not extraordinary) the composting alternative under evaluation will not be cost-effective relative to the alternative. This calculation required specifying one or more annual costs in the composting method with an explicit mortality term D that could be solved, but this requirement is easily met because the carbon source is used in a 1:1 proportion with mortality volume and can logically be expressed on a per mortality basis. As with the solution for N, the solution for D began with Equation 3 but culminated in Equation 5.

$$D(i) = A'(i)/B'(i) \qquad \text{[Eq. 5]}$$

where

$A'(i)$ = Construction cost (Forced air system) + Start-up medium (Forced air system) + PVD (Forced air system)*Energy (Forced air system)/yr

$B'(i)$ = PVD(i)*(Cost *savings* of forced air system composting over current practice in the first year *per mortality*).

In every study area, the cost equations of current practices and alternative mortality management options were modeled using known or estimated costs combined with the specific business practices of the study area. Specifically, most case study mortality records required supplementation by means of estimation to approximate FY14 totals. In study areas where mortality diaries covered only October 2013 through May 2014, annual mortality was estimated based on percentages for June–September mortality derived from 6 years of contractor records for Interstates 81 and 64, which were available to the researchers.

Case studies included an analysis of the economic effect of using compost to replace the purchase of soil for roadside development or site restoration projects. These evaluations used the price of Topsoil Class A, a roadside development item in VDOT's *Road and Bridge Specifications* (VDOT, 2007). VDOT compost characterization tests have demonstrated that the compost complies with the specifications for Topsoil Class A (B. Donaldson and M. Crawley, unpublished data).

Each study area featured different combinations of costs and mortality levels in FY14, leading to different outcomes for cost-effectiveness among mortality disposal alternatives in each study area. Some costs, however, were common to all case studies including the cost for a carbon source (unless otherwise specified), the cost for composting equipment, and the annual energy cost of specific composting equipment. Study areas within the same VDOT district also had a single value for Topsoil Class A.

Develop General Rule for Determining Cost-effectiveness of Vessel Composting

After each case study had been modeled, it was feasible to extrapolate the results to two sketch-level generalizations that could predict whether a vessel composting option was likely to be cost-effective compared to an alternative. Development of the generalizations required three steps: (1) identify the case studies for which either one of the vessel composting options was determined to be cost-effective, including those that became feasible after a no-cost carbon source scenario was applied; (2) based on Equation 4 and according to the composting method, fit a trendline to pairs of N(i) and A(i)/B(i) values identified in the cost-effective outcomes; and (3) use the forced air system trendline equation to solve for the value of A(i)/B(i) that corresponded to N = 50 (expected service life) for a forced air system and use the rotary drum trendline equation to solve for the value of A(i)/B(i) that corresponded to N = 20 for the rotary drum.

Each of these two vessel-specific values for A(i)/B(i) identify the maximum ratio of start-up costs to savings accrued in the first year (i.e., attributable to vessel composting) that can be allowed before the composting method ceases to be cost-effective over its service life relative to current practice.

RESULTS AND DISCUSSION

Area Headquarters Data Collection

VDOT AHQ Superintendents Survey

Of the 178 VDOT AHQ superintendents, 100 responded, representing approximately 56% of VDOT AHQs. Figure 2 illustrates the percentage of respondents by VDOT district. Most of the responding AHQs (74%) managed only their own animal mortalities, and 16% shared mortality management with other AHQs or used a contractor. Of respondents, 77% reported using a landfill in the past year. Most of the remaining respondents strictly buried the mortalities (10%), and 1 AHQ (1%) brought the mortalities to a local zoo; 12% used a contractor to manage their mortalities.

Although no survey question specifically asked if the AHQs were or were not satisfied with their current method of mortality management, 3 respondents added a comment that represented an urgency for a solution (i.e., “We need help we have no place to put them” and “We need a place to take them ASAP”). Two others commented that the landfill or burial method they were currently using was satisfactory and they saw no need for a change (i.e., “The landfill is located only 3 miles from my AHQ” and “What we are doing [burial] requires no transport of the animals.”)

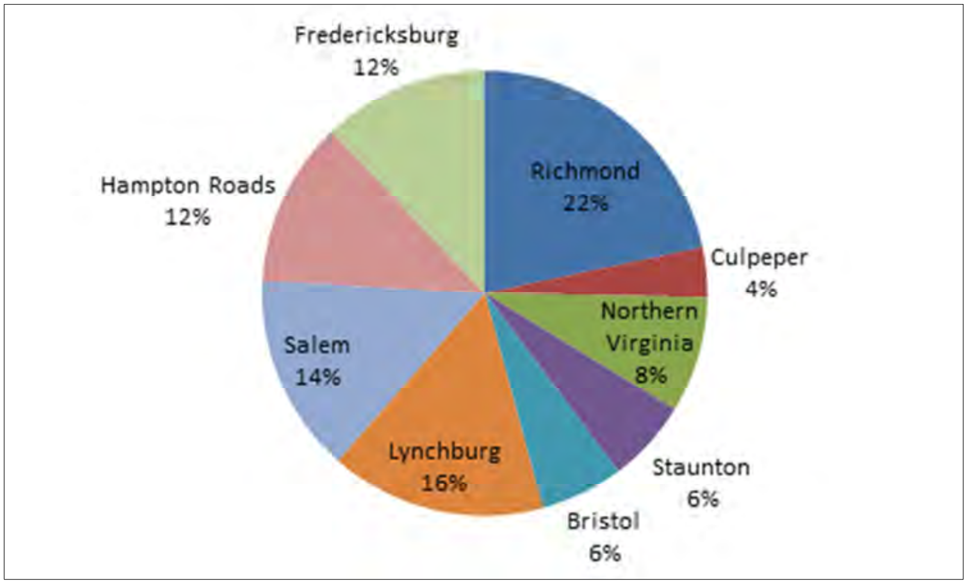

Figure 2. Percentage of Survey Respondents by VDOT District (N = 100)

With regard to the question asking whether composting would be considered at their AHQ, 24 (24%) answered "yes"; 10 (10%) answered "maybe"; and 66 (66%) answered "no" (Figure 3). Reasons given for the majority of the "no" responses were related to respondents' perceptions that their AHQ lot did not meet setback requirements (i.e., the distance from the composting site to the AHQ boundary, surface water, and/or residencies and public areas). However, these distances are now decreased from those listed in the survey.

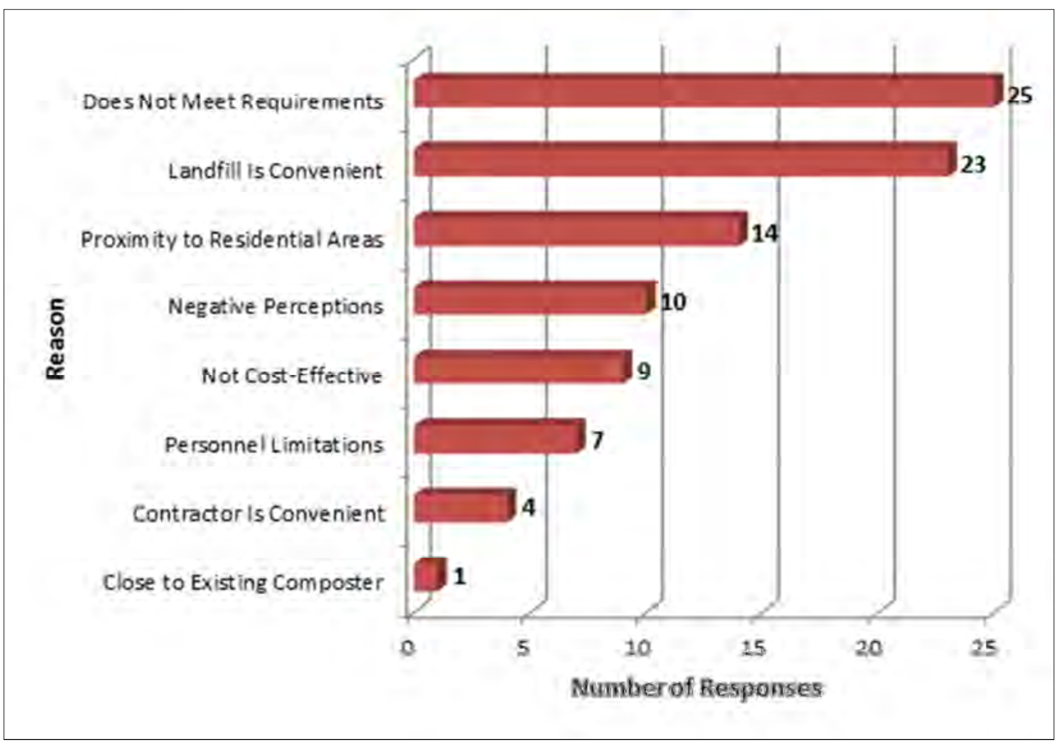

Figure 3. Reasons Given by Area Headquarters (AHQ) Superintendents Who Answered "No" to Survey Question Regarding Whether Composting Would Be Considered at Their AHQ

As specified in the MOU between VDOT and DEQ (DEQ and VDOT, 2015), the agencies agreed on a setback distance requirement from the composting site to the AHQ boundary that is consistent with that specified in a waste guidance memo for livestock mortality (DEQ, 2009). This change will increase the number of AHQs eligible to conduct composting. Further, more AHQs might become interested in composting if they were provided information on its costs, operational logistics, and personnel requirements. Upon hearing positive composting experiences from other AHQ superintendents, some AHQ superintendents might also change some of their negative perceptions that may be false (e.g., offensive odor, laborious, costly).

Weekly Maintenance Area Diaries

As noted in Figure 1, the AHQs that provided weekly diaries varied with regard to their method of deer mortality management. The Windsor and Stony Creek AHQs were dissatisfied with the only mortality management method currently available to them; these AHQs buried their mortalities and expressed frustration with a lack of viable burial locations. Burying each deer was a time-consuming process; it took an average of 27 and 88 minutes for the Stony Creek and Windsor AHQs operators, respectively, to bury each deer. For these reasons, both AHQs planned to install compost vessels.

The Fairfield, Oilville, and Toms Brook AHQs disposed of their mortality at landfills and were satisfied with this disposal method. Landfills were within the AHQ boundary for the Fairfield and Toms Brook AHQs but outside the boundary for the Oilville AHQ. Trips to landfills occurred up to an average of 14 times per month over the course of the diary collection period.

The Fishersville and Hanging Rock AHQs replaced their previous method of mortality management (landfill) with a compost vessel. The Fishersville AHQ acquired a rotary drum composter in 2013. The Hanging Rock AHQ, which acquired a forced air system in 2013, shared its mortality removal responsibilities with the Southwest AHQ. The Hanging Rock AHQ's weekly diaries included information from the Southwest AHQ. The neighboring Troutville AHQ, however, also used the forced air system at the Hanging Rock AHQ but was not included in this study. For the Southwest and Troutville AHQs, the Hanging Rock AHQ's forced air system was a more convenient mortality management option than the more distant landfill. The Fishersville and Hanging Rock AHQs reported being highly satisfied with the performance of the compost vessels.

The Leesburg and Charlottesville residencies employed FSC management of animal mortality during FY14, which entailed a set price for pickup and disposal of each mortality (in each residency the contract price was renegotiated mid-year). These residencies provided the best-documented data available for this study: diaries were provided by a residency administrator and an AHQ administrator, and data from VDOT's fiscal management database on contractor charges and mortality levels for the entire FY14 were provided by both residency staffs. The Leesburg Residency plans to install a compost vessel and continue the use of an FSC, who would pick up mortalities and deliver them to the composting site at a fixed rate per mortality.

A total of 1,209 deer mortalities were reported over an 8-month period by eight AHQs (including the Southwest AHQ) (Figure 4), and 3,016 were reported by the Charlottesville and Leesburg residencies over a 12-month period (Figure 5). Mortalities peaked from late October through November.

Most deer mortality managed by AHQs was removed from primary roads (68%); 32% was removed from secondary roads. The majority of mortality removals occurred from 5 to 10 miles from the AHQ (39%) and more than 10 miles from the AHQ (36%); 22% occurred from 1 to 5 miles from the AHQ, and 3% at less than 1 mile from the AHQ.

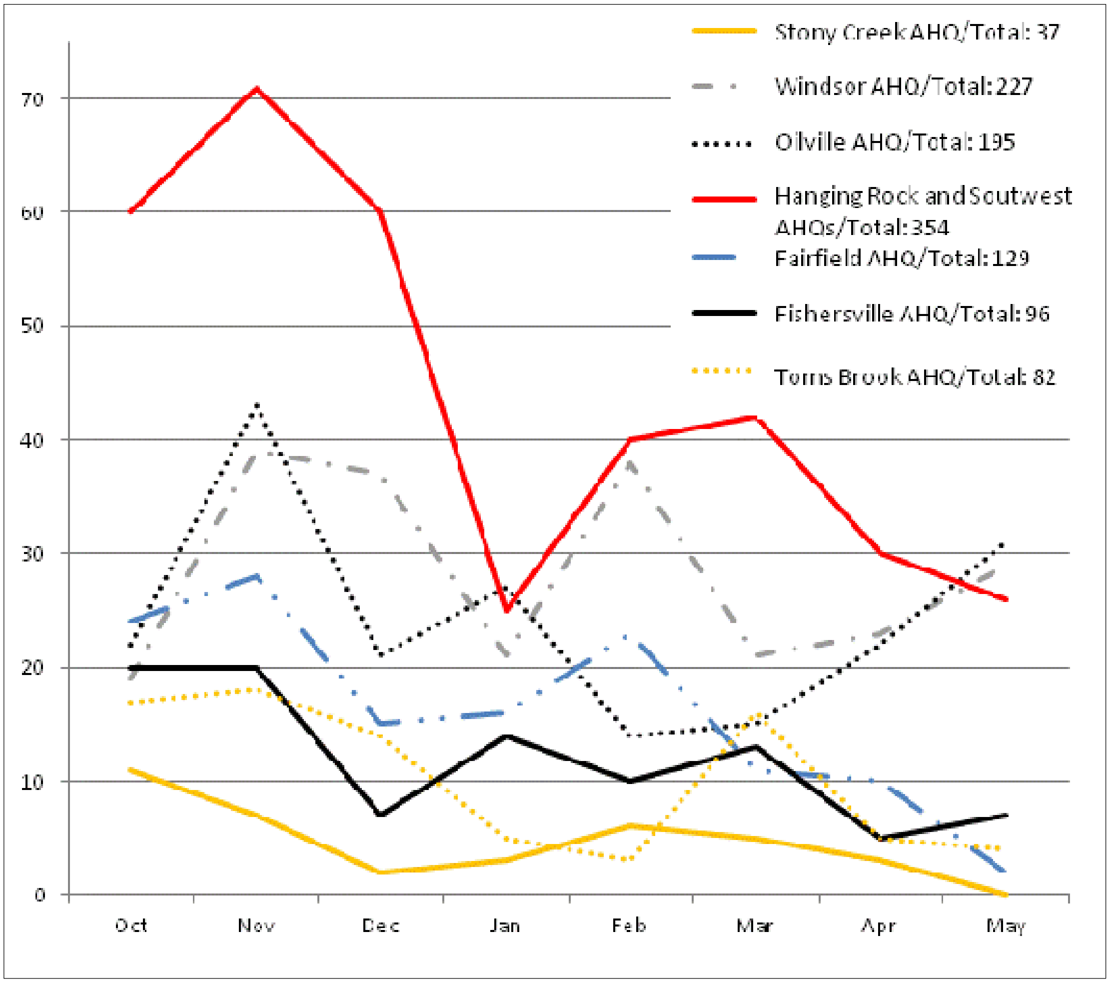

Figure 4. Monthly Deer Mortality Reported in Area Headquarters (AHQ) Diaries (October 2013–May 2014). Total deer mortality numbers for this date range are provided in the legend.

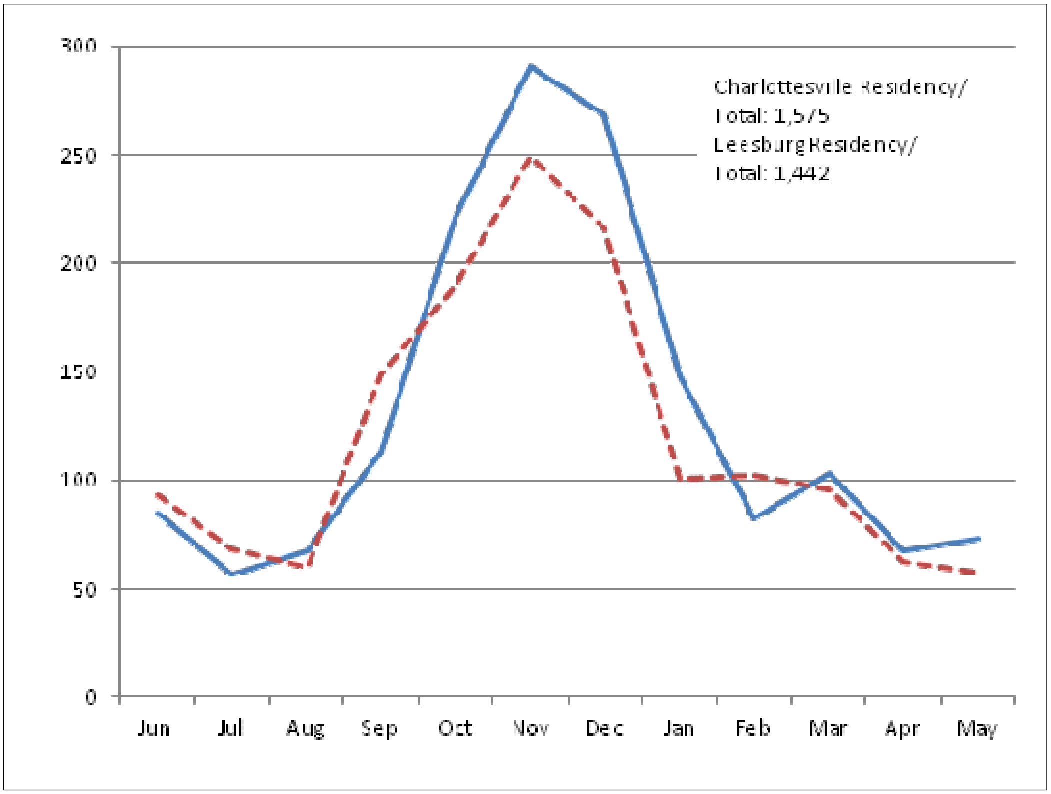

Figure 5. Monthly Deer Mortality Reported in Residency Diaries (June 2013–May 2014). Total deer mortality numbers for this date range are provided in the legend.

Cost Models

Assumptions

Composting Equipment, Site Preparation, and Operations

- The forced air system features an up-front cost for site preparation of $20,000 and a cost for the forced air system and storage building of $118,900 (total $138,900). Up-front rotary drum site preparation was assumed to cost $5,000, and the drum itself cost $38,375 (total $43,375).

- Manufacturer estimates of the service life of the forced air system and the rotary drum were 50 years (K. Warren, personal communication) and 20 years (B. Irwin, personal communication), respectively.

- Energy used by a forced air system was estimated at 2.237 kilowatts/hour of usage (manufacturer's estimate) or 19,597 kilowatts/year when the system is running constantly. Valued at an average cost of $0.09 per kilowatt-hour, forced air system energy use was assumed to cost $1,783/year; rotary drum energy use was priced at $120/year (manufacturer's estimate).

- The forced air system and rotary drum composting methods require up-front expenditures for equipment and possibly for a carbon source if a free source is not available.

Carbon Source and End Product Valuation

- Unless specified otherwise, the price of a carbon source for forced air system and rotary drum use was set at the rate documented for the Bethel AHQ ($300/tandem load or 384 ft^3), resulting in a carbon source cost per average deer mortality of $7.34 (based on applying composting carbon source to deer mortality in an equal volume).

- Recycling of 50% of the composted carbon source is possible only in a forced air system.

- The composting process results in an end product that can be valued at the weighted average price of Topsoil Class A (2-in depth) in the VDOT district in which the study area is located.

- A carbon source (woodchips) is available at no cost for windrows since vegetative debris removed from the VDOT right of way is suitable for windrow use. Sources of no-cost material are likely available throughout Virginia. The Hanging Rock AHQ previously obtained sawdust from a local furniture manufacturer. The Fishersville AHQ had access to no-cost sawdust from a local saw mill and turkey litter from a nearby farm. Landscape companies may also be a source of free woodchips.

Mortality Characteristics

- An “average” deer mortality was evaluated at 105 lb in order to include fawn mortality (N. Lafon, personal communication).

- An average deer mortality yields 0.161 $yd^3$of compost end product.

VDOT Equipment and Labor

- VDOT vehicles achieve 14 mpg, and diesel fuel costs $3/gal.

- The labor costs for loading deer and managing compost were estimated at 1.75 minutes per deer for windrows, 3 minutes per deer for the rotary drum, and 5.8 minutes per deer for the forced air system.

- All study areas have sufficient labor resources to implement composting with no additional staffing.

- Labor effort associated with each composting method is the same in all study areas.

General

- Relative costs are stable over the service life of each composting option.

- A discount rate of 0.04 was employed unless otherwise noted.

Case Studies

The study areas were grouped according to their method of animal mortality management. The cost results for each case study provide a value that assumes a cost for the carbon source and another that assumes a no-cost carbon source was used. As stated previously, a composting method was considered cost-effective if the PV of its lifetime cost was equal to or less than the savings from replacing the previous mortality management method used.

Leesburg and Charlottesville Residencies

In discussions with Leesburg Residency staff, the researchers learned that the Leesburg Residency plans to install a compost vessel and continue the use of a contractor for mortality collection and delivery to the composting site   It was assumed that the Charlottesville Residency would also continue to employ a contractor for pickup and delivery of mortality to the residency composting site. Both residency cost models assume contractor services in a composting scenario would be procured at a fixed rate per mortality, as in their current mortality management. For both residencies, the assumption of continued use of a contractor in the composting scenarios precluded any explicit travel cost savings to VDOT resulting from the implementation of composting; instead, lower contractor mortality pickup (CPU) costs (i.e., lower than FSC rates per carcass) were presumed because of time and labor savings from a reduced drive distance for the contractor for mortality disposal. A CPU rate of $29 per mortality was employed for each baseline composting scenario analysis for the residencies in Tables 3 through 5, after discussion with residency staffs.

Table 3 summarizes current mortality management costs for the Leesburg and Charlottesville residencies. In Tables 4 and 5, the cost of the current practice of FSC mortality management was compared with the cost of each composting method over the service life of the composting method equipment for each residency.

Table 3. Study Area Costs: Leesburg and Charlottesville Residencies

Residency	FY14 Mortality	Topsoil Class A (2-in depth) ($/acre)	Full Service Contractor Cost/Deer ($)[a]	Total Expenditure on Contractor Mortality Management, FY14 ($)
Charlottesville	1,575	3,185	38	60,455
Leesburg	1,442	3,761	36.90	54,164

[a] Final FY14 rate after mid-year contract renegotiation.

For the cost comparisons, the PV of FSC costs (Eq. 3) was calculated over the specific service life of the equipment for each composting method for comparison with the costs of the composting alternatives:

PV (FSC over service life of composting method (i)) = PVD(i)*(Annual FSC cost) [Eq. 6]

where

Annual FSC cost = FSC ($)/Deer*FY14 mortality.
PVD(i) are as shown in Table 2.

The results of the first cost comparisons, i.e., those between PVs of lifetime costs, are provided in Table 4. Ranges are provided to illustrate the gains from valuation of the end product at the weighted average price of Topsoil Class A at a 2-in depth (the lower cost includes valuation of the compost end product).

Table 4. PVs of Lifetime Costs of Mortality Management Methods: Charlottesville and Leesburg Residencies

Residency (FY14 Deer Mortality)	Forced Air System (50-yr SL)[a] ($ millions)	Rotary Drum (20-yr SL)[a] ($ millions)	Windrows (100-yr SL) ($ millions)
Charlottesville (1,575)			
PV of FSC cost over composting equipment service life	1.29	0.824	1.47
PV of lifetime cost of composting method; no recycling of carbon source, carbon source at $7.34/mortality	1.42 -1.49	0.824-0.866	N/A
PV of lifetime cost of composting method if no-cost carbon source were available	1.16-1.23	0.653-0 .695	1.07-1.14
Leesburg (1,442)			
PV of FSC cost over composting equipment service life	1.15	0.733	1.31
PV of lifetime cost of composting method; no recycling of carbon source, carbon source at $7.34/mortality	1.31-1.38	0.752-0.796	N/A
PV of lifetime cost of composting method if no-cost carbon source were available	1.07-1.14	0.595-0.640	0.970-1.05

PV = present value; SL = service life; FSC =-full service contractor; N/A = scenario not evaluated for static windrows.
[a] Service life as determined by manufacturers' estimates (K. Warren and B. Irwin, personal communication).

The results presented in Table 4 support three conclusions for the Charlottesville and Leesburg residencies.

1. Neither residency can employ the forced air system as cost-effectively as FSC mortality management over the service life of the forced air system (50 years) under the baseline assumptions including a carbon source price at around $7.30 per deer. A free carbon source, however, makes the forced air system highly cost-effective in both residencies.

2. Rotary drum composting is marginally cost-effective in the Charlottesville Residency compared with FSC over the service life of the drum (20 years). During periods of heaviest mortality, however, the residency would probably exceed the loading capacity of the rotary drum model considered in this study. However, a free carbon source makes rotary drum composting highly cost-effective relative to FSC over 20 years in both residencies.

3. Windrow composting is more cost-effective than FSC in both residencies over the 100-year period for which it was evaluated. (Windrow composting has an unlimited service life, but the PVD evaluated for even 100 years is mathematically limited to a value of 25, which allows computation of "lifetime" costs for windrows.) As noted earlier, compost is assumed to be free for windrows as a byproduct of debris removal from VDOT right of way.

Table 4 indicates whether lifetime costs of alternatives will converge within the equipment service life and, if convergence occurs early enough, reverse their initial relative order during the equipment service life. Table 5 provides slightly different information: (1) the number of years N required for the PV of the costs of the composting method to equal those of FSC mortality management given FY14 mortality, and (2) the annual mortality D required for the two methods under comparison to have equal lifetime costs within the service life of the composting equipment.

The values in Table 5 support the conclusions that windrows are always cost-effective compared to FSC mortality management; that the forced air system will become cost-effective in both residencies if a carbon source is available at no cost; and that rotary drums could be highly cost-effective (i.e., within a few years of their implementation and early in their service life) if a carbon source is available at no cost. Again, during periods of heaviest mortality, both residencies will probably exceed the loading capacity of this model of rotary drum. Windrows or a landfill could be used as an occasional alternative.

Table 5. Time N and Annual Deer Mortality D Required for PV Cost Parity Between Composting Methods and FSC Mortality Disposal

Residency (FY14 Deer Mortality)	Forced Air System (50-yr SL)[a]	Rotary Drum (20-yr SL)[a]	Windrows (100-yr SL)
Charlottesville (1,575)			
Carbon source at $7.34/mortality	N = DNE, D = 5,145	N = 20, D = 1,579	N/A
With recycling of 50% of carbon source in forced air system only	N = DNE, D = 1,981	N/A	N/A
If no-cost carbon source were available	N = 15, D = 908	N = 3, D = 329	N = 0, D = 0
Leesburg (1,442)			
Carbon source at $7.34/mortality	N= DNE, D = 9,258	N = DNE, D = 2,193	N/A
With recycling of 50% of carbon source in forced air system only	N = DNE, D = 2,496	N/A	N/A
If no-cost carbon source were available	N = 20, D = 991	N = 4, D = 356	N = 0, D = 0

PV = present value; FSC = full service contractor; SL = service life; DNE = the computed value does not exist; N/A = scenario not evaluated.

[a] Service life as determined by manufacturers' estimates (K. Warren and B. Irwin, personal communication).

Three variables in the model were manipulated to observe their effects on comparative lifetime costs: the recycling of carbon source in the forced air system, the CPU rate per deer, and the availability of a free carbon source. Assuming a CPU rate of $29 per deer mortality and the median annual salary for each residency for composting-related labor, mere recycling of the carbon source in the forced air system did not cause the forced air system to become cost-effective in either residency over the forced air system service life. On the other hand, lowering the CPU rate will cause declines in N and D in both residencies. Assuming the recycling of one-half of the annual carbon source used in the forced air system, a CPU rate per deer of no more than $27 allows the forced air system to be more cost-effective than FSC well within the forced air system service life in the Charlottesville Residency. For the Leesburg Residency, a CPU rate per deer of no more than $26 allows the overall costs of the forced air system to fall below those of FSC well within 50 years. These results presume a carbon source priced at the Bethel AHQ rate.

Assuming the availability of a free carbon source, however, the CPU rate per deer for the Charlottesville Residency may be as much as $32.50 without causing the forced air system to lose its lifetime cost advantage over FSC. In the Leesburg Residency, the CPU rate per deer may be as much as $31.50 without causing the forced air system to lose its lifetime cost advantage over FSC mortality management. Since the start-up costs of the rotary drum are far less than those of the forced air system, the outcomes are even more advantageous for rotary drum composting relative to FSC, although windrow use may be needed to supplement drum capacity during high mortality periods.

Stony Creek and Windsor AHQs

The Stony Creek and Windsor AHQs each currently employ two AHQ crew members to retrieve mortality and to bury it in VDOT right of way. The cost models for these AHQs capture the vehicle and labor time expended for burial activity. There are no changes to travel for mortality collection entailed in the composting options, hence no travel savings were modeled other than those associated with foregone burial activities. Labor was valued at the median annual AHQ-specific salary since mortality management is essentially a duty of all operators. Table 6 gives mortality and local costs for the study areas.

Table 6. Study Area Costs: Stony Creek and Windsor AHQs

AHQ	FY14 Mortality[a]	Topsoil Class A (2-in depth) ($/acre)[b]	Median Annual AHQ Salary ($)	One-way Travel Distance for Mortality Burial (mi)
Stony Creek	44	4,261	35,455	1.5
Windsor	273	4,261	40,246	12

AHQ = area headquarters.
[a] Estimated.
[b] Weighted average, Hampton Roads District.

The cost equation describing current practice at these AHQs, with which composting alternatives were compared, is given generally by Equation 7.

PV (Burial over service life of any composting method (i)) = PVD(i)*(Annual cost of burial) = PVD(i)*(Vehicle cost + Labor cost for burial) [Eq. 7]

The comparative results for lifetime costs at these study areas are shown in Table 7. Estimated mortality in FY14 for the Windsor AHQ was sufficient to make the rotary drum cost competitive with current burial practices during the drum service life. Neither cash benefit from windrow composting should be taken at face value given the horizon of 100 years over which it was calculated, but the potential cumulative costs of $550 and $3,800 emphasize the low cost of windrow composting over long periods of time even when end product value is disregarded.

Table 8 summarizes the time N and annual mortality D required to cause a composting alternative to reach parity in PV of lifetime cost with the total cost of current practice, i.e., burial, in these AHQs. The results shown in Table 8 support the conclusion that mortality in either AHQ alone is insufficient to make the forced air system cost competitive during the forced air system service life, even given the availability of a free carbon source. The Stony Creek AHQ mortality is so low that windrows are clearly the most cost-effective option. Yet if the forced air system equipment at the Stony Creek AHQ were shared with other AHQs, it seems possible that PV costs of composting by means of the forced air system could reach lifetime parity with PV costs of other disposal methods. Further detailed analysis is recommended in order to consider the influence of travel costs entailed in sharing a composting facility among several AHQs at the Stony Creek AHQ.

The results shown in Table 8 indicated that rotary drum composting was cost-effective at the Windsor AHQ even with a carbon source assumed to cost the Bethel AHQ rate ($7.34) per deer. Cost-effectiveness can only increase with the availability of a no-cost carbon source.

It is important to note that regardless of whether composting is cost-effective for the Stony Creek and Windsor AHQs, they are examples of AHQs for which the need for an alternative mortality management method outweighs the cost. With no landfill options and a decreasing availability of viable burial locations, composting is an available alternative.

Table 7. PVs of Lifetime Costs of Mortality Management Methods: Stony Creek and Windsor AHQs

AHQ (FY14 Deer Mortality)	Forced Air System (50-yr SL)[a] ($)	Rotary Drum (20-yr SL)[a] ($)	Windrows (100-yr SL) ($)
Stony Creek (44)			
PV of burial disposal cost over composting equipment service life	14,300	9,100	16,300
PV of lifetime cost of composting method; no recycling of carbon source, carbon source at $7.34/mortality	184,000-186,400	48,800-50,300	N/A
PV of lifetime cost of composting method if no-cost carbon source were available	176,600-179,000	44,000-45,500	(2,200)-550
Windsor (273)			
PV of burial disposal cost over composting equipment service life	118,700	75,600	134,700
PV of lifetime cost of composting method; no recycling of carbon source, carbon source at $7.34/mortality	218,700-233,800	68,700-78,200	N/A
PV of lifetime cost of composting method if no-cost carbon source were available	173,400-188,500	39,100-48,700	(13,300)-3,800

PV = present value; AHQ = area headquarters; SL = service life; N/A = scenario not evaluated.
Dollar amounts in parentheses indicate revenue gained from use of end product.
[a] Service life as determined by manufacturers' estimates (K. Warren and B. Irwin, personal communication).

Table 8. Time N and Annual Deer Mortality D Required for PV Cost Parity Between Composting Methods and Mortality Disposal by Burial: Stony Creek and Windsor AHQs

AHQ (FY14 Deer Mortality)	Forced Air System (50-yr SL)[a]	Rotary Drum (20-yr SL)[a]	Windrows (100-yr SL)
Stony Creek (44)			
Carbon source at $7.34/mortality	N = DNE, D = 971	N = DNE, D = 355	N/A
With recycling of 50% of carbon source in forced air system only	N = DNE, D = 757	N/A	N/A
If no-cost carbon source were available	N = DNE, D = 565	N = DNE, D = 197	N = 0, D = 0
Windsor (273)			
Carbon source at $7.34/mortality	N = DNE, D = 617	N = 16, D = 238	N/A
With recycling of 50% of carbon source in forced air system only	N = DNE, D = 524	N/A	N/A
If no-cost carbon source were available	N = DNE, D = 420	N = 9, D = 151	N = 0, D = 0

PV = present value; AHQ = area headquarters; SL = service life; DNE = computed value does not exist; N/A = scenario not evaluated.
[a] Service life as determined by manufacturers' estimates (K. Warren and B. Irwin, personal communication).

Oilville, Fairfield, and Toms Brook AHQs

The Oilville, Fairfield, and Toms Brook AHQs crews each currently retrieve mortality from VDOT-maintained roads in their respective area in two-person teams. Each AHQ also disposes of animal mortality at no-fee landfill or transfer stations. The Oilville AHQ uses two landfills outside the AHQ area; in this model, travel savings from composting by any method at the Oilville AHQ consisted of round trip mileage between the AHQ boundary (the location at which any AHQ maintenance responsibility would terminate) and each landfill location. The Fairfield and Toms Brook AHQs disposed of mortality at a facility within the AHQ area; travel savings from composting by any method at these AHQs consisted in this model of the mileage of the return trip (a travel cost that would be avoided altogether if no mortality were delivered to the disposal facility) from the disposal facility to the AHQ offices. As in all preceding analyses, labor was valued at the median annual AHQ-specific salary since mortality management is essentially a duty of all operators.

Table 9 gives local costs, mortality, and estimated travel distances for the study areas. The cost equation describing current practice at these AHQs, with which composting alternatives were compared, is given generally by Equation 8.

Table 9. Study Area Costs: Oilville, Fairfield, and Toms Brook AHQs

AHQ	FY14 Mortality[a]	Topsoil Class A (2-in depth) ($/acre)[b]	Median Annual AHQ Salary ($)	Travel Distance Saved by Composting (mi)
Oilville	234	4,901	35,892	15.84[c]
Fairfield	155	5,348	33,181	13.3[d]
Toms Brook	124	5,348	31,766	12.2[d]

AHQ = area headquarters.
[a] Estimated.
[b] Weighted averages for Richmond (Oilville AHQ) and Staunton (Fairfield and Toms Brook AHQs) districts.
[c] Weighted average of roundtrip distances from AHQ boundary to landfill.
[d] One-way distance between landfill and AHQ.

PV (No-fee landfill disposal over service life of any composting method (i))
= PVD(i)*(Annual cost of no-fee landfill disposal) = PVD(i)*(Annual vehicle cost
+ Labor cost for travel distance to no-fee landfill) [Eq. 8]

The comparative results for the PVs of lifetime costs at these study areas are shown in Table 10. Table 10 indicates that in addition to windrows, which were everywhere cost-effective whether the end product was used or not, the Oilville AHQ mortality was sufficient to make rotary drum composting cost competitive during the drum service life under the assumption of the Bethel AHQ cost of a carbon source. If a carbon source were available at no cost, the use of rotary drum composting by the Fairfield and Oilville AHQs would be highly cost-effective compared to current practices. The Toms Brook AHQ travel costs and mortality level were low compared to those of the other AHQs, and even a free carbon source was insufficient to make a rotary drum cost-effective in that location. In all three locations, however, topsoil is relatively valuable and compost end product by windrow composting could provide VDOT with a nontrivial benefit.

Table 10. PVs of Lifetime Costs of Mortality Management Methods: Oilville, Fairfield, and Toms Brook AHQs

AHQ (FY14 Deer Mortality)	Forced Air System (50-yr SL)[a] ($)	Rotary Drum (20-yr SL)[a] ($)	Windrows (100-yr SL) ($)
Oilville (234)			
PV of landfill disposal cost over composting equipment service life	106,100	67,600	120,400
PV of lifetime cost of composting method; no recycling of carbon source, carbon source at $7.34/mortality	210,000-224,800	63,800-73,200	N/A
PV of lifetime cost of composting method if no-cost carbon source were available	171,000-186,000	38,400-47,800	(14,000)-2,900
Fairfield (155)			
PV of landfill disposal cost over composting equipment service life	80,800	51,500	91,800
No recycling of carbon source, carbon source at $7.34/mortality	197,600-208,400	56,700-63,500	N/A
PV of lifetime cost of composting method if no-cost carbon source were available	171,900-182,600	39,900-46,800	(10,400)-1,800
Toms Brook (124)			
PV of landfill disposal cost over composting equipment service life	17,900	11,400	20,300
PV of lifetime cost of composting method; no recycling of carbon source, carbon source at $7.34/mortality	193,400-202,000	54,300-59,800	N/A
PV of lifetime cost of composting method if no-cost carbon source were available	172,800-181,400	40,900-46,300	(8,400)-1,400

PV = present value; AHQ = area headquarters; SL = service life; N/A = scenario not evaluated.
Dollar amounts in parentheses indicate revenue gained from use of end product.
[a] Service life as determined by manufacturers' estimates (K. Warren and B. Irwin, personal communication).

Table 11 summarizes the time N at FY14 mortality and, alternatively, the annual mortality D required for a composting alternative to reach lifetime PV cost parity with the cost of current practice, i.e., landfill or transfer station disposal. The values in Table 11 support the feasibility of rotary drum composting at the Oilville AHQ: the required minimum annual mortality of 217 is below what was estimated for FY14 (234), and, alternatively, breakeven N is within the 20-year service life of the drum equipment at FY14 mortality. By contrast, the forced air system and rotary drum composting methods for the Toms Brook AHQ require exceptionally high annual mortality levels to achieve breakeven costs with current practice using landfill disposal. The likeliest explanation is that trip costs of current practices and mortality were relatively low for the Toms Brook AHQ.

Table 11. Time N and Annual Deer Mortality D Required for PV Cost Parity Between Composting Methods and Mortality Disposal at Landfill or Transfer Station: Oilville, Fairfield, and Toms Brook AHQs

AHQ (FY14 Deer Mortality)	Forced Air System (50-yr SL)[a]	Rotary Drum (20-yr SL)[a]	Windrows (100-yr SL)
Oilville (234)			
Carbon source at $7.34/mortality	N = DNE, D = 558	N = 18, D = 217	N/A
With recycling of 50% of carbon source in forced air system only	N = DNE, D = 486	N/A	N/A
If no-cost carbon source were available	N = DNE, D = 370	N = 10, D = 142	N = 0, D = 0
Fairfield (155)			
Carbon source at $7.34/mortality	N = DNE, D = 448	N = 24, D = 175	N/A
With recycling of 50% of carbon source in forced air system only	N = DNE, D = 403	N/A	N/A
If no-cost carbon source were available	N = DNE, D = 318	N = 14, D = 123	N = 0, D = 0
Toms Brook (124)			
Carbon source at $7.34/mortality	N = DNE, D = 7,831	N = DNE, D = 1,889	N/A
With recycling of 50% of carbon source in forced air system only	N = DNE, D = 2,641	N/A	N/A
If no-cost carbon source were available	N = DNE, D = 978	N = DNE, D = 359	N = 0, D = 0

PV = present value; AHQ = area headquarters; SL = service life; DNE = computed value does not exist; N/A = scenario not evaluated.
[a] Service life as determined by manufacturers' estimates (K. Warren and B. Irwin, personal communication).

Fishersville AHQ

The Fishersville AHQ crews collect mortality on roads in their maintenance area and use rotary drum composting as their current mortality management method. The Fishersville AHQ can obtain sawdust for $100 per tandem load, which is estimated to contain about 14 yd^3 of material and generate a cost of $2.45 per deer (on a 1:1 volume basis), as opposed to $7.34 per deer used in other analyses based on the Bethel AHQ carbon source costs. As with the Fairfield and Toms Brook AHQs, the landfill location is within the AHQ maintenance area, so travel savings, at a minimum, are the vehicle and labor costs of the return trip from the landfill to the AHQ, a trip that would not occur if mortality were not delivered to the landfill. Since the Fishersville AHQ has "sunk" costs in the rotary drum, the forced air system was not evaluated; instead, the rotary drum was contrasted with windrows and with the no-fee landfill option, which was formerly its primary method of mortality management.

Table 12 gives mortality, local costs, and travel distance for the study area. The cost equation describing current practice at the Fishersville AHQ, i.e., rotary drum composting, is given in Equation 9, and the alternative is given in Equation 10. The windrow equation is not specified here although it was included in the analysis as an alternative.

PV (Rotary drum composting method over drum service life) = Up-front cost of drum + PVD (Drum)*(Annual total cost of drum composting) [Eq. 9]

PV (Cost of landfill disposal over service life of drum) = PVD (Drum)*(Total trip cost/yr) [Eq. 10]

The comparative results for the PV of lifetime costs at the Fishersville AHQ are shown in Table 13. The values in Table 13 suggest that the rotary drum currently in use at the Fishersville AHQ would not be judged to be cost-effective on the basis of the PV of its lifetime cost, even given a low carbon source cost, if it were under evaluation relative to landfill use rather than already implemented. On the other hand, Table 14 provides a target annual mortality volume, i.e., 181, that would cause the drum to be cost-effective within its 20-year service life, a goal that might be well within reach if the drum were shared with other AHQs.

Table 12. Study Area Costs: Fishersville AHQ

AHQ	FY14 Mortality[a]	Topsoil Class A (2-in depth) ($/acre)[b]	Median Annual AHQ Salary ($)	Travel Distance Saved by Composting (mi)[c]
Fishersville	120	5,348	32,916	16.2

AHQ = area headquarters.
[a] Estimated.
[b] Weighted average for Staunton District.
[c] One-way from AHQ to landfill facility.

Table 13. PVs of Lifetime Costs of Current Rotary Drum Composting System and Alternatives: Fishersville AHQ

AHQ (FY14 Deer Mortality)	Rotary Drum (20-yr SL)[a] ($)	Windrows (100-yr SL) ($)
Fishersville (120)		
PV of landfill disposal cost over composting equipment service life	30,100	53,700
PV of lifetime cost of composting method; no recycling of carbon source, carbon source at $2.45/mortality	45,400-50,700	N/A
PV of lifetime cost of composting method if no-cost carbon source were available	41,000-46,300	(8,100)-1,400

PV = present value; AHQ = area headquarters; SL = service life; N/A = scenario not evaluated.
Dollar amounts in parentheses indicate revenue gained from use of end product.
[a] Service life as determined by manufacturer's estimate (B. Irwin, personal communication).

Table 14. Time N and Annual Deer Mortality D Required for PV Cost Parity Between Composting Method and Mortality Disposal at Landfill or Transfer Station: Fishersville AHQ

AHQ (FY14 Deer Mortality)	Rotary Drum (20-yr SL)[a]	Windrows (100-yr SL)
Fishersville (120)		
Carbon source at $2.45/mortality	N = DNE, D = 181	N/A
If no-cost carbon source were available	N = DNE, D = 158	N = 0, D = 0

PV = present value; AHQ = area headquarters; SL = service life; DNE = computed value does not exist; N/A = scenario not evaluated
[a] Service life as determined by manufacturer's estimate (B. Irwin, personal communication).

Table 14 also indicates that if a carbon source were available at no cost, the rotary drum could become cost-effective if mortality were only 26% greater, or around 40 mortalities above the estimated mortality for FY14. Nearby AHQs that are incurring vehicle, labor, and/or dump costs from mortality management might find mortality delivery to the Fishersville AHQ an attractive option.

Hanging Rock, Southwest, and Troutville AHQs

The Hanging Rock AHQ is the site of a forced air system that is used by the Hanging Rock, Southwest, and Troutville AHQs. Although mortality processed in the forced air system is composed of the mortality from all three AHQs, weekly diaries were available only from the Hanging Rock and Southwest AHQs. Prior to composting mortality at the Hanging Rock AHQ, the Hanging Rock and Southwest AHQs in Roanoke County delivered their mortality to a facility in Montgomery County using a two-person crew consisting of one person from each AHQ. The facility accepted VDOT mortality for a fee of about $2.73 per (average) deer until fiscal year 2015 (FY15), when the fee rose to about $2.84 per (average) deer. In this analysis, travel savings from the implementation of composting at the Hanging Rock AHQ consisted of the round trip distance between the AHQ boundary on I-81 and the landfill location in Montgomery County, since this travel would become altogether unnecessary for mortality disposal once the forced air system was in operation. A carbon source was available for about $1 per average deer.

Table 15 gives local costs, mortality, and travel distance for the study area. The cost equation describing the current practice at the Hanging Rock AHQ, i.e., a forced air system, is given by Equation 11.

PV (Forced air system over system service life) = Up-front cost of forced air system
+ PVD (Forced air system)*(Annual total cost of forced air system composting) [Eq. 11]

Table 15. Study Area Costs: Hanging Rock and Southwest AHQs

AHQ	FY14 Mortality[a]	Topsoil Class A (2-in depth) ($/acre)[b]	Median Annual AHQ Salary ($)	Travel Distance Saved by Composting (mi)[c]
Hanging Rock and Southwest	463	8,195	32,019 (Hanging Rock) 29,480 (Southwest)	43.1

AHQ = area headquarters.
[a] Combined, estimated.
[b] Weighted average for Salem District.
[c] Round trip from AHQ boundary to landfill facility.

The current design of forced air system was compared with the alternatives of landfill, rotary drum, and windrows at the Hanging Rock AHQ; the comparative results for the PV of lifetime costs are given in Table 16.

Table 16. PVs of Lifetime Costs of Current Forced Air Composting System and Alternatives: Hanging Rock and Southwest AHQs

AHQ (FY14 Deer Mortality)	Forced Air System (50-yr SL)[a] ($)	Rotary Drum (20-yr SL)[a] ($)	Windrows (100-yr SL) ($)
Hanging Rock and Southwest (463)			
PV of landfill disposal cost over composting equipment service life	197,900	126,000	224,700
PV of lifetime cost of composting method; no recycling of carbon source, carbon source at $1.04/mortality	154,600-203,700	25,700-57,000	N/A
PV of lifetime cost of composting method if no-cost carbon source were available	143,800-192,900	18,700-49,900	(50,700)-5,100

PV = present value; AHQ = area headquarters; SL = service life; N/A = scenario not evaluated.
Dollar amounts in parentheses indicate revenue gained from use of end product.
[a] Service life as determined by manufacturers' estimates (K. Warren and B. Irwin, personal communication).

The values in Table 16 indicate that composting mortality from multiple AHQs in the forced air system at the Hanging Rock AHQ was a cost-effective means of mortality disposal compared to the landfill option. The combination of a relatively large travel savings, landfill dump charges, high topsoil value, and mortality levels allowed the forced air system costs to amount to about 78% of landfill costs over the forced air system service life if the composting end product were used by VDOT in place of topsoil. If a no-cost carbon source became available, the most significant gain would be that the composting end product would not need to be used in order for the forced air system composting to be effective compared to the landfill option.

The values in Table 16 also indicate that the rotary drum and windrows were also cost-effective methods for management of the combined mortality of these AHQs. The estimated $50,000 in reusable end product at current prices over the 100-year horizon of windrows should not be taken at face value, given the distant horizon over which the benefit is calculated. Yet the low cost of about $5,000 for windrow composting, even if the end product value is disregarded, relative to the landfill alternative over the hypothetical time horizon of 100 years emphasizes the cumulative cost advantage of windrows.

Table 17 summarizes the time N and annual combined mortality D required to cause a composting alternative to be equal in PV of lifetime cost to the total cost of landfill disposal of the same mortality.

Table 17. Time N and Annual Deer Mortality D Required for PV Cost Parity Between Composting Methods and Mortality Disposal at Landfill or Transfer Station: Hanging Rock and Southwest AHQs

AHQ (FY14 Deer Mortality)	Forced Air System (50-yr SL)[a]	Rotary Drum (20-yr SL)[a]	Windrows (100-yr SL)
Hanging Rock and Southwest (463)			
Carbon source at $1.04/mortality	N = 27, D = 372	N = 5, D = 144	N/A
With recycling of 50% of carbon source in forced air system only	N = 33, D = 408	N/A	N/A
If no-cost carbon source were available	N = 24, D = 355	N = 4, D = 137	N = 0, D = 0

PV = present value; AHQ = area headquarters; SL = service life; N/A = scenario not evaluated.
[a] Service life as determined by manufacturers' estimates (K. Warren and B. Irwin, personal communication).

The high value of topsoil in the study area caused the counterintuitive result that recycling of one-half the carbon source caused the cost-effectiveness of the forced air system to fall relative to that of the landfill option, but the result is reasonable given that halving the annual volume of end product causes a greater dollar loss than is gained by halving annual carbon source purchases. In any case, however, the forced air system at the Hanging Rock AHQ that is shared by three AHQs is very likely to be a cost-effective investment in mortality management over its service life since N in all three scenarios for the forced air system was well below 50 years and D is well below the combined mortality of the Hanging Rock and Southwest AHQs alone (i.e., excluding the Troutville AHQ mortality).

Summary Results for All Case Studies

Key summary results for the case studies are shown in Tables 18 and 19. Table 18 contrasts mortality in FY14 with that required to enable the parity of composting costs with landfill costs over the service life of the composting equipment (i.e., 50 years for forced air system, 20 years for rotary drum). Differences between actual and target mortality levels draw attention to the economic value captured by the sharing of composting facilities when they are underused. Two CPU rates were applied for comparison in each set of residency costs.

Table 18. FY14 Deer Mortality and Annual Mortality Required for Cost Parity With Landfill Option Over Vessel Service Life: All Case Studies

Case Study Area	FY14[a] Mortality	Forced Air System: Required Mortality	Rotary Drum: Required Mortality
Charlottesville Residency	1,575	5,145 (908)[b]	1,579(329)[b]
		DNE (1,482)[c]	DNE (508)[c]
Leesburg Residency	1,442	9,258 (991)[b]	2,193 (356)[b]
		DNE (1,420)[d]	DNE (489)[d]
Stony Creek AHQ	44	971 (565)	355 (197)
Windsor AHQ	273	617 (420)	238 (151)
Oilville AHQ	234	558 (370)	217 (142)
Fairfield AHQ	155	448 (318)	175 (123)
Toms Brook AHQ	124	7,831 (978)	1,889 (359)
Fishersville AHQ	120	N/A	181 (158)
Hanging Rock and Southwest AHQs	463	372 (355)	144 (137)

AHQ = area headquarters; N/A = scenario not evaluated. Numbers in parentheses are annual mortalities required for cost parity if a no-cost carbon source is available. DNE = cost-effective level of mortality does not exist at carbon source price of $7.34/deer.
[a] Estimated for AHQ, actual for residencies.
[b] Assumes a contractor mortality pickup (CPU) rate of $29/mortality.
[c] Assumes a CPU rate of $32.50/mortality.
[d] Assumes a CPU rate of $31.50/mortality.

Table 19 summarizes the maximum savings potentially available from vessel composting at each of the case study areas. Although windrow composting is everywhere cost-effective and can even turn mortality into revenue if a carbon source is obtained at no cost *and* the end product is used by VDOT in place of Topsoil Class A 2 in (Item Code 27012) or a similar item, it is clear from Table 19 that in some locations vessel composting—especially by rotary drum—is cost-effective in the present. In others, the values in Tables 18 and 19 together indicate that mortality management by composting has the potential to become relatively cost-effective by means of combining the mortality of several AHQs at a vessel location.

The savings represented in Table 19 consist of the lifetime cost differences between the non-compost mortality disposal method available to the study area and the vessel when a no-cost carbon source is assumed available and the end product is used in place of items VDOT normally purchases. It should be noted that the locations showing huge savings attributable to the rotary drum (i.e., the Hanging Rock AHQ and the Charlottesville and Leesburg residencies) would need a forced air system to accommodate their large mortality volumes. Others would likely need supplemental windrows to handle surges in mortality during peak months when mortality arrivals exceeded the drum loading rate.

Table 19. Maximum Savings (or Losses) of Mortality Management by Composting Rather Than Alternative Over Equipment Service Life and at FY14 Mortality: All Case Studies

Case Study Area	Forced Air System	Rotary Drum
Charlottesville Residency	$11,148[a]	$94,655[a]
Leesburg Residency	$2,703[b]	$87,624[b]
Stony Creek AHQ	($162,200)	($34,900)
Windsor AHQ	($54,800)	$36,500
Oilville AHQ	($65,000)	$29,200
Fairfield AHQ	($91,048)	$11,600
Toms Brook AHQ	($155,000)	($29,500)
Fishersville AHQ	N/A	($10,900)
Hanging Rock and Southwest AHQs	$54,000[c]	$107,400

AHQ = area headquarters; N/A = scenario not evaluated.
Values in parentheses are losses relative to current mortality management methods from the implementation of composting.
[a] Assuming a contractor mortality pickup (CPU) rate of $32.50/mortality.
[b] Assuming a CPU rate of $31.50/mortality.
[c] Forced air system is currently implemented at this location.

General Rule for Determining Cost-effectiveness of Composting

The ratio of start-up costs to the initial year of savings from implementation of composting can suggest the likelihood of cost-effectiveness of composting for a maintenance area. In Equation 4, N is defined as the number of years required for the PV of the lifetime costs of the current practice to equal that of a composting method given FY14 mortality. The ratio A/B (the ratio of a specific composting method's fixed start-up costs incurred in the first year to operational cost *savings*, excluding all fixed costs captured in A, from disposing of annual mortality by the specific composting method rather than the current non-composting method) is a factor in the calculation of N. Therefore, analysis of the correlation between pairs of A/B and the corresponding N allows development of sketch-level generalizations for estimating the cost-effectiveness of compost vessels. (Windrows are always cost-effective provided a carbon source is available at no cost and provided the cost model assumptions are valid for a maintenance area.)

In the calculation of N, A and B have the following definitions for a given level of mortality (FY14 in the current cost models):

A = Costs of composting equipment + Site construction + First year of carbon source [Eq. 12]

B = Operational cost difference between annual mortality disposal by the current mortality management method and by the composting method, excluding fixed costs [Eq. 13]

The ratio of A to B gives the relative magnitude of start-up costs to the first year of operational *savings* made possible by the specific method of composting under consideration.

Table 20 summarizes the outcomes for all the case studies under two scenarios: (1) the base case (no recycling of compost and carbon source at local price), and (2) the no-cost carbon source case. The cost-effectiveness of composting by either vessel method is indicated by a value of N that is equal to or less than the equipment service life. Cost-effectiveness for the forced air system requires a calculated N of 50 (i.e., equipment service life) or less and for the rotary drum a calculated value of N of 20 or less.

As a general rule, a value for A/B that is correlated with a maximum value for N of 50 for the forced air system and a maximum value for N of 20 for the rotary drum would indicate the maximum ratio between composting start-up costs and annual cost savings made possible by composting that could still result in lifetime cost-effectiveness of vessel composting. Beyond these two values for A/B, N would exceed 50 or 20, respectively, and thus breakeven total (lifetime) costs would never be achieved by a compost vessel relative to the current mortality management practice.

To determine such A/B values that correlate with N = 50 for the forced air system and N = 20 for the rotary drum composting methods, cost-effective pairs of A/B and N values (i.e., in Table 20, bold N and corresponding A/B values) were separated and graphed by composting method. Trendlines were fit and examined for the highest R^2 values. Equations 14 and 15 give the selected trendlines and their R^2 values for the forced air system and the rotary drum, respectively.

$$N = 0.3165*(A/B)^2 - 7.6291*(A/B) + 66.466 \qquad R^2 = 0.9996 \qquad \text{[Eq. 14]}$$

$$N = 0.0475*(A/B)^2 + 0.7294*(A/B) + 0.7683 \qquad R^2 = 0.9993 \qquad \text{[Eq. 15]}$$

Setting Equation 14 equal to 50 (i.e., N = 50) and solving for A/B gives A/B = 21.71. In other words, as a general rule the forced air system ceases to be cost-effective if its start-up costs are more than about 22 times greater than the first year of operational savings expected from the forced air system.

Setting Equation 15 equal to 20 (i.e., N = 20) and solving for A/B gives A/B = 13.86. In other words, as a general rule the rotary drum ceases to be cost-effective if its start-up costs are more than about 14 times greater than the first year of operational savings expected from rotary drum composting.

Table 20. Summary of Case Study Outcomes for Two Cost Scenarios: Base Case and No-Cost Carbon Source

Composting Method		Charlottesville Residency	Leesburg Residency	Stony Creek AHQ	Windsor AHQ	Oilville AHQ	Fairfield AHQ	Toms Brook AHQ	Fishersville AHQ	Hanging Rock and Southwest AHQs
Forced Air System										
Base case	A	$150,461	$149,484	$139,226	$140,903	$140,620	$140,038	$139,810	N/A	$139,380
	B	($4,619)	($4,033)	($1,406)	$1,890	$1,700	$1,076	($1,653)	N/A	$8,452
	A/B	(33)	(37)	(99)	75	83	130	(85)	N/A	16.5
	N	DNE	DNE	DNE	DNE	DNE	DNE	DNE	N/A	**27**
Free carbon source	A	$138,900	$138,900	$138,900	$138,900	$138,900	$138,900	$138,900	N/A	$138,900
	B	$6,942	$6,551	($1,137)	$3,545	$3,420	$2,214	($743)	N/A	$8,932
	A/B	20.0	21.2	(122)	39	41	63	(187)	N/A	15.6
	N	**40**[a]	**47**[b]	DNE	DNE	DNE	DNE	DNE	N/A	**24**
Rotary Drum										
Base case	A	$54,936	$53,959	$43,701	$45,378	$45,095	$44,513	$44,285	$43,669	$43,855
	B	($1,533)	($1,068)	$292	$3,800	$3,552	$2,854	$99	$2,064	$10,473
	A/B	(36)	(51)	150	12	127	15.6	447	21	42
	N	DNE	DNE	DNE	**16**	**18**	24	DNE	47	**5**
Free carbon source	A	$43,375	$43,375	$43,375	$43,375	$43,375	$43,375	$43,375	$43,375	$43,375
	B	$10,027	$9,516	$619	$5,803	$5,272	$3,992	$1,009	$2,358	$10,953
	A/B	4.3	4.6	70.1	7.5	8.2	10.9	43.0	18.4	4.0
	N	**5**[a]	**5**[b]	DNE	**9**	**10**	**14**	DNE	DNE	**4**

AHQ = area headquarters; A as defined in Eq. 12; N/A = scenario not evaluated; B as defined in Eq. 13; DNE = value of N cannot be computed or exceeds the relevant equipment service life. Values in bold indicate cost-effective conditions for composting.

[a] Assuming a contractor mortality pickup (CPU) rate of $32.50/mortality.

[b] Assuming a CPU rate of $31.50/mortality.

CONCLUSIONS

- *Although some AHQs are satisfied with their current disposal methods and have access to nearby landfills, others have an urgent need for an alternative and they consider composting a potentially viable solution.*

- *AHQs with inefficient and/or costly methods of animal mortality disposal can save time and costs by replacing their current method with a composting alternative.*

- *Of the AHQs evaluated, windrows were always cost-effective assuming AHQs have adequate space or right of way in which to meet setback requirements.*

- *Of the AHQs evaluated that use a contractor to pick up mortalities and bring them to an AHQ compost vessel, vessels can be cost-effective if the AHQ has negotiated a sufficiently favorable contractor pickup rate per mortality and has access to a free carbon source.*

- *Of the AHQs evaluated that replace their landfill method of disposal with composting, a rotary drum can be cost-effective even for the relatively low mortality of an individual AHQ and a forced air system can be cost-effective for AHQs that share the system with one or more AHQs.*

- *Of the AHQs evaluated, using a carbon source at no cost to the AHQ increases the number of cost-effective choices available to individual maintenance areas. Conversely, the cost of the carbon source may restrict the cost-effective use of either vessel system at a particular facility.*

- *Sharing a compost vessel between two or more AHQs will increase the cost-effectiveness of vessel composting assuming mortality-related travel costs will not be significantly increased.* This is especially the case with forced air systems, which can accommodate greater volumes of mortality than rotary drums. The Charlottesville and Leesburg residencies could employ forced air systems with great cost-effectiveness if a no-cost carbon source could be obtained. This high cost-effectiveness would be the result of combining mortality from multiple AHQs in each residency.

- *As a general rule for composting to be cost-effective compared to current practice, the start-up costs of composting with a forced air system cannot exceed 22 times the operational savings from composting in the first year and the start-up costs of composting with a rotary drum cannot exceed 14 times the operational savings from composting in the first year. Operational savings rise with mortality volumes for both vessel composting methods.*

RECOMMENDATIONS

1. *To provide guidance to AHQs on maximizing the cost-effectiveness of composting, VCTIR should include the following in a "Cost Considerations" section of forthcoming VDOT animal mortality composting guidelines.*

    - *Use compost windrows whenever possible, including to supplement vessel composting during periods of high mortality. Windrows may be placed on VDOT right of way where feasible.*

    - *Identify a no-cost carbon source whenever possible, such as wood shavings or sawdust from local sawmills, furniture manufacturers, and landscape companies. Woodchips from VDOT vegetative debris removal are an ideal carbon source for windrow composting.*

    - *If purchasing a rotary drum or forced air system, seek other nearby maintenance areas with which to share the vessel (if it is not already at maximum capacity).*

    - *When a contract for animal mortality management remains in place but a composting alternative is planned to replace the contractor's disposal method, negotiate lower contract rates if the compost vessel reduces the contractor's travel distance.*

    - *Use finished compost for transportation project applications in place of purchasing comparable material. Uses include vegetation establishment, erosion and sediment control, and mulch for landscaping.*

2. *VCTIR and VDOT's Environmental Division should coordinate with VDOT's Maintenance Division to incorporate the forthcoming VDOT animal mortality composting guidelines into VDOT's Maintenance Best Practices Manual.* The guidelines will include measures to maximize the cost-efficiency of composting.

3. *The VCTIR implementation coordinator should meet with VDOT district maintenance engineers to communicate (1) the composting methods available to VDOT, (2) cost considerations for maintenance areas considering composting, and (3) the forthcoming release of VDOT's animal mortality composting guidelines.*

4. *The VCTIR implementation coordinator should pursue the design of a forced air system with a smaller capacity and lower construction costs. Having access to a smaller system would substantially improve the cost-effectiveness of forced air composting for AHQs that do not have a readily available no-cost carbon source; that have smaller mortality volumes; and/or for which pooling of mortality with other AHQs is infeasible.*

BENEFITS AND IMPLEMENTATION

Implementation of the recommendations in this report is underway, including coordination between VCTIR and the vendor of the forced air system on the design elements of a smaller unit. The findings of composting research conducted at VCTIR, including the economic considerations determined in this study, are being incorporated into a guidance document for VDOT animal mortality composting. VCTIR staff is working with the state maintenance division administrator to ensure acceptance of these guidelines into VDOT's Maintenance Best Practices Manual. The VCTIR implementation coordinator will also schedule meetings with VDOT's Transportation Maintenance and Operations Committee to communicate these best practices. In addition, a MOU was recently executed between VDOT and DEQ that allows VDOT to compost using the methods shown to be effective in recent VCTIR composting studies (DEQ and VDOT, 2015). This is expected to increase composting implementation prospects for VDOT.

The economic analyses in this study demonstrated that even the most expensive composting option available to VDOT, i.e., the current design of forced air system, is cost-effective for the combined mortality of Hanging Rock and Southwest AHQs (Table 17). The forced air system in VDOT's Salem District will provide Hanging Rock and Southwest AHQs with a needed means of mortality management but also is expected to save VDOT up to $54,000 over the service life of the equipment. Further, a rotary drum could save the Windsor AHQ up to $36,500 within the lifetime of the equipment. In addition, the time saved by eliminating a potentially long trip to the landfill could be reallocated to other maintenance activities.

Making use of the finished compost for transportation projects increases the cost-effectiveness of composting and provides numerous environmental benefits. Costs are saved by replacing the need to purchase other material for use in transportation projects such as vegetation establishment and erosion and sediment control (measures that help prevent pollution). Other environmental benefits include enriching soil, remediating contaminated soil, and saving valuable landfill space (U.S. Environmental Protection Agency, 2014), making composting a preferred means of animal mortality management by regulatory agencies such as DEQ (2009).

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APPENDIX A

E-MAIL AND CARCASS MANAGEMENT SURVEY

E-Mail

To: District Resident Administrators
Subject: Animal Carcass Management Survey for VDOT Maintenance Superintendents
Sent: 11/19/2013

Statewide Resident Administrators,

Would you please forward this e-mail to your Area Superintendents? I would be grateful for their help by completing the imbedded survey.

Jimmy White
Implementation Coordinator
VDOT/VCTIR
540 460 1462

Maintenance Superintendents:

Many VDOT maintenance areas have been struggling with cost effective methods to deal with animal carcasses. Roadkill composting pilot studies initiated in 2010 resulted in successful composting operations in the Salem, Lynchburg, and Staunton Districts, and several additional AHQs plan to introduce composting in the near future. However, the comparative costs of composting versus other means of carcass disposal are not documented sufficiently for VDOT to support the practice unconditionally. For this reason, VDOT's research division is now undertaking a final composting study that will lead to guidance for VDOT maintenance staff on the costs and requirements of composting as a means of carcass management.

An essential component of the study will be a survey of VDOT AHQ Superintendents. The survey has two key objectives: (1) to gather current information on roadkill management at your AHQ and (2) to determine the suitability for and interest in composting at your AHQ.

Your help is needed so we can gain a better understanding of the costs and interest in this roadkill management method. The survey has 10 questions. We greatly appreciate you taking the time to complete it.

Please respond by Wed, November 27.

[http://survey link]

Bridget Donaldson and Audrey Moruza
VCTIR

Survey: VDOT Animal Carcass Management

Many VDOT maintenance areas have been struggling with cost effective methods to deal with animal carcasses. A number of VDOT AHQs are successfully composting carcasses, and several AHQs are currently composting or plan to be composting in the near future. This survey has two primary objectives: (1) to gather current information on the management of animal carcasses (2) to determine the suitability for and interest in composting at maintenance area headquarters.

The survey has 10 questions. We greatly appreciate you taking the time to respond.

1. Name, VDOT District, and VDOT AHQ (We will NOT use your name or other identifying information without your prior permission.)

2. How does your AHQ staff "manage" animal carcasses collected within your maintenance area? "Manage" means to pick up and dispose of carcasses at a facility or within the right of way.

Other (For example, we pick up our carcasses and another AHQ disposes of them).

3.

IF YOUR AHQ STAFF HAS NO INVOLVEMENT IN CARCASS MANAGEMENT IN YOUR MAINTENANCE AREA, PLEASE GO DIRECTLY TO QUESTION #7.

Please estimate the number of large animal carcasses (deer and larger) collected per month in a typical year in your maintenance area.

January

February

March

April

May

June

July

August

September

October

November

December

4. Please estimate the PERCENTAGE of large animal carcasses (deer and larger) collected in your maintenance area in a typical year within the given road distances from your AHQ. (The percentages should add up to 100%.)

Up to 1 mile from your AHQ

1-5 miles from your AHQ

5-10 miles from your AHQ

More than 10 miles from your AHQ

5. For each route type, please estimate the percent of large animal carcasses (deer and larger) collected in your maintenance area in a typical year.

Primaries

Secondaries

6. For disposal of large animal carcasses (deer and larger), please estimate the number of trips your AHQ takes to a landfill or other disposal facility per month in a typical year. (It is acceptable to estimate weekly trips and multiply by 4.)

January

February

March

April

May

June

July

August

September

October

November

December

7. Please name the landfill(s), transfer station(s), or other disposal facility, if any, used for carcasses collected in your maintenance area in the last year.

8. VDOT AHQs have successfully started composting as a means of large animal carcass disposal. Finished compost can be used for any road project (grass establishment, erosion control, soil amendment, mulch).

Compost WINDROWS are mounds of carcasses layered with woodchips and left undisturbed for 10-11 months while the composting process occurs. If the woodchips are free and/or available to your AHQ, there is no cost. Approximately 6 deer can be fit per 10 ft x 10 ft area.

Compost CONTAINERS (rotary drums or forced air system) require less space than windrows, and speed up the composting process considerably, but may require more management by employees. Rotary drums cost under $60,000 and can accommodate 4-6 deer per day. Forced air containers cost approximately $100,000 and can accommodate 300 deer (100 in each of its 3 containers at one time).

Would any of these composting methods be considered for carcass disposal at your AHQ?

- Yes, I would consider composting (windrows or containers)
- No, I am not interested in switching to composting (please explain in comment box)
- Maybe (please explain in comment box)

Comment

9. If you answered YES or MAYBE to Question #8, is there potential space within your maintenance area for a composting site that is (select all that apply):

- Less than a 5% slope
- As large as 40 ft x 60 ft
- As large as 65 ft x 80 feet
- At least 50 ft from the VDOT property line
- At least 50 ft from surface water (stream, lakes, etc.)
- At least 200 ft from residences and public areas and facilities

Comment

10. If you were to begin composting carcasses at your AHQ, which of the following might be uses of the finished compost in your maintenance area? Select all that apply.

- Slope stabilization
- Vegetation establishment

- [ ] Water quality management (compost berms can replace silt berms and hay bales)
- [ ] Erosion/sediment control
- [ ] Wetlands construction
- [ ] Other (please specify)

APPENDIX B

INITIAL SET OF QUESTIONS FOR MAINTENANCE AREA SUPERINTENDENTS AND WEEKLY DIARY FORM FOR PARTICIPANTS

Initial Set of Questions for Maintenance Area Superintendents

Where do you dispose of carcasses picked up in your maintenance area?
If you use a disposal facility, do you take carcasses straight to disposal facility or do you sometimes return to your AHQ first?
Do you share carcass pick up and disposal work with other AHQs? If so, which AHQ(s)?
Do you make special runs to search for carcasses or do you only respond to requests from VDOT's Asset Management System?
Do you ever make carcass runs specifically or do you always task-chain?
What is the name of the disposal facility (landfill) you use or that you would use, and what are the costs of the landfill?
Are there interstates in your maintenance area and if so, who is the TAMS contractor?
Do you use a contractor for non-interstate roads? If so, what do they charge VDOT per carcass? How do they dispose of them?
What type of task-chaining (ex. picking up debris in ROW), if any, do you do with carcass pick-up?
If you use a disposal facility, how long does it take you *once you're there* to hand off the carcasses?
What is the typical number of personnel on carcass management duty?

Weekly Diary Form (For AHQs That Bury Mortalities or Take Them to a Landfill)

Weekly Questions	Mon	Tues	Wed	Thurs	Fri
Please write dates for each day:					
How many carcasses did you pick up?					
How many carcasses by each distance range:					
Up to 1 mile from your AHQ:					
1-5 miles from your AHQ:					
5-10 miles from your AHQ:					
More than 10 miles from your AHQ:					
Number of carcasses collected on primary routes:					
Number of carcasses collected on secondary routes:					
How many times did you go to disposal facility?					
Did you take carcasses straight to disposal facility or burial area each time? (yes or no)					
How many times did you leave your AHQ specifically to pick up carcasses or take them to a landfill?					