INTEGRATED METEOROLOGICAL AND HYDROLOGICAL NETWORKS – FROM SENSORS TO DATABASES

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***Abstract*:** Information technology, sensor technology, electronics and data communication have developed rapidly in recent years. This has made the automation of meteorological and hydrological networks more affordable and attractive to meteorological and hydrological institutes, power corporations and other authorities that need to monitor and manage water systems such as rivers, lakes, reservoirs and ground water. Hydrometeorological systems, which consist typically of several dozens of automatic monitoring stations, telecommunication systems, databases and application software for users, are installed over wide geographical areas that often include remote areas. The equipment must be able to survive harsh weather conditions while providing the information on precipitation, water quality and existing water reserves that the authority needs to manage its water resources – whether scarce or overabundant.

Meanwhile, demand for meteorological and hydrological data is growing constantly due to new requirements arising from legislation, environmental awareness and the push for efficiency in many of the industries that drive our modern society. Nowcasting, including the nowcasting of floods and severe weather events, is creating new requirements for real-time monitoring.

Operating large networks of automatic weather stations is always an economic burden. Most of the Total Life Cycle Cost (TLCC) of a network is generated by maintenance, calibration and update/upgrade costs. Meteorological and/or hydrological networks should not be built separately. In many cases, the same basic network infrastructure can serve several users and applications. Complementary meteorological and climatological observations can frequently be made in a hydrological network to produce timely and accurate local forecasts, warnings, reports and other end products for the network owner and third party customers. Economies of scale offer a means to control the TLCC cost.

By using the same data logger and telecommunications technology, communication protocols, data formats, databases and the same sensors wherever possible, the network operator can reap the economies of scale and scope by reducing the cost of network design, hardware and software maintenance services including spare parts and training. The savings realized in network operation can be put towards further automation of the conventional network or otherwise improving the hydrometeorological service.

This paper describes how using a flexible and integrated monitoring and data management system, significant savings can be obtained in the TLCC of operating of a modern and steadily upgraded surface weather observation network.

***Key words*:** Hydrology, meteorology, automation, telemetry, integrated networks, Total Life Cycle Cost.

INTEGRIERTE METEOROLOGISCHE UND HYDROLOGISCHE NETZWERKE – VON DEN SENSOREN BIS ZU DEN DATENBANKEN

***Zusammenfassung*:** Informationstechnologie, Sensortechnologie, Elektronik und Datenkommunikation haben sich während der letzten Jahre sehr schnell weiter entwickelt. Damit ist die Automatisierung meteorologischer und hydrologischer Netzwerke für meteorologische und hydrologische Institute, Energieunternehmen und andere Stellen, die Wassersysteme, beispielsweise Flüsse, Seen, Staubecken und Grundwasser, überwachen und verwalten müssen, erschwinglicher und attraktiver geworden. Hydrometeorologische Systeme, die normalerweise aus mehreren Dutzend automatischer Überwachungsstationen, Telekommunikationssystemen, Datenbanken und Anwendungssoftware für Benutzer bestehen, sind in geografisch großen Bereichen installiert, die oft auch abgelegene Gebiete umfassen. Die Geräte müssen rauen Wetterbedingungen standhalten und dabei all die Daten über Niederschlag, Wasserqualität und vorhandene Wasserreserven liefern, die die zuständigen Stellen für das Verwalten ihrer – knapp oder überreichlich vorhandenen – Wasserressourcen benötigen.

Gesetzgebung, Umweltbewusstsein und Effizienzbemühungen in vielen Industriezweigen, die eine treibende Kraft unserer modernen Gesellschaft sind, haben inzwischen mit neuen Anforderungen die Nachfrage nach meteorologischen und hydrologischen Daten gesteigert. Kurzvorhersagen, einschließlich Kurzvorhersagen von Hochwasser und rauen Wetterbedingungen, stellen neue Anforderungen an die Echtzeitüberwachung.

Der Betrieb großer Netzwerke automatischer Wetterstationen stellt immer eine hohe wirtschaftliche Belastung dar. Der größte Teil der TLCC (Total Life Cycle Cost, Gesamt-Folgekosten) eines Netzwerks wird durch die Kosten von Wartung, Kalibrierung und Update/Upgrade verursacht. Meteorologische und/oder hydrologische Netzwerke sollten nicht separat aufgebaut werden. In vielen Fällen kann dieselbe Basis-Infrastruktur eines Netzwerks von verschiedenen Benutzern und Anwendungen genutzt werden. Häufig können in einem hydrologischen Netzwerk komplementäre meteorologische und klimatologische Beobachtungen gemacht werden, mit denen sich zeitgerechte und genaue lokale Vorhersagen, Warnmeldungen, Berichte und andere Endprodukte für den Netzwerkbesitzer und Dritte erstellen lassen. Diversifikationsvorteile sind ein Mittel zur Steuerung der TLCC.

Wenn der Netzwerkbetreiber dieselben Datenlogger- und Telekommunikations-technologien, Datenformate, Datenbanken und Sensoren einsetzt, wo immer das möglich ist, kann er durch Reduzierung der Kosten für Netzwerkkonzeption, Hardware- und Softwarewartung, einschließlich Ersatzteile und Schulung, von Diversifikations- und Größenvorteilen profitieren. Die beim Netzwerkbetrieb erzielten Einsparungen können für die weitere Automatisierung des traditionellen Netzwerks oder sonstige Verbesserungen der hydrometeorologischen Dienstleistungen eingesetzt werden.

Dieses Dokument beschreibt, wie durch die Verwendung eines flexiblen und integrierten Überwachungs- und Datenverwaltungssystems beträchtliche Einsparungen bei den TLCC für den Betrieb eines modernen und ständig verbesserten Netzwerks zur Beobachtung des Oberflächenwetters erzielt werden können.

***Schlüsselwörter*:** Hydrologie, Meteorologie, Automatisierung, Telemetrie, integrierte Netzwerke, Total Life Cycle Cost.

1. Total Life Cycle Cost

The managers of meteorological and hydrological networks face a number of challenges in operating their networks (R. P. Canterford, 2000). These include but are not limited to:

- Operating the network efficiently with limited resources; having to cope with a reduction in personnel.
- Economic pressures lead to an increase in automation; this results in more stringent requirements for calibration and quality assurance.
- As the equipment becomes more sophisticated, the number of instrument specialists in the organization is reduced. This leads to a greater need for support from the equipment vendors and manufacturers (e.g. a need to refine subcontracting practices).
- Need to replace obsolate systems or take advantage of new technologies with frequent updates.
- Use the same capital investment to produce more data for a larger number of users.

Although some procurement officers will always favour a "lowest bidder wins" policy, the Total Life Cycle Cost (TLCC) of a network should always be considered. Cheap, poorly documented and performing systems increase TLCC, and more importantly, they have a major impact on climate records, appearing as shifts or discontinuities in the long-term time series.

The TLCC is the total cost during the expected lifetime of the meteorological and hydrological equipment. TLCC can be expressed as containing the following four basic elements:

$T = P + R + O + C$,

where: P = Product Cost
R = Resource Cost
O = Operating Cost
C = Contingency Cost

An optimum selection would be a combination of a low T and good overall, long- term performance of the equipment to be purchased.

1.1 Product Cost

The Product Cost contains, in addition to the basic price quoted, the testing and documentation, packaging and transportation, taxes, import duties, and so on. Being able to share this cost with other users of the equipment provides immediate cost savings.

The ease of installation, including the manpower requirements, plays a significant role. Therefore, e.g. ready-made connectors in the cables and a meteorological mast that can be tilted by one man will have a significant positive effect on the installation cost.

1.2 Resource Cost

The Resource Cost includes site preparation work such as site purchasing, building access to the site, possible building(s), installing electrics, telecommunications and so on. Modern systems are compact, lightweight and easy to install. Frequently, they are powered by a small solar panel and communicate via wireless telemetry, thus minimizing the site preparation costs as well as improving the reliability of the systems.

1.3 Operating Cost

In the network operation of unmanned, automated equipment, the major part of the Operating Cost is generated by maintenance and telecommunication costs.

Although the quality and reliability of automatic measurements have been improved significantly and the need for maintenance has been considerably reduced in the last decade, many savings can still be realized in maintaining networks of automatic weather stations. Easily interchanged sensors, extended calibration intervals, self-diagnostics and reporting, remote maintenance (including access to intelligent sensors via data logger) and accurate METADATA records are all ways of reducing the Operating Cost.

As we all know, telecommunications technology is advancing very quickly. In days gone by, we could assume that systems would be operated continuously and uniformly for almost all their lifetime. Now, we must be prepared for changes soon after taking a new system into use. However, we can benefit from new and economically effective ways of collecting and distributing data and end products. Meanwhile, we must take telecommunications developments into consideration when planning the system design to accommodate modifications and upgrades. It can be very costly not to have done so when implementing them. Regardless of the installation site, if the range of telemetry options is wide enough, an economical and reliable alternative for data transmission will be found.

The automatic stations should have field-proven extended Mean Time Between Failure (MTBF) rates. Also, the maintenance should be eased as much as possible by using modular, easy-to-replace modules and sensors.

Another significant part of the Operating Cost is taken up by upgrades. When the technology advances rapidly, supporting “older technology” with spare parts and engineering may become a disproportionately large element of TLCL if it is not carefully planned and looked after. To succeed, an upgrade strategy requires support from reputable, established equipment manufacturers and compatibility with the existing system that is built into the system design.

1.4 Contingency Cost

The primary Contingency Cost covers the possible purchasing risks, such as: a defective product, late delivery, or the vendor’s inability to deliver at all. It also covers the vendor’s inability to support the purchase with spare parts and upgrades during the lifetime of the equipment, commonly considered to be a default of 10-15 years. Other concerns when planning future updates/upgrades include: reliability of the published performance data, compatibility of the design in the future and the availability of long-term support for spare parts, training and calibration.

2. Network Automation and Integration

“Improving reliability and accuracy” has driven automation development (J.P. Van der Meulen, 1993). *“Cost-effectiveness”* is now becoming another major driver of automation. Many organizations are seeking ways to reduce the cost of operating their networks. Automation certainly offers significant savings. In many cases, network integration offers significant further savings, since the capital investment can be used to produce more data for more users. Before an integrated network can be taken into use, several matters must be considered in the network design (e.g. site selection, telemetry) and in selecting the right equipment.

2.1. Sensors

Sensors play the key roles in any measurement system. This is true not only with respect to the accuracy and long-term consistency of the data, but also in reducing the cost of calibrating and maintaining the sensors. In addition, we should not forget the effect of the sensor selection on the continuity of the long-term measurement records. Therefore, in order to extract the full benefit out of an integrated system a set of alternative sensors with documented performance should be available for any parameter. From these sets, the optimum selection can be easily made to meet the needs of all the network users.

Fig 1. Different types of wind speed and wind direction sensors, also with heating for severe winter conditions

In addition, site selection for the sensors is very important in developing an integrated system. In hydrometeorological networks, it is often necessary to locate one or more sensors in a properly representative place (e.g. wind and temperature sensors need to be located far enough away from the riverbank). Therefore, options must be available for installing sensors even hundreds of meters away from the data logger.

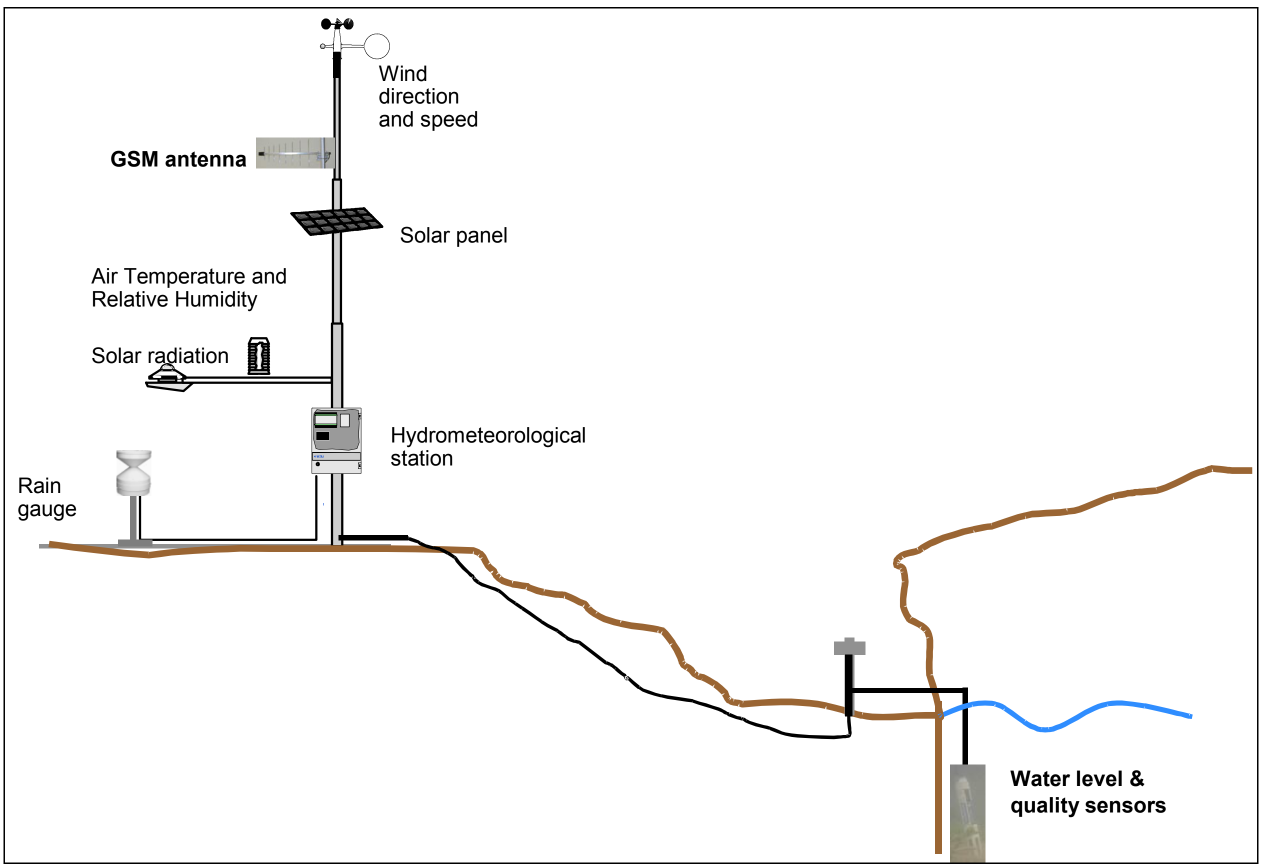

Fig. 2 Example of relocated sensors in hydrometeorological installation

2.2 Data Collection

An important part of an observation network, data loggers must provide cost-effectiveness, security, simplicity of operation and maintenance, and reliable and accurate data.

Flexibility and adaptability are central to the design philosophy: the data logger should be usable with many types of sensors, telemetry devices and across a wide range of technical and environmental settings. In addition, sensor requirements differ from country to country and organizations will often have particularly stringent performance requirements for sensors, which will need to be accommodated, too. New modern sensors will be extensively exploiting the microprocessor technology providing instant and statistical data via serial line or fieldbus. If this is not accounted for in the data logger design, the cost of updating a system with new sensors can be prohibitive.

The development of new end products such as numerical weather prediction models (NWP's) will require data to flow in more frequently (e.g. every 10 minutes or ”as required”). Data from alternative meteorological parameters will also be needed in the future. The ability to remote configure the automatic stations is therefore a basic requirement. Data must be made constantly available, not only by autosending or polling at preset intervals, but also whenever real-time data is requested.

In addition to the measurement tasks, it may occasionally be necessary in carrying out hydrological projects to interface the observation station with other automated systems and environmentally friendly equipment such as aerating turbines and fish bypass devices.

2.3 Telemetry

Telecommunications costs frequently account for the largest portion of the annual operating budget. Since data flow will have to become more continuous in future, telemetry will often be the most critical area of network design from the operating cost point of view. During the network design stage, therefore, the widest possible range of telemetry options should be specified so the most economical telemetry solution can be found for each monitoring site. This also greatly reduces the odds of making a costly misstep when the network is updated in future.

As already mentioned, telemetry solutions are developing fast. Where today we may have a remote station that can only be reached for data transmission with an expensive satellite link, tomorrow the coverage of the local GSM network may be extended over this site. If the station hardware already has built-in GSM communication capability, the upgrade will be easy and economical to accomplish without additional hardware module(s) or software redesign.

One way to reduce telecommunication costs is to use one or several of the stations in the network as *main station(s)* with primary telemetry (e.g. GSM or satellite). These main stations can have *Substations* that send data to the main station via radio modem, for example, which has practically no extra operating cost.

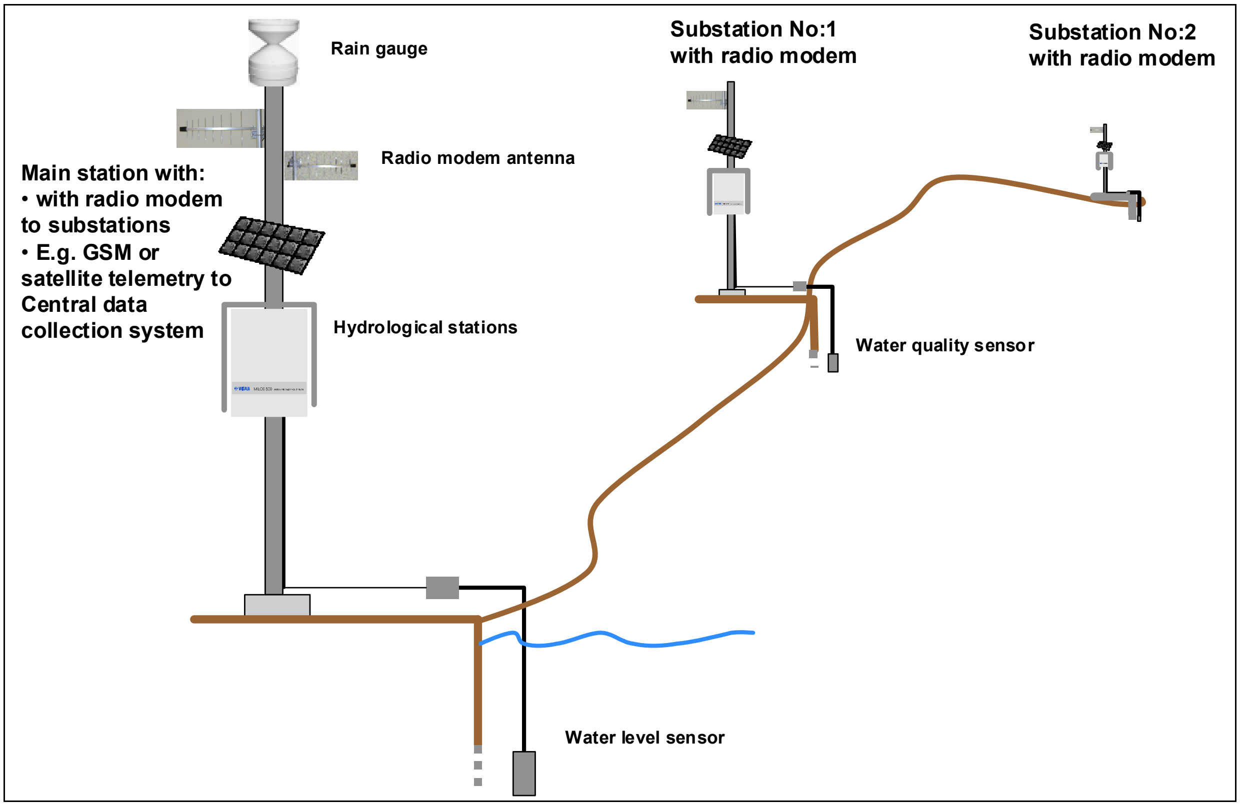

Fig. 3 Main stations with substation using radio modem for telemetry

2.4 Central Data Collection & Database

In addition to the routine data collection schedules, which will become more frequent in future, there will be also a requirement for “on-request” data. “On-request” data will make it possible to respond promptly and appropriately in an emergency situation such as a flood, approaching thunderstorm or other real-time situation that requires decisions to be made immediately.

Increasing automation requires the establishment of sound quality management procedures. In addition to scheduled field inspections, comprehensive and accurate METADATA records should be kept for the sensors, site maps and the equipment itself. A modern central data collection (CDC) system should offer this facility, and also allow it to be used and updated remotely e.g. during field inspections.

In addition to conventional meteorological and hydrological forecasting, demand will grow for interfacing with systems that aid decision-making in the short-term and long-term: e.g. flood or hazardous weather warnings, or optimizing the generation of hydroelectric power.

With the goal of reducing the total operating costs of the network, the CDC system must include integrated functions that perform remote maintenance and checking of the network.

When a large database system is installed, dedicated and professional personnel are needed to look after it, and support and guide its users. Therefore, considerable savings can be achieved by using a common database system, even for a countrywide network.

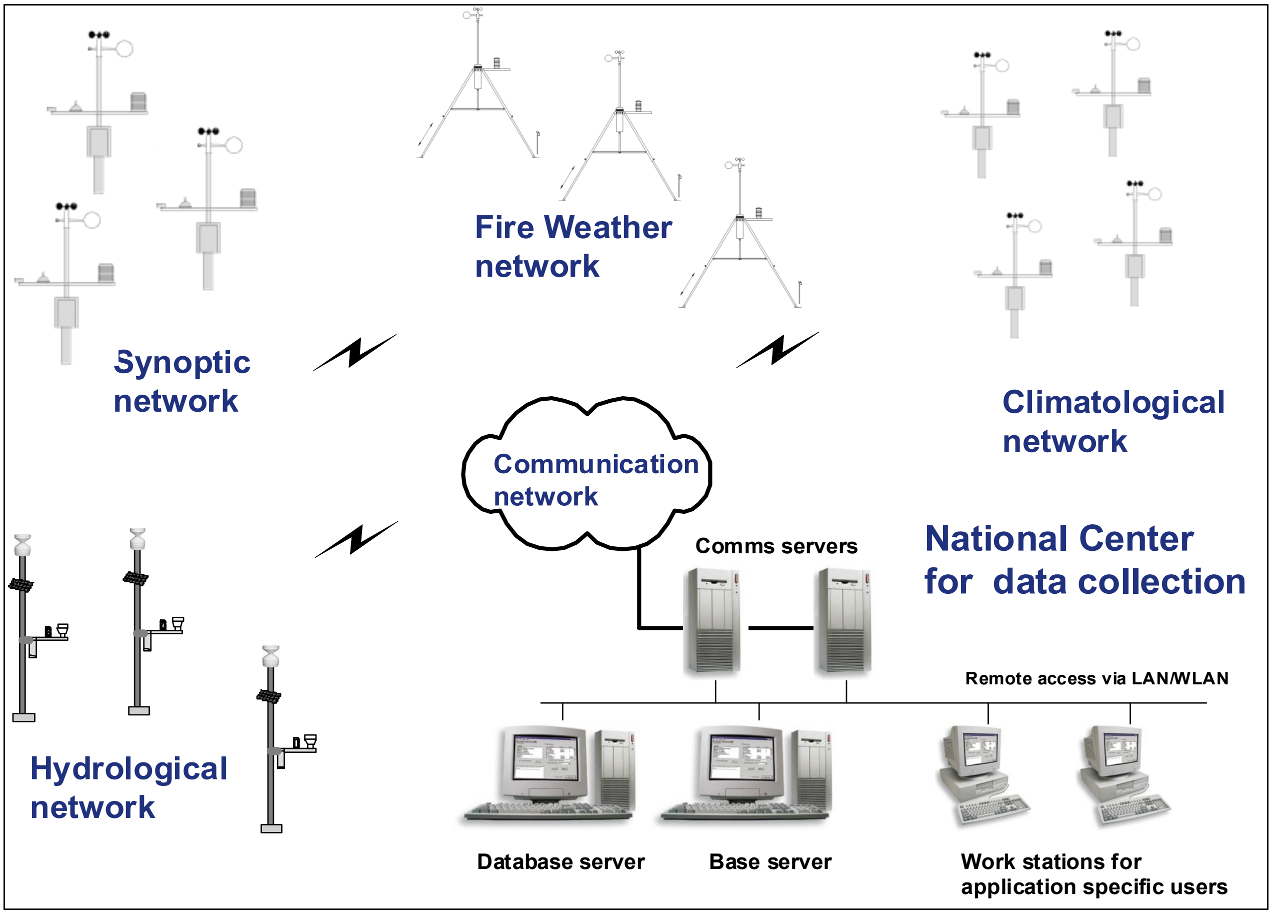

Fig. 4 Example of a large Central Data Collection System with many users

Requirements for real-time applications such as forecasts ("nowcasts"), warnings, control and commercial services will increase significantly. Therefore, a special attention must be paid to selecting a database, which can support all these functions and increased number of users also in the future. Selecting right commercially available tools, the updates are easily and economically available, too.

3. Building on Existing Technology

Most of the sensing technology – such as meteorological sensors, water level sensors and water quality sensors – has been in use for many years. However, enhancements to these technologies are on the horizon: sensors will become more intelligent and will be combined together with more sophisticated and fast-evolving telecommunications, data management, decision-making support and real-time systems. New opportunities will appear for integrating environmental monitoring with the goal of generating more accurate data while operating the network more efficiently and economically throughout its lifecycle.

4. References

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