International Water Resources Association
Water International, Volume 25, Number 1, Pages 139–147, March 2000

Present Challenges in Water Management
A Need to See Connections and Interactions

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Abstract: *This paper characterizes present challenges in water management worldwide and explores interdependencies between present technologies in water supply, sanitation, organic waste management, agriculture, and food production. The purpose of this discussion is to increase the sensitivity of readers to the connections between actions planned or already taken in different sectors that are usually only marginally considered by the scientific water community. A related purpose is to show how present problems may be turned into opportunities provided that actions in water management, sanitation provision, solid waste management, agriculture and food production are seen and approached as highly interdependent. An overriding premise of the discussions is that the scientific community of water scientists has a crucial role to play in future actions towards securing not only access to water and decent sanitation to everybody but also in global struggle to deliver enough food for a growing world population.*

Keywords: *Water management, water availability, sanitation, organic waste, agriculture, water reuse, ecological engineering.*

Introduction

Uneven distribution of water over the earth and in time creates regional problems, but the more general problem is that present patterns of human water use and sanitation are based on needs and experiences from countries in temperate climate zones. These patterns and the corresponding technological solutions are forming the present water management paradigm that is expected to be universally valid. The application of this paradigm has brought progress in many countries but also, mostly due to high costs and need of advanced scientific knowledge and technical skills, has delayed progress and caused environmental degradation and other water-related problems in other countries.

The present lack of water supply and sanitation in many parts of the world is a result of our inability to take advantage of the basic law of nature: cyclical flow of materials in nature. This law is clearly manifested, by the fact that the nutrient content in the excreta of one person is just sufficient to produce agricultural products with all the nutrition necessary to maintain the life of one person.Thus, theoretically, there should be no reason for anyone to be hungry. In spite of the obvious cyclicity of water flows in nature, humanity is now on the edge of global water catastrophe caused in part by wasteful water uses in agriculture and sanitation.

There is a fundamental connection between water supply, sanitation, organic waste management, and agricultural development worldwide. In order to secure water, sanitation, and food for all, the world community of water scientists and practitioners must see these connections and use such vision in finding new ways to solve present problems and to turn them into future opportunities. The new goal is to develop technologies and management strategies that protect water resources and the environment and, simultaneously, make organic residuals from human settlements useful in the production of food to feed the growing population of the world.

It is time to realize that a new paradigm in water and sanitation is on its way. This emerging paradigm is based on deeper understanding of connections and dependencies between water management, sanitation, organic waste management, and agricultural food production. It is understood that in order to solve the present multi-faceted problems relating to depleted water resources, lack of decent sanitation, and environmental pollution, future actions must be based on multi-disciplinary knowledge and scientific cooperation across narrow occupational interest areas and across national borders. Such new approaches can help boost agricultural production without further depletion of water resources and global degradation of the environment. Not only the sanitation paradigm but other paradigms must also change. The present agricultural paradigm based on the intensification of rain-fed and irrigation-driven agriculture must be complemented with new solutions and finally replaced with a new paradigm based on the use of recycled water and nutrients, smaller scale production,and a greater variety of production methods, crops and products.

Water Availability and Domestic Water Uses

Along with growing urban population, drinking water demand increases, especially in megacities in developing countries which are taking an increasing part of the total water resources of the world. Urban populations use only a small part of all available water for drinking purposes but delivery of sufficient amounts of water constitutes a difficult logistic and economical problem. Problems of water delivery for all people, including those without sufficient economic means has been neglected in many countries resulting in the serious problem of increasing use of contaminated water for drinking purposes. For example, in the city of Hyderabad, India, people dig pits to the level of un-tight water mains. Contaminated water from the pits is used for drinking. Sometimes, when pressure in water pipes is low, water from the pits enters the water mains polluting entire water delivery networks (Niemczynowicz, Tyagi, and Dvivedi,1998). In Dar es Salaam, due to a lack of water supply in some areas, people make unauthorized connections to the mains and run water via small plastic pipes to their houses. Because these pipes are often damaged, and water pressure is fluctuating water in those pipes may be contaminated with sewage from pit latrines and dirty soil (Mwaiselage, 1997). In spite of great efforts over several decades, there are still about 1.2 billion people in developing countries lacking access to safe drinking water supply.

Pollution of water sources is responsible for the death of about 25 million people each year. Half of all diseases in the world are transmitted through water. It is estimated that about 50 percent of the world´s total population in 1996 was lacking safe drinking water and 37 percent lacking access to adequate sanitation (Simpson-Hebert, 1996). According to Appan (1999) in 1980, "40.5 percent of world population did not have sanitation facilities, this was reduced to 23.3 percent at the end of Sanitation Decade in 1990. By the year 2005 it is anticipated that this figure will rise again to 43.3 percent." By the year 2050 an estimated 65 percent of the world population will live in areas of water shortage (Milburn, 1996). Newer sources (Knight, 1998) say that the pace of population growth is slowing down and if this trend continues "only" 25–40 percent of the population will face shortages of fresh water. Between 1900 and 1995 water use in the world has increased by a factor of six, that is more than double the rate of population growth. (WMO, 1998).

According Engelman and Le Roy (1993), from approximately 113,000 km^3 of water per year that falls down on the land, about 72,000 km^3 evaporates back to the atmosphere, the rest i.e., 41,000 km^3, replenishes aquifers or returns to the oceans by rivers; most of it in flush flows that are not captured by humans. The authors assume that only between 9,000 and 14,000 cubic kilometers per year constitutes renewable fresh water resources available but, according to the authors a "substantial amount," approximately 70 percent is needed to sustain natural ecosystems and thus only 30 percent or 4,200 km^3/year remains for all human uses. That volume divided by six billion people equals 700 m^3/person per year. Irrigation is by far the largest water consumer using about 69 percent of water (483 m^3/person per year), followed by industry using 23 percent equal to 161 m^3/person per year, and thus only eight percent of all available fresh water, or 56 m^3/person per year equal to 153 liters per person per day (Lpd) remains the average for all domestic uses in the world (see Figure 1). It is an interesting coincidence that European average water consumption of around 200 Lpd only slightly exceeds the above theoretical global water availability. Many other developed countries use much more, up to 600 Lpd. many developing countries use much less. An absolute minimum might be around five or six Lpd, that is approximately what a nomad in Sahara uses.

Of the 200 Lpd, the average water consumption per capita in Sweden, 5 liters is used for drinking, 15 for dish washing, 60 for bathing, 35 for laundry, 45 for house cleaning, and 40 for toilet flushing. The figure of water consumption for toilet flushing increases in families with many children and in old houses not equipped with water saving toilet equipment. New types of water closets, and increasing use of urine separating toilets reduces toilet water used as much as 80 percent because they are equipped with two flush buttons: one using only about 0.2 liters (two deciliters) for flush of urine only (several times a day) and another for flush of feaces with about one liter. Water consumption for toilet flushing in other countries and especially in developing countries often uses toilet types that are already out of date in Europe, using possibily as much as eight liter per flush.

It is usually taken for granted that all water delivered to a household must have the same high water quality. But, actually, highest water quality is only needed for

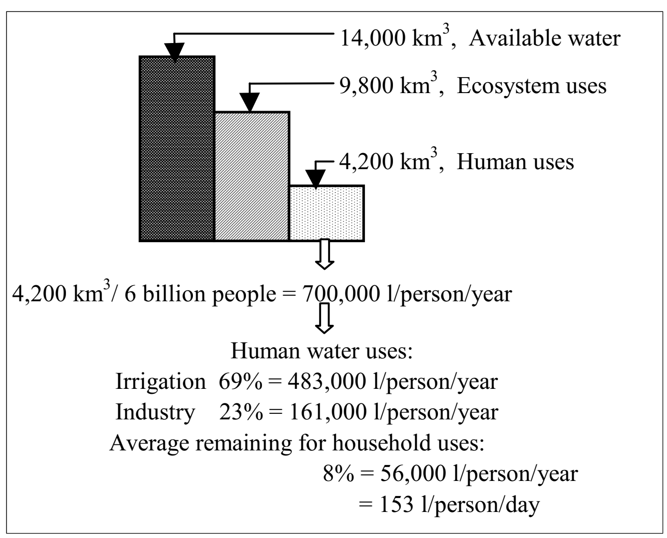

Figure 1. Global availability and uses of freshwater.

drinking i.e., three percent of total water consumption in a developed country (200 Lpd). In housing equipped with water sanitation, all this water is contaminated by bacteria present in human excreta. All delivered water becomes wastewater requiring treatment before it can be released to the environment.

Water Supply and Sanitation Paradigm

Traditional methods used in water resources development and in supply of sanitation were and still are unable to satisfy rapidly growing needs of cities in developing countries. According to the International Water Resources Association, this problem has already become the number one problem in the world (Milburn, 1996) and is recognized as one of the greatest obstacles in the process towards sustainable development. Solving this problem depends on research and on introducing innovative technologies in the water sector and, especially, on choosing what type of sanitation will be included in the future long-term national development plans. Because the present sanitation paradigm is still valid in provision of sanitation, water-borne sanitation is usually considered first in new housing developments in cities of both developed and developing countries. All calculations of necessary water volumes for growing cities are based on this axiom.

Understanding that future sanitation should not be based on water is growing among scientists and practitioners dealing with water and sanitation provision. It is understood that water-born sanitation creates not-easily-reversible, long-term obligations. It is costly and resource-consuming to construct, maintain, and upgrade sewerage systems and treatment plants to satisfy ever increasing requirements for outflow water quality and sludge quality. Simultaneously, water closets in developing countries that usually use several times more water than modern sanitation uses, for example, in Sweden, are the largest water consumers in a household. Just by the use of dry or separation sanitation, water use in a household can be decreased by as much as 70–80 percent. However, the most important reason for growing advocacy for alternatives to water-born sanitation is that sustainable sanitation systems must offer the possibility of safe reuse of nutrients present in human organic residuals for food production. Once mixed, wastewater contains both highly useful organic material and non-organic pollution heavily contaminated with pathogen organisms. Once mixed, it is difficult to utilize wastewater in food production.

Thus, the choice of sanitation type and sewerage for future cities becomes a central issue in a complex area of future human needs, and a very fundamental part of the water management challenge.

Here it may be appropriate to note the words of the President of WHO Collaborative Council Working Group on Water and Sanitation who said: "instead of linking sanitation just to water, the (new) paradigm should connect sanitation to the entire eco-system" (Simpson-Hebert, 1996). And further: "Aid agencies are encouraged to support research into sanitation systems without water," and: "Educational and training institutions need to adjust their curricula away from sewerage and other water-related sanitation systems and focus on the realities of the world with scarce water resources, growing populations and increasing urbanization" (WHO, 1996). These statements show that the WHO Working Group has, during several meetings in more than three years of discussions and investigations, come to the right conclusion that future sanitation systems for the growing world population cannot be based on water. It is worthwhile to notice that it takes time and effort to come to such a conclusion. This is one reason why such a conclusion is not yet generally accepted. It is doubtful that the above mentioned educational and training institutions have even noticed or understood WHO's statement. Certainly, they did not change their curricula as required.

UNCHS Habitat II Agenda, 1996, Chapter IV, item 141j says as follows: "Governments at the appropriate levels, in partnership with other interested parties, should: (1) Promote the development and use of efficient and safe sanitary systems, such as dry toilets, for the recycling of sewage and organic components of municipal solid waste into useful products such as fertilizers and bio-gas."

These statements connect several issues that were seldom connected before. It is clear that the issue of sanitation is much wider than previously: the wastewater nutrients or, in general, all organic refuses from human settlements, may constitute valuable material that in a due time may break present dependency on artificial fertilizers in agriculture and possibly boost food production without increasing use of fossil fertilizers. Simultaneously, organic wastes from households, animal farms, some industries and agriculture may deliver source of clean energy. It is clear that at least some researchers and practitioners in the water profession have begun to accept the need for change in type of promoted sanitation. It is expressed by wording from the conclusions from Stockholm Water Symposium 1999, Workshop 8 on long-term water and sanitation solutions that state: "future sanitation systems should be developed so that they do not use water as transportation media. It is particularly important in arid and semi-arid regions," and: "new solutions are explored in a multidimensional fashion, including water and nutrient cycles as well as energy saving as a natural component." It is a pity that this understanding can only seldom be found among scholars even in highly developed countries. The origin of the present problem of inadequate sanitation in developing countries has its roots in the history, present form and status of water-borne sanitary systems in developed countries from the North. Before this development, present developing countries from the South have had their own local sanitation solution often not based on water. For example, in Yemenite towns dry toilets separating urine and faeces were used for centuries even in multi-story houses. The traditional system of excreta disposal in the town of Ourgala in the Algerian desert consists of composting latrines. In city of Sana in Yemen "long drop latrines" separating urine from feces were used and still can be seen in some old multistory buildings (Niemczynowicz, 1993, 1996, 1997) [see Figure 2]. Moreover, these solutions often included some form of reuse of sanitary nutrients. Flush toilets became compulsory in new houses in British towns starting in1848, and much later in most other countries (Drangert, 1999). Attempts to introduce full coverage with water sanitation in all countries failed, and this began to influence people responsible for water and sanitation provisions in developing countries. There are examples of actions in which both local authorities and citizen organizations put a concerned effort into providing locally acceptable and simplified sanitation to more people. One example is the city of Dar es Salaam in Tanzania where even new housing for middle class citizens is equipped with simplified sanitation using cesspits (Mwaiselage, 1996). Another example, is a local initiative known as the Brantas river project, which has been designed to investigate if the community based small-scale sanitation can work in a densely populated area in Indonesia. The Brantas project is in itself a complete, interesting, quantitative and qualitative study of an Indonesian river and its basin, perhaps the most densely populated region of all Asian countries. The project can stand as a good model

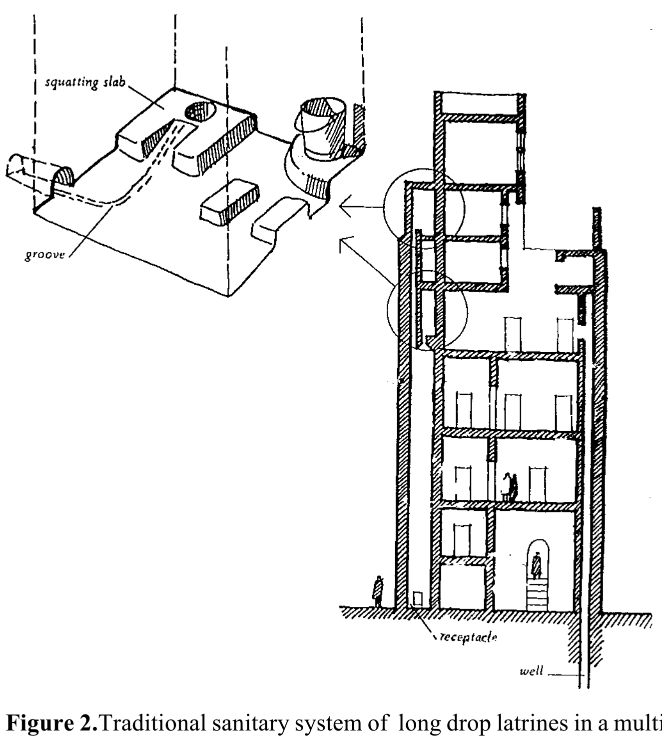

Figure 2. Traditional sanitary system of long drop latrines in a multistory building.

for any Asian country. The project was thoroughly described in Suriptono (1999). Thus, the objective of the Brantas project study is multi-purposed and can be characterized as an attempt to develop a model of appropriate community based wastewater treatment and management as well as to test the applicability of small-scale technologies and to investigate if conclusions from the study could be extended to cover other Asian cities. These objectives are achieved in the thesis and clearly described and illustrated with photographs, diagrams and good self-explanatory figures and boxes summing up technological descriptions and results of the study. The study concludes that it is possible to apply small-scale domestic wastewater treatment systems in densely populated areas. The results were discussed and conclusions formulated during an international symposium held in 1996 at Merdeka University.

Main motives for accepting the need for a different approach to sanitation issues vary between countries. Municipalities in highly developed countries fully equipped with traditional sanitation, sewerage and wastewater treatment plants still have problems with making wastewater sludge useful in agriculture. Evidence is increasing that wastewater sludge contains not only toxic heavy metals such as cadmium and other conservative pollution, but also residues of medicines, hormones, flame protection chemicals etc. Therefore, in spite of high investments and running costs of sewerage systems and wastewater treatment plants, wastewater sludge is still too dangerous for long-term use in agriculture, and is stored or incinerated. Nutrients are lost and pollution from deposited sludge or sludge ashes will, sooner or later, enter the aquatic environment.

In many coastal cities, especially in Latin America and Africa, wastewater is collected in pipe systems but released through out-falls without treatment to the sea. This brings devastation to coastal sea areas with fragile shallow water ecosystems where all marine life/food chains begin. Potential for using wastewater nutrients is also lost here. But majority of all wastewater produced in cities in the world is not treated at all and, if anything, stored for some time and later conveyed to the environment. To give one example, just one river in India, the Yamuda river passing through Delhi, receives 200 million liters of untreated sewage every day (Water Aid, 1996).

Water Reuse and Stormwater

It is clear that in order to alleviate problems with water supply it is necessary to develop methods for multiple and/or quality dependent water use in households and to introduce more efficient economical incentives to save or reuse water. It is also clear that some dry countries return to ancient habits of collecting and using stormwater for non-consumptive water uses. For example, roof stormwater may be used after separation of runoff from first minutes of the rainfall using simple mechanical devices. Consider the volume of water that is delivered to urban areas by the nature in the form of rainfall: 100 mm of rain on 1.0 km^2 impermeable area gives 100,000 m^3 of water. At the rate of water use of 150 Lpd, this is enough to supply 1,830 people during one year. If dry sanitation is used, water consumption of households may be reduced by 70 percent, that is 5,500 people may obtain all necessary water from 1.0 km^2 of impermeable area and a rainfall 100 mm/year. In other words, theoretically a 182 m^2 impermeable area can deliver all of the water that one person needs. This amount of water is considerable, and it should be considered as an important resource. Utilization of this water requires a basic change in applied technology of stormwater management. Traditional technology, i.e., pipes for fast removal of stormwater from urban areas, was developed for wet climate conditions and, thus, people living in semi-arid and arid climate countries make a mistake in copying this technology. It is important to develop technical methods for harvesting this important resource and making it available for less demanding water uses, or after purification, even for drinking purposes. The topic itself is exciting and broad, and cannot be discussed in depth here. It deserves special discussion in a separate paper.

Small inventions can sometime greatly contribute to alleviating present health problems connected to the use of water with bacterial contamination for drinking purposes. An exapmple of such an astonishingly simple solution called SODIS was presented at a poster session of Stockholm Water Symposium 1999 (Wagelin, 1999). The SODIS acronym stands for Solar Water Disenfection that may be performed on the scale of one CocaCola bottle. A black painted CocaCola bottle is filled with undisenfcted water in the morning and exposed to sun during the day. The water in the bottle is recirculating through the bottle and a sling of plastic pipe also painted black. After a sunny day, the water is disinfected and ready to drinking in the evening (Wagelin, 1999).

Water and Agriculture

Availability of water is a limiting factor in traditional rain-fed agricultural production and it is clear that rain-fed agriculture alone cannot satisfy the growing demands for food for growing populations. There is more and more evidence that irrigated agriculture also has development limits and cannot cope with the growing demand for food production because availability of water is a limiting factor, especially in Africa. Thus, in order to secure food production for the growing population, it is necessary to further develop rain-fed agriculture that already produces more than 60 percent of the food in the world, excluding meat production from grazing (Lundqvist and Sandstrom, 1997).

In this context it is important to further explore possibilities to save large water volumes lost in inefficient irrigation systems and to make those volumes available for consumption in rural and urban areas. The most important issue in this context is to reduce irrigation system leakages that amount for up to 80 percent of delivered water volume. To give one example, according to Andersson et al. (1993), a study and measurements performed on a 63-ha date-palm producing oasis in western Tunisia, El Djerid region showed that approximately 60–80 percent of irrigation water pumped from two small rivers and groundwater is lost via leaky concrete channels. One date-palm needs approximately 240 liters of water per day, for a total of 8,500 palm trees, i.e., 2,040 m^3/day is needed while ca 8,400 m^3 is withdrawn.

Seriously addressing the problem of agricultural irrigation leakages is a task of global importance. It should be addressed by scientists developing new irrigation technology and wide introduction of new plant types requiring less water. Another important issue is to develop water saving methods in existing agriculture through repairs and other improvements to present systems and by gradual change to application of innovative technologies in agricultural soil processing. Simultaneously, it is necessary to review present crop production methods and to develop innovative crops and methods using less water, and/or new sources of water. If irrigation leakage could be captured and retured to the supply it would cover all present consumption needs in urban areas.

In the same way that the present sanitation paradigm is gradually falling apart, there are signs that the present agricultural paradigm is also being questioned. There is a realization that new opportunities may be created if a fundamental connection between the present state in urban water supply, sanitation, organic waste management and agricultural development worldwide were fully understood.

The need for increased agricultural production requires new developments in sanitation and solid waste handling technology to make recycling of nutrients from households to agriculture possible. If urban stormwater, wastewater and other water from domestic uses (graywater) could be accepted as a new source of irrigation water in small-scale agriculture, and if organic residuals from all human uses could be accepted as a source of nutrients for agricultural production then a crucial interface between sanitation, organic solid wastes management and agricultural production could be created. This connection could make it possible to increase agricultural production without increasing the use of fossil fertilizers. Such development can already be observed in urban and peri-urban agriculture where wastewater is used

Wastewater and Agriculture

Methods of safe and hygienic utilization of wastewater from water-borne sanitation systems that are presently used in central parts of many large cities in developing countries have been discussed for a long time, but still there is no generally accepted way for utilizating wastewater in agriculture. The problem is discussed, and it seems that it may be technically addressed in two ways: the first one is to introduce changes in water supply systems e.g., introduce dual supply systems in urban areas, one for less polluting water uses and a second for heavily polluted uses such as sanitation. Less polluted effluents can be used directly in peri-urban agriculture while wastewater from sanitation could be used only for irrigation of non-consumptive crops. Due to high costs of this solution, another approach is direct use of raw wastewater for agriculture. In agricultural production of non-consumptive crops wastewater could be used without treatment, or after primary treatment only, and for consumptive crops wastewater could be treated to carefully calculated standards depending on risks for crop uptake of chemical and bacterial pollution (Bahri, 1998). Some of the most advanced innovations in inexpensive wastewater purification systems using aquatic plants to purify wastewater are very promising in this context. One example of this system is the so called Phytodepurational Activated Sludge Systems (Bifotem@aol.com, 1999). Perhaps most experiences with wastewater use in agriculture was gathered in Mexico where effluents from cities, including Mexico City have been used in peri-urban agriculture since 1890 (Jimenez et al., 1999).

Urban Agriculture and "Ecological Engineering"

Urban agriculture is as old as human settlements and cities. People have always tried to improve their living conditions by cultivating crops in the vicinity of their houses. Parallel with urban growth, urban agriculture is growing for better or worse, often without research, approval, and control by central organizations. In several places, urban agriculture has a long tradition and no adverse effects on the health of the population have been noticed. Most known examples of successful cases in urban agriculture are from Calcutta where wetlands were traditionally used as highly productive multilevel aquaculture systems. Wastewater from the city together with solid wastes are used in a chain-production of bio-mass beginning with the growing of non-consumptive trees, fruit trees and ending with consumptive products such as vegetables and fish as outputs. In 1992, this system was first recognized by central authorities as an ecological treatment and bio-mass production plant , i.e., an object worth protection and further development. Recently aid agencies and governments have begun to realize the potential of urban agriculture.

It may be important for water scientists to know that many interesting developments related to water use and food production take place outside an established educational and research institutions. The development towards small-scale urban agriculture, that is possible to arrange on a very limited area in a densely populated city is driven by the local ingenuity of people, often coupled with experiences from old local traditions and experiences. One example of such technologies comes from Botswana where so called "Sanitas wall" (Figure 3) has been developed. The invention is based on the application of gray water from households for growing crops for consumption. In conditions of limited space in an urban environment, a wall made of two-compartment concrete stones (or sun-burned clay) is constructed. One compartment is filled with sand and the other with compost where plants can grow. These bricks are put on top of each other to a height of about three meters. Plants are irrigated with household´s gray water. Three meters high and about three meters long the wall is large enough to absorb an average volume of gray water from one household and is, essentially, enough to deliver nutrition necessary for survival of a three-person family (Gunther, 1998; Esrey et al., 1998). Another new solution to apply in small-scale agriculture is the so called permanent growing strips shown in Figure 4 (Jarlov, 1998). Instead of ploughing, soil is ripped in strips to which rainwater is concentrated to take the crops through drought periods. The amount of water for irrigation is significantly less than in normal agriculture. The method can yield an astonishing 10 to 20 times more grain per hectare than traditional agriculture. Yet another solution is to grow vegetables in concrete Bow Benches, i.e., concrete pots with bow shaped bottom.

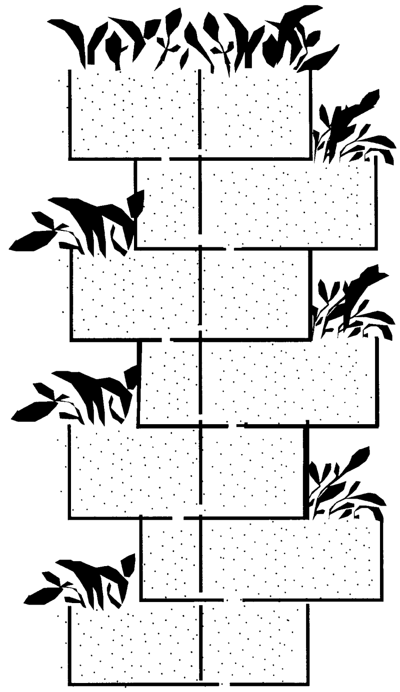

Figure 3. Use of the Sanitas wall in urban agriculture.

The scientific community of water researchers has

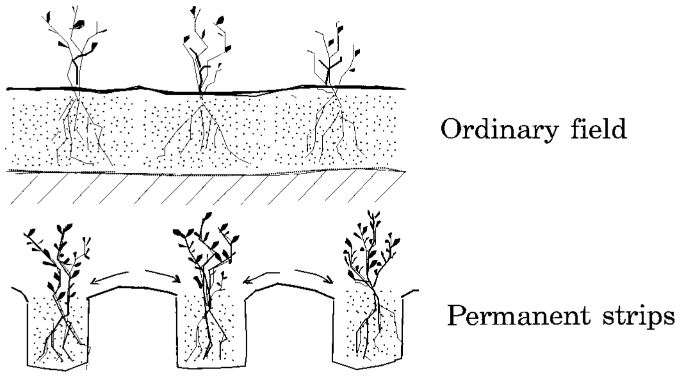

Figure 4. Use of growing strips in urban agriculture (Jarlov, 1998).

an important role to play in further development of methods used in urban agriculture, including aquaculture, pond systems, irrigation with wastewater, and newer types of small-scale gray water-feed agriculture in peri-urban areas. Scientists should see the benefits of such developments and contribute with their knowledge in order to find safe and efficient technical solutions. It is important to conduct local studies leading to establishment of safety rules with respect to construction, water quality standards and consumption restrictions.

There is a growing experience with innovative small-scale technologies for production of food on a limited area and using limited volumes of recycled household water. Besides aquaculture, other interesting emerging technologies include: soil processing, use of various new crops , sea-water fed agriculture, and several small-scale innovative technologies for production of food, that sometimes fall under "ecological engineering." Examples of such technologies are: "food production chains" or "living machines," i.e., systems that use organic refuse in several consecutive steps ending with consumable products. To give one example, such chain production can begin with digestion of organic household wastes using mushrooms, residuals go to a bio-digester producing bio-gas, new residuals go into a horticultural plant food, new wastes end the process and the next cycle can begin. Such, or similar systems are also called "multi-level small scale food production chains using biotechnology," "integrated biosystems," "closed cycle horticulture," garbage-bag gardens, etc. The development in this area is going very quickly now and the subject deserves separate paper. Example of such systems can be found in Rose (1999), Foo (1998), Goins (1997), Wang (1998), Medina (1998), Garbage Bag Gardens (1999), and NASA (2000).

Solid Waste, Wastewater Sludge, Agriculture, Energy, and Space

Agricultural production worldwide is not only bound to irrigation but also to the use of fertilizers. The main fertilizing minerals necessary in production of bio-mas are nutrients: phosphorous, nitrogen and kalium. These nutrients are present in wastewater, wastewater sludge and any organic material, which represents approximately 85 percent of solid wastes. At the moment, only about five percent of solid wastes that households generate in the industrialized world is biologically digested to recover nutrients. Theoretically it is possible to use all 85 percent of solid wastes as a recyclable resource (Gajdos, 1995). However, agricultural recycling of organic material present in solid wastes and in wastewater sludge calls for development of new policies and new handling methods. The wastewater sludge contains all the nutrients necessary for plants, but it is polluted with non-biodegradable substances that will accumulate in the soil if used as an agricultural fertilizer. These substances include several heavy metals of which cadmium is one of the most harmful because it accumulates in the human body over a lifetime. For example, in Holland and Germany the levels of agricultural cadmium products (as the ascent continues) will exceed tolerable limits within a few years, and will result in increased frequency of kidney disease. Therefore, any increase in the delivery of cadmium amounts to agricultureal lands is unacceptable. The problem is that while cadmium content in commercial fertilizers is about 2-3 mg Cd per kg phosphorous, but in sludge the level is about 50 mg Cd per kg P (Lindgren, 2000). On top of that, it is realized that the sludge contains other, often even unknown chemical compounds with unknown composition and toxicity. In the last months of 1999, a new discussion about these issues was going on among Swedish scientists and in the press. It was found that residuals of highly toxic flame-protective chemicals, used mainly in computer production but also in production of many other household articles and in construction materials are present in wastewater sludge. These substances will, sooner or later, enter surface waters bodies and groundwater. In time, these substances may also enter agricultural products. Similar discussion in late 1999, includes denoted hormonal substances found in many rivers and lakes in the country. No one can say what the long-term ecological effects and influence on human health will be. Based on a "precautionary principle," the wastewater sludge should not be used as a agricultural fertilizer.

Generally speaking, at the moment, there is no risk-proof method of handling and using wastewater sludge. Incineration, deposition, pelleting, and other methods that may be used, will, sooner or later, result in potentially harmful substances entering ecological systems, and eventually human bodies. However, perhaps the largest problem with present water and sewerage systems, including water sanitation, is that these systems have no ability to safely recycle organic biogenic residuals from human settlements to agriculture. In order to realize this goal, it is necessary to further develop bio-reactors that are able to decompose household wastes and other organic refuse from human activities. Microbiological processes in bioreactors can digest all organic residuals and the end products are bio-fertilizers and bio-gas. Thus, the solid waste management becomes more a question of recycling nutrients and recovering energy than just collection and disposal of solid wastes. Instead of pollution creating problems, the end products may be used in agriculture to feed the growing population and be a source of clean energy. To realize this target it is not enough to change the sanitation and water supply system, it would require development of new total system solutions for management of all human residuals.

Another type of technology development has been initiated by NASA. The necessity to support the lives of the crew going to Mars requires development of closed cycles of matter including water, food, and air. Based on NASA´s experiences to this day it seems that it will be no major obstacle to achieve closed cycles of material on a limited scale (NASA, 2000). Then, it should also be possible to do this on our "space ship" planet Earth and to bring welfare to all human beings.

Conclusions

Solving present problems by securing provision of water, decent sanitation, and food for the growing population of the world depends on our ability to understand connections and interdependencies that exist between several sectors of the society. Water management is not a single issue, but a central component of complex human-environment system interactions that may together bring the world to the edge of catastrophe or create improvements in welfare and equity for all people.

An important message is that it is possible to arrange closed cycles of water, sanitation and food production in a very limited area. In the long run, recycling technologies will always be less expensive than present resource wasting technologies. Applying closed cycle technology is a final goal of water management, sanitation provision, solid waste management and food production. Based on current experience, this target may not be a product of science fiction, instead, it is an imperative necessity for the survival and development of people in all nations. The world´s educational and research institutions have a very important new role to play. The world, including developed countries, still has many problems related to water management, sanitation provision to all, and agricultural production without using harmful substances. However, technical matters cannot be considered without connection to social and economical development and involvement of a wide spectrum of technology users. It is of the utmost importance to include the needs of the developing world in our discussions, educational programs, and research.

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Discussions open until September 30, 2000.

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