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Energy and Environmental Impacts of Materials Alternatives: An Assessment of Quantitative Understanding

By **Arthur H. Purcell,** School of Engineering and Applied Science, George Washington University, Washington, D.C. 20052, and **Fred L. Smith,** U.S. Environmental Protection Agency, Washington, D.C. 20460, U.S.A.

The considerations disclosed in this paper will enable developing countries to avoid environmental impacts that already belong to the established technologies of industrialized countries. Thus, it is advisable to examine any plant in project with regard to refuse impacts in the widest possible sense as described by the following.

Introduction

A major obstacle to effective materials policy making aimed at resource conservation is the lack of understanding and sound quantitative data on energy environmental impacts of materials production and use. Without such data, efforts to conserve our materials resources will fall short and could even lead to preferential allocations of resources that cause severe energy and environmental strains. For example, in the United States, a number of proposed legislative measures allude to establishment of guidelines or regulations to minimize use of what are usually termed "energy intensive" or "environmentally degrading" materials, particularly packaging materials, without giving the means for establishing adequate data bases by which such guidelines might be formulated. As a consequence, the measures to minimize energy or materials intensity will probably have considerably less than their potentially maximum positive effect.

To assess the state of the art of quantitative measurement of energy and environmental implications of materials, the authors have analysed a number of major studies performed in the past few years on this subject (1–37). These efforts have ranged considerably in depth, scope, and clarity.

Background

Three major categories can be identified by which to measure the impacts of material product alternatives on the utilization of natural resources and the environment:

(1) The quantity of material and energy resources required by an alternative.

(2) The amount of residues or pollutants generated in the activities associated with alternatives.

(3) The extent to which natural resources are redistributed by alternatives – for example, the extent to which soil nutrients are removed from the soil if whole tree harvesting becomes widespread.

The energy crisis, a possible "materials crisis", and continuing environmental concern, all have created interest in quantifying and better understanding how these impacts affect our society. However, much work remains to be done. Only the resource category of impact – the amount of material and energy resources required by each production/use alternative – has received substantial quantitative attention with major emphasis on energy impacts. No consistent data exist on the flow of the major materials in our economy; work that would allow the construction of an input-output matrix in physical units – volume of wood, mass of steel, etc. – has scarcely begun.

Work on the second category of impacts – the residues generated by specific production/use alternatives – is limited. Residual impact data, which provides direct measurements of environmental effects, has begun to appear with some regularity, but the efforts directed toward its collection and analysis lag far behind our understanding of the resource requirements of a production sequence. A third impact category – the evaluation of the extent to which resources are dissipated or redistributed by any specific alternative – is even more poorly researched.

Our analysis of major studies addressing the first two impact categories reveals that energy impacts have, understandably, been of far greatest concern; two thirds of the works reviewed concentrate exclusively on energy impacts. Similarly, impacts for finished products – especially consumer packaging – have been of much greater interest than those for bulk materials. The latter is indicative of the highly visible and economically significant role of packaging in materials resource use.

The levels of these efforts have varied widely from simple manipulations of such standard data as that found in Statistical Abstracts (38) to extensive studies involving the development of totally new information and evaluation procedures. The results of these studies have been far from uniform, due mainly to the complexity of such an evalua-

tion task. A number of interdependent variables are responsible for this complexity. To assess the overall environmental and resource implications of any material product, the following must be known:
- specific materials involved
- processes used to acquire the raw material
- grade of the raw material
- processes used in the refining, production, and fabrication of the product
- extent to which process effluent discharge controls are in effect
- bounds of the material processing systems being considered
- geographic location of material production facilities
- geographic location of material use and disposal

Total Systems Approach

Most of the studies attempt to calculate impacts through a so-called total systems approach, in which calculations begin at the mining, drilling, or harvesting level and proceed through the fabrication, marketing, use and discard stage. Calculations at significantly varying levels of details are given. For example, some studies simply report a total energy consumption figure for paper while other studies may break down this figure into the energy requirements of harvesting, pulping, bleaching, and paper-making. Factors such as transportation are generally included, while less direct effects such as those resulting from manufacturing the equipment used to carry out a particular process are not. However, although many studies attempt a system approach, few delineate clearly the boundaries of the system being evaluated. This makes cross-comparison very difficult.

Data Bases

From our review, it is apparent that the precision and timeliness of the data bases used by different authors vary considerably. In a systematic comparison of major beverage container impact studies, Haller (18) concludes that while it is generally not possible to decide which impact estimates are "correct" in the absolute sense, it is possible, in studies where data bases are sufficiently detailed, to identify points where differing assumptions were made. One of the most important of these assumptions is in regard to the technological systems considered: does the study assume use of the best available technology, the "average" technology, or does it make separate assessments for each major alternative? Generally, it is difficult to determine this answer from the studies.

Other important aspects that any data base should consider are the following:
- role of secondary or indirect impacts (land use, etc.)
- geographic scope (treatment of impacts of imported materials)
- derivations of fuels to generate electricity
- use of gross or net energy
- currency of data
- source of information (private sources vs. public sources)
- specificity of data (individual plants or industry data vs. generalized data, e.g., SIC*)
- "directness" (analysis of processes vs. input-output analysis)

It is not possible to compare directly studies that utilize different assumptions in their data bases because of the wide range of assumptions used by various authors, and because of the difficulty in determining what assumptions were used in each study.

The impacts measured fall into the following categories:
- energy consumption (fossil fuel equivalent)
- materials consumption (virgin and recycled)
- wastewater volume
- air emissions (particulates, SO_x, NO_x, CO, etc.)
- water effluents (BOD, suspended solids, etc.)
- solid wastes

Energy

As noted, most studies deal only with energy. In nearly every case, a *total energy* figure, composed of gross energy consumption inputs from each disaggregated process step, is given. However, in some studies of paper manufacture, a distinction is made between gross and net energy consumption to account for the energy obtained from process wastes. A few studies — for example, those done by Gordian Associates (14, 16, 17) and Midwest Research Institute (30, 31) — even further delineate the various types of energy consumed (purchased electricity, coal, oil, gas, nuclear, hydro).

Accounting for energy usage from various sources is probably the major source of variation in energy impact data. As Haller (18) points out:

> Perhaps the most significant difference (among the reports reviewed) concerns the value assigned to a delivered kilowatt hour (kwhr) of electric power. No one questions the fact that the energy equivalent in British thermal units (BTU) of one kwhr is 3,412.76. But very large differences in assumed BTU equivalent occur depending on the assumed efficiency of the conversion of fossil fuel heat to electric power transport, mix of thermal and hydroelectric generation and the method used to average in the hydroelectric portion.

Most studies assume a conversion efficiency of about 35 percent for electricity generation from fossil fuel. Generally, hydroelectric power is measured in terms of its fossil fuel equivalent; the rationale is that use of hydropower "ties up" this pollution-free form of energy and necessitates use of fossil fuel powered electricity for other purposes. However, industries that rely heavily on hydropower have argued that hydropower should not be assessed in this way because to do so attributes to materials processed through hydropower, environmental impacts for fossil fuels that it does not use.

Another important question in energy impact reporting is whether the heat values of organic materials should be included as part of their overall energy intensiveness. While most authors include the heat value in energy calculations, Hunt and Welch (22) disaggregate their energy data to show the differences between energy intensiveness of selected plastic and paper containers with and without heat value included; their findings show that the heat value of a plastic product can account for up to half of the total energy impact.

Free Energy

Berry and Makino (6) use the concept of free energy which, because it includes the effects of entropy, they claim is a more accurate indicator of energy impact than what is ordinarily considered simply energy. These authors state that free energy takes into account such factors as variations

*Standard Industrial Code used by U.S. Department of Commerce.

in quality of raw materials through the entropy; they make their impact calculations accordingly. While it is not altogether clear how the entropy term should be or is calculated, their distinction between energy and free energy is important.

Environmental Impacts

The underlying factor in environmental impact calculations in the studies is that impacts are not localized, i.e., point sources are not considered. Hence, the environmental impacts reported are of limited use on an aggregated level. The few studies reporting environmental impacts on a disaggregated basis, e.g., Gordian (14—17), Yaksich et al. (37), or Midwest Research Institute (31) provide what we regard as the best means of judging the effect of a given process change on a given environmental impact.

Noise pollution, an important environmental parameter, is not considered. Similarly, esthetic environmental impacts such as litter, land disturbance, social displacement, etc., are not considered. (For a discussion of the significance of these impacts in materials use, see ref. 39.)

Secondary Impacts

Certain secondary impacts are considered only partially or, in most cases, not at all. Among these are mining waste effects and impacts from manufacture and marketing of the machines used to produce materials and products. Transportation impacts of materials and products generally are considered, although, not always in a very clear manner. Inputs from processing which occur outside of our borders are usually neglected.

Major Findings

The studies reviewed generally present strong documentation for the material, energy, and environmental benefits possible through reuse, or recycling, of secondary materials. Recycling of paper, steel, aluminum, and glass is shown to entail reductions (ranging from modest to large) in virtually all major impact categories provided that a maximum amount of secondary materials are used in the respective recycling processes.

Hunt and Franklin (23), for example, report that use of secondary fibers in paper making results in reduction of energy, resource, and environmental impacts in the pulp production in every category studied except for large suspended solids produced at de-inking mills. The Yaksich et al. (37) study, which examines three dozen impacts of steel and aluminum production, indicates large improvements in virtually all energy and environmental impact categories from aluminum recycling (in the range of 1/20 to 1/40 those of virgin production), small improvement from steel recycling using the basic oxygen process, and significant improvements by recycling steel via electric furnaces. The Bravard et al. (9) report supports the Yaksich et al. (37) findings in regard to energy impacts. Comparisons of the data indicate fair agreement among the major studies on the impact of recycling paper, steel and aluminum. Discrepancies exist as to energy benefits of glass recycling. Gordian (17) assesses a modest saving in energy from glass recycling, while Berry and Makino (6) claim zero net savings from glass recycling on a free energy basis in the total system.

While plastics have received considerable attention as a packaging material, essentially all calculations have dealt with virgin production; a few (e.g., Haller (19)) have treated the reuse of plastic products. Little effort has been directed toward plastics recycling because of current technological limitations in this area. However, Berry and Makino (6) report a drop in energy intensiveness for raw material production from more than 51.62 MJ/kg to less than 2.38 MJ/kg for the recycling case, although they acknowledge the practical difficulties of such recycling.

The FDA environmental impact report (36) on alternative containers shows plastics coming out "best" in overall impact ranking *if* plastic containers can be *reused* by being made refillable. This is an unlikely option, however, due to creep of the plastic material.

The studies clearly point out the difficulties in rating different materials and products in terms of their impacts, due to the number of variables that affect these measures.

Berry and Makino (8) rate energy intensiveness of the major materials in significantly different ways for the virgin and recycled cases (highest to lowest):

Virgin material	Recycled material
aluminum	steel
steel	aluminum
plastics	glass
glass	paper
paper	plastics

While the inherent nature of aluminum makes it many times more energy intensive to produce a ton of it from virgin ore than a ton of virgin steel, its recycled energy intensiveness is (according to ref. 37) roughly half that of virgin steel and comparable to that of recycled steel. Since under present technological conditions where aluminum is much easier to recycle than steel, it can be argued that aluminum may be less energy-intensive than steel. But increased recycling is the key, since only about a fourth of aluminum now used in say can manufacturing, is obtained from recycled aluminum.

Resource intensiveness drops in proportion to the degree of recycling, although, as a Gordian (17) study points out for the case of paperboard recycling, it sometimes requires more weight equivalent of secondary material than virgin material to produce equivalent amounts of products. Hence, recyclability plays a direct role in reducing virgin resource use. For this reason, plastics (collectively) fare badly in the resource intensiveness category, while aluminum looks much better because it is more readily recycled.

The number and variety of impacts associated with given materials and products make their comparison a kind of "apples and oranges" problem. To resolve this difficulty, a few investigators — most notably those at Midwest Research Institute (30, 31) — have devised impact profile analyses. Their "Resource and Environmental Profile Analysis" (REPA) is set up in the following manner to measure relative impacts of differing products:

For each product, impacts are measured in the seven general categories listed below. For each impact category the impacts derived for all products considered are summed so that the relative contribution of each product can be determined. In this way, an unweighted index showing the relative (vis à vis all other products) contribution of each product type with respect to each impact measure, can be obtained. In applying REPA to comparing plastic and glass containers, for example, the total amount of energy used in the manufacture of one million poly(vinyl chloride) (PVC) bottles and one million glass bottles is 39.9 terajoules. Of this total, PVC contributes 12.9 TJ (or 32.1 percent of the total), while glass contributes the remaining 27 TJ (or 67,9 percent of the total). Thus, PVC's unweighted index for energy use is 32.1, while glass is 67.9.

In a major study on beverage containers (30), the following weighting factors were assigned to each impact category:

raw materials	5
energy	40
water volume	5
solid wastes (industrial)	5
atmospheric emissions	20
waterborne wastes	20
post-consumer solid wastes	5
	100

By multiplying the weighting factors by the unweighted indexes, weighted index values were obtained. It is interesting to note that this method resulted in plastic containers ranking lower than non-plastic containers in six of the above impact categories and tying in the seventh. The authors were quick to point out, however, the limitations of such rankings, noting: (a) that the REPA analysis is specific to the particular product (and its weight) being considered and direct extrapolations should not be made; (b) the analysis tends to soften isolated highly adverse impacts, and (c) it does not take into account toxicological effects, social values, esthetic factors and other less tangible impacts.

Summary — Concluding Remarks

The major materials and product impact measurement studies have generated considerable data of varying quality and consistency. Their most important contribution to date appears to be the quantification of the wide array of relative impact reductions possible through recycling. They have documented that recycling of materials can make substantive contributions to reducing energy, environmental, and resource-intensiveness of our supply of material goods.

Analysis of these studies indicates that much work remains. A wider base of data for neglected environmental impacts and for non-packaging products must be developed. Many gaps remain in the standardization of precise methodologies necessary to develop data bases that can provide non-conflicting reports of absolute impacts. The major variables of impact measurement — particularly those related to geographic factors — must be handled more adequately.

Further development of impact profile analyses will be necessary in order to better answer the questions of which materials or products are the least energy or environmentally-intensive. Some promising work has been done in the impact analysis area, but it must be refined to better reflect certain secondary impacts, as well as the more intangible primary ones. Standardized weighting methodologies need to be established to insure that analyses do not reflect researcher biases, if possible.

All indications point to growing national and international concern over energy, resource, and environmental issues. Policy decisions will be increasingly oriented toward these issues. To guide these policies, greater understanding of the interaction of materials, energy, and the environment is needed. A well-defined standardized system of impact measurement and analysis is necessary to provide reliable and readily available data to facilitate such understanding.

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News from WHO

Working group

Experts recommend ten-year development plans to reach targets of water and sanitation decade
Based on a news release from the WHO Regional Office for the Western Pacific. WHO Chronicle, 1978, 32, No. 1, 42–43

Ten-year national development plans for rural and urban water supply and wastes disposal systems were recommended by a working group that met in Manila on 10–15 October 1977. The group, sponsored jointly by WHO and the Asian Development Bank, considered these plans to be the "most appropriate way" for providing all people with access to a safe water supply by 1990. It would also be in keeping with decisions made at the 1976 Conference on Human Settlements (Habitat) and the 1977 United Nations Water Conference, which had urged that the 1980s be declared the International Drinking Water Supply and Sanitation Decade.

The working group further advocated concerted efforts to remove the financial, managerial, and technical obstacles to water and sewerage development. Fundamental policy changes were now needed for ensuring continuity of funds, strengthening the institutions and manpower, and getting the maximum support from the people, particularly for rural water systems.

Two sets of recommendations were made – one for urban areas and the other for the rural sector.

Countries represented at the meeting were Afghanistan, Bangladesh, Burma, Fiji, Indonesia, Malaysia, Nepal, Pakistan, Papua, New Guinea, Philippines, Republic of Korea, and Thailand. Observers were present from the International Bank for Reconstruction and Development, UNICEF, and the WHO Regional Office for South-East Asia.

Conference

International Conference on Primary Health Care

The International Conference on Primary Health Care was organized by the World Health Organization (WHO) and the United Nation's Children's Fund (UNICEF) at Alma Ata, USSR, from 6 to 12 September 1978. The intergovernmental conference was attended by delegations from 134 governments and by representatives of 67 United Nations organizations, specialized agencies and non-governmental organizations in official relations with WHO and UNICEF.

The Conference called for "urgent action by all governments, all health and development workers, and the world community to protect and promote the health of all the people of the world". The following item is from the ten-point Declaration of Alma Ata:
"VII. Primary health care . . . includes at least: education concerning prevailing health problems and the methods of preventing and controlling them; promotion of food supply and proper nutrition, an adequate supply of safe water and basic sanitation; maternal and child health care, including family planning; immunization against the major infectious diseases; prevention and control of locally endemic diseases; appropriate treatment of common diseases and injuries; and provision of essential drugs".

Reorganization of the Division of Environmental Health, WHO

The Division of Environmental Health now consists of:
- a Director's office, strengthened in its capacity to carry out Division-wide planning and management in support of WHO's technical cooperation in the field of environmental health, and to ensure coordination at the global level;
- three structural units with assigned staff and headed by a manager with the titles "Environmental Technology and Support (ETS)", "Environmental Health Criteria, and Standards (HCS)", and "Global Promotion and Cooperation for Water Supply and Sanitation (GWS)".

In the Office of the Director, **Mr R.E. Novick** has been assigned special responsibility for regional cooperation and **Mr J.N. Lanoix** for technical coordination.

The managers of the three units have been designated as follows:

1. Environmental Health Technology and Support (ETS)
   Mr P.A. Stevens

2. Environmental Health Criteria, and Standards (HCS)
   Dr V.B. Vouk

3. Global Promotion and Cooperation for Water Supply and Sanitation (GWS)
   Mr D.V. Subrahmanyam

IRCWD News

It is with sincere regret that we have learnt of the sudden death of **Mr Luis A. Orihuela,** Chief, Community Water Supply and Sanitation, Division of Environmental Health, World Health Organization, Geneva; on 5 October as a result of a heart attack.

Following the recent organizational changes within the Division of Environmental Health, he had been appointed with Mr R.E. Novik in the Office of the Director.

During the many years we worked together we all learnt to appreciate Mr Orihuela's personal and professional qualities.

New Publications

The International Development Research Centre, P.O. Box 8500, Ottawa, Canada, K1G 3H9, has compiled a collection of papers entitled **"Compost, Fertilizer, and Biogas Production from Human and Farm Wastes in the People's Republic of China",** edited by Michael G. McGarry and Jill Stainforth in 1978.

This report covers the use of human and agricultural wastes for compost, fertilizer, and biogas production in China and discusses various methods of hygienic waste disposal, composting and parasite elimination.

Building materials and construction techniques for village sanitation equipment and fuel-producing biogas plants are also described.

It is one of the very few reports from China giving empirical data on these processes.

Sanitation without Water, preliminary edition by Uno Winblad, Wen Kilama and Kjell Torstensson. Available from Mr L. Rosenhall, Industry Division, SIDA, S-10525 Stockholm, Sweden.

Contrary to many publications dealing with sanitary problems in developing countries claiming the transfer of sophisticated installations from industrialized parts of the world, this book contains practical information on how to design and build compost latrines and improved pit latrines with emphasis on simple measures that can be implemented with limited resources.

This book is primarily intended for health officers, sanitarians, medical auxiliaries and village technicians in East Africa. It should also be of relevance to medical officers interested in prevention and to physical planners, architects, and civil and sanitary engineers concerned with appropriate technology.

The general background information and the examples should be useful also to readers outside East Africa.

The first part of the book contains two chapters with general background information on the relation between sanitation and disease and on the composting process. In Part II, ten different dry sanitation systems from various parts of the world are described. Part III is a manual. Finally there is an appendix on fly control in dry latrines.

At the beginning of 1978, Compost Science Journal underwent some major changes. It acquired a new name and a new editor/publisher in the person of **Jerome Goldstein.**

The Journal is called now **Compost Science/Land Utilization,** Journal of Waste Recycling, published by The JG Press which took over from Rodale Press.

The editorial board is directed by Dr Clarence G. Golueke, University of California and includes among others: Cord Tietjen of the Institute for Crop Science in Braunschweig, Germany, Dr Hardy Vogtmann, Director of the Research Institute of Biological Husbandry in Oberwil, Switzerland, Eliot Epstein, Soil Scientist of the Biological Waste Management Laboratory in Beltsville, Maryland and David G. Wilson of the Massachusetts Institute of Technology in Cambridge, Massachusetts.

Abstracts

The following abstracts have been taken from our documentation on solid wastes which contains over 2900 publications.

Giordano, P.M., Mays, D.A.: Effect of land disposal applications of municipal wastes on crop yields and heavy metal uptake, April 1977, PB 266 649/RC, 72 pp, NTIS, National Technical Information Service, US Department of Commerce.

This report provides the cumulative data acquired from 1969 through 1975 from field and greenhouse investigations pertaining to the effects on selected soils and plants from municipal compost and sewage sludge applications. Multiple applications of composted municipal refuse resulted in satisfactory crop growth with only moderate increase of some heavy metals in plant tissue. In contrast, lower rates of several domestic sewages resulted in significant uptake of certain metals, especially in more sensitive species, such as leafy vegetables and string beans. Plant availability of metals derived from sewage seems to be related to product matrix rather than to total metal content. Little downward movement of heavy metals was observed under conditions of heavy leaching in the greenhouse or natural rainfall outdoors.

Stickelberger, D.: The problem of the fast and slow cycles of fertilization, May-June 1977, **18,** No. 3, 12–20, Compost Science.

The energy balance shows that the nutrient supply with compost (Brikollare) needs less energy than the same amount NPK in the form of artificial fertilizer. The probably higher leaching rate of fertilizer is not considered. Depending on local conditions, the amounts from composting refuse and sludge are sufficient for 30 tons/ha to 111 tons/ha. The organic material that is applied together with the main nutrients and the trace elements saves more energy. The same is true for the overground cultivation. Because of re-establishing a slow nutrient cycle by fertilizing the soil instead of the plants, the soil gets a structure and becomes resistant against erosion and leaching out. Additional fertilizing should be done with organic or barely soluble material in order to maintain the soil biology. There are not only ecological advantages but also economic ones. Pests and plant sickness are probably controlled more easily and with less harmful methods.

The specific questions of soil and plants are put into the general statement that is found in the Encyclopedia of Environmental Science and Engineering: "Generally the less complex a natural eco-system, i.e. the smaller the number of species (less diversity), the more liable it is to perturbations and to catastrophe."

McIntyre, D.R., Silver, W.J., Griggs, K.S.: Trace element uptake by field-grown food plants fertilized with wastewater sewage sludge, May-June 1977, **18,** No. 3, 22–29, Compost Science.

Garden vegetables and grains were field-grown in San Ysidro loam amended with lagoon-dried, municipal wastewater sewage sludge at 235 tonnes/ha (84 dry ton/acre). Our objective was to stimulate a family garden plot in which the only fertilizer used was several cubic yards of sewage sludge. The garden was sprinkler irrigated and moisture levels were maintained near field capacity. At harvest time, both soil and plants were analyzed for 35 elements by neutron activation, atomic absorption spectrophotometry, or both. Crops grown in an adjacent plot in soil without sewage sludge provided our control data. The sludge-grown plants contained elevated levels of K, Ca, Mg, Zn, Cu, Pb, and Cd. Low soil concentrations of cadmium appear to be readily taken up and assimilated by plants. In general, concentrations of metals were higher in leaf tissues than in roots; for example, zinc was higher in radish leaves (290 μg/g Zn) than in the edible radish roots (145 μg/g Zn).

Answers to Pollution Puzzle

1 S	2 I	3 B		4 C	5 A	6 N	7 A	8 L		9 O	10 U	11 T
12 R	O	E		13 O	X	I	D	E		14 I	R	E
15 I	N	T	16 A	K	E		17 D	A	18 H	L	I	A
			19 R	E		20 L		21 D	E			
22 A	23 R	24 E	A		25 S	A	26 G		27 A	28 L	29 M	30 A
31 C	O	N	C	32 E	N	T	R	33 A	T	I	O	N
34 O	M	A		35 M	O	R	A	L		36 V	D	I
37 R	E	C	38 E	P	T	I	V	I	39 T	I	E	S
40 N	O	T	E		41 S	N	E		42 I	D	L	E
			43 L	44 E		E		45 F	L			
46 E	47 N	48 I	S	L	49 E		50 F	I	L	51 T	52 E	53 R
54 L	A	C		55 S	O	56 L	A	R		57 U	D	O
58 L	Y	E		59 A	N	I	O	N		60 B	O	D

S. Peter, Editor
"IRCWD News"
Swiss Federal Institute for Water Resources and Water Pollution Control (EAWAG)
Ueberlandstrasse 133, CH-8600 Duebendorf, Switzerland