An intelligent water quality monitoring & prediction system

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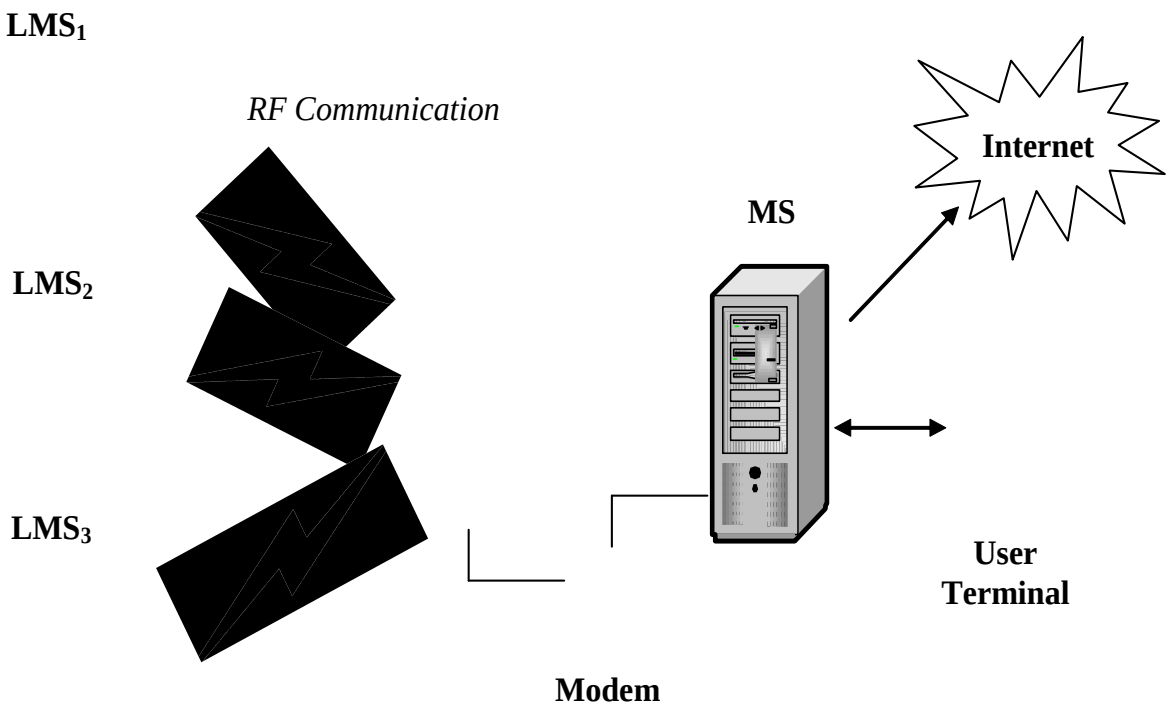
System characteristics (I)

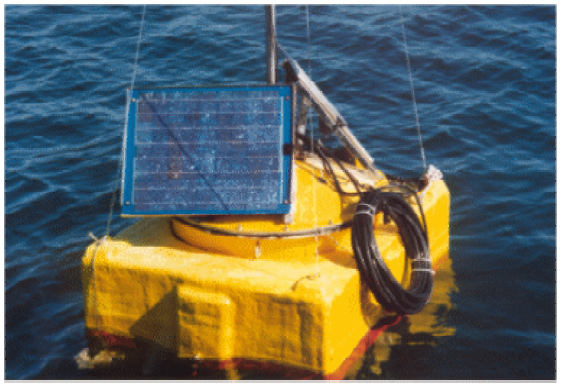
- Two sensor-telematic networks for collecting water quality measurements in real time were developed and deployed:
  - **Andromeda** for sea waters and
  - **Interisk** for fresh waters + surface air
- Readings transmitted wirelessly (SCADA) to a main station for processing and storage by
  - RF (Andromeda)
  - GSM (Interisk)
- Solar cells + batteries for power
- PLCs (temporary storage and processing of sensor readings)

System Characteristics (II)

- **Intelligence:**
  - **Expert system + fuzzy logic (fuzzy expert system): issues alerts** when certain environmental parameters exceed certain "pollution" limits, which are specified either by the authorities (legislation) or by environmental scientists
- **Forecasting:**
  - **Machine Learning** + **Adaptive Filtering** techniques are utilised to predict measurements **a day ahead**, as well as techniques to incorporate the window of past values in order to be able to make a more precise prediction.

ANDROMEDA/INTERISK





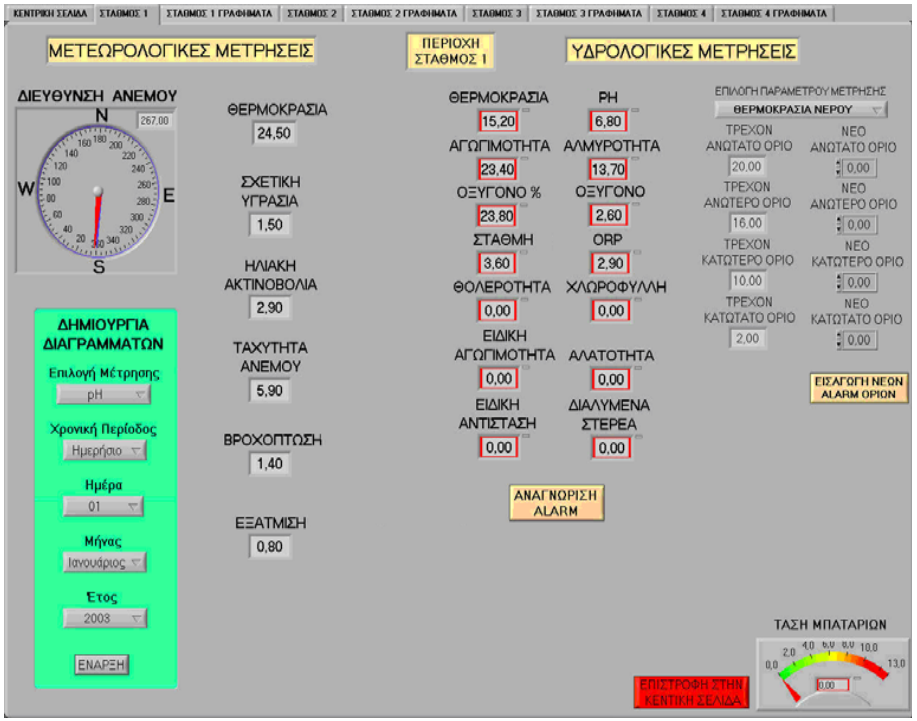
ANDROMEDA LMS

INTERISK LMS

System deployment

- **ANDROMEDA sea water network:** Thermaikos Gulf (Thessaloniki bay, Greece)
  - 7 Hydrological parameters: *water temperature, pH, dissolved oxygen, conductance, turbidity, sea currents, and salinity*.
  - Data transmission: radio (RF) modems.
- **INTERISK fresh water network**: lake Doirani, lake Kerkini and Strymonas River
  - 8 Hydrological parameters: *water temperature, pH, dissolved oxygen, % oxygen, turbidity, conductivity, water depth*
  - 7 Meteorological parameters: *air temperature, air relative humidity, solar radiation, wind speed, wind direction, rainfall, evaporation*.
  - Data transmission: GSM Modems.

System GUI


ΚΕΝΤΡΙΚΗ ΣΕΛΙΔΑ
ΣΤΑΘΜΟΣ 1
ΣΤΑΘΜΟΣ 1 ΓΡΑΦΗΜΑΤΑ
ΣΤΑΘΜΟΣ 2
ΣΤΑΘΜΟΣ 2 ΓΡΑΦΗΜΑΤΑ
ΣΤΑΘΜΟΣ 3
ΣΤΑΘΜΟΣ 3 ΓΡΑΦΗΜΑΤΑ
ΣΤΑΘΜΟΣ 4
ΣΤΑΘΜΟΣ 4 ΓΡΑΦΗΜΑΤΑ
ΜΕΤΕΩΡΟΛΟΓΙΚΕΣ ΜΕΤΡΗΣΕΙΣ
ΠΕΡΙΟΧΗ ΣΤΑΘΜΟΣ 1
ΥΔΡΟΛΟΓΙΚΕΣ ΜΕΤΡΗΣΕΙΣ
ΔΙΕΥΘΥΝΣΗ ΑΝΕΜΟΥ
ΘΕΡΜΟΚΡΑΣΙΑ
24,50
ΣΧΕΤΙΚΗ ΥΓΡΑΣΙΑ
1,50
ΗΛΙΑΚΗ ΑΚΤΙΝΟΒΟΛΙΑ
2,90
ΤΑΧΥΤΗΤΑ ΑΝΕΜΟΥ
5,90
ΒΡΟΧΟΠΤΩΣΗ
1,40
ΕΞΑΤΜΙΣΗ
0,80
ΔΗΜΙΟΥΡΓΙΑ ΔΙΑΓΡΑΜΜΑΤΩΝ
Επιλογή Μέτρησης
pH
Χρονική Περίοδος
Ημερήσιο
Ημέρα
01
Μήνας
Ιανουάριος
Έτος
2003
ΕΝΑΡΞΗ
ΘΕΡΜΟΚΡΑΣΙΑ
15,20
PH
6,80
ΑΓΩΓΙΜΟΤΗΤΑ
23,40
ΑΛΜΥΡΟΤΗΤΑ
13,70
ΟΞΥΓΟΝΟ %
23,80
ΟΞΥΓΟΝΟ
2,60
ΣΤΑΘΜΗ
3,60
ORP
2,90
ΘΟΛΕΡΟΤΗΤΑ
0,00
ΧΛΩΡΟΦΥΛΛΗ
0,00
ΕΙΔΙΚΗ ΑΓΩΓΙΜΟΤΗΤΑ
0,00
ΑΛΑΤΟΤΗΤΑ
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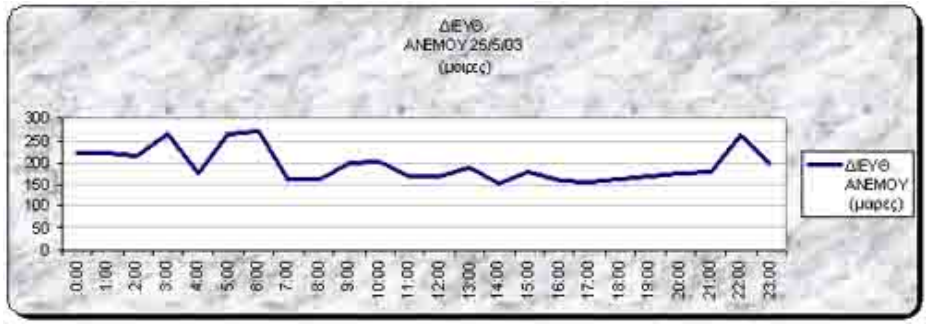
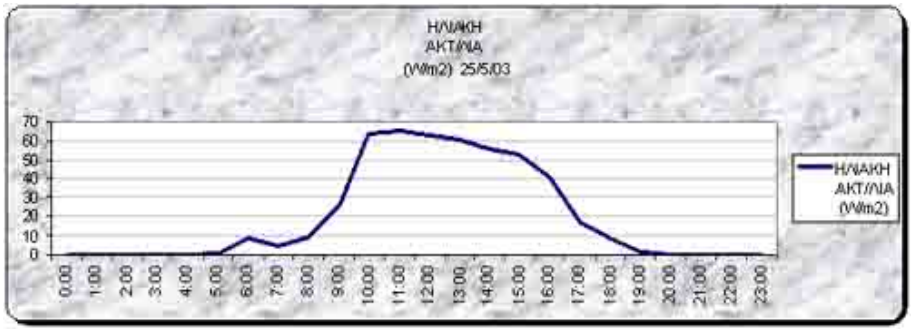
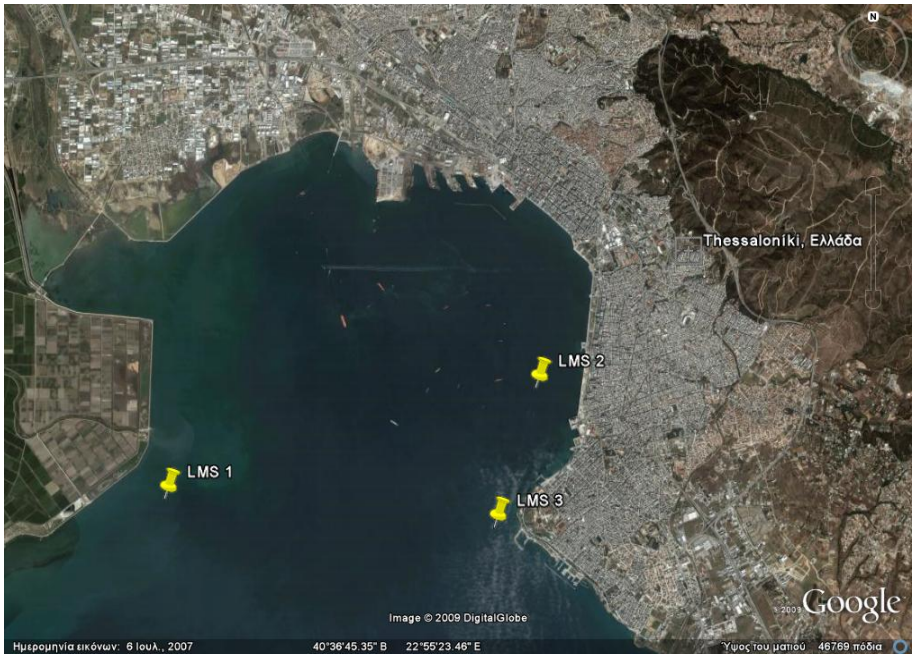
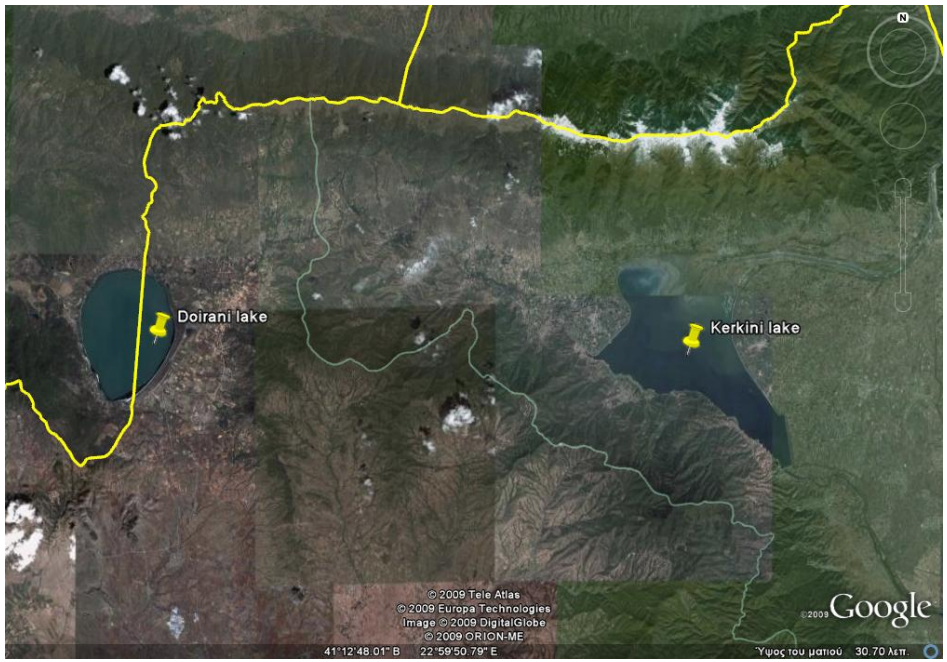
ΕΙΔΙΚΗ ΑΝΤΙΣΤΑΣΗ
0,00
ΔΙΑΛΥΜΕΝΑ ΣΤΕΡΕΑ
0,00
ΑΝΑΓΝΩΡΙΣΗ ALARM
ΕΠΙΛΟΓΗ ΠΑΡΑΜΕΤΡΟΥ ΜΕΤΡΗΣΗΣ
ΘΕΡΜΟΚΡΑΣΙΑ ΝΕΡΟΥ
ΤΡΕΧΟΝ ΑΝΩΤΑΤΟ ΟΡΙΟ
20,00
ΝΕΟ ΑΝΩΤΑΤΟ ΟΡΙΟ
0,00
ΤΡΕΧΟΝ ΑΝΩΤΕΡΟ ΟΡΙΟ
16,00
ΝΕΟ ΑΝΩΤΕΡΟ ΟΡΙΟ
0,00
ΤΡΕΧΟΝ ΚΑΤΩΤΕΡΟ ΟΡΙΟ
10,00
ΝΕΟ ΚΑΤΩΤΕΡΟ ΟΡΙΟ
0,00
ΤΡΕΧΟΝ ΚΑΤΩΤΑΤΟ ΟΡΙΟ
2,00
ΝΕΟ ΚΑΤΩΤΑΤΟ ΟΡΙΟ
0,00
ΕΙΣΑΓΩΓΗ ΝΕΩΝ ALARM ΟΡΙΩΝ
ΤΑΣΗ ΜΠΑΤΑΡΙΩΝ
ΕΠΙΣΤΡΟΦΗ ΣΤΗΝ ΚΕΝΤΡΙΚΗ ΣΕΛΙΔΑ

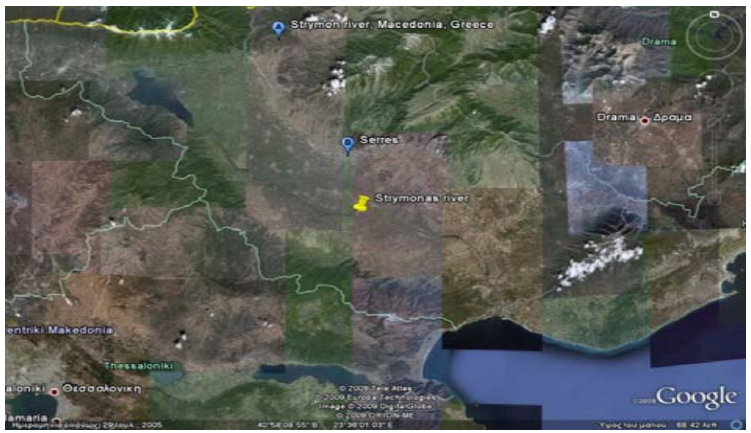

ΔΙΕΥΘ. ΑΝΕΜΟΥ 25/5/03 (μοίρες)
ΔΙΕΥΘ ΑΝΕΜΟΥ (μοίρες)


ΗΛΙΑΚΗ ΑΚΤ/ΝΙΑ (W/m2) 25/5/03
ΗΛΙΑΚΗ ΑΚΤ/ΝΙΑ (W/m2)

Maps of deployment locations





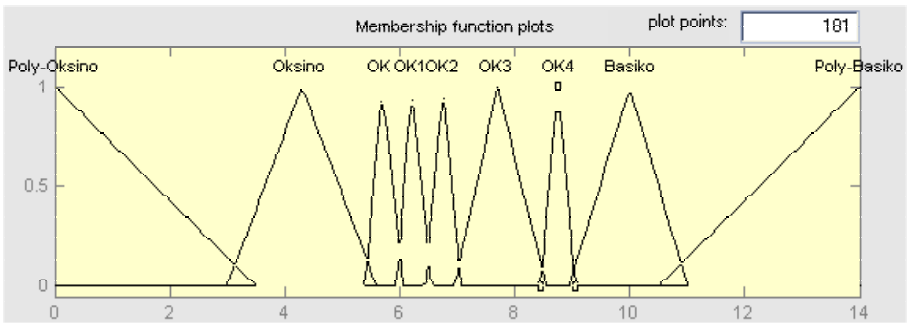


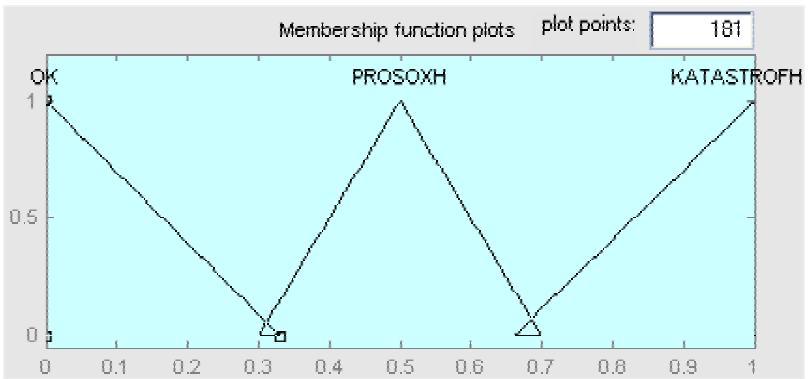
Fuzzy Expert System

- The scientific knowledge required for the expert system was elicited from the Greek environmental legislation depending on the aquatic use: *shell cultivation*, *swimming*, *Cyprinidae* and *Salmonidae* cultivation
- Why Fuzzy expert system?
  - To allow for fluctuations in sensor readings, due to either limited sensor accuracy or random fluctuations of physical conditions.
  - Fuzziness can cater for the rigidness imposed by the legislation, which had to be formulated precisely, using crispy values. However, in practice such limits are never rigidly defined, since they are derived statistically.
- The overlapping of the fuzzy ranges are narrow, since
  - the legislation cannot be highly disputed.
  - Having large overlaps would cause more pollution alarms that would trigger authorities unnecessarily
- The degree of overlapping was experimentally established tuned for smooth behaviour of the **Fuzzy Inference System (FIS)** transition function.

Fuzzy Expert System II

- One FIS per hydrological parameter.
- Each FIS has one input variable and four output variables, one per aquatic use.
- Input variable is split in as many membership functions as needed to utilize the desired and allowed ranges for each aquatic use.
- The output variables affected by this particular measurement contain three membership functions: OK, CAUTION and DANGER.
- Output to user: The system provides answers to questions like: "*Is the water suitable for swimming*?"

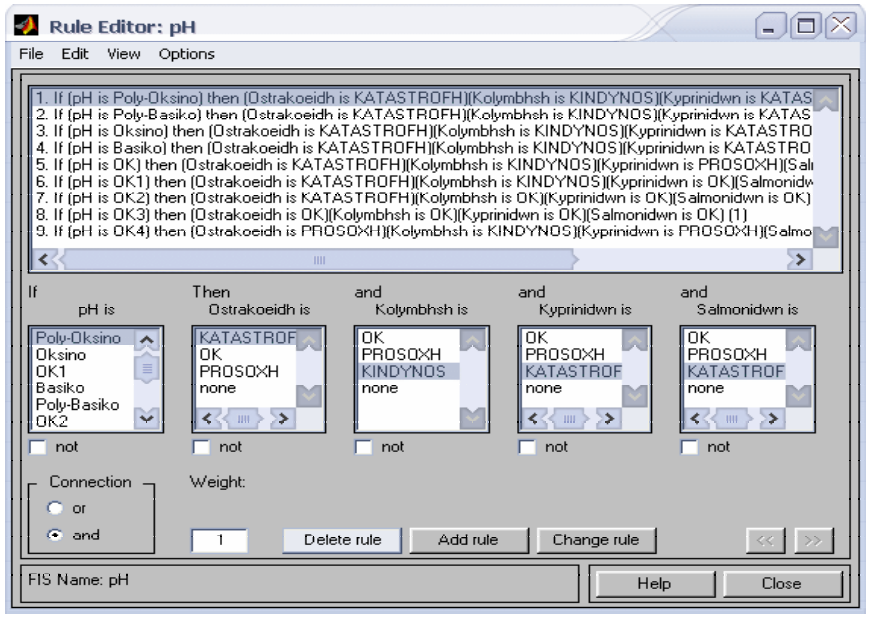




Membership functions of the input variable “pH” and the output variable “Shell”

ES rules and output

- The rules for each FIS were formulated by taking into account: a) the correlation between the input and the output variables, and b) the definitions of the membership functions.



The set of rules of the pH FIS.

<<<DATE / TIME: 25-Jul-2002 / 06:50>>>

SHELL CULTIVATION:
DANGER: The allowed value ranges have been exceeded!
Values that have exceeded the ALLOWED VALUE RANGE are:
TEMPERATURE: 25.390 Code: 0.8613494
PH: 11.180 Code: 0.8485162
%O2: 37.100 Code: 0.8691869
Values that have exceeded the DESIRED VALUE RANGE are:
SALINITY: 3.000 Code: 0.5000000

SWIMMING:
DANGER: The allowed value ranges have been exceeded!
Values that have exceeded the ALLOWED VALUE RANGE are:
PH: 11.180 Code: 0.8485162
Values that have exceeded the DESIRED VALUE RANGE are:
%O2: 37.100 Code: 0.5000000

CYPRINIDAE CULTIVATION:
DANGER: The allowed value ranges have been exceeded!
Values that have exceeded the ALLOWED VALUE RANGE are:
PH: 11.180 Code: 0.8485162
Values that have exceeded the DESIRED VALUE RANGE are:
TEMPERATURE: 25.390 Code: 0.5000000
DISSOLVED O2: 0.080 Code: 0.5000000

SALMONIDAE CULTIVATION:
DANGER: The allowed value ranges have been exceeded!
Values that have exceeded the ALLOWED VALUE RANGE are:
PH: 11.180 Code: 0.8485162
Values that have exceeded the DESIRED VALUE RANGE are:
TEMPERATURE: 25.390 Code: 0.5000000
DISSOLVED O2: 0.080 Code: 0.5000000

Sample expert system output.

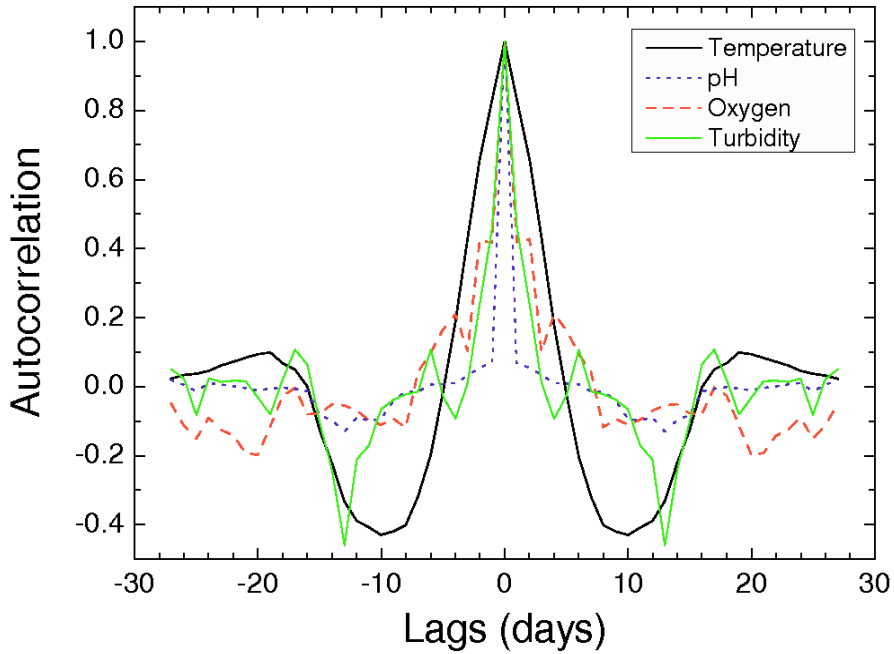
Forecast of water quality variables: Why?

- To Prevent undesirable environmental situations, as well as
- To enforce longer term actions for regional growth and development.
- The ability to predict the quality of water in an ecosystem one or more days ahead is very useful, giving the possibility to the authorities for the necessary precautionary actions in time
  - In our system we focused on one-day ahead predictions of certain water quality variables

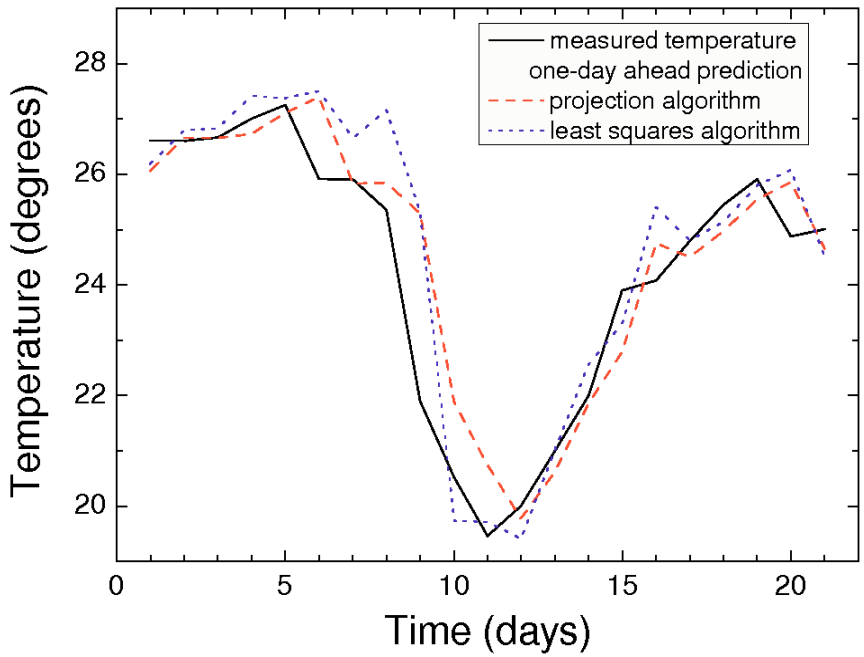
Forecast of water quality variables: Methodology

- **Machine Learning** and **Adaptive Filtering** techniques
  - In case of Machine Learning, we incorporate the window of past values in order to make a more precise prediction more than one days ahead.
  - Adaptive Filtering is performed via a *projection* and a *least squares* algorithm exploiting correlations among different quality variables as well as autocorrelations of time series of a single variable

Forecast of water quality variables: results



Autocorrelation sequences for temperature, pH, oxygen and turbidity.



Temperature prediction

Advantages of system

- The main advantage of the system and its architecture is its flexibility/versatility by means of extensibility and mobility.
  - Concerning the sensor network, new sensors for a variety of environmental readings (e.g. hydrological, meteorological, etc.) can be and have been easily added to the system.\
  - Existing LMSs can be easily moved to different locations and new LMSs can be easily added, without disturbing the rest of the system.
  - The communication between the LMSs and the MS can be and has been implemented with a variety of technologies, depending on the geomorphologic and socioeconomic features of the installation area.
  - New methodologies and techniques both for predicting and monitoring can be used without disturbing the rest of the system.

ANDROMEDA OPERATION

- The Andromeda network was working productively from 1998 until 2005, when it ceased working due to lack of Governmental funding. The monitoring system has been working 18 months during 2004-2005. During that period a large number of “pollution events" were recorded, for which the system responded issuing alerts properly, since the LMSs were installed near the port and the industrial area of Thessaloniki, where sea quality is very poor.
- However, only one severe event was recorded when all sensors indicated strongly a very large deterioration of water quality, which turned out to be due to a spill from a ship.
- Finally, there were also some false and/or missed alarms occurring on days when the maintenance of sensors was inadequate, or when litter was cluttering sensor readings, in both cases resulting in untrustworthy measurements

Conclusions

- An intelligent system for monitoring and predicting water quality, whose main aim is to help the authorities in the "decision-making" process in the battle against the pollution of the aquatic environment
- The system is realized via two sensor-telematic networks for collecting water quality measurements in real time (Andromeda, for sea, and Interisk, for fresh waters). Sensor readings are transmitted wirelessly to a main station for processing and storage.
- The intelligent system monitors sensor data, reasons, using fuzzy logic, about the current level of water suitability for various aquatic uses, such as swimming and piscicultures, and flags out appropriate alerts.
- Furthermore, the system employs Machine Learning and Adaptive Filtering techniques and algorithms which successfully predict measurements a day ahead

Future Work

- To integrate the prediction algorithms employed in the MS with the fuzzy expert alerting system, so that the system will be able to issue early warnings based on predicted hydrological and/or meteorological parameters values.
- Explore the possibility to construct prediction models for the other variables on shorter time-scales than the one-day ahead prediction.
- Use model-based reasoning for predicting spatial pollution propagation among LMSs.
- **Build LMS network for**
  - **Urban water tanks/urban water infrastructure**
  - **Underground water**

Thank you!!!

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