River Water Management System and Supply Water Quality Monitor System

Hiroshi Tada
Tokio Ohto
Yoshiharu Tanaka

1. Introduction

Water supply systems are essential for the maintenance of health in our society. In Japan, two thirds of all water supply systems use lake and river water as their primary source. Therefore, the quality of source water significantly affects that of tap water. In recent years, public interest in the protection of the water environment has increased.

To cope with the above, Fuji Electric has lined up a variety of sensors and water quality monitor systems to examine the entire water environment. Among them, two systems introduced in this paper, river water management system and supply water quality monitor system.

2. Recent Change in Water Environment

Recently, the quality of river water in Japan has been substantially improved thanks to stricter effluent standards and such things as the widespread construction of sewerage. On the other hand, sudden water pollution has frequently been reported due to the effluence of oil and other harmful chemicals into rivers and the unlawful dumping of waste. These pollutants jeopardize the quality of urban life and the healthy functioning of the river ecosystem.

River water pollution is particularly a threat to cities whose water supply system intake point for water purification lies primarily in the lower reaches of a river.

Previous river water pollution reviews have stated that there has been a recent increase in the size of polluted areas and length of exposure of pollutants. It is difficult to say if adequate remediation measures have been taken in a timely fashion.

Because river water pollution may affect a larger area as time progresses, it is most important to detect the occurrence as early as possible.

By the end of fiscal 1996, 95.8% of all households were using waterworks. The doctrine of construction has changed from quantity to quality, or in other words, to the pursuit of "safe and good tasting water". Most notably is the comprehensive inspection of water quality from water source to spigot by water quality managers.

In response to the recent changes and needs of the water environment, Fuji Electric has developed, in the field of river management, a river water (quality) management system. Monitoring river conditions 24 hours a day, this system detects water pollution promptly and supports various countermeasures against pollution. This system enables river water pollution to be minimized.

In the field of tap water quality control, Fuji Electric has developed a multi-color recognition system, based on the recognition algorithm for service water hue as specified in the Standard Methods for the Examination of Water. Fuji Electric has also completed a supply water monitor system, which automatically inspects daily items, whereby coloration of supply water can be measured. This equipment enables water supply utilities to monitor the colored water on-line after renewing the aged pipes.

3. River Water Management System

In Fuji Electric's river water management system (Fig. 1) various management tasks (Fig. 2) are carried out to ensure the proper water quantity and quality. Maintenance of appropriate river water quality requires both sewerage construction and formation of a system responsive to sudden water pollution.

Figure 3 shows the tasks of the river water administrator in the event of water pollution and the support function of Fuji Electric's river water quality monitor system.

Explanation is given below for each task phase.

3.1 Detection of water pollution

Water pollution, (effluence of harmful substances from specific enterprises, run off of agricultural chemicals from fields, unlawful dumping of toxic substances, spills from overturned industrial shipping trucks near rivers, etc.), can occur suddenly and spread rapidly. Therefore, rivers must be monitored 24 hours a day in order to detect pollution as early as possible.

Fig.1 Configuration of river water management system

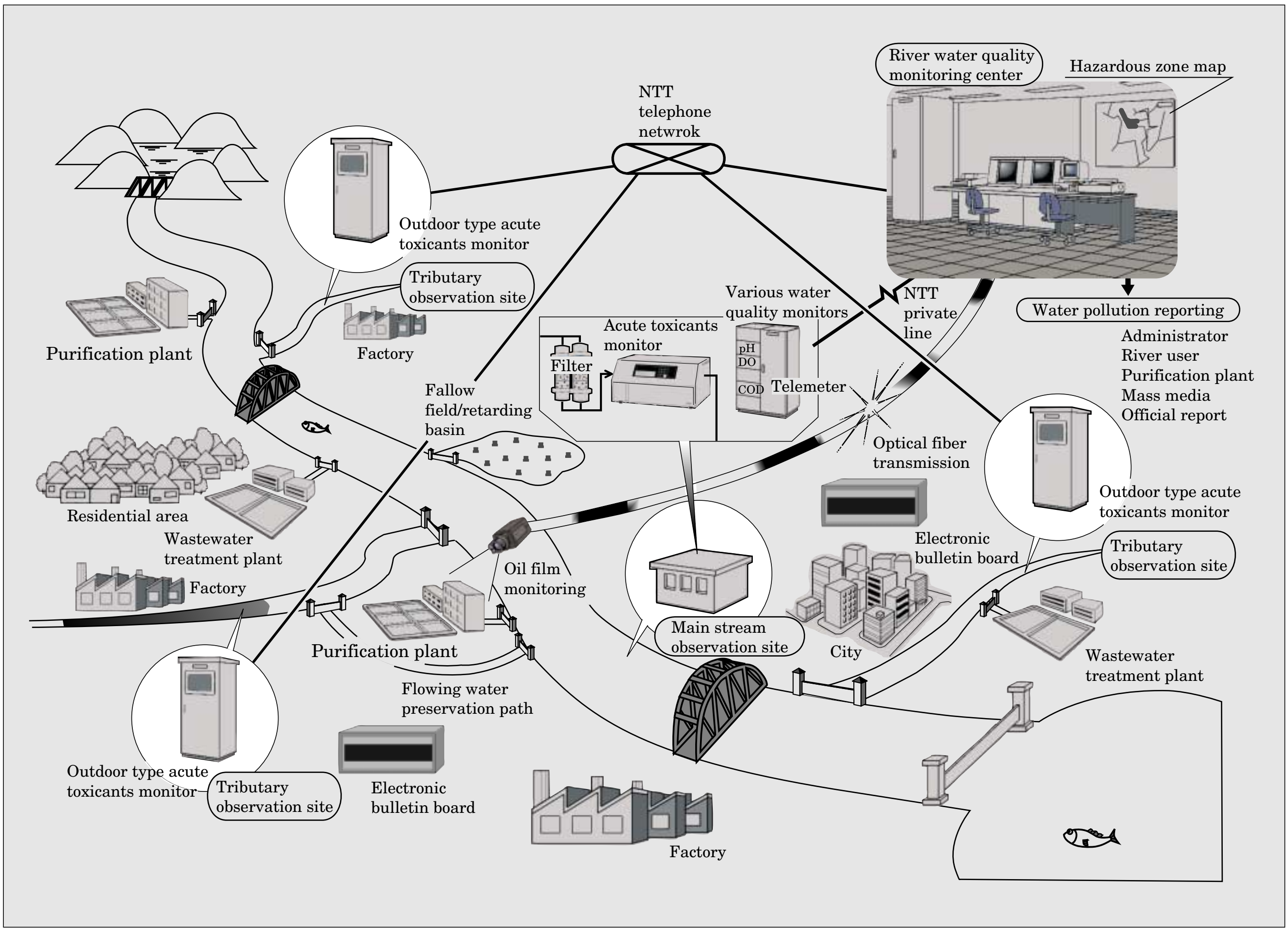
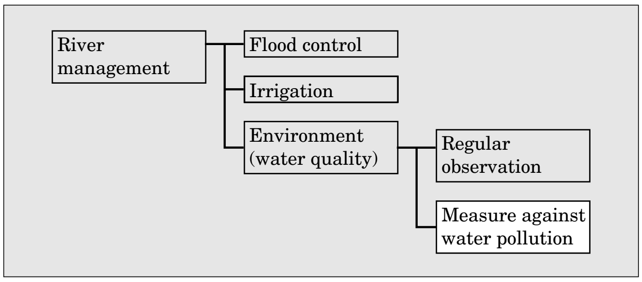


Fig.2 River management tasks



3.1.1 Oil detection

As oil flows down a river it disperses upon the surface of the water. Using an image analysis method, an infrared ray camera can observe slight changes in the refractive index of the water surface due to arrival of oil.

3.1.2 Acute toxicant monitor

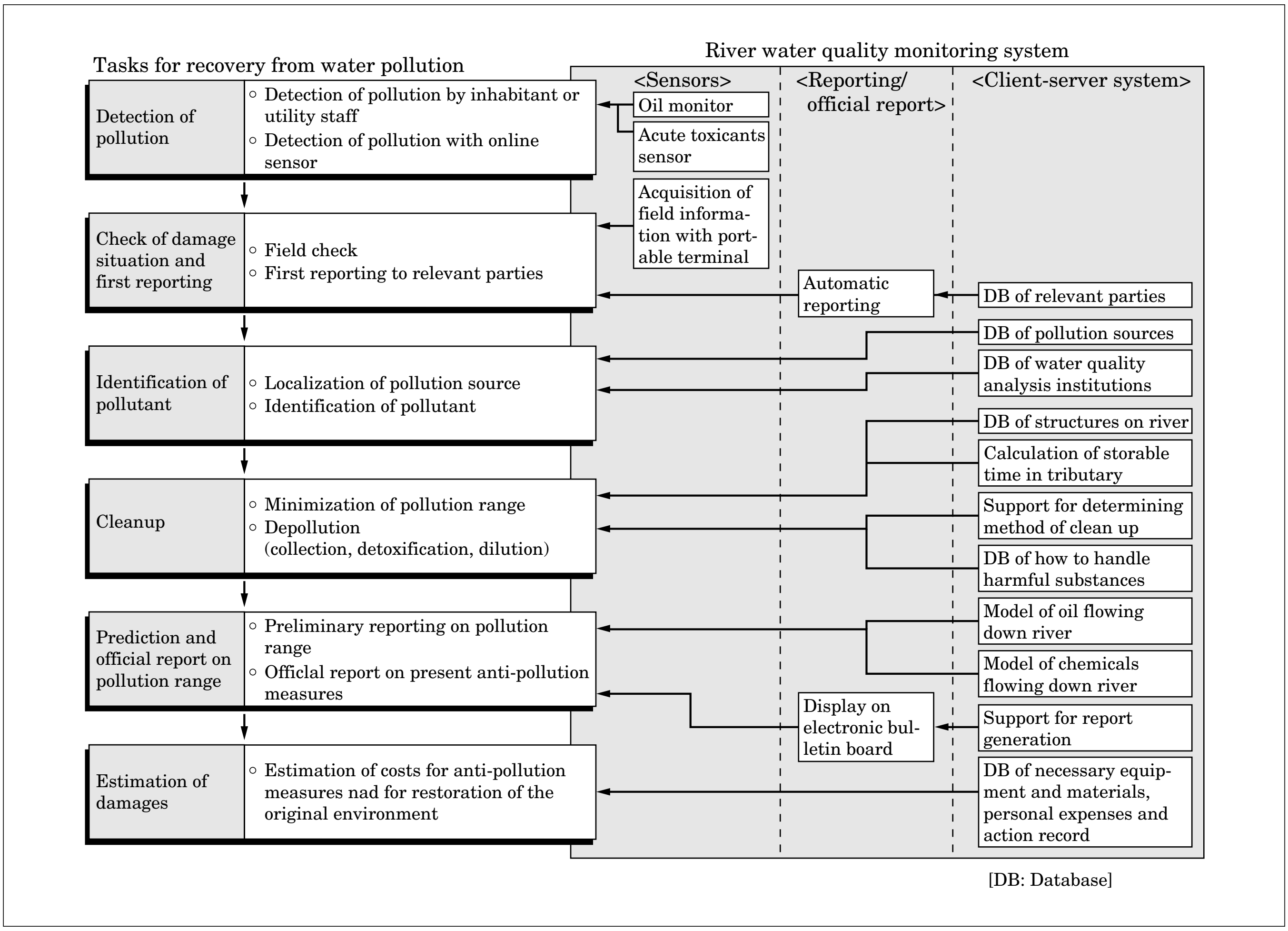
When the cause of water pollution is dissolved chemicals such as cyanide or phenol, it is difficult to defect the pollution early or before its effect appears. At present, the accepted method is to breed fish and continuously observe their behavior as they respond to the water environment. But this method has drawbacks such as lengthy breeding time, individual variation in resistance to toxicity and ambiguity in judgment of an abnormal state.

Fuji Electric has developed a biosensor, which detects toxicants using the activity of nitrifying bacteria. These microorganisms are a reliable index of pollutants because they are extremely sensitive to toxic substances. Acute toxicants such as cyanide, chlorinated organic compounds and agricultural chemicals are detectable with this type of sensor. Although toxicants cannot be identified, they can be screened. Detection sensitivity in terms of concentration is about 10 times as high as the fifty percent (median) lethal concentration for fish in 24 hours, and detection time is about 20 minutes. Details are listed in Table 1. Further, this sensor has a function for storing test water as soon as a harmful toxicant is detected. The stored water is usable for chemical identification of the toxicant by subsequent water quality analyses.

3.2 Check severity of damage and report to concerned parties

Once water pollution has occurred, it is important

Fig.3 Tasks for recovery from water pollution and methods of support by river water quality monitor system



to evaluate the severity of the damage closely at the site and report the results to an anti-pollution activity center. It is also necessary to share information with both the river water users and the party concerned with the cleanup. Because water pollution can occur at unknown locations, fixed-point observations alone are insufficient. A highly mobile information acquisition system is required.

3.2.1 Acquiring field damage information

Damage due to water pollution can have various effects, and there are cases where it is difficult to understand the situation exactly by the oral and written reports sent from the field. Due to the rapid growth of mobile computing technology in recent years, image information of pollution sites is now transferable to anti-pollution activity centers immediately by using a combination of digital cameras, portable information terminals and cellular phones. Moreover, when a portable map coordinate recognition unit, which utilizes a geo-stationary satellite, is added to the above combination, live image information and direct correspondence from the exact location can be established between multiple pollution sites and the anti-pollution activity center. This will facilitate all subsequent tasks for recovery from water pollution.

3.2.2 First reporting function

After checking the severity of damage at the site, it is necessary to arouse attention by issuing a preliminary report of pollution to all river users, including water supply utility companies, fishermen's cooperative associations, and river administration organizations such as the water pollution control liaison council. For this purpose, automatic reporting is made to all parties concerned by means of telephone, facsimile, electronic mail, etc.

3.3 Localization/identification of pollution source and pollutants

Because water pollution occurs suddenly, adequate preparations need to be made. Particularly at the early stage of water pollution, it is important to localize the pollution source and identify the pollutant, thereby preventing the pollution range from expanding.

3.3.1 Pollution source database (DB)

With regard to riverside enterprises dealing with harmful substances, this database contains the names of those substances, their possible destinations in the

Table 1 Chemicals detectable with acute toxicants monitor

No.	Item	Reference value	Detectable concentration	Toxicity to fish
1	General bacteria	100m/L or less		
2	Coliform group	Not detectable		
3	Cadmium	0.01mg/L or less		
4	Mercury	0.0005mg/L or less	———	0.1: "C", 0.2: "R"
5	Selenium	0.01mg/L or less		
6	Lead	0.05mg/L or less		
7	Arsenic	0.01mg/L or less		
8	Hexavalent chromium	0.05mg/L or less		
9	Cyanide	0.01mg/L or less	0.05	0.48 to 0.78: "C"
10	Nitrogen in nitric acid/nitrous acid	10mg/L or less		
11	Fluorine	0.8mg/L or less		
12	Carbon tetrachloride	0.002mg/L or less	20	
13	1,2-dichloroethane	0.004mg/L or less	60	430: "B" (96h)
14	1,1-dichloroethylene	0.02mg/L or less	30	74: "B" (96h)
15	Dichloromethane	0.02mg/L or less	30	
16	cis-1,2-dichloroethylene	0.04mg/L or less	15	140: "B" (96h)
17	Tetrachloroethylene	0.01mg/L or less	6	13: "B" (96h)
18	1,1,2-trichloroethane	0.006mg/L or less	10	
19	Trichloroethylene	0.03mg/L or less	9	45: "B" (96h)
20	Benzene	0.01mg/L or less	60	46: "G" (24h)
21	Chloroform	0.06mg/L or less		
22	Dibromochloromethane	0.1mg/L or less		
23	Bromodichloromethane	0.03mg/L or less		
24	Bromoform	0.09mg/L or less		
25	Total trihalomethanes	0.1mg/L or less		
26	1,3-dichloropropane (D-D)	0.002mg/L or less	4	
27	Simazine (CAT)	0.003mg/L or less	0.6	
28	Thiuram (thiram)	0.006mg/L or less	0.06	0.10: "C"
29	Thiobencarb (Benthiocarb)	0.02mg/L or less	80	1.6: "C"
Items related to properties which tap water should have : 17 items				
30	Zinc	1.0mg/L or less		
31	Iron	0.3mg/L or less		
32	Copper	1.0mg/L or less		
33	Sodium	200mg/L or less		
34	Manganese	0.05mg/L or less		
35	Chlorine ion	200mg/L or less		
36	Calcium, magnesium, etc. (hardness)	300mg/L or less		
37	Residue on evaporation	500mg/L or less		
38	Anion surface active agent	0. 2mg/L or less		18.7: "C", 3.7: "S"
39	1,1,1-trichloroethane	0.3mg/L or less	16	72: "B" (96h)
40	Phenols	0.005mg/L or less	0.7	24.7: "C" (24h)
41	Organic substance, etc. (potassium permanganate consumption)	10mg/L or less		
42	pH level	5.8 or more and 8.6 or less		
43	Taste	Not abnormal		
44	Odor	Not abnormal		
45	Chromaticity	Level 5 or less		
46	Turbidity	Level 2 or less		

(shaded) : Detectable item

< Note > Toxicity to fish is indicated in median lethal concentration (TLm). The alphabetic letter suffixed to each numeral abbreviates the name of the test sample fish shown below. The numeral in parentheses denotes an exposure time (h).
[Test sample fish] "C": Carp, "S": Sweetfish, "R": Rainbow trout, "G": Gold fish, "B": Bluegill
TLm stands for median tolerance limit.

event of pollution, responsible persons, etc.

3.3.2 Localization of pollution source

The pollution source database is correlated with the aforementioned field information (pollution site, severity of damage, etc.) to locate the pollution source.

3.3.3 Database of water quality analysis institutions

This database contains information such as a list of analyzable substances, the availability of nighttime and holiday analysis, addresses and telephone numbers.

3.4 Cleanup

Cleanup methods can be roughly classified into collection, detoxification by neutralization, and dilution. The optimum method varies with pollution site (tributary or main stream), scale of pollution, pollutant, etc. However, the basis of any cleanup procedure is to confine the range of pollution. When pollutants invade a tributary, it is imperative to restrict the range of pollution within the tributary. This will prevent the harmful substance from flowing into the main stream. Once a harmful substance reaches the main stream, it will be swept up by the stronger current and disperse over a wide range, making cleanup work very difficult.

Once pollutants have entered the main stream, area confinement through collection or neutralization of the pollutant is generally impossible. In this scenario the pollutant becomes diluted by the influx of water reserved in a dam or from other rivers in the same river system. In both cases, it is essential to know the proper procedure for handling harmful chemicals and to know the current inventory of cleanup equipment/materials.

3.4.1 Database on river structures

Information is stored about the locations of weir/gate installation, remote controllability and amount of time necessary for closing. In addition, an on-river structure capable of blocking the flow of a pollutant is selected at a downstream point closest to the pollution site.

3.4.2 Calculation of storable time in tributary

The amount of time water can be stored in the tributary area is calculated through correlating the water level at the occurrence of pollution, Q-H characteristics and information about the flow blocking point.

3.4.3 Estimation of cleanup time

Cleanup time is estimated depending on the severity of pollution and the equipment/materials to be used.

3.4.4 Equipment and material storage database

This database stores information on the performance, application, storage location and storage quantity for all equipment and materials used during cleanup. This helps locate the necessary materials in the shortest time possible.

3.4.5 Support for decision making on cleanup method

Choices of possible cleanup methods are presented and given a preferential order through a combination of the aforementioned measures, thereby supporting determination of a cleanup plan.

3.4.6 Harmful substance database

Special knowledge required for cleanup is easily accessible. Using a desired keyword one can access information about various harmful substances. This system can automatically convert image data to text, and is able to retrieve data after reading sources such as technical literature and books with an image scanner. Therefore, a rich database can be configured with less time spent on data entry.

3.5 Prediction and official report on pollution range

In the instance of a large-scale water pollution event, it may be a necessary to stop water intake at a purification plant, in addition to immediately reporting to inhabitants, river water users, water supply utilities and the mass media. In such cases, it is necessary to not only enact all possible de-polluting measures and report the current damage situation, but also to predict an expansion of the polluted area. This may enable water users to prepare for an unexpected situation before the pollution reaches their territories. The river administrator must officially report the progress of countermeasures against the pollution to all parties concerned and obtain their consent.

3.5.1 Predictive calculation of damage range due to oil

Dispersion of oil is comparatively easy to estimate. Therefore, the down-flow of oil can be predicted by cumulatively adding the river flow velocity at each point on the river to the rate of oil dispersion. When we correct this predicted result by the actual measurement obtained by the oil sensors within the water quality observatory stations installed at each point on the river, the range of damage can be confidently predicted and the effects of disturbance factors such as wind and sea level are minimized. The predicted range of damage can be accessed simply by an online-display superimposed on the water system map at the anti-pollution activity center, thus enabling the center to take preliminary measures.

3.5.2 Predictive calculation of damage range due to chemicals

Dispersion of the dissolved chemicals can be estimated. The online display of the predicted damage due to the relevant chemical can be calculated by correcting the estimated dispersion according to the river flow velocity by the actual measured data as in the above calculation for oil.

3.5.3 Official report

The specific countermeasures undertaken must be officially reported to all parties concerned. The mass media is entitled to press conferences on the countermeasures currently taken against pollution using either CRTs or large-size television displays, which are located at the anti-pollution activity center. Municipalities and inhabitants are able to access information on electronic bulletin boards installed at city halls. The river administrator especially must urge inhabitants to recognize that he/she is responsible for implementing the countermeasures against water pollution. This is required for the following reason. Usually inhabitants report water pollution sightings to the police or a fire station. A report to the river administrator, the organizer of the cleanup, is a rare case. Hence, there are many cases when critical time is lost.

3.6 Estimation of damages

Article 67 of the River Act stipulates the principle that it is responsibility of the party, which caused the water pollution accident to bear the expenditure of the countermeasures taken.

In this regard, the river water management system offers the following support function.

In the pollution damage estimation database, the rate of each expenditure item, such as equipment/materials used or personnel expense, is determined for each step in the cleanup procedure (i.e. countermeasure against pollution and restoration of water environment). Rates, which are specifically due to the occurrence of pollution, are then multiplied by the number of actions taken by the staff and entrusted party to estimate the total damage to be claimed.

4. Supply Water Quality Monitor System

In this new age of water quality, the role of the tap water supply has evolved from providing simple volumetric assurance to ensuring "safe and good tasting". On the other hand, this new age is responsible for negative factors affecting water quality, such as the aforementioned degradation of the entire water environment and the sudden pollution of rivers, which serve as tap water sources. In light of these negative factors, more attention is being drawn towards management of water supply systems and their ability to ensure emergent water supply and prompt restoration of disasters.

To cope with this, it is imperative to establish a general automatic water quality monitoring system that can oversee a wide range of processes. This system must not only inspect the water purification process but must overlook every step from the outlet of purification plants to the water supply terminals. In response to these needs, a variety of automatic water quality monitoring systems with a wide range of applications has been developed. One example, required by the Waterworks Law, is the fully automated, daily inspection (of color, turbidity, residual chlorine concentration) at the water tap.

Fuji Electric has proposed "hue" and "coloration grade" as new indexes which quantitatively describe the appearance of water, and has developed a device, (the "color-turbidity sensor") which can automatically measure both these new indexes and the preceding indexes, chromaticity and turbidity respectively. "Hue" indicates the color of the water and "coloration grade" represents the degree of water coloration. For instance, a yellowish hue suggests coloration due to an organic substance and a reddish hue may be attributable to inflow of iron rust. According to the coloration grade, the level of abnormality can be surmised.

4.1 Principle of coloration grade and hue measurement

Figure 4 shows the configuration of this sensor. The while light from the light source is dispersed with the above-mentioned optical color filters of three primary colors to obtained red, green and blue spectral-sensitivity lights. These lights are radiated to water samples to measure their respective transmittance values. The resulting hue of the water sample is judged to be any of five bands; colorless, white/black, yellow, red and other. This color judgment method, known as the CIE 1931 standard colorimetric system by the Commission Internationale de I'Eclairage, was introduced as an effective tristimulus filter method for measuring coloration of tap water in the Standard Methods for the Examination of Water (explanatory edition).

Next, the newly defined "coloration grade" is described. First, luminance is introduced as the z axis into an xy coordinate scheme that defines the hue and purity of color in a three-dimensional color space (Fig.

Fig.4 Configuration of color-turbidity sensor

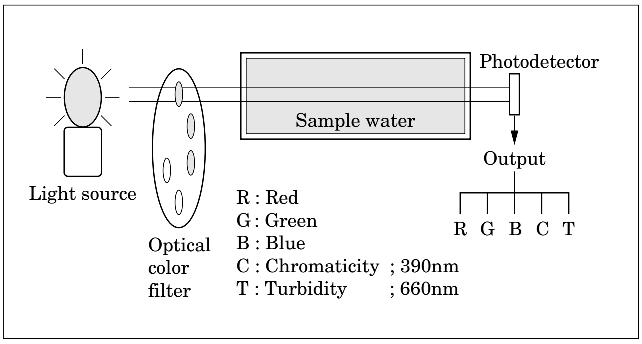


Fig.5 Principle of coloration grade and hue measurement

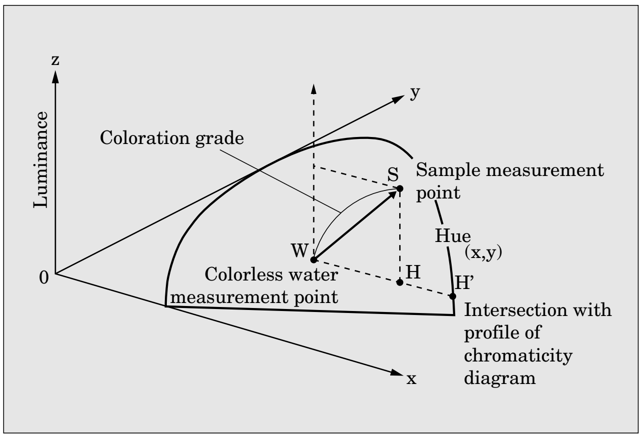


Fig.6 Configuration of the monitor system

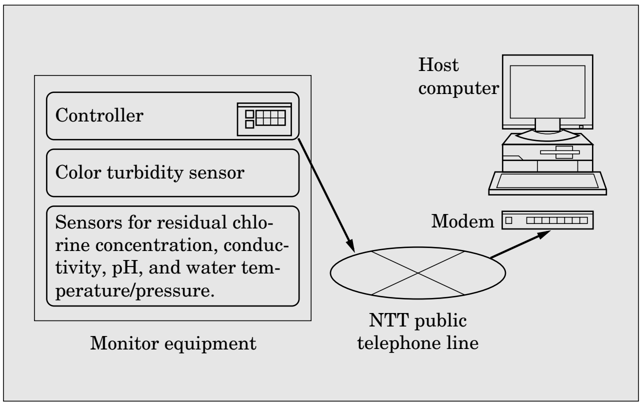
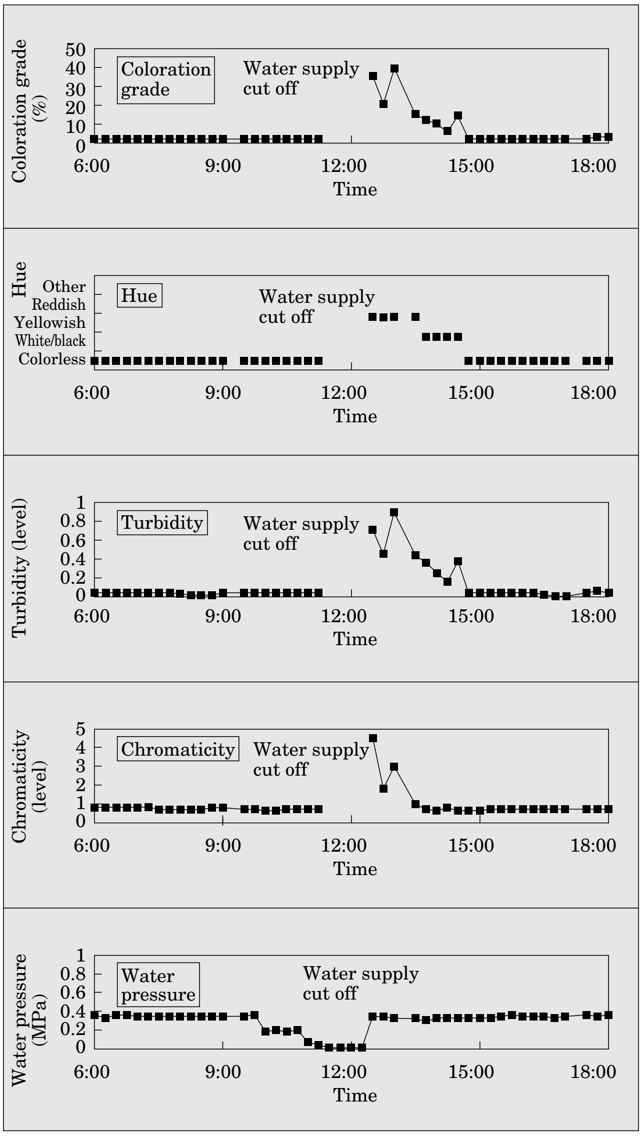


Fig.7 Situation of field test in city A



5). Next, a colorless water measurement point is replaced with W and a sample water measurement point is replaced with S. S's projection onto the xy plane is point H and the intersection of the line extended from W through H with the profile of chromaticity diagram is H'. The coloration grade can be expressed by the vector, which connects W and S. The range of coloration grade measurements is set 10 times higher than the visual threshold (roughly corresponding to chromaticity 5).

4.2 Configuration of monitor system

The configuration of this monitor system is illustrated in Fig. 6. The monitor equipment examines each sensor for residual chlorine concentration, electrical conductivity, pH, water temperature and water pressure in addition to the aforementioned color-turbidity sensor. The measured data is transmitted to the host computer via an NTT (Nippon Telegraph and Telephone Corp.) public telephone line.

4.3 Example of field test

Below is an example field test where the monitor equipment was set up at the water tap in city A and the host computer was installed at Fuji Electric Corporate Research and Development, Ltd. to measure coloration grade, hue, turbidity, chromaticity, etc (GL), 24 hours a day.

Figure 7 shows data of water quality through a water tap in city A, which was observed with the monitor equipment at the time of water interruption. The interruption lasted from 11:30 to 12:45. From 13:00, shortly after recovery from the interruption, levels of coloration grade, chromaticity and turbidity rose and the hue turned yellowish. Then at 14:30, chromaticity returned to normal levels. At the same time, hue turned white/black. Later, at 15:45, coloration grade and turbidity returned to normal levels, and hue turned colorless.

From the above data, the following assumptions can be made. Yellowish water containing suspended matter flowed in from 13:00 to 14:30. Then only suspended matter continued flowing in until 15:45. This assumption is reasonable, because the suspended matter, which repeatedly rises and settles, remains in pipes longer than dissolved substances, which determine chromaticity.

4.4 Usefulness of coloration grade and hue measurement in the supply water quality monitor system

The color-turbidity sensor allows for simultaneous multi-measurement of hue, such as the red color of iron rust (typical coloration of tap water), the black color due to manganese, the yellow color derived from dissolved organic substances, the white color due to bubbling or mixing of zinc, etc. This measurement is more useful for water quality control than the conventional chromaticity measurement, which detects only the presence of a yellowish brown color. Clearly, this measurement is extremely useful for both checking the deterioration of water pipes and tracing the behavior of water each minute after recovery from a water interruption event, such as an earthquake or water leakage correction, to name a few.

5. Conclusion

The river water management system and supply water quality monitor system have been introduced above. These systems contribute to the protection of the environment, which is one area drawing great attention in the field of river management. In addition, both systems provide fully automated, daily water supply inspection by water supply utilities. These systems respond to a wide range of changing water conditions, providing general maintenance of water quality from water source to tap water supply. Finally, the authors would like to express their gratitude to the river management authorities and the Japan Water Works Association for their guidance and recent advancements in the field of water quality control.