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Development of a framework for the assessment of operation and maintenance (O&M) performance of urban water supply and sanitation

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ABSTRACT

This paper is part of a study in execution to develop a general framework for the assessment of the O&M function in urban water supply and sanitation systems. The wider objective of the study is to contribute to ensuring the long-term sustainability of water and sanitation services and to improved sector performance at better standards of service.

The crucial role of good operations and maintenance (O&M) practices in both urban and rural water supply has been recognized for many years. Adequate maintenance was shown to be essential to achieve *consistent* treated water quality and service to the consumer.

It is apparent that public utilities (into which category the vast majority of water supply agencies still fall) have lagged far behind manufacturing industry in maintenance management. This can be attributed in part to the fact that maintenance problems which result in loss of production of manufactured goods have more immediately quantifiable effects on sales and profits.

The suggested framework comprises firstly an *audit of the O&M function* and secondly an outline of a *O&M performance reporting tool*, using a number of O&M performance indicators (PIs). A conscious attempt has been made to suggest only those performance indicators which are of primary relevance to O&M and which can be assessed without much difficulty. PIs are suggested in the following areas of activity in O&M of urban water supply : service, systems & equipment, cost, personnel, materials, work order control.

The audit procedure enables periodic 'snapshots' of the O&M function to be taken in order to make rapid assessments for strategic purposes. The performance reporting tool is meant to be used on a regular basis by the O&M management for close follow-up of the O&M function and its activities. There is no attempt to devise a diagnostic procedure for fault detection, as it is beyond the scope of this paper; guidelines for this have been proposed by UNCHS (1989).

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1. Introduction

The crucial role of good operations and maintenance (O&M) practices in both urban and rural water supply has been recognized for many years.

The International Drinking Water Supply and Sanitation Decade (1981-1990) resulted in a proportional increase in coverage, but made only a marginal impact in reducing the total number of unserved people. Poor operation and maintenance was identified as one of the main reasons at the recent Ministerial Conference on Drinking Water and Environmental Sanitation in Noordwijk, the Netherlands.[9]

Important linkages between the water supply sector and other infrastructure sectors/society as a whole result from deficiencies in operation and maintenance leading to contamination of water or disruption of or inadequate water supply. Frequent disruption of water supply or inadequate water quality reduce health conditions especially among the poor.

There may be serious impacts on a number of manufacturing processes, besides affecting human health. Value of lost production for food processing companies etc. may be essential and by far exceed expenditures necessary for proper operation and maintenance of the water supply system, but will normally be difficult to evaluate. It is not anticipated that knowledge of these costs is available, but research work may be initiated and such costs should anyhow be taken into account when maintenance efforts and strategies are considered.[15]

Special consideration should be give to coordination with departments responsible for sewerage/sanitation, landfills and hazardous waste. Both sewerage, landfills and hazardous waste (including waste of petrol, oil and chemicals) may be important sources for contamination of ground and surface water and hereby affecting quality of drinking water.

Other but not less important linkages between the water supply sector and other sectors include :[14]

- Increased energy/fuel consumption for boiling of water for drinking purpose/food preparation;
- Production losses within manufacturing which utilize water in the production process e.g. food production;
- Lack of cleaning within public buildings e.g. hospitals and other infrastructure sectors and parts of society, where water is utilized for cleaning purposes;
- Increased wear and tear of buildings, vehicles equipment and other capital assets where frequent cleaning is essential.

A survey recently conducted in the U.S.A. of over one hundred facilities to identify the reasons for noncompliance with quality regulations, revealed that operation and maintenance factors were frequently identified as limiting plant performance, but it also disclosed that administrative and design factors were contributing to poor plant performance. Additionally, each plant evaluated had a unique list of multiple factors limiting its performance. Adequate maintenance however was shown to be essential to achieve *consistent* treated water quality and service to the consumer.[10]

It is apparent that public utilities (into which category the vast majority of water supply agencies still fall) have lagged far behind manufacturing industry in maintenance management. This can be attributed in part to the fact that maintenance problems which result in loss of

production of manufactured goods have more immediately quantifiable effects on sales and profits.

Very inadequate information is available on the situation of water supply & sanitation (WS&S) facilities with respect to operation and maintenance in both urban and rural areas in lesser developed countries (LDC's). Attempts have been made to review operation and maintenance in several areas of the world but the quality and quantity of available information do not cope with requirements for a comprehensive assessment of the current situation. A main cause of this situation is that the tools and methodology to collect the information on the status of O&M in a systematic way are not developed for the WS&S sector.[4][6]

If water supplies are to be operated and maintained satisfactorily, it is essential to have an effective O&M management system. In order to be effective, O&M managers (whether they be public utilities or community-based organizations) need to be able to measure the status of the O&M functions. In this exercise O&M performance indicators would be a valuable tool at either the utility or project level, and may be used by external evaluators; by local planners and managers.

2. Definitions

The term "Operation and Maintenance" (O&M) is used as a general concept covering all kinds of activities carried out by technical departments in WS&S utilities in order to sustain its public services and to maintain its existing capital assets.

The term "Operation" refers to the procedures and activities involved in the actual delivery of services to the public e.g. treatment, pumping, collection of waste water, transport and distribution of drinking water. "Maintenance" stands for activities aimed at keeping existing capital assets in serviceable condition e.g. repair of water distribution pipes, and pumps etc. Classification and responsibilities of O&M activities may vary substantially from place to place and are summarized in Table 1.[11]

O&M and especially maintenance decisions concerning equipment can be long term (strategic), medium term (tactical) or short term (operational).

Strategic planning is concerned with providing the resources to ensure a continuous satisfactory performance of the plant. This includes decisions concerning construction of new WS&S facilities, capacity enlargement projects and major rehabilitation projects.

The purpose of tactical planning is to ensure effective and efficient plant operation. It consists of finding the right O&M policy for maintenance e.g. finding the right mix of preventive and corrective maintenance interventions. This, however, assumes that costs may be estimated and that equipment failure behavior can be predicted (based on inspection or on historical data). After making an aggregate allocation of the resources, it is necessary to deal with the daily operational planning. This assumes that a sound work order and job documentation system exists.

3. Audit of the O&M Function

Auditing of the O&M function is not very common yet, although it gains popularity. The audit results are a valuable asset in understanding the way O&M works. The audit is a systematic procedure to objectively obtain and evaluate evidence on the O&M organization and practice of a given "organization".[11]

The audit or assessment procedure takes a "snapshot" of the O&M systems. The audit can be carried out by the O&M department itself or, what is often the case, by a third party. Such an audit is carried out occasionally, e.g. (i) whenever a checkup on O&M is desired, with the focus on the overall system rather than on a particular detail; (ii) before making any important organizational or policy modification; (iii) when an "outside" opinion is needed in addition to internal viewpoints; and, (iv) for bench marking purposes, to compare similar existing facilities or to establish performance targets for new facilities. Experience gained by conducting audits helps to perform new audits more efficiently and allows for additional insights in inter-organization differences and similarities.

Audits are mostly, if not uniquely, carried out with the help of checklists and questionnaires. Well structured checklists must be supported by a framework. (cf. Figure 1) This framework should contain all O&M elements, the link between them and the interrelationships of the O&M function with other organizational functions. The answers to the checklist or questionnaire questions should be evaluated against this framework.

Performance evaluation in an audit procedure of the O&M function will be more difficult in the WS&S sector than it is in the manufacturing industry. In the manufacturing industry, bottleneck facilities which suffer from a severe breakdown which lasts several hours will inevitably have a production loss and thus lost sales opportunities. The opportunity cost is easy to compute here. In case of a WS&S system a breakdown of one of the units may lead to low quality of the supplied water which may cause health or environmental problems. These of course are not easy to capture in monetary values or any concrete numbers. This makes it difficult to consider trade-offs like investing more in O&M versus having fewer or shorter breakdowns.

Sometimes maintenance philosophies such as RCM (reliability centered maintenance), TPM (total productive maintenance), etc. are adopted and implemented. A very useful concept is life cycle costing or terotechnology. This concept offers a view on maintenance engineering which is a combination of management, financial engineering and other practices applied to physical assets in pursuit of economic life cycle costs. Although already some twenty years old, it is only recently that companies in different sectors of industry are implementing it. It is obvious that this life cycle cost approach should also guide decisions concerning the procurement, construction or rehabilitation of WS&S systems. The integrated approach taken in a life cycle cost analysis makes sure that all cost components-(investment and operating costs) and all O&M related aspects are properly taken into account over the service time of a certain equipment, project, or system.[2][11]

4. O&M as a Performance-Limiting Factor

Utility operation and maintenance represent complementary activities with the potential for enhancing the quality of service, extending the useful lives of sector facilities, postponing investments,

and improving financial performance. The World Bank routinely reviews the operating and maintenance performance of its borrowers. Loan and credit agreements regularly include conditions related to various aspects of operating performance. Action plans are frequently part of the agreement, and monitoring performance indicators are virtually always used albeit they are usually confined to production and financial data.[18]

Although seemingly a rather obvious element, in practice one rarely finds clear and concrete objectives for the O&M function. From a management point of view objectives should be as concrete as possible. Clear objectives may then be used as guidelines for determining the O&M policy and for supporting O&M decisions. Moreover, setting realistic target values motivates people to try to achieve them. Measuring actual performance versus target performance is indispensable in every management process. This is of course only possible when clear objectives have been formulated.

A significant aspect is the identification of factors that limit the existing facility's performance. This step is critical in defining the focus of follow-up efforts. A factor should only be identified if it impacts plant performance. After all performance-limiting factors are identified, they should be prioritized in order of their adverse effect on achievement of desired plant performance. This prioritization establishes the sequence and/or emphasis of follow-up activities necessary to optimize facility performance.

Prioritization of factors can be accomplished by individually assessing all factors with regard to their adverse impact on plant performance and by assigning an "A", "B", or "C" rating. "A" factors are major sources of a performance deficiency and are the central focus of any subsequent improvement program. Factors are assigned a "B" rating if they fall in one of two categories: (1) those that routinely contribute to poor plant performance but are not the major problem; (2) those that cause a major degradation of plant performance, but only on a periodic basis. Factors receive a "C" rating if they contribute to a performance problem, but have minor effect.[10]

Maintenance performance-limiting factors are evaluated by data collection, observations, and questions concerning reliability and service requirements of pieces of equipment critical to plant performance. If units are out of service routinely or for extended periods of time, maintenance practices may be a significant contributing cause to a performance problem. However, equipment breakdowns are often used as excuses for performance problems. It is important that maintenance activities be evaluated with respect to their impact on plant performance and not on the basis of comparison to the availability of a documented preventive maintenance program.

The O&M performance perceived will also depend on the perspective applied: accountants will think of O&M in term of costs, while engineers e.g. will focus on performance in terms of availability/reliability/maintainability of the equipment, etc. The O&M manager must face the whole management complexity of his department: planning, procurement, personnel, quality control, inventories, technical problems and budgets.

Until recently performance reporting for the O&M function has been largely neglected in practice. This is partly due to the low profile this function had in the past, but also to the difficulty of performance reporting in this case. Maintenance is a service function, but both merits and shortcomings of the service rendered are not immediately

apparent. Because of the time-lag effect it is difficult to specify the amount and intensity of the service (and the required amount of money) needed for assuring proper system performance. Another fact which makes it difficult to evaluate the O&M output is the close interrelationship between operations and maintenance: more extensive maintenance may be needed because of operator faults or simply because more plant activity was required.

5. O&M Performance Indicators for Urban Water Supply & Sanitation Systems

The application of performance indicators to the water supply sector is by no means new. However, most of the literature reviewed pertained to the overall evaluation of projects and programs rather than specifically focusing on the status of O&M. This means that whilst lists of performance indicators already exist, it is important to review their relevance specifically to the O&M function.[3][19][20]

Associated with each performance indicator (PI) is a performance target; the status, or "performance", of O&M is then assessed by comparing each PI with its respective target value. This assessment procedure is not an end in itself. The end objective is to improve the performance of O&M; therefore, having assessed the status of O&M, action must be taken by O&M managers firstly to rectify shortcomings in existing performance and secondly to improve future performance. This enables performance comparisons to be made.

Performance evaluation is not confined to providing a bottom-line judgment, but also involves diagnosis to understand sources of problems and achievements. There exits an important methodological distinction between a general performance criterion (e.g., profitability) and a particular criterion value (or target) which differentiates "good" from "bad" performance.

The sources of information which can assist in setting criterion values include: (i) comparison with similar utilities elsewhere; (ii) comparison with the same utility in previous years; (iii) professional judgments by third parties; (iv) professional judgments at the enterprise level. Inter-temporal and inter-enterprise comparisons are essential inputs into the process of setting criterion values, but in the end a subjective professional judgment is required.[7]

Whilst such an approach has the apparent advantage of simplicity, the characterization of performance in this way is obviously dependent on the number of indicators used and the quality of the data upon which they are assessed. Difficulties can arise when interpreting performance indicators; for example, it may be difficult to determine exactly which are the decisive factors in a particular situation, and the information gathered may not offer any real guidelines for improvement.

When starting the search process for the appropriate PI's, for example PI_X will be used for measuring performance in area X, then following questions should be considered: - is X an area under control of O&M? - will PI_X measure what is required? - will problems in area X be detected by the use of PI_X? - does PI_X gives also an idea of the magnitude of the problem ? - is data available to compute PI_X? - is PI_X accepted by the operators involved? - are there any other indicators that can help to find the cause(s) of the problem? - who, beside O&M, will use PI_X?

A bad performance for some indicators is not necessarily a sign that O&M does not perform well. Sometimes O&M does a good job in a very difficult environment (e.g. inappropriate technology, excessive spare parts lead time, etc.) without that this shows from the indicators. This will lead to the wrong conclusions and work demotivating for O&M. It is therefore very important, especially when starting with a more formal performance reporting system, that (i) a thorough understanding of the O&M function and its environment has been achieved, e.g. by auditing O&M, and (ii) that expectations concerning O&M performance are realistic and that willingness to make the right corrective actions if necessary is there.

As on the one hand prioritization depends too much on the local working environment, and on the other hand an overall picture should be the purpose, PI's should not be considered on an individual basis, but as part of a whole system. Low O&M expenditure can indicate either insufficient maintenance leading to poor water quality and frequent system breakdowns, or very efficiently organized O&M ensuring high water quality and few breakdowns!

In this study, it is proposed to group the O&M PI's for urban WS&S systems in six areas: (i) service; (ii) systems and equipment; (iii) personnel; (iv) materials; (v) work order control; (vi) costs. In Table 2 a,b & c an overview of O&M PI's is shown. There is no attempt to devise a diagnostic procedure for fault detection, as it is beyond the scope of this paper; guidelines for this have been proposed by UNCHS (1989).[14][15]

The focus of service PI's is on the performance of the WS&S as perceived by the consumer, and is measured by two important elements of the consumer service, i.e. the water quality [17] and, the continuity of service. O&M practices contribute highly to a satisfactory performance for these two aspects.

Providing good quality and safe water and maintaining this quality in the distribution system are two of the most significant tasks facing the water utility industry. Water quality problems can go unnoticed for long periods of time because of insufficient monitoring and control of water quality at the treatment plant and distribution system. Water quality control is a vital but often troublesome aspect of maintenance in a large number of agencies in LDCs. Water quality deterioration in the distribution system adds to the cost of water services, beyond those associated with health problems, in several ways including (i) increased pumping costs as a result of accumulation of scaling products in pipes that restrict water flow; (ii) accelerated internal corrosion rates resulting in the need to rehabilitate or replace water mains and infrastructure parts; (iii) additional water treatment costs by households, commerce and industry.[19]

Continuity of service is one very important performance indicator of the industry and one that the population at large probably more conscious of. Continuity is affected by inadequate maintenance programs that result in unreliable service and frequent equipment failures and by high water losses. The cost of building alternative supplies to compensate for an unreliable water service can also be substantial. The cost to the poor that procure water from vendors can become as high as five times the cost of investments needed to develop a reliable supply to attend to their needs.[19]

The focus of systems & equipment PI's is on the O&M performance of treatment plants, pumping stations, waste water collection systems; water transport mains, distribution networks and maintenance vehicles. Five of the PI's suggested are drawn from maintenance PI's as commonly used in manufacturing industry, namely MTBF (Mean-Time-Between-Failures); MTTR (Mean-Time-To-Repair) The MTBF is often used as a measure for the system's reliability, while the MTTR measures the system's maintainability; combined they measure the system's availability. It has been reported that production capacity of water treatment plants can be reduced up to 30 percent due to lack of maintenance. [19] An in the manufacturing industries often used indicator is the "top ten critical item list" which contains the ten toughest jobs carried out the past period. If some piece of equipment really causes problems (because it is worn out, it is too complex, etc.) it will show up several times in this list.

The O&M cost PI's aim at O&M budget control on the one hand, and at relative measurements of costs and revenues of WS&S on the other hand, whereby average costs and/or revenues per consumer (capita served), per connection, per km of distribution mains, etc. are computed. These indicators are useful for inter-system comparisons, but a note of caution should be given however regarding conclusions from these comparisons which are only valid if the systems in question are similar. The information gathered in the O&M audit is indispensable here.

Computation of personnel PI's ratios are meant to obtain an insight in the workload of the employees and assumes that a good administrative system for employee follow-up exists which is very often not the case.

The efficiency and effectivity of O&M depend very much on the availability of the (right) materials and spare parts. The purpose of proposed materials PI's is to bring insight in the current materials management practices. They provide information on the following aspects: (i) the financial importance of the materials component in the O&M function; (ii) the MRO (Materials, Repair and Operating) supply activity; (iii) how defective spares are replaced; (iv) spare parts service levels. Although it is not obvious to define exact target values for these indicators, the numbers obtained may be used for comparing similar systems, and to alter management practices: e.g. if the number of issues and receipts is very large, additional personnel may be necessary to check, to store, to retrieve, to administrate things properly. Again the information gathered in the audit will be necessary to help in the evaluation process.

The work order control PI's may be used to evaluate (i) the work order system (many small jobs are difficult to plan (complexity), and so are too few large jobs (follow-up)); (ii) the backlog which gives an indication on the future workload; (iii) the category of maintenance work; and (iv) the O&M planning process.

6. Conclusion

This paper is part of a study in execution to develop a general framework for the assessment of the O&M function in urban water supply and sanitation systems. The wider objective of the study is to contribute to ensuring the long-term sustainability of water and sanitation services and to improved sector performance at better standards of service.

The proposed framework comprises firstly an *audit of the O&M function* and secondly an outline of a *O&M performance reporting tool*, using a number of O&M performance indicators (PIs). A conscious attempt has been made to suggest only those performance indicators which are of primary relevance to O&M and which can be assessed without much difficulty. PIs are suggested in the following areas of activity in O&M of urban water supply : service, systems & equipment, cost, personnel, materials, work order control. The recommended procedure is currently being applied to a number of selected case-studies where the status of O&M is assessed by comparing each PI with its respective target, which should lead firstly to rectifying shortcomings in existing performance and secondly to improve future performance. Ultimately such procedure may lead to defining monitoring directives for operation and maintenance.

Performance indicators should be used with circumspection to characterize a utility or group of utilities. Invariably the base data will portray an incomplete picture of operations because they exclude contributing factors that are not readily quantifiable.

Furthermore, indicators can only be as good as the base data from which they are derived. Aside from the fact that certain indicators are service specific, not all the utilities will be able to provide the data required for the extraction of each indicator.

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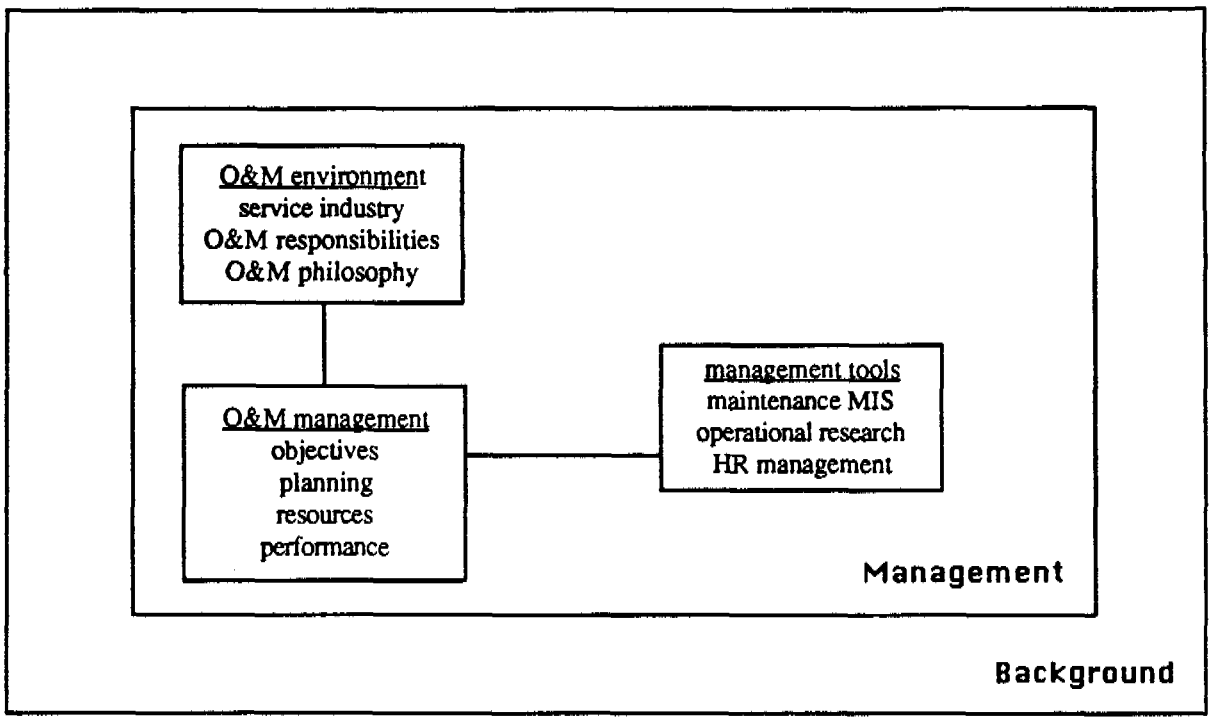

Figure 1: Framework for O&M performance measurement [1]

Term / Concept	Definition
Failure based maintenance (FBM)	maintenance to be carried out only on occurrence of failure or breakdown
Use based maintenance (UBM)	time based or fixed period maintenance
Condition based maintenance (CBM)	maintenance to be activated when a value of a given system parameter reaches or surpasses a preset value
Opportunity based maintenance (OBM)	when a component fails, the opportunity may be taken during the ensuing shutdown to carry out preventive maintenance on other components which have not yet failed
Design-out maintenance (DOM)	the focus is on improvements in the equipment design in order to simplify maintenance operations and/or increase reliability
Corrective maintenance (CM)	activities in response to breakdown, or detected defects
Periodic maintenance (PEM)	activities normally carried out at intervals of more than one year, often as part of large scale programmes of predetermined cycles
Preventive maintenance (PM)	activities aimed at interruption of the deterioration process at an early stage based on systematic, prescheduled programmes of providing early detection of beginnning effects
Routine maintenance (RM)	preventive and corrective maintenance normally not of major scale and typically carried out one or more times every year
Rehabilitation	activities carried out to correct major defects, wear and tear, often as a result of inadequate maintenance, in order to restore a facility to a good working condition without significantly expanding beyond its originally designed function or extent

Table 1: Terms and concepts with respect to O&M planning and management [1][11]

O&M Performance Indicator	Definition
Service	
Water quality	WHO guidelines [17] % of samples with E.coli colony count per 100 ml ≥ target value
Continuity of service	# hours of water supply per day (distribution system) / 24 hours
Consumer complaints	# complaints / 1000 connections / year
Systems & Equipment	
# failures	
# severe failures	failures taking more than one day to repair
top ten critical item list	ten toughest maintenance jobs carried out over the period considered
Reliability (MTBF)	length of period considered (days) / # failures in that period
Maintainability (MTTR)	total time spent on repairs (mandays) / # repairs
Availability	MTBF / (MTTR + MTBF)
Unaccounted-For-Water (UFW) (1)	total annual production - (total annual metered consumption + estimated annual non-metered consumption)
Unaccounted-For-Water (UFW) (2)	liters / day / connection
Unaccounted-For-Water (UFW) (3)	liters / day / km distribution network
Percent UFW	UFW / total annual production
Breaks (1)	# / km distribution network / year
Breaks (2)	# / km pipe material / year
Percent metered consumption	metered annual consumption / total annual consumption
Percent metered connections	# metered connections / # total connections
Percent of consumers meters in working	# consumer meters in accurate working condition / # total meters
Chemicals (1)	amount added (tons/yr) / total annual production (m3/yr) (per chemical)
Chemicals (2)	chemical annual cost / total annual production (m3/yr) (per chemical)
Percent waste water	(total annual raw water - net annual production) / total annual raw water
Energy (1)	total annual kWh (electricity) / total annual production (m3/yr)
Energy (2)	total annual kWh cost (electricity) / total annual production (m3/yr)

Table 2a: Water Supply O&M Performance Indicators adapted from [1] [3] [14] and [19]

O&M Performance Indicator	Definition
Costs	
Budget control (YTD)	year-to-date O&M expenditure (comparison with annual O&M budget)
Percent O&M cost component	labour, materials, energy, contractors, etc. cost / total cost
Oper. rev. per capita served	operating revenue (total water bills paid) / population served
Oper. costs per capita served	annual operating & maintenance cost / population served
Oper. surplus (loss) per cap. serv.	(oper. rev. - O&M cost) / population served
Oper. rev. per m3 produced	annual operating revenue / annual total water production
Oper. costs per m3 produced	annual O&M cost / annual total water production
Oper. costs per m3 billed	annual O&M cost / annual total water billed
Oper. costs per connection	annual O&M cost / # connections
Working ratio	annual O&M costs / annual operating revenue
Percent oper. costs to asset value	total annual O&M costs / total revalued asset value
Percent expenditure for O&M staff to total O&M expenditure	total annual expenditure for O&M personnel / total annual O&M expenditure
annual maintenance expenditure per annual new capital investment	
annual maintenance expenditure per km of distribution network	
annual maintenance expenditure per m3 of water produced	
Personnel	
Employees per 1000 connections	# employees / 1000 connections
O&M Employees per 1000 conn.	# O&M employees / 1000 connections
Employees per 100 km distribution network	# employees / 100 km distribution pipes
O&M Employees per 100 km distribution network	# O&M employees / 100 km distribution pipes
Employees per Mm3 produced	# employees / annual total water production
O&M Employees per Mm3 produced	# O&M employees / annual total water production
Percent overtime	time worked in overtime / total time worked
Percent absenteism	amount of time lost through absenteism / total time

Table 2b: Water Supply O&M Performance Indicators adapted from [1] [3] [14] and [19]