The Three Ages of Engineering for the Water Industry[1]

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Abstract

This paper attempts to stimulate the reflection on water policies and economic dimensions, by the presentation of a broad review of the interaction of society and technology in the field of water industry, all the way from its inception in the second half of the 19^th^ century. After presenting the context in which this research was done, and in particular the issues at stake in the E.U. Water Framework Directive, we cover progressively the three eras or ages of technologies and engineering for water industry: civil, chemical/sanitary, and environmental. Then we develop some of the features of environmental engineering needed today for a sustainable water management, like public involvement, and a conception of demand side management based on a better balance between supply and demand side. We finally address the issue of third world cities, because they may also be the future of our water industry if we cannot maintain the overall confidence which European urbanites had developed towards their local water industry.

An STS approach to city infrastructure

In the 1970's, French social sciences were applied to the changes imposed on urban space and city management by the voluntaristic action of Gaullist central government; in the 1980's, with decentralisation engaged by the left wing government, researchers and academics rediscovered the "thickness" and importance of local government. Also, they had witnessed the growing role of the giant multi-service-and-public works companies which operated many local utilities by "delegation" from municipalities (but not electricity, natural gas and railroads which were nationalised since the second World War), and many were critical about it. Yet these companies were not nationalised in 1981despite they were on the list : this situation clearly suggested that the subject needed more thought, so a new theme of research emerged around the notion of *urban engineering* and of public-private partnerships after the seminal report of State engineer Martinand (1986). One of the issues was indeed the potential for innovation in the partnership between local authorities and the companies, and for transfers of innovation between various utilities. In particular, a new laboratory was jointly created by the Ecole Nationale des Ponts et Chaussées[3] and Paris Town planning Institute (*IUP* located in Paris Val-de-Marne University), *Laboratoire Techniques Territoires et Sociétés* (LATTS). Its aim is to develop a Science, Technology & Society approach to city infrastructure and utilities, as well as to large firms which are engaged in globalisation (i.e. a de-territorialisation / re-territorialisation process). In partnership with other teams in Europe and in the United States (e.g. Thomas Hughes, Joel Tarr, Martin

1. This is a revised version of a conference given at Stanford University in May 2003, in the STS department.
2. Doctor CNRS, LATTS (Paris).
3. This school is the oldest civil engineering school in the world (created in 1747) and trains the engineers of the Corps in the ministry chiefly in charge of infrastructure. Mr Martinand is a typical representative of the Corps.

Melosi), various historical and comparative analyses of urban / national technical systems were developed under the leadership of Gabriel Dupuy; they were eventually extended to the specific problems of large third world cities, and to the present infrastructure financing crisis (Dupuy, 1984; Dupuy and Tarr, 1988; Konvitz & al. 1990; Rosen & Durkin Keating, 1991).

In the case of water, if most countries had left the responsibility of service provision in the hands of local authorities, apparent growing problems of water scarcity, or of quality, led many States to develop either regional or national institutions to modernise the process of allocation of water resources between users, and also to concentrate or even centralise, privatise, delegate, incorporate, (etc.) the utilities themselves. A European comparison of institutions in charge of resource allocation and of services provision, was developed as a means to understand why France had two specific features: giant water companies, which were in fact multi-service and also public works companies; and the well known *Agences de l'eau*, the 6 French river basin institutions which were already mentioned in the seminal book of Kneese and Bower (1968) even though they still were in limbo. While we were doing this, Britain which had fully regionalised its water planning and water industry in 10 river-basin institutions in 1973-4, privatised the water industry. Under influence of the anglo-saxon liberals, the motto of privatisation was picked up by international financial institutions. But we thought the analysis should go beyond the privatisation debate (Barraqué, 1992). At least two other debates, centralisation vs decentralisation, and unbundling vs transversal utility management, had to be considered simultaneously. And there were other forms of modernisation and of "new governance" in Europe than the French and British models, where the role of private sectors were the most important, even though very different. This water policy analysis led to systematise a presentation of both integrated water resource management and water services provision policies in each of the 15 member States of the European Union (Barraqué, 1995). These issues were also addressed in greater detail in a comparative presentation of water policies in five contrasted member States of the E.U., France, Germany, Netherlands, Portugal and United Kingdom[4]. The 'Eurowater' research process led to analyse politicians, civil society and water engineers' attitudes vis-a-vis environmental policy, as well as the evolution of institutions for integrated water resources management (Correia, 1998).

Sustainability and water policy

Under the acronym *Water 21*, a second research for the European Union allowed the same partnership to address both issues of future water resources and water services (i.e. public water supply, PWS and public sewage collection and treatment, PSCT) in the light of the United Nations' definition of sustainability: how do we reconcile the three economic, environmental and

4. Eurowater is the name of this research in partnership funded by DG Research of the European Union, LAWA in Germany, the NRA in Britain, and the Gulbenkian foundation in Lisbon. The partners were Tom Zabel and Yvonne Rees of the WRc in England, Jan Wessel and Erik Mostert in River Basin Administration centre in Delft T.U. (Netherlands), R. Andreas Kraemer and his colleagues at Ecologic, an environmental policy consultancy in Berlin, my team within LATTS, a social sciences laboratory in Ecole Nationale des Ponts et Chaussées, under the leadership of Francisco Nunes Correia, hydrology and environmental policy professor in Lisbon's civil engineering faculty. The first research was published in German first (Correia and Kraemer, 1996-1997) and then in English (Correia, .1998). The second research, Water 21 is yet unpublished, except for what was presented in a World Bank and Brazilian water resources association conference in April 1999 in Foz de Iguaçu.

ethical/equity sustainability criteria? This is what we call the 3 E's *problematique*. This definition is useful to sketch what the important issues are in water policy. For instance, if we take the Water Framework Directive (WFD) adopted by the E.U. in October 2000 (published in December, EC 2000/60), there are three broad goals to achieve:

- Rehabilitate, protect and enhance the quality of the aquatic environment within the next 15 years;

- Adopt an efficient economic policy, and get closer to the notion of full cost recovery from water users;

- Make water policies more transparent, and develop public information and participation.

And, if we apply this same approach to the water utilities, we develop again a triple set of questions:

a) How is the enormous capital accumulated in water services technologies since 150 years maintained and reproduced on the long run? Are depreciation schedules correct, how do they reflect in the water bills or charges, in particular since subsidies are being phased out by governments after initial investments? What compromise is found between the risk of over-manning for the sake of very good maintenance, and poor maintenance of the systems compensated by more frequent renewal investments, with an greater involvement of outside contractors? Can one separate normal maintenance and replacement of old infrastructure? Tracking water losses is a good example of this search for compromises: there obviously is an optimum of maintenance which is away from a zero leak objective, and relining leaky pipes is often cheaper than changing them. But what impact of all this on water bills?

b) In order to improve the environmental performance of existing systems, what kind of new investments are needed, from a national standpoint, and due to the European Directives? How will operation costs increase (e.g. with increased volumes of sludge)? What would be the extra burden on water consumers, of extra investment and operation costs, in particular if the loans would have to bear normal commercial rates? How far are national policies from the formally accepted polluter-pays principle and user-pays principle (e.g. in the lately published Framework Directive and subsequent guidelines by the *wateco* task force)?

c) Iif all the "sustainability costs" (long term reproduction and environment) are passed on to the consumers, can they afford it, and is it politically acceptable? If not, what kind of technological, financial or planning adaptations are necessary? What could be national and European priorities? Is it at all possible to do without subsidies, i.e. without some funding from taxes and general budgets at local or supra-local level?

Some economists could consider that each of these three questions corresponds to one of the 3 parts of the "full cost" to be recovered: self financing corresponds to the full direct cost, while question b corresponds to the environmental cost, and question c to the resource or users cost (in case there is scarcity and conflict over water allocation).

There are then several specific issues to be addressed: concerning drinking water, an obvious one is the cost of the potentially increased number of criteria and of their reinforcement (e.g. lead from pipes), another one is biocides and nutrients from agriculture: should we go on removing them in the drinking water production processes, or devise planning and economic incentive policies aiming at reducing their use in agriculture? And who should bear the associated cost, water consumers (like in the case of the German Wasserpfennig) or farmers? Another issue concerns metering : in the case of England and Wales, putting individual meters in all homes, as some economists tended to associate with privatisation[5], would be very expensive, and might not be economically efficient, given the relatively low elasticity of in-house water demand to prices. But conversely, with no meters, it is difficult to track water losses, and there is no incentive given to consumers to fix leaky facilities. There probably is an optimum to find. Yet there is pressure from consumer NGOs, experts and politicians to generalise metering for all consumers, for equity reasons, even in flats (France and Germany).

Concerning waste water collection and treatment, at least four issues are at stake : are industrial effluents acceptable in public sewers, and how much should they be charged? Or which pretreatment should be requested? What kind of technologies are appropriate in low density areas and in small local authorities, if full cost recovery is considered? What would be the cost and the environmental benefit of a stronger policy on stormwater pollution and run-off control, and how could it be funded? What is going to be the impact of increased volumes of sludge to process, at a time when farmers are increasingly reluctant to spread it on their fields?

Concerning both types of services, one important issue is personnel redundancies, which are allegedly more frequently found in services operated under direct labour. Are these services overmanned? Does this eventual overmanning allow to reduce the long term rehabilitation (replacement) costs? Is the integration of various parts of the industry into large companies able to do the engineering, the building and the operation (like in the French, and increasingly in the British, models) more efficient than the traditional split linked to public operation and the "shopping list" in the calls for tenders? And above all, what would be the best "subsidiary" size of services? Is local operation preferable to regionalisation? What about intermediary formulas, like local operation with regional financing schemes and pooling of charges?

In fact, it is quite difficult for economists to find optimal solutions, and even to calculate the three parts of the full cost to be recovered from water users, because of lack of many data, in particular concerning the expression and aggregation of preferences of citizens. Most of these questions indeed can be answered only if we confront the economic, environmental and social performances of all sorts of technologies of the water industry, and theses technologies have changed in the last 150 years, along with innovation and changes in the professionalisation of engineers; in particular, with the rise of environmental engineering, and its superseding the more traditional sanitary engineering. This is why a historical approach of an STS type is needed. In this paper, we

5. Privatisation did not in fact request metering, but phasing out the charging system based on rateable value; some water companies proposed to use the current community charge as the basis for charging for water. There seems to be a general agreement now in Britain that only large consymers, and domestic ones with automatic lawn sprinkling, hose pipes ans swimming pools, should be metered separately.

are not going to focus on particular technologies. In the LATTS for instance, we have a group of historians, engineers, policy analysts and economists, who prepare a political history of water meters and of the debates between pros and cons (Chatzis & Coutard, 2002). Here, we would like to sketch the history of water industry (i.e. history of PWS and PSCT), under three "ages" separated by "crises" which can be analysed with the concept of *reverse salient* put forward by Thomas Hughes (1983) in his history of electricity supply and systems: urban technologies are subject to economies of scale so that systems usually expand, until some over-complexification breaks the positive feedback loop which motivated their expansion. If at that moment another technical paradigm is available, systems will expand differently afterwards.

To summarise, we'll start with the age of quantity of water (more from further) and civil engineering; we'll pursue with the age of quality (cleaner and closer) and chemical/sanitary engineering; and we'll finish with the age of integrated and demand side management and environmental engineering. After this overview, we'll try to explain what kind of training environmental engineers should need to be able to face their complex tasks, and we'll insist on the difference between the needs of the north and those of the south.

The age of water quantity and long distance transfers

In the 19th century, or rather until the Koch and Pasteur discoveries were popularised, PWS developed on the assumption that water should be drawn form natural environments far from the cities. The trend had been set in the previous century by kings and landlords for their castles or for capital cities. With the industrial revolution and urbanisation, large cities in particular would have to get water from further and further. This was made possible by the possibilities of municipalities to obtain "cheap money", in particular from the early popular savings banks which they controlled. Their bonds were found attractive by the public, and on top of this governments would subsidise projects. This is why in most cases, while private companies, often created by visionary engineers, had initiated the water supply within homes with water under pressure, municipalities usually took over and managed to develop the systems to serve all urbanites, while making the industry more profitable. Take the example of Glasgow: "direct municipal provision seemed to offer several advantages to the city. The existing private company had (…) outdated infrastructure consequently was unable to cope with the demands of the rapidly growing population (…) Moreover, the company was not in a position to raise the necessary capital for improvements, unlike the Town Council, whose extensive community assets made it eminently creditworthy. Public accountability meant that unpredictable market forces could be over-ridden, and a stable service provided (…) Loch Katrine was located in the Perthshire Highlands, some 55 km from Glasgow, and thus well away from the polluted city (…) The official opening by Queen Victoria on an appropriately wet autumn day in 1859 was an event of enormous significance for Glasgow (…) Loch Katrine was unquestionably the prime municipal showpiece for the city, combining the wonders of Victorian technology with the nurturing quality of pure Highland water" (Maver, 2000). Joel Tarr (1996) has illustrated this broad approach in the US: getting cleaner water from further on the one hand, and using the rivers as sewers on the other, the latter decision relying on the assumption of natural dilution and self purification of rivers.

This overall *problematique* has remained dominant in the New World, and was also extended in the rest of the world after the Second World War, due to the co-occurrence of International Financing Institutions offering cheap money, and of various forms of support for national governments' intervention in infrastructure provision (Keynesian or socialist). Large hydraulic projects of the 1950's and 60's were increasingly devoted not to cities, but to irrigated agriculture which was then associated with development. Today, still, many States in developing countries base their water policy on large water transfers, so as to indirectly subsidise the production of irrigated cash crops to integrate in the world market. In some cases the ceiling of extractable water resources has been reached, and the present crisis offers the possibility to check the unsustainability of these past policies. California, which has become indeed the "largest artificial river basin in the world", thanks to enormous State and Federal investments in infrastructure, is a leader in experiencing this need for change.

The second age of water technologies: from further quantities to nearer qualities

However, a similar crisis occurred a long time ago in (northern) Europe: growing population densities and smaller natural resources endowment increased competition for pure water, while the development of bio-chemical analyses better showed the risk of contamination. Irrigation being unnecessary in northern Europe, there wasn't so much a resource quantity problem than a quality problem. In the end, it was decided that water should be filtered (end of XIXth century), and later chlorinated, ozonised or disinfected through GAC beds (around the first World War), which ever source it would come from. But then, taking water from the river just upstream the cities would not change anything in term of public health, while it would save a lot of investments. So in that still early period, large European cities changed strategy from investments to increase quantities to investments to improve quality, with of course a serious rise in operation costs. But delivery of pressure water within the homes changed status, from a luxury good to a normal comfort, and made it possible to have customers pay water bills. Eventually, this reinforced the legitimacy of local authorities as services providers, or at least organisers. Following the example of British Fabianism, direct municipal involvement in the economy via infrastructure provision generalised. We can term this the era of municipalism.

This is exactly what happened in the city of Paris a century ago. From Napoleon the idea had prevailed that Paris should get water from distant sources, and indeed, the work of engineer Belgrand under Baron Haussman's general approach of the public service as a monopoly, was turned towards securing longer distance sources of water (around 100 km). It was even felt that one day the capital city would have to get water from the Loire, except that this river has very low flows in the summer, precisely when water demands would request it. Then, in 1890, an engineer named Duvillard came up with a project to draw water from lake Leman , i.e. 440 km away! It sounds as a fancy project, because of the Alps and of the international character of the Rhone (would the Swiss accept?); yet it was technically quite simple, even at that time. Proponents of the project soon came up with all sorts of arguments to convince Paris Council and the State: a Capital of the world would need at least 1000 litres per capita per day (lcd) to have more luxurious fountains, more street cleaning[6], better domestic comfort and hygiene; besides, such a quantity of water, once discharged in the Seine after use, would alleviate navigation problems in drought periods, help flush waste water from the new sewer system away to the sea, and let other water resources available for local economic development. In the end they said, a huge transfer would securise Paris PWS forever, and the bigger it would be, the cheaper each cubic metre would be! It's indeed very amusing to see that it's the same type of arguments which have recently been raised by the Franco-Spanish partnership to transfer water from the Rhone to Barcelona (350 km)! This also shows how irrigation makes southern member States of the European Union change the whole picture: cities have to get water from ever further because all the local surface and ground water is given away for quasi-free to farmers. Back in Paris a century ago, while proponents were finalising the studies, some epidemic disease broke out, and it was found that one of the distant natural intake points (the Loing springs) was to blame; even distant pure water could be contaminated. So that water should be filtered and treated even in that case! In 1902 Paul Brousse, one of the father founders of French so called "municipal socialism" (equivalent to what was derided in England as 'water-and-gas socialism'), inaugurated the new water filtration plant in Ivry, just upstream Paris (the one which has been redesigned a few years ago to serve as a showcase of French water technological know-how). A long lasting choice was unconsciously being made. And chlorination was added after the first world war. Water demands were growing incrementally and the big jump then appeared as too risky. Lastly, the project was discarded by Paris Council for national defence reasons: what would happen if next war the Germans would rush on the aqueduct and cut it off?!! Even though this decision didn't help much for the next war (are there ever real water wars?), it's clear that quality investments replaced quantity ones just as chemical engineering replaced civil engineering as the dominant paradigm of water industry. Chemical engineering was the technical translation of public sanitation policies, and allowed sanitary engineers to reach their goal with minimal interaction with the public.

After the second World War, the Government took advantage of a severe flood to obtain the construction of three large upstream reservoirs on the Seine, the Marne and the Aube, in fact to increase summer flows and meet Paris water demands even in very serious droughts like happened in 1976. Interestingly enough, a fourth reservoir was planned by mayor J. Chirac's councillors, but it was abandoned for the same reasons (we must and can purify the water anyway, said the giant water supply companies) plus the fact that Paris water demand went down by 13% between 1990 and 1996 (Cambon-Grau, in Barbier, 2000). This is another reverse salient which also hits most cities in Europe, and also in the United States.

The crisis of municipal water services: towards the third age

In France like in other northern European countries, important efforts were made on city sewerage from the 1950's onwards, and on sewage works from the 1970's. There is by the way an

6. Paris is one of the few cities in the world where streets are washed clean : for political and business reasons linked with Haussmann's decision to merge suburban communes and extend Paris from 12 to 20 *arrondissements*, it was decided that water would be produced by the city and delivered for free through a public network, while a second network would serve domestic and other private homes under pressure the payment of water bills. This is why Paris still has 2 PWS, one potable and the other non-potable by today's standards. The non potable network produces hardly filtered Seine water to flush the sewers, to supply the lakes in the Bois, and to clean the streets. Other public uses like fire hydrants have quit because of unreliability, lower pressure, sprinkler clogging etc.

interesting parallel with drinking water treatment earlier in the century: if sewer pipes are a very high fixed cost, conversely waste water treatment has high operation costs in proportion of waste water volumes, which can be easier passed on to the consumers. To make the investment funding easier, it was decided to change the status of PSCT from an imposed system to a service, and then to have it paid in the water bills. But in the same period, PWS itself became a mature business, i.e. it had to face the issue of renewing ageing infrastructure without any more subsidies. This is the fundamental reason why European municipalism adapted in various ways towards legal private status: traditional public accounting rules impeded to depreciate the assets and to make renewal provisions, while private accounting could. PWS, and later PSCT, slowly turned towards depreciation and provision practices, and this of course meant a rise in water bills. Besides governments are under the influence of economists arguing in favour of full or at least fair cost pricing, and they phase subsidies out. In turn water bills rise dramatically, and an increasing number of large users (industry, services) either quit PWS, change their processes or fight their leaks. This explains the recent stagnation of volumes sold. In some countries even domestic consumers have reduced their demand for PWS, through changing fixtures and domestic facilities, different garden design, and also with rainfall storage or other alternative sources of water for non drinking uses.

At the same moment, water suppliers discover that it's going to be ever harder to comply with the drinking water standards (DWS) all the time at reasonable costs. Ecotoxicologists' control over standards' production tends to privilege a traditional "no-risk" strategy (Lave, 1981) without taking the implied costs into account: in Europe, the lowering of the lead content from 50 to 10 µg/l will cost up to 35 billion dollars while there is no evidence that the former level provokes lead poisoning. The multiplication of criteria is slowly bringing the situation into over-complexification: chlorination byproducts give cancer. There are many other examples, and anyway, year after year, the media can report a growing proportion of people receiving non-complying water, even though the treatment is improving on the long run. To lower the risk of being unable to make it, along with local, national and European authorities, water supplies turn to a new strategy: Land-use control on water resources protection areas, usually implying agriculture re-extensification, and farmers compensation programs (for a history of drinking water criteria and the present result, see e.g. Okun, 1996). This policy eventually turns out to be cheaper than water treatment sophistication, and to be a positive sum-game with farmers. Yet it seems to be a long way to a new and more sustainable equilibrium. And worse, in the meantime, the drinking water criteria are being reinforced regularly as new risks are discovered, and the spiral of growing treatment costs and loss of consumer confidence is going on.

Costs are becoming so high, and the future so uncertain, that technologies of the first age are definitely in crisis: conversely to what some hydroschizoïd water engineers seem to think in Spain (Llamas, 2001), the present time is not appropriate for big long water transfers. What happened in California starting in the 1970's is now general in Europe: it is getting ever harder to build dams, because environmental movements have been joined by economists and liberals who advocate full cost payment of water infrastructures by their beneficiaries. Then the new slogan seems to be "first conserve and manage the demand, there is no cheap money in sight for subsidised water transfers" (Barraqué, in Vlachos & Correia, 2000). Copenhagen is not going to buy water from Sweden, Palermo isn't either going to have Albanian water, London will have to cut the leaks down before it eventually can purchase water from Scotland, etc. And what about all the other fancy projects in other continents which are dying like hydrodinosaurs …

New York City, like many US and Canadian cities, could follow a different path from European ones, because of the abundance of clean water. The tradition grew to use a lot of water and to take from further and further, while protecting the water intake points through extensive land-use control. Yet, the metropolis might have to catch up with the European story, because clean natural resources are not immune from cryptosporidium and other new (lethal) diseases. An USEPA experts' panel concluded that New York should not be given any further derogation on the need to filter and treat water extensively, while City engineers were arguing that increased land use control would suffice (Okun et al, 1997; Ashendorff et al, 1997). The new requested treatments are likely to seriously increase water prices. In particular if metering is introduced to replace the outdated frontage rates system, negative redistributive effects could be serious, (Netzer & al., 2001). In turn this might lead to a water demand collapse, and to raise a further question: in that case, why not just pump the water in the Hudson river, and forget about projected transfers and the water of the damned Quebecois! In Europe, the smaller per capita potable water demand reduces the scope for conservation, but when it occurs, it can also threaten the utility's budget balance, while having unforeseen negative distributive effects (Van Humbeeck, in Dinar 2000). This is why in-depth social science analysis is needed.

Some features of environmental engineering as paradigm of the third age

A history of the yet short existence of environmental engineering (Hendricks et al., 1990) shows its origin in sanitary engineering. Interestingly enough, in the U.S., the corps of engineers, which was involved in civil engineering and in large hydraulic projects, did not take interest in potabilisation or in pollution control, and left it to sanitary engineers. These would then mobilise chemical but also biological science. In particular during the second World War, tropical disease control in the troops fighting the Pacific war gave an impetus to applied research in ecology. Then the thrust for "big science" funded by post war governments, and the development of epidemiology applied to urban pollution consequences transformed sanitary engineering. Harvey Ludvig, who had graduated in California in 1942, played a particular role in developing a systematic content in the education of sanitary engineers, including applied research in masters programs and PhDs, which eventually professionalised them away from the traditional empiricism of medical doctors. Starting in 1960, sanitary engineering departments organised the "seven-year-conferences" to harmonise and develop the third cycle education. It is in that process that they were taken by the environmental movement from the end of the 1960's, and changed the name of sanitary to environmental. Environmental engineering aims at protecting not only populations from negative environmental factors, but also global and local environments from potentially dangerous human activities. Of course, improving the knowledge of natural processes was an important issue, but a large part of the programs were focusing on urban issues and technical systems. Also it was agreed that the core education of environmental engineers should include chemistry and biology, but also systems analysis, applied social science, and project design in practice. Water services were always concerned, but in a more global approach than in traditional sanitary engineering. Indeed, if we look back at the two first "ages" we have presented, beyond the difference between them (quantity vs quality, civil vs chemical), their common characteristic is to focus on supply-side solutions, while necessarily environmental approaches have to consider what is termed demand side. Let us now try to understand the meaning of demand side.

Along our research, a strong overlap appeared between what the French call *le génie urbain* (urban engineering) and what the Anglosaxons call environmental engineering for what applies to cities. As we mentioned earlier, if in French the words grid or network are distinguished from system, the latter being more abstract, in English they can be substituted. And the development of systems analysis has indeed paralleled and even heavily relied on the notions of environment and ecology. However, this systems-and-the-environment approach is much more recent than the initial development of infrastructure, and for instance, engineers waited until the '30s to discover that streets of a city formed a system, and that a local improvement might have non-intuitive consequences elsewhere. Now, with the multiplication of networks and connections, we realise that they do characterise the modern city, all the more so that periodically, ecologists or "ruralist" planners advocate returning to nature and disconnecting for truth-finding in autonomy.

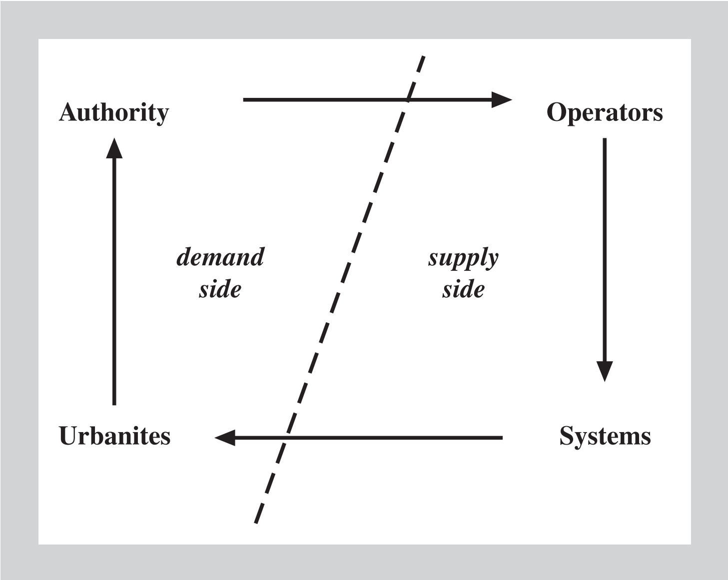
When urban systems started, they were called infrastructure, because they were hidden from the people, for both technical and social reasons. Some systems like water-supply were essential to improve health and reduce (fire) risks. But in the end, all can be seen as having brought apparent degrees of freedom to the urbanites, as time and space saving devices : clearly water-supply not only reduces time lost in diseases, it also allows young girls in many traditional societies to go to school instead of walking hours with jars on their heads. German wastewater engineers rank sewage treatment technologies in order of decreasing needed space to do the same purification : in a village an artificial wetland or a sewage farm will do, but with growing density (and land price), they will choose trickling filters, and further, activated sludge technology. As concerns the subway, all the way since the creation of the underground ring in the silver-mining city of Guanajuato by the conquistadores, it has saved both time for the people and space for the city.

Until recently, however, urbanites underestimated the importance of these systems, because their vision of the world was centred on landownership. It was not the infrastructure, but the plot of built or buildable land, which provided political legitimacy. City aldermen and elected representatives were competent on issues like valorisation/devalorisation of urban land, and they did not know much about the systems. In a way, Baron Haussmann was sacked by the Parisians, because they could not stand that the Boulevard, symbolising a global circulation concept, would dominate the Plot of land, symbolising territorial rooting of shop-keepers and housing-owners[7]. Conversely, early sanitary engineers were convinced that public health was a too important issue to be negotiated with either landowners or their tenants, and they preferred to impose connection to systems located under public space. The choice of the *Tout-à-l'égout* in Paris is typical (Dupuy & Knaebel, 1982). In turn, this constrained public procurement of services within municipalism let to the oblivion by people of the importance of systems: "out of sight, out of mind"

7. Thanks to an obscure imperial decree, Prefect Haussmann could achieve what his predecessors could not: buying all the land plots which were struck by the projected public works for more than 10% of the surface. He would build the boulevard, and then re-sell the unused land at the new value reached thanks to the enlargement. Petty-bourgeois like Thiers viewed this as a speculation of the city on the back of landowners, but today, we would much more accept it as a necessary public recovery of the added-values generated by public works.

and NIMBYism characterise the public's attitude and is at odds with a conservation attitude (Melosi, 1983).

This is how most cities got into a typically "second age" authority vs operator relationship: the elected authority would gather the demand of the citizens for urban technology, and they would pass it globally on to the operators, engineers and professionals who stayed in the dark, and remained out of the political space as most as they could. But, be they local civil servants or private contractors, they had no interaction with the public and with demand side problems: the idea was that everybody should be served and at the same unit price. Operators just had to match the demand with more or less invisible infrastructure and that was it.



In this sketched circular relationship in the service provision, clearly the operator has the quasi-monopoly of the supply-side, while the authority is on the demand side. So that the operator tends to solve his problem with the authority only through increased supply. And this is how we get the best potable water for all the uses we need in unlimited quantity, while only 5 to 10% really need to pass the increasingly numerous drinking water quality standards; this is also how we build new highways to alleviate traffic, only to discover that they are soon jammed too, and that we need extra ones. With our "systemic" eyes of today, we can see how the municipalist model comes to a crisis. Sewer systems too have to become bigger and bigger to accommodate increasing volumes of stormwater, because planning regulations seldom include limitations on soil imperviousness. Because urban services are finally meeting diseconomies of scale when the last urbanites are finally connected, a systems approach is then possible to consider some rationalisation. But it is not a purely market based rationalisation as claimed by environmental economists. When we move to demand side solutions, in fact we consider the interaction between supply and demand.

Thanks to the concept of environment, we have learnt that sometimes causes act on consequences not linearly, but exponentially, that there are feed-back loops, and that supply and demand are not really independent, but interacting. This is what we call the “network effects”: cumulative and non-linear processes can bring very positive outcomes, but they can also bring the worst crises, with the peak-flows. The urban transportation problem is a good example: the traffic forecast model based on the gravity formula, which is still widely in use, assumes that the demand is independent from the supply, and that is why it often plans new roads which will be jammed shortly after their opening.

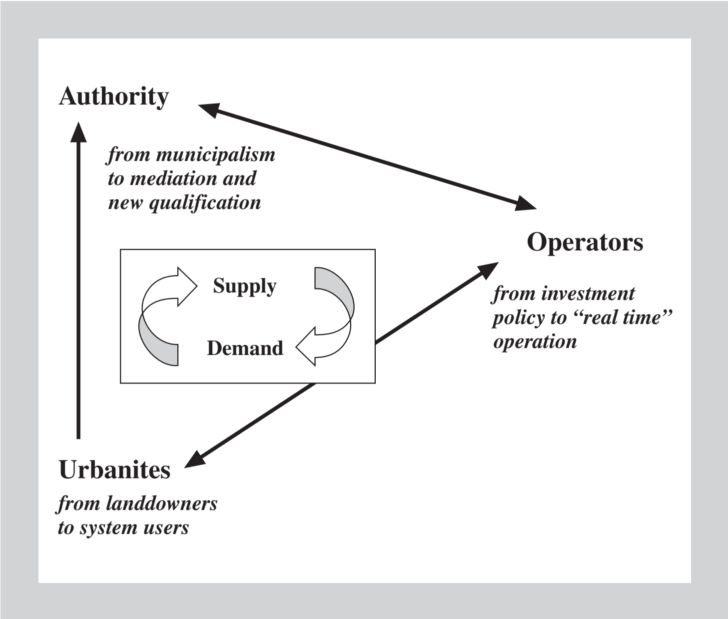
Redefining the operator, and inventing new technologies

This leads the reflection towards redefining the very notion of “operator” in ecological terms. If supply and demand interact permanently, then the traditional relationships sketched on the previous table are blurred. The operator needs a direct contact with the public, at least to know in detail what the needs are, so as to get away from coarse linear and overoptimistic projections for the demand. He may also want to go one step further, with what is called demand-side management : getting the users of the system to use it more efficiently, and alleviate the negative network effects. But if the traditional operator does that, it may be resented by the elected authority as undermining its aldermanship and patronizing power.

Besides, many of the decisions to be taken involve planning and zoning measures, which are highly political decisions, just as well as differential pricing for incentives. Basically, the traditional operator cannot do it alone, and he needs a much stronger interaction with the authority. Too often, local authorities have decided to privatize some urban infrastructure, thinking that they would be rid of a too difficult or too costly problem. But this type of privatization often fails, because conversely, it was increased local authority implication that was needed, in the definition and the control of the service if not in the financing.

In the end the new grid-based systems operator is a complex mix of people and institutions who can only master the networks effects when they interact. In some cases, the users themselves become part of the operator: when they read carefully the variable message screens on the highways, they can discover that there is a traffic jam on their route and change it, thus saving their own time as much as the others’ (Sirius system in the Paris area). I heard that in Sweden a special electric light would turn on when simultaneously plugged appliances exceeded the normal power subscribed, thus indicating in real time that extra kilowatts would be charged higher. Conversely, just putting individual meters in apartment buildings will not reduce water consumption much if people cannot vision where they could conserve water, all the more so that elasticity to price raises is very small for indoor uses. In that case, door-to-door public information is more effective.

The triangular figure below summarises the necessary changes for a better social and ecological handling of urban technology. Local authorities should move away from traditional patronising, and become mediators between the conflicting interests among the various groups of users. This is contractual policy, and political leaders should not be afraid of organising consultative commissions where various types of users are qualitatively represented. But they must also remain conscious of possible negative outcomes in terms of equity: a "casual contractual view" of politics can end up increasing the discrepancies between social groups. Like for instance, in the name of efficiency and consensus, the incinerator always ends up in the black ghetto. But anyway the old and blind municipalism leads to unsustainable systems operation, and a new dialectics must be built between the anglosaxon-type efficiency approach based on the consensus and the mediation between interest groups, and the more continental view of equal and substitutable citizens sharing the same "rights to water".



Citizens should accept the outcomes of modern urban society: they are not little landowners any more, they are massively wage-earners, and users of all sorts of public utilities and facilities, which will become unsustainable if they do not participate in the definition and in the provision of the services. In some cases they will have to accept to abandon their "prior appropriation" on environmental resources. It is the case with groundwater, at least in Europe: three Latin countries of Europe, Spain, France and Italy, have declared that even shallow ground water could not anymore be freely used by the landowners, and that reasonable use would prevail, eventually giving priority to public water supply needs. However, urbanites should also learn to conserve drinking water, so as to diminish the need for future investments in capacity. In California, several utilities have developed subsidies programs for people who accept to change their facilities for lower water consumption ones. Water conserved is then made available for extra PWS users, and calculations show that this water is by far cheaper than long distance transfers or even water bought from farmers (Dickinson, 2000). However, if too many users quit PWS or dramatically reduce their consumption, then the utility will end up being in trouble, because it usually has to reimburse long term debts: an important reduction in volumes purchased will oblige the operator or the authority to raise the unit prices. This is only a short term negative outcome, but it has to be carefully explained to consumers to avoid distrust to build up.

Urban and environmental engineers then face a new role, since they must partially quit their habit of solving problems through investments and end-of-pipe technology, and turn towards real-time operation of the systems and to increased relationships with the public. Systems modelling should be adapted to take complexity into account : there is plurality of decision makers with conflicting interests, there is uncertainty in the forecasting of the outcomes of decisions, and there is non linearity and feed-back loops. All this makes the decision-making process very difficult. However, if long-term future is difficult to grasp, short-term action can be improved : we can to some extent rely on new technologies of communication. We do not see clearly yet to which extent all urban grid-based systems will be sooner or later doubled by a second network, devoted to information, just as sharks are led by pilot-fish. But it seems that monitoring and remote control are in constant progress, for pollution generated by systems as well as for people carried or served by systems. As mentioned above, one important issue is whether this real-time information will be only for the use of the engineers operating the systems, or be shared with the users, in real time. Most subway systems could let passengers know the reasons why they are blocked under a tunnel, or that some interconnections are temporarily unavailable. Yet operators do not like to do it, because they still too often think that it is the role of the authority to talk to the users. At any rate, it should be clear that environmental engineers must take interest in social sciences, if only to learn that public participation is unescapable. For instance, real-time operation of stormwater utilities, implies to "unearth" water flows, to make water and the related risk visible again in the city (Moss, 2000).

A new generation of grid-based systems planners and operators will also need an intelligence of the limits of urban technologies, which means reverting parts of technical systems to other forms of service delivery, for the sake of extending the services to new areas. A perfect example of this is decentralised sewerage systems. In most European countries official statistics never mention explicitly what happens to the population which is not connected to sewers, just as if these were bad polluters to eliminate shortly. Yet in most rural areas, and in low density suburbs, it is economically unreasonable to connect everybody to a sewer. Besides, biology technologies allow us to use the soil as a reactor to eliminate bacteriological pollution better than small treatment plants. But once the habit has been given to most urbanites not to care about their wastes, they tend to feel that a septic tank is a low grade technology. What we need to invent then is a service in- between the costly and heavy traditional centralised sewerage system, and the full autonomy of rural people, who have to do everything themselves. Some countries have developed public services for the control and the emptying of the tanks, but it is still exceptional to have "public" septic tanks installed and operated by a utility in private homes, the users paying exactly the same volumetric charges as sewered people. In that case the network has been extended into a service, which saves money and provides equal opportunity to citizens.

Lastly, managers of urban technologies will learn to develop non technological solutions, in order to get out of the cycle of over-complexification. One good example is the development of new catchment-based land use policies to protect water resources devoted to potabilisation from diffuse agricultural pollution. Increasingly, in Germany, the Netherlands, and to a lesser degree in

Denmark and France, utilities or their organising authorities develop contracts with farmers or groups of farmers, to obtain the re-extensification of their practices, with much less fertilisers and biocides, and they give them appropriate compensation for the corresponding loss of revenues. In some German Länder this policy is funded by "waterpenny" taxes on water bills of domestic consumers, which allows to have much more money available for contracts with farmers. Yet this policy is criticised by some economists and ecologists together, who argue that the polluters should be the payers, not the victims. Other economists just acknowledge that it is an efficient policy, and probably the only one, until society will be able to place a policeman behind each farmer…

A differential sustainability in third world cities

The situation is critical in the developing world: contrary to the expectations of the "water decade" starting in 1990, she situation did not improve much, and the World Water Council has calculated that in order to achieve the connection of urbanites to both PWS and public sewage collection and treatment (PSCT), our planet was just short of 100 billion $ per year during 25 years ... Since this amount of subsidies is impossible to find, it is expected that the rate of connection of people to water services in cities will decrease in the coming 20 years! The reason is that poor people are moving faster into the cities than the services would be extended anyway.

Third world cities experience tremendous inequities towards water services: while the richer part of the population doubles the PWS with private systems allowing them to use the same volume of water than the average in the U.S., for a very cheap price, middle classes have to face an "inconstant" service (variable quality, low pressure, service interruptions), and therefore they are reluctant to pay for this poor service, which in turn deprives the operator of money to fight the leaks and other deficiencies. Worse, there is no financial capacity building to extend the service to the poorer, who have to purchase the little water they can afford from vendors or to carry it from fountains, at an overall cost which is of one or two orders of magnitude higher than the cost of piped water (Zerah, 1997). By the way, this is why the generous motto of the Rio conference in 1992, 40 lcd of potable water which ever the capacity to pay, is problematic: 40 lcd would be too expensive to buy from street vendors, and too heavy to carry from fountains, while once people are connected, it makes no difference whether they use 40 or 100 lcd, the marginal cost of tap water being very low. So that, on the one hand the emergency is to develop public-private partnerships to develop non conventional water services with alternative management and technical formulas. And on the other hand, the long term solution is probably capacity building at local level to generate solidarity between social classes, and collectively fund the extension of water service to the yet unserved areas. This is the centennial experience of Europe: organising sustainability of a great innovation (systems for water services) first at local level, but with the help of government money. An southern Europe illustrates this in its way: water services are almost for free, because large transfers paid by central governments makes bulk water cheap. But water is not taken care of, it is wasted, while service is not yet universal. It shows impossible to rationalise what is still under rationing. Recent outcomes of privatisation attempts in various parts of the world, starting with British water companies, show the limits of a system which just forgot that infrastructure's life time is not in tune with the time horizon of bankers today. Water services in that case really need special skills from environmental engineers. Yet, presently, water and city engineers in third world countries, having received no training to the socio-economic dimensions of their activity, just try to develop the technological part of the occidental model of cities, with no socio-economic basis to do so. Worse: together with large consulting and international contractors, they still promote the realisation of large water transfers, thinking that these project will lower the cost of water and make it really available for the poor. But the poorest cannot afford to pay any water at all, and many other people still think in terms of the previous colonial period, where the absence of civil rights should be compensated by free services (Jeter, 2002).

Conclusion

The expression "three ages of engineering for the water industry" should not be taken literally, because of course they overlap and do not come in sequence. There are projected water transfers today which are still quite necessary and sustainable. And if sanitary engineers of African cities stop chlorinating potable water on the basis that by products can have carcinogenic effects on the long run, they will have far more casualties from dysenteria than from cancer … (Okun, 1996). But the aim is to develop an STS approach with historical dimension, so as to show what is needed for engineers to have a good vision of what is at stake in water services provision today. Note that a similar evolution could be traced concerning water resources integrated management, and the need for social sciences in what we call "hybrid forums" where stakeholders are confronted to conflicting scientific or technical representations within the scientific community, and can eventually build up alternative and innovative "advocacy coalitions" to lead more sustainable water policies (Sabatier, 1993). There is a need for conservation, demand side management, but in a more applied manner than in neo-classical economics: it's more the systemic interaction between demand and supply which is at the heart of the problem, and should therefore mobilise interdisciplinarity in environmental engineering. We think that may be the most important is to give engineers a "socio-economic and historical culture" of their action.

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