JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 9 2001

CONCEPTUAL MODELING FOR MANAGEMENT OF THE CITARUM/CILIWUNG BASINS, INDONESIA

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Problems relating to the unsatisfactory state of water supply and quality within the Citarum/Ciliwung catchment that feeds directly to the city of Jakarta are reported. The various complex mechanisms of waterways are analyzed, along with the dispersion processes that affect pollutant discharges, with emphasis on iron and manganese. The analysis is carried out by developing a conceptual model for the watershed, upstream of the intake at Buaran Water Treatment Plant that feeds the eastern part of Jakarta. Within the conceptual model, a deterministic (numerical) model for simulating the hydraulic and dispersion components within the Citarum catchment that feeds the treatment works through the West Tarum Canal will be developed. The use of the model should, in the long run, provide a valuable tool for testing different cost-effective water supply management strategies.

INTRODUCTION

In developing countries, the supply of clean water is still a major problem. In Jakarta, Indonesia, clean water supply is one of the major problems experienced on a daily basis as a result of severe shortages in efficient management and appropriate technology. Currently, PAM (Perusahaan Air Minum) Jaya (Jakarta's Drinking Water Company) has a production rate of 1.7 million m^3/day of a low quality (e.g. turbidity, odor, color) water supply. With this rate, it is estimated that only 40 percent of water demand in Jakarta can be supplied. To compensate for the lack of sufficient technical and financial resources, reputable water companies from Europe, namely UK Thames Water International and the French Lyonnaise, were invited to help in setting an efficient and reliable code of practice in the water industry. As such, two joint venture companies, the Thames PAM Jaya (TPJ) and PAM Lyonnaise Jaya (PLJ), were officially launched in 1998. The Thames PAM Jaya (TPJ) is a joint venture, in which Thames Water plc is the major shareholder, serving around 4 million people in the eastern part of the province of Jakarta. In order to expand its activities, TPJ needs to invest in its distribution network systems and attracting more customers; it is inevitable that TPJ be able to supply clean water to the various sectors of the city of Jakarta.

Thames Pam Jaya has carried out several investigations in order to identify the main problems associated with supplying water to Jakarta. By looking at the complexity of the problems, TPJ developed a strong network by establishing collaboration links with local authorities, ministries, universities and other water companies in Jakarta. One of the main advantages of this initiative is a strong five-year collaborative program with the University of Indonesia (UI), jointly with University of Surrey (UniS) in England, UK. The aim of this collaboration is to enhance the understanding of the complex issues associated with catchment management planning and protection of water sources. In addition, the program aims at providing expert, up-to-date knowledge in environmental and water engineering management to potential candidates from local government bodies as well as from academia.

In recent meetings, which involve the stakeholders of water management in greater Jakarta, there has been considerable concern regarding the problems associated with the discoloration of the clean water supplying customers in East Jakarta. Preliminary investigations have revealed that the main source of the problem is related to a high content of manganese and iron in water at the intake of the treatment plant. This obviously poses a great obstacle in realizing the drinking water standards set by PAM Jaya. Excess manganese in water causes stains to sanitary ware and laundry, as well as an undesirable taste in beverages. Iron concentration in water above 0.3 mg/l stains laundry and plumbing fixtures, but there is usually no noticeable taste in water for concentrations below 0.3 mg/l, although turbidity and color may develop (WHO, 1996). The neurological effects of inhaled manganese have been well documented in humans chronically exposed to high levels in the workplace (WHO, 1996). In contrast, the oral route often regards manganese as one of the least toxic elements, although there is some controversy as to whether the neurological effects observed with inhalation exposures also occur with oral ingestion. The literature lacks detailed studies on the effects of manganese in drinking water.

Similar to an excess level of manganese, there is no health-based threshold concerning the level of iron in drinking water. The guideline for both iron and manganese is based on taste and odor that result from high concentration levels. As such, it is important to minimize the level of excessive iron and manganese in order to avoid possible long-term health hazards (WHO, 1996). In addition, taste and odor in water will result in negative public perception regarding use of surface water for drinking purposes. This would eventually cause the population to switch to groundwater for drinking purposes, which may, in the long run, result in an imbalance in groundwater storage, and water resource problems in the catchment.

This study aims at highlighting the problems relating to the poor state of water supply and quality within the Citarum/Ciliwung catchment, that feeds directly to the city of Jakarta. Furthermore, the paper addresses the various complex mechanisms of water motion and possible pathways of chemical dispersion processes (with emphasis on iron and manganese) within the catchment. This is carried out by developing a conceptual model for the watershed, upstream of the intake at the Buaran Water Treatment Plant. This treatment plant represents TPJ's largest plant with a production rate of 5 m^3/s. In order to accomplish this aim, a deterministic model capable of simulating the complex processes of hydraulic and dispersion properties in the Citarum catchment that feeds the Buaran WTP, Jakarta through West Tarum Canal will be developed. The detailed formulation of the model, its numerical procedure and application to this case study is beyond the scope of this paper. Such information will be reported in due course. The implementation of the model should, in the long run, provide a valuable tool for testing the appropriateness of adopting different management strategies for cost-effective solutions.

GENERAL BACKGROUND OF THE JABOTABEK AND CITARUM/CILIWUNG BASINS

Jakarta is the capital of the Republic of Indonesia, located on the coast at the North of Java Island which is bordered by Java Sea in the North and West Java Province in the South (Kabupaten Bogor), West (Kabupaten Tangerang), and in the East (Kabupaten Bekasi). The province of Jakarta (DKI Jakarta) is geographically located in area of latitude 6°00'-6°20' S and longitude 106°42'-107°00' E (see Figure 1). The city is divided into five municipalities or wilayah. These municipalities are Central, North, South, West, and East, each of which is divided into administrative districts known as kecamatan.

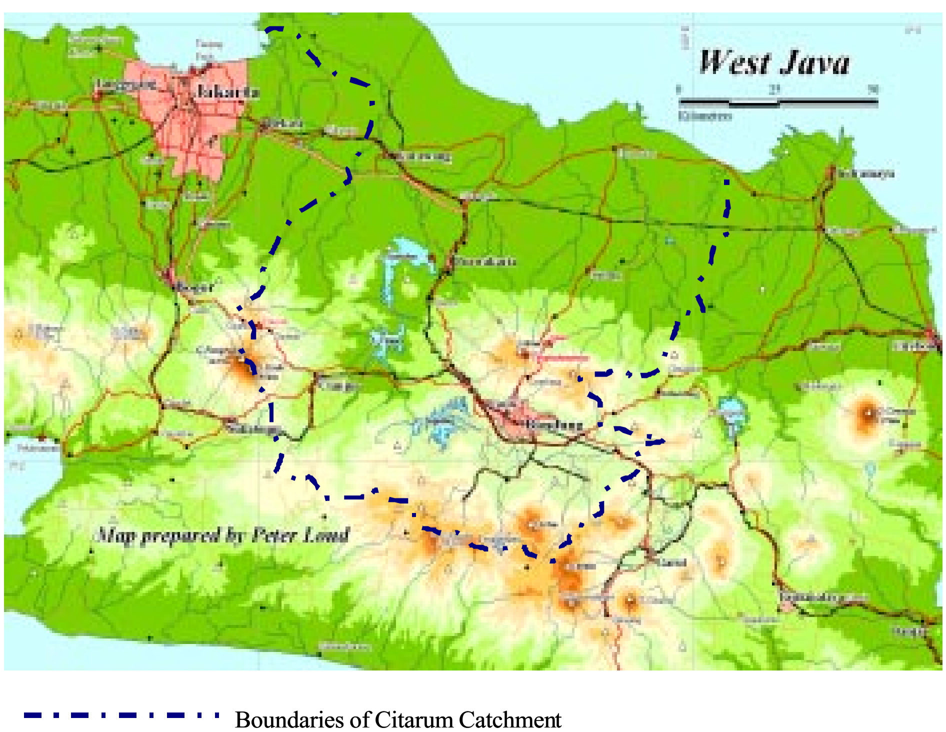

Figure 1. Map of West Java and Jakarta (Source: http://users.powernet.co.ukmkmarina).

The province of Jakarta and its surroundings are known as Jabotabek, which comprise Jakarta, Bogor, Tangerang and Bekasi. The Jabotabek catchment covers an area of approximately 7,200 km^2, of which Jakarta covers about 652 km^2. The population of Jakarta, which was about 800,000 just before 1945, the year of independence, has now increased to about 8.2 million according to the 1990 national census. The 1990's population of Botabek (Bogor, Tangerang, and Bekasi) was about 8.78 million, making a total of 17 million for Jabotabek. The annual increase of population over the 1980 - 1990 period has been 2.41 percent. According to the 1999 Directorate of Environmental Geology, the population of Jakarta is predicted to be 12 million, with that of Jabotabek reaching 23.4 million by the year 2005. It is estimated that over 75 percent of the population occupies urban areas. Jakarta and its surroundings have a humid tropical climate that is very much influenced by the Monsoon winds. The Monsoon season, being driven by the continental effect of Australia and Asia, splits the year into two main seasonal weather patterns: a wet season (the East-Monsoon) and a dry season (the West-Monsoon). Long-term mean monthly temperature is between 26^{o}C and 28^{o}C, and mean annual is 27^{o}C.

The main sources of water in Jakarta are groundwater and surface water sources. The groundwater abstracted from shallow and deep wells is normally used for human consumption without any treatment. The surface water is, however, treated and supplied by PAM (Perusahaan Air Minum) Jaya (Jakarta's Drinking Water Company), as the principal company for potable water supply. PAM Jaya relies heavily on surface water intake from two river basins, the Citarum and Ciliwung basins which are linked through the West Tarum Canal, as shown in Figure 2.

CHARACTERISTICS OF THE CITARUM/CILIWUNG/WEST TARUM CANAL ARRANGEMENT

Many investigations have been carried out on the Citarum catchment (Sriwana et al., 1997, Jatiluhur water resources management – Ministry of Public Works, 1998). Nevertheless, many studies are still needed to address the problems and options for managing the Citarum in a sustainable

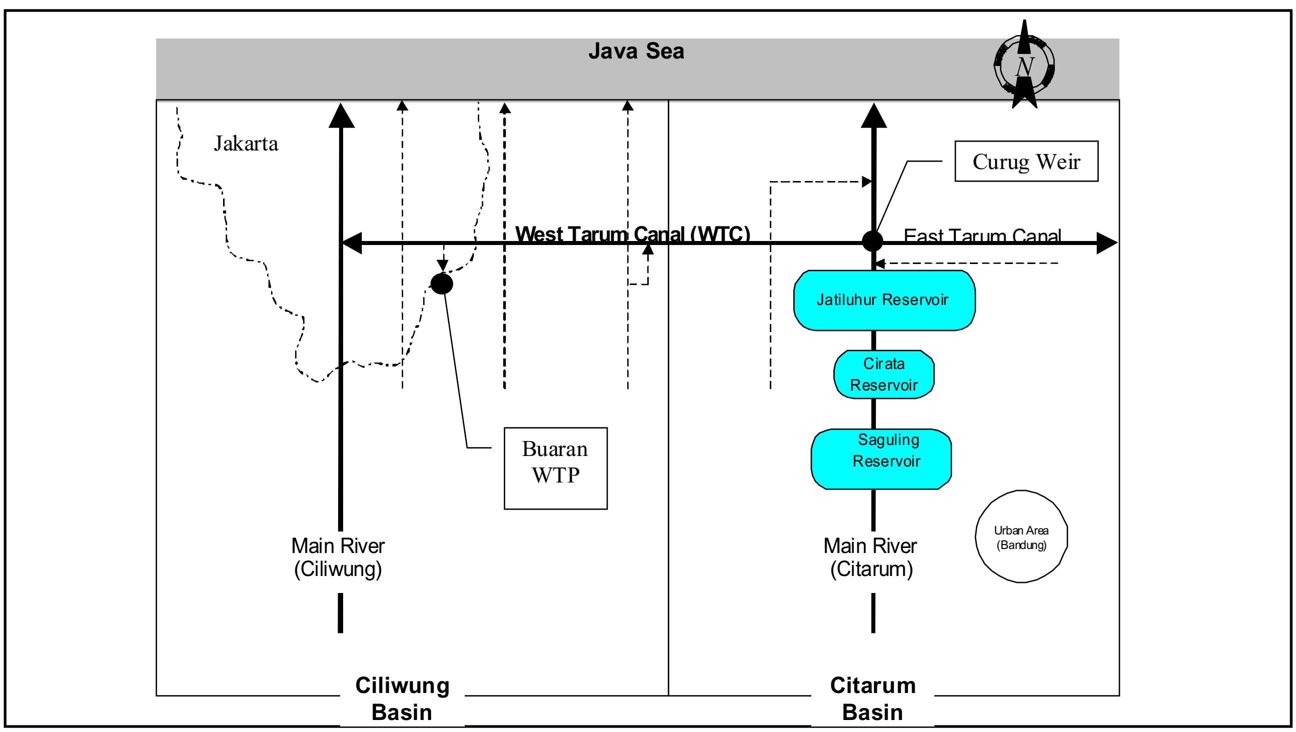

Figure 2. Schematic layout of the Citarum and Ciliwung basins.

fashion. In particular, the application of an holistic (integrated) catchment management approach with its complex related issues (science/ social/ engineering) are still lacking. Sustainable development of the catchment and conservation (or preservation) of water resources against extreme vulnerable situations and risk management should be central to the successful agenda of catchment management (Clarke, 1994). It is recognized that holism is the key element in managing such a complex catchment effectively. However, this is not a straightforward process, particularly for this complex Citarum/ Ciliwung/Tarum Canal arrangement. The proposed integrated management approach has to evolve a set of processes and principles acceptable to stakeholders (i.e. all those with legitimate interest in the outcome) by which policy, strategy, and activities in general can be reviewed (Gardiner, 1994).

For the purpose of managing the water supply to Jakarta effectively, the city is fed from two main rivers, the Citarum River and the Ciliwung River. The water flowing through the Citarum River passes through a system of three reservoirs, the largest of which is known by the Jatiluhur Reservoir. This reservoir feeds in turn the West Tarum Canal that supplies the western part of the western side of Jakarta (seeFigure 2). For the eastern side of Jakarta, water is supplied directly from the Ciliwung River and its tributaries.

Problems with Raw Water Supply

Figure 3 shows the arrangement of the West Tarum Canal between the Ciliwung and Citarum basins. As can be seen, the most important rivers are the Citarum, Ciliwung, Cibeet, Cikarang, Bekasi, and Cisadane rivers. The Jatiluhur Reservoir is one of three reservoirs located in the Citarum basin. It has a capacity of 0.9 x 10^{12} m^3 and a surface area of about 83 x 10^9 m^2. The other two reservoirs are the Saguling and Cirata Reservoirs. The Saguling Reservoir has a capacity of 2.75x10^9 m^3 with a surface area of 53.4 x10^6 m^2. With the exception of Jakarta, the Citarum basin has always been the most populated catchment in West Java. This obviously indicates that this catchment produces large quantities of waste (and hence pollution) as a consequence of the high degree of human activities (agricultural, domestic but mainly industrial). The industrial activities include textiles, clothing and footwear, particularly in the City of Bandung. To a lesser extent, activities such as electronics, aviation, extractive and building industries also contribute to the level of pollution. As a result, the quality of water in the Saguling Reservoir is extremely deteriorated. Furthermore, it was noted that most local companies tend to discharge their effluent directly to Citarum River (or to its tributaries) without any kind of treatment. This highlights the need for strict enforcement of water acts and regulations as set by local governments within the catchment, and imposes procedures for compliance by companies.

The West Tarum Canal itself is a 70 km man-made canal that was originally designed for irrigation and water supply purposes for the city of Jakarta and its surroundings. The Canal supplies raw water to both PAM Jakarta (16.1 m^3/s) and to PAM Bekasi (0.133 m^3/s) in addition to about 57,600 hectares of irrigation area at Kabupaten Kerawang and Bekasi. It is estimated that the West Tarum Canal supplies approximately 80 percent of Jakarta's raw water. The main source of water in the canal is the Jatiluhur Reservoir, which receives, in turn, its water from the Citarum River. The Citarum River has an annual average flow of 180 m^3/s, with dry season flow averages of 64 m^3/s. Three main rivers intersect with the West Tarum Canal; these are the Cibeet, Cikarang and Bekasi Rivers (Figure 3). These rivers contribute about 51.5 percent of the water budget in the West Taum Canal. In addition, water quality sampling stations are placed along the Canal, for monitoring its state regularly.

The upstream intake of the West Tarum Canal is the Curug weir, located at the intersection with the Citarum River (Figure 3). The flow rate in the West Tarum Canal reduces from about 80 m^3/s

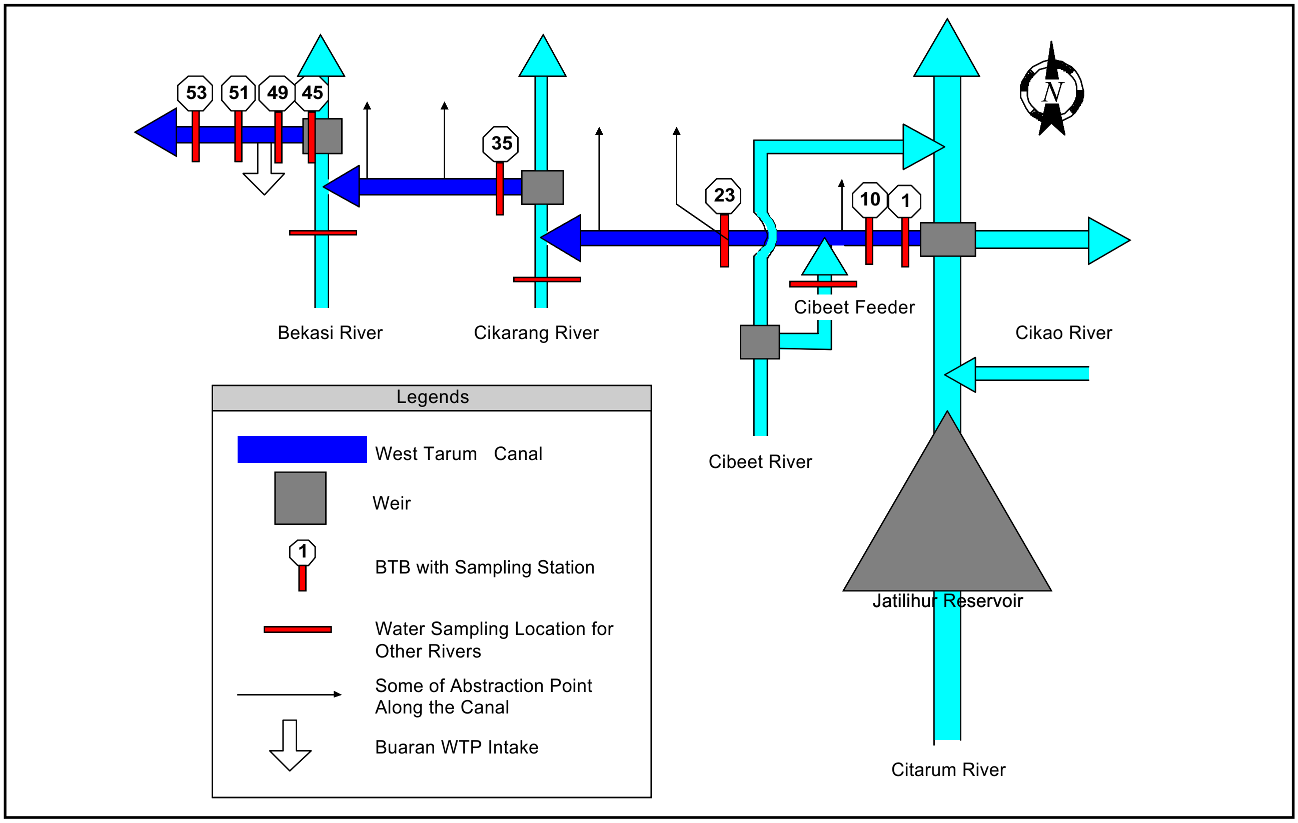

Figure 3. Schematic presentation of the West Tarum Canal arrangement.

at the intake (Curug weir) to about 21 m^3/s at the intake of the Buaran WTP at the eastern side of Jakarta. The flow is further reduced to 10 m^3/s at Cawang, where it feeds back into the Ciliwung River. Because of the changeable Monsoon weather patterns, the mixing of the Tarum Canal waters with the three bypass rivers induces high levels of turbidity due to mixing in addition to making the water supply to Jakarta become vulnerable and unreliable. As a consequence, deterioration of the water quality always exists along the Tarum Canal from point and diffused pollution sources, in addition to high build up of sediment, and sometimes blockages, at the junctions with crossing rivers. In order to ensure a constant supply of water from the West Tarum Canal, several weirs along the course of the Canal has been constructed, known as Bendung Tarum Barat (BTB). A total of 53 BTB weirs have been constructed (see Figure 3). One weir was built at the feeder from Cibeet River and the other two weirs were located at the junction with the Bekasi Cikarang Rivers. In addition, there are 144 control structures across the West Tarum Canal (e.g. tunnels, siphons and aqueducts). Most of these are placed at the several intakes of PAM Jakarta and related industries.

Problems with Water Quality in West Tarum Canal

Large catchment size, high population and intensive agricultural and industrial activities coupled with lack of proper regulation and law enforcement highlight the complexity associated with supplying raw water of reasonable quality and suitable for treatment in the Buaran Treatment Works, located southeast of Jakarta. Raw water of reasonable quality has therefore become a very difficult commodity to find since the drainage area within the West Tarum Canal suffers from water quality degradation caused by untreated wastewater discharges. Furthermore, the quality of water supplying the Canal (i.e. from Cibeet, Cikarang, and Bekasi) has systematically deteriorated for the past few years. This has resulted in restricting the use of the canal's water for treatment during severe dry periods of the year. One of crucial problems in Jakarta's water supply system is the discoloration of water. Identifying possible sources of discoloration of water in the distribution system has been investigated, such as high iron and manganese content, treatment processes, state of pipe network, corrosion of iron mains, etc. The high level of turbidity in the West Tarum Canal is considered to be one of the key problems identified at the Buaran Treatment Works in realizing acceptable water treatment standards. Figure 4 shows the recorded turbidity in the West Tarum Canal (WTC) and the crossing rivers during the period 1994-1999, as recorded by the Ministry of Public Works and the Buaran Treatment Works.

According to the guidelines of 1984 World Health Organization (WHO) drinking water standards, the maximum turbidity level for drinking water is 1.0 NTU. With levels of turbidity as high as 1500 NTU (downstream WTC), it would be difficult to meet the WHO limit. With three main rivers crossing the Tarum Canal along its course, each of which increases the turbidity in the river water, it is virtually impossible. Despite the fact that the turbidity levels of the rivers intersecting the WTC are high, it can be seen that the turbidity levels upstream and downstream of WTC are similar (Figure 4). This may be the result of suspended solids being trapped at the sampling station located at the (BTB) weirs along the Canal (Figure 3). It is also possible that suspended sediments have been generated during water abstraction for irrigation.

An additional factor that may be responsible for the discoloration of water is the high loading levels of iron and manganese at the intake of Buaran Treatment Works. On exposure to oxygen, manganese and iron form insoluble oxides that may result in undesirable deposits and coloring problems in the distribution network systems. Many studies have been carried out to determine the potential source of pollution in water, particularly on iron and manganese. Geological processes, including volcanic action, related hydrothermal activity and changeable weather conditions can lead to variations of iron (Duke, 1996).

Recent research studies in Owerri City, Nigeria, (Ibe, 1999) have revealed that anthropogenic pollution in its central part and industrial area occurs in shallow unconfined and deeper confined aquifers. In the same time, the study has shown almost no pollution effects on surface water. Another study carried out in urban areas has revealed large amount of heavy metals in runoff water, as a result of heavy traffic, vehicle exhaust, abrasion from tires and paved surface, corrosion of vehicles, or

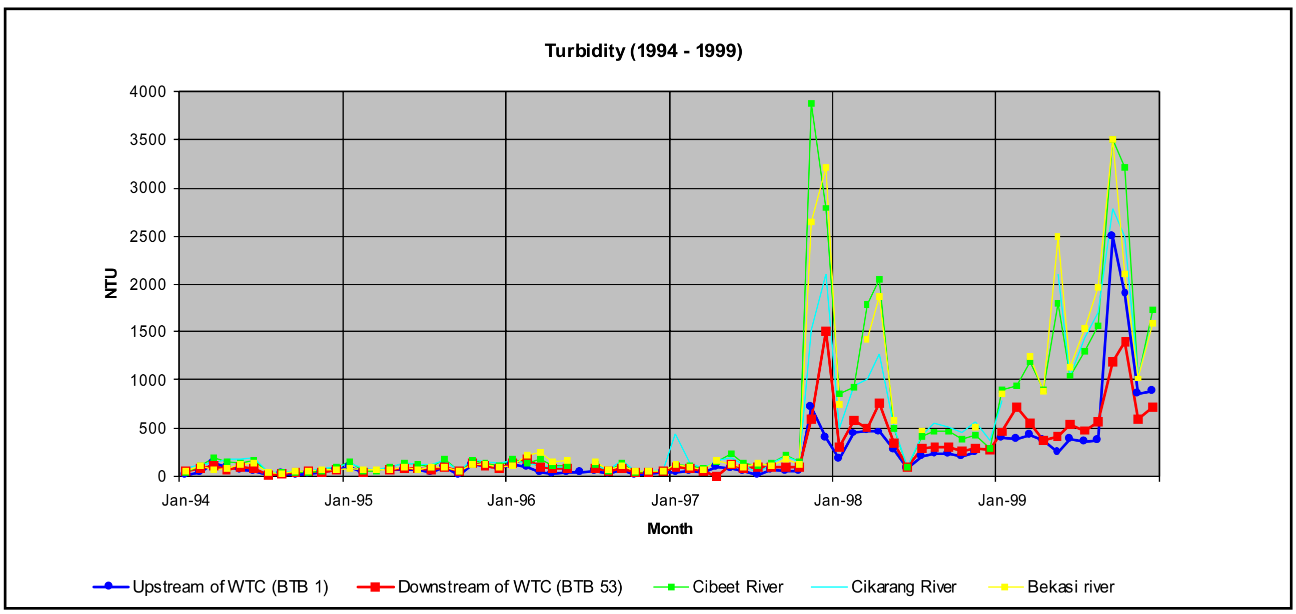

Figure 4. Turbidity levels at West Tarum Canal and crossing rivers during the period 1994-1999.

corrosion of roofing materials (Legret et al., 1999). It can therefore be concluded that local activities determine largely the most probable pollution sources. Industrialization and urbanization, together with intensified agricultural activities, have led to increasing demands for water and at the same time, have become the main source for large-scale release of contaminants (Holt, 2000).

Preliminary investigations on iron and manganese dispersion in reservoirs have shown that water quality during heavy rainfall can deteriorate significantly. With the use of artificial mixing in the reservoir, marked improvement in the water quality state can be observed, which consequently reduces the soluble levels in water (Zaw et al., 1998). Therefore, the potential sources and effects of iron and manganese in the catchment can be generated from one or more of the following; (i) underlying geology, (ii) industrial disposal, (iii) agriculture practices, and (iv) water quality management in reservoirs.

It has been recognized for some time that high concentrations of manganese and iron are found in the raw water supplied for treatment. The manganese concentration ranges from 0.3–1.9 mg/l, with peak levels > 2mg/l, and the iron concentration ranges from 3.2–19.4 mg/l, with peak levels > 30 mg/l. After treatment, water often has a high concentration of manganese ranging from 0.08–0.24 mg/l. These levels are much higher than the treatment target of 0.1 mg/l, as set by 1984 WHO guidelines. Similarly, the mean monthly iron concentration in treated water ranged from 0.03–0.16 mg/l, with maximum concentration of about 0.72 mg/l.

Figure 5 shows the average monthly concentration levels of iron and manganese during the period January 1994 – December 1999, as reported by the Ministry of Public Works. As can be seen in the figure, the concentration levels downstream of WTC range from 0.007– 0.680 mg/l for manganese and 0.015–0.625 mg/l for iron. The fluctuations of the profiles inFigure 5 may be related to the water sampling procedure. Preliminary visual inspection of the profiles has however confirmed the presence of high concentrations of iron and manganese. It should be mentioned, however, that because of the uncertainty involving in the sampling procedure used in field measurements, definite conclusions could not be reached. A rigorous and continuous monitoring program for devising a

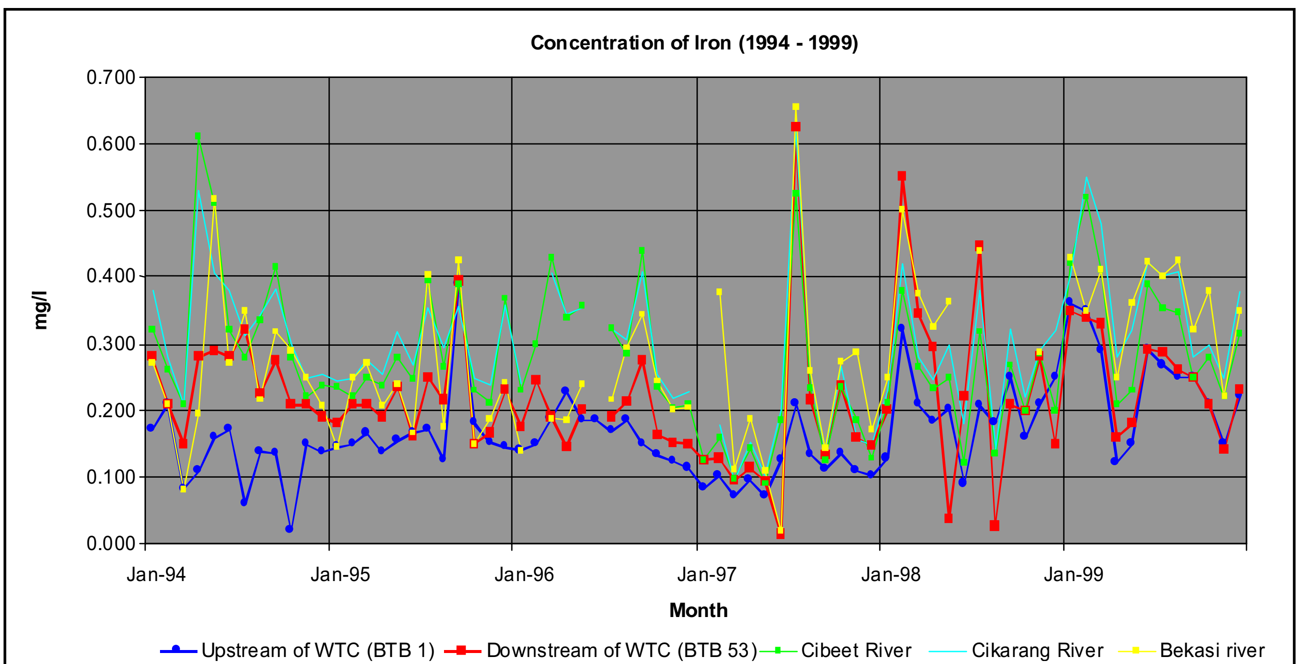

Figure 5a. Mean monthly concentration of iron levels during the period 1994-1999.

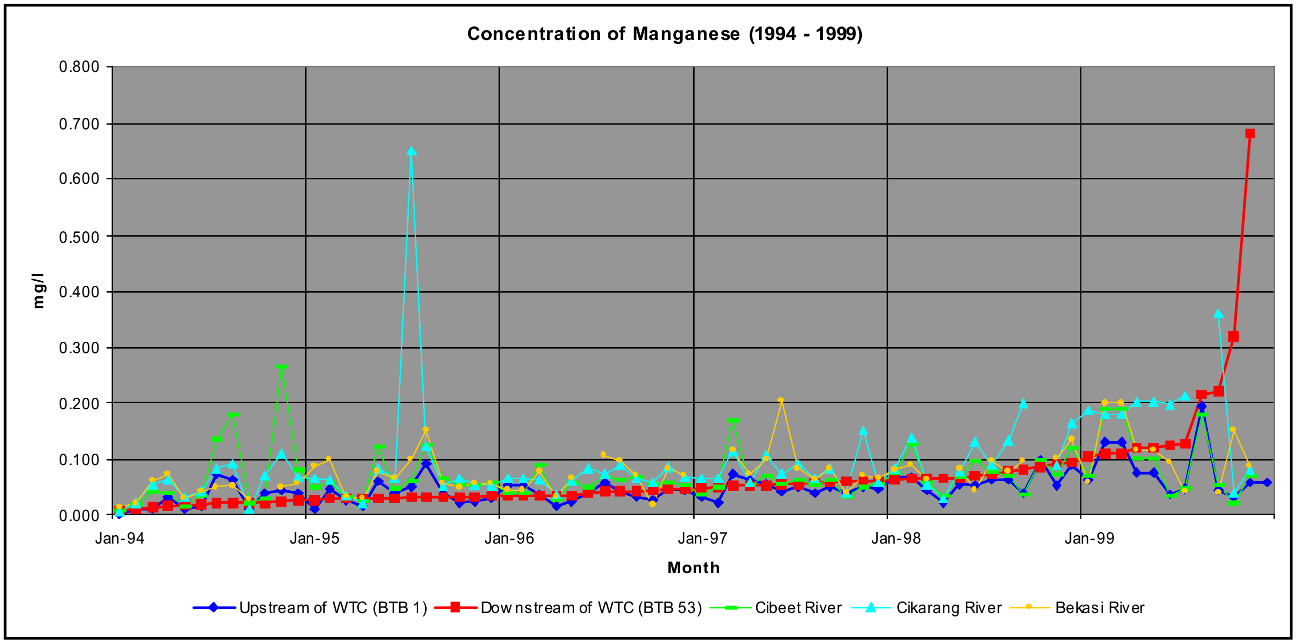

Figure 5b. Mean monthly concentration of manganese levels during the period 1994-1999.

sound database for the water quality parameters in the West Tarum Canal, and the catchment as a whole, has to be carried out. This is to be investigated thoroughly by the University of Indonesia, and results will be published in due course.

In general, the two possible pathways for the dispersion of manganese and iron compounds in the catchment are surface water and groundwater. These pathways are shown schematically in Figure 6. These two pathways differ in the time and length scales associated with the transport of Mn and Fe compounds. Following preliminary investigations, it was agreed that surface water is the most likely pathway of these chemicals. It should be mentioned that at this initial stage of the research project, the main attention is centered on the surface water pathway. Contribution of groundwater

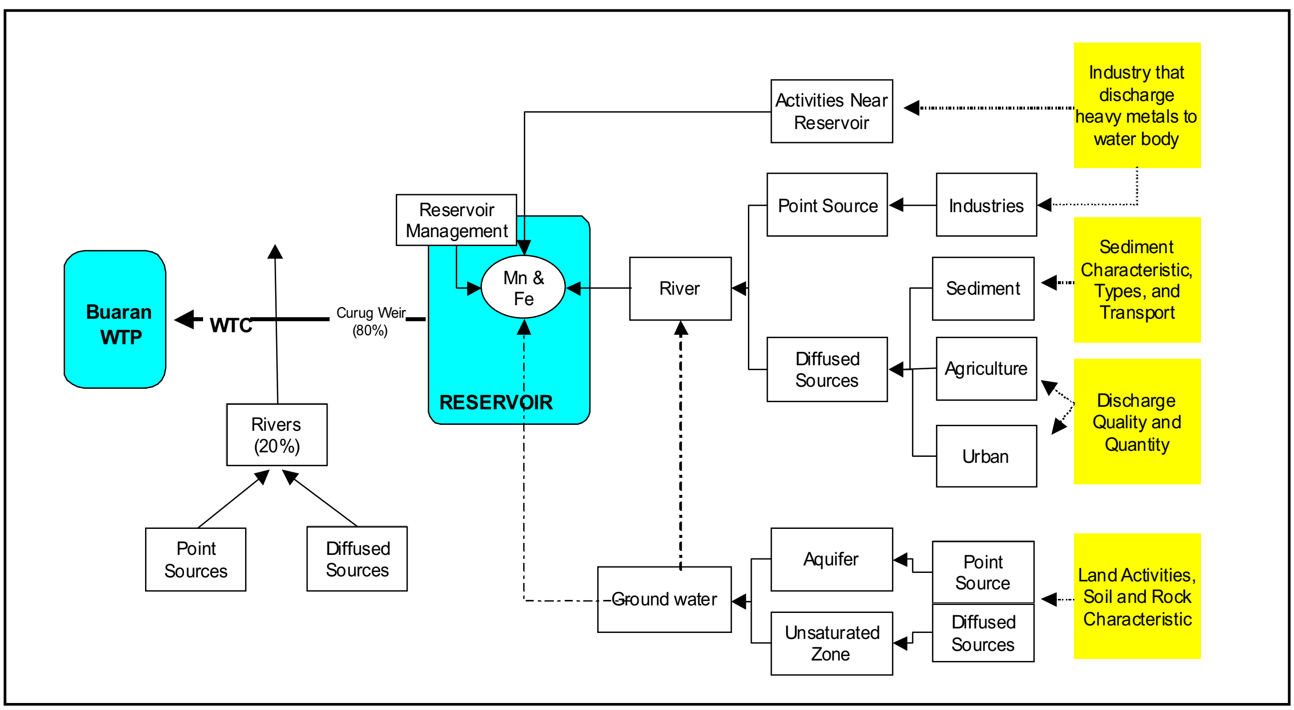

Figure 6. Possible pathways of manganese (Mn) and iron (Fe) dispersion in the catchment.

to high concentration of manganese and iron compounds can be considered at a later stage depending on sound evidence based on field measurements.

CONCEPTUAL MODELING

As previously mentioned, at this early stage of the study, the focus will be on developing a conceptual model capable of providing better understanding of the mechanisms involved in the transport processes of pollutant discharges of the West Tarum. This conceptual model would, on the long term, provide a valuable tool for comparing different management strategies for cost-effective solutions. Because of the complicated nature of the catchment and the lack of available information, the development of the model would have to be carried out in phases. In each phase, an assigned set of objectives (or targets) would be clearly identified and linked into the overall aims of the model (Ikhwan, 2000). Within the conceptual model, deterministic models will be used intensively for simulating the hydraulic and water quality processes in the complex pathways of the catchment. Therefore, a field measurement program is imperative for the calibration and verification of these models. Until such measurements become available, the dynamic simulation of all hydraulic and water quality components of the system should be considered preliminary at this stage. Proper calibration and verification of such models should follow in due course once reliable field data become available.

The System Components

Since the system involves two basins (Citarum and Ciliwung) connected through the West Tarum Canal with its crossing rivers, it has therefore been divided into two units. One unit represents the Citarum basin with Citarum River and the other unit represents the West Tarum Canal within the Ciliwung catchment. Within each unit, several subunits interacting with each other may be added whenever necessary. Future studies will be required to determine the degree of interaction of the units and the subunits within the system.

The main elements of the suggested conceptual model are shown in Figure 7. As can be seen in the figure, the method depends on dividing the catchment into zones or sub-catchment(s). However, because of the large size of the catchment and the lack of available information, the study at this stage will only focus on the West Tarum Canal. As previously stated, it is important to realize that in the absence of sound field data, the model results should obviously be regarded preliminary.

The West Tarum Canal with its tributaries is defined hypothetically as one sub-catchment. This sub-catchment includes Citarum Catchment, which is the upper and middle Citarum, the Cibeet Catchment, Cikarang Catchment and Bekasi Catchment. The hypothetical boundaries of the sub-catchment are shown inFigure 8. This assumption is utilized because the Tarum Canal, being a man-made canal, does not have natural catchment boundaries. As stated earlier, the deteriorating state of the canal water quality is a result of many uncontrolled and unmonitored polluted sources along the canal. For the purpose of applying the conceptual model, two sets of input data are assumed; the first and most difficult to quantify is the effluent fed into the canal along its path, and the second is directly from the tributaries.

Water Resources and Hydraulic Mapping in the Sub-catchment

At this stage, the water resources map to be used is the river flow data. This should be again taken as a first approximation since a direct relationship between rainfall and runoff distributions with river flows could not be established. Recently reported investigations in the literature (Komuscu et al.,

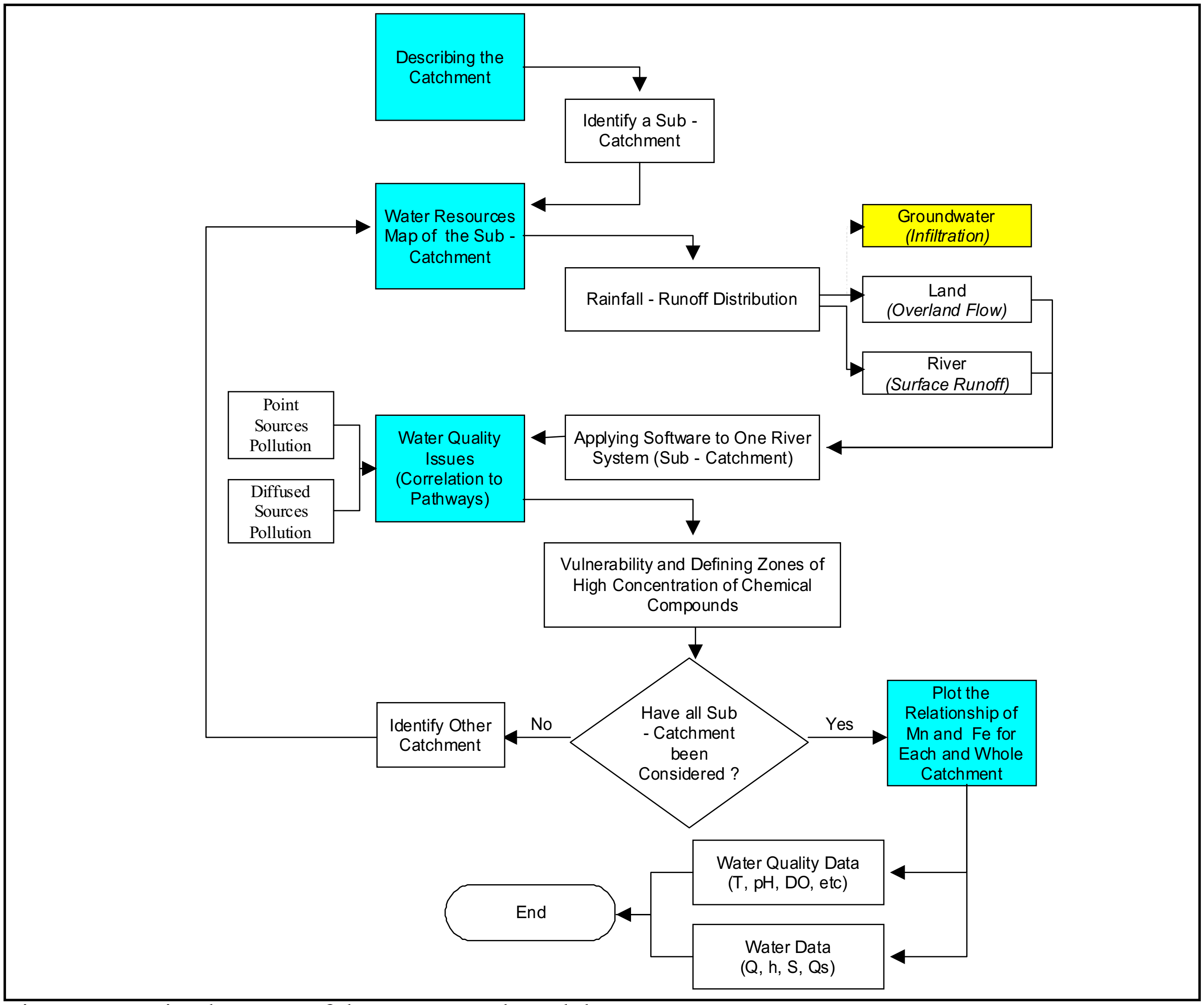

Figure 7. Main elements of the conceptual model.

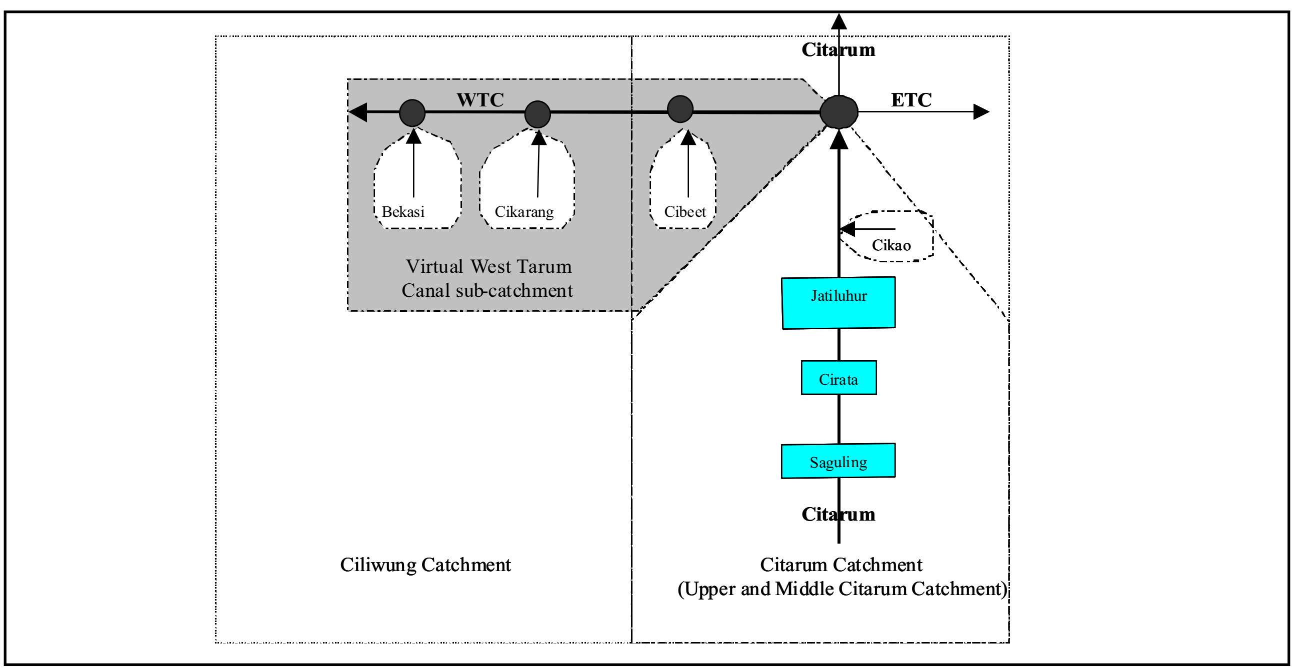

Figure 8. Virtual boundaries of the West Tarum Canal sub-catchment.

1999) have applied the same hypothesis, since their main objectives were focusing on determining on the critical levels within each sub-catchment, and not on carrying out in-depth analysis on the factors (e.g. activities, land use, hydrological and climate, etc) that affect the catchment properties. The determination of the hydraulic characteristics of each sub-catchment is an essential input data in determining the water quality variations.

Water Quality Aspects in the Sub-catchment

With the knowledge of the catchment hydrological properties and river hydraulics, the water quality aspects can be identified at any point (station) along the river network. Particular emphasis is placed on mapping the dispersion characteristics of iron and manganese compounds, from which zones of their high and low concentration are identified. From this output, point and diffused sources of pollution could be identified and backtracked within the catchment. This task obviously requires detailed information of the various activities in each sub catchment because of their relevant link to the water quality view point.

The mapping of water resources and tracing its quality criteria in the catchment is believed to be the first step towards sustainable management in the catchment. As more information becomes available in future, locations of potential pollution sources will be revealed (e.g. industrial effluent, geochemistry, etc). In general, the results should also address the interrelationship between the water quality aspects of the river and the corresponding hydraulic/hydrodynamic conditions of the catchment and its river network.

CONCLUSIONS

The paper reported the water supply and quality problems within the Citarum/Ciliwung catchment that feeds the city of Jakarta. Furthermore, the principal elements of a conceptual model for dealing with the various complex mechanisms of water motion and possible pathways of pollutant dispersion (with emphasis on iron and manganese) within the catchment are given. The detailed formulation of the model, its calculation procedure and full-scale application to this case study will be reported in due course. It is hoped that the implementation of the model should provide a valuable tool for testing the appropriateness of adopting different management strategies for cost-effective solutions.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the Research and Technology Department of Thames Water Utilities, UK, for their financial sponsorship of this study. The support and encouragement of the Centre for Environmental & Water Engineering Research, Civil Engineering Department, University of Indonesia, is also appreciated. This study forms a part of the second author's MSc dissertation, which is originated at the University of Surrey, UK. The views expressed in this paper are those of the authors and not of Thames Water Utilities.

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