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Pollution from Capital Urbanization to the Nhue River: Proposed Solutions

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Study report:

Pollution from capital urbanization to the Nhue River: Proposed solutions

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Abstract

Rapid urbanisation and major economic development in Viet Nam has led to dramatic degradation of the environment and increased health risks due to inefficient processing of the increased burden of effluent and solid wastes. A major example of this is the Nhue River, a tributary of the Red River, which is polluted by Ha Noi City. With a population of more than three million and no wastewater treatment facility, the city's domestic wastewater has resulted in severe environmental issues for the Nhue downstream its confluence with the city's main sewer, the To Lich River.

The objective of this report is to investigate the situation of discharged waste waters in the Nhue River, methods of pollution estimation. Some proposed solutions to improve the situation in the future are recommended.

Keywords: water pollution, water resource, river basin, urbanization.

1. The Nhue River and site description

1.1. The Nhue-To Lich river basins

The Nhue River, as a branch of the Red river, takes its source from the Red River at the Thuy Phuong Gate (N1) to the north west of Ha Noi (Figure 1). Like other rivers running in the northern delta of Viet Nam, the Nhue River flows south and southeast throughout its course without abrupt redirection or disruption. At several portions, its course was straightly rebuilt during French colonization for irrigation and waterway transportation. The river basin is bordered by the Red river to the north and the east, the Day River to the west, the Chau Giang River to the south. To the west, the Day River almost runs parallel with the Nhue River at the distance of 10 km. To the south, the Nhue River joins the Chau Giang River at the Luong Co gate, 72 km from its source. To the east, the Nhue basin is actually limited by the national highway number 1 and this highway also runs parallel with the river. The distance between river and the high way varies between 5 and 10 km. The basin elevation is gradually reduced from 9 m north to 1 m south. The area under 3 m elevation, called the low land area, accounts for 49.6% of total basin. In general, the basin topography is high in the north and low in the south with highest areas near the Day and Red Rivers and lowest near the Nhue at the center (Ngo Ngoc Cat, 2001).

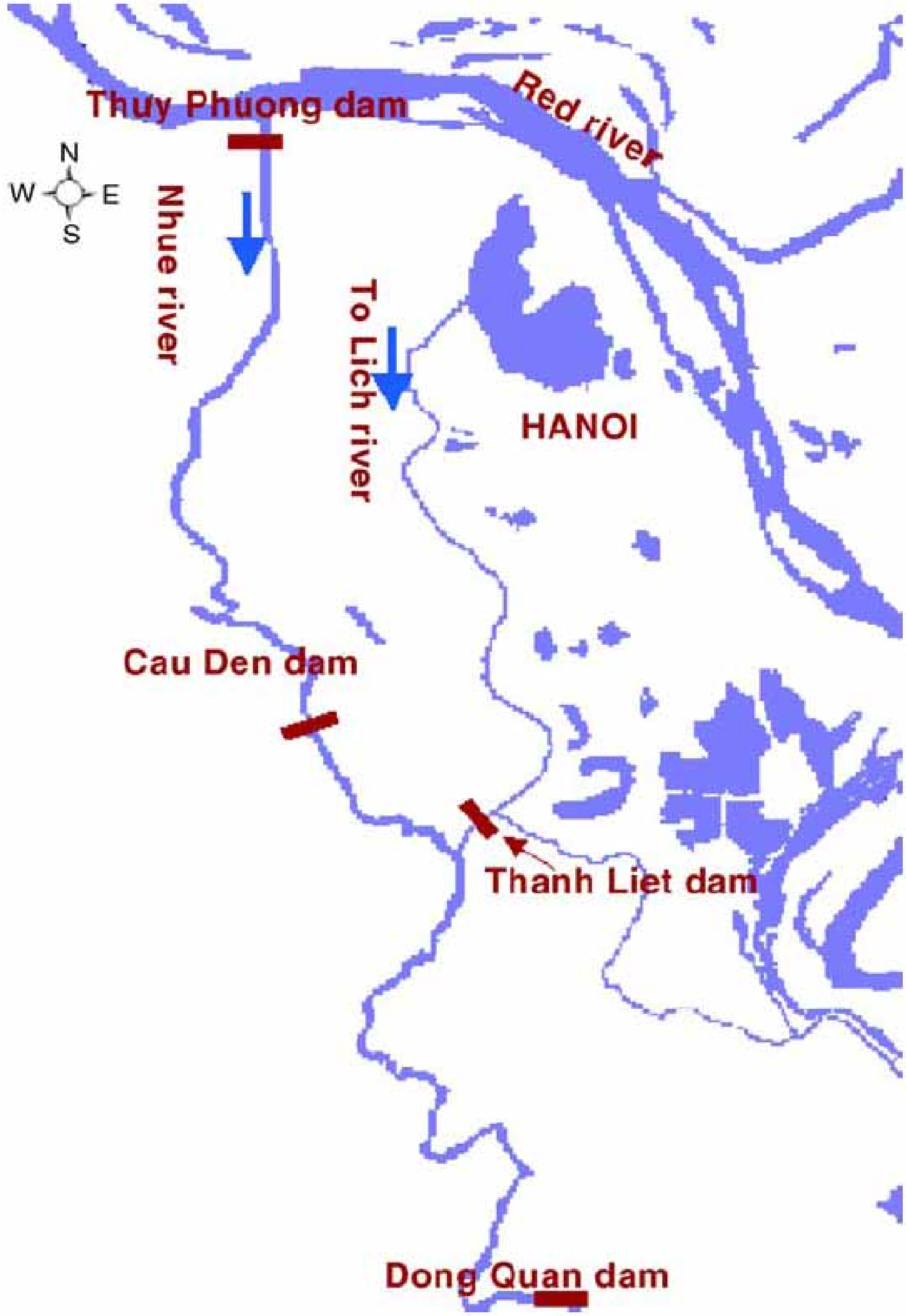

Figure 1: Map of the Nhue River

The river has also several significant inflows such as La Khe, To Lich, and Van Dinh. Of which La Khe, Van Dinh are outward canals while the To Lich River, a tributary of the Nhue River, is reportedly responsible for 77.5 (km^2) portion of Ha Noi area. The La Khe and Van Dinh Canals connect the Nhue River to the Day River at distances of 15 and 40 km calculated from the Nhue River source, respectively and they were built and canalized for irrigation and drainage of the surrounding paddy fields. In order to prevent flood and to ensure irrigation during crop season, the discharge in the river system is entirely regulated by dams/sluice gates (Table 1).

Table 1: Technical configuration of dams in the Nhue River system; designed configuration but have been upgraded several times to cope with new situations

No	Name	Distance from junction with the Red river (km)	Bottom elevation (m)	Designed capacity (m^3/s)	Function
1	Thuy Phuong	0.12	+1.00	20.15	Inflow
2	La Khe	6.73	+0.40	20.00	Outflow
3	Cau Den	15.90	-0.81	30.00	Control
4	Dong Quan	43.75	-2.23	50.00	Control
5	Van Dinh	11.79	-0.55	20.00	Outflow

The irrigation water is supplied from the Red river through the Thuy Phuong dam. Water level at the Thuy Phuong Dam in dry season corresponding to frequency of 75% is 3.16 m and 3.77 m for low and high irrigation, respectively. The consultant conditions for irrigation of winter/spring crops are shown in Table 2.

Table 2: Hydraulic conditions for regulating the dam during Winter/spring crop (Ngo Ngoc Cat, 2001)

Gate	At the start irrigation			At the end irrigation		
	Operation	Up (m)	Down (m)	Operation	Up (m)	Down (m)
Thuy Phuong	Open	3.72	4.00	Close		
La Khe	Close			Open	2.40	2.50
Ha Dong	Regulating	3.56	3.54	Open	2.40	
Dong Quan	Regulating	3.40	3.56	Open	1.66	

All along its course, the river basin presents a netted canalization system in charge of irrigation for villages and paddy fields. It is observed that irrigation canals spread all over the river basin and hook up to the Nhue every 2 or 3 km. The area is located on flat terrain on a river delta with elevation ranging about 4 m above sea level. Drainage is very difficult as there are many lowland areas. The elevation of the urban area is particularly low compared to the Red River water level. As a consequence, Ha Noi area is regularly threatened by inundation despite having the most complex and enduring banking system.

As centered in the Red River delta, the Nhue River basin inherits a fairly flat topology thanks to some quaternary alluvial sediment deposited over 120000 years. The total height of the sediment layers can be up to few hundred meters. This very thick layer of alluvial deposits gives Ha Noi area a natural richness in ground waters. According to the recent surveys, 90%

people in suburban area exploit groundwater for their domestic use. It is generally said that the aquifer near the ground in the urban area is polluted but with the wells drilled to the depth of 24-31 m, the water is safe and consumable without prior treatment.

The general meteorology relevant for the study area is observed at the Lang meteorological station in the center of Ha Noi (105°48'E, 21°01'N), about 5 km northeast from the Nhue-To Lich confluence, and the Ha Dong Station (105°46'E, 21°58'N), 15 km south from the upstream point. In fact, the climate of the Ha Noi region is typical monsoon. The monthly average temperature recorded at the two meteorological station mentioned above for two consecutive years (2001 and 2002) increases from 15°C in winter (December to January) to 30°C in summer (June to July). The average annual rainfall for years 2001 and 2002 in the area is about 1800-2200 mm, 80% of which occurs during the rainy season from May to October. The rainfall of July, August and September accounts for 60% of total annual rainfall. In dry season from November to February, rainfall is only 8% of the total annual. Monthly evaporation varies from 60 mm to 100 mm throughout the year, while the mean monthly temperature fluctuates between 16°C and 28°C. Evaporation reaches maximum in July as the summer temperature is maximum. Over the whole year, the monthly average solar hours increases sharply from April or May due to monsoon and decrease gradually from October to December due to movement of the earth. The solar hours stay high till October.

According to JICA (1995), the To Lich river basin accounts for 7,750 ha and includes 7 urban districts and parts of suburban districts – Tu Liem and Thanh Tri. About 3500 ha or 45 % of the total area is used for residential purposes, which reflects the rapid urbanization of the Ha Noi urban and suburban area (figure 2). It must be noted that at the year 2002 and 2003, this percentage reaches over one half of the total area. The ancient city area, government offices and public area occupy about 9% of the total area, while industrial area accounts for only 5%. About 26% of the total basin is occupied by lakes, ponds and water canals. Agricultural area is only 13% (JICA, 1995).

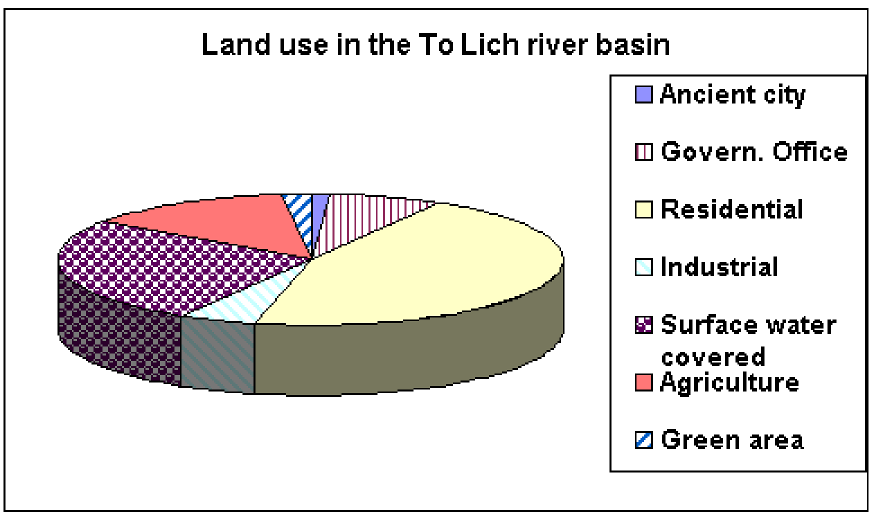

Figure 2: Pie chart of land use in the To Lich river basin

Assuming that impermeable area of the river basin includes all artificial construction areas, 58.6% of the To Lich area is impermeable. The rest 41.4% including surface water coverage and natural landscape area is permeable. Majority, the soil in the Nhue basin consists of mud/sand in the areas close to the Day and Red Rivers, and mud or mud/clay in the areas around the Nhue River. This is favorable for agricultural production with rice, potatoes, sweet potatoes, and vegeTables. Total agricultural area in the basin is 81,790 ha. The Nhue River basin with its fertilized soil is considered as an inter-province hydro-agriculture system with different industrial and agricultural zones. The Nhue hydro-agriculture system is responsible for activate irrigation of 81,710 ha in normal condition and inundation relief of 107,530 ha with designed frequency of 10%, particularly 10 l/s/ha of Ha Noi.

1.2. Environmental state of the Nhue River and its tributaries

It is very clear that inadequate drainage system which relies mainly on the transport capability of natural waterways running inside the city is causing great risk to the To Lich and Nhue Rivers' water.

Figure 3: Solid waste and fresh excreta released to the To Lich River

Domestic and industrial wastewater from Ha Noi mainly discharges to the To Lich River without prior treatment and the river is effectively the principal open-air-sewer of the city. The Nhue River, as a branch of the Red River, takes its source from the Red River about 11 km to the north west of Ha Noi and is joined with the To Lich some 20 km downstream of Ha Noi. The mean in-flow to the Nhue River from the Red River is 26 m^3/s and it typically receives around 5.8 m^3/s of untreated wastewater from the To Lich River. In the course of the present report, water discharge flowing from the To Lich River to the Nhue River was recorded as having doubled, from 5.8 m^3/s in 2002 to 11.0 m^3/s in 2006. This discharge has increased with the urbanization development of Ha Noi.

In detail, in the Ha Noi's suburb rivers and channels, water quality does not meet the Vietnamese standards (TCVN) for surface water (TCVN 5942-1995, type B). Typically, at some places water quality even does not meet the standards for domestic wastewater (TCVN 6772-2000, level IV). In dry period, the quality deteriorates even further. The monitoring results conducted in late 2005 show that the DO value was very low; the COD content exceeded permitted level by 7-8 times; the BOD5 content - 7 times (figure 4); the coliform concentration was higher than the TCVN 5942-1995 (type B) standard. Another infrastructural problem for the city is that rain water and wastewater share the same pipelines and flow to the surrounding waterways by gravity. This water mixture then outflows to the To Lich which ultimately discharges to the Nhue River through the Thanh Liet Dam. Recently as the Yen So Regulation Lake has been operated, this lake receives regularly a significant part of the To Lich River's water which then pumps to the Red River after some preliminary/simple treatment. This lake operates mainly in the dry season as in rainy season water from the To Lich River must be discharged to the Nhue River for the security reason which bring most pollutants to the Nhue River without treatment or partly diversion.

Because of the To Lich River's water, the Nhue River is severely polluted after the confluence between the two rivers. Although the upstream of the confluence is less impacted, water quality of the river section from the Ha Dong Town to the confluence point is increasingly deteriorated due to the increase of urbanization and industrial development. BOD5 and COD exceeded the standards (TCVN 5942-1995) by 3-4 times. Water downstream the confluence is totally polluted with quality characterized of untreated sewage. It could only be ameliorated in heavily rainy periods. In addition, as the irrigation role of the Nhue River to the upstream watershed is reduced (this area has been fast urbanized over the last several years), the Thuy Phuong Dam which regulates water flow from the Red River to the Nhue River is usually closed leading to the low water volume regulated upstream and concentrating polluted water throughout water course. In rainy season, although The Nhue River receives supplement rain water, the typical pollution indicators such as BOD5, COD, nutrients, and coliforms are still higher than the TCVN 5942 - 995 (type B) standards. From the confluence with To Lich River downstream, water quality is slightly and gradually improved due to the self – purifying process though it is still higher than the TCVN 5942 - 1995 (type B) standards. Although in the dry season, water from the To Lich River has been partly diverted to the Yen So Regulation Lake and the Red River, the pollution level in The Nhue River still worsens every year due to fast urbanization and economic development (Figure 6).

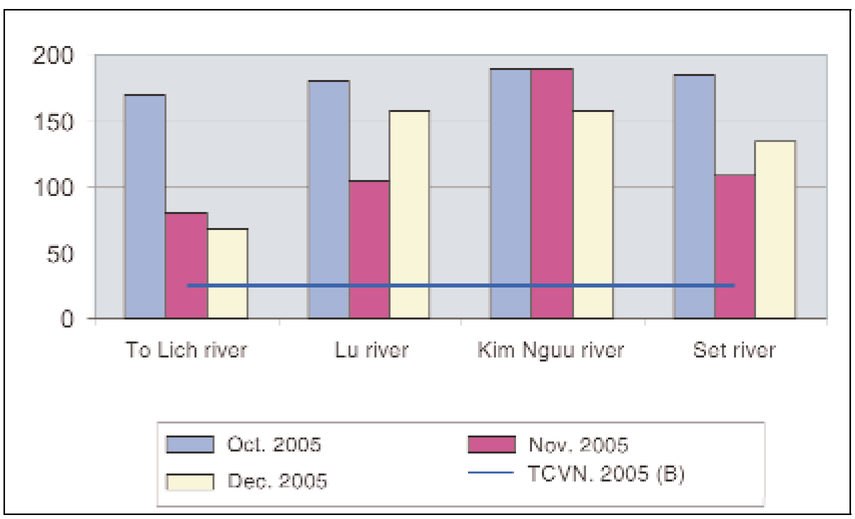

Figure 4: BOD5 content in some rivers in the inner part of Ha Noi (VEPA, 2005)

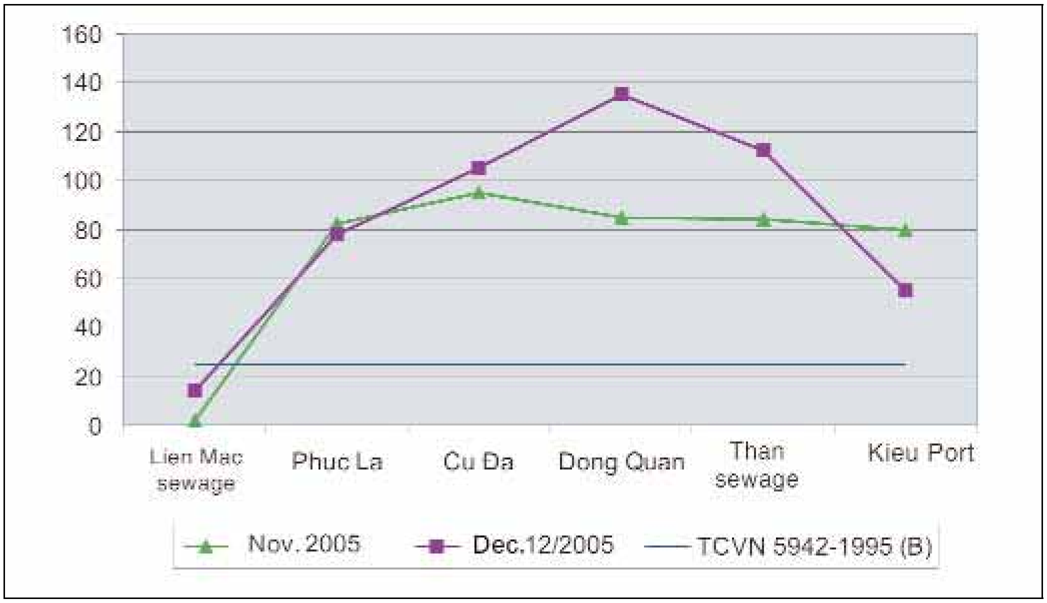

Figure 5: BOD5 trends in the Nhue River (in some pollution-peak times of 2005) (VEPA, 2005)

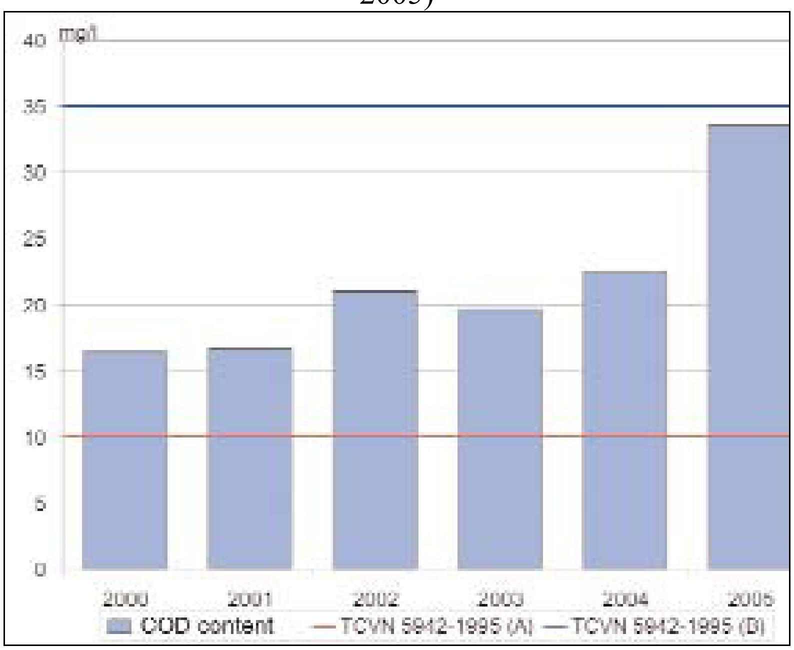

Figure 6: COD trends (annual average content) over several years at Nhat Tuu, Ha Nam (Ha Nam DONRE, 2006)

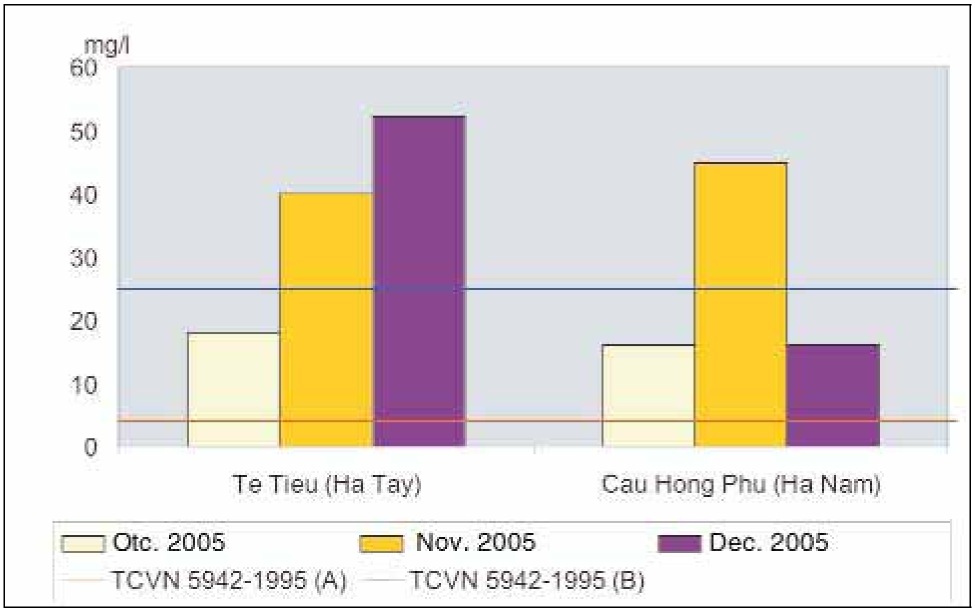

Figure 7: BOD5 trends at Te Tieu and Hong Phu bridge (the confluence of Nhue, Day and Chau Giang rivers) (VEPA, 2005)

2. Sources of pollution discharged to the Nhue River

The pollution sources in the Nhue River basin come from various activities of human which are categorized as domestic waste, hospital waste, industrial waste, agricultural waste, and craft village waste. Of which, domestic waste contributes most with more than 50% in volume (Figure 8).

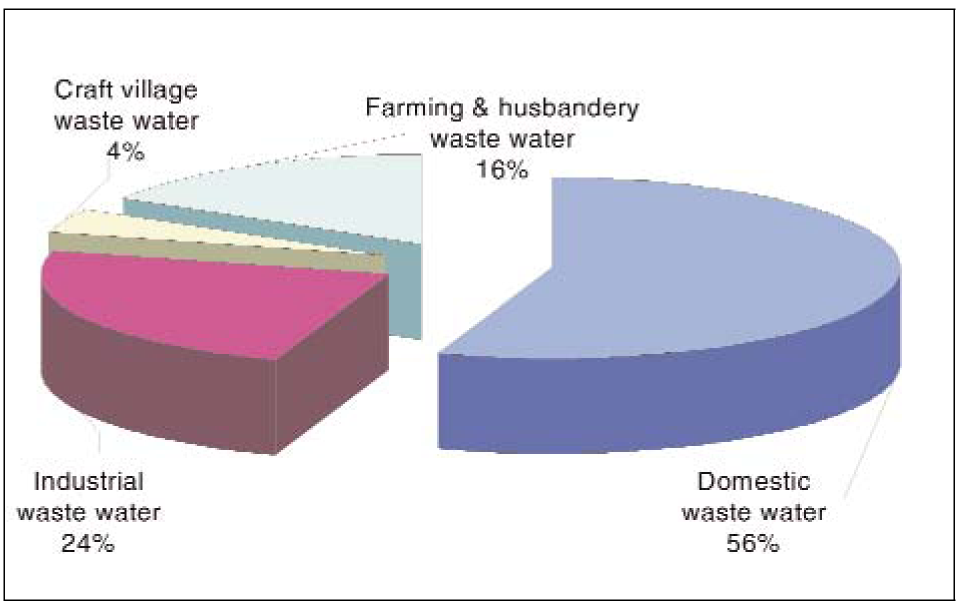

Figure 8: The percentage of waste sources per waste volume in the Nhue river basin (VEPA, 2006)

2.1. Domestic wastewater

Domestic wastewater in high volume and concentrated organic matter has made the water quality of the Nhue River severely polluted. In fact, the Ha Noi downtown contributes 71% of the total domestic wastewater. With the high average population density and high population growth, the wastewater volume in the Nhue river basin is consequently increasing. The rapid urbanization, accompanied by the incompatibly developed urban technical infrastructure, has led to the increased pollution resulted from domestic wastewater. Most of the domestic wastewater is directly discharged to rivers, lakes in the basin without prior treatment and this is the most important cause for the increased water pollution of the Nhue River basin.

2.2. Hospital wastewater

Hospital wastewater is a categorized as hazardous and should be completely treated in proper manner before dumping. However to date most of medical establishments have no accepTable treatment systems for hospital wastewater. The wastewater is directly discharged to the receiving bodies and then to surface water sources of the river basin. At the moment, in the whole basin, there are more than 20000 patient beds (of which Ha Noi contributes 47%) in nearly 1400 medical establishments, with the average wastewater of 100000 m^3/day.

2.3. Industrial wastewater

Statistical data revealed that in the Nhue river basin there are nearly 4000 industrial facilities (of which Ha Noi contributed 67% of the total) (the General Statistic Directorate, 2005). These industrial facilities generate significant amount of waste (solid, liquid and airborne) which causes pollution and has great impacts on the environment of the Nhue river basin. This pollution is an important factor deteriorating the water quality in the region. Taking wastewater volume into account, Ha Noi generates the largest part, (about 180000 m^3/day, comprising 55% of the total). According to the recent surveyed results of more than 200 large scale production facilities contributing wastewater to the Nhue and partly the Day Rivers, the mechanical industry contributes up to 33% (Figure 9). Wastewater of different industries has different features and levels of impact on water quality. Wastewater from the mechanical industry contains oil and hardly settling suspended solids (SS) and wastewater from the food processing sector contains many organic matters. Wastewater from textile and dying industry consists of many environmentally damaging chemicals such as alkali, detergent, alumni, pine resin, and artificial coloring agents.

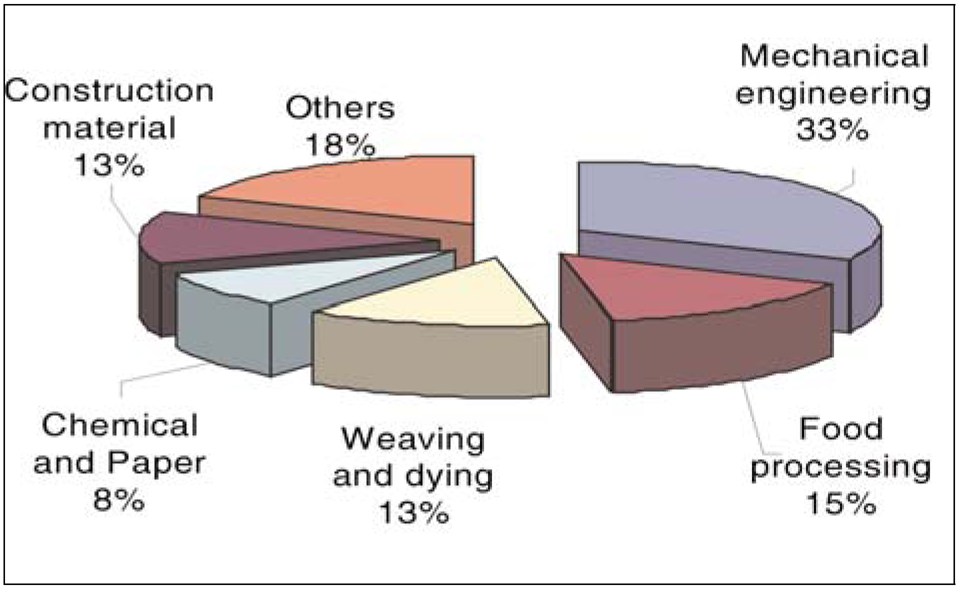

Figure 9: Production establishments per main waste generating industries in the Nhue River basin (Cu, 2005)

2.4. Agricultural production activities

As urbanization is getting the pace, number of households participating in agricultural production activities is shrinking along with the agricultural area. In fact, canal network in Nhue river basin once serve as a provincial irrigation system supplying water for agricultural production in the whole region. The flow regimes once regulated for agricultural purposes is now mostly served to drain the urbanized watershed. As the water regime is strictly controlled by the dams and sluice gates setup around the confluences of the outlets/inlets, the operation of this water flow regulation system has strong influence on the water quality of the basin. Livestock rise is an important fraction of total agricultural production in the basin as it is encouraged to serve the dense population in the area. The number of livestock is steadily increasing. The increasing livestock number correspondingly leads to the increase of wastewater volume. Regrettably, to date, even the large husbandry facilities in the area have limited treatment system. Therefore, most of the waste, especially wastewater, is discharged to the surrounding surface waters, which ultimately contaminates the Nhue River.

2.5. Wastewater from craft villages

According to statistics of the relevant provincial departments of Natural Resources and Environment, there are approximately 400 craft villages in the whole basin and they also contribute to the deterioration of water quality of the river. Production activities of the craft villages generate about 45000 m^3/day of wastewater. Most of the small production establishments in craft villages are developed spontaneously to meet the market demands. They are characterized by simple equipment, outdated technologies, small workplaces and limited investment in wastewater treatment facilities. The wastewater from these craft villages is usually discharged to receiving sources without prior treatment. This leads to severe pollution of the surface water sources. Some investments have been made in building central wastewater treatment facilities for numerous villages though the effectiveness is insignificant. The surface water pollution caused by production activities of craft villages in Nhue river basin has become relatively severe with different characteristics featuring different types of manufactures. Of the craft villages active in the river basin, agricultural food processing villages are among the biggest wastewater generators, causing huge impacts to the surface water environment of the basin. In most of the craft villages in the basin the water quality parameters have totally exceeded permitted standards. Though the contamination is high locally, total contribution of the wastewater from craft villages comprises only 4% of wastewater of the whole basin.

2.6. Solid waste

Solid waste is one of the polluting sources of the surface water in the basin. Along with the economic development, urbanization, and population growth, total amount of solid waste in the basin has been continuously increasing (especially in urban areas). Of the total amount of solid waste, domestic waste comprises 80% and the rest is waste from industrial production establishments. Although they are small in amount, industrial and hospital wastes are hazardous and harmful to the environment and human health unless proper treatment procedures are in place. The average waste collection rate is rather low. In rural area, the collection rate in very low (averaging at 20%). In big cities the collection rate of domestic solid waste is higher. Solid waste is dumped in an indiscriminate manner with some is piled on banks of water ways, resulting in pollution of the surface water in the basin. On the other hand, floods produce a flushing effect on streets and channels, carrying away dust sediments, and solid waste upstream of the Nhue River, this cause damage to living condition and human health. The collection and transportation of urban and industrial solid waste has not yet met requirements. Except for Nam Son Landfill site of Ha Noi, other landfill sites in Nhue river basin are using outdated burying technologies leading to surface and ground water pollution in the basin.

3. Review of simulation and forecasts of pollution by modeling

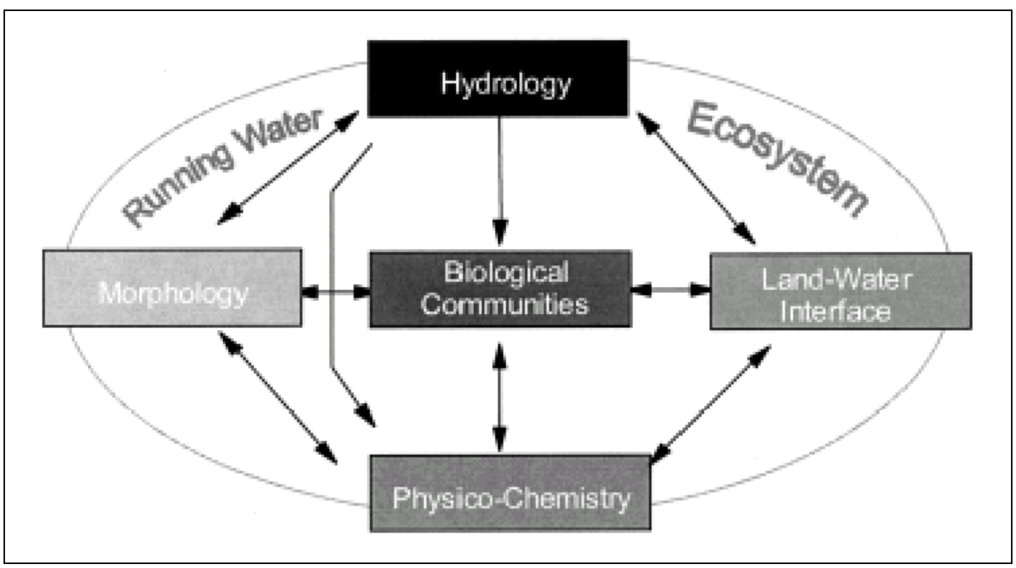

Figure 10: Structure of running water ecosystem (Shanahan, 2001)

As illustrated in Figure 10, an all-round conceptual model of running water ecosystems consists of abiotic and biotic elements linked within a hydrological continuum. Processes within and between elements are complex and can be described by a series of physicochemical, hydro-morphological, and biological parameters. The abiotic and biotic structures of running waters are characterized by longitudinal, vertical, lateral, and temporal gradients.

3.1. Mass transport in river water

Water quality changes in rivers due to physical transport and mixing processes (such as advection and diffusion/dispersion, the description of which requires one way or another the application of a hydraulic model as an input) and biological, chemical, biochemical, and physical conversion processes. The above processes in the water phase are governed by a set of well-known extended transport equations (see e.g. Somlyódy and van Straten, 1986).

$$\frac{\partial c}{\partial t} = -u\frac{\partial c}{\partial x} - v\frac{\partial c}{\partial y} - w\frac{\partial c}{\partial z} + \frac{\partial}{\partial x}\left(\varepsilon_x \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_y \frac{\partial c}{\partial y}\right)\frac{\partial}{\partial z}\left(\varepsilon z \frac{\partial c}{\partial z}\right) + r(c, p) \qquad (1)$$

where c - n-dimensional mass concentration vector for the n state variables;
t - time; x, y, and z - spatial coordinates;
u, v, and w - corresponding velocity components;
εx, εy, and εz - turbulent diffusion coefficients for the directions x, y and z, respectively;
r - n-dimensional vector of rates of change of state variables due to biological, chemical, and other conversion processes as a function of concentrations, c, and model parameters, p (subject to calibration).

Equation 1 offers not only the basic governing equation of water quality models, but it also specifies a useful framework and the main model elements. These are the following: The hydrodynamic model for deriving velocity components u, v, and w, and turbulent diffusion coefficients εx, εy, and εz; The transport (or advection-diffusion) equation (describing the behavior of so-called conservative substances) and its solution; The conversion process, r(c,p). It has much less solid theoretical grounds than hydrodynamics and, thus, for its development an adequate combination of theoretical and empirical knowledge is needed. For the latter purpose, methodologies such as calibration, validation, identification, sensitivity, and uncertainty analyses are required (Beck, 1987) which aid model selection and testing. The model that is fully designed on the basis of the above steps and elements may require a powerful computer and variety of supporting software (and hardware) (Rauch, 1998).

3.2. Hydrodynamics and hydraulics

Flow of water in a river is described by the continuity and momentum equations. The latter is known as the Navier-Stokes or Reynolds equation. The actual form of a hydrodynamic model depends on assumptions made on characterizing turbulence. Methods vary from the use of eddy viscosity as known parameters to the application of the so called k-ε theory (see Bedford et al., 1988 or Rodi, 1993 for an overview of the state of the art of turbulence models). Complex models are available (see e.g. Abbott, 1979; Naot and Rodi, 1982) but for water quality purposes mostly the well-known, cross-sectionally integrated (1D) Saint Venant equations or approximations to these equations are used (see e.g. Mahmood and Yevjevich, 1975; Abbott, 1979).

Many different forms and approximations to the St. Venant equations are known, depending upon whether the flow is steady or unsteady and which simplifications are made. Thus, for water quality studies often the equation of steady, gradually variable flow is employed (which may be further simplified to the so-called Manning equation). Unsteady models include the kinematic, diffusive, and dynamic wave approaches, all based on the continuity and momentum equations. The difference stems from simplifications of the latter: dynamic wave models solve the full equation, diffusive ones exclude the acceleration terms, while kinematic ones disregard also the pressure gradient term that is essential for the description of backwater effects.

The hydrodynamic equations are generally solved by efficient finite difference methods (see e.g. Mahmood and Yevjevich, 1975). For water quality issues the acceleration terms in the momentum equation rarely play a significant role and the typical time scales are amplified by conversion processes. For these reasons, the diffusive wave approach is often a satisfactory approximation.

Before the introduction to the employed computer program, the selection objective is deliberated. Initially, it should be mentioned that there are numerous computer programs dealing with quality of running water bodies. In principal, they resolve simultaneously the transport equation and the conversion processes. However, the above discussion has raised 3 problems to be solved for one computer program: (1) its flexibility in model construction, (2) its capability in performing sensitivity analysis and (3) its function of performing parameter estimation. Usually, a computer program is objectively built to resolve only the first problem; the model construction. The latter problems are more or less mistreated or ignored. So, it is preferable if three problems are resolved by a unique computer program (or a series of compatible programs).

3.3. Approach to river water quality modelling

River water quality models seek to describe the spatial and temporal changes of constituents of concern. Components or state variables have been gradually incorporated into models over the past seven decades following the evolution of water quality problems. Water quality models characterize among others oxygen household, nutrients and eutrophication, toxic materials, and so on. The complexity covers a broad range from the simple Streeter-Phelps model (Streeter and Phelps, 1925) with two state variables to QUAL2 and similar tools describing comprehensively O, N and P cycling with about ten state variables (Brown and Barnwell, 1987), to ecosystem models that may consider suspended solids, several classes of algae, zooplankton, invertebrates, plants, and fish (Boling et al., 1975). The model choice depends on many different factors such as the objectives of the analysis, as well as data and time availability. Among the objectives two broad categories are usually distinguished: understanding/research and management/practice. Stemming from our goals, the Task Group has limited its attention to only models handling the "traditional" constituents O, N, and P. Water quality changes in rivers due to physical transport and exchange processes (such as advection and diffusion/dispersion, the description of which requires one way or another the application of a hydraulic model as an input) and biological, chemical, biochemical, and physical conversion processes. The above processes in the water phase are governed by a set of well-known extended transport equations (see e.g. Somlyódy and van Straten, 1986).

3.4. Software and computer program

Other than the simplest approaches, all mathematical models for prediction of water quality in rivers require the use of a computer to be worked with. Due to the considerable effort needed to develop and implement a site-specific model, the use of existing computer programs is preferred whenever possible. The following classification only aims to give an overview of the most important computer programs and is by no means meant to be exhaustive. Relevant features for classification are the description of hydrodynamics and transport, model structure (important variables, processes and submodels), software structure (open/closed - meaning that the user can change the model structure), and systems analytic features supported by the program. Table 3 gives an overview of some important software products for river water quality modelling.

Table 3: Computer programs: 1 = QUAL2 (US EPA; Brown and Barnwell, 1987); 2 = WASP5 (US EPA; Ambrose et al. 1988); 3 = CE-QUAL-ICM (US Army Engineer Waterways Experiment Station; Cerco and Cole, 1995); 4 = HEC5Q (US Army Engineer Hydrologic Engineering Center, HEC 1986); 5 = MIKE11 (Danish Hydraulic Institute; DHI 1992); 6 = ATV Model (ATV, Germany; ATV, 1996); 7 = Salmon-Q (HR Wallingford, UK; Wallingford Software 1994); 8 = DUFLOW (University of Wageningen, The Netherlands, Aalderink et al ., 1995); 9 = AQUASIM (EAWAG, Switzerland; Reichert, 1998); 10 = DESERT (IIASA; Ivanov et al., 1996).

	Program	1	2	3	4	5	6	7	8	9	10
Hydrodynamic	External input	Y	Y	N	N	Y	N	N	N	N	Y
	Simulated	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Control structure	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Transport	Advection	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Dispersion	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sediment	Quality model	N	Y	Y	N	Y	Y	N	N	Open structure	Y
Water quality	Temperature	Y	N	Y	Y	Y	Y	Y	Open structure		N
	Bacteria	N	N	Y	Y	Y	Y	Y			N
	DO-BOD	Y	Y	Y	Y	Y	Y	Y			Y
	Nitrogen	Y	Y	Y	Y	Y	Y	Y			Y
	Phosphorus	Y	Y	Y	Y	Y	Y	Y			Y
	Silicon	N	N	Y	N	Y	Y	Y			N
	Phytoplankton	Y	Y	Y	Y	Y	Y	Y			Y
	Zooplankton	N	N	Y	N	Y	Y	N			N
	Benthic algae	N	N	N	N	Y	Y	Y			N
System analysis	Parameter estimation	N								Y	Y
	Sensitivity analysis	Y								Y	Y

4. Proposed solutions

4.1 Legal acts

4.1.1 *Development and improvement of legal regulations, policies and institutions*

- To revise the Law on Water Resources toward integrated management with clearer definition of responsibilities and coordination mechanisms between central and local authorities, among ministries, and among local governments of related provinces;
- To promulgate a Decree on integrated management of river basin, which shall address the duplication in the functions of state management on water resources (belonging to Ministry of Natural Resource and Environment-MONRE) and the state management of river basins of Ministry of Agriculture and Rural Development (MARD) stated in the Decree No. 86/2004/ND-CP;
- To promulgate environmental protection mechanisms for the river basin with clear indication of environmental problems and provision of codes of conduct for relevant parties, including management agencies, businesses and local communities;
- To develop zoning plans of water resource exploitation and wastewater discharge systems for each sub-watershed. This will be the foundation for the issue of wastewater discharge permits based on the assessment of the self-purification capacity and specific standards of each sub-watershed in the basin.

4.1.2 *Inspection and monitoring of law enforcement*

- To concentrate on the enterprises that seriously pollute the environment as listed in Decision No. 64/2003/QD-TTg of the Prime Minister. To continue the investigation to identify sources of environmental pollution in river basin to be dealt with in accordance with Decision No. 64/2003/QD-TTg;
- To resolutely prevent the occurrence of new pollution sources. To ban new constructions which threaten to pollute the environment and generate environmental incidents. Depending on specific areas, investment in some production types that potentially pollute the environment should be limited;
- To carry out regular environmental inspection and investigation. To prescribe measures to enforce enterprises to implement self-monitoring programs and other regulations according to the Law on Environmental Protection 2005;
- To immediately design integrated measures on gradual reduction of pollution generated from urban domestic wastewater;
- To strengthen the water quality monitoring, focusing on monitoring and evaluating of the inorganic pollution level. To develop databases of river basin water environment to provide to, and share with, all relevant stakeholders at central and local levels.

4.1.3 *Application of economic tools, scientific and technological solutions*

- To revise and issue fees on wastewater discharge based on the principle "polluters pay";
- To carry out a comprehensive study on the hydraulic regimes of the waterways in the basin and propose technical solutions on changing environmental currents, supplementing water source and strengthening the self-purification capacity to protect the water environment of the river;

- To carry out a comprehensive assessment of the impacts of irrigation works and domestic activities in order to propose measures to prevent and reduce landslides and sedimentation and to recover river landscapes and eco-balance.

4.1.4 *Capacity strengthening*

- To issue clearer policies and mechanisms on the operation of staff performing environmental protection task with focus on the quality and quantity of staff and financial resources for effective operation of committees to ensure the benefit of all river basins;
- Local authorities should allocate resources for the environmental protection of river basin from the 1%- of annual-State- budget funds for environmental protection. The resources must be spent for appropriate purposes and in an effective manner;
- To create favorable conditions for enterprises to access loan sources from Viet Nam's Environmental Protection Fund as well as other financial sources;
- To diversify investment sources, increasing the share of official development assistance sources in the total investment in environmental protection;
- To mobilize financial sources from international organizations and other countries to invest in river basin environmental protection.

4.1.5 *Public participation and responsibility*

- To develop mechanisms to attract participation of all relevant stakeholders, including local communities in planning and the development of plans and in the implementation of measures to protect the river basin environment;
- To enhance active roles of communities in water sources management and utilization;
- To publicly disseminate through mass media information and data concerning the pollution status and pollution sources in the river basins.

4.1.6 *International cooperation*

- To develop cooperation mechanisms in preventing and addressing water environmental pollution in transboundary rivers;
- To expand international cooperation on regional river basin protection in forms of bilateral and multilateral programs and projects. To further strengthen the cooperation with international, governmental and non-governmental organizations in order to take advantage of international assistance in all forms as well as experience and techniques in river basin environmental protection.

4.1.7 *Proposed explicit methods for the Nhue River Basin*

- To concentrate on treatment of domestic wastewater, especially in Ha Noi capital; industrial wastewater in Ha Noi and Ha Nam; and wastewater from craft villages in Ha Noi and Ha Nam;
- To strictly control the seriously polluted areas in the river basin:
    - To Lich river and lakes and rivers in the inner part of Ha Noi;
    - The section of The Nhue River from the Ha Dong town to Phu Ly, the Ha Nam province.
- To accelerated the development of the Master Scheme on the environmental protection of the Nhue river basin to submit to the Government for approval;

- To limit the number of investment permits for 5 industrial types that threaten to generate serious pollution of the environment, including: cassava starch processing, basic chemicals production, dying, leather tanning and paper pulp production;
- To coordinate the regulation of river water in the dry and flood seasons, to ensure the source of fresh water for domestic use, agricultural production, and flood drainage and the self-purification capacities of rivers in the basin;
- To zone some vegeTable safety areas, and warn people not to use polluted water sources for agricultural production.

4.2. Pollution forecast/simulation toward best management practices

Within the scope of this study, an established guidance/tool, the total maximum daily load (TMDL), is used to quantitatively evaluate several possible management alternatives. In principle, a TMDL is the sum of the individual waste load allocations (WLA) for point sources and load allocations for non-point sources (LA) and natural background with a margin of safety, MOS (USEPA, 1999). It is described as TMDL =PWLA +PLA + MOS. Here, the PWLA is identified as wastewater impact from the To Lich River. The PLA is equal to total loadings of the Nhue's upstream input and lateral wastewater inflow along the Nhue to the confluence point. In this case study, the Margin of Safety is expressed as two causes: increase of population in the study area and the evapotranspiration and infiltration. The former was taken as 5% of the total discharge since the population increase was about 5% per year (Cu and Cham, 2006) and this calculation was derived the annual average. The latter was estimated as 2% of the total discharge based on the annual fluctuations of precipitation/evapotranspiration and water Table level in the area. Thus, since the calculation did not take into account these two factors, the MOS is totally taken as 7% of TMDL. Also based on the above analysis, the water quality parameters of major concern are BOD, DO, SS, NH4 and NO3. At average flow, the TMDL, the current PWLA, and the current PLA of the considered parameters were calculated and represented in Table 4. The results indicate that BOD, NH4, and partly DO have severely violated water quality regulation/consents.

The management method herein focuses on reducing the loadings of NH4 and BOD while maintain reasonable levels of SS and NO3 (DO is not necessarily considered because if the levels of NH4 and BOD are low, the level of DO will automatically be high). Most BOD and NH4 are derived from WLA (the To Lich River) and therefore management must focus on reduce the loadings from WLA. In this case study, the model was used to evaluate the applicability of management alternatives by calculating levels of parameters at defined position; 5 km downstream the impact zone. The idea behind the choice of 5 km point is to let the system stabilise after mixing of two different water masses (Trinh et al., 2006b; McAvoy et al., 2003). Since the loading five km downstream of the confluence has changed compared with it at the confluence due to biogeochemical activities (e.g. NH4 is oxidized and reduced or BOD reduces), the model is needed to precisely calculate this loading change at different management alternatives.

Three management alternatives practicable in this study site are proposed, the rationale for the analysis for the three approaches were as follows.

Treatment of the To Lich wastewater

A wastewater treatment plant (WWTP) was constructed at the Thanh Liet dam to treat the wastewater of the To Lich River's water before rejecting to the The Nhue River. One factor needs to be established for this management alternative is the change in amounts of materials and micro-organisms before and after treatment by WWTP (treatment efficiency). Such a change is evaluated as the content ratios between treated and untreated wastewater and shown in Table 5 – the ratios were manipulated from the study of Servais et al. (1999). Moreover, because sewer system in Ha Noi collected both wastewater and rainwater, the scenario was assessed under dry and rainy conditions. For the dry period, the treatment volume was set up as 90% of the total water input. Correspondingly, during the rainy period treatment volume was taken as 50% of the total river water input. To Lich discharges were set as 5.82 and 15 m^3/s in dry and rainy conditions, respectively. The seasonal variation is not considered here because in this river portion, hydrology is strictly regulated by human and therefore barely dependent from hydrology of the watershed as a whole.

Reduce the discharge of the To Lich water

Based on the calculation of current load allocations and water quality standards (Table 4), the discharge reduction by one third was selected for calculation since it would apparently reduce NH4 closely to the allowable loadings.

Increase the upstream discharge of the Nhue River (polluted water flushing)

For this alternative, the upstream discharge was set at of 50 (m^3/s) – this value is the maximum possible discharge not causing flooding in the watershed. The increase of discharge dilutes the pollutant contents to meet standards. Because the water discharges applied for these management alternatives are different, the simulation results are shown in concentration units instead of loading for an easy comparison (Table 6). The results of this exercise indicate that the first and second methods would lead to similar outcomes since most parameters met the standards. For the third alternative, the two parameters NH4 and SS did not meet the standards. Therefore, load allocations were computed for the first two management alternatives (three scenarios) and represented in Table 7. For the treatment in dry period, the WLA of NH4 and BOD were equal to only one third and a half of the present WLA, respectively. For the other two scenarios, after the loadings were normalised by discharge for comparing with present average flow condition, the WLA of NH4 and BOD of these two scenarios were equal or less than a half of the present WLA. Therefore, in order to meet the water quality standards, the point source loadings of the pollutants BOD and NH4 should be diminished by at least twice of the current loadings, respectively.

Table 4: The Total Maximum Daily Load (TMDL), the current Wastewater Load Allocation (ΣWLA), and the current Load Allocation (ΣLA)

Environmental parameters	Surface water standards for purposes other than domestic water supply (mg /l)	TMDL (ton/d)	Current LA	Current WLA
BOD	< 30	70.1	64.2	62.8
DO	> 2	5.6	14.9	0.7

SS	< 80	224.2	156.0	38.0
NH4+ (as N)	< 1.5	4.2	1.7	6.3
NO3-(as N)	< 3.4	9.5	1.6	0.2

Bold: Current loads do not meet the Vietnamese standards for surface water

Table 5: Fractions of contents of nutrients, organic matter and organisms between treated and untreated wastewater employed in the treatment scenario

No	Variable	Ratio	No	Variable	Ratio
1	Phytoplankton	1.00	7	Nitrifying bacteria	0.65
2	Dissolved degradable organic matter	0.30	8	NH4	0.53
3	Particulate degradable organic matter	0.09	9	NO3	33.90
4	Inert particulate organic matter	0.19	10	PO4	0.99
5	Inert dissolved organic matter	0.94	11	pH	1.00
6	Heterotrophic bacteria	0.13	12	DO	1.00

Table 6: Water quality indicators at different management alternatives simulated by the ecological model

Parameters	Unit	Sim. Treated of TL water dry	Sim. Treated of TL water rainy	Reduce TL disch.	Ups. Disch. 50 m^3/s
BOD5	mg/l	30.6	25.2	33.8	30.4
DO	mg/l	6.1	4.9	5.7	6.0
SS	mg/l	59.7	62.4	58.2	96.7
NH4+ (as N)	mg/l	1.4	1.4	1.4	1.6
NO3-(as N)	mg/l	2.9	1.2	0.7	0.7

Bold: The indicators do not meet the Vietnamese standards for surface water

Table 7: Allocations of loadings at accepTable management alternatives for two parameters NH4 and BOD; MOS is taken implicitly as 7% of TMDL

	Treated in dry period		Treated in rainy period		Decrease To Lich's flow	
	BOD	NH4	BOD	NH4	BOD	NH4
TMDL(ton/d)	85.8	3.8	90.5	5.0	83.4	3.4
LA (ton/d)	49.8	1.2	44.2	0.5	58.8	1.4

WLA (ton/d)	30.0	2.4	39.9	4.2	18.8	1.8

5. Conclusion

With the help of the modelling tool, the pollutant load reduction requirements were determined according to the TMDLs and allocated to each parameter. The requirements show that the current environmental state failed to meet the TMDL goals for BOD, DO, and NH4. From this evaluation, the followings were concluded and recommended to satisfy/achieve the TMDLs from the current environmental state:

1. The existing runoff and flow regime of the Nhue River can no longer cope with the untreated domestic wastewater loads of more than 3 million people in Ha Noi city today.
2. The organic matter in the To Lich's wastewater need to be minimised and a WWTP for To Lich water treatment is highly recommended.
3. If recommendations 1 and 2 are not used, two third of the current To Lich water discharge should be diverted to other water bodies, for instance the Red River, in order to stop pollution in the Nhue water. This diversion would not alter the environmental state of the Red River because the very high discharge in the Red River (average 3577 m^3/s; Quynh et al., 2005) would greatly dilute To Lich domestic wastewater.

This evaluation implies that the management alternatives should be proposed and evaluated based on the water quality criteria, practical aspects, and a calibrated model which then identify the Best Management Practice (BMPs) among possible alternatives, allowing the TMDL program to be complemented more effectively.

It is concluded that there are straight-forward means of alleviating the problem and that this is shown by a combination of measurement (with hydrochemical interpretation such as end-member mixing analysis), laboratory experimentation of rates of change in pollution with contaminated sediment loading and modelling.

References

Abbott, 1979 - Abbott M. B. (1979) Computational hydraulics: Elements of the theory of free surface flows. Pitman London.

Ambrose et al. 1988 - Ambrose R.B. Jr., Wool T.A., Connolly J.P. and Schanz R.W. (1988). WASP4, A Hydrodynamic and Water Quality Model--Model Theory, User's Manual and Programmer's Guide, Report EPA/600/3-87/039, U.S. EPA, Athens, GA, USA.

ATV, 1996 - ATV (1996) Allgemein verfuegbares Gewaesserguetemodell. Projektabschlussbericht 02 WA9104/4. ATV, Hennef, Germany.

Beck, 1987 - Beck M.B. (1987) Water Quality modelling: a review of analysis of uncertainty. Water resource research 23(8), 1393-1442.

Bedford et al., 1988 - Bedford K., Findikakis A., Larock B.E., Rodi W. and Street R.L. (1988) Turbulence modeling of surface water flow and transport. J. Hyd. Eng. 114(9), 970-1073.

Boling et al., 1975 - Boling, R.H., Petersen, R.C. and Cummins, K.W. (1975). Ecosystem modeling for small woodland streams. In: Systems Analysis and Simulation in Ecology, B.C. Patten (ed.), Vol. III, Academic Press, New York, 183-204.

Brown and Barnwell, 1987 - Brown L.C. and Barnwell T.O. (1987) The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual, Report EPA/600/3-87/007, U.S. EPA, Athens, GA, USA.

Cerco and Cole, 1995 - Cerco C.F. and Cole T. (1995) User's guide to the CE-QUAL-ICM three dimensional eutrophication model, release version 1.0, Technical Report EL-95-15, US Army Eng. Waterways Experiment Station, Vicksburg, MS, USA.

Cu and Cham, 2006 - Cu N.V., Cham D.D., 2006. Planning and implementation of the Nhue-Day River survey (In Vietnamese). Final report, Ministry of Natural Resources and Environment.

DHI 1992 - DHI (1992) MIKE11 User Manual. Danish Hydraulic Institute, Denmark.

Ha Nam DONRE (Department of Natural Resource and Environment), 2006. Annual report of environmental situation (unpublished).

HEC 1986 - HEC (1986) HEC-5 Simulation of Flood Control and Conservation Systems, Appendix on Water Quality Analysis, Report CPD-5Q, Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA, USA.

Wallingford, UK; Wallingford Software 1994 - Wallingford software (1994) SalmonQ - User Documentation Version 1.01. Wallingford, Oxfordshire, UK.

Cu Nguyen Van, 2005 Concluding report of the national scientific research program on the Nhue Day River System. Institute of geography, Viet Nam Academy of Science and Technology (in Vietnamese).

Ivanov et al., 1996 - Ivanov P., Masliev I., De Marchi C. and Somlyódy L. (1996) DESERT - Decision Support System for Evaluating River Basin Strategies, User's Manual. International Institute for Applied Systems Analysis, Laxenburg, Austria.

JICA (Japan International Cooperation Agency), 1995. The study on Urban Drainage and Wastewater Disposal System in Ha Noi city, Final report.

Mahmood and Yevjevich, 1975 - Mahmood K. and Yevjevich V. (1975) Unsteady Flow in Open Channels. Vol. 1. Water Resource Publications, Littleton, CO, USA.

McAvoy et al., 2003 - McAvoy D.C., Masscheleyn P., Peng C., Morrall S.W., Casilla A.B., Lim J.M.U., Gregorio E.G., 2003. Risk assessment approach for untreated wastewater using the QUAL2E water quality model. Chemosphere 52, 55–66.

Naot and Rodi, 1982 - Naot D. and Rodi W. (1982) Calculation of secondary currents in channel flow. J. Hyd. Div. 108(HY8), 948-968.

Ngo Ngoc Cat, 2001 - Ngo Ngoc Cat (2001) De an Phap Viet: Nghien cuu tai nguyen nuoc o Viet Nam voi trong diem chat luong nuoc, che do thuy van va da dang sinh hoc cua he thong song To Lich-Nhue. Institute of geography, National Center for Natural Science and Technology (in Vietnamese).

Quynh et al., 2005 - Quynh L.T.P., Billen G., Garnier J., Thiery S., Fezard C., Minh C.V., 2005. Nutrient (N, P) budgets for the Red River basin (Viet Nam and China). Glob. Biogeochem. Cyc. 19, GB2022.

Rauch, 1998 - Rauch W, Henze M., Koncsos L., Reichert P., Shanahan P., Somlyódy L. and Vanrolleghem P. (1998) River water quality modelling : I.state of the art.

Reichert, 1998 - Reichert (1998) AQUASIM 2.0 User Manual. Swiss Federal Institute for Environmental Science and Technology (EAWAG).

Rodi, 1993 - Rodi W. (1993) Turbulence Models and their Application in Hydraulics, 3rd ed., IAHR/AIRH Monograth, Balkema, Rotterdam.

Servais et al. 1999 - Servais P., Garnier J., Demarteau N., Brion N., and Billen G. (1999) Supply of organic matter and bacteria to aquatic ecosystems through waste water effluents. Water research 33(16), 3521-3531.

Somlyódy and van Straten, 1986 - Somlyódy, L. and van Straten, G. (1986) Modelling and Managing Shallow Lake Eutrophication. Springer Verlag, Berlin.

Streeter and Phelps, 1925 - Streeter, W.H. and Phelps, E.B. (1925), A study of the pollution and natural purification of the Ohio River, Public Health Bull. 146, U.S. Public Health Service, Washington D.C.

The General Statistic Directorate, 2005 Annual Report. Statistics department.

Trinh et al., 2006b - Trinh A.D., Akamatsu Y., Ikeda S., Le L.A., Vu D.L., 2006b. Application of a 2—D numerical model for computing suspended sediment and nutrients transports to Nhue River (Ha Noi, Viet Nam). Ann. J. of Hydr. Eng. JSCE 50, 19-24.

Aalderink et al., 1995 - Aalderink R.H., Klaver N.J. and Noorman R. (1995) DUFLOW V 2.0: Micro-computer package for the simulation of 1-dimensional flow and water quality in a network of open water courses. Modelling water quality and flow in river Vecht using DUFLOW. In: Water Quality Modeling, Proceedings of the International Conference on Water Quality Modeling, Heatwole C. (ed.), ASAE, Orlando, FL, USA 416-426.

USEPA, 1999 - USEPA, 1999. Protocol for Developing Nutrient TMDLs, EPA 841-B-99-007.

VEPA, 2005. Environmental assessment report of the Nhue-Day River system. Viet Nam Environmental Protection Agency (VEPA) (in Vietnamese).

VEPA, 2006. Environmental assessment report of the Nhue-Day River system. Viet Nam Environmental Protection Agency (in Vietnamese).