SENSOR NEEDS FOR WATER MONITORING

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1. Introduction

Measurement is easy but getting the correct result is difficult and convincing others even more so.

The market needs are :

- Higher confidence in the data; better reliability, reduced sensor fouling, better calibration audit trails, better sampling
- Lower skill requirements
- Lower cost of ownership
- Better integration of multi-variable data

To meet changing European Directives, competitive pressures and customer expectations all sectors of the water and waste treatment industries are trying to improve the monitoring of water quality. The number of water quality parameters to be measured is increasing rapidly and a greater precision is being demanded from existing sensors in the water and waste water industry (W&WT).

Technology is changing at an unprecedented speed, providing new opportunities and new challenges. However the W&WT industry has a small installed base of sensors and, in general, the users lack the resources to deal with any sophistication.

The data derived from the on-line analysers will increasingly be used by a wide range of users (clients) to make decisions in operations, business management and regulatory matters and this is a considerable challenge to both the manufacturers and the users.
The demand for rapid, accurate and simple methods of analysing key components in the W&WT industry, without the need to resort to costly, tedious, slow and error prone, sample to Laboratory method, will continue to grow. However potential users of the data rarely have any understanding of the dynamics of the sampling to Laboratory chain or the difficulties in obtaining a sample which accurately represents the process. This leads to unrealistic ideas as to the certainty which can reasonably be applied to the results of samples evaluated in a laboratory. It follows that unrealistic views are expressed about the performance required of measurements to be made in the field.

2. Market

It is possible, with little effort, to amass a bewildering amount of information on sensors for the UK water and waste treatment industry. It is in the nature of such accumulations that the reader becomes more confused as the information grows. This report, therefore, concentrates on the structure of the market sector and the issues that are seen to be the pacing factors for the introduction of new ideas and for the growth of established sensors. The statistics provided are used as a necessary basis for making macro judgements and as a starting point from which the reader can develop a specific market sector analysis for individual projects.

One of the problems for the application of measurement technology in the W&WT is that the European market is relatively small and probably declining. It is fairly easy to obtain estimates and forecasts for expenditure on Environmental protection equipment but it is less easy to obtain detailed information on the market sizes for the various monitoring market sectors. The OECD is a source for forecasts for environmental equipment some of which are reviewed in an article. (Ref. 1). On behalf of the UK department of Trade & Industry (Ref. 2), the author concluded, three years ago, that the UK market for water monitoring instruments was no more than 60M pa and anecdotal evidence suggests that it has decreased since then to probably 40M. The market for the water and waste treatment industry alone is certainly less. That 40m is made up of a number of sectors; for example test kits for water amount to no more than 6M and flow to no more than 20M and it is doubtful whether the market for Awet chemical analysers@ is more than three hundred units in the UK pa. It is traditional for market estimates to multiply the UK figures by seven or eight to obtain a European estimate (or divide the European figure by the same numbers!) But the result is still very small numbers. The problem is made more difficult since the number of measurands is large and increasing. It is easy to find wish lists of sixty or seventy measurands from the Water companies and the Regulators, with limits of detection which are close to or even smaller than current laboratory practice.

To provide a scale against which individual sensors market studies can be judged the chart provides estimates for the major sensor markets in the UK=s W&WT industry. Estimates of market size are completely dependent on definitions and the ability, or willingness, of suppliers to divulge useful numbers. The definition difficulty is shown in the overlap in flow; many level sensor sales are for open channel flow and not every supplier differentiates between types of flow measurement.
The "consumable" figure is even more difficult because it includes replacement probes as well as test kits and some companies treat replacement probes as base sales. Consumables may be overstated because of the difficulty of separating out, for example, test kits for private and municipal swimming pools. The non-quantified inclusion of Laboratory measurement is because many suppliers do not have a clear distinction between on-line sales and Laboratory sales. Some sample collecting and Laboratory procedures are often very close to the process and many users consider that they have on-line control. It is possible that the on-line sector is overstated by a few m. because of this overlap.

To provide another perspective of the potential market size it should be noted that the Water companies in the UK have 7,000 major sewage works consents and 21,000 combined sewer overflow consents and this when considered alongside the large equivalent industrial numbers this should represent a massive market. However very few of these measurement opportunities will be realised in the immediate future. Most of the publicly available market estimates, showing significant growth, are dependent on enforcement, by the regulators, of Legislation although a part of the drive will be because the water suppliers and waste treatment industries will need to operate more efficiently; the need to be a good neighbour may contribute a little to the market.

The available market statistics are distorted by events such as the need to protect against Crypotspiridium and Giardia; largely satisfied in the USA as well the UK with turbidity measurements which probably do not make an effective measurement for that application. The drive in some parts of Europe in the early '90s towards control of pollution by monitoring nutrient load also distorted the figures with a surge in the need for nitrate, phosphate and ammonia monitors. Once the need for a particular parameter is satisfied the maintenance levels of sales is very low. The most significant factor for anyone introducing or demanding a new measurement is the fact that there is no new money.

The market is driven by the need to meet and to demonstrate compliance with Legislation. Expenditure is therefore not seen as contributing to profits

The W&WT industry is extremely cost conscious and this combined with technological innovation, which is also driving down costs, will limit growth for existing products. Sales by numbers of units will grow significantly, but sales by value will be less buoyant unless the regulators force the adoption of new measurements. Substantial growth could come from new measurements but even with pressure from the regulators the user still has to find new money to fund increased expenditure.

3. Decision makers

The problem for the busy user is that legislative pressures and commercial demands impose a need for a considerably better understanding of how the business affects, and is affected, by the environment. The user therefore cannot avoid the challenges but often does not have the necessary time or knowledge to deal with new technology.
The decision making processes and the allocation of resources, for instrumentation, must usually come from a wide range of management groups and disciplines and the necessary co-ordination has often been missing. The result is that anecdotal stories abound about on-line analysers which have never worked. There is a current trend by the UK W&WT industry to remove all those analysers which make no contribution to the business and to properly resource those which are vital to the business. However this is a long process and it will be some time before the positive news dominates the black museum stories.

The result is that the supplier of sensor technology, whether a University supplying know how in some manner, or a manufacturer supplying a sensor, has difficulty locating the business and then has difficulty communicating to an often widely dispersed decision making mechanism.

It is suggested that a sound understanding of the business needs for a measurement and the circumstances of the use of the measurement device are more important than innovative technology.

Commercial success for the supplier is dependent on identifying the measurement need, selecting the appropriate format and incorporating the user's working conditions.

4. Cost of ownership

There is an increased awareness that the purchase cost of process sensors can represent a small part of the total cost of ownership and such factors as installation, calibration, validation and the cost of consumables of on-line instruments are receiving more attention. This is not a new consideration, but little progress has been made over several years of discussion and it is widely believed that the traditional purchasing structure, for new processes and plant, of the W&WT industry must be changed before "cost of ownership" becomes more important than "lowest price". The problem is that the sensor suppliers must inform a broad range of decision makers but they are rarely involved in the details of the final decision. More importantly, the supplier is rarely contracted to support the final user site. The Contractor receives an Order from the User based on design work by a Consultant and meets the terms of that Order at the lowest possible cost. There are many anecdotal stories of multiple suppliers for one particular measurand on a site because there has been no requirement on the Contractor to take existing measurements into consideration. There are also many anecdotal stories of analysers mounted in place but never properly commissioned because appropriate skills were not made available.

A major, and probably increasing, part of the W&WT market will be the supply of single or customised systems for specific applications. The supply chain may not be any simpler but the suppliers cost of selling as a percentage of Order value will be significantly greater and this will cause problems for both the supplier and the user.

The W&WT industry has yet to find a satisfactory structure for the allocation of resources, risk and reward for small monitoring applications.

5. Alternative technology

The major need for the W&WT industry is to show that organic and inorganic substances are only present, if at all, in quantities less than those determined by the prevailing regulations. This means that many measurements are at trace levels; certainly at low ppm, often at ppb and already down to ppt for some substances. Even Laboratory GCMS has problems quantifying herbicides at the EU required level of 0.1m/l.

Another problem is that different chemicals pose different risks for whole animals and chemical analysis must be an integral part of the risk assessment process for the business. Cocktails of chemicals may have different affects and individual chemicals may be themselves benign but cause other unwanted affects. The dilemma is that if you need to detect to very low levels then a GCMS laboratory analysis is needed; but are the assay techniques good enough to tell you when you need to take a sample and does the sample accurately represent the stream being monitored ?

It seems unlikely that the need for increased measurements will be met by increasing the number of single parameter on-line analysers; capital cost, cost of ownership and support resources would be a problem. True ownership includes purchase price, consumables, reagents, service and depreciation and might be as high as 5k per annum for each instrument and as already stated the number of chemicals, metals, organics and bacteria which need to be identified and measured at trace levels is increasing rapidly; a trend which can be expected to continue or even increase in the short and medium term future. There is room for improvement in the majority of the single measurand field measurements even including such common measurements as flow, pH and chlorine but the real challenge is to develop robust multi-variate packages to inform the user on the Astate@ of a water or waste stream. The need is to understand the organic and inorganic content of particular aqueous bodies or streams and an interesting solution might be to develop surrogate and broad band measurements.

For on-line measurement there are two possible routes for the W&WT industry. The adoption of broad band measurements and surrogates and/or the use of multi-variate analysers. Neither approach is mutually exclusive and both need to be supported by and integrated with proper sample collection and analysis procedures and structures.

A EuroEnviron Brokerage Workshop in Manchester October 1996 identified strong interest for measurements of organic load and biomarkers both of which would give imprecise but extremely helpful information.

Data rich multi-variate process analysers could be a source of data for a wide variety of clients within the business. The data would be used, with other data, to derive different information depending on the different needs of the client. Proper integration of these analysers into an open distributed information system would provide significantly more benefits than treating them as mere data providers.

6. Understand the needs

The user's need for sensors might come from a range of considerations; public relations, cost, regulation, prudence, safety, etc ... Sensor technology is changing at an unprecedented rate and key enabling technologies for water monitoring are appearing from unfamiliar sources. Both old and new sensor technologies are constantly being reviewed.

Successful commercial sensors increasingly depend on the blending of a number of technologies and skills; the problem is how to locate and blend those technologies and skills.

The most difficult problem for the W&WT industry is how to develop an holistic understanding of what the user really needs and then to steer the organisation of multi-skilled technology teams to satisfy those needs. There is little doubt that the largest part of the W&WT market for sensors is in the monitoring of trace materials and the market size and growth will depend on the regulator's diligence. The Hazardous Waste Directive (91/689/EEC) provides an interesting list of substances which must be monitored but it does not provide the measurement limits. It is reasonable to assume that the measurements will be at the trace levels with low ppb as a starting point. The Drinking Water 1993 Report by the Chief Inspector Drinking Water Inspectorate, (Ref 3) lists the determinands being regulated together with the levels required and achieved.

It shows that more than 3.5m determinations were made, in 1993, in the regulation of the drinking water sector of this industry and only 1.3% exceeded PCV. Careful reading gives some insight into the needs of the industry.

The UK Environment Agency now monitors 35,000 kilometres of rivers with 10,000 sampling points; each needing at least 12 samples per year. A number of measurands are needed at each sampling point and all of the measurement formats, to be described later, will be applicable. While this is a very large potential market the EA are investing a considerable amount of effort into understanding the sensor needs to support the proper prosecution of their responsibilities. Some of the thinking is in the public domain and it seems that the EA will concentrate on generating a sound understanding of the current state of the UK and its constituent definable areas. This macro approach inevitably means that they will be concentrating on broader measurement concepts and leave the detailed measurement to those who generate pollution. There are consequent influences on the type and number of measurements to be made.
The Water Companies are a ready focus for attention but are only part of the picture. The Regulators, are also influential and are potential users of sensors, but the new Environmental Agency has to settle down and decide how it will operate; this makes planning and forward thinking difficult for the suppliers. A trend to on-site waste treatment and the minimisation of effluent reinforces Industry as an important market.

No reliable statistics are available but an intuitive guess of the split in monitoring device sales suggests :

Water Companies	40%
NRA/HMIP/Factory Inspectorate	10%
Industry	60%

Industry represents perhaps 60% of the environmental sensor market from both the process measurement and control and the monitoring needs and may well, in the longer run, be the most attractive market. Industry includes the such diverse sectors as hydrocarbon processing, pharmaceutical, food, beverage, mineral processing, pulp and paper etc; each with specific problems and sensor needs.

The potable market is almost completely confined to monitoring with almost no closed loop control needs, whereas both the dirty water and the sewage sectors often have control loop implications. The use of closed loop control is expected to increase and it is suggested that suppliers to the dirty water and sewage would enhance their potential if they included process control skills in their offering.

7. Measurement opportunities

It is not difficult to find an opportunity for a new measurement but it is very difficult to present a solution to the W&WT industry in a mutually profitable manner. For example, the trade press has published articles for the prospects for bio-sensors in the W&WT for some years industry but as yet commercial success is extremely limited. One Water plc is seeking better solutions for the following list of measurements:

Aluminium	Clean water
Ammonia	Clean water/Dirty water/Sludge liquors
Bacteria	Raw water
Blanket level	Sludge
BOD(5)	Dirty water/Sludge liquors
Boron	Raw water
Bromate	Clean water
Chlorinated solvents	Raw water
Chlorine	Clean water
Chlorophyl A	Raw water
Coagulant iron	Clean water/Dirty water
COD/TOC	Dirty water
Colour	Clean water/Dirty water
Density	Sludge
Dissolved oxygen	Dirty water/Clean water/activated sludge
Fluoride	Clean water
Hypochlorite conc	Clean water
Iron	Clean water
Manganese	Clean water
Nitrate	Clean water/Dirty water
Ozone	Air
Ozone	Clean water
Particle size up to 0.5mm	
Particle size C	lean water/Raw water/activated sludge
Pesticides	Clean water
pH	Dirty water/Sludge
Phosphate (Total)	Clean water/Dirty water
Polymer concentration	Clean water/Dirty water
Redox	Dirty water
Respiration rate	Dirty water

Sludge	Dry solids content
Surfactants	Raw water
Suspended solids	Clean water/Dirty water
Taste & odour	Clean water
Toxicity	Dirty water
Turbidity	Clean water/Dirty water
Weight	

There does not seem to be a consensus on the detection levels for the vast majority of water quality measurements. A number of commercial companies publish lists but here are significant variations between them and even between different issues of the same document. Anglian Water plc in the UK have put the following list of measurands and limits of detection into the public domain.

Sourceworks Output Quality

	Action Limits and PCV's	
Parameter	*PCV*	*Action Limit*
Colour mg/lPt/Co scale	10	20
Turbidity F.T.U.	1	4
Odour 25C Dilution no.	2	3
Taste 25C Dilution no.	2	3
Odour 60C Dilution no.	5	NA
Temperature C	25	25
pH	6.5-8.5	5.5-9.5
Conductivity uS/cm at 20C	1350	1500
Chloride**mg Cl/l	360	400
Sulphate mg SO_4/l	225	250
Calcium mg Ca/l	low 70 high 160	250
Magnesium mg Mg/l	45	50
Sodium mg Na/l	150	150(80%)
Potassium mg K/l	10	12
Aluminium ug Al/l	50	200
Total hardness mg $CaCO_3$	low 160 high 400	min 150
Dry residues mg/l		1500
Dissolved oxygen (S) % saturation* min 50	-	
Dissolved oxygen (U) % saturation*min 30	-	
Nitrate mg NO_3/l	45	50
Nitrite mg NO_2/l (NH_2Cl)	0.02	0.1
(Cl_2)	0.05	0.1
Ammonium mg NH_4/l(NH_2Cl)	0.25	0.50
(Cl_2)	0.05	0.50
Kjeldahl nitrogen mg/l		1

	Action Limits and PCV's	
Parameter	*PCV*	*Action Limit*
Oxidisability mg0_2/l	4	5
Hydrocarbons ug/l	ND	10
Phenols ug C_6H_5OH/l	0.4	0.5
Boron ug B/l	1500	2000
Surfactants ug/l as lauryl sulphate	150	200
Trihalomethanes ug/l	100	100++
Trichloroethylene ug/l	30	30+
Tetrachloroethylene ug/l	10	10+
CCl_4ug/l	3	3+
Iron ug Fe/l	50	200
Manganese ug Mn/l	20	50
Copper ug Cu/l	1000	3000
Zinc ug Zn/l	2000	5000
Phosphorus ug P/l	high 1500	2200
	low 600+++	
Fluoride ug F/l	high 1300	1500
	low 900+++	
Barium ug Ba/l	800	1000
Silver ug Ag/l	5	10
Arsenic ug As/l	25	50
Cadmium ug Cd/l	2	5
Cyanide ug CN/l	20	50
Chromium ug Cr/l	20	50
Mercury ug Hg/l	0.5	1
Nickel ug Ni/l	20	50
Lead ug Pb/l	20	50
Antimony ug Sb/l	5	10
Selenium ug Se/l	5	10
Pesticides ug/l individual	0.05	0.1
total	0.25	0.5
PAH ug/l	0.1	0.2
Benzo 3,4 pyrene ng/l	4	10
Coliforms no/100ml	0	0(95%)
E Coli no/100 ml	0	0
Faecal Streptococci no/100 ml	0	0
Clostridia no/20 ml	<1	<1
Aeromonas hydrophila no/100 ml	0	
Colonies per ml 1 day @ 370E C	10	
Colonies per ml 3 days @ 22E C	100	
Chloride/Alkalinity ratio	1.0	
Alkalinity mg/l $CaCO_3$**	min 55	min 50

++ 3 monthly average +++ where dosed + annual average
*S = Surface Waters *U = Underground Waters **See also Cl/Alk ratio

The UK National Rivers Authority, now part of the Environment Agency have published the following detection limits :

	% bias	% precision	Limit of detection
ammonia (total)	10	10	0.03mg/l
pH	10	10	0.05
dissolved oxygen	10	10	0.2mg/l
TOC	10	10	0.2mg/l
BOD	10	10	1.0mg/l
phosphate	10	10	20:g/l
nitrate	10	10	0.2ng/l
COD	10	10	12.0ng/l
arsenic	10	10	5.0:g/l
cadmium	10	10	0.01:g/l
mercury	10	10	0.01:g/l
lead	10	10	0.1:g/l
copper	10	10	0.1:g/l
zinc	10	10	0.5:g/l
PCBs	20	30	0.3ng/l
DDTs	20	30	5.0ng/l
lindane	20	30	0.3ng/l
dieldrine	20	30	1.0:g/l
atrazine	20	30	10.0:g/l

UK/EC Heavy Metal in Water Concentration Limits:

Material	UK Drinking Water Limit	EC Drinking Water Limit	Discharge Limit 1	Discharge Limit 2	Dangerous Substances Listing
Mercury	1ppb	1ppb	5ppb	50ppb	EC Black/UK Red List
Lead	50ppb	40ppb	200ppb	2ppm	EC Grey list
Cadmium	5ppb	5ppb	20ppb	500ppb	EC Black/UK Red List
Copper	3ppm	-----	300ppb	2ppm	EC Grey List
Nickel	50ppb	50ppb	200ppb	3ppm	EC Grey List
Zinc	5ppm	-----	5ppm	-----	EC Grey List
Chromium	50ppb	50ppb	500ppb	3ppm	EC Grey List

A booklet, prepared by Graham Dennett, Commercial Officer, British Consulate-General, Sydney, in 1995, Ref. 4, lists the water quality measurands and detection levels required by the Australian liquid industrial effluent. It also lists the substances targeted for further reductions in New South Wales by the year 2000. It is unlikely that all these measurements will be made outside the laboratory and even in the laboratory the measurements will be infrequent with samples that may not adequately replicate the water being monitored. This leaves the question as to how the water is to be properly monitored for accidents or other incidents.

8. Summary

Although the market for water quality monitoring is small there are many business opportunities. However it is increasingly difficult to satisfy these opportunities by just concentrating on research and development; technology is only an enabling aspect of useful water quality monitoring instrumentation. A commercially viable product is unlikely to be developed by devoting effort exclusively to pure technology subjects such as optics or biochemistry or electrochemistry. Multi-discipline teams, including a continuous market aware input, are needed to integrate technologies for the provision of solutions to user problems. Such teams will help avoiding getting trapped in the minute details of one sensor in one application field with the consequent small market possibilities. These teams, if properly balanced and led, will also consider the different performance characteristics appropriate for different applications and will track changing needs in the market place.

The key drivers are >business needs=, >business dynamics= and >technology dynamics= and the winners will be those who develop an holistic understanding of the market and an appreciation of the user's real needs before developing products for the market.

An understanding of the 'megatrends' and the 'limitations' is very important to the setting up of profitable projects. For example it is extremely unlikely that all the individual polluting substances will be measured to the detection limits and uncertainties required and hence there is a growing concentration on the use of surrogates. Such broad band measurements as biological activity, oxygen demand, toxicity, nutrient load and possibly bulk pollution measurement are being considered and may prove to be a significant market for monitoring instrumentation. However these surrogate measurements will, by definition, have an imprecise correlation with specific chemicals and calibration audit trails will be an intellectual problem. Most sensor research and development is by scientists, trained in the use of rigorous methodologies, and a cultural change in both the researcher and the user will be required user before broad band surrogates are used with confidence.

9. Conclusion.

It is suggested that future market opportunities will require a realistic assessment of the market sector and the supply of an integrated package of measurement and support services. The ability to make a particular measurement will not be sufficient in itself but merely an enabling feature for the provision of a solution to the user's need.
The challenge to scientists and engineers is to provide simple measurement concepts so that society at large can take part in informed debate leading to a rational control of the industrial and leisure activities.

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Figure 1 : Sensor needs for the water industry