Strategies to close water supply and demand gap

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Abstract The growing water and sanitation crisis in the world calls for enormous efforts from water professionals as well as economic and political leaders. The climate change contributes to the acuteness of the problem, with dryer areas in some parts of the world and severe floods and rains in other parts. The European Water Supply and Sanitation Technology Platform (WSSTP) is an industry driven organisation aiming to strengthen the potential for technological innovation and the competitiveness of the European Water Industry but is also a response to global challenges and regional demands to ensure safe, secure and sustainable water and sanitation services for the benefit of industry, the society and the environment. The supply of electrical energy has to be carefully considered as a pre-requisite for water supply and sanitation. The production of biogas can be significantly increased by using instrumentation and control. The use of monitoring and control has wide consequences for safe and reliable water supply and sanitation.

Keywords Control; electrical energy; monitoring; sustainable development; water supply; wastewater treatment

Introduction – the growing water crisis
The growing water and sanitation crisis in the world is causing nearly 2 million child deaths every year, according to the 2006 Human Development Report (UN, 2006). Throughout much of the developing world, unclean water is a greater threat to human security than violent conflict. Each year, according to the UN report, 1.8 million children – 3 children every minute around the clock – die from diarrhoea that could be prevented by access to clean water and sanitation. (The simple act of washing hands with soap and water can reduce diarrhoeal diseases by over 40%, according to the British Medical Journal). Almost 50% of all people in developing countries are suffering, at any particular time, from a health problem caused by lack of water and sanitation. To add to these human costs, the crisis in water and sanitation holds back economic growth, with sub-Saharan Africa losing 5% of its gross domestic product annually – more than the region receives in aid, a UNDP news release explained.

Other disturbing facts were pointed out in a UNICEF report from October 2006. Over one thousand million people are still living without access to improved drinking-water sources (defined as: water piped into a dwelling, plot, or yard; public tap/standpipe; tube well/borehole; protected dug well; protected spring; and rainwater collection (UNICEF, 2006, p. 27)) while some 2.6 thousand million people – two in five – are without access to improved sanitation (defined as follows: flush/pour toilet to piped sewer system, septic tank, or pit latrine; ventilation-improved latrine; pit latrine with slab; and composting toilet). Providing water and sanitation for these people is, naturally, the most acute challenge in the context of water and sustainability.

On September 8th 2000 the General Assembly of the UN resolved unanimously to support the Millennium Development Goals (MDG). The 191 member states of the UN promised to take all measures to halve by the year 2015 the number of people living in deep poverty, suffering extreme hunger, lacking basic education, dying of major, often water-borne diseases or without access to safe drinking water and basic sanitation.
The objectives set in Johannesburg all have some relation to the availability of safe water and sanitation and have to be achieved. It is a dramatic challenge. During the remaining 2500 working days we have to create clean water access to 200,000 people and provide adequate sanitation for more than 500,000 people every day. Then half the job is done, given a constant population! As most of these people live in cities, this is largely a question of developing urban water systems. In countries where urban water systems are comparatively well developed, on the other hand, there is reason to look critically at existing systems, especially as these may serve as models for developing countries.

The recently issued report from the UN Commission for Sustainable Development identifies that low cost appropriate technologies are desperately needed in the developing parts of the world. Equally, capacity shortcomings on the human and institutional side call for an emphasis on operation and maintenance of existing installations. Clearly, the future investment required to achieve the MDG will need to be immense. However, it must be remembered that technology is not the only solution. New approaches to financing, managing and maintaining systems must be developed, as well as approaches to involve local communities.

In this paper we will look at still another threat, the climate change. Then a brief description is made of the European initiative, the Water Supply and Sanitation Technology Platform (WSSTP). The energy issue is crucial, both for the water supply and for the sanitation. Electrical power systems suitable for both rural and urban areas can be built today and serve the water needs. Biogas can be produced to generate energy. In both these cases instrumentation, control and automation (ICA) are essential technologies for success. Other ways to further improve the robustness of operation and economy of operation by using ICA are mentioned.

**Climate change**

Anthropogenic climate change is the paramount environmental issue of our time. As water professionals we all have to help to reduce the effects of climate change to better prepare the water quality community for its effects. In our treatment plants and related operations we have to take steps to reduce the greenhouse gas emissions. The 2007 report of the Intergovernmental Panel on Climate Change (IPCC, 2007) has both confirmed that climate change is occurring and largely put to rest debates about whether human activities are the cause. It has been noted that the winter of 2006-07 was the warmest for more than a century (the second and third warmest winters were in 2004 and 1998). According to the IPCC the annual precipitation trends from 1900 to 2000 indicate that Africa and the western parts of South America will be particularly hit by dryer weather. Other areas will risk more floods. The global costs of extreme weather events have tripled since 1980. More extreme events place a strain on water and wastewater systems, whether this is due to storms, floods or droughts. The water industry also needs to make a contribution to the targeted reduction in carbon emissions by reducing energy inputs, and making better use of the potential for energy generation from sewage sludge.

In Europe the ability to provide water is affected by climate change, with precipitation reducing by 20% across Europe from 1900 to 2000. A further 1% reduction in precipitation every 10 years is forecast with 5% reduction during the summer (WSSTP, 2007).

**Sustainable water and wastewater management – indicators**

How, then, can we determine whether or not an urban water system is sustainable? How can we determine and influence the development direction and speed of an urban water system with regard to sustainability? Indicators of sustainability or of sustainable development are frequently recommended tools in this context (Verbruggen and Kuik, 1991;
Hellström et al., 2000; Balkema et al., 2002; Bradley et al., 2002). Palme (2007) has investigated whether and how such indicators can best be made useful with regard to these broad questions and give more references. In the literature there is a wide range of definitions of sustainability. The authors form a heterogeneous group including engineers, natural scientists, and social scientists. Their emphasis often depends on their scientific background. Maksimovic (1996) provides one formulation: “Sustainable solutions should seek to address the sustainable utilization of water resources respecting both social and economic as well as environmental interests”. As Beck (2002, p. 23) observes, books and articles on sustainable development are full of “uncertainty, ignorance, nonlinearity, surprise and inherent unpredictability”; resilience is thus needed to cope with a changing environment.

Conventional urban water systems may meet the requirements set up today but they are not necessarily sustainable (Wilderer 2004a). The design of most conventional water systems in industrialized countries follows what Wilderer (2004b) calls “the classical concept of urban water supply and sanitation”, in which the flow is linear from the source (the water reservoir) to the sink (the receiving water) and the main purpose of wastewater treatment is conversion and destruction rather than the recovery of materials. There are several reasons to question their sustainability, but perhaps the most obvious one is that they are resource intensive: directly and primarily with regard to water consumption, and indirectly in the sense that recycling nutrients, such as phosphorus and nitrogen, from wastewater is hindered by the presence of various pollutants. For these and other reasons conventional urban water systems need to be developed in the direction of increased sustainability. A lot of alternative systems and small scale solutions for developing countries have been suggested, see for example Otterpohl et al. (2003), Wateraid (2007).

Within IWA there are several conferences aimed at just this goal; to design and operate small and decentralized systems. Another important development to meet the MDG is rainwater harvesting, a theme for IWA workshops.

In this paper we limit scope of our sustainability and take a pragmatic engineering view of the plant operation. We will consider what instrumentation, control and automation can do to contribute to better use of resources. This is related to the use of electrical energy (e.g. for pumping and aeration), production of energy via heat pumps or biogas, use of chemicals, leakage detection, detection of pollutants and pathogens. Better monitoring and control can contribute to minimizing operating costs. This includes energy management, storm water management, early warning systems, and automatic handling systems. In dealing with sustainability it is always a risk to let the short-term routines and immediate technical problems be dominating so that the long-term perspective on sustainability is lost (Palme 2007). While we deal with the short-term operation, however, it will certainly affect the long-term effects. Therefore an integrated approach is crucial.

The European WSSTP platform

By the year 2004, the EU Commission (EC) in recognition of the almost overwhelming problems mentioned in the introduction initiated the foundation of the Water Supply and Sanitation Technology Platform (WSSTP), a new instrument of the EC to develop and implement innovative technology. Since its foundation the WSSTP has produced various documents. A recent overview of these documents is found in Wilderer and d’Arras (2007).

Technology Platforms provide a framework of stakeholders, led by industry, to define research and development priorities, timeframes and action plans on a number of strategically important issues. They are considered to be powerful actors in the development of the European research policy, and are expected to address technological challenges result-
ing from the various facets of global change, and contribute to a timely development and deployment of new technologies with a clear commitment to sustainable development.

A Vision Document has been presented taking as a horizon the world as it may or should look in 20–30 years from now. Based on the vision a strategy (Strategic Research Agenda) has been developed on how to meet the various targets. Finally a plan has been developed to show means to meet the targets. All the documents are available on-line, see WSSTP (2007).

One of the thematic working groups (TWG 2) – in which the author participated – dealt with water for people. It has to be recognized that the challenges are much more than technical and scientific. The various private sectors, scientific disciplines, and the authorities that finance, govern and use water and water infrastructure will have to join their forces and act in an integrated manner. Strong public awareness and confidence will lead to enhancement of the political will to invest in water research and the installation of water infrastructure. The water sector is an at-times fragmented amalgam of public and private organizations of all sizes and has quite a different structure than the European industrial sectors (aerospace, construction, chemical). For example, France has over 36,500 municipalities, which are responsible for drinking water supply and sanitation. They are served by 16,300 drinking water supply utilities, and 18,000 sanitation water utilities.

Many of the presented research needs and priorities are related to monitoring and control. Water savings techniques need to be improved and automatic leakage detection is one element. Smarter and lower cost treatment of alternative water resources often requires good monitoring and control. This will aim at reduced inputs and wastage, a better efficiency of electrical power and chemical use and a better re-use and recovery of materials from water and wastewater treatment. The development of low-cost sensors and models is of key interest. There has to be ways to assess the progress, so benchmarking tools and frameworks for capital and operating expenditures will be much needed. However, it has to be remembered that it is not only an engineering challenge. The financing becomes one crucial issue, where one has to understand the relationships between the level of service, costs and the willingness to pay.

**Electrical energy production**

Treatment and transmission of water and wastewater requires large amounts of energy. In a country like Sweden, water and wastewater operations use about 1% of the total national electrical energy supply. The demand on electrical energy will have an environmental impact, which means that the sustainability issue is critical also from an energy perspective. Clean water requires electrical energy: for pumping of drinking water and of sewage, for mixing and for aeration of wastewater, for chemicals, for transportation of sludge. Desalination for water supply is rapidly increasing. In the Mediterranean area there is an 18% annual increase and in Saudi Arabia a 17% increase every year. This requires huge amounts of energy.

In developing countries billions of people have not yet turned on the first electrical light. For example, in Tanzania only every 5th person has access to electricity. In the rural areas even fewer people are connected, only every 20th person. Electrical energy is so vital for the whole of developed society today, that we cannot imagine a life without electricity. Again, to reach the Millennium Development Goal the world can probably not afford an electrical power system structure similar to the one in the industrialized countries. Other local and sustainable solutions are needed. In a research project, in which the author has been involved (Ehnberg 2007) new electrical power supply solutions have been analyzed and tested, suitable for small scale operation in developing countries. The use and great potential for rural areas of photovoltaic devices (“solar”) is...
discussed in Rabah (2005). Wind is another interesting alternative for rural electrification but the stochastic behavior of the wind is a problem (Lew 2000). Ehnberg (2007) has considered and analyzed in detail the combination of the two sustainable energy sources solar and wind. It is intuitively obvious that one of the sources is not sufficient. The solar energy is only available during the day. This requires energy storage during the night. Furthermore, the wind is not blowing all the time, but can often deliver power during the night. In areas where small rivers are available the use of small-scale hydropower stations presents an option (Paish 2002). Biogas production for electrical power generation is another option discussed below.

A system based on solar and wind cannot always produce at its maximum capacity. This requires that the power supply has an overcapacity that is often not used. In any electrical power system the production and consumption have to match at any moment. When there is more energy available than the load demand the extra production should be used and not wasted, since the power supply is “free”. Normally a power management system will control the power supply so as to match the load requirement. However, an extra load can also be connected by the control system while there is an overproduction. Such a load may consist of a pumping system that can store water for either irrigation or other water consumption purposes. Two key parameters have to be controlled within certain limits, the voltage and the frequency. It has been demonstrated that this can be achieved in a “power island” operation, thus providing the essential electrical energy for pumping. In order to be feasible for developing countries the components of such an electrical power system should be commercially available and robust. The price reduction for solar and wind power systems has been significant during the last few years, so power systems based on these technologies will become not only technically but also socially and financially sustainable.

There are certainly other problems to be solved. The personal safety relates to the level of competence of the user. Maintenance cannot be neglected and the supply of spare parts has to be solved. Security and theft are other issues to be considered.

**Biogas production**

Recent data show that anaerobic digestion (AD) uses only some 20% of the energy content of the sewage. By-products from sewage treatment could provide a valuable source of energy if managed and utilized effectively. In addition, costs of sludge transportation and disposal, which currently place a major burden on the industry, could be reduced.

A main disadvantage of AD is that it often is perceived as being unstable during both the start-up and steady-state operations, due to the interdependence of the different microbial groups involved in the degradation (Gujer and Zehnder 1983). Imbalance in the microbial ecosystem may lead to organic overload, which can cause a severe reduction in degradation capability and washout of the microorganisms, resulting in poor reactor effluent quality. The traditional way of avoiding this kind of instability is to operate the process far below its theoretical reactor capacity. In addition, the nature of the influent characteristics involves dynamic variation in both flow rate and composition, which can be considered to be disturbances to processes. Handling of these disturbances by attenuation or rejection is thus important for stable operation. A more economically viable approach to overcoming the problem is by applying close monitoring and automatic control of the process in order to enhance the operational stability, to attenuate and reject disturbances and to allow the treatment of waste and biogas production at a higher specific rate (Liu 2003).

Many anaerobic bioreactors are still being operated without close monitoring and control. This is not only due to the fact that the anaerobic process involves a complicated mechanism of degradation steps, but it is also due to the lack of proper analytical devices.
In fact, sensor technology is the weakest part of the process chain (Liu 2003; Olsson et al. 2005). Close monitoring and control of the AD process firstly requires identification of suitable process parameters, which can give indications of imbalances in the microbial ecosystem and warnings of external disturbances. The activity of the different microbial groups involved in the AD process can be measured indirectly by monitoring the metabolites. In general, it is now possible to analyse pH, alkalinity, biogas flow and composition, VFAs, biodegradable organic matter, dissolved hydrogen, and toxicity on-line by less expensive sensors and instruments (Liu 2003).

Some control approaches reported previously include on/off control (Denac et al. 1990), adaptive control to maintain the concentration of propionate constant (Renard et al. 1991), various rule-based expert systems and fuzzy logic control (Bernard et al. 2001; Puñal et al. 2002). The control and automation of a manure based biogas system is reported in Wiese and Haeck (2006). Further references are found in Liu (2003), Liu et al. (2005) and Olsson et al. (2005). Typical measurement variables are pH and gas-phase information due to their reliance on commercially available measuring devices that are nowadays quite reliable, robust, inexpensive and require low maintenance. In some cases the alkalinity and hydrogen content in the gas phase have also been used. Usually the feed rate is the control variable. Another interesting approach reported in recent years is the probing control strategy based on analysing the effect of disturbances added on purpose to the influent flow rate (Steyer et al. 1999). By increasing the influent flow rate for a short period of time, the increased biogas yield was compared to the expected one. Overloading or inhibition could be interpreted as a negative effect of the disturbance (i.e. an unsatisfactory gas yield).

Monitoring and control for reduced operating costs
On-line monitoring will almost surely be in an increasing demand. For the clean water supply on-line monitoring will be required throughout the system including at the tap. The availability of low cost instrumentation will encourage better leakage detection and water quality monitoring. In wastewater treatment systems the use of instrumentation, control and automation has proven to significantly reduce the costs for operation. Apparent examples are dissolved oxygen (DO) control, DO profile control and the control of nutrient removal based on on-line sensors. Control based on advanced online nutrient sensors are not low cost alternatives in developing countries but have proven to be cost-effective in advanced nutrient removal control, contributing to lower energy waste, and thus to lower greenhouse gas production (Olsson et al. 2005).

Sequencing batch reactors (SBR) are versatile systems that can be used for a wide range of different wastewater types for different purposes (Wilderer et al. 2001). An SBR system is a very efficient system for biological nutrient removal. The succession of anaerobic, anoxic and aerobic conditions can be arranged to obtain carbon oxidation, nitrification and denitrification. The SBR is never in steady state. Instead it operates in a transient mode all the time. This makes it very suitable and profitable to use instrumentation and control to use the potential of the system to its maximum. For example, the aerobic phase should be shut off as soon as the carbon and ammonia components have been oxidized. Similarly, the anoxic operation should be finished as soon as the nitrate reduction has been completed. Even low-cost instrumentation can be used favorably in such an operation (Olsson et al. 2005, ch. 5)

Telemetry can offer a lot of advantages, both for decentralized urban systems and for rural installations. For example, this will allow the monitoring of remote plants by trained personnel. The cost of programmable logical controllers (PLCs) and signal transmission systems has been greatly reduced in recent years. The PLC system can also be used for
the basic control of equipment and some effluent quality related parameters, like dissolved oxygen.

Pumping is a major energy consumer, both for clean water distribution and for wastewater treatment. Many pumping systems are operated either with low efficiency pumps or at operating points far from the optimum efficiency. Frequency converter technology is a proven technology and variable speed pumping can significantly contribute to energy savings.

Biogas production should be considered in a more systematic way for energy supply, not only for energy efficient waste treatment. While methane leakage is a dangerous greenhouse threat, the use of biogas for energy production has an enormous potential. Applying monitoring and control can significantly increase the digester capacity. This is true in both industrialized countries and in the developing countries.

**Conclusions**

The challenges in front of us are monumental. The report UN (2006) makes some clear recommendations, crucial for success:

- Make water a human right, and mean it. “Everybody should have at least 20 litres of clean water per day and the poor should get it for free.”
- Draw up national strategies for water and sanitation. Governments should aim to spend a minimum of 1% of the gross domestic product on water and sanitation.
- Increase international aid. The UN report calls for an extra 3.4 – 4 billion US$ annually. Development assistance has fallen in real terms during the past decade, but to bring the MDG on water and sanitation into reach, aid flows will have to doubled. This would be money well spent. The economic return in terms of saved time, increased productivity and reduced health costs will be $ 8 for each $ 1 invested, if the target is reached.

Technology is one part of the solution. Many different low-cost wastewater treatment systems have been suggested for rural and urban areas, including septic tank systems, constructed wetlands, floating aquatic ponds and waste stabilization ponds. It is of primary interest also to consider the energy issue together with the water supply and sanitation challenges. Too often lack of electrical energy will prevent the implementation of better water supply and sanitation. Monitoring and control can provide solutions to enhance the productivity, make the operation more robust and assure a consistent quality of both drinking water and of wastewater effluents. This can be done by early warning systems, detection of disturbances, minimizing the effect of disturbances, using energy and other resources wisely and more efficient ways to produce energy.

**References**


WSSTP (2007). The European water supply and sanitation technology platform. All documents produced can be downloaded from www.wsstp.org.