User requirements for water quality remote sensing products and means of meeting them

T. Pyhälahti [a,*], S. Anttila [a], S. Korhonen [a], R. Teiniranta [a], M. Hynninen [a],
J. Pulliainen [b], J. Vepsäläinen [a], K. Kallio [a], S. Koponen [b]

[a] Finnish Environment Institute (SYKE),P.O. Box 140,00150 Helsinki, Finland – timo.pyhalahti@environment.fi
[b] Helsinki University of Technology, Laboratory of Space Technology, P. O. Box 3000, FIN-02015 HUT, Finland

Abstract – A user survey was conducted among Finnish professional users on their requirements on water quality information, which could be produced with remote sensing. The purpose of the survey was to direct the related research and development to the most interesting applications from the user perspective. The results additionally highlight the requirements for related remote sensing techniques and information systems: Information on properties of land areas influencing the observed water body was one of the main parameters requested. The potential of target area based monitoring system ULAPPA in meeting the user requirements was investigated. ULAPPA is designed to integrate remote sensing and other information on pre-specified areas of interest.

Keywords: satellite remote sensing, end user requirements, water quality, survey, information system

1. INTRODUCTION

A user survey on requirements for information was conducted among Finnish professional users of water quality information. It covered experts on aquatic management, monitoring and research within governmental administration, academic sector and other public and private parties involved. The emphasis was on requirements and potential for practical use of information, which is derivable with satellite and airborne remote sensing. The purpose of the survey was to direct the research and development work on water quality remote sensing. Satellites have been used to monitor algae blooms and surface temperatures in the Baltic Sea for several years, and similar methods are being developed for lakes too. Finnish Environment Institute (SYKE) has been very active on both research and operational application of these methods.

In order to meet these requirements, several sources of information need to be combined: "General knowledge" of the monitored area, measurement information on it and naturally previously made assessments of the same area. To use earth observation in monitoring of for example lake water quality, traditional images have limited value: How could they be used for example when one wishes to draw a graph of time series from several lakes in order to compare them? Indicator values stored in a database would be required. To solve these data use problems in water quality monitoring, ULAPPA system was developed using target area approach. Typically monitored areas have clear boundaries (e.g. lakes) or such boundaries can be selected based on water management or administrative reasons (e.g. Baltic sea). ULAPPA is capable of handling different overlapping definitions of these "areas of interest" as well as to combine different sources of information to them.

2. MONITORING REQUIREMENTS

2.1 Finnish Lakes and the Baltic Sea

Lakes cover relatively large proportion, about 10%, of the Finnish territory. They are mostly small and shallow, and the large ones are typically divided into sub-basins with peninsulas and islands. The number of lakes with an area larger than 0.01 km2 is 56 012 and 2 609 of these have an area greater than 1.0 km2 (Table 1). Small ponds with an area between 0.0005 and 0.01 km2 are even more numerous: 132 000. (Raatikainen and Kuusisto, 1988) They are typically shallow, thus there is relatively small volumes of water to dilute any external environmental loads. Characteristically of the Finnish nature, rivers and creeks interconnect these lakes into complex drainage basin systems. Their water, with the exception of the northernmost Finland, eventually flows into the Baltic Sea.

The Baltic Sea is a semi-enclosed brackish sea in the boreal Northern Europe. Shallow and narrow entrance of the saline water from North Sea through Danish Straits and large freshwater inflow of many rivers cause its brackish nature. Hence, the water quality in the lakes and rivers influences strongly on the Baltic water properties. The coast of Finland, our main area of interest, is characterized by quite small number of islands in the Gulf of Bothnia, moderate amount of islands in the Gulf of Finland and an extensive, dense archipelago in South-western Finland and Aland. (Rönnberg, 2001; Stålnacke 1996) The entire coast is quite shallow, so the water quality near the coast is not always in synchronization with the quality in the open sea.

2.2 Observed Phenomena

Due to their elementary role in the Finnish nature and their vulnerability of anthropogenic influences, there are extensive monitoring systems to support water management. Eutrophication is currently the main environmental problem on the aquatic ecosystems, accompanied with problems like

* Corresponding author.
** The work was co-financed by TEKES and the Academy of Finland

migratory species, toxic substances accumulating in food chains, illegal oil discharges etc. New challenges are imposed on the national monitoring systems by the European Union Water Framework Directive (WFD) (EU, 2000). WFD requires the member states to take actions in order to reach ecological status "good" in for example coastal seas and lakes by 2015. This involves both characterization of water bodies in order to decide what "good ecological status" exactly means in each case and implementation of monitoring systems to verify the ecological status.

Remote sensing technology can assist WFD-related tasks in several ways. Perhaps the most relevant for medium resolution satellite instruments is detection of algae blooming events: In WFD the reoccurring events of sudden massive increases in phytoplankton concentrations is generally considered an indicator between "good" and "moderate" ecological status (EU, 2000).

3. TARGET AREA APPROACH AND ULAPPA

3.1 Target Area Approach

As described in the introduction, raster images from satellite data and thematic maps derived from them do not answer to all requirements of the monitoring systems. For creating the required information services, target area approach (Pyhälahti *et al*, 2002) was developed. The general idea is to gather satellite observations from pre-defined areas of interest, the *monitored entity*. In this application they are lakes and parts of the Baltic Sea, in other applications of target area approach they could be fields, forest parcels etc stationary geographical objects.

Not all parts of the monitored entity may be monitorable with the available observing resolutions used instruments. For example in the case of lakes and coastal sea water quality detection: It is not likely there will be practical medium resolution instruments capable of providing qualitative water information from mixed land/water pixels. These areas naturally depend on the resolution of the used instrument. For example dense aquatic vegetation patches can further limit these areas. Area deemed observable of a monitored entity with a certain resolution is called *target area*.

It is worth noting that the target area is often not likely to be homogeneous in its properties. Municipal, industrial or agricultural loads, depth and current structure or water inflow may cause significant differences in the ecologic and geophysical characteristics of different parts of the monitored entity. In user-need-driven monitoring systems it may be necessary to divide the monitored entities in parts according to different administrative boundaries. Due to problems in using mixed pixels in deriving useful information, different parameters – in case they are measured with different kinds of instruments – may be available for significantly different sub-areas of the whole monitored entity. Thus it is necessary not only to derive monitoring information of the whole area, but also to have separate statistics for these special areas of interest. Thus, within target areas of the monitored entity, several potentially overlapping *monitoring areas* are defined. All monitoring results are to be connected with some monitoring area, and users will select the results they need

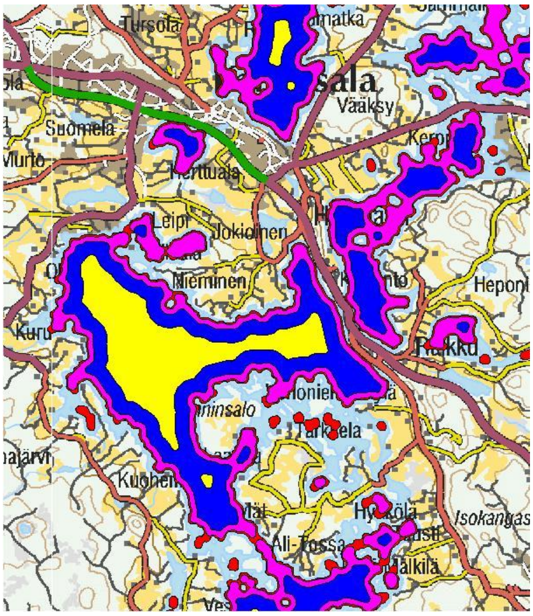

Figure 1: Resolution areas for different resolution instruments in ULAPPA system (Genimap Oy ja MML, Lupa L4715/02)

from the pre-calculated results associated to a single monitoring area.

In addition, monitoring areas are the key entities in integrating other than remote sensing data to the system. These include in situ sampling, weather-related data as well as a priori information on the monitored entity, such as expected normal variation of water quality parameters in a certain lake or lake type.

As it comes to remote sensing observations, it does not really matter how many overlapping monitoring areas are defined to cover any point. For example, the same set of satellite observations useful for deriving average concentration of chlorophyll in a certain bay is going to be a subset of the set of satellite observations for calculating the same average for the whole lake. For satellite observations, the idea is to store only the useful satellite observations, and to store them as 'packages' according to their location. This is accomplished by dividing the target areas to parts according the desired monitoring area borders, creating a set of *resolution areas*. The borders of different resolution areas will thus follow the borders of target areas for different resolution instruments as well as other necessary borders (ecologically selected, administratively feasible etc.) The monitoring areas will then be constructed simply as unions of these resolution areas. Figure 1 shows a real-world example on this system.

3.2 ULAPPA

Target area approach is the term for the described methodological approach in using remote sensing in practical monitoring systems. The general technology developed for practical implementation of it is called SADB (Satellite Archive Data Base). The implementation of SADB to the specific problem of monitoring Finnish lakes and coastal sea is called ULAPPA. *Ulappa* is a Finnish word for large open water area – the type of area from where daily medium resolution satellite observations are available.

In addition to administrative boundaries, resolution is the main parameter in defining monitoring and resolution areas in ULAPPA system. Resolution areas with higher resolution form buffer zones around coarser resolution areas, which are only observable with higher resolution level instruments. In ULAPPA these levels are currently 250-300 m (MODIS channels 1,2), 300-500 m (MERIS; MODIS 1,2), 500-1000 m (MERIS, MODIS 1-7) and 1000 m (MERIS, MODIS, SeaWiFS, AVHRR etc.) Further details of target area approach and ULAPPA are available in (Pyhalahti *et al*, 2005).

4. SURVEY

4.1 Methods

The survey consisted of a web questionnaire and a workshop for expert analysis of the questionnaire results. A four-person task force defined the query scope and questionnaire questions, had the questions checked by some external experts, organized the web query, analyzed the results for the workshop, organized the workshop and gathered the final results.

The web questionnaire consisted of 33 questions in five areas:

1. Background and current tasks of the replier
2. Information requirements
3. Current opinion and experiences of remote sensing products
4. Requirements for information systems
5. Modeling & data assimilation related questions.

Last two sections were optional. The questionnaire addressed both currently available products and those available in foreseeable future for different kinds of aquatic ecosystems. Even if future use of ULAPPA was anticipated when the questions of the questionnaire were created, other types of services and solutions were considered as well. The purpose of these questions in the optional part of the query was not to blindly justify implementation of previously developed technical solutions, but to assess the true requirements of the user community.

Currently the main emphasis of water remote sensing research is on medium resolution optical instruments like ENVISAT MERIS. However, interest in high-resolution imagery applications (littoral phenomena, macrophytes), synthetic aperture radar applications (ice conditions) and even airborne LIDAR applications (water depth) were mapped.

An email invitation to the web questionnaire was sent out to 716 Finnish professionals in public and private as well as research and management branches, and 150 replied to the query. 63% of the replies were from the national administration (environmental or other branch), 26% from universities and 11% from non-governmental or private organizations. 56% defined themselves as researchers, 33% as planners or experts not so much involved in research, and the rest included tasks from management to technical monitoring tasks. 56% were involved in lake, 28% in river and 17% in sea monitoring – these interests were not mutually exclusive.

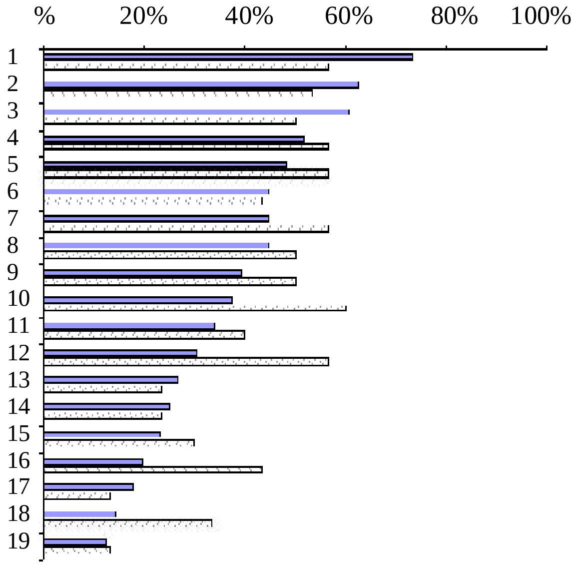

Figure 2: Preference of remote sensing products among pelagial (dark blue) and littoral (grey) end users: 1)Surface chlorophyll concentration 2)Drainage basin land use 3)Floating algae blooms 4)Macrophyte abundance 5)Secchi depth 6)Surface temperature 7)Euphotic depth 8)Macrophyte type 9)Drainage basin topology 10) Benthic type & coverage down to 3 m depth 11) Surface water dissolved organic matter concentration 12)Benthic topology down to 3 m depth 13)Ice break-up 14)Freezing 15)Surface water re-suspended sediment concentration 16)Water level during summer 17)Snow and snow melt in the drainage basin 18)Water level during winter 19)Ice and snow properties on the water area

Additionally there were people interested in ponds etc of which it is not possible to get satellite data.

The workshop was attended by 35 experts on both research and monitoring of water as well as experts on remote sensing technology. The idea of analyzing the questionnaire results in an open workshop was to bring in the requirements and opinions of the whole water quality data end user community. If remote sensing research concentrates solely on the requirements and problems of those experts who are interested in the technology and whose needs are more easily covered with it, the remote sensing technology development might serve few users and miss whole branches of applications.

4.2 Questionnaire Results

In general, most of the different types of information were 'very useful' or 'somewhat useful' to over 50% of respondents – so basically there are users for almost any new information which airborne or satellite remote sensing can provide. In this comparison Secchi depth was the most useful information, followed by drainage basin land cover, surface water chlorophyll, surface temperature and macrophyte abundance. If comparison is limited to 'very useful', the most useful was drainage basin land cover. Figure 2 highlights the preference differences of 'very useful' information between users interested in littoral vs. pelagial phenomena. Researchers tended to be more interested in temperature and optical properties (Secchi & euphotic depths), when water managers and management planners put more emphasis on drainage basin properties. Research and monitoring related personnel were more in to phytoplankton properties as water management related tasks implied interest towards macrophyte and benthic properties and topology.

Fortunately highest annual interest on water property data was during summer months, when – as ice cover is absent - remote sensing is capable of providing data. Notable exception is lake data in March: Those measurements on water quality and temperature near the bottom in the deepest parts of the lake during ice covered stratification could not be replaced with remote sensing using any foreseeable technology.

The users are generally dissatisfied (68%) with the traditional point-wise water sampling and the resulting extrapolation of data in order to characterize for example the whole lake. However, the users seem to be mostly interested in time series information with potentially much more frequent measurements (over 50%) than time- and area averages or statistical information on local variations (ca 20%). Most of the users would require the results to be available within one month, and typically weekly/bi-weekly averages are suitable – with the exception of temperature, where averaging time should be less than a week.

Users would like to receive both the data to be processed by themselves (digital maps, data files) and web services to provide access to this data. The users would mainly (76%) rely on accuracy information provided with the service.

4.3 Workshop Results

A clear outcome of the workshop 10th October, 2004 in SYKE was that remote sensing can replace totally none or only few traditional methods of water quality monitoring, but it can be of great importance and a way of reducing required resources in complementing and optimizing the existing monitoring systems. An important requirement for integrated monitoring in which remote sensing and other methods are used together is the ability to reduce the required traditional sampling and analysis work. One possibility is to use remote sensing to detect the lakes and areas that require more intensive research. Another important application area is to fill in the gaps of too sparse sampling networks. An important approach is to include remote sensing in a major role to the extensive surveys of the status of national water resources and for example implementation of the EU Water Framework Directive (EU, 2000).

It was noted that in addition to land cover monitoring it is important to have up-to-date information on land cover change. Specially open terrain parameters are of importance. Chlorophyll and Secchi depth and potentially turbidity monitoring were considered as key areas to concentrate upon. As traditional techniques have their own limitations in accuracy, the typical 10-30 % accuracies of remote sensing are acceptable, and often 50% errors can be accepted. With increasing use of remote sensing products information on mutual accuracy properties of remote sensing and traditional data will be increased.

5. CONCLUSIONS

Neither compilation of remote sensing data users queries nor analysis of their results are simple tasks, thus careful planning and analysis of the goals of the query as well as use of external experts for testing the questions really pay off in the end. Even with most careful planning there will be areas, which the questions and the available answer options do not cover sufficiently. Limiting the scope of the query as well as considering partial or total transfer to individual user interviews are options to be considered.

The information most frequently characterized as 'very useful' by all responded water experts was land use characteristics of the drainage basin affecting the water. In addition, the results show great variability in the user needs. As ULAPPA can help to integrate different sources of information, it has certain potential even as an end user tool and definitely as an engine for providing different kind of web services.

In general terms the survey showed that there are a lot of users with strong practical interest and potential use of the products and services which are being developed and produced by SYKE. No major corrections are required for the development. Main issue is merely to get the currently available methods to operational production and to real use in practical water research and management. User feedback and user experiences will increasingly be providing further requests and requirements for the methods development in the future.

6. REFERENCES

6.1 References from Journals

Pyhälahti, T., Anttila, S., Korhonen, S., Teiniranta R., Hynninen, M., Pulliainen, J., Vepsäläinen, J., Kallio, K., Koponen S. Target area based relational database system for managing earth observation information, 31st International Symposium on Remote Sensing of Environment: Global Monitoring for Sustainability and Security, June 20-24, 2005 Saint Petersburg, Russia

Pyhälahti, T., Teiniranta, R., Kallio, K., Vepsäläinen, J., Koponen, S., Pulliainen, J. Target Area Approach In Remote Sensing Of Lakes And Coastal Zone. Ocean Optics XVI, Nov 18-22, 2002, Santa Fe, USA

Raatikainen M, Kuusisto E. The number and surface area of lakes in Finland (in Finnish with English abstract). Terra 1988;102(2):97-110.

Rönnberg C., 2001, Effects and Consequences of Eutrophication in the Baltic Sea, specific Patterns in Different Regions. Licentiate Thesis, Department of Biology, Environmental and Marine Biology, Åbo akademi University, Finland, 132 p.

Stålnacke P. (1996) Nutrient loads to the Baltic Sea. Ph.D. thesis, Linköping studies in Arts and Science, 146, 148 pp.

6.2 References from Websites

EU, 2000. Directive 2000/60/EC of the European Parliament and the Council establishing a framework for the community action in the field of water policy (EU Water Framework directive(WFD)) http://europa.eu.int/comm./environment /water/water-framework/index_en.html