COMPOST SITE DESIGN MODEL: A COMPUTER-AIDED TOOL FOR EFFICIENT SITING

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ABSTRACT

With the current emphasis on yard waste composting technologies for reducing the organic fraction of the residential waste stream, the use of a computer model can greatly improve the compost site designer's efficiency in considering the variables and evaluating tradeoffs. The sample model discussed in this paper accepts data that describes the community context—population factors, site size—and characteristics of the site operation, such as intensity and equipment. Using community-specific or standardized data, it calculates the incoming material volumes and seasonal variations.

Then it calculates the following design parameters:
(a) Site material flow based on variable efficiencies.
(b) Mass balance.

The model provides the planner or engineer with an efficient way of comparing different sites and the effects of varying material flows and specific pieces of major operating equipment. It allows the facility designer to respond flexibly to the needs of clients, and to spend more time attending to the less quantifiable aspects of design that are crucial for community acceptance.

NOMENCLATURE

Composting is the biological decomposition of organic wastes under controlled conditions to a state where handling and land application can be achieved without adversely affecting the environment [1]. Composting can be used to break down yard wastes, food wastes, wood wastes, and food-related paper products, along with a whole host of other organic industrial and animal wastes.

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Potential Scope of Composting in the United States

As more and more states, counties, and municipalities have moved to ban the disposal of yard wastes in landfills, many composting facilities have begun to operate and even more are planned. Composting of the entire municipal solid waste (MSW) stream has also been considered. For now, however, problems with waste stream contamination and the lack of markets for MSW-finished compost markets have kept this technology in its infancy. Therefore, the current emphasis remains on yard waste composting technologies.

Table 1 shows that simple yard waste composting programs alone can recover up to 18% of the waste stream by themselves. If food waste and wood wastes are added to the list, composting can potentially recover another 20% of the waste stream, or nearly 38% in total. Clearly no program can have 100% success, but indeed the organic waste stream available for recovery through the composting process is large enough to warrant serious consideration. This paper considers strictly the design problems associated with windrow yard waste composting facilities; however, many other

TABLE 1 COMPOSITION OF MUNICIPAL SOLID WASTE IN THE UNITED STATES [2]

Material	Quantities Generated		Quantities Discarded after Recovery and Composting	
	Million Tons	Proportion of Waste Stream	Million Tons	Proportion of Waste Stream
Paper and paperboard	71.8	40.0%	53.4	34.2%
Ferrous	11.6	6.5%	10.9	7.0%
Aluminum	2.5	1.4%	1.7	1.1%
Other non-ferrous	1.1	0.6%	0.4	0.3%
Glass	12.5	7.0%	11.0	7.1%
Plastics	14.4	8.0%	14.3	9.2%
Wood	6.5	3.6%	6.5	4.2%
Rubber and Leather	4.6	2.6%	4.4	2.8%
Textiles	3.9	2.2%	3.8	2.4%
Other	3.1	1.7%	2.4	1.5%
Subtotal: Non-Food Product Waste	*132.1*	*73.6%*	*109.0*	*69.9%*
Yard wastes	31.6	17.6%	31.1	19.9%
Food wastes	13.2	7.3%	13.2	8.5%
Misc. inorganics	2.7	1.5%	2.7	1.7%
Subtotal: Other Wastes	*47.5*	*26.4%*	*47.0*	*30.1%*
TOTAL	**179.6**	**100.0%**	**156.0**	**100.0%**

Source: *Characterization of Municipal Solid Waste in United States: 1990 Update*, U.S. EPA

potential and more aggressive composting processes can be considered.

Composting or direct application to the land of agricultural wastes has long been practiced in rural areas. However, with dwindling landfill volumes in areas of higher populations, the push for yard waste composting is becoming a priority in more populated areas. These areas are far less tolerant of "mistakes" that might result in odors and the suspicion that surface water and groundwater might be contaminated by composting operations. All of these concerns are valid but also surmountable, with careful research and consideration during the site design process and appropriate attention to site management practices.

Finding an appropriate and acceptable site for a community yard waste composting facility may always be difficult, particularly in densely populated urban or suburban areas. Yet locating a facility as close as possible to waste generators is a vital ingredient to the development of a cost-effective composting program. This paper describes a multidimensional tool, a computer model, that affords the compost facility planner the flexibility to evaluate many of the design issues important to implementing a successful yard waste composting facility.

Obstacles to Composting and Some Solutions

Obstacles to successful yard waste composting plague every facility designer. A clear anticipation of these obstacles can alleviate some of the potential mistakes that early compost facility developers have encountered. The problems usually center on misunderstanding of composting by the public and its decision makers or on improper site management by the site operators.

Handling of Odor and Leachate

Accelerated composting is a process that requires acceptance of the natural odors associated with aerobic decay and the production of some site runoff or subsurface leachate. To the public and regulators who are rightfully sensitive to serious environmental degradation, it can often seem that compost site managers and designers are not being completely honest about the impacts of their operations. To overcome this natural tendency to object to an unfamiliar technology, well-considered site design and operational protocol is required, along with well-conceived public education programs.

The model presented here provides the flexibility to analyze a wide variety of potential sites quickly and easily and to present a summary of approximate physical and operational site parameters that can help simplify determination of site suitability for yard waste composting.

Quantifying Material Recovery

Composting has yet to be removed from the shadow of recycling as a legitimate and well-understood alternative for waste reduction and recovery. Recycling has "cleaner" and more sophisticated technologies that attract greater public attention and understanding. The results of recycling—recovery of a certain fraction of the waste stream—are much more easily quantifiable. The products sold are much smaller in quantity and more valuable on a per-ton basis than finished compost. However, as composting becomes more familiar and common, it will gradually become more accepted and mainstream.

The model discussed here provides a method of calculating recovery through a mass balance analysis that is necessary for accurate quantification of compost material recovery.

Operational Experience and Training

Because of the high percentage of yard waste in the total waste stream, composting provides a very high potential for material recovery and diversion from landfills. This incentive has pushed people with all levels of training and preparation into the task of managing a successful composting facility, often with undesirable results.

The newness of yard waste composting facilities has another side effect on implementation of successful programs: empirical data on successful composting programs is simply not widely available. Equipment development remains in its early stages of maturation in the

U.S., even though some European equipment technologies are being introduced. Site managers and researchers have not had enough opportunity to optimize operating procedures and equipment.

With the current learning process, mistakes are being made and solved by individual managers at individual sites. Correspondingly, there has been an accompanying fall-out in public reaction. Knowledge levels are increasing and improving this situation; however, a concerted effort is needed to ensure that no fatal mistakes are made in the meantime which could render composting an unacceptable waste recovery technology in the public's mind for the future. As equipment and operating limitations are overcome, the quality and efficiency of composting will improve dramatically.

Seasonal Variation in Yard Wastes

Of a more practical nature, another obstacle to the implementation of successful yard waste composting is the seasonal variability of yard waste generation. Using either community-specific seasonal generation rates or standard seasonal variations from model communities, a seasonal operating plan can be tuned to incoming yard waste volumes and compositions. This issue of seasonal variation, as well as growing participation by the public in mulching and home composting, makes it all the more important that techniques be developed to measure the effect of composting on the yard waste stream. The model presented in this paper provides a framework for measuring the success or failure of a facility through the consideration of economic standards of site utilization.

Equipment Specification

Choice of equipment, or appropriate technology, also requires consideration of a number of factors. These factors can include site size, projected incoming volumes, surrounding community needs, and funding constraints. The model provides the designer with a simplified method of iteratively choosing specific pieces of equipment based on multiple variables.

Market Development

Market development for materials recovered from waste has always been an important consideration. The fear of a product glut has routinely been used as an argument against comprehensive recovery activities. To overcome this concern, finished composted humus product needs to be proven as a quality soil additive that is economically competitive with other soil products. Careful attention to the mass balance and recipe afforded by the model will assist the site manager in developing a quality end product.

Tradeoffs in Compost Site Design

The designer of a successful yard waste composting facility needs to be able to carefully and critically judge the tradeoffs to be made between active composting acreage, screening and storage areas, equipment selection and costs, recipe development, the windrow turning schedule, and public acceptance of the composting process.

The design process requires that the designer prioritize the facility requirements. For instance, if the location and acreage are predetermined, technology must be chosen that allows the operation to work in a constrained area. If public acceptance of the site is the most important factor, site designers must provide absolute assurance that there will be no odor problems. Low operating costs may be the major factor if the initial capital expenses are easiest to fund. Proximity to the generation source may be the most important issue.

Balancing all of these issues requires iteration and reiteration of the site design to focus on the best possible solution. Determining the solution efficiently requires either tremendous experience in yard waste composting (something only a handful of people have) or the assistance of a comprehensive design tool in the hands of a site engineer. Using the data provided by the model, the engineer can develop a detailed final design.

This model can also be used to remediate problem sites and recommend improvements. Using the model to analyze a variety of factors simultaneously, the designer can prioritize a set of solutions for implementation.

Compost Site Design and Use of the Model

The compost design model consists of a series of seven sets of input nodes and seven sets of output nodes. A flow chart showing the model is presented in Fig. 1. The flow chart organizes the modeling process into a series of four modules: generation, seasonal variation, composition, and site design.

Generation Module

Yard waste generation calculations provide the foundation for the entire model. The aim is to determine total generation based on the different types of populations (rural, suburban, and urban). To more accurately calculate the total amounts of yard waste generated, it is necessary to account for community demographic differences.

Differing features among population types can include: lot size; maturity of trees; on-site waste reduction; community lawn standards; and property owner-

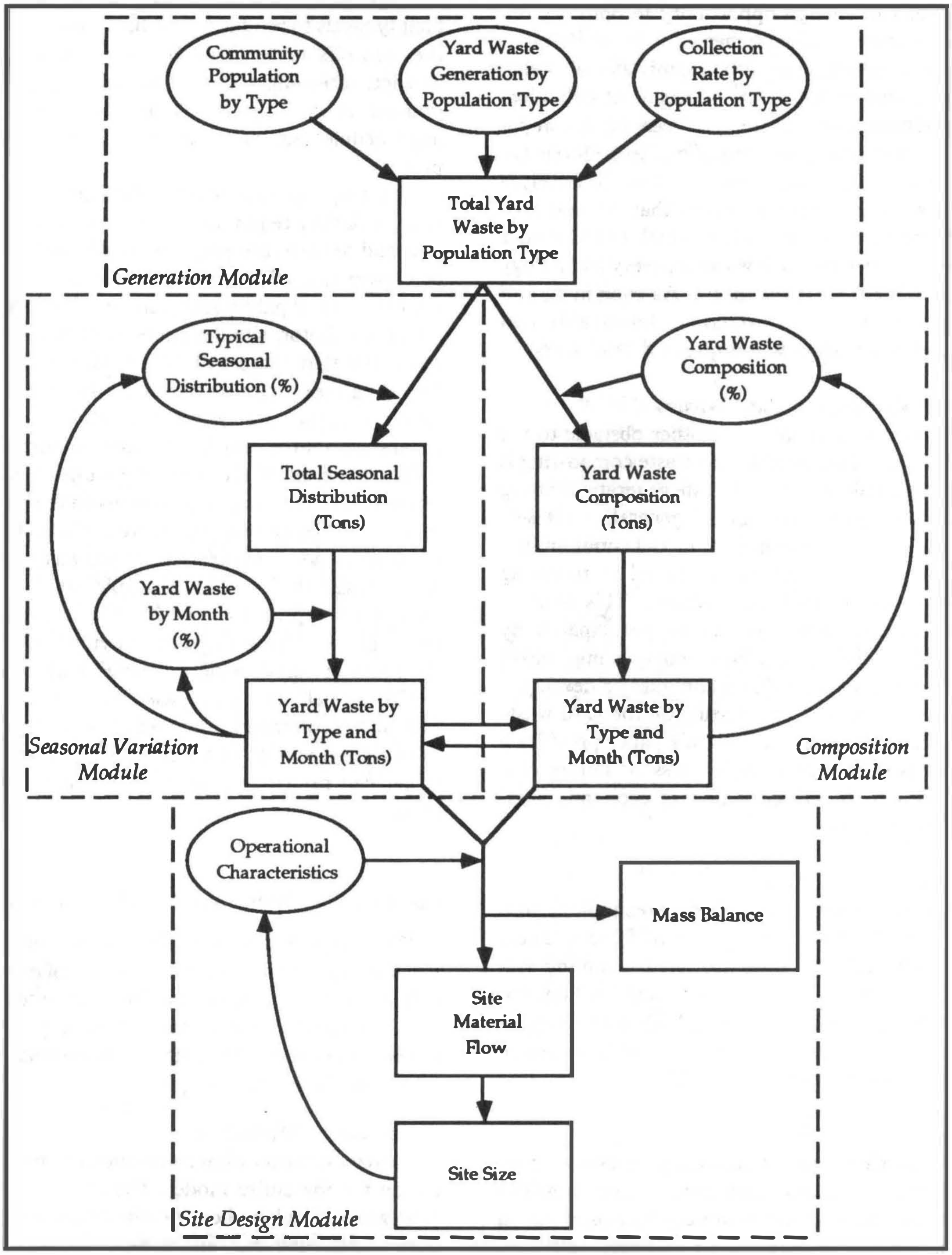

FIG. 1 COMPOST FACILITY DESIGN AND SIZING FLOW CHART
(Courtesy of Resource Recycling Systems, Inc., 1992)

TABLE 2 COMMUNITY POPULATION BY TYPE

Area	Population
Urban	71,429
Suburban	81,818
Rural	107,144
Total	260,391

TABLE 3 YARD WASTE GENERATION BY POPULATION TYPE
(Pounds Per Person Per Year)

Population Type	Generation Rate
Urban	450 pounds/person/year
Suburban	550 pounds/person/year
Rural	350 pounds/person/year

TABLE 4 YARD WASTE COLLECTION RATES BY POPULATION TYPE

Population Type	Collection Rate
Urban	70%
Suburban	50%
Rural	30%

TABLE 5 TOTAL YARD WASTE GENERATION BY POPULATION TYPE

Population Type	Total Generation
Urban	11,250 tons/year
Suburban	11,250 tons/year
Rural	5,625 tons/year
Total	28,125 tons/year

ship. These all combine to produce a unique yard waste generation profile for every community.

Tables 2, 3 and 4 are the input nodes for this module. Together they combine community population by population type, waste generation by population type, and collection rate by population type to calculate total yard waste production by population type.

The final yard waste generation totals, shown in Table 5, are one of the necessary inputs for both the seasonal variation module and the composition module.

TABLE 6 TYPICAL SEASONAL DISTRIBUTION OF YARD WASTES

Month	Typical Seasonal Distribution	
	% of Total Waste Stream	*Tons*
January	3.5%	1,406
February	1.5%	563
March	1.5%	563
April	4.0%	1,125
May	12.0%	3,375
June	8.5%	2,531
July	7.5%	2,813
August	9.5%	3,094
September	7.0%	2,813
October	15.0%	3,375
November	27.5%	5,484
December	2.5%	984
Total	100.0%	28,125

Seasonal Variation Module

Seasonal variation of yard waste generation is an important factor in compost site design. Different geographical and climatological characteristics can all affect how frequently grass must be mowed, leaves must be raked, and hedges require pruning. Again, the judgment of the designer is required to accurately determine the profile of incoming yard waste to the site.

Table 6 shows the input and output nodes of the initial step of the seasonal variation module. Typical seasonal distribution (or known data, where available) is used to divide the total yard waste quantities over the 12 months of the year.

The final step in calculating the seasonal variation is to take the information generated in the last column of Table 6 and apply to it the information presented in Table 7 to determine the total amount of each type of yard waste produced every month, shown in Table 8.

Composition Module

Alternatively, total yard waste generation by type can be calculated based on composition by population type (Table 9). Composition percentages can be applied to the totals generated in the last column of Table 6 to ascertain Yard Waste Composition (Tons) in Table 10.

The totals for Leaves, Grass, and Brush shown in Table 10 should be compared with the same totals shown in Table 8. The percentages in Tables 6, 8, and 10 can be adjusted so that the total tons by yard waste type in Tables 8 and 10 converge. This step is an important part of checking for reasonableness in composition estimates, because it accounts for a variety of assumptions that must be balanced to ensure model accuracy.

TABLE 7 TYPES OF YARD WASTE BY MONTH (%)

	Estimated Monthly Distribution		
Month	**Leaves**	**Grass**	**Brush**
January	5%	0%	95%
February	5%	0%	95%
March	25%	15%	60%
April	20%	50%	30%
May	15%	60%	25%
June	0%	95%	5%
July	0%	95%	5%
August	0%	95%	5%
September	5%	90%	5%
October	70%	15%	15%
November	70%	0%	30%
December	20%	0%	80%

TABLE 8 TYPES OF YARD WASTE BY MONTH (Tons)

	Estimated Monthly Distribution			
Month	**Leaves**	**Grass**	**Brush**	**Total**
January	70	0	1,336	1,406
February	28	0	534	563
March	141	84	338	563
April	225	563	338	1,125
May	506	2,025	844	3,375
June	0	2,405	127	2,531
July	0	2,672	141	2,813
August	0	2,939	155	3,094
September	141	2,531	141	2,813
October	2,363	506	506	3,375
November	3,839	0	1,645	5,484
December	197	0	788	984
Total	**7,509**	**13,725**	**6,891**	**28,125**

TABLE 9 YARD WASTE COMPOSITION BY POPULATION TYPE (%)

	Leaves	**Grass**	**Brush**
Urban	35%	40%	25%
Suburban	20%	60%	20%
Rural	20%	50%	30%

TABLE 10 YARD WASTE COMPOSITION (Tons)

	Leaves	**Grass**	**Brush**	**Total**
Urban	3,938	4,500	2,813	11,250
Suburban	2,250	6,750	2,250	11,250
Rural	1,125	2,813	1,688	5,625
Total	**7,313**	**14,063**	**6,750**	**28,125**

TABLE 11 OPERATIONAL CHARACTERISTICS

Windrow Turner	**Wildcat CX-750-ME**
Cost	$65,000
Capacity	1,800 cubic yards/hour
Average Speed	20 feet/minute
Windrow Base	14 feet
Windrow Height	5 feet
Passes	2
Windrow Volume	1.67 cubic yards/ linear foot
Aisle Width	8 feet

TABLE 12 SITE MATERIAL FLOW

	Optimum Site Efficiency			Minimum Site Efficiency
Design Parameter	**(highest month)**	**(mean month)**	**(lowest month)**	**(highest month)**
Total Windrow Length	47,413 Ft	31,328 Ft	20,301 Ft	73,140 Ft
Total Windrow Area	15.24 Acres	10.07 Acres	6.52 Acres	23.51 Acres
Total Aisle Area	8.71 Acres	5.75 Acres	3.73 Acres	13.43 Acres
Active Composting Area	23.95 Acres	15.82 Acres	10.25 Acres	36.94 Acres
Time to Turn Site (ft/min)*	39.5 Hours	26.1 Hours	16.9 Hours	61.0 Hours
Time to Turn Site (cy/hr)**	44.0 Hours	29.1 Hours	18.8 Hours	44.0 Hours

* Based on average speed (feet/nuinute)

** Based on capacity (cubic yards/hour)

TABLE 13 MASS BALANCE

Yard Waste/Compost Characteristics	**Leaves**	**Grass**	**Brush**	**Total**
Incoming Yard Waste (tons)	11,559	11,088	5,477	28,125
Rejects	0%	0%	0%	
Incoming Waste Less Rejects (tons)	11,559	11,088	5,477	28,125
Portion of Material that is Solid	70%	20%	50%	
Solids (tons)	8,092	2,218	2,739	13,048
Solids Reduction	20%	20%	10%	
Solids After Reduction	6,473	1,774	2,465	10,712
With 40% Moisture				14,997
Final Screen Rejects				10%
Final Screen Rejects (tons)				2,813
Finished Compost (tons)				**12,185**
Finished Compost (cubic yards, at 850 pounds per cubic yard)				**28,670**

Site Design Module

After the seasonal characteristics of yard waste generation have been determined, the site design can begin. With input from the results of Tables 8 and 10, and the operational characteristics shown in Table 11, a determination can be made about the amount of material on-site. The operational characteristics are based primarily on windrow turner specifications. They are then combined with the incoming yard waste data to help determine both site sizing and material flow information (Table 12) and a compost material mass balance (Table 13).

While the model calculates only active composting area, the designer should account for other functions, such as material screening and storage. The size requirements for these particular functions depend on local market conditions, regulatory requirements and site operating procedures.

Where site size is a constraint, the windrow turner specifications can be varied in Table 11 to increase the site management intensity. The specifications can also be changed in response to the turning requirements of different yard waste compositions.

Optimum site efficiency, as shown in Table 12, assumes that the windrows are combined regularly, at the very least when volume reduction has reached 30% since the last combination. Because the site is analyzed on a month-by-month basis, the highest month is that month projected to have the greatest amount of yard waste on-site. If there is adequate operating acreage (which includes only acreage for windrow placement) to handle yard waste volumes in the highest month, the site should be adequately large. However, mean month information can be used to develop operating costs and to determine equipment requirements. Minimum site efficiency assumes calculation of site acreage requirements based on no combination of windrows. This is clearly the worst case scenario—the greatest acreage need per cubic yard of yard waste. The mass balance information generated in Table 13 is used in material balance calculations. It provides a common method for calculating incoming yard waste, outgoing finished compost, and ultimate recovery from the waste stream.

Case Studies

Two different uses of the model are presented as case studies. The model was used for distinctly different purposes in each instance. Nonetheless, it successfully served as a device for analyzing design tradeoffs. In each case, different segments of the model were used to judge the most important tradeoffs.

Socrra Compost Facility

Southeast Oakland County Resource Recovery Authority (SOCRRA) is a predominantly suburban area of Oakland County, 20 miles north of the Detroit, Michigan, city limits. At a projected incoming material quantity of 45,000 ton/year, SOCRRA operates one of the largest windrow yard waste composting facilities in the nation. The compost facility has been operating a full-service yard waste processing center at its present site in Rochester Hills, Michigan, since 1988, but had a great deal of experience with land application methods for a 16-year period prior to that.

In the SOCRRA case, the model was used to optimize the tradeoffs between pad area, incoming waste volumes, and windrow turning equipment. After seasonal variation of incoming yard waste was established, different site configurations were analyzed both for construction cost and for adequacy of pad size.

The compost site is situated almost entirely on top of an Oakland County monofill landfill that was closed in the mid 1960s. The surface pad remained unimproved, without adequate drainage and pad surfacing, until SOCRRA was selected as a Clean Michigan Communities (CMC) grant recipient under a program funded by the Michigan Department of Natural Resources (MDNR). Greater popularity of yard waste collection programs within SOCRRA member communities led to increasing amounts of incoming yard waste. Soon, both the site capacity and the available yard waste management equipment were overwhelmed as the incoming volumes mounted.

Relationships with nearby residents were worsening as well, due to the impression that the facility was smelly and poorly managed. The combination of complaints caused facility operators to come under great pressure to change operating procedures to prevent public outcry.

During the CMC facility design phase, SOCRRA and RRS engineers and planners were faced with both the growing incoming yard waste volumes and the accompanying scrutiny of the MDNR, which wanted the SOCRRA operation to be a CMC "model facility," free from local complaint and above regulatory reproach. To meet this expectation, the facility had to meet strict leachate emission and runoff collection standards, beyond those yet required of most Michigan yard waste composting facilities.

Pad placement expense and setback requirements provided an incentive for minimizing the final windrow pad size. Because the pad was to be placed on a closed landfill, surface slope requirements of 1.5% overlying the otherwise relatively level surface could be achieved only by expensive fill placement. Furthermore, a relatively large setback (at least 250 ft) was required between the active windrows and the nearest private residence. After the addition of a large shallow retention pond, access roads, a staging area, and a curing area, the final available area for windrow layout was only 18 acres.

This final area was arrived at through a series of design iterations that involved pad design, drainage design, equipment selection, and operating intensity tradeoffs. A recommendation for a pad size of 28 acres and 2.0% slope was finally reduced to 18 acres and 1.5% slope by carefully balancing the projected monthly incoming material volumes, and predicting periods of low and high site utilization. In this case, the degree of site utilization was measured in linear feet of windrow.

Over a period of three months, in early 1991, different design concepts were suggested and modified by SOCRRA and RRS engineers in conjunction with MDNR compost specialists. Finally, an agreeable solution that balanced many different design tradeoffs and constraints was concluded, allowing SOCRRA to move forward with implementation of the entire plan. The facility is now in successful operation, gradually phasing into the final compost site design as shown in this paper.

Grand Traverse County

During the spring of 1991, Grand Traverse County, Michigan, was progressing with implementation planning for Phase II of its Solid Waste Plan. This plan called for the development of a county-wide yard waste composting program, with some level of collection and processing services available to all 65,440 residents. Yard waste requiring processing was projected to total 7800 ton/year.

During program development, a plan providing for a Phase I centralized processing facility for approximately 82% or 6400 ton/year of this total was proposed as the centerpiece of the yard waste composting program. However, it was unclear where the processing facility would be sited.

A number of potential siting options were available. Initially, the most attractive option was an existing composting site in Traverse City, the county seat. This 13-acre site lies atop a closed landfill that is alongside the Boardman River, a favorite location for trout fishing. The site processed approximately 2500 ton/year of yard waste, which predominantly consisted of leaves collected by Traverse City collection vehicles. The site was also used for wood chip storage and as an overflow work area for city crews engaged in anything from storm clean-up to highway brick reclamation. These noncompost activities required more than 30% of the available site area.

Because of the considerable experience of the Traverse City compost facility operators and the ready availability of the existing site, this area became the first choice for the proposed centralized Grand Traverse compost facility. However, constraints to its successful operation with expanded volume (three times the existing volume) and expanded services (grass and wood chips in addition to leaves) needed to be resolved.

The model was used to predict the incoming and seasonally varying amounts of yard waste. Several iterations were required to successfully account for the unique demographic and climatological nature of the Traverse City area. A disproportionate amount of leaves appears to exist in the Grand Traverse County yard waste stream. This factor, combined with the shortened growing season of the northern area, resulted in unusual variation in monthly incoming yard wastes.

Analysis of total site capacity showed that operational procedures would need to be more intensive. Even with greater attention to windrow turning frequency, incoming volumes approached the oversaturation marks in the fall during leaf collection season. This result led to the design recommendation that the incoming yard waste be reduced through the use of alternative composting approaches, backyard composting drives, and yard waste reduction educational programs.

Ultimately, Traverse City was asked to remove all noncomposting functions from the site as well. The final design optimized windrow layout, incoming waste quantity, and operational intensity. It also produced a full site operating budget, based on the assumptions built in to the incoming yard waste management, screening and finishing, and windrow turning needs predicted by the operating plan.

The success in upgrading the site from a 2500 ton/year leaf composting operation to a 7500 ton/year full yard waste composting facility has never been judged. The compromise was ultimately determined to be politically infeasible.

Conclusion

A tool for designing and analyzing a cost-effective, smoothly run composting facility has been presented here. The model is not structured to consider the last level of detail for each composting facility. Rather, planners and engineers should perform the detailed analyses needed for final design. However, the model does provide the planner or engineer with an efficient way of comparing different sites and the effects of varying material flows and specific pieces of major operating equipment. It accounts for the following design factors in a consistent manner:

(a) Community population.

(b) Geographical yard waste generation differences.

(c) Seasonal variations in composition and generation.

(d) Available acreage.

(e) Site management characteristics (intensive to relaxed).

(f) Equipment selection (windrow turner type).

But the most important lesson to be learned is that composting facility design cannot occur outside of the context of the community. The service needs to fit the needs of its residents. The most efficient design will never be implemented if the community is not ready to accept the basic tenets upon which the design is based.

Many communities are finding their compost facilities more publicly acceptable than prospects of siting more landfills and incinerators. The engineer and planner must find more tools that make the technical challenges of facility design more flexible and responsive to the needs of their clients. Tools that increase efficiency and technical insight allow the planner to spend more time attending to the less quantifiable aspects of design.

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