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SEWAGE SLUDGE DISPOSAL IN AUSTRIA

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Abstract

Sewerage systems serve about 70% of the Austrian population, producing 6 million m^3 of sewage sludge per year with a dry matter content of 4-5%. At present about 52% of this sludge is disposed of in land fills, 33% is incinerated, and only about 15% is used in agriculture. Although agricultural utilization is becoming increasingly important, several problems, especially those related to public opinion, need to be resolved before increased use will be possible. In this paper, wastewater treatment and sewage-sludge production in Austria, and problems associated with sludge disposal are discussed.

1. INTRODUCTION

One of the most effective treatments for municipal wastewater is the activated sludge system: purification by microorganisms The residue, along with the solid matter that originates from human metabolism, is sewage sludge. Currently there is no convenient means of disposal of sludge, it is a major problem for every treatment plant in Austria. As long as we are unable to find economically and ecologically rational solutions for sludge disposal, the problem of wastewater treatment remains to be solved. Preserving water quality is important even for a privileged country like Austria, situated as it is in an alpine region with relatively high precipitation. At present, the principal demand for drinking water is met by the Alpine sources, but with increasing population it is becoming necessary to use ground and surface waters. Therefore, wastewater treatment is of increasing importance for safeguarding these alternative water resources.

2. SEWAGE TREATMENT

2.1. Collection system

A little more than 70% of the Austrian population (about 5.6 million people) is served by a sewerage system. There are two different types of collection system:

- combined sewer system
- separate sewer system.

In a combined sewer system, storm water and sewage are collected together. In Austria, treatment plants are usually designed for a through-put of twice the dry-weather-flow (DWF). Surplus flow is diverted to the receiving stream by storm-water discharge systems. The discharge system type (overflow or retention tank) depends on the quality of the receiving stream. The initial, highly polluted flush water can be stored in a retention tank, and only subsequent less-polluted run-off water discharges into surface water. Thereafter, the content of the storage tank flows to the treatment plant. This means that pollutants from surface deposition, e.g. heavy metals, can reach the treatment plant and will be concentrated in the sludge. There are no data available on the magnitude of this effect, but investigations are currently in progress.

In separate sewerage systems, storm-water run-off is collected in a separate sewer and discharged directly into the receiving stream. Only wastewater flows to the treatment plant. This decreases the probability that pollutants from surface deposition will reach the treatment plant.

There is no current information available about the spread of these two collection systems in Austria, but in 1970 about 95% of the population was served by the combined system. Since then, the number of autonomous sewerage systems also increased sharply.

2.2. Wastewater treatment

About 70% of wastewater is treated with biological systems: activated sludge systems, trickling filters, and rotating disc filters. This means that about 20 million population equivalents (PE) are treated in municipal and industrial plants. Since 1990, new wastewater-treatment regulations have been in force in Austria [1, 2]. Along with carbon removal, additional elimination of nitrogen and phosphorus is required. Due to a need for cost effectiveness and to abide by legal strictures, the multistage activated sludge system is now in most common use. An overview of recent technological developments is shown in Table I.

2.3. Sewage sludge

2.3.1. Sewage-sludge production

The treatment technology affects how much sewage sludge is produced. Teller et al. [3] estimated quantities produced by various treatment systems (Table II). In comparison to singular carbon removal, additional nitrification/denitrification diminishes the specific production of sewage sludge due to lower growth rates of nitrifying and denitrifying microorganisms.

TABLE I. DEVELOPMENTS IN MUNICIPAL SEWAGE TREATMENT

Rank	Regulative demands	Technology	Necessary facilities
1	Carbon removal	Biological degradation (oxidation theoretically to CO_2)	One aeration tank
2	Additional ammonia removal	Biological oxidation of NH_4 to NO_3	One long-term aeration tank (nitrification)
3	Additional nitrogen removal	Biological reduction of NO_3 to N_2/N_2O	Two tanks: nitrification and denitrification tank
4	Additional phosphorus removal	Luxury biomass uptake with respect to the energy metabolism and/or chemical precipitation	Three tanks: anaerobic tank and/or precipitation station, nitrification and denitrification tank

TABLE II. ANNUAL SPECIFIC SEWAGE-SLUDGE PRODUCTION (DRY SOLID MATTER PER POPULATION EQUIVALENT) [3]

Treatment system	Sewage sludge production (kg/PE/yr)
C-removal	+12
N-removal:	
Nitrification, denitrification	- 2
P-removal:	
Simultaneous precipitation	+6
(flocculation and filtration)	(+5)
Total production	16
Primary sludge (primary settling tank)	15

In Austria, an annual sewage sludge amount of 6 million m^3 with 4-5% dry solid matter (DSM) is produced. This means that about 300,000 tons DSM have to be disposed of every year. With a water content of 70% this amounts to a total of about 900,000 tons/yr.

2.3.2. Nutrients and pollutants

When considering agricultural utilization, it must be borne in mind that sewage sludge consists of water, solid matter, precipitation products, nutrients, microelements, heavy metals and organic pollutants. The ranges of these constituents, set out in Table III, are based on long-term investigations in different provinces [4].

2.3.3. Sewage-sludge disposal

Currently, most of Austria's sewage sludge is deposited in landfills (52%), and only 15% is utilized in agriculture. The amount incinerated is relatively high (33%) because all of capital city Vienna's sewage sludge is so treated at a central plant.

2.4. Future outlook

Up to an 85% increase in wastewater disposal is expected in the next several years. Treatment plants will be upgraded for more complete removal of nitrogen and phosphorus, which will further increase sewage-sludge production. The implementation of a phosphorus-precipitation step alone will increase production by between 15 and 20%.

It is expected that sludge production will double in the medium term [5]. On the other hand, disposal in landfill sites will be sharply restricted in future, by limiting the maximum permissible content of organic substances to approximately 5%. A pre-treatment by e.g. incineration will therefore be necessary. A 10-year transitional phase is scheduled. However, it is not expected that the necessary incineration capacity will then be available, and so a large increase in agricultural utilization is likely in the near future.

TABLE III. SEWAGE SLUDGE CONSTITUENTS [4]

Parameter	Unit	Range		Most frequent value	Limits for Lower Austria Class III (Class II)
		From	To		
Dry solid matter	%	0.2	99.8	7.9	
Organic substance	(% DSM[a])	1.5	91.3	5.4	
Nitrogen		0.3	38.5	3.9	
P_2O_5		0.2	24.2	3.0	
K_2O		0.04	6.5	0.6	
CaO		0.06	65.4	8.1	
Copper	(mg/kg)	12	4310	190	500 (300)
Zinc		18	14370	1320	2000 (1500)
Lead		5	19150	145	400 (100)
Chromium		5	97600	64	500 (50)
Nickel		2	1840	37	100 (25)
Arsenic		0.1	54	4	
Mercury		0.01	460	2	8 (2)
Cadmium		0.1	285	3	8 (2)
AOX[b]	(mg/kg)	78	1000	200	500
PAH[c] (3,4 BP)	(μg/kg)	n.n.	7700	260	
PCB[d] (6 Cong.)		60	1836	570	1200
PCDD[e]		25	2670		100

[a]Dry solid matter. [b]Adsorbed organic halogens. [c]Polycyclic aromatic hydrocarbons
[d]Polychlorinated biphenyls. [e]Polychlorinated dibenzo-p-dioxin.

3. TREATMENT SYSTEMS AND SLUDGE QUALITY

The amount of sludge produced and its quality depend on the wastewater- and sludge-treatment systems. In this section, the relationhip between phosphorus removal/sludge stabilization and sludge amount/nutrient content will be described. The data are from investigations on two treatment- plant systems conducted by the Department of Sanitary Water Management, Technical University of Vienna [6].

3.1. Specific sludge production

Sewage sludge can be viewed as a mixture of organic and inorganic substances. The organic matter consists mainly of products of human metabolism and microorganisms from the activated sludge system. The inorganic component consists of the wastewater and additives for precipitation and sludge stabilization, e.g. lime.

Specific sludge production per PE depends on the treatment system (Table IV). The average can be estimated at 20 kg DSM/PE/yr. The organic solid component constitutes about 50% of the total dry matter.

3.2. Specific nutrient content

The specific nutrient content of sewage sludge also depends on the composition of the wastewater and on the treatment system (Table V). The average specific nutrient content (per PE and year) is approximately 7.5 kg organic matter, 0.5 kg nitrogen and 0.5 kg phosphorus.

4. UTILIZATION OF SEWAGE SLUDGE

As previously described, sludge utilization is becoming increasingly important in Austria [5]. However, public opinion and official agricultural policy are at odds with this trend: sewage sludge is considered to be a poison. Consequently, work has to be done to remove this prejudice. One step in this direction is to decrease the concentration of pollutants by introducing new legal restrictions. Another, in parallel, is a program to find out where pollutants originate and eliminate them, and to demonstrate the advantages of sludge utilization in pilot projects.

TABLE IV. RANGE OF SPECIFIC DRY SLUDGE PRODUCTION PER POPULATION EQUIVALENT AND YEAR

Sludge-treatment system	Wastewater-treatment system	Specific sludge production (kg/PE/yr)
Extended stabilization	Conventional system	15 - 20
	Additional P-removal	20 - 25
Simultaneous aerobic stabilization	Conventional system	20 - 25
	Additional P-removal	25 - 30

TABLE V. RANGE OF SPECIFIC NUTRIENT CONTENT PER POPULATION EQUIVALENT AND YEAR [6]

Sludge-treatment system	Nutrient	Specific nutrient content (kg/PE/yr)
Extended stabilization	Organic matter	5.5 - 7.5
	Nitrogen	0.4 - 0.5
	Phosphorus	0.4 - 0.5
Simultaneous aerobic stabilization	Organic matter	7.5 - 11
	Nitrogen	0.5 - 0.8
	Phosphorus	0.4 - 0.5

4.1. Austrian regulations

In Austria, sewage-sludge utilization is regulated by provincial soil-protection laws [6]. The maximum concentrations for pollutants in soil and sewage sludge, and permissible application rates per ha are defined. The permissible rates range from 1.25 to 5.0 tons DSM/ha/yr. Some provinces, such as Carinthia, Salzburg, Tyrol and Vienna, have not yet introduced any such regulations, and there is on-going discussion as to whether or not to institute a general ban on sludge utilization in agriculture. The limits differ little among the provinces, and are generally lower than those set by the European Union (Tables VI and VII). Burgenland and Lower Austria have set two Quality Classes (Table VII). No soil analysis is necessary in Burgenland when the sludge quality is within that of Class 1. In Lower Austria, Class III limits will apply until the year 2004 at the latest, from which time Quality Class II will be enforced for agricultural use.

4.2. Model of lower Austria

The province of Lower Austria has tried to increase sewage-sludge utilization for many years, but without much success. Since 1993, efforts have been made to improve sludge quality, the main thrust of which is a change from the philosophy of disposal to a philosophy consistent with sustainable development. The chief aspects of this program are:

- A new sewage-sludge utilization regulation.
- Measures to improve sludge quality.
- Establishment of a "liability fund" to ensure against unknown risks.
- Institution of several pilot projects.

The new regulation sets higher limits for heavy metals and new limits for organic pollutants, and introduces three classes of sludge quality. Quality Class III, with higher limits, will be permitted only for the next ten years. Then, Class II will be enforced, and eventually target Class I. Quality Class I is defined in terms of usual regional soil qualities. To reach Class II limits, most treatment plants in Lower Austria will have to decrease the concentrations of pollutants. Therefore, effluent analysis will be needed and appropriate technologies installed. These are being worked out.

4.3. The Mödling pilot project

The catchment area of the wastewater treatment plant in Mödling consists of eight communities with a total population of 50,000. It encompasses rural communities, settlement districts, and commercial and industrial zones, producing typical municipal wastewater.

The Mödling plant was built to take a load of 100,000 PE. Its technological capacity for nitrification, denitrification, biological phosphorus-elimination and phosphorus-precipitation concurs with the Water Regulation Act (Wasserrechtsgesetznovelle) of 1990. The wastewater flows to the treatment plant through two main sewers in Brunn and Mödling. The Brunn sewer belongs to the combined system, whereas the Mödling is separate.

Technically, it is an activated sludge plant with two anaerobic tanks for biological phosphorus elimination, two connected activated sludge tanks with simultaneous denitrification, and three final clarification basins. Additionally, it is possible to precipitate phosphorus at the outflow of the activated sludge tanks. Pre-dewatering is carried out in rotary drum strainers with added polymers, and further dewatering is achieved with chamber-type filter presses and addition of ferric chloride and polymers.

Sewage sludge is stabilized usually by low aeration during denitrification following standard methodologies. During the simultaneous aerobic stabilization, the average oxygen concentration in the activated sludge tank is 0.5 mg L^{-1}. In practice at Mödling the transformation rates are insufficient to guarantee sludge-stabilization, which has led to considerable stench and problems in the course of handling.

TABLE VI. SOIL LIMITS (mg/kg) FOR SEWAGE-SLUDGE UTILIZATION

	EU[a]	Bgld[b]	Ktn[c]	NOE[d]	OOE[e]	Sbg[f]	Styria	Tyrol	Vbg[g]
Mercury	1-1.5	1.5	-[h]	1.0	1,0	-	2.0	-	2.0
Cadmium	1-3	2.0	-	1.5 (1)[j]	1.0	-	2.0	-	3.0
Nickel	30-75	60	-	50	60	-	60	-	60
Cobalt	-	-	-	-	-	-	50	-	-
Chromium	-	100	-	100	100	-	100	-	100
Copper	50-140	100	-	60	100	-	100	-	100
Lead	50-300	100	-	100	100	-	100	-	100
Zinc	150-300	300	-	200	300	-	300	-	300

[a]European Union. [b]Burgenland. [c]Carinthia. [d]Lower Austria.
[e]Upper Austria. [f]Salzburg. [g]Vorarlberg. [h]Limit not yet defined.
[j]Where pH < 6

TABLE VII. SEWAGE-SLUDGE LIMITS FOR AGRICULTURAL UTILIZATION

	Units	EU[a]	Bgld[b]		NOE[c]		OOE[d]	Styria	Vbg[e]
			Class 1	Class 2	Class II	Cls. III			
Mercury	(mg/kg)	16 - 25	2	10	2	8	7	10	10
Cadmium		20 - 40	2	10	2	8	5	10	10
Nickel		300 - 400	60	100	25	100	80	100	100
Cobalt					25	100		100	100
Molybdenum								20	
Lead		750 - 1200	100	500	100	400	400	500	500
Copper		1000 - 1750	100	500	300	500	400	500	500
Chromium			100	500	50	500	400	500	500
Zinc		2500 - 4000	1000	2000	1500	2000	1600	2000	2000
AOX[f]	(mg/kg)				500	500	500		
PCB[g] per congener	(μg/kg)				each 200	each 200	each 200		
PCDD/F[h]	(ngTE[j]/kg)				100	100	100		
Hygienic conditions (for grasslands only):									
Enterobacteriaceae	(1/g FM[k])				1000	1000			
Salmonella					0	0			
Nematodes					0	0			

[a]European Union. [b]Burgenland. [c]Lower Austria. [d]Upper Austria. [e]Vorarlberg.
[f]Adsorbed organic halogens. [g]Polychlorinated biphenyls.
[h]Polychlorinated dibenzo-p-dioxin and -furane. [j]Toxicity equivalent. [k]Fresh matter.

Toxic substances found in Lower Austrian Quality Class III sewage sludge in the last two years are summarized in Table VIII. According to the existing legal standards, this sludge can be applied to agricultural land. However, the production of Quality Class III sludge will be permitted only until the year 2004, and thereafter it must concur with the more rigorous criteria of Quality Class II (Table VII). For this reason, a comprehensive programme entitled "Agricultural Application of Sewage Sludge" is being developed (Fig. 1). A detailed system analysis of the catchment area will be made, with comprehensive and precise investigations of the sewage. Pilot compostings of sludge are being set up, and the effects of sludge and compost compared with commercial fertilizers in

TABLE VIII. HEAVY METALS AND TOXIC ORGANIC SUBSTANCES IN QUALITY CLASS III SEWAGE SLUDGE FROM THE WASTEWATER-TREATMENT PLANT IN MÖDLING (100,000 POPULATION EQUIVALENTS)

Parameter	Unit	n	Average value	Standard variance	Minimum	Maximum
Zinc	(mg/kg)	14	1139	185	815	1450
Copper		14	253	47	161	324
Chromium		14	77	11	61	102
Lead		14	128	30	73	185
Nickel		14	36.0	9.3	23.3	53.0
Cobalt		14	4.2	1.1	2.3	6.2
Cadmium		14	5.7	4.0	2.4	16.9
Mercury		14	2.4	0.8	1.0	4.2
AOX[a]	(mg/kg)	6	338	119	173	470
PCB[b]:						
PCB 101	(μg/kg)	6	14	6	5	21
HxCB 138		6	36	16	12	55
HxCB 153		6	38	17	14	61
HpCB 180		6	33	18	14	58
TriCB 28		5	17	10	1	26
TeCB 52		4	20	20	1	48
Total-PCB		6	201	106	95	401
PCDD/F[c]	(ng TE[d]/kg)	6	6.9	3.8	2.9	11.9

[a]Adsorbed organic halogens. [b]Polychlorinated biphenyls.
[c]Polychlorinated dibenzo-p-dioxin and -furane. [d]Toxicity equivalent.

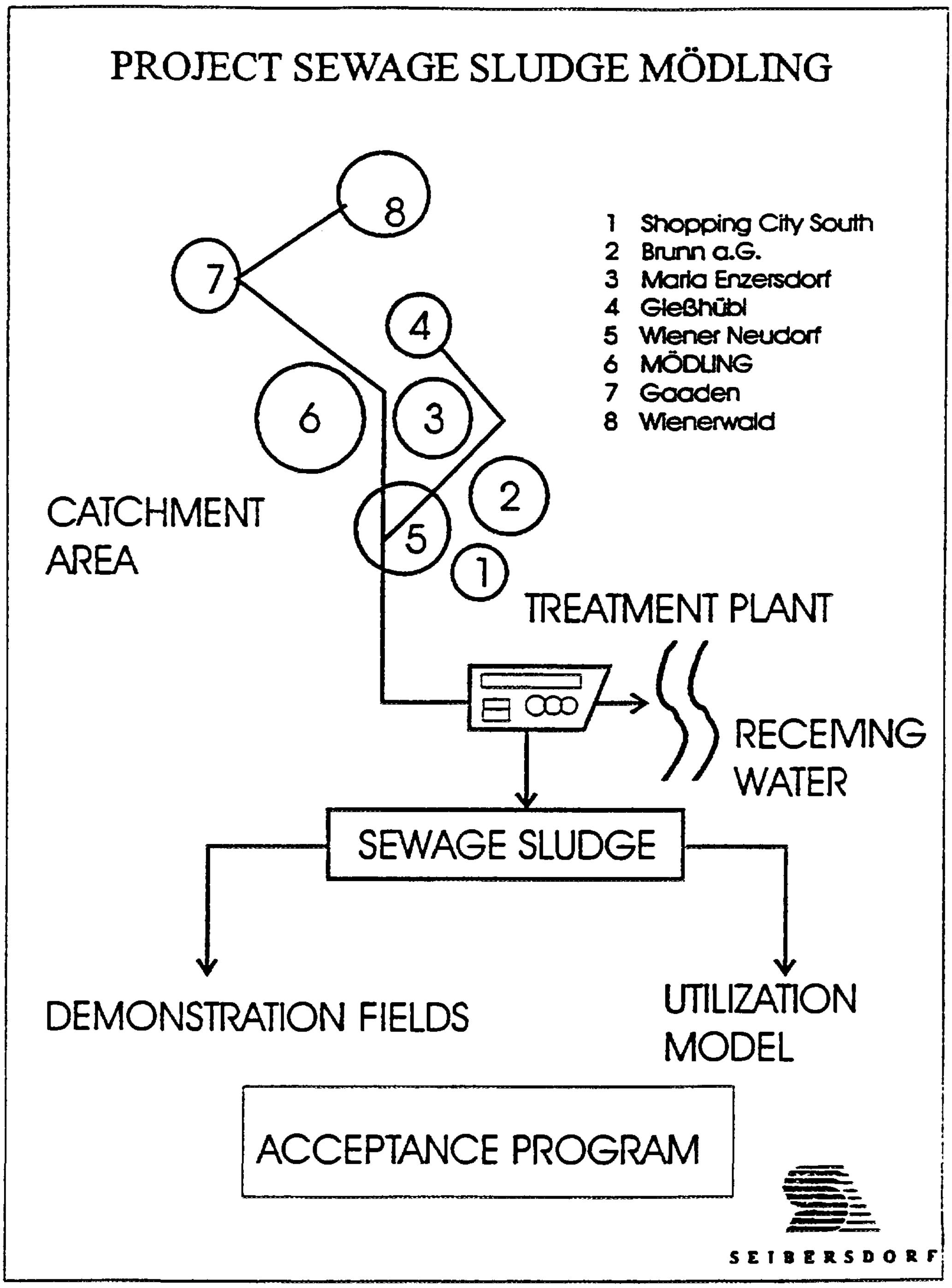

FIG. 1. Sewage-sludge pilot project in Mödling.

demonstration trials. Information will be disseminated, for example listing toxic substances that must not be added to wastewater, to improve public consciousness of problems, and to foster acceptance by target groups of disposal/utilization on agricultural land. Some aspects of the development of technical and public relations components of the project are described below.

4.3.1. Composting

Through composting, the organic substances in sewage sludge are transformed into a stable, plant-friendly, humus-like substance. The benefits from compost lie, on the one hand, in improving soil structure, bringing stabilization of texture, better aeration, and improved moisture-holding capacity. On the other hand it decreases nutrient loss, prevents nutrient leaching, improves nutrient availability to plants, and has phyto-sanitary properties. In general, composting sewage sludge improves soil qualities and hygienic conditions.

Up to now, two composting experiments have been carried out. As expected, composting decreased the nutrient content of the sludge. Although the total amount of nitrogen remained the same, its chemical form was changed. The ratio of nitrate to ammonium exceeded 2, which is particularly appropriate for agricultural application. The most important nutrients, nitrogen phosphorus and potassium were present in the proportions 1 : 2 : 0.3.

The concentrations of toxic substances in a compost depend on their respective concentrations in the prior sludge. In general there are only insignificant changes in heavy-metal concentrations in the transformation from sludge to compost. At the beginning of the process their concentrations decrease due to overall increase in mass as a consequence of the addition of a substantial amount of straw. Later, however, because of decay, this effect almost disappears. Investigations of hygienic aspects show significant decreases in counts of reference *Enterobacteriaceae* microbes during composting.

In the second experiment, we attempted to further improve the hygienic state of the compost by optimizing temperature changes with time. Substantial ammonia emissions occurred, and the experiment had to be abandoned so as not to expose neighbouring residents. There were several possible reasons for these emissions. The Mödling treatment plant produces a sludge that is not fully stabilized. In the course of further decomposition, there is a rapid transformation of organic substances accompanied by an increase in temperature (Fig. 2). Moreover, the concentration of ammonium in this sewage sludge is high at 1.6%, well above the average of 0.75%. Under these conditions, the following chemical reactions can take place:

$$NH_4^+ + OH^- \rightleftharpoons NH_4OH \rightleftharpoons NH_3 + H_2O \qquad (1)$$

$$NH_{3\,solution} \rightleftharpoons NH_{3\,gas\text{-}phase} \qquad (2)$$

$$2NH_4OH + CO_2 \rightleftharpoons (NH_4)_2CO_3 + H_2O \qquad (3)$$

According to Equation (1) ammonium is in dissociative equilibrium with ammonia, through an ammonium hydroxide intermediate. The equilibrium can be shifted by change of pH or by alteration of temperature. In the course of the heating that accompanies decomposition, ammonia is emitted; the more rapid the temperature rise, the more intensive is the emission of ammonia. The process is amplified by the rapid microbial transformations that occur with the high organic organic content of the non-stabilized sludge. Equation (2) shows the prevailing liquid/gas equilibrium. When the amount of the gas phase decreases as a consequence of aeration, equilibrium is restored by additional release of ammonia from the liquid phase. Moreover, aeration brings about a reduction of the carbon dioxide in the decomposing organic material, in accordance with Equation (3), this causes a shift in equilibrium and transformation of ammonium carbonate to ammonium hydroxide. In turn, this increases the release of ammonia according to Equation (1). Therefore, the measures taken to improve hygiene conflict with the requirements for reducing stench and ammonia emission, making necessary a closed system with aeration for future composting.

4.3.2. Public-relations work

Initial opinion-surveys in the communities of the catchment area revealed no public or political interest in the topics of wastewater treatment and sewage-sludge disposal. The most important organ of communication is the community newspaper issued by the municipal administration. Other local methods of communications possibilities are seldom used and are of little account (Fig. 3).

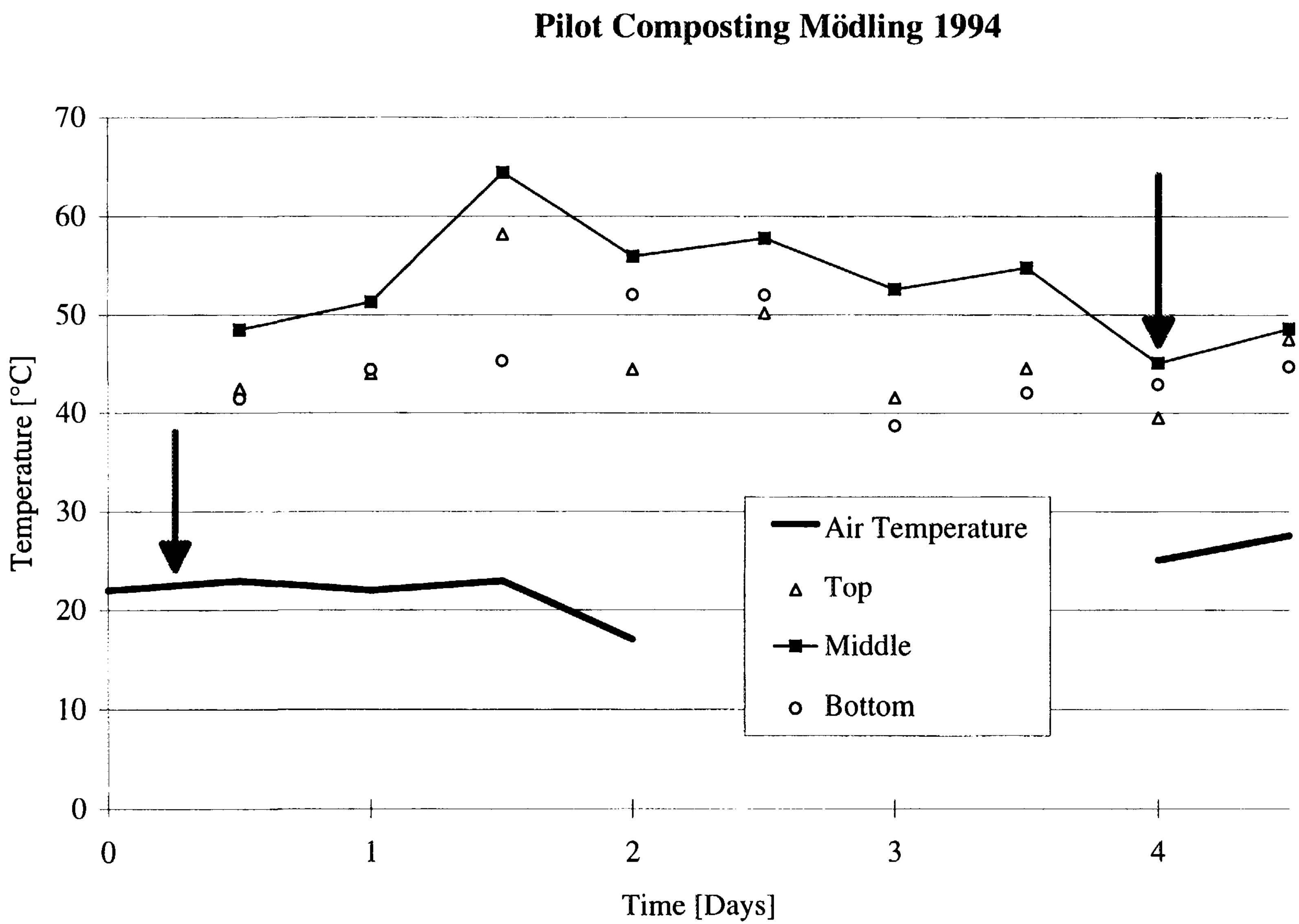

FIG. 2. Temperature as a function of time of composting (aeration introduced at arrows).

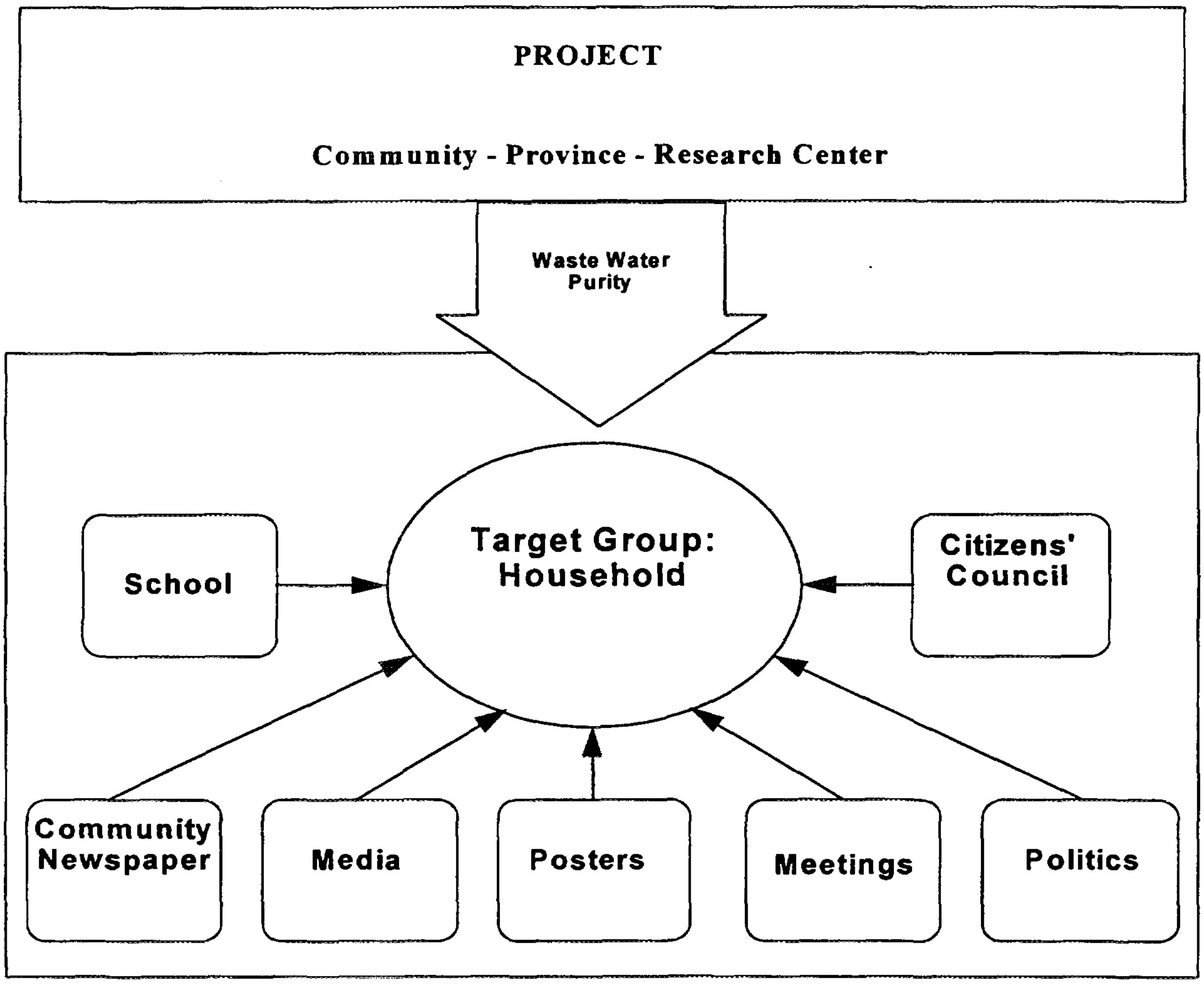

FIG. 3. An example of a target group: a household.

The municipal newspapers in the catchment area are of various types. Some offer exclusively service news, and only in the town of Mödling does the newspaper provide a platform for discussion. In the present case, there have been continual reports on the sewage-sludge project, and the citizens are now accustomed to reading "something related to sewage sludge." However, although it is thus possible to improve public awareness, it is more difficult to achieve improvement in wastewater quality. Therefore a long-term strategy was devised, utilizing the school system. A survey of textbooks for primary and secondary schools (ages 6 to 14 years) showed that the subjects of drinking-water quality and wastewater are touched upon only occasionally and then very restrictively. For this reason a teacher-oriented instruction brochure was published, directed principally at primary schools (ages 9 to 11 years) and dealing with water in general and with special reference to the impact of residual substances in wastewater. The test-period recently came to an end, and positive responses have led to the preparation of a province-wide edition.

Agricultural sludge utilization requires a measure of mutual understanding and confidence between farmers and sewage-treatment plants. Such confidence must be rebuilt to reverse past misunderstandings. An essential precondition lies not only in improving, but also maintaining the quality of the sewage sludge. By the enforcement of legal restrictions, significant improvements are possible through technology. But, so-called background pollution can be reduced only by long-term educational work. Developing public consciousness of problems inherent in the preservation of water, the treatment of wastewater, and the disposal/utilization of sewage sludge is rather similar to doing so for recycling. Just as recycling has been successfully brought to public attention so can an awareness of wastewater. The Lower Austria model as well as the Mödling project are steps in the right direction, with positive responses from farmers. Ultimate success, however, will depend both on future detailed work and on the introduction of meaningful technical measures in the sewage-sludge processing.

Sewage sludge is a fertilizer and a soil conditioner. From the point of view of recycling and acceptable economies in agriculture, it must be applied continuously, like other commercial fertilizers. However, the disposal of biologically degradable substances has become a concern for present and future generations. The transition period of 10 years must therefore be used to develop alternative models acceptable to municipal councils and farmers, and, more importantly, with benefit for the environment.

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