2.5 Water Quality

In this section, the results of water quality monitoring and water quality modeling are described. In the course of the Study, the Study Team carried out eight periodical monitoring and three longitudinal simultaneous monitoring surveys, with the objectives of: 1) to understand the current water quality condition around the Mak Hiao River basin, and 2) to conduct the water quality modeling of the Mak Hiao River basin. The Study Team also conducted a site visit to the existing factories to know how the industrial wastewater is treated and/or discharged to public water bodies in the Study Area.

Based on the survey results mentioned above, the Study Team conducted water quality modeling, and projected the pollution load runoff and natural purification in Mak Hiao River basin for the present (2009) and the target year (2020)

2.5.1 Methodology of Water Quality Monitoring

(1) Periodical Monitoring

(a) Monitoring Points

The monitoring points were selected focusing on the mainstream of Mak Hiao River and its major tributaries, Hong Ke and Hong Xeng. The selected monitoring points consist of six main monitoring points and nine sub-monitoring points, totaling fifteen points, as shown in **Table 2.5.1, Fig. 2.5.1** and **Fig. 2.5.2**.

At the main monitoring points, the analysis was conducted for all parameters including heavy metals and pesticides. At the sub-monitoring points, it was targeted at the parameters other than heavy metals and pesticides. The analyzed parameters are enumerated in **Table 2.5.4**.

Table 2.5.1 Number of Points for Periodical Monitoring

Symbol	Classification	Number of points
MP	Main monitoring points	6
SP	Sub monitoring points	9
	Total	15

Details about the location and monitoring purpose for the fifteen points are tabulated in **Table 2.5.2**. Of the fifteen points, MP1, MP2, MP3, SP3, SP 6, SP7, SP8 and SP9 (eight points in total) are the same as those of WERI-WREA.

Table 2.5.2 Location of Periodical Monitoring Points

No.	Monitoring Point	Monitoring Purpose
MP 1	Downstream end of Hong Xeng	To check water quality of major channel
MP 2	Downstream end of Hong Ke	Ditto
MP 3	Upstream end of That Luang Marsh	Ditto
MP 4	Upstream end of Na Khay Marsh	To measure natural purification function by the marsh
MP 5	Downstream end of Na Khay Marsh	Ditto
MP 6	Confluence of the Mekong River and Mak Hiao River	To measure natural purification function by the river
SP 1	Downstream end of Hong Wattay	To check water quality of tributaries of Hong Xeng
SP 2	Downstream end of Nam Pasak	To check water quality of tributaries which drain suburban and/or rural areas
SP 3	Downstream end of Hong Pasak	To check water quality of tributaries of Hong Xeng
SP 4	Downstream end of Hong Thong	To check water quality of tributaries of Hong Ke
SP 5	Downstream end of Hong Khoua Khao	Ditto
SP 6	Downstream end of Hong Kai Keo	Ditto
SP 7	Midstream of Hong Ke	To check water quality of major channel
SP 8	Downstream end of Hong Ouay Louay	To check water quality of tributaries of Hong Ke
SP 9	Downstream end of That Luang Marsh	To measure natural purification function by the marsh

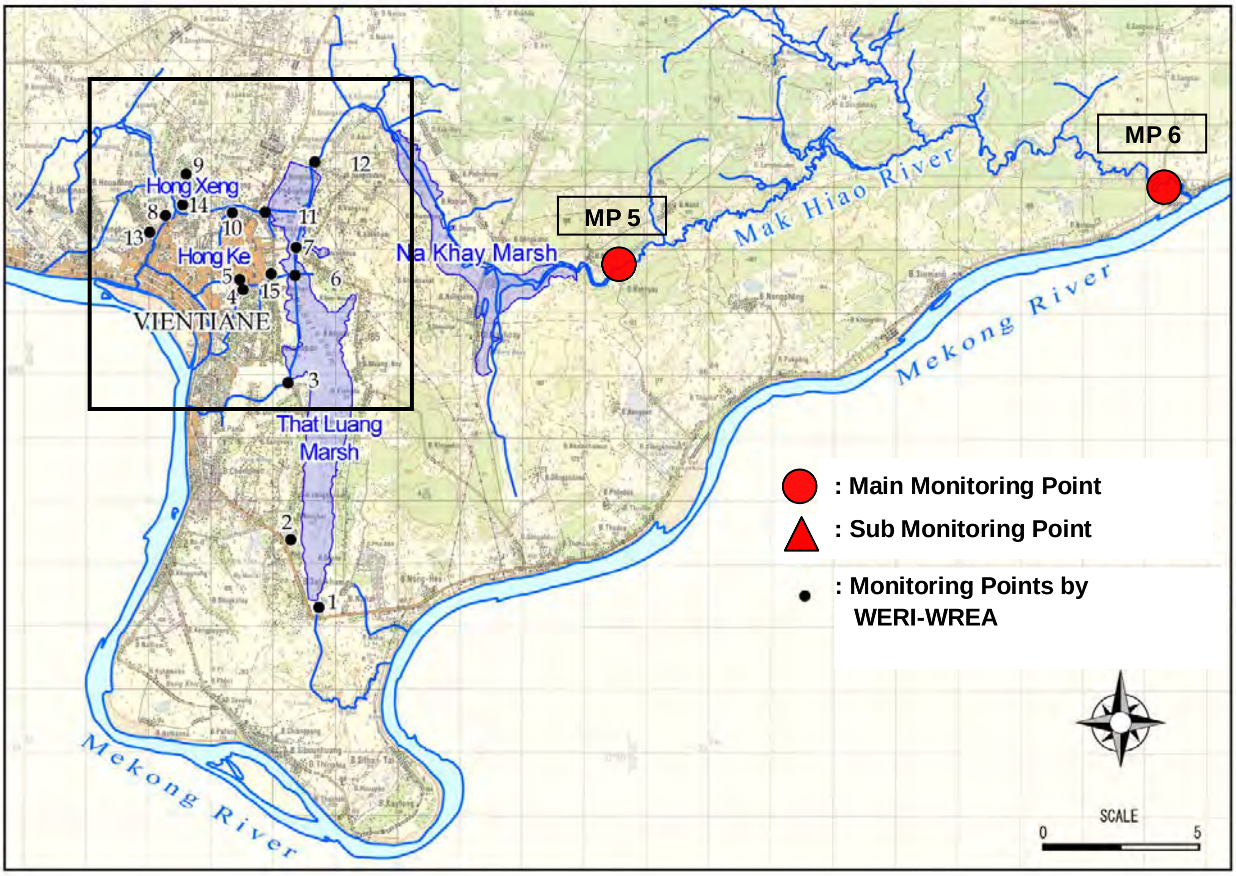


Fig. 2.5.1 Location of Periodical Monitoring Points (1/2)

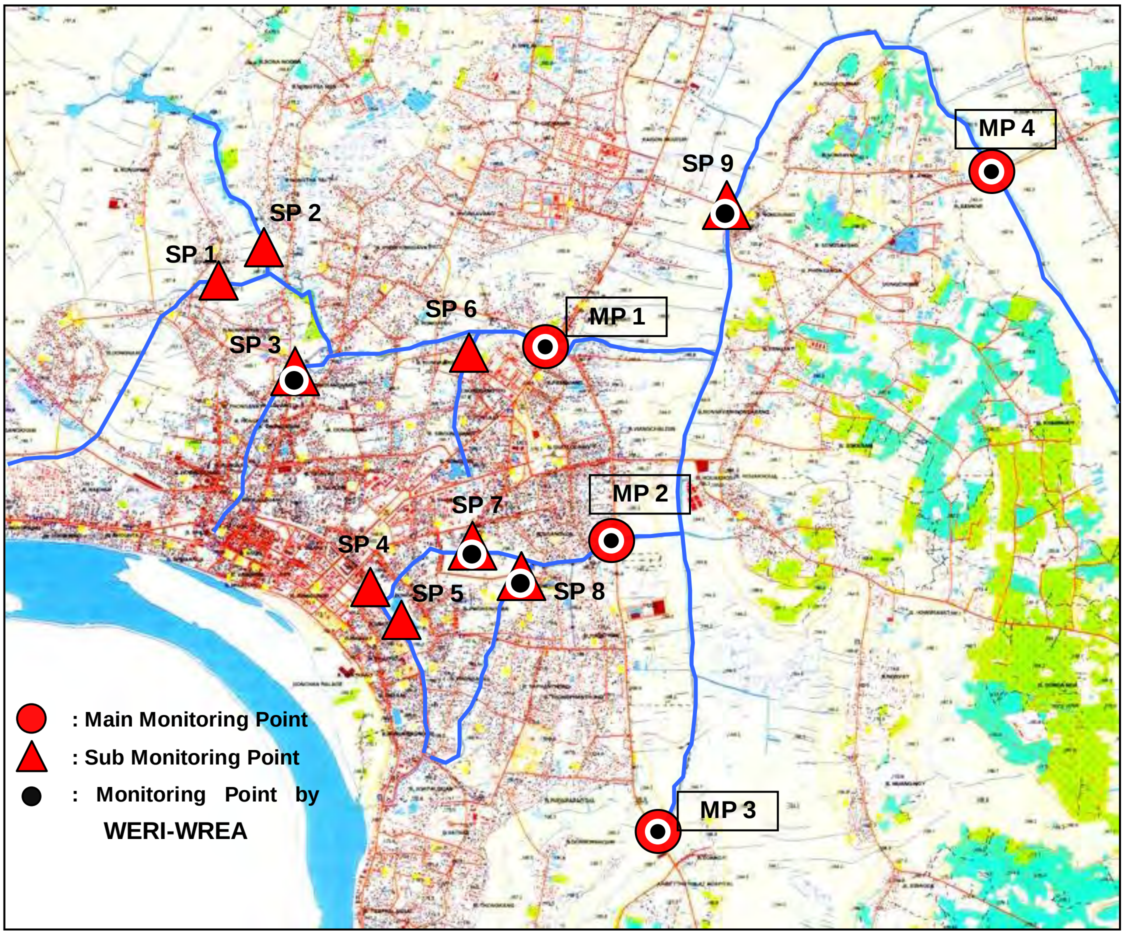


Fig. 2.5.2 Location of Periodical Monitoring Points (2/2)

(b) Frequency of Monitoring

Periodical monitoring were carried out eight times from 2009 to 2010, namely, six times in the dry season (November to April) and two times in the rainy season (May to October), as shown in **Table 2.5.3**.

Table 2.5.3 Frequency of Periodical Monitoring

Month / Year	Dry season				Rainy season						Dry season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009		X	X			X					X	X
2010		X					X				X	

(c) Analysis Method and Items

In principle, water quality was analyzed by utilizing potable equipment. A reliable laboratory in Lao PDR or Thailand conducted the analysis for such parameters as BOD, SS, total/fecal coliform, heavy metals (six items) and pesticide (three items).

At the main monitoring points (six points), the analysis was conducted for all parameters as shown in **Table 2.5.4**. However, at the sub-monitoring points (nine points), only the parameters other than heavy metals and pesticides were analyzed, as also shown in **Table 2.5.4**.

Table 2.5.4 Water Quality Parameters and Methods of Periodical Monitoring

Group	Classification	Parameters	Analysis Methods	Analytical Equipment	Monitoring Points
I	Streamflow	Depth and width of flow, velocity	Field measurement	Potable electro-magnetic velocity meter (KENEK/VE20)	15 points (SP and MP)
II	Field observation items	Odor, color, air temperature	ditto	Surveyor	
III	Basic items	(1) pH, EC, turbidity, DO, water temperature, TDS, ORP	ditto	Potable equipment (Horiba Multi Water Quality Checker U-50)	
		(2) NH_3-N, NO_2-N, NO_3-N, PO_4-P, hardness, sulfide, acidity, alkalinity, Zn, Fe, Mn	ditto	Potable equipment (HACHCEL/850)	
IV	Organic pollutants	(1)COD_{Mn}	ditto	Pack test (WAK-COD)	
		(2)BOD, SS, total coliform, fecal coliform	Analysis in Laboratory	WREA-WERI or a laboratory in Thailand: BOD:Azide modification method SS :Total suspended solids dried at 103-105 degree Celsius Total/fecal coliform:Multiple tube fermentation technique	
V	Heavy metals	Cadmium(Cd), Mercury(Hg), Selenium(Se), Lead(Pb), Arsenic(As), Hexavalent Chromium (Cr^{6+})	ditto	A laboratory in Thailand: Cd,Pb:Nitric acid digestion and direct air-acetylene flame method Hg : Cold vapor atomic absorption spectrometric method Pb :Nitric acid digestion and inductively coupled plasma method Se,As:Hydride generation AAS method Cr^{6+} :Colorimetric method	6 points (MP only)
IV	Pesticides	Simazine, Thiram, Thiobencarb	ditto	A laboratory in Thailand: Simazine:Gas chromatography/mass spectrometric method Thiram :High performance liquid chromatographic method Thiobencarb:Gas chromatographic method	

(2) Longitudinal Simultaneous Monitoring

In addition to the periodical monitoring, longitudinal simultaneous monitoring was carried out from June 2009 to evaluate the longitudinal water quality variation and natural purification function of Hong Ke and Hong Xeng and their tributaries.

(a) Monitoring Points

Monitoring points are 23 in total, as shown in **Table 2.5.5** and **Fig. 2.5.3**. Details of locations are shown in **Table 2.5.6**

Table 2.5.5 Number of Points for Longitudinal Variation Monitoring

Symbol	Classification	Number of Points
LA	Hong Ke and its tributaries	9
LB	Hong Xeng and its tributaries	14
	Total	23

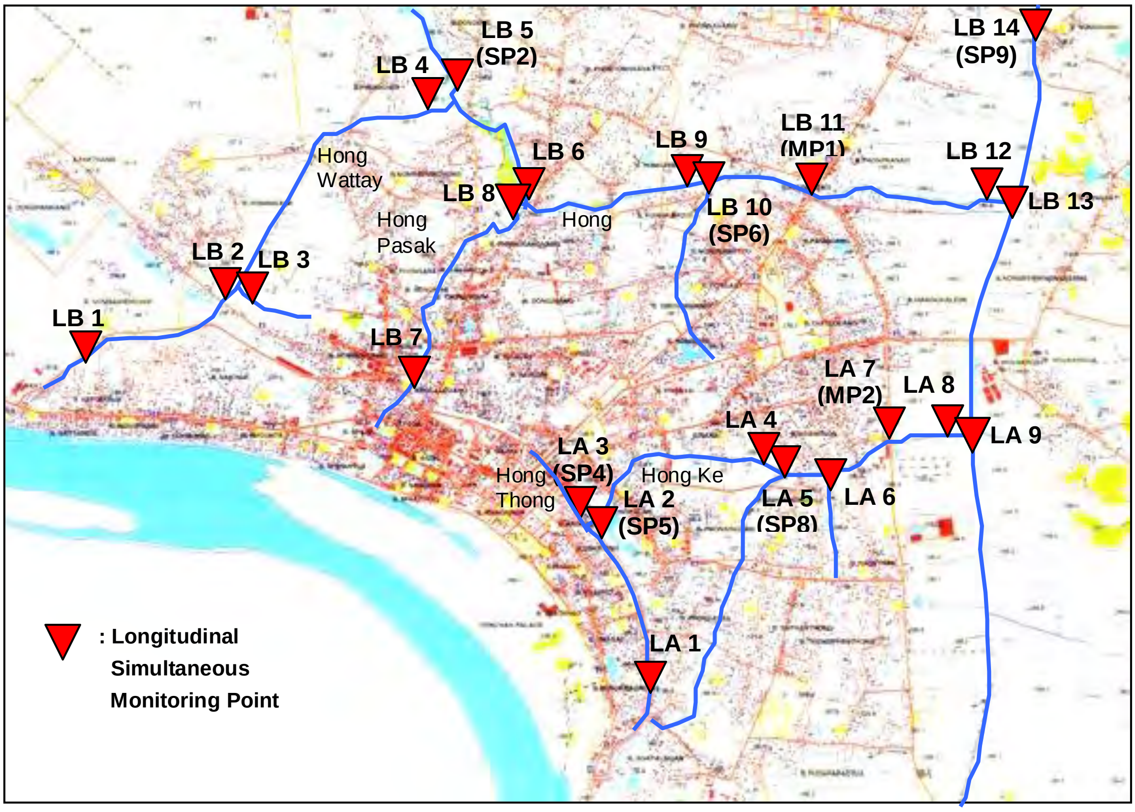


Fig. 2.5.3 Location of Longitudinal Simultaneous Monitoring

Table 2.5.6 Location of Longitudinal Simultaneous Monitoring

No.	Monitoring Point	Remarks
LA-1	Upstream end of Hong Khoua Khao	
LA-2	Downstream end of Hong Khoua Khao	Same location of SP 5
LA-3	Downstream end of Hong Thong	Same location of SP 4
LA-4	Confluence of Hong Ouay Louay and Hong Ke	
LA-5	Downstream end of Hong Ouay Louay	Same location of SP 8
LA-6	Downstream end of Hong Phone Thanh	
LA-7	Downstream of Hong Ke (Hong Ke Bridge)	Same location of MP 2
LA-8	Downstream end of Hong Ke (at the confluence with That Luang Marsh)	
LA-9	That Luang Marsh at downstream end of Hong Ke	
LB-1	Upstream end of Hong Wattay	
LB-2	Confluence of a tributary and Hong Wattay	
LB-3	Downstream end of a tributary of Hong Wattay	
LB-4	Confluence of Nam Pasak and Hong Wattay	
LB-5	Downstream end of Nam Pasak	Same location of SP 2
LB-6	Confluence of Hong Pasak and Hong Xeng	
LB-7	Upstream end of Hong Pasak	
LB-8	Downstream end of Hong Pasak	
LB-9	Confluence of Hong Kai Keo and Hong Xeng	
LB-10	Downstream end of Hong Kai Keo	Same location of SP 6
LB-11	Downstream of Hong Xeng (Hong Xeng Bridge)	Same location of MP 1
LB-12	Downstream end of Hong Xeng (at the confluence with That Luang Marsh)	
LB-13	That Luang Marsh at downstream end of Hong Xeng	
LB-14	Downstream end of That Luang Marsh	Same location of SP 9

(b) Frequency of Monitoring

The longitudinal simultaneous monitoring was conducted three times: two times in the dry season (November to April) and one time in the rainy season (May to October), as shown in **Table 2.5.7**.

Table 2.5.7 Frequency of Longitudinal Monitoring

Month / Year	Dry Season				Rainy Season						Dry Season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009						X					X	
2010											X	

(c) Analysis Method and Items

In principle, water quality was analyzed by utilizing portable equipment. A reliable laboratory in Thailand conducted the analysis for BOD and SS. The objective parameters and the analysis method are described in **Table 2.5.8**.

Table 2.5.8 Water Quality Parameters and Methods of Longitudinal Monitoring

Group	Classification	Parameters	Analysis Methods	Analytical Equipment
I	Streamflow	Depth and width of flow, velocity	Field measurement	Portable electro-magnetic velocity meter (KENEK/VE20)
II	Field observation items	Odor, color, air temperature	ditto	Surveyor
III	Basic items	(1) pH, EC, turbidity, DO, water temperature, TDS, ORP	ditto	Potable equipment (Horiba Multi Water Quality Checker U-50)
		(2) NH_3-N, NO_2-N, NO_3-N, PO_4-P	ditto	Portable equipment (HACHCEL/850)
IV	Organic pollutants	(1) COD_{Mn}	ditto	Pack test (WAK-COD)
		(2) BOD, SS	Analysis in Laboratory	A laboratory in Thailand: BOD:Azide modification method SS :Total suspended solids dried at 103-105 degree Celsius

2.5.2 Monitoring Results

(1) Periodical Monitoring

The results of periodical monitoring are as described below:

(a) Streamflow

Fig. 2.5.4 shows the seasonal variation of streamflow at 15 monitoring points. According to the figure, at SP1, SP3 to SP8 and MP3, which are located at up/middle stream of Hong Ke, Hong Xeng and That Luang Marsh, or their tributaries such as Hong Pasak and Hong Wattay, the stream flow in the rainy season (June and July) was observed in about 1 to 5 times of that of the dry season (February, March, November and December).

On the other hand, at monitoring points such as SP2, SP9, MP1, MP2 and MP4 to MP6, which drain the large catchment area of Hong Ke and Hong Xeng or Mak Hiao mainstream, the streamflow of the rainy season increased to about 5 (at MP2) to 45 times (at SP2) of the dry season.

Considering monthly variation in the dry season, at MP4, MP5 and MP6, which are located at the downstream of Mak Hiao River, the streamflow in November was bigger than those of February and March, showing some impact of stormwater. However, in December, the impact of stormwater gradually decreased, and as a result, the streamflow was close to those of February and March.

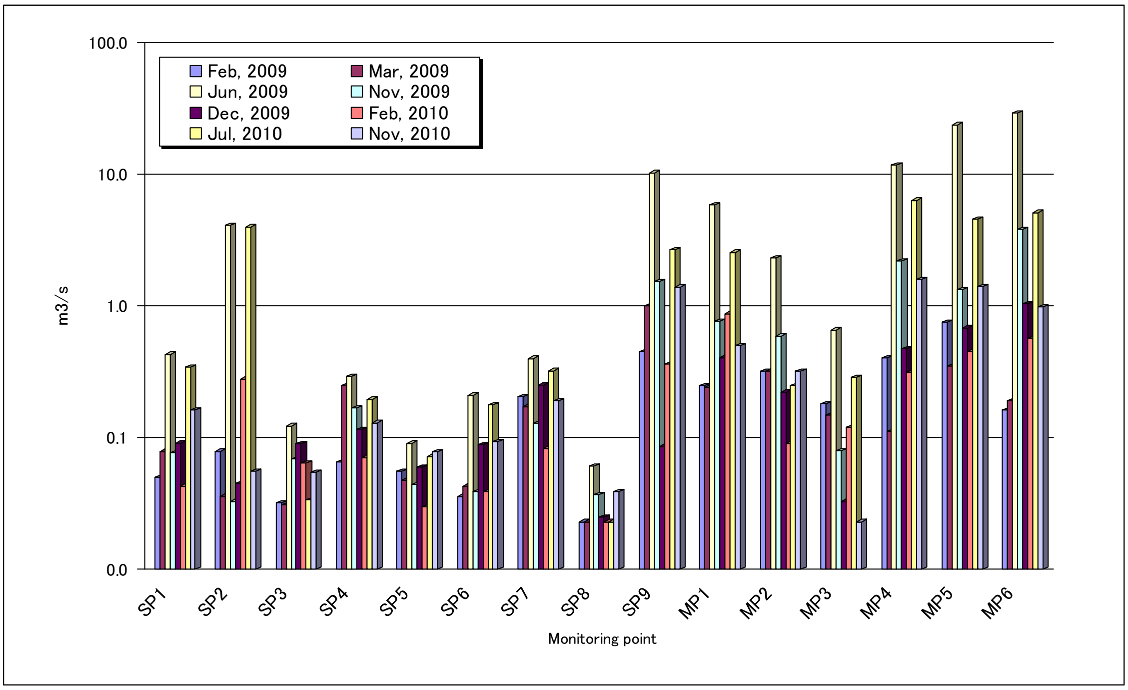


Fig. 2.5.4 Streamflow in Periodical Monitoring (Logarithmic Display)

(b) BOD, SS

BOD was analyzed by WERI-WREA in February and March 2009 and by a laboratory in Thailand from June 2009. The results of BOD from June 2009 to November 2010 are shown in the **Fig. 2.5.5** to **Fig. 2.5.10**.

At the middle- and downstream of Hong Ke and Hong Xeng, BOD gradually increased in the early dry season (November and December), compared with those in the rainy season (June and July). On the other hand, at MP5 and MP6, which are located at the downstream end of Mak Hiao River, not so high BOD ranging from less than 2.0 mg/l to 3.1 mg/l was continuously recorded. Thus the seasonal variation was not observed at these points.

The highest BOD of 32.6 mg/l was observed in November 2010 at the downstream end of Hong Pasak (SP3), followed by 29.2 mg/l in December 2009 at the downstream end of Hong Xeng (MP1) and 29.0 mg/l in February 2010 at SP3. In general all the results of BOD remained about 30 mg/l at a maximum.

As for SS, at the Hong Ke and Hong Xeng and their tributaries, values ranging from about 10 to 50 mg/l were observed. In contrast, at Mak Hiao River mainstream (MP4, MP5 and MP6), values ranging roughly from 40 to 100 mg/l were observed. The highest SS was observed at the upstream end of That Luang Marsh (MP3) in February 2010 with value of 198 mg/l, followed by 184 mg/l in June 2009 at MP3 and 168 mg/l in December 2009 at MP5. These high values resulted not from organic pollutants but sand and silt coming from bare land and/or fields in the catchment areas (see **Fig. 2.5.11**).

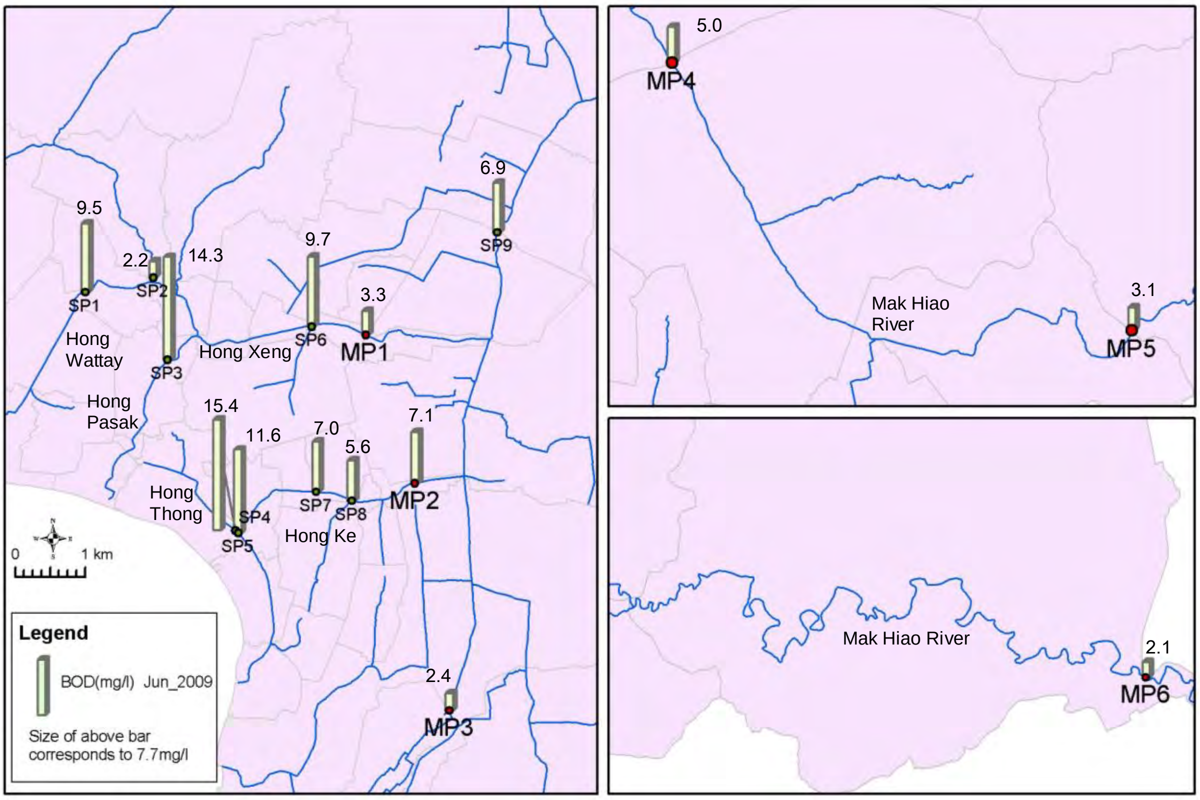


Fig. 2.5.5 Schematic Diagram of BOD in Periodical Monitoring (June 2009)

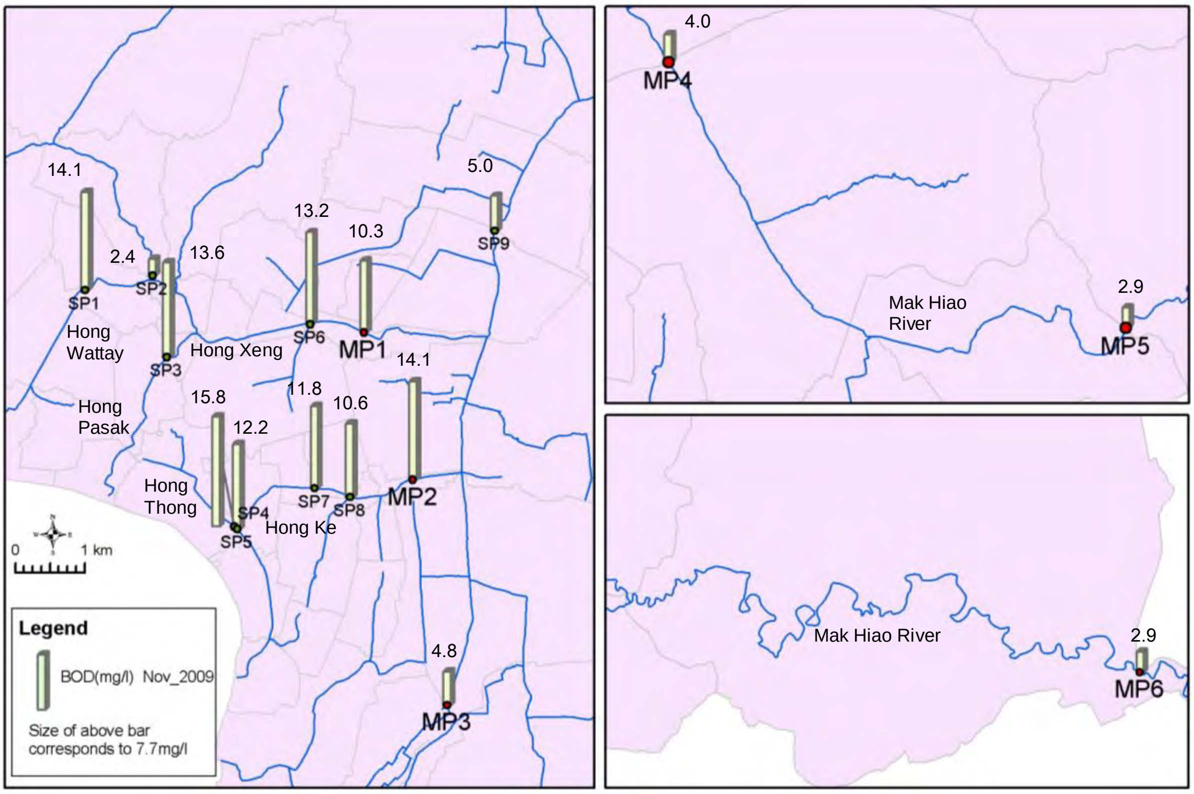


Fig. 2.5.6 Schematic Diagram of BOD in Periodical Monitoring (November 2009)

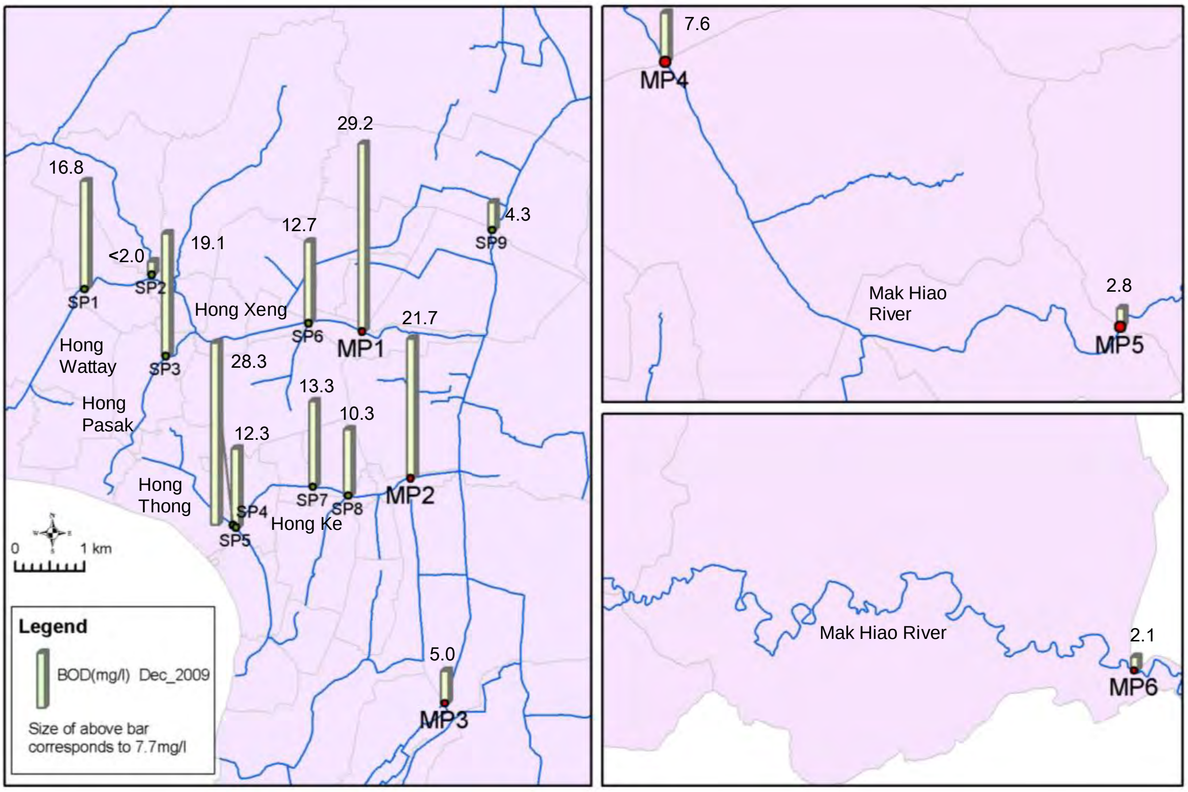


Fig. 2.5.7 Schematic Diagram of BOD in Periodical Monitoring (December 2009)

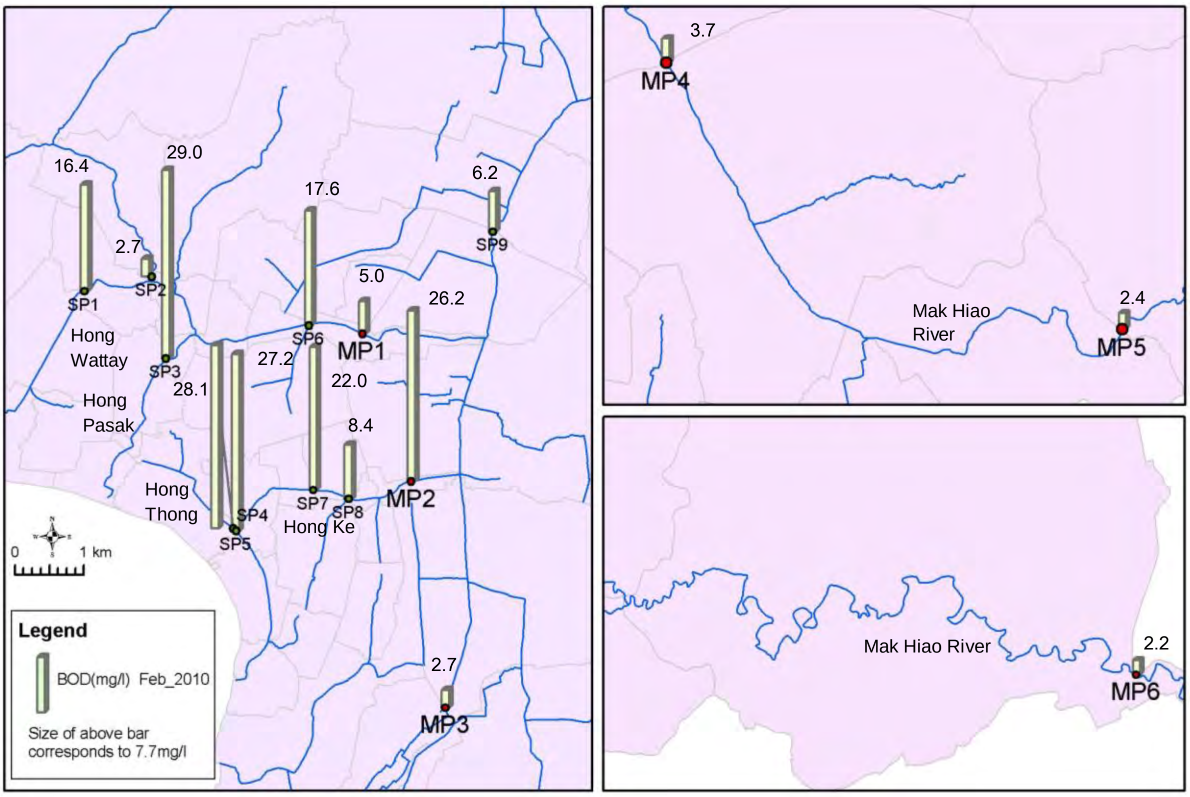


Fig. 2.5.8 Schematic Diagram of BOD in Periodical Monitoring (February 2010)

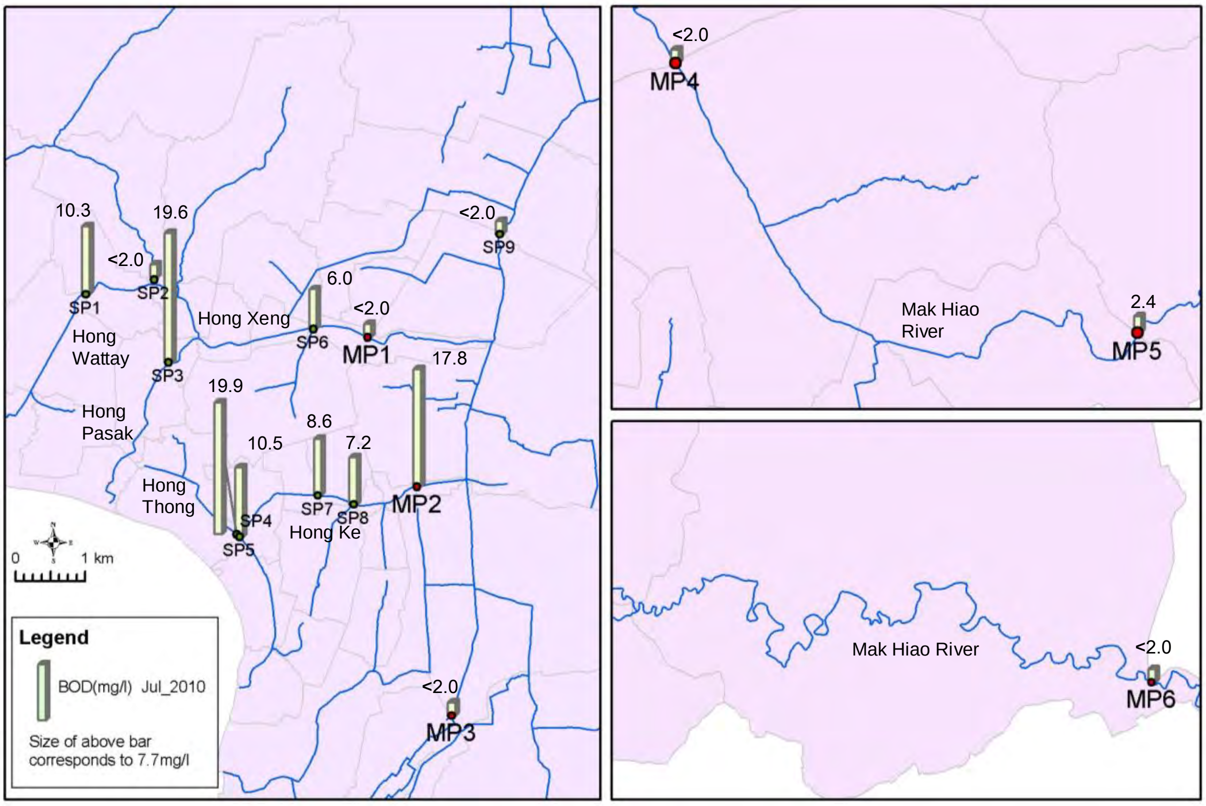


Fig. 2.5.9 Schematic Diagram of BOD in Periodical Monitoring (July 2010)

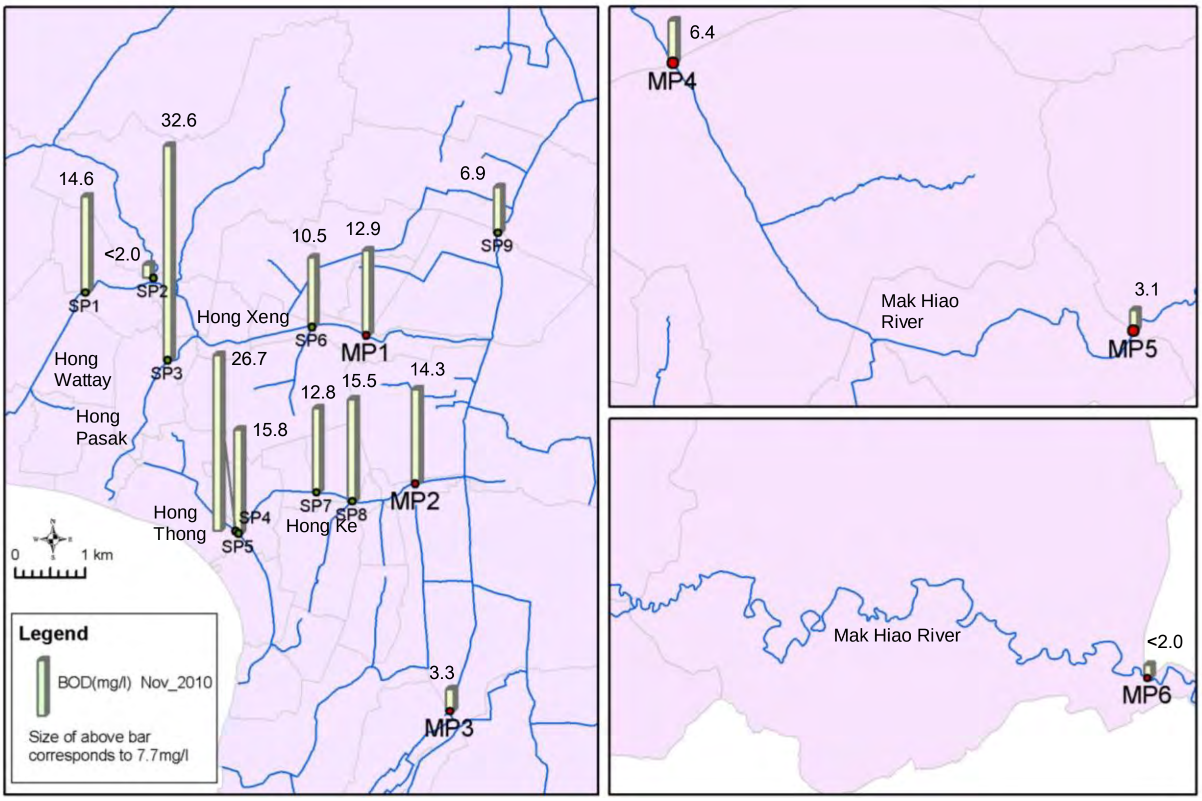


Fig. 2.5.10 Schematic Diagram of BOD in Periodical Monitoring (November 2010)

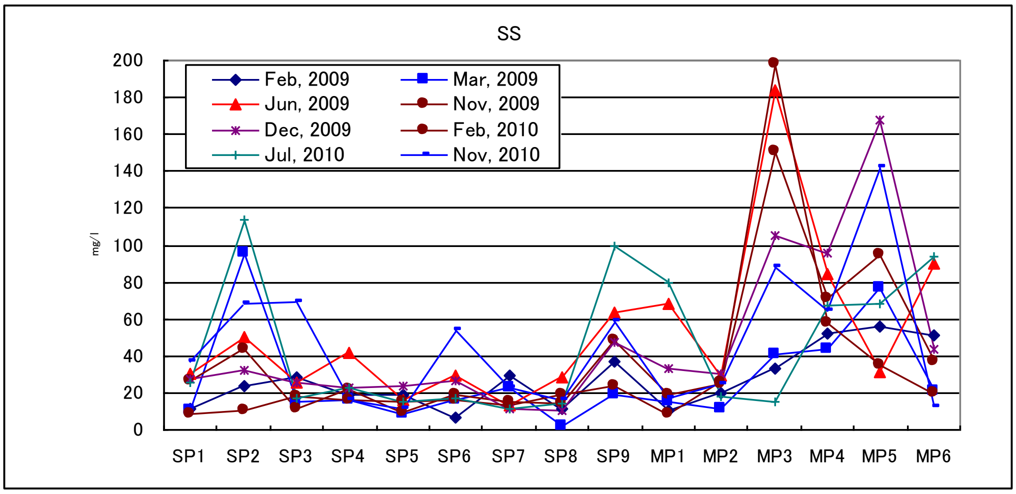


Fig. 2.5.11 SS observed in Periodical Monitoring

(c) Total and Fecal Coliform

The coliform numbers were analyzed by WERI-WREA in February and March 2009 and by a laboratory in Thailand from June 2009. **Fig. 2.5.12** presents the number of total and fecal coliform observed from November 2009 to November 2010. The result of June 2009 was not included in **Fig. 2.5.12** because the differences in coliform number were unclear due to the selection of dilution rate.

At the downstream end and tributaries of Hong Ke or Hong Xeng such as SP3, SP4, SP6, SP7 and MP2, total/fecal coliform were detected with the number of 100,000 MPN/100 ml or more even in the rainy season, which means the streamflow is dominated by domestic and commercial wastewater (according to *"Guidelines for Comprehensive Basin-wide Planning of Sewerage Systems",* Japan Sewage Works Association, influent total coliform number exceeds 100,000 MPN/100 ml in more than 60% of sewage treatment plants).

During the monitoring surveys from November 2009, only MP5 in November 2009 and MP6 in November and December 2009, as well as February and November 2010, achieved the surface water quality standard in Laos (less than 5,000 MPN/100 ml of total coliform and less than 1,000 MPN/100 ml of fecal coliform).

In the figure BOD value is also presented as a reference. At the monitoring points where the low BOD (about less than 5.0 mg/l) was observed, the total/fecal coliform number was also small as a whole and thus the correlation between BOD and total/fecal coliform was given to some extent.

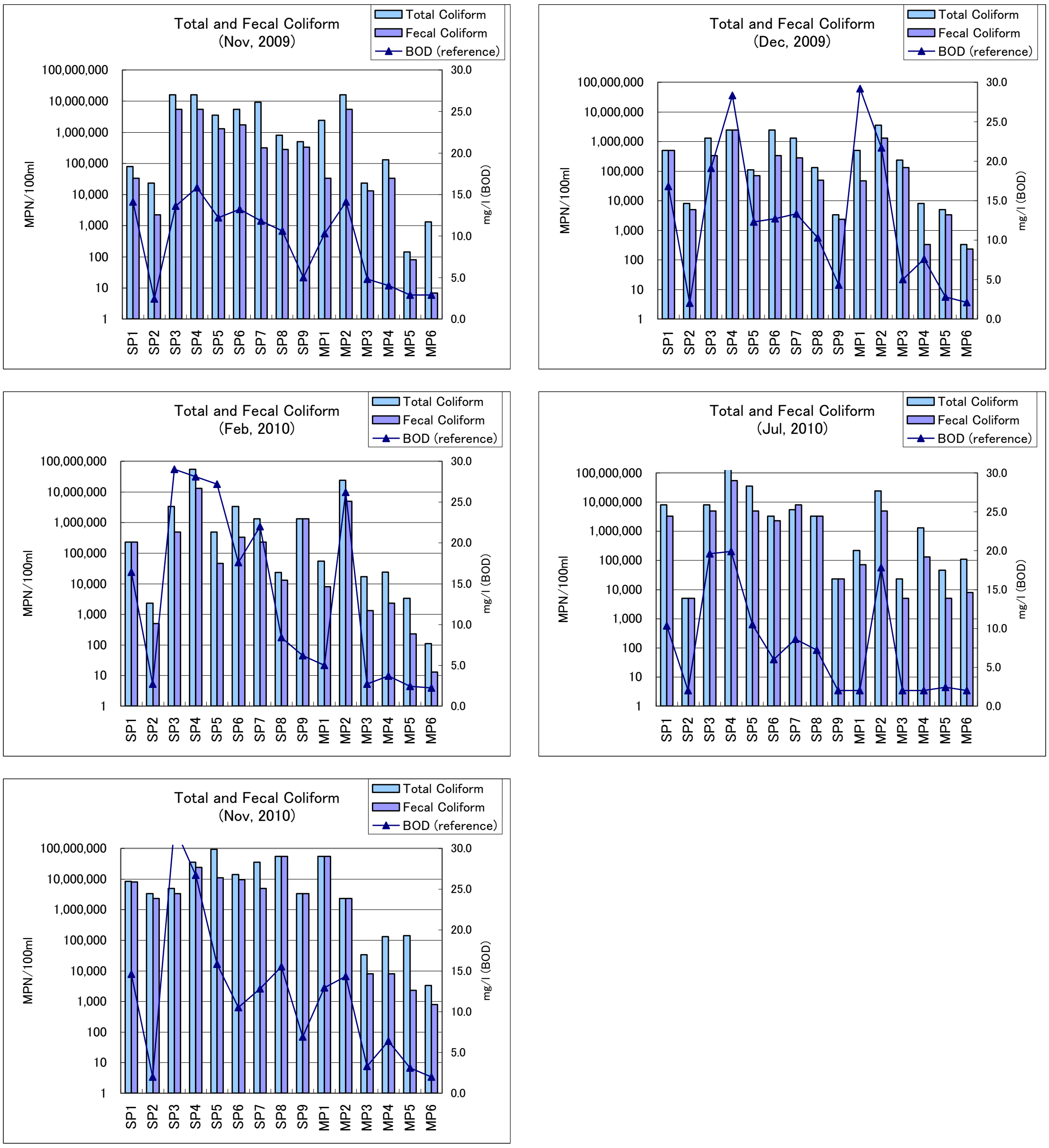
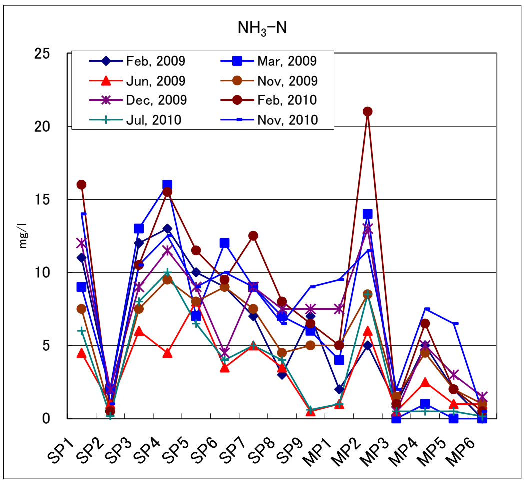


Fig. 2.5.12 Total and Fecal Coliform in Periodical Monitoring

(d) Nitrogen and Phosphorus

As shown in **Fig. 2.5.13**, NH_3-N observed in up- and middle stream of Hong Ke and Hong Xeng as well as their tributaries were higher than those of the downstream of Hong Ke and Hong Xeng as well as Mak Hiao River mainstream as a whole. As with BOD, low concentration of NH_3-N at Mak Hiao River mainstream resulted from dilution effects.

Unlike NH_3-N, NO_3-N was less than 1.0 mg/l even at the monitoring points where high NH_3-N was observed, and variations between the monitoring points were not observed. This is because the time of flowing down from the source to the monitoring points in the tributaries of Hong Ke and Hong Xeng, is not enough for nitrification. Meanwhile, at the mainstream of Mak Hiao River, NO_3-N became lower, mainly due to dilution effects.



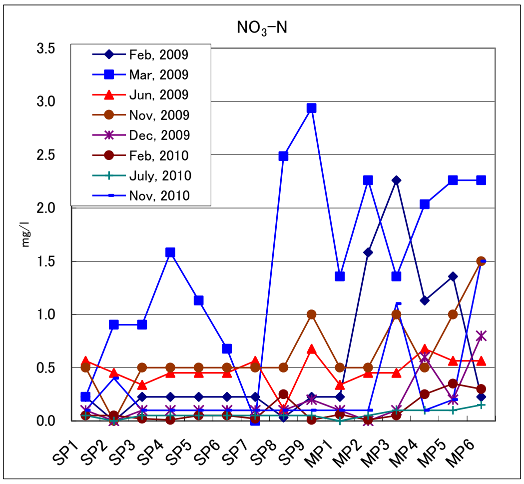


Fig. 2.5.13 NH_3-N and NO_3-N observed in Periodical Monitoring

Concerning phosphorus (PO_4-P), the concentration was observed with less than 1.0 mg/l as a whole, as shown in **Fig. 2.5.14**. Occasionally, however, relatively high concentrations ranging from 1.5 to 2.5 mg/l, were observed at some locations especially in the dry season. According to the longitudinal monitoring results discussed in the next subsection, the high concentration of SP1 might result from wastewater from a slaughterhouse located at the upstream of longitudinal monitoring point of LB3.

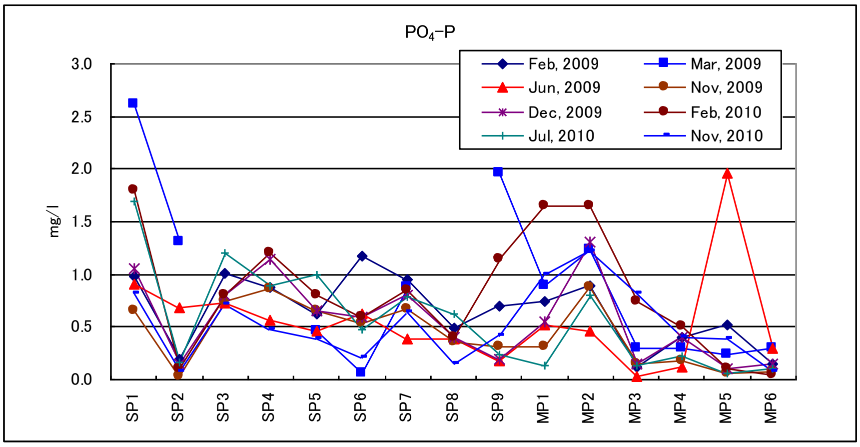


Fig. 2.5.14 PO_4-P observed in Periodical Monitoring

(e) Heavy Metals and Pesticides

As shown in **Table 2.5.9**, Cadmium (Cd), Selenium (Se) and Hexavalent Chromium (Cr^{6+}) were not detected (which means all the results were below detection limit) in all the monitoring surveys. Other metals (Mercury (Hg), Lead (Pb), Arsenic (As)], were occasionally detected but the concentrations were very low (within the proposed surface water quality standard in Lao PDR: Cd=0.005 mg/l, Hg=0.002 mg/l, Se=(no standard), Pb=0.050 mg/l, As=0.010 mg/l, Cr^{6+}=0.050 mg/l).

Table 2.5.9 Heavy Metals observed in Periodical Monitoring

No.	Parameters	Unit	2009				Detection Limit
			Feb	Mar	Jun	Nov	
(1)	Cadmium(Cd)	mg/l	<0.006	<0.006	<0.006	<0.006	0.006
(2)	Mercury(Hg)	mg/l	<0.0005	<0.0005	<0.0005	0.0006 -0.0011	0.0005
(3)	Selenium(Se)	mg/l	<0.0005	<0.0005	<0.0005	<0.0005	0.0005
(4)	Lead(Pb)	mg/l	<0.031	<0.031	0.005 -0.015	0.006 -0.019	1)
(5)	Arsenic(As)	mg/l	0.0022 -0.0036	0.0020 -0.0050	0.0004 -0.0020	<0.0003	0.0003
(6)	Hexavalent chrome(Cr^{6+})	mg/l	<0.006	<0.006	<0.006	<0.006	0.006

No.	Parameters	Unit	2009	2010			Detection Limit
			Dec	Feb	Jul	Nov	
(1)	Cadmium(Cd)	mg/l	<0.006	<0.006	<0.006	<0.006	0.006
(2)	Mercury(Hg)	mg/l	<0.0005	0.0005 -0.0012	0.0005 -0.0009	0.0007 -0.0030	0.0005
(3)	Selenium(Se)	mg/l	<0.0005	<0.0005	<0.0005	<0.0005	0.0005
(4)	Lead(Pb)	mg/l	0.016 -0.027	0.015 -0.018	<0.003	<0.003	1)
(5)	Arsenic(As)	mg/l	<0.0003 -0.0055	<0.0003 -0.0016	0.0009 -0.0024	0.0017 -0.0047	0.0003
(6)	Hexavalent chrome(Cr^{6+})	mg/l	<0.006	<0.006	<0.006	<0.006	0.006

Notes: Detection limit is changed due to the change of analysis method, as follows:
1) 0.031 mg/l for February and March, 2009 with method of nitric acid digestion and direct air-acetylene flame method
0.003 mg/l from June 2009 with method of nitric acid digestion and inductively coupled plasma method

As for pesticides, in all the monitoring surveys started from 2009, three parameters of pesticides (Simazine, Thiram and Thiobencarb) were below the detection limit; therefore, the monitoring of pesticides was omitted from June 2010.

Table 2.5.10 Pesticides observed in Periodical Monitoring

No.	Parameters	Unit	2009					2010	Detection Limit	Reference 3)
			Feb	Mar	Jun	Nov	Dec	Feb		
(1)	Simazine	μg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	≤ 3
(2)	Thiram	μg/l	<0.1	<0.1	<10.0	<10.0	<10.0	<10.0	1)	≤ 6
(3)	Thiobencarb	μg/l	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	2)	≤20

Notes: Detection limit is changed due to the change of analysis method, as follows.
1) 0.1 μg/l for February and March, 2009 with method of gas chromatography/mass spectrometric method
10.0 μg/l from June 2009 with method of high performance liquid chromatographic method
2) 0.1 μg/l for February and March, 2009 with method of high performance liquid chromatography/mass spectrometry/mass spectrometric method
0.5 μg/l from June 2009 with method of gas chromatographic method
3) Environmental quality standards for human health, Japan

(f) Others

The following characteristics were also found in the analysis results:

- *pH:* The pH values of the rainy season were lower than those of the dry season.
- *Turbidity*: At the monitoring points such as SP2, MP3 and MP5 where high SS was observed, turbidity was also high and thus correlation between these parameters was observed.

- *ORP:* At the SP4 and MP2 where high BOD was observed, ORP was less than zero, which indicated their anaerobic condition.
- *Alkalinity*: Alkalinity in the rainy season was also lower than those of the dry season as a whole.
- *Iron:* Concentration of iron (Fe) in the rainy season was higher than those of the dry season.

(2) Longitudinal Simultaneous Monitoring

Longitudinal simultaneous monitoring was conducted three times from June 2009 (June and November 2009, and November 2010). The monitoring results are characterized as follows:

(a) BOD, SS, Nitrogen and Phosphorus

As for BOD, the highest one was observed at LB3 with value of 362.0 mg/l in November 2009 as shown in **Fig. 2.5.16.** At LB3, very high BOD of 209.0 mg/l was also observed in November 2010, and further high BOD of 48.3 mg/l was observed even in the rainy season (June 2009), as shown in **Fig. 2.5.15** and **Fig. 2.5.17**.

In general, high BOD was observed at the monitoring points such as LB7 (upstream of Hong Pasak), LA3 (downstream end of Hong Thong) and LA8 (downstream end of Hong Ke), which are located at the tributaries or downstream of Hong Ke and Hong Xeng, with the maximum values of 37.6 mg/l, 28.0 mg/l and 27.9 mg/l, respectively. On the other hand, BOD was not so high at the mainstream of Mak Hiao River such as LB13 mainly due to dilution effect.

At LB3, where extremely high BOD was observed, extremely high SS, NH_3-N and PO_4-P were also observed. In November 2009, for instance, SS, NH_3-N and PO_4-P were observed with values of 262.0 mg/l, 34.0 mg/l and 6.70 mg/l, respectively. A slaughterhouse located at the upstream of LB3 must be a major pollution source. However, at LB4 which is located at the downstream of LB3, the concentration of BOD, SS, NH_3-N and PO_4-P were considerably recovered with the value of 11.9 mg/l, 17.9 mg/l, 8.5 mg/l and 0.49 mg/l, respectively. This is mainly due to the dilution effect (streamflow observed at LB3 and LB4 in November 2009 were 0.025 and 0.118 m^3/s, respectively). Moreover, NO_3-N at LB3 and LB4 were equivalent, 0.5 mg/l.

As for SS, the concentration ranging from about 20 to 50 mg/l was observed, excluding LB3.

(b) DO

Fig. 2.5.18 shows the monitoring results of DO. In the rainy season (June 2009), especially at LB8 and LA5 which are located at downstream of Hong Pasak and Hong Ouay Louay, extremely high DO was observed with values of 18.88 mg/l and 14.37 mg/l, respectively. In the dry season (November 2009), high DO with values of 18.71 mg/l and 17.84 mg/l were observed at LA4 and LB4.

These DO values reach the level of oversaturation. In general, the channels where high DO values were observed show similar characteristics such as shallow water depth (about less than 10 cm) and overgrowth of vegetation. Considering the conditions, the high DO seemed to result partly from surface aeration due to shallow water depth, and partly from oxygen supply brought about by the photosynthetic process in algae. At the monitoring points, high pH resulting from increased number of hydroxide ion (OH^-) due to the photosynthetic effect, were also observed.

On the other hand, at the monitoring points where high BOD was observed, low DO was observed as a whole.

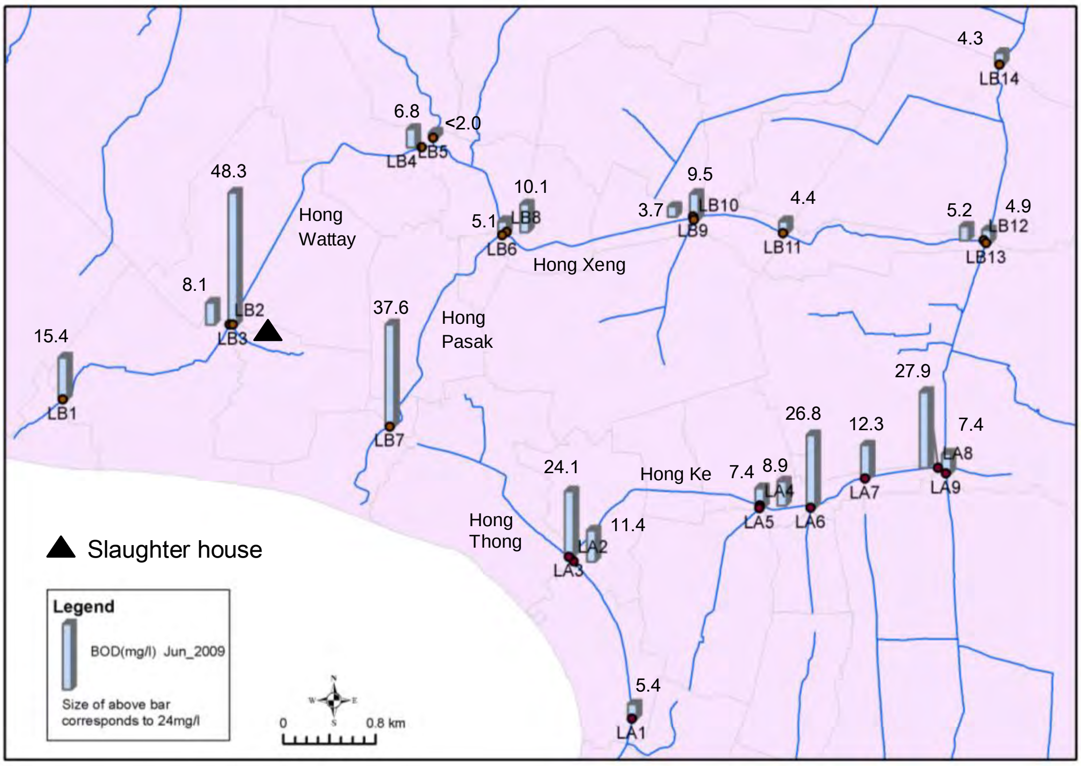


Fig. 2.5.15 Schematic Diagram of BOD in Longitudinal Monitoring (June 2009)

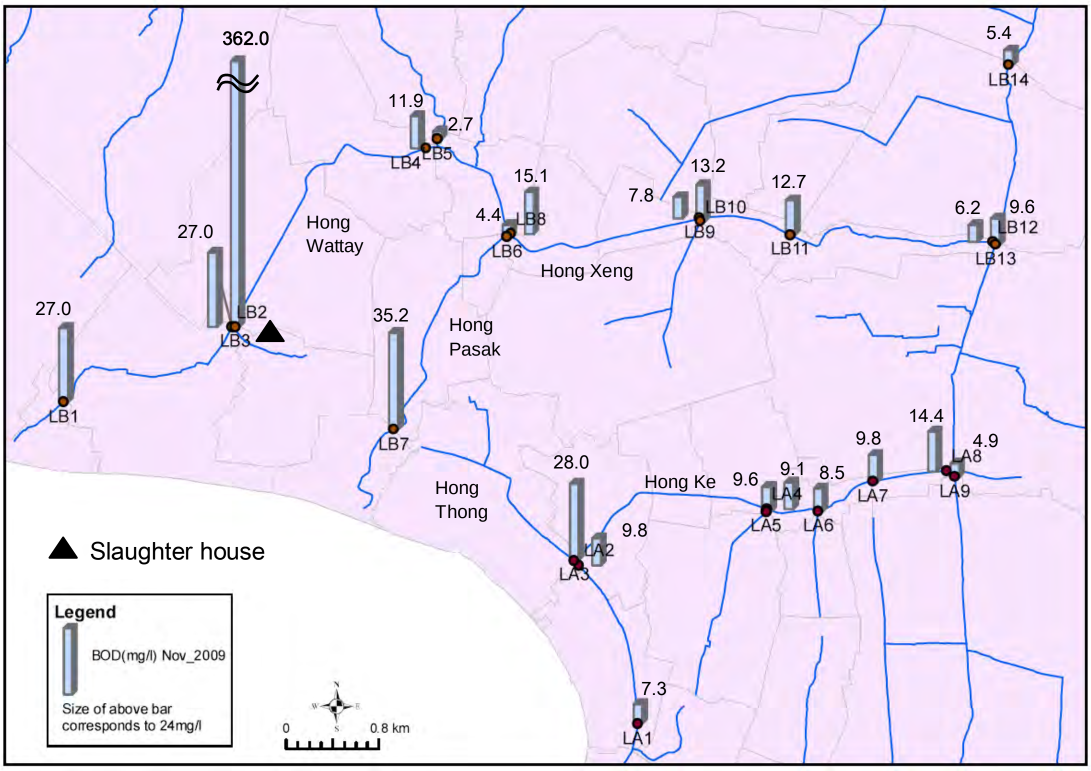


Fig. 2.5.16 Schematic Diagram of BOD in Longitudinal Monitoring (November 2009)

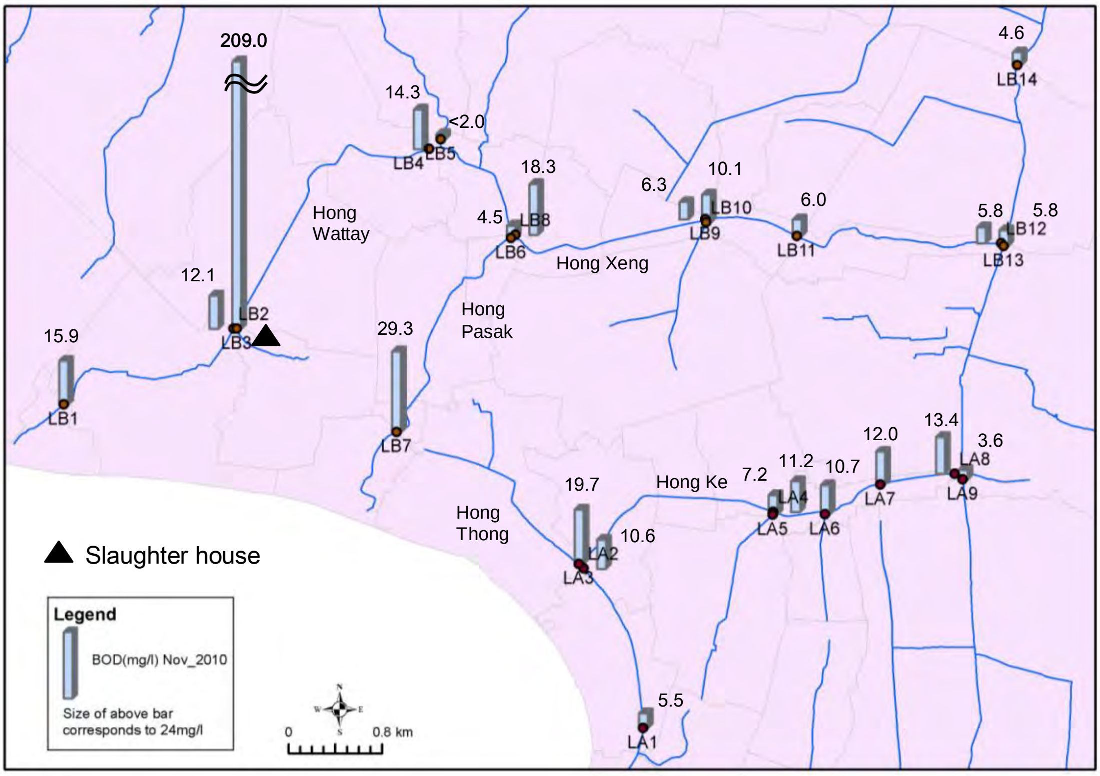


Fig. 2.5.17 Schematic Diagram of BOD in Longitudinal Monitoring (November 2010)

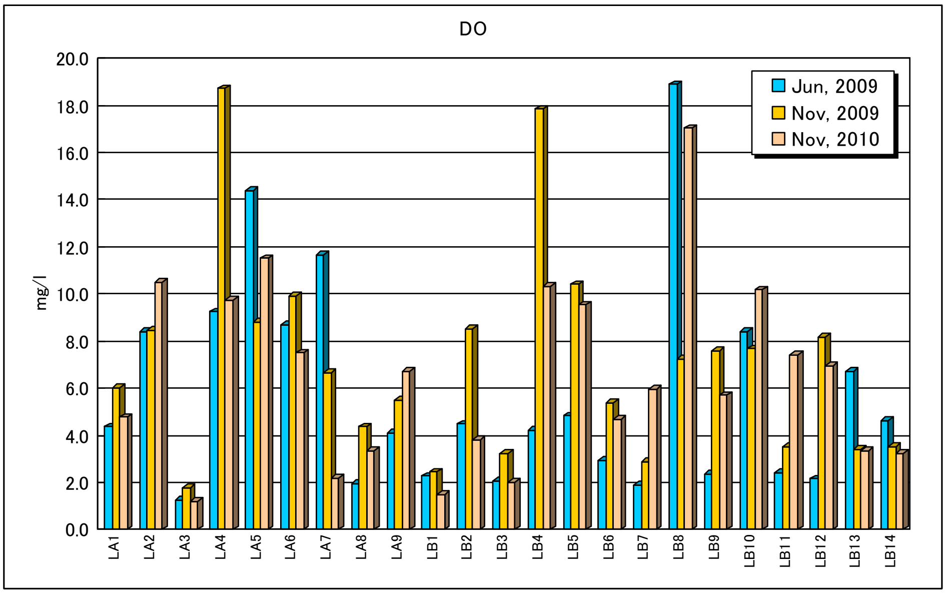


Fig. 2.5.18 DO observed in Longitudinal Monitoring

(3) Summary of the Monitoring Results

Periodical and longitudinal simultaneous monitoring results are summarized below.

- Judging from the coliform number observed at the monitoring points located along mainstream or tributaries of Hong Ke and Hong Xeng, the stream is dominated by domestic and commercial wastewater. However, in general, not so high BOD ranging from about 10 mg/l to 35 mg/l was observed even in the dry season. On the other hand, at monitoring points along mainstream of Mak Hiao River, BOD ranging from about 2 to 3 mg/l was recorded and thus the seasonal variation was not observed.
- At the monitoring points along mainstream or tributaries of Hong Ke and Hong Xeng concentration of NH3-N was high, but as with BOD, the concentration considerably dropped at monitoring points along mainstream of Mak Hiao River.
- In general, NO3-N was below 1.0 mg/l at most of the monitoring points and thus variations between the monitoring points were not observed.
- Except for some data, a range of observed PO4-P concentration was less than 1.0 mg/l as a whole.
- All the heavy metals (six parameters) and pesticides (three parameters) were either undetected or negligible, causing no problem on the water environment.

2.5.3 Industrial Wastewater

The Study Team conducted site visits to the existing factories in the study area to examine the conditions of wastewater discharged and/or treated. The visited factories were selected in consultation with WERI-WREA and the Ministry of Industry and Commerce.

WERI-WREA, the Ministry of Industry and Commerce as well as the Department of Industry and Commerce, Vientiane, have inventories of factories. They understand the importance of monitoring and inspecting industrial wastewater. However, due to limitation of budget and human resources, such activities are not conducted properly. Accordingly, very little data on industrial wastewater is available.

Table 2.5.11 shows the survey results of the existing factories, including whether the factories affect the water quality of Mak Hiao River and its tributaries. In short, the impact by the factories is limited on the water environment of Mak Hiao River basin or they are located out of Mak Hiao River basin.

Table 2.5.11 Survey Results of Existing Factories in the Study Area

No.	Name of Factories	Existing Condition of Factories
1	Beer Lao	Beer Lao is a large-scale factory located at the southern edge of That Luang Marsh, producing beverages such as beer and drinking water. Wastewater generated is treated using a combination of anaerobic and aerobic process in its own treatment plant with the capacity of 3,500 m^3/day. The treated water is then discharged to the open channel next to the factory. The channel drains the water directly to the Mekong throughout the year, which means the treated water will not affect the water quality of Mak Hiao River basin.
2	Paper factory	Located in the north of 1.5 km from Beer Lao, the factory discharges white colored wastewater. However, the wastewater is scarce in quantity and this factory is out of the catchment area of Mak Hiao River.
3	Slaughterhouse located in Dondou Village	This slaughterhouse is located in Dondou Village in the west of That Luang Marsh. A pit for stocking the residues arising from the slaughter process is installed. Howeverer, the wastewater is not observed and the factory is found to be out of the catchment area of Mak Hiao River.
4	Slaughterhouse located in Nongdouang Village	As discussed in the previous **Subsection 2.5.2**, the factory is located at the upstream of the monitoring point LB3 and discharges considerably polluted wastewater. According to the monitoring result, the impact of wastewater seems to be limited but pollution load discharged from the slaughterhouse is considered in water quality modeling.
5	Noodle factory	This factory is located in Nongsanokham Village in the east of Wattay International Airport, but the factory is small in scale and wastewater discharged can be negligible.
6	Garment factory located in Nakham Village	This factory is located in Nakham Village in the east of Wattay International Airport, but the factory is small in scale and wastewater discharged can be negligible.
7	Garment factory located in Donparlap Village	This factory is located in Donparlap Village, the neighboring area of the monitoring point SP3. Small amount of wastewater seems to be discharged to the marsh nearby, but the connection of the marsh and the public water body (Hong Pasak) is not clearly identified.
8	Existing factories located at Vientiane Industrial Park	Around seventeen factories are located in the Vientiane Industrial Park. The categories of the factories are steel mill, wood products, silicon and so on. Wastewater discharged by the factories is found to be negligible.
9	Others	Other factories such as tannery, which are discharging toxic and/or heavily polluted wastewater, are not located in the Study Area.

2.5.4 Water Quality Modeling

To evaluate and improve water environment in Vientiane for the target year, the water quality modeling for evaluating pollution load runoff was conducted considering changes in living standard of the people as well as socioeconomic, meteorological and hydrological conditions. Projection of water quality and evaluation of structural measures are made for the target year 2020 in Chapter 3 using this model.

(1) Target Water Quality Parameter and Streamflow

In water quality modeling, a water body falls into two categories: stream water and closed water. As shown in **Table 2.5.12,** the characteristics of stream water and closed water, and hence the target water quality parameter(s), are different from each other.

In this Study, the water quality modeling was carried out focusing on the dry season in which the pollution load is scarcely expected to be purified by dilution effect. Unlike in the rainy season, Mak Hiao River basin can be regarded as stream water in the dry season due to the extreme reduction of streamflow.

As a result, BOD is set as the target water quality parameter, and low flow is set as the target streamflow in the water quality modeling.

To calculate BOD concentration, low flow (75% flow, Q_{75}) is utilized based on the *"Guidelines for Comprehensive Basin-wide Planning of Sewerage Systems",* The Japan Sewage Works Association.

Table 2.5.12 Characteristics of Stream Water and Closed Water in Water Quality Modeling

	Stream Water (River)	Closed Water (Lake and Sea)
Target water quality parameter(s)	BOD	COD, Nitrogen, Phosphorus
Water quality modeling in the water body	- Self-purification function such as decomposition, sedimentation and absorption, are considered. - Water quality is calculated using pollution load runoff and streamflow in the dry season.	- Pollution load reduction by advective flow, diffusion, decomposition and sedimentation is considered. Pollution load production by the activities of algae, is also considered - Pollution load accumulated over a long period of time affects the water quality
Runoff coefficient of pollution load discharged from the basin to the water body	- Runoff coefficient in the dry season is applied.	- Pollution load accumulated in the dry season and then discharged to the water body in the rainy season is considered. In general, the average runoff coefficient is bigger than that of stream water.
Unit load of non-point load	- Pollution load discharged from area such as paddy field and vegetable field is considered.	- Most of pollution load accumulated in the dry season is discharged by rainfall - Unit load is set according to the land use such as paddy field, vegetable field, urban area, forest land - Pollution load originating from precipitation is considered.

Source: *Guidelines for Comprehensive Basin-wide Planning of Sewerage Systems,* The Japan Sewage Works Association

(2) Pollution Load Generation and Runoff

To conduct the water quality modeling, the generated pollution load, which is usually expressed in kilogram or gram, has to be calculated. The generated pollution loads are classified into two categories: 1) point load originating from domestic, commercial, industrial wastewater and/or livestock; and 2) non-point load originating from paddy/vegetable fields and/or forest areas.

The generated pollution loads enter the receiving water through ditch/small channel or drainage pipes. Then the pollution loads gradually decrease due to self-purification function of the tributaries and the main river while flowing down, and finally reach the reference and/or monitoring points. The pollution loads reaching the reference point are defined as pollution load runoff. In the Study, the following equation was used to estimate the pollution load runoff at the reference points:

$$\text{Pollution load runoff} = \text{Generated pollution load} \times R_1 \times R_2$$

where R_1: runoff coefficient
R_2: self-purification rate

In the above equation, the runoff coefficient is defined as the rate of generated pollution loads which reach the receiving water. Self-purification rate is defined as the residual ratio of pollution load which is purified by the effects such as sedimentation, absorption and/or decomposition before reaching the reference point. **Fig. 2.5.19** shows the schematic diagram of pollution load generation and runoff.

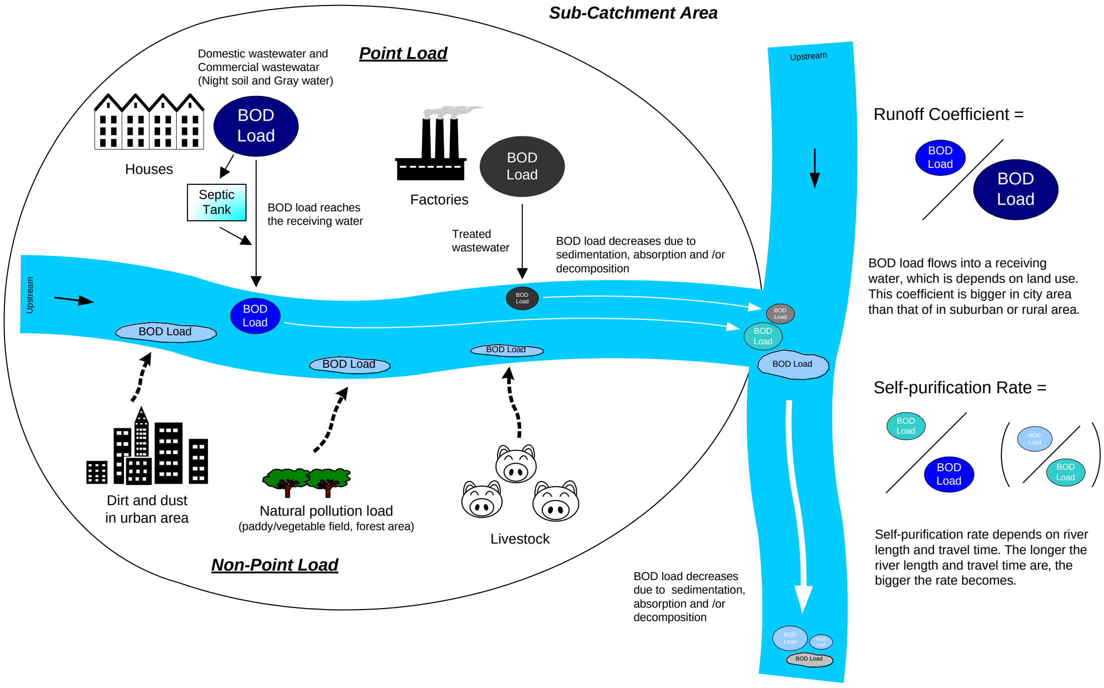


Fig. 2.5.19 Schematic Diagram of Pollution Load Generation and Runoff

(3) Runoff Coefficient

Runoff coefficient is discussed in detail in the next **Subsection 2.5.5**.

(4) Self-purification Rate

The Streeter-Phelps Formula was used to calculate the self-purification rate of rivers and their tributaries. According to the formula, the self-purification rate exponentially decreases according to the flowing time. The equation is shown below.

$$C_{pur} = \exp^{-}\left(\frac{C \times L \times 1000}{v_{ave} \times 86400}\right)$$

where C_{pur} : *self-purification rate*
C : *self-purification coefficient*
L : *length of river channel (km)*
v_{ave} : *average velocity (m/s)*

BOD concentration at the reference point is obtained by the runoff coefficient, self-purification rate given by the above formula and the stream flow, as shown in **Fig. 2.5.20**.

Self-purification coefficient applied in the model is discussed in detail in the next **Subsection 2.5.5**.

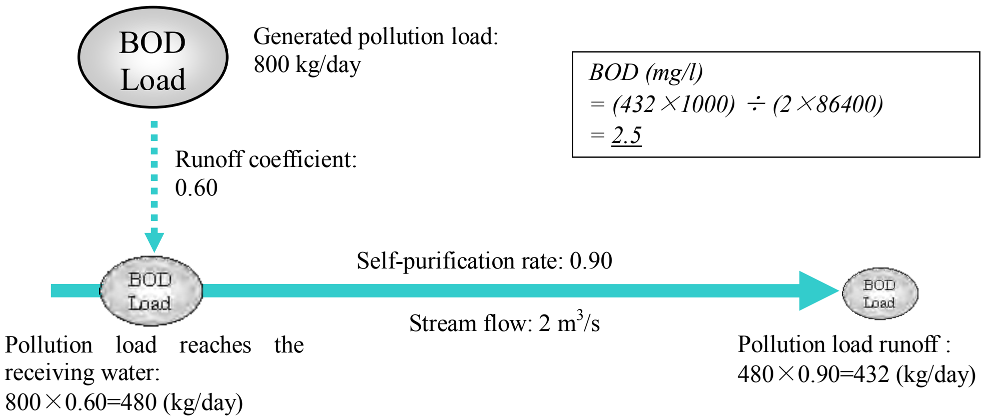


Fig. 2.5.20 Calculation Method of BOD Concentration at Reference Point

(5) Pollution Load to be Considered

Pollution loads to be considered in the water quality modeling are shown in **Table 2.5.13**.

Table 2.5.13 Pollution Load to be considered in the Model

Pollution load		Description
Point load	Domestic wastewater	This pollution load, which is usually given by the amount of unit pollution load per capita, comprise of night soil and gray water, which originates from human activities. Since actual data is not available in Vientiane, 45 g/capita/day, which is used as typical value in developing countries given by a WHO manual[1], is applied. Population projection is carried out using the *Population and Housing Census*, issued by the Department of Statistics, Ministry of Planning and Investment, Lao PDR.
	Commercial wastewater	This pollution load originates from commercial activities. In the Study, the pollution loads are assumed to generate from urban area where the drinking water is serviced by piped line; whereas, this pollution load is not considered in suburban or rural area where the water is supplied by wells. Amount of pollution load is set as 20% of domestic wastewater considering water consumption in 2007 provided by the Water Supply Enterprise, Vientiane.
	Industrial wastewater	This pollution load originates from industrial activities such as processing and cleaning. Since most of the factories in the Study Area are small in scale, the pollution load is considered as part of the commercial pollution load, except for pollution load generated from a slaughterhouse in Nongdouang Village. For the year 2020, pollution load generated from Vientiane Industrial Park is considered.
	Livestock	Pollution loads generated from livestock (cow, buffalo, swine and goat) are considered. The number of livestocks is estimated by using the data provided by the Department of Agriculture and Forestry, Vientiane. For estimating the number of livestocks in 2020, the annual growth rate of 4% in the *National Socio Economic Development Plan (2006-2010)* is applied.
Non-point load		This is the pollution load originating from paddy/vegetable fields, and/or forest areas. Since the actual data is not available, 0.75 $kg/km^2/day$, which is an intermediate value of 0.5 to 1.0 $kg/km^2/day$ given by the *Guidelines for Comprehensive Basin-wide Planning of Sewerage Systems*, The Japan Sewage Works Association is applied.

[1] *Wastewater Stabilization Ponds, Principles of Planning & Practice*, WHO

(6) Catchment Area and Population Projection

The catchment area in the simulation model is 412.6 km^2 (2009) and 412.9 km^2 (2020) in total. The catchment is further divided into 59 sub-catchment areas, considering topographical features, flow direction of existing open channels, and existing drainage pipe network in Vientiane.

The overall catchment area is shown in **Fig. 2.3.11** in **Section 2.3**, and the sub-catchment areas of Hong Ke and Hong Xeng are shown in **Fig. 2.5.21**.

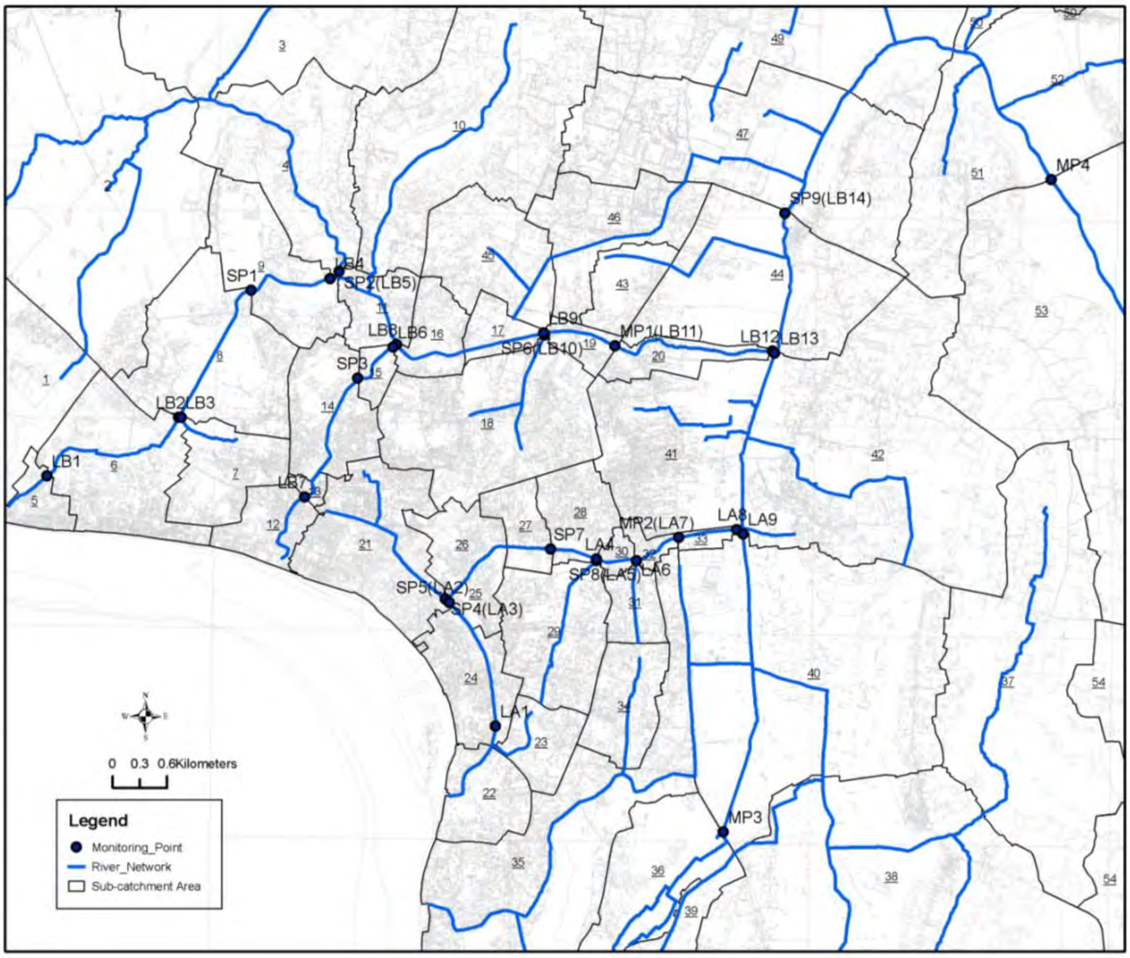


Fig. 2.5.21 Sub-Catchment Areas in Hong Ke and Hong Xeng Basin

Table 2.5.14 shows the population projection in the Study Area for the year 2009 and 2020, including the population distribution of Hong Ke and Hong Xeng basin. The population for the year 2009 is estimated using the annual average growth rate (2005 to 2020) of each sub-catchment area.

Since the population data in the four new development areas (i.e., That Luang Development Area, Dong Phosy Development Area, Stadium Development Area and Vientiane Industrial Park), is not available, the population projection and pollution load generated in the areas are assumed and taken into account in the water quality modeling on the safe side.

Table 2.5.14 Population Projection in the Water Quality Modeling

	Catchment Area (km^2)		Present (2009)=(1)	Target (2020) =(1)	Annual growth rare	Remarks (2)/ (1)
	2009	2020				
Hong Ke catchment area	9.5	9.5	50,620	44,173	-0.90%	0.87
Hong Xeng catchment area	53.1	56.6	111,698	163,852	2.59%	1.47
Other area	350.0	346.8	200,490	290,897	2.51%	1.45
New development area	-	-	-	*36,800*	-	-
Sub-total (without new dev area)	-	-	-	462,122	-	-
Total	412.6	412.9	362,808	498,922	2.15%	1.38

Note: Value in italics is assumed one by the Study Team.

In **Table 2.4.15**, the population projection in the new development areas is shown in detail. The population of each area is computed by multiplying residential area by an assumed population density of 80 person/ha.

Table 2.5.15 Population Projection of New Development Areas

	Area	Area (ha)						Pop. Density (person/ha)	*Pop. Assumed*
		Total	Resi-dential	Indus-trial	Pub. Facili-ties	Untrans-ferable	Others		
1	That Luang Dev. Area	670.0	230.2	-	71.1	368.1	0.6	*80*	*18,400*
2	Dong Phosy Dev. Area	100.0	41.1	-	4.1	54.8	0.0	*80*	*3,300*
3	Stadium Dev. Area	430.0	129.9	58.7	58.2	150.9	32.3	*80*	*10,400*
4	Vientiane Industrial Park	*484.5*	*58.5*	*410.0*	-	-	*16.0*	*80*	*4,700*
	Total	1,684.5	459.7	468.7	133.4	573.8	48.9		*36,800*

Note: Values in italics are assumed ones by the Study Team.

(7) Others

(a) Industrial Wastewater Discharged from Vientiane Industrial Park

Industrial wastewater discharged from Vientiane Industrial Park is considered for the target year 2020. According to the report of the *Preparatory Survey on Industrial Zone Development in the Lao People's, Democratic Republic*, the framework including water demand estimation is given, as shown in **Table 2.5.16**.

Considering the above demand estimation, the amount of wastewater discharged from the Vientiane Industrial Zone for the year 2020, is assumed as **26,000 m^3/day**, which is the intermediate value of 5,600 m^3/day (for 2015) and 46,400 m^3/day (for 2025).

Pollution load discharged is assumed to be **1,040 kg/day**, which is computed using the discharge criteria for general factories (40 mg/l) of the Ministry of Industry and Commerce, because the wastewater treatment system in Vientiane Industrial Park is not fixed yet.

Table 2.5.16 Framework and Demand Estimation of Vientiane Industrial Park

	Unit	2015	2025	最終計画
Framework				
Industrial Zone Development Area	ha	130	690	1,540
Residential Area	ha	10	107	286
Commercial Area	ha	-	19	174
Amenity Area	ha	-	19	
Logistic Area	ha	-	10	
Total		140	845	2,000
Demand estimation				
Water Supply	m^3/day	7,000	58,000	-
Wastewater	m^3/day	5,600	46,400	-

Source: Progress Report, *Preparatory Survey on Industrial Development in the Lao People's, Democratic Republic*, JICA

(b) SEA Game Stadium

Wastewater discharged from the SEA game stadium is regarded as a part of commercial wastewater from the Stadium development area, because the stadium is not likely to be operated everyday.

2.5.5 Projection of Water Quality in 2020

First, calibration for the model is carried out in terms of water quantity (stream flow) and quality (BOD). Then water quality for 2020 is projected and alternatives for improvement of water environment in Mak Hiao River basin are proposed.

(1) Calibration for the Model Building

Calibration for stream flow and water quality (BOD) is conducted, here. Comparative evaluation among the Alternatives will be conducted with the Model constructed here.

(a) Calibration of Stream Flow

As discussed in the previous **Subsection 2.5.2**, the stream flow was affected by storm water even in November. The calibration of stream flow is, therefore, conducted focusing on the monitoring result of December.

In the dry season, stream flow is dominated by wastewater originating from water supplied by the piped network or wells and, normally, most of the water is used in the daytime. Therefore, a peak factor is introduced to match the actual condition of water use.

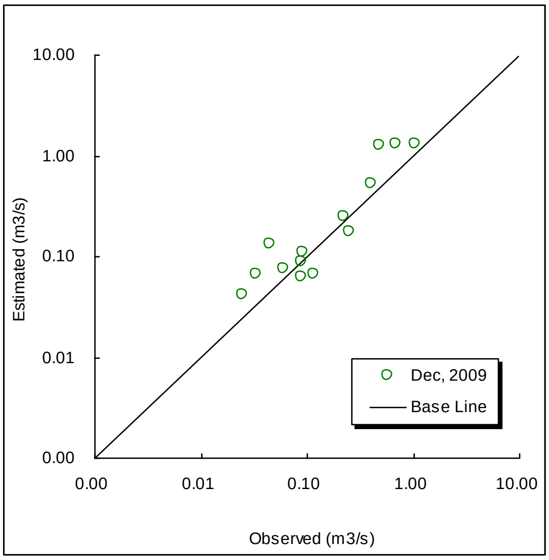


Fig. 2.5.22 Relations of Observed and Estimated Stream Flow

As a result, the following equation is given for estimating the stream flow in each sub-catchment area. In the equation, the peak factor 2.0 is applied to the sub-catchment area in the central area (the areas with high population density and small catchment area along Hong Ke and Hong Xeng), while 1.0 is applied to the other sub-catchment areas.

(Stream flow) = (Amount of water supply by pipe network and wells) × (Peak factor)

Fig. 2.5.22 shows relations between observed and estimated stream flow at the monitoring points, suggesting the validity of the model to a large extent. Stream flow obtained by using above equation corresponds to low flow discussed in the **Subsection 2.3.3**, Low Flow Analysis..

(b) Setting of Runoff Coefficient

Runoff coefficient for 2009 and 2020 are set up, considering land use (present and future) and monitoring results, and referring to standard values given in the *"Guidelines for Comprehensive Basin-wide Planning of Sewerage Systems,"* The Japan Sewage Works Association.

In urban, suburban and rural areas, the coefficients are classified by the population density of each sub-catchment area. Reflecting the monitoring results (relatively low BOD, less than 30 mg/l even in the urban area such as Hong Ke and Hong Xeng basin), runoff coefficient for 2009 is set up at a low level compared with a typical value. In contrast, the coefficient for 2020 is set up as double of 2009's, considering the improvement plan of small ditches and drainage channels by VUDAA, as shown in **Table 2.5.17**.

Table 2.5.17 Runoff Coefficients

Area	Pop density[1] (person/km^2)	2009	2020	Typical Value[2]
Service area of conventional sewer system		-	0.80	1.00
Urban Area	6,000≤x	0.25	0.50	0.6 - 1.0
	4,500≤x<6,000	0.15	0.30	
	3,000≤x<4,500	0.10	0.20	
Sub-urban	1,500≤x<3,000	0.10	0.20	0.1 - 0.6
Rural	0<x<1,500	0.05	0.05	0.0 - 0.2
Livestock		0.05	0.05	-
Non-point		0.05	0.05	-

Note 1) Population density of sub-catchment area
2) Source: *Guidelines for Comprehensive Basin-wide Planning of Sewerage Systems*, The Japan Sewerage Works Association

(c) Setting of Self-Purification Rate

Self-purification rate of 0.2 is set up for drainage channels in central Vientiane. For rural area and downstream of Mak Hiao River (from the stretch of MP4 to MP6), a rate of 0.3 is set up considering low BOD (normally less than 5.0 mg/l).

Drainage channels in the central area: **0.2**
Downstream of Mak Hiao River and the rural area: **0.3**

(d) Calibration of BOD

BOD is calibrated using the monitoring results in December as well as the runoff coefficient and self-purification coefficient set up in the previous item.

As shown in **Fig. 2.5.23**, relations of observed to the estimated BOD are satisfactory. Thus the water quality model formulated in the study proves appropriate for estimating future water quality.

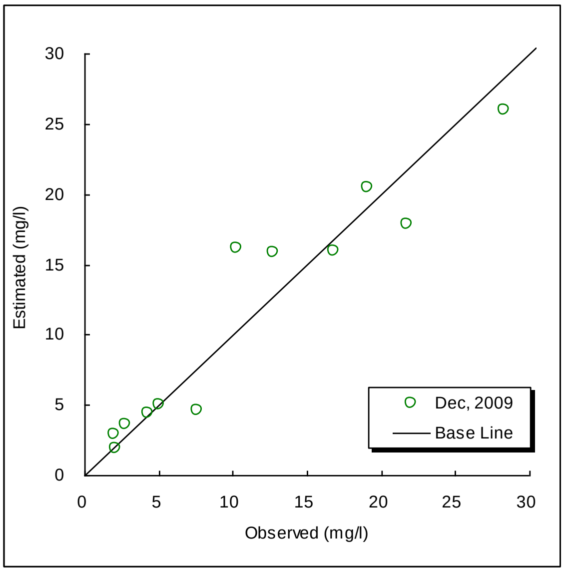


Fig. 2.5.23 Relations of Observed to Estimated BOD

(e) Summary of Other Parameters in the Modeling

Parameters other than run-off coefficient and self-purification coefficient are summarized in **Table 2.5.18**.

The parameters include BOD unit load per capita, water consumption per capita, and removal rate of treatment facilities such as septic tank and soak pit, as well as activated sludge process, anaerobic treatment, contact aeration treatment and so on.

Table 2.5.18 Summary of Parameters in the Model

	Item	Sub-item	Unit	Parameters		Remarks
				Present (2009)	Target Year (2020)	
1.	Point loads					
(1)	Domestic wastewater	Night soil	gpcd	25	25	
		Gray water		20	20	
		Total		45	45	1)
(2)	Commercial wastewater	Night soil	gpcd	25	25	
		Gray water		20	20	
		Total		45	45	
(3)	Industrial wastewater			- Slaughter house in Nongdouang Village	- Slaughter house in Nongdouang Village - Vientiane Industrial Park	
(4)	Livestock	Cow, Baffalo	g/unit	640	640	2)
		Swine, Goat	g/unit	200	200	2)
2.	Non-point load					
(1)	Non-point load		kg/day/km^2	0.75	0.75	2)
3.	Water consumption per capita					
(1)	Supplied by piped line		lpcd	180 3)	170 4)	
(2)	Supplied by wells		lpcd	70	70	5)
(3)	Commercial use			20% of domestic use	20% of domestic use	
4.	BOD removal rate of treatment facilities					
(1)	Modern toilet with septic tank		%	40	40	6)
(2)	Soak pit and others (without septic tank)		%	20	20	7)
(3)	Activated sludge process		%	90	90	
(4)	Anaerobic treatment		%	-	70	
(5)	Contact aeration process		%	-	70	

Notes: Sources
1) *Wastewater Stabilization Ponds ,Principles of Planning & Practice-*, WHO
2) *Guidelines for Comprehensive Basin-wide Planning of Sewerage Systems*, The Japan Sewerage Works Association
3) Water consumption data of 2007 provided by Water Supply Enterprise, Vientiane
4) *The Study on Vientiane Water Supply Development Project in Lao PDR, January 2004, JICA*
5) Information from JICA senior volunteer in-charge of water leakage investigation in Vientiane
6) Report on the Disposal of Domestic Wastewater in Urban Vientiane, issued on October 1988 under project UNDP-UNCHS LAO/85/003 Urban Development Programme in the Prefecture of Vientiane.
In the report, a removal rate of 40% is given to remove both night soil and gray water, but in the water quality modeling, 40% is applied for removing night soil only, considering the fact that few septic tanks in Vientiane receive gray water.
7) Twenty percent (20%) which is half of BOD removal rate of septic tank (40%) is given by the Study Team due to the lack of information.

(2) Pollution Load Generation and Runoff in 2009

Table 2.5.19 and **Fig. 2.5.24** show pollution load generation and runoff in 2009 computed by applying the water quality model. Total pollution load generation is 31,485 kg/day. The pollution load is discharged to the river/drainage channel after treatment in septic tank or without treatment. Due to low runoff coefficient, only 2,579 kg/day or 8.2% of the total reaches the river/drainage channel. Pollution load at the downstream end of Mak Hiao River drops to 217 kg/day or 8.4% of the load reaches the river, which results from the natural purification function in Mak Hiao River due to low velocity (less than 0.1 m/s to 0.2 m/s) as well as long distance of about 30 km from central Vientiane.

By category, pollution load generation of domestic and commercial accounts for 59.6% (18,767 kg/day) of the total, followed by livestock (38.4% or 12,107 kg/day). However, due to low runoff, pollution load from livestock hardly affect the water quality compared to that from domestic/commercial.

Table 2.5.19 Pollution Load Generation and Runoff (2009)

		Pollution load (kg/day)			Percentage (%)		
		Generated	Reaches to the river	D/S end of Mak Hiao River	Generated	Reaches to the river	D/S end of Mak Hiao River
1	Domestic	16,326	1,437	70	100.0	8.8	0.4
2	Commercial	2,441	221	8	100.0	9.1	0.3
3	Industrial	300	300	4	100.0	100.0	1.2
4	Livestock	12,107	605	131	100.0	5.0	1.1
5	Non-point	309	15	3	100.0	5.0	1.0
	Total	31,485	2,579	217	100.0	8.2	0.7

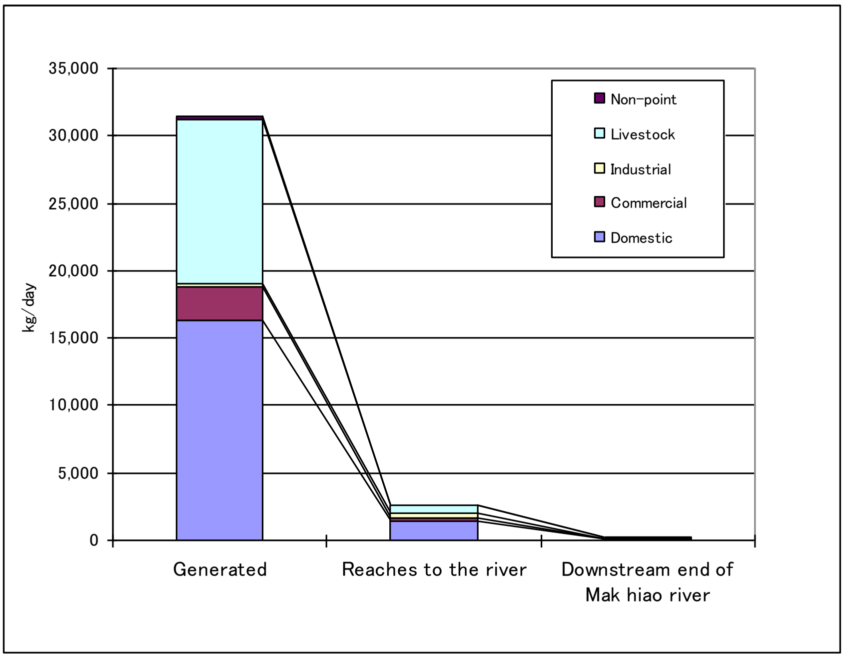


Fig. 2.5.24 Pollution Load Generation and Runoff (2009)

2.6 Aquatic Biology

2.6.1 Biological Survey

(1) Objective of the Biological Survey

In general, aquatic species composition differs depending on water quality at the site; therefore, aquatic species are used as indicators to evaluate water quality.

The biological survey aims to comprehend the current biological conditions in the Mak Hiao River basin by conducting a field survey and developing biological indicators by analyzing the relationships between species and water quality based on the survey results. The developed biological indicators are expected to be utilized for supplementing water-quality monitoring and understanding water environment from ecological viewpoints.

(2) Methodology of the Survey

(a) Survey Points

Fourteen survey points in the Mak Hiao River basin were selected as shown in **Table** 2.6.1 and **Fig. 2.6.1**. The regular survey points, B1-B9, were selected to be the same location as the water-quality monitoring points to analyze the relationships between species and water quality. The additional survey points, B10-B14, were set in the marsh area, upstream of the Mak Hiao River, to comprehend natural biological condition not affected by the wastewater from the city.

Table 2.6.1 List of Biological Survey Points

Classification	Biological survey points	Correspondent water-quality monitoring points	Location
Regular survey points	B1	SP2	Downstream end of Nam Pasak (Upstream of Hong Xeng)
	B2	SP3	Downstream end of Hong Pasak
	B3	SP6	Downstream end of Hong Kai Keo
	B4	SP7	Midstream of Hong Ke
	B5	MP3	The Mak Hiao River
	B6	SP9	The Mak Hiao River
	B7	MP4	The Mak Hiao River
	B8	MP5	The Mak Hiao River
	B9	MP6	The Mak Hiao River
Additional survey points	B10	-	That Luang Marsh
	B11	-	That Luang Marsh
	B12	-	That Luang Marsh
	B13	-	That Luang Marsh
	B14	-	Upstream marsh of Nam Pasak

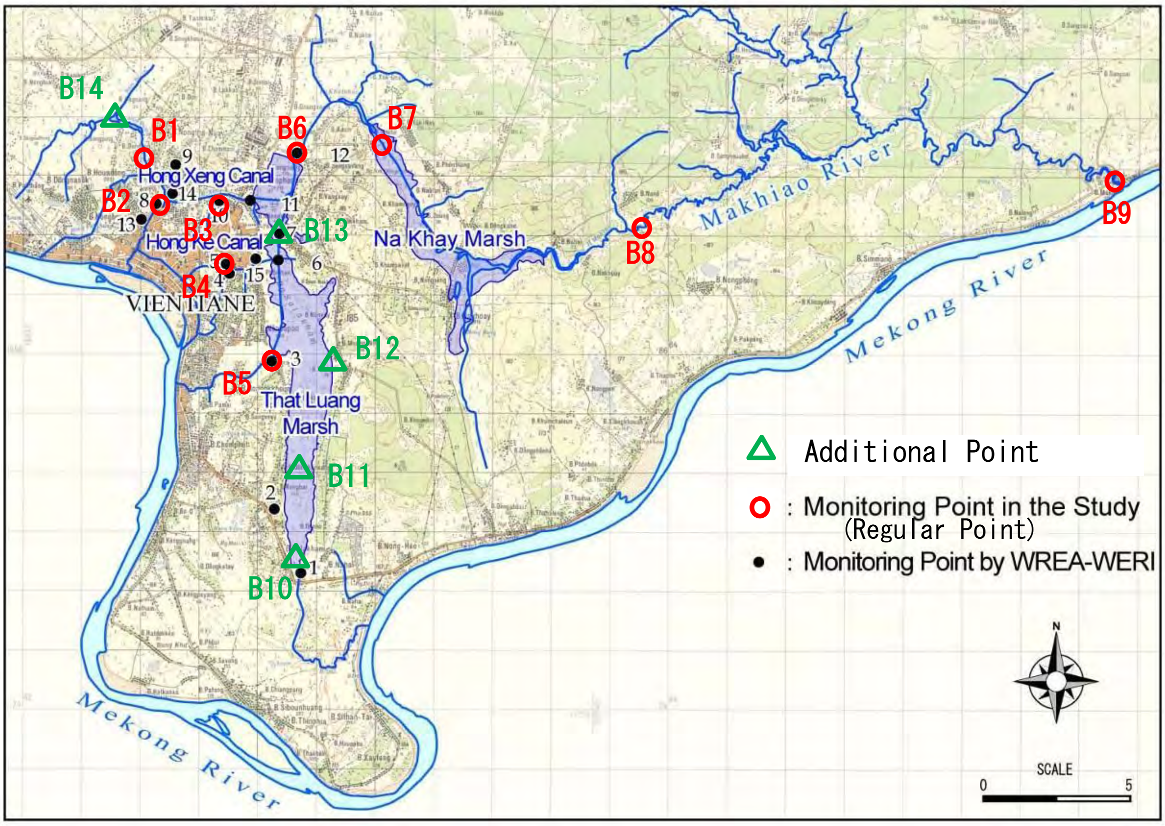


Fig. 2.6.1 Location of Biological Survey Points

(b) Frequency of Survey

The overall frequency of the field survey and the implementation dates are shown in **Table** 2.6.2 and **Table** 2.6.3, respectively. The regular survey sites were explored every time, while the additional sites were once in every rainy and dry season.

Table 2.6.2 Overall Frequency of Biological Survey

Month Year	Dry season				Rainy season						Dry season	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009		X	X				XX					X
2010	X	XX						X			X	

Note: X: only regular survey points, XX: both regular and additional survey points

Table 2.6.3 Implementation Dates of Field Survey

Date	Season	Survey Points
13-15 February, 2009	Dry season	Regular points (B1-B9)
21-22 March, 2009	Dry season	Regular points (B1-B9)
15-17 July, 2009	Rainy season	Regular points (B1-B8)* and additional points (B10-B14) * B9 was not explored due to high water level.
14-15 December, 2009	Dry season	Regular points (B1-B9)
27-28 January, 2010	Dry season	Regular points (B1-B9)
26-28 February, 2010	Dry season	Regular points (B1-B9) and additional points (B10-B14)
16-17 August, 2010	Rainy season	Regular points (B1-B9)
26 and 29 November, 2010	Dry season	Regular points (B1-B9)

(c) Survey Methodology

(i) Fish

The name of each fish species observed at each survey point was recorded. Observation was conducted using nets such as spoon net, seine net and cast net. Also, approximate individual number of each species observed during the survey time was recorded. Fishes caught by fishermen at the survey points were also observed and recorded.

(ii) Benthic invertebrates (Quantitative sampling)

Benthic invertebrates inhabiting the riverbed were collected using quadrat (50cm × 50cm) with net (mesh size 0.5mm). The sampling position was selected from the typical environment in the middle of the river. In case the quadrat was unusable due to site conditions, the samples were collected using grab sampler (Peterson grab, 18cm × 15cm × 9times). Collected samples were sieved using mesh of 0.5mm in size, fixed with formalin solution and then brought to the laboratory.

In the laboratory, the samples were washed with water using net or sieve (mesh size 0.5mm). The invertebrates were picked up from the materials remaining on the net, or sieved using forceps. Species names were identified under microscope. The individual number of each species was counted and their wet weights were measured.

(iii) Benthic invertebrates (Qualitative observation)

Species name of invertebrates observed at each survey point were recorded. Observation was conducted using nets such as spoon net and seine net. Also, approximate individual number of each species observed during the survey time was recorded.

(iv) Aquatic plants

Species name of plants observed at each survey point was recorded.

(v) Others

Sediment condition, sediment color, smells and water depth were observed for information.

(3) Survey Results

(a) Water Quality Classification

In order to understand the biological conditions in accordance with water quality, water quality at each survey point was overviewed based on the water-quality survey results.

Fig. 2.6.2 shows schematic diagram of water-quality classification of the Mak Hiao River basin, which consists of five classes from _very good‘ to _very bad‘. Actual water-quality survey results at each biological survey point are summarized in **Fig. 2.6.3**.

[Urban area (B2, B3 and B4): Very Bad]

Water quality in the urban area (urban drainage), where B2, B3 and B4 are located, is highly polluted especially in the dry season. Observed BOD at each point in the dry season exceeded 10mg/l maximally (**Fig. 2.6.3**) and the average at nine water quality survey points in the urban drainage reached 20mg/l (**Fig. 2.6.4**); therefore, it was classified as _very bad‘ water quality. On the other hand, the highly polluted water quality is improved in the rainy season, briefly. The BOD and nitrogen (NH_3-N) concentration dropped in the rainy season; they almost reached the level of the other survey points especially at B3 and B4 (**Fig. 2.6.3**).

[Middle to Downstream of Mak Hiao River (B6, B7, B8 and B9): Bad→Fair→Good→Very Good]

The points in Mak Hiao River (B6, B7, B8 and B9) showed relatively lower BOD compared with the urban area, i.e., below 8mg/l throughout the year (**Fig. 2.6.3**). Especially, the water quality changed to better and better conditions toward the downstream area (the classification changes as ‗bad'→‗fair'→‗good'), then finally BOD reached less than 3mg/l at B9 of the river mouth (classified as ‗very good' water quality).

Although the difference of BOD and nitrogen (NH_3-N) concentration between B6 and B7 in the middle stream was not clear, B6 seems to be more affected by the pollution load from the urban area because DO showed a lower level than the other points (**Fig. 2.6.5**) and sludge accumulation was observed on the riverbed (**Photo** 2.6.1).

[Upstream of the Urban Area (B1, B5): Good]

In the upstream of the urban area, where B1 and B5 are located, the water quality is also in good condition because it is not affected by the wastewater from the city. The BOD and nitrogen (NH_3-N) concentrations were almost in the same level with the downstream area (**Fig. 2.6.3**); therefore, it was classified as ‗good' water quality.

[Additional Survey Points (B10-B14)]

Water quality survey was not conducted at additional survey points (B10-B14) which include That Luang marsh; therefore, NH_3-N was examined in each of the rainy season (August, 2010) and the dry season (November, 2010) as references. As shown in the results (**Fig. 2.6.6**), the water quality was in good condition with low level of NH_3-N concentration except B13.

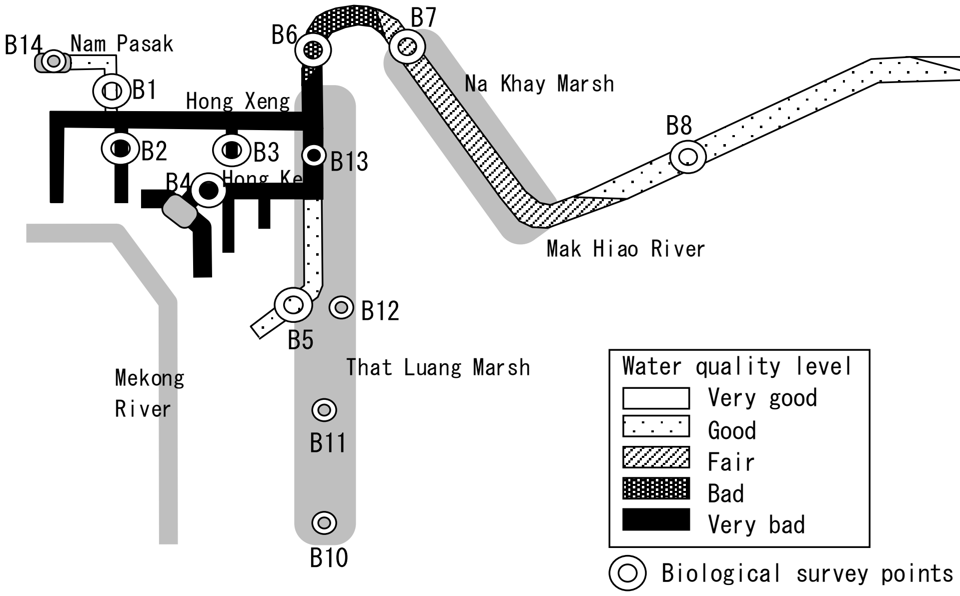


Fig. 2.6.2 Schematic Diagram of Water Quality Classification of the Mak Hiao River Basin

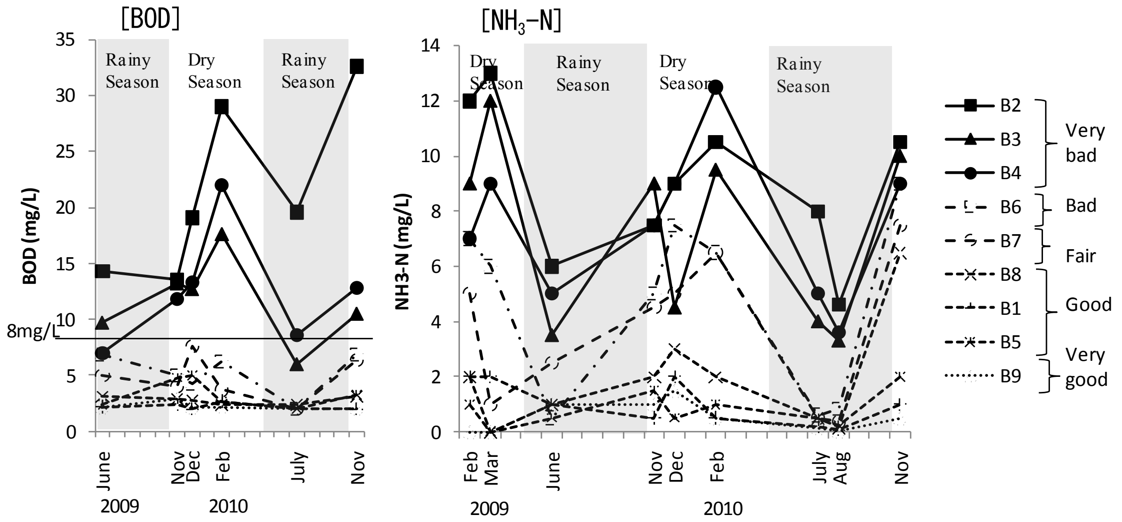


Fig. 2.6.3 Observed Water Quality at Each Survey Point

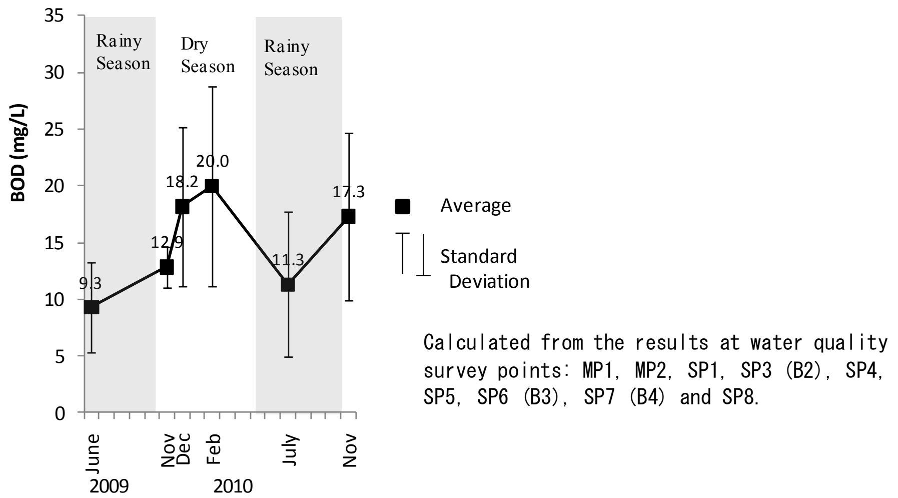
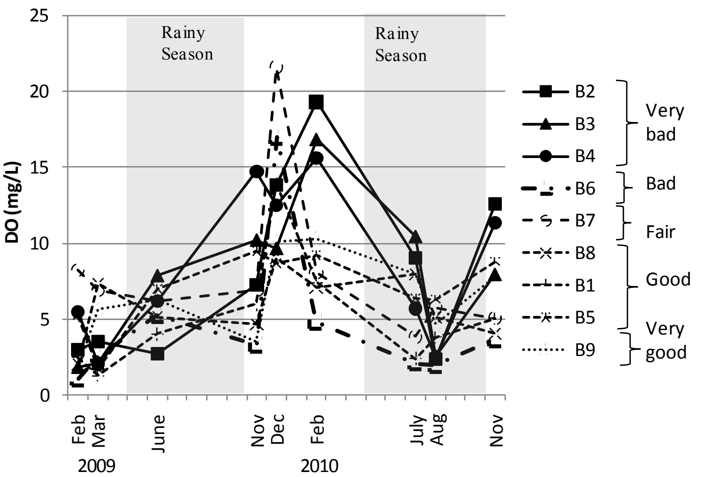


Fig. 2.6.4 Average of BOD at Water Quality Survey Points in the Urban Drainage



August, 2010

Fig. 2.6.5 Observed DO at Each Survey Point

Photo 2.6.1 Sludge at B6

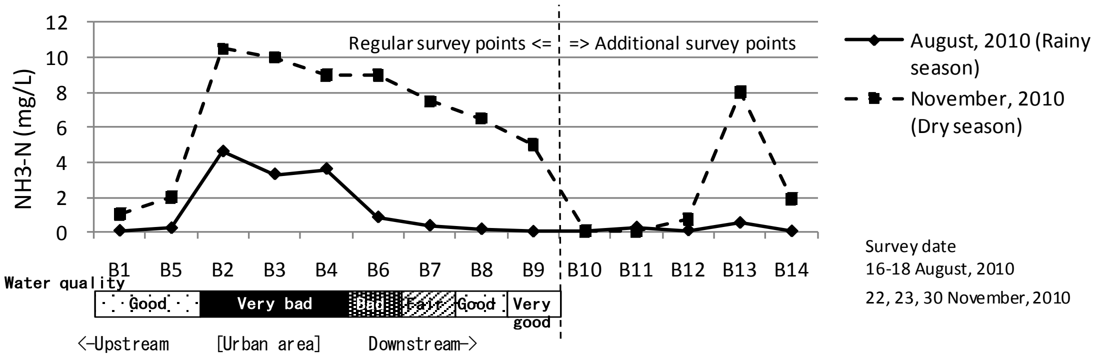


Fig. 2.6.6 NH_3-N at the Additional Survey Points and the Regular Survey Points

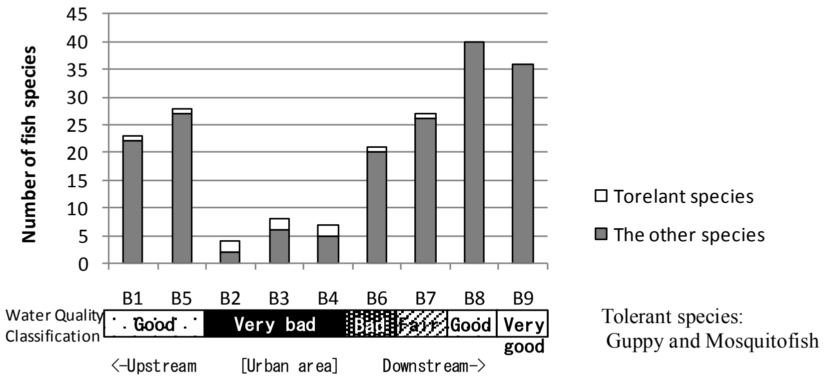
(b) Fish

Fig. 2.6.7 shows the total number of fish species observed at each survey point during the eight surveys. In urban area (B2-B4) with ‗very bad' water quality, the number of fish species was obviously smaller than the other sites. Furthermore, pollution tolerant species accounts for larger portion of the total number of species in this area compared with the other sites. These facts are deemed to indicate that the highly polluted water quality in this area is hindering most fish species from inhabiting except a limited number of species with pollution tolerance.

Comparing the situation between the dry season and the rainy season (**Fig. 2.6.8**), the difference of the number of species between in the urban area (B2-B4) and in the other sites was more critical in the dry season, while it was relatively not clear in the rainy season. In addition, the number of species except pollution tolerant species (**Fig. 2.6.9**) tended to increase in the rainy season in the urban area. These facts indicate that the habitat condition in the urban area is briefly improved and enable fish to come into and inhabit in the area due to water flow increase and brief improvement of water quality brought by dilution. In addition, the relationships between BOD and the number of fish species except tolerant species (**Fig. 2.6.10**) showed that the number of species was larger at the sites with low BOD. In **Fig. 2.6.9**, there was a case that larger number of species was observed in the dry season (in November, 2010 at B3); however, the observed BOD was 10.5mg/l, relatively lower than the other value in the dry season.

The species observed in the urban area in the rainy season except pollution tolerant species (**Photo** 2.6.2) seem to live in the main stream of Mak Hiao River and the upstream of the urban area in the dry season.

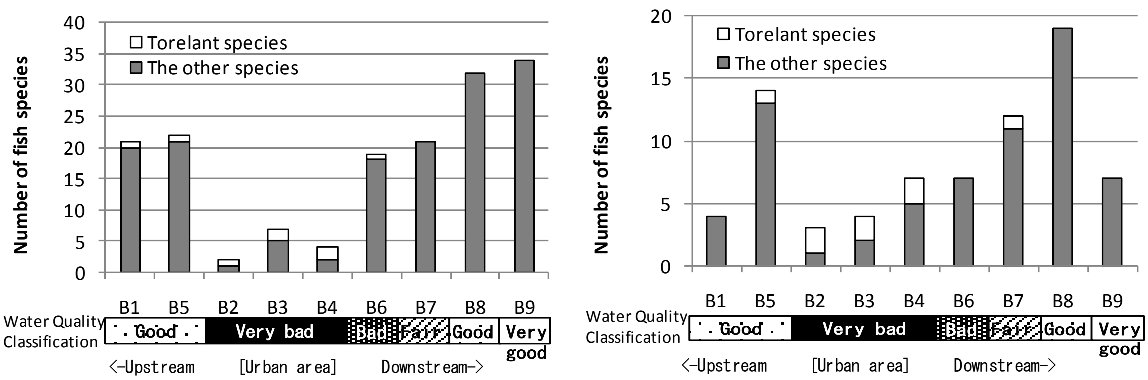
Quantities of observed fish species at the additional survey points are shown in **Fig. 2.6.11** compared with the regular survey points. At B11 and B12 located in That Luang Marsh, the number of fish species was in the same level as the regular survey points with good water quality classified as ‗fair' to ‗very good'. At B10 and B14, the number of species was small; however, it was deemed to be due to morphological condition or the other factors because the water quality was in good condition as mentioned above.



Surey frequency: Eight times excepting B9. B9 is seven times since it was not explored in July 2009 due to high water level.

Fig. 2.6.7 Total Number of Fish Species Observed during the Eight Surveys

[The dry season] **[The rainy season]**



Surey frequency: Six times.

Surey frequency: Twice excepting B9. B9 is once since it was not explored in July 2009 due to high water level.

Fig. 2.6.8 Total Number of Fish Species Observed in the Dry Season and the Rainy Season

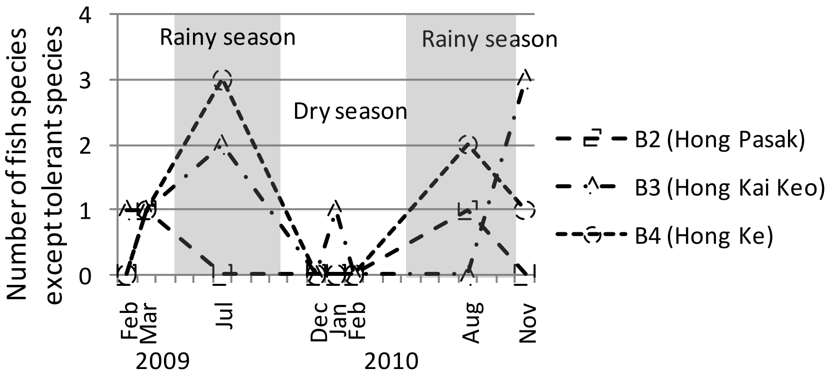


Fig. 2.6.9 Number of Fish Species except Pollution Tolerant Species (Guppy and Mosquito Fish) in the Urban Area

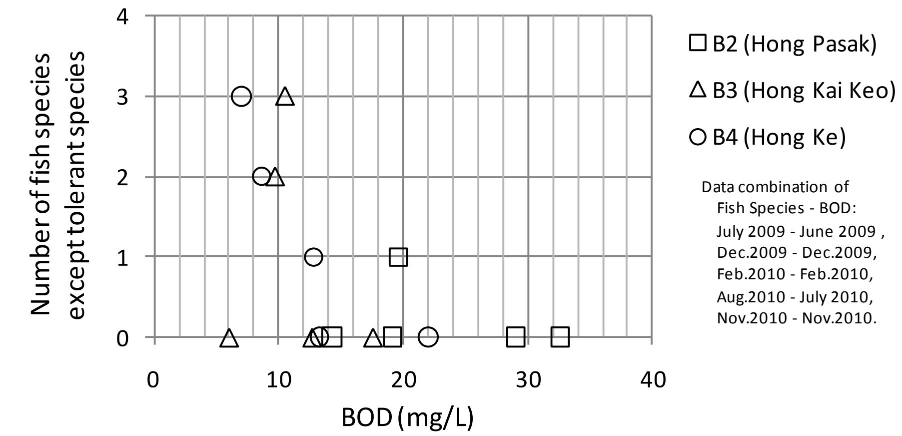


Fig. 2.6.10 Relationships between BOD and the Number of Fish Species except Pollution Tolerant Species in the Urban Area


Flying Barb (B2)


Swamp Barb (B4)

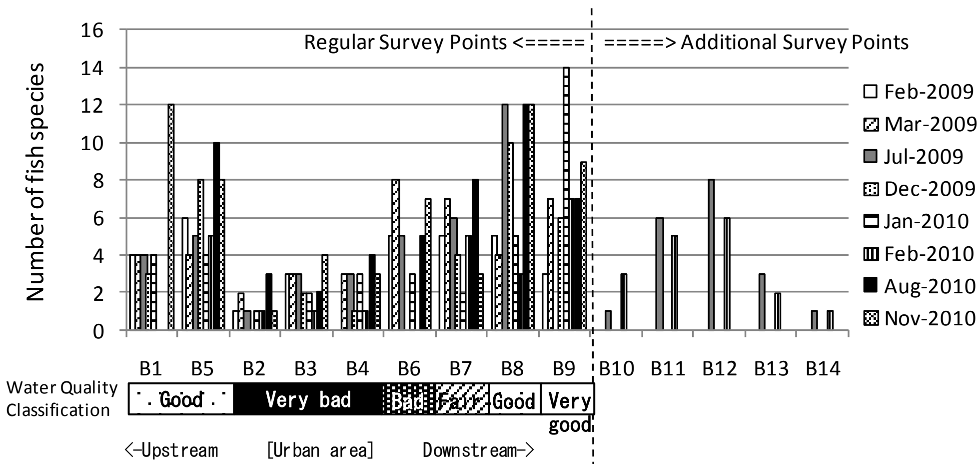

Climbing Perch (B4)


Great Snakehead (B4)


Nile Tilapia (B4)


Three-spotted Gourami (B3,B4)

Photo 2.6.2 Species Observed in the Urban Area in the Rainy Season



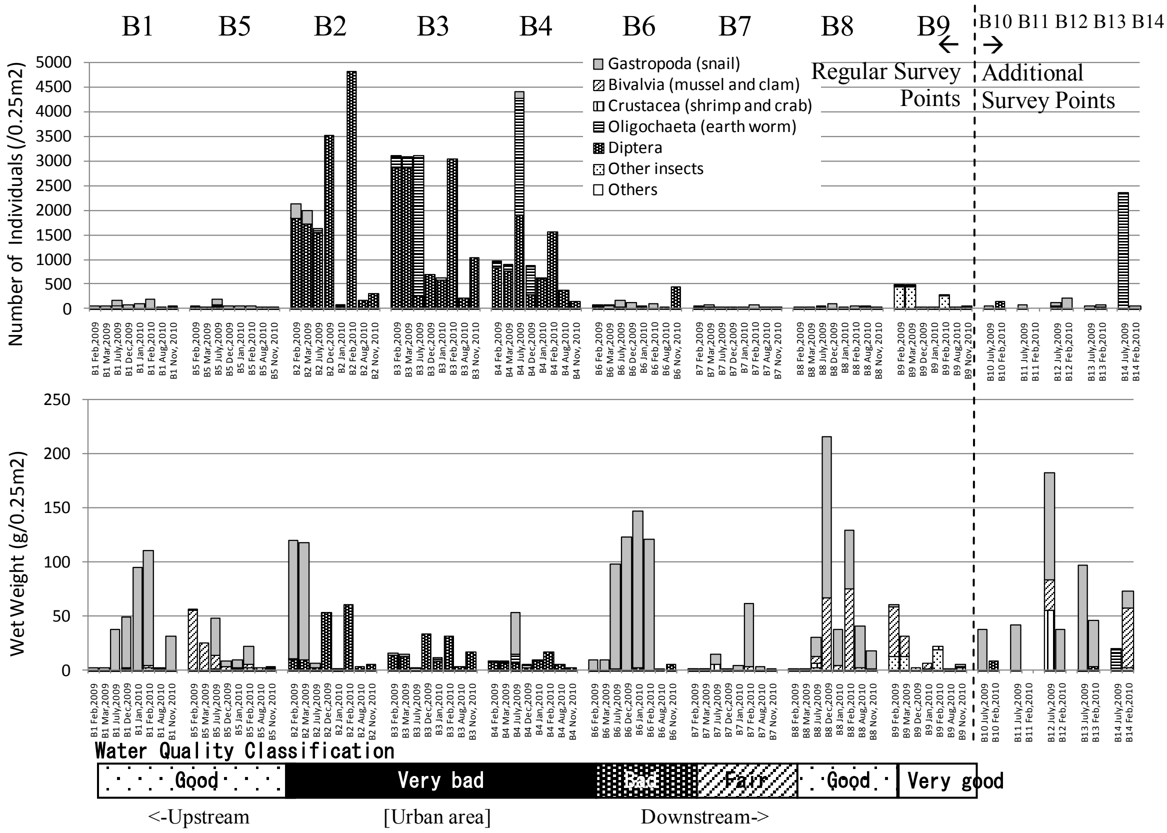
Surey frequency: Additional points are twice, while the other points are eight times excepting B9.
B9 was not explored in July 2009 due to high water level.

Fig. 2.6.11 Number of Fish Species at the Additional Survey Points and the Regular Survey Points

(c) Benthic Invertebrates

The individual number and wet weight of collected benthic invertebrates are summarized in **Fig. 2.6.12**. Different benthic invertebrate species were found in accordance with the difference of water quality at each survey points.

In _very bad' water quality area (B2-B4), large number of diptera larvae (blood worm, mosquito and moth fly) and oligochaeta (aquatic earthworm) were collected. In terms of the wet weight, gastropoda (snail) and bivalvia (mussel and clam) dominated at many sites; bivalvia tends to concentrate in _good' and _very good' water quality while gastropoda was deemed to be distributed in a wide range of water quality. Also, caddis fly (categorized into other insects) dominated in B9 with _very good' water quality.



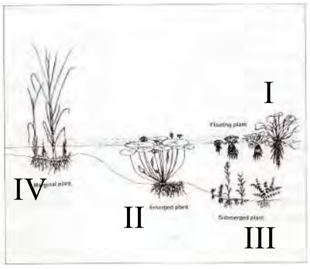
Notes 1) Additional survey points were explored only in July and February, 2010.
2) B9 was not explored in July 2010 due to high water level.

Fig. 2.6.12 Number of Individuals and Wet Weight of Collected Benthic Invertebrates

(d) Plants

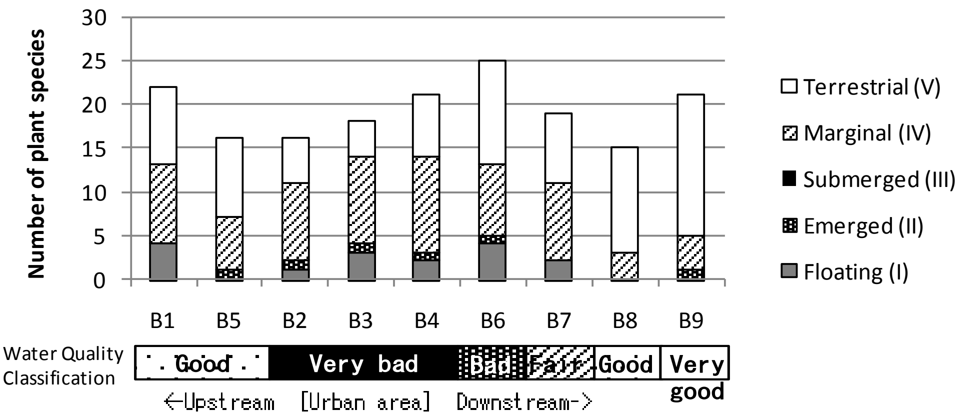
Plant species is not directly related to the water quality classification; a lot of species are found even in the _very bad' water quality area. In general, aquatic plant species are categorized into four groups in accordance with their living styles: floating species, emerged species, submerged species and marginal species (**Fig. 2.6.13**). Adding terrestrial species as the fifth group, the observed species at each regular survey point are categorized and the number of species is as summarized in **Fig. 2.6.14**. Except the terrestrial species, a lot of aquatic species are observed in the urban area indicating richness of aquatic flora in the urban drainages. Aquatic plants provide habitat to fish and the other aquatic organisms as the organisms inhabit among the roots and leaves of the plants; therefore, the richness of the aquatic plants are deemed to be indicating that various fish and the other organisms may inhabit if the water quality is improved.

Quantities of observed plant species at the additional survey points are shown in **Fig. 2.6.15** compared with the regular survey points. The number of plant species at the additional survey points including That Luang Marsh is almost in the same level with the regular survey points.



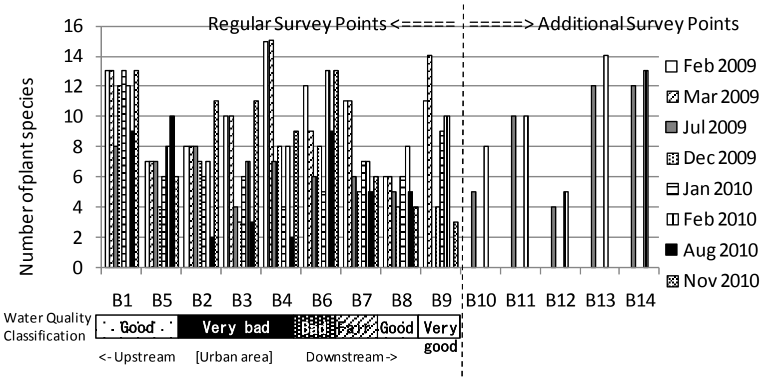
Category I:	Floating species
Category II:	Emerged species
Category III:	Submerged species
Category IV:	Marginal species
Category V:	Terrestrial species

Fig. 2.6.13 Categorization of Plant Living Style



Surey frequency: Eight times excepting B9. B9 was not explored in July 2009 due to high water level.

Fig. 2.6.14 Number of Plant Species Categorized by Living Style



Surey frequency: Additional points are twice, while the other points are eight times excepting B9.
B9 was not explored in July 2009 due to high water level.

Fig. 2.6.15 Number of Plant Species at the Additional Survey Points and the Regular Survey Points

(4) Developing Biological Indicator

The survey results show that each species of fish and benthic invertebrates is distributed in accordance with the water quality; for example, some species are found mainly in ‗good‘ or ‗very good‘ quality water, while others concentrate in ‗very bad‘ water quality area. Based on the bias of their distribution, species shown in **Table** 2.6.4 are selected as indicator species for water quality. They are categorized into six groups; three of them are fish (F-I, F-II and F-III) and the other three are benthic invertebrates (B-I, B-II and B-III). The range of water quality indicated by each group is shown in **Table** 2.6.5. Also, pictures of each species are shown in **Table** 2.6.6 together with their indicating water quality and general conditions.

In the most polluted urban area with ‗very bad‘ quality water, mostly pollution tolerant species (F-I and B-I) are found and it is deemed to be difficult for the other species to inhabit at these locations. Species categorized into F-I, guppy and mosquitofish, tend to concentrate in the polluted area although they are capable to live in the better quality water. B-I consists of blood worm, mosquito and moth fly larvae, which are generally uncomfortable species for human life.

Better water quality areas categorized into ‗bad‘ and ‗fair‘ are indicated by the other fish species except guppy and mosquitofish (F-II). Some of them are valuable for fishery; loach, climbing perch and tilapia, for example. In this area, there are no specified benthic invertebrates to indicate the water quality although several kinds of snail can be observed (Snails are distributed in a wide range of water quality).

In the ‗good‘ and ‗very good‘ quality water, the number of valuable fish species for fishery increases; for example, freshwater garfish, leaffish, catfish and eel are included in the indicator species (F-III). Also, valuable benthic invertebrates such as mussel, clam and dragonfly larvae are found in ‗good‘ quality water (B-II). In ‗very good‘ quality water, another mussel and caddis fly indicate the condition (B-III).

These indicator species were selected from the observed species during the survey. The selection criteria were to be observed frequently, to be recognized as showing bias on their distribution against water quality and their species name had been identified especially for fish. However, the range of water quality indicated by each group and species was sometimes overlapped and not clearly divided. Therefore, it is desirable that the indication of each species will be examined and revised when further survey data and information is accumulated in the future.

Table 2.6.4 Selected Indicator Species

Group		Species Name			
		Scientific name	English name	Local name	
Fish	F-I	*Poecilia reticulate*	Guppy	ປາຫາງນົກຍູງ	
		Gambusia affinis	Mosquitofish	ປາຫາງນົກຍູງ	
	F-II	*Acanthopsoides delphax*	Loach	ປາຮາກກ້ວຍ	☺
		Esomus longimana	Mekong flying barb	ປາຊິວຫນວດ	☺
		Puntius brevis	Swamp barb	ປາຂາວກົກຫາງລ້ຳ	
		Rasbora rubrodorsalis	Red-fin rasbora	ປາຊິວດອກເຂົາ	☺
		Anabas testudineus	Climbing perch	ປາເຂັງ	☺
		Trichopsis vittata	Croaking gourami	ປາມັດ	
		Oreochromis niloticus	Nile tilapia	ປານິນ	☺
	F-III	*Xenentodon canciloides*	Freshwater garfish	ປາສິບໃຫຼງ	☺
		Cyclocheilichthys repasson	White eye barb	ປາດອກງິ້ວ	☺
		Osteochilus lini		ປາອີມຸມ	☺
		Pristolepis fasciata	Malayan leaffish	ປາກ່າ	☺
		Mystus albolineatus	Striped catfish	ປາຂະແຍງ	☺
		Mystus atrifasciatus	Catfish	ປາຂະແຍງ	☺
		Mystus mysticetus	Striped catfish	ປາຂະແຍງ	☺
		Mystus mysticetus	Catfish	ປາຂະແຍງ	☺
		Ompok bimaculatus	Butter catfish	ປາເຊືອມ	☺
		Macrognathus siamensis	Peacock eel	ປາຫຼິດ	☺
Benthic invertebrates	B-I	*Chironomus tentans*	Blood worm		
		Procladius sp.	Blood worm		
		Culicidae	Mosquito		
		Psychoda alternate	Moth fly		
	B-II	*Ensidens ingallsianus*	Mussel		☺
		Corbicula sp.	Clam		☺
		Tricorythodes albilineatus	Mayfly		
		Cercotmetus sp.	Water scorpions		
		Anax junius	Dragonfly		☺
		Epicordulia sp.	Dragonfly		☺
	B-III	*Anodonta cygnea*	Mussel		☺
		Macrostemum sp.	Caddis fly		
		Cheumatopsych pettiti	Caddis fly		

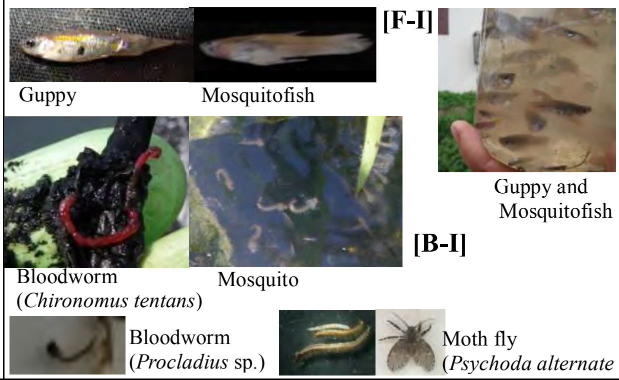
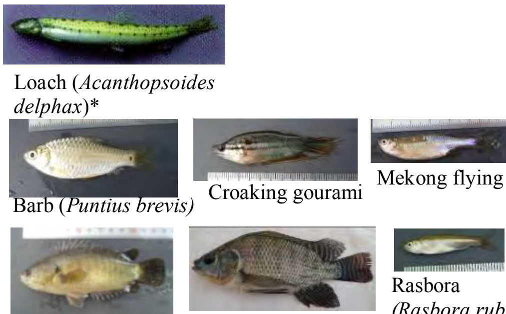
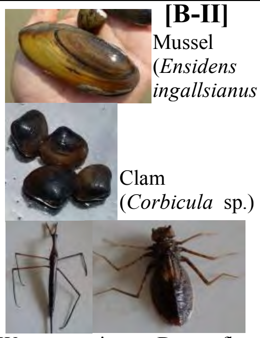
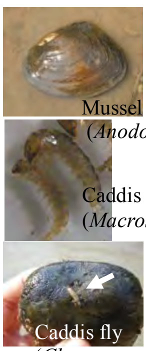
Note: ☺ shows valuable species for fishery.

Table 2.6.5 Range of Indication of Water Quality by Selected Species

Group	Water quality level	Very bad	Bad	Fair	Good	Very good
	BOD	>10 mg/l *	4-8 mg/l	4-8mg/l	2-5mg/l	2-3mg/l
	NH_3-N	>3mg/l	1-9mg/l	1-8mg/l	<3mg/l	<2mg/l
	DO		Low			
	Survey points	B2,B3,B4	B6	B7	B1,B5,B8	B9
Fish	F-I	←→	- - - -	- - - -	- - - →	
	F-II		←——	————	——→	- - - →
	F-III				←——	——→
Benthic invertebrates	B-I	←→				
	B-II				←→	
	B-III					←→

Note: *Dry season.

Table 2.6.6 Biological Indicator

Water Quality	General Condition	Indicator Species
Very bad	 BOD >10mg/l, NH_3-N>3mg/l Smelly black colored mud with rubbish.	 [F-I] Guppy Mosquitofish Guppy and Mosquitofish [B-I] Bloodworm (*Chironomus tentans*) Mosquito Bloodworm (*Procladius* sp.) Moth fly (*Psychoda alternate*)*
Bad to Fair	 BOD 4-8mg/l, NH_3-N 1-9mg/l Turbid yellowish water. A little muddy sediment.	 [F-II] Loach (*Acanthopsoides delphax*)* Barb (*Puntius brevis)* Croaking gourami Mekong flying barb Climbing perch Nile tilapia Rasbora (*Rasbora rubrodorsalis)*
Good	 BOD 2-5mg/l, NH_3-N <3mg/l Turbid water without pollution. Riverbed consists of clean soil.	 [B-II] Mussel (*Ensidens ingallsianus*) Clam (*Corbicula* sp.) Water scorpion (*Cercotmetus* sp.) Dragonfly (*Epicordulia* sp.)  [F-III] Catfish (*Mystus atrifasciatus*) Catfish (*Mystus mysticetus*) Malayan leaffish Freshwater garfish Butter catfish Peacock eel
Very good	 BOD 2-3mg/l, NH_3-N <2mg/l Water flows washing the riverbed which consists of gravels.	 [B-III] Mussel (*Anodonta cygnea*) Caddis fly (*Macrostemum* sp.) Caddis fly (*Cheumatopsych peltiti.*)

Source of the photo with *
Moth fly (*Psychoda alternate*) http://hydrobiology-bg.com/ and http://entoplp.okstate.edu/ddd/insects/mothfly.htm
Loach (*Acanthopsoides delphax*) http://www.fishbase.org/

(5) Target of Water Quality Improvement for Aquatic Organisms

Based on the aquatic biological condition clarified through the survey, the target of water quality improvement in the Mak Hiao River basin is proposed for each division shown in **Fig. 2.6.16**.

[Urban Area (Urban Drainage): Target BOD <8-12mg/l]

In Hong Xeng, Hong Ke and the other urban drainages connecting to these two, aquatic biological condition is very poor due to water pollution; only limited fish species with pollution tolerance and uncomfortable invertebrates such as bloodworm and mosquito larvae manage to inhabit. On the other hand, various species can be observed at the upstream and the downstream of the urban area. Therefore, if the water quality in the urban area is improved to be the same level as the upstream and the downstream, the migratory species such as fish will be able to migrate throughout the river and it is expected that the biological productivity of the river basin will be increased. Observed BOD at the upstream and the downstream was 8mg/l at the highest; therefore, 8mg/l is proposed as a desirable target of the water quality improvement in the urban drainages (see **Fig. 2.6.17-**a).

However, the actual BOD in the urban drainages is showing extremely high level especially in the dry season; the average BOD of the nine water-quality survey points reaches to 20mg/l. Therefore, an immediate target is required because it is deemed to be difficult to achieve the desirable target, 8mg/l, directly. It has been observed that BOD in the urban drainages becomes lower in the rainy season due to dilution and it enables fish without pollution tolerance to come into and inhabit in the drainages briefly. Based on this fact, the immediate target is proposed as the same level of the BOD in the rainy season. Since the average of BOD observed during each of the two times surveys in the rainy season was below 12mg/l, BOD 12mg/l is proposed as the immediate target (see **Fig. 2.6.17-**b).

[Middle stretch of Mak Hiao River including That Luang Marsh: Target BOD <8mg/l]

Water quality in Mak Hiao River including That Luang Marsh is still in inhabitable condition for the species without pollution tolerance except around the area traversed by Hong Xeng and Hong Ke. The current BOD in most areas is 8mg/l at the highest. However, at the downstream of the urban area (B6), the habitat condition is not sufficient as shown by the accumulated sludge and low level of DO. If the pollutant load from the urban area will continue or increase, the habitat condition in this area will be worse and only limited species may be able to inhabit like in the urban area. Therefore, it is recommended to monitor the condition carefully to keep the current water quality with BOD 8mg/l.

[Down-most stretch of Mak Hiao River (Near Rivermouth): Target BOD <5mg/l]

Water quality near the rivermouth of Mak Hiao River is in good condition throughout the year showing low BOD below 5mg/l; various species have been observed including valuable species for fishery. Any indication toward deterioration has not been identified so far. Therefore, it is desirable that the current condition will be maintained continuously.

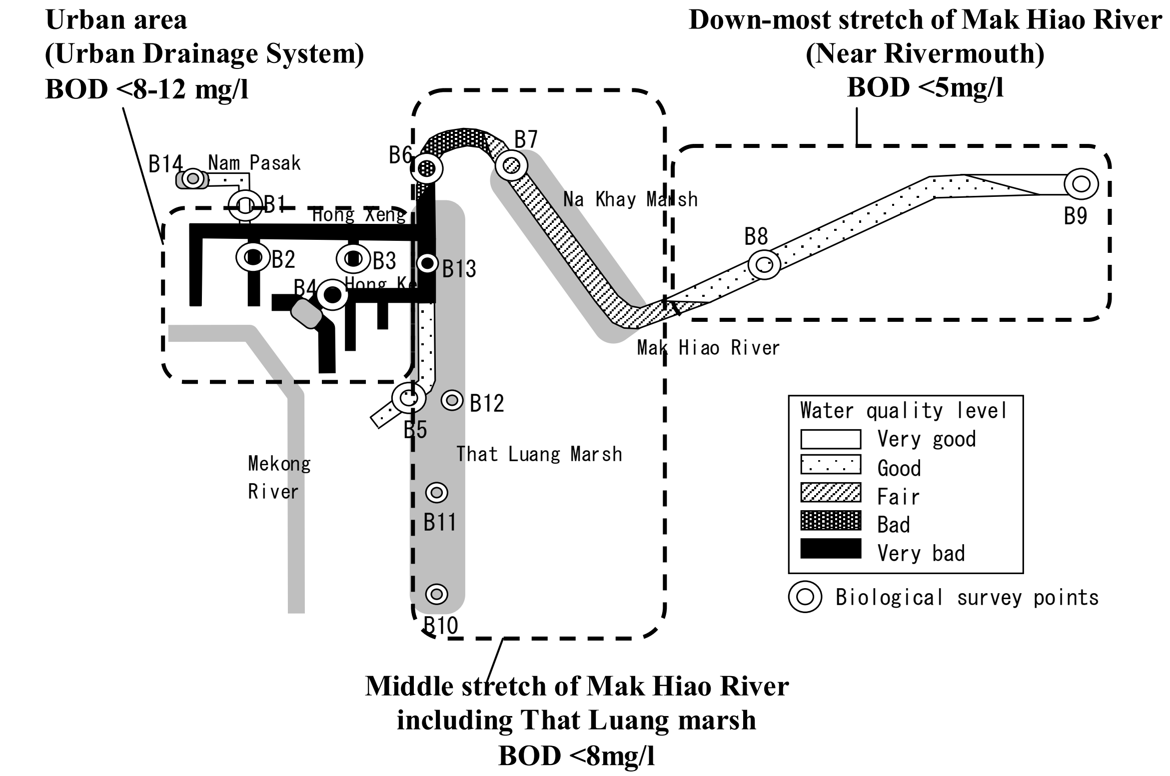
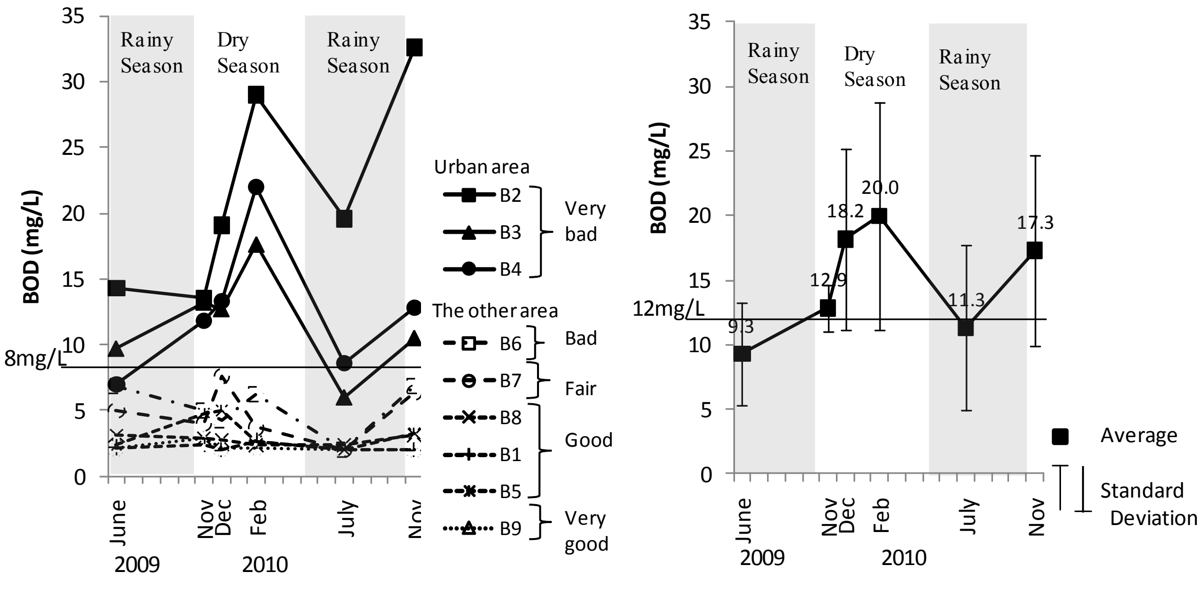


Fig. 2.6.16 Target of Water Quality Improvement of Mak Hiao River Basin



a. Observed BOD at the Biological Survey Points and the Desirable Target (8mg/L)

b. Observed BOD at the Nine Water Quality Survey Points in the Urban Drainages and the Immediate Target (12mg/L)

Fig. 2.6.17 Observed BOD and Target Water Quality in the Urban Drainages

2.6.2 Fishery

Fishery is one of the most important livelihoods for people living in the Mak Hiao River basin. It consists of two measures: one of them is capture fishery and the other is aquaculture. Most of their running styles are in small scale for personal consumption; therefore, there is no statistical information about fish catch in the Mak Hiao River basin, according to the Ministry of Agriculture and Forestry.

According to The previous study conducted in the villages around That Luang Marsh had estimated the total fish catch in That Luang Marsh to be 1,547,836 to 2,050,439 kg for one year, as shown in **Table** 2.6.7. Although all of the target species are fish, frogs and invertebrates such as snails are also included. Species caught by capture fishery are shown in **Table** 2.6.8.

The fish catch by aquaculture in That Luang Marsh is relatively small: 159,807 kg for one year (Gerrard, P., 2004). Aquaculture is conducted in constructed or natural ponds in two ways: the first one is putting fingerlings into the ponds to grow them, the second one is catching fish which come into the pond by themselves in the rainy season. Examples of the species which come into the natural ponds are *Channa lucia*, *Channa striata* (snakehead fish), *Anabas testudiens* (climbing perch), *Barbodes gonionotus* (java barb), according to the Department of Agriculture and Forestry of Vientiane.

Table 2.6.7 Fish Catch by Capture Fishery in That Luang Marsh

Type of Species	Average Collection per Household (kg/year)	Total Collection for the Entire That Luang Marsh (kg/year)
Fish	300-480	837,672-1,340,275
Snails	175	488,642
Frogs	17	48,402
Inverts	62	173,119
Total	554-734	1,547,836 – 2,050,439

Source: Gerrard, P., 2004, Integrating Wetland Ecosystem Values into Urban Planning: The Case of That Luang Marsh, Vientiane, Lao PDR, IUCN − The World Conservation Union Asia Regional Environmental Economics Programme and WWF Lao Country Office, Vientiane

Table 2.6.8 Species Collected by Capture Fishery in That Luang Marsh

	Fish	Others
Species name	Walking catfish Broadhead catfish Grass carp Great white sheatfish Eel Croaking gourami Glass catfish Swamp barb Asiatic snakehead Fighting fish Silver carp Climbing perch Chevron snakehead Common carp Tilapia Common silver barb Snakesking gourami Striped flying barb Asiatic swamp eel	Frogs Toads Snails June Beetles Freshwater Shrimp

Source: Samuelsson, T. 1998. Inventory of Wetlands in Vientiane, Lao PDR; School of Engineering Kristianstad University, Sweden [cited from Gerrard (2004)]

2.7 Environmental Education

2.7.1 Environmental Education in Existing Related Projects

(1) Guideline of Urban Environment for Urban Management in Lao PDR (PTI-Quebec/Canada, 1998-2001)

This TOT (training of trainers) project on the environmental education for MPWT staff was conducted for four years by PTI with the assistance of Quebec Province, Canada. The themes were 1) general environmental management, 2) water environment preservation, 3) solid waste management, and 4) environmental regulation.

In the first 1.5 years, four university teachers from Quebec and Montreal provinces conducted TOT for seven MPWT staff for 3 months. In the second 2.5 years, seven trained MPWT trainees implemented the TOT workshops for the working level MPWT staff (division director class). Several village chiefs also attended the workshops. (Easier lecture was conducted considering their intelligibility.)

The deliverable is a published Laotian general environmental textbook for government staff.

(2) Strengthening Environment Management Project, Phase II (WREA-SIDA, 2005-2010)

This project is a comprehensive capacity development (CD) of WREA on environment as a whole with the support of SIDA. The Phase I (2001-2005) and Phase II (2005-2010) of the project have already been completed.

Environmental education and awareness (EEA) component of Phase II was implemented by the Environment Promotion Division, Department of Environment, WREA based on the ―National Strategy on Environment Education and Awareness to the years 2020 and Action Plan for the years 2006-2010" issued by STEA (predecessor of WREA) in 2004.

Various EEA activities were implemented with the cooperation of many line agencies such as the National Research Institute for Educational Science (NRIES), the Department of General Education of the Ministry of Education, and the National Media Department.

The main EEA activities implemented are as follows:

- Curriculum for EEA in all formal education (questionnaire survey and workshop activity)
- Mass media campaign such as:
  - Celebratory campaign, provision of environment banners and provision of TOT for mass media and public bus drivers
  - Production of environment songs
  - Provision of environmental TV and radio programs
- Dissemination workshops for private sector and NGO
- Green school model for 14 target primary schools including TOT for teachers

Since there were so many activity items in the EEA, each item was comprehensive (general and extensive).

The EEA deliverable was developed as follows:

- Side readings on ―climate change", ―solid waste management" and ―trash separation" for primary school pupils and adults (2007-2009) (refer to Photo 2.7.1)

- A publication on the training approach and training guideline for EEA (2009)
- Enlightenment posters, pamphlets and stickers such as ―climate change” and ―solid waste management” (printed in 2007)
- Original song book and CDs of world environment day concert (June 5, 2007) (supported by SIDA, UNDP, WB, WWF and IUCN)

Photo 2.7.1 Supplementary Readings by WREA-SIDA Project

(3) That Luang Marsh Project (STEA-WWF, 2007-2009)

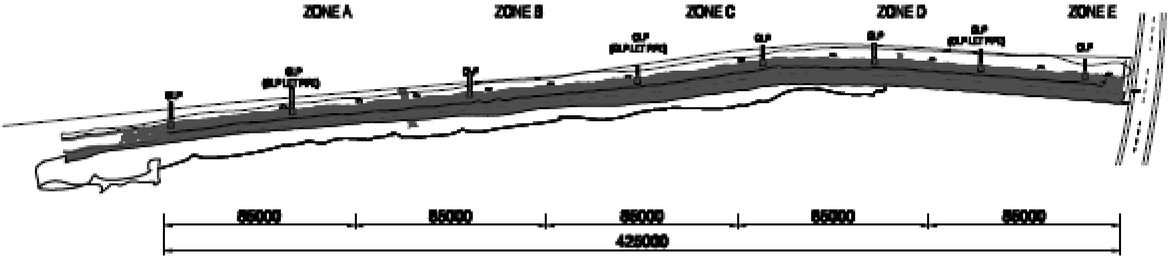
The Science, Technology and Environment Agency (the former organization of WREA) and WWF implemented the ―That Luang Marsh Project” from 2007 to 2009 and created artificial wetlands as structural measures for water quality improvement at the following five sites in Vientiane. They are scheduled to carry out Phase 2 of this project thereafter with the concept to create more large-sized artificial wetlands.

- None Khor Primary School, None Khor Village, Xaysetha District
- Residents in None Khor Village, Xaysetha District
- Small canal connecting Hong Xeng in Viengchalearn Village, Xaysetha District
- Nong Hai Village, Hatxaifong District
- Canal around Beer Lao Factory, Hatxaifong District

[Case Example] Canal around Beer Lao Factory was constructed as a model project for industry in Lao PDR. Industrial wastewater is basically being treated by a treatment plant inside the factory; some washing water and stormwater were discharged without treatment before. Drainage canal along the site of the factory is collecting all rainwater and factory water to treat them finally.

Source: WWF

Photo 2.7.2 Canal around Beer Lao Factory



Source: WWF

Fig. 2.7.1 Canal around Beer Lao Factory

(4) Sanitary Model Village Project (Department of Health, Vientiane, 2003-)

The Department of Health, Vientiane (DOH) is conducting the ―Sanitary Model Village Project" as the sanitary education activity since 2003. The activity was conducted in cooperation with the related city department through discussions at the Committee of Urban and Rural Area Development of Vientiane.

The target of the activity is all the villages in Vientiane. The activity includes vaccination, wastewater disposal, public health and solid waste disposal. Staffs of nine district health offices of the DOH have implemented the activity in the villages under their jurisdiction as lecturers.

The educational activities were 80% completed in 2010. The staffs of the nine district health offices evaluated the achievement of each village by a common evaluation sheet and gave awards to the villages that attained excellent achievement.

(5) Green School Project (Department of Education, Vientiane, 2006-)

The Department of Education of Vientiane (DOE) is carrying out the ―Green School Project” which performed tree-planting as environmental beautification of school grounds since 2006 based on city policy. Many primary, junior high and senior high schools (107 schools: 86 public and 21 private schools) selected have been conducting the activity. DOE evaluates the result of each school in three steps, and had commended top nine schools (3 primary, 3 junior high and 3 senior high schools) which obtained excellent results.

(6) VIUDP (ADB, 1997-2000)

In the VIUDP (Vientiane Integrated Urban Development Project) by ADB, the proposed environmental education in communities was canceled and only environmental campaign activity was carried out. In the succeeding VUISP (Vientiane Urban Infrastructure and Services Project, ADB, 2003-2007), environmental education was not also conducted.

2.7.2 Community and Education System of Vientiane

(1) Community Structure in Vientiane

Vientiane consists of nine districts and 491 villages (―Ban” in Laotian) as the minimum administrative unit are placed under these districts. A village is also an aggregate of several hamlets (―Ngoi” in Laotian).

The merger of villages is advancing in Vientiane at present according to the policy of the Lao PDR Government. Especially in Chanthaboury District covering the urban central area, the village number decreased from 39 to 32 by the merger in June 2009. The typical organization of a district office is shown in **Fig. 2.7.2**.

A village (Ban) organization mainly consists of a village chief, two deputy chiefs, security committee, economic committee, and social and culture committee with several units under them. In addition, there are village level units of mass organizations such as Lao Women‘s Union, Lao Youth Organization and Lao Front for National Reconstruction. This basic structure is almost the same at all the villages in Lao PDR. The typical organizational structure of a village office is as shown in **Fig. 2.7.3**.

In the four urban center districts, some villages have a village environment unit (VEU) organized by WREO. In Lao PDR, the basic composition of one community (village) is one village office, one primary school and one temple. Junior high school and high school are not fundamental compositions of a community (village) as compared with the primary school. The not so many schools are distributed unevenly and they are not compulsory educational facilities.

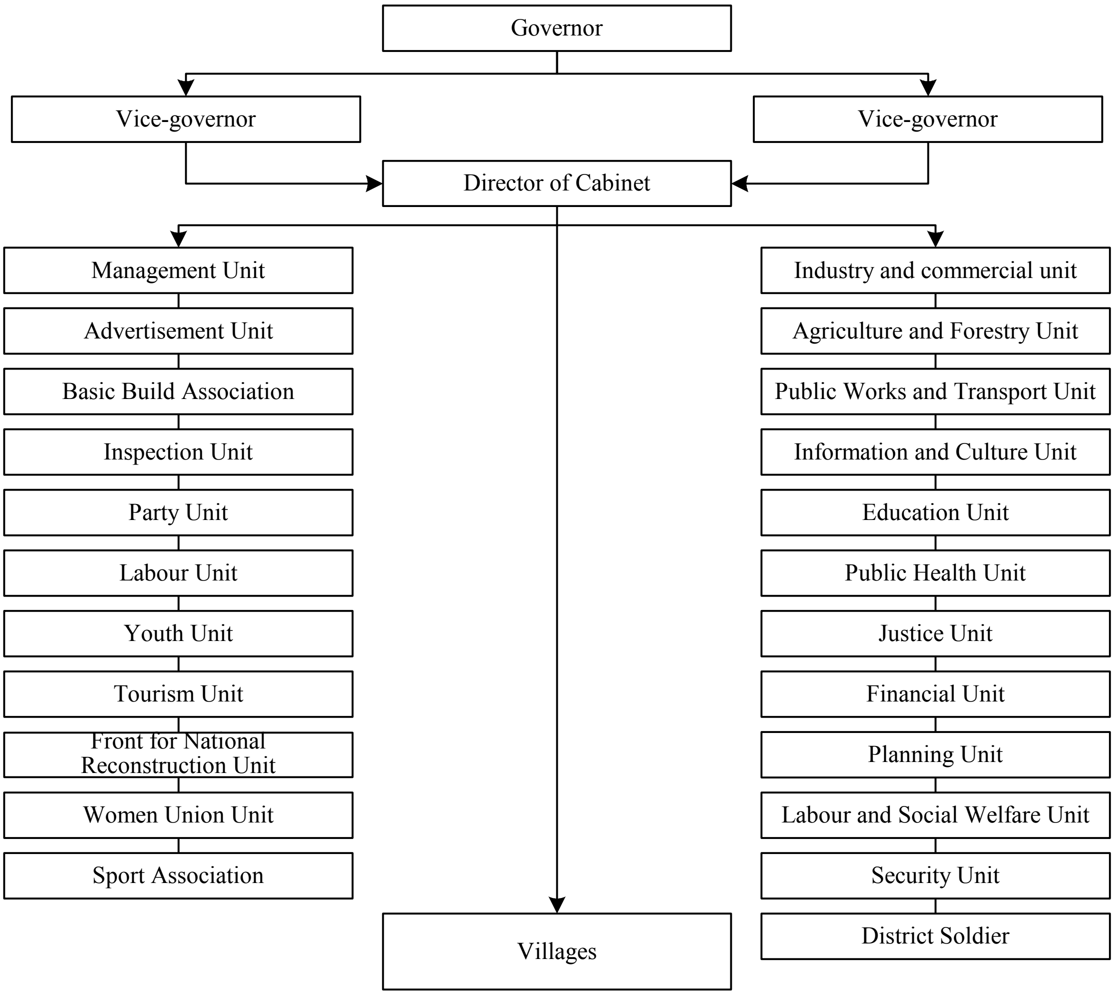


Fig. 2.7.2 Organizational Structure of District Office

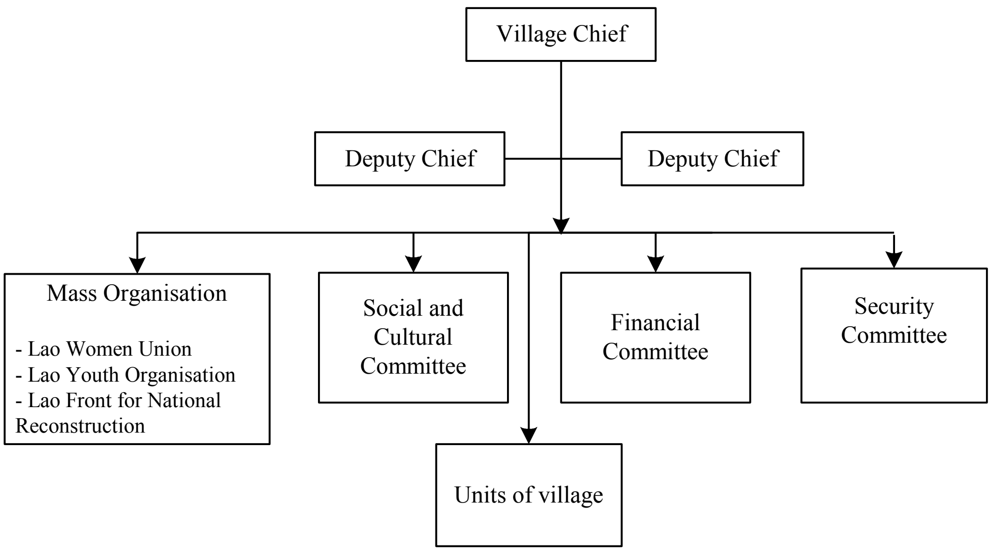


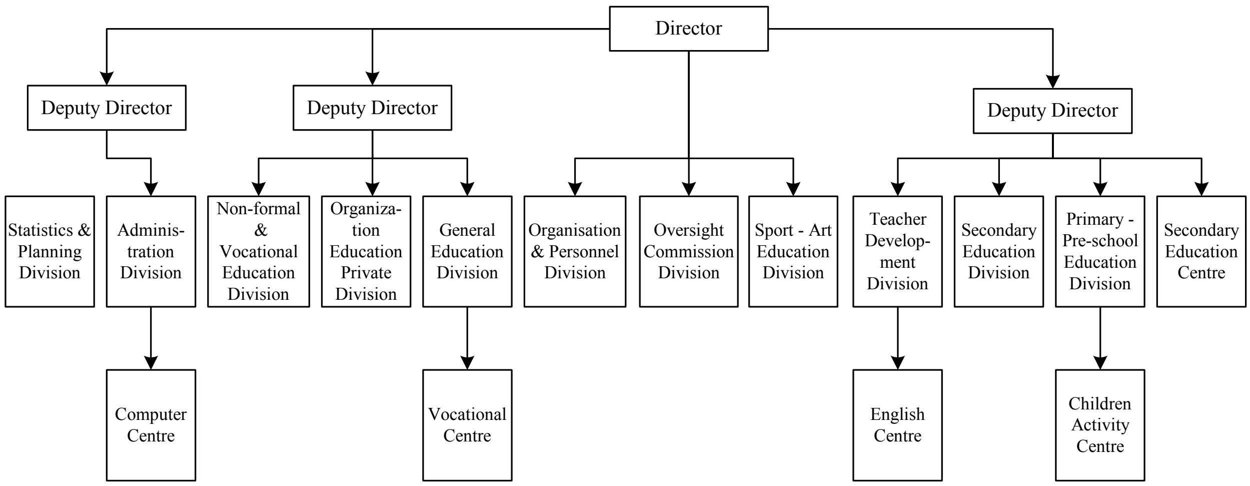
Fig. 2.7.3 Organizational Structure of Village Office

(2) Educational Situation in Vientiane

In Lao PDR, primary school (compulsory education: 5 grades), junior high school (4 grades), and high school (3 grades) are fundamental public education. Junior high school was changed from 3 to 4 grades in 2010. Although the Ministry of Education formulates the whole education policy, actual school management is divided into the following jurisdictions in Vientiane:

- University and vocational school : Ministry of Education (MOE)
- Secondary (junior high & high) school : Department of Education, Vientiane (DOE)
- Kindergarten, primary & secondary schools : District Educational Office, DOE

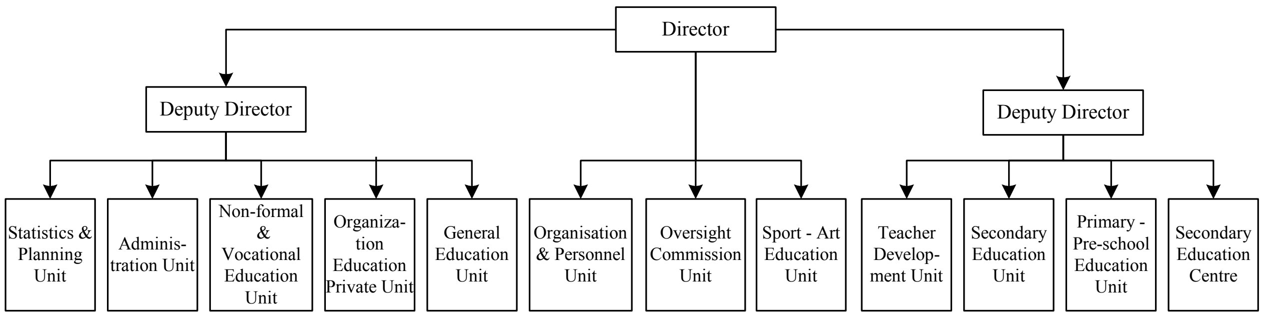
The organizational structure of the Department of Education, Vientiane (MOE) is as shown in **Fig. 2.7.4**.



Source: Department of Education, Vientiane

Fig. 2.7.4 Organizational Structure of the Department of Education, Vientiane

The organizational structure of the District Educational Office is as shown in **Fig. 2.7.5**. There are nine district offices under DOE in Vientiane.



Source: Department of Education, Vientiane

Fig. 2.7.5 Organizational Structure of the District Educational Office

(3) Outline of Primary School

The environmental education of the pilot project was carried out mainly for the primary schools as described in **Section 3.3**.

In Lao PDR, one public primary school is established in one village (Ban) in principle. In Vientiane, the total number of villages is 491 and the total number of public primary schools is 399 (of which 353 are complete schools with 4-5 grades) in 2010. In some urban villages in Vientiane occupied mostly by commerce, industry or administration institutions, there is no primary school.

The curriculum of a primary school consists of 80% of seven regular subjects, and 20% of extracurricular activities. The regular subjects are Laotian, mathematics, our surroundings (including history, natural science, moral, etc.), art, music, gymnastics and craft work. The extracurricular activities are equivalent to the ―Integrated Study Period" in Japan. The first term is from September 1 to January 31, and the second term is from February 1 to May 30. School vacation is for three months from June to August.

(4) Relationship between Residents and Primary School in Village

The partnership between the primary school and the residents in a village is very strong through the PPA (Pupils' Parents Association) and the village office. Many village meetings are held in the primary school or temple. Since the budget of the District Educational Office has been tight, the maintenance of the primary school facility is substantially conducted by the village office. The primary school head submits the purchase/repair budget plan of required equipment to the village office, and the residents are to pay the expenses after the village office has approved the plan.

2.8 Verification of Water Purification Effects by Water Spinach in the Canals

2.8.1 Background

It has been confirmed that the canals in Vientiane suffer from some water pollution accompanying bad odor, sludge sedimentation, and the others, mainly due to the direct discharge of domestic wastewater. This situation could be improved by installing wastewater treatment facilities including sanitation improvement measures such as the community-based sanitation (CBS) system at suitable sites.

However, the soil from surrounding roads or farmlands can still enter the canals even after the wastewater treatment facilities have been installed, so that some amount of soil will accumulate as sediment on the riverbed reducing the flow capacity of the canals. On the other hand, the sediment on the riverbed can provide the base ground for plants to grow in the canal as shown in some water surface areas of the canals covered with natural vegetation, including wild water spinach (Ipomoea aquatica Forsk).

It has been reported that natural vegetation has some water purification effects in water bodies in many countries. Thus, it would be valuable to verify the effects of natural vegetation in a real canal as an experimental approach for water environmental improvement measures in the city along with the installation of a wastewater treatment system.

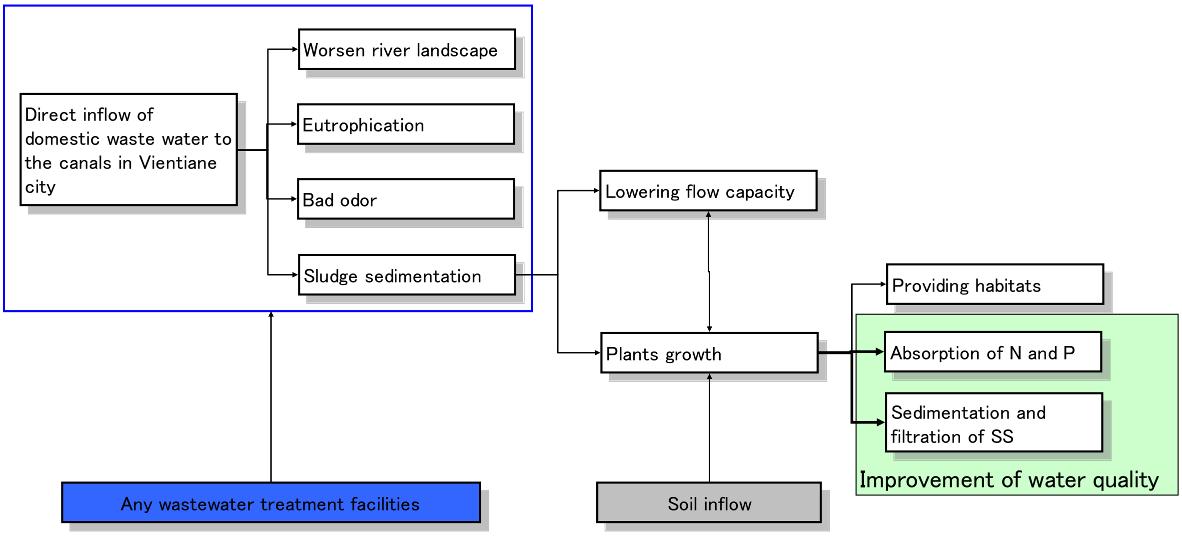


Fig. 2.8.1 Situation of Canals in Vientiane

2.8.2 Objectives of the Verification

It has been reported that natural vegetation has the following water purification effects in water bodies in general:

- Decrease in Suspended Solid (SS) by acceleration of sedimentation and filtering effect;
- Absorption of nutrients (phosphorus (P), nitrogen (N)) by vegetation; and
- Decomposition of organic substances by adhering micro-organism.

In general, the verification of water purification effects by vegetation is necessary to conduct a long-term monitoring with an artificial vegetation facility. However, an artificial vegetation facility may cause adverse impacts on the natural flow or healthy environment in the canal, if no continuous and appropriate management for the facility is done. The understanding and cooperation of local residents along a canal is essential for appropriate management; however, it must be said that this management will be very difficult in the Study Area at present.

Therefore, this verification was done by a simple method without any artificial facility. Field survey and experiments were conducted under the following objectives:

- To verify the water purification effects by wild plants, mainly wild water spinach quantitatively in some sections in a real canal in Vientiane; and
- To understand the water purification mechanism by wild plants, mainly wild water spinach.

This verification was divided into the following three components:

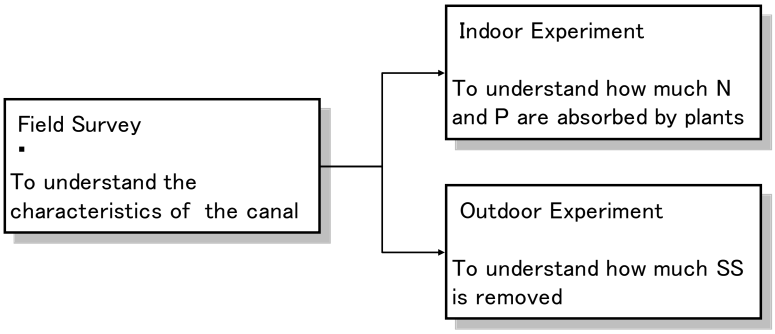


Fig. 2.8.2 Three Components of Verification of Water Purification Effects of Wild Water Spinach in Canals

2.8.3 Field Survey

(1) Survey Area

Based on the results of the longitudinal water quality monitoring of this JICA Study, which was conducted in June 2009, the BOD values in downstream points of the Hong Pasak Canal were considerably decreased, as compared with the values in the upstream points (LB7 to LB8: the longitudinal water quality sampling).

Therefore, Hong Pasak Canal was selected as the survey area of this verification. The Survey Area covered the top upper reach point of Hong Pasak Canal up to the junction point with Hong Xeng Canal. The water quality was measured at almost 500 m intervals from the upper reach to the junction point (see **Fig. 2.8.3**).

(2) Analyses Items and Dates

The analyses items of the water quality were water temperature, pH, EC, turbidity, DO, TDS, ORP. The water quality measurements were conducted using a portable equipment to understand contribution factors for decreasing the BOD values in the canal on 28 June 2009, 08 July 2009, and 28 July 2010. These parameters were measured by the JICA Study Team with a portable detector, and then analyzed and used as analysis values.

Fig. 2.8.3 Survey Points of the Field Survey

(3) Main Findings of the Field Survey

(a) Vegetation

Based on the field reconnaissance, it was observed that most species of the vegetation were water spinach *(Ipomoea aquatica Forssk)* and sessile joyweed *[Alternanthera sessilis (L.) DC.]*, which grow on the sludge sediment soils. There were some differences on the growth situation of vegetation among the sections (many vegetation sites and less vegetation sites). However, the variety of species was not observed. (**Photo 2.8.1** shows the above water spinach and sessile joyweed in the Survey Area).

	
Water spinach (Ipomoea aquatica Forssk)	Sessile joyweed [Alternanthera sessilis (L.) DC.]

Photo 2.8.1 Water Spinach and Sessile Joyweed

(b) Water Quality

Concerning the water quality measurement in the survey, the main findings were as follows:

- In the section from the top upstream to H.P. 4, the stream flow in the canal has increased, which may be caused by the wastewater influent of the section.
- In the section from H.P. 3 to H.P. 6, the turbidity value has decreased, and the Suspended Solid (SS) might have reduced in the section. (The turbidity value showed a strong correlation with the SS value, according to periodical water quality monitoring in this Study).
- In the section from H.P. 4 to H.P. 6, the DO value has increased, which may be caused by the photosynthesis of algae on the gravel and riverbed. For the section where increase of DO value was not observed, sapropel may have accumulated and the riverbed may not be suitable for the growth of algae. Also, sunlight for photosynthesis may not be enough due to high turbidity of water.
- Water quality at 6 checkpoints along the Hong Pasak Canal did not vary much between 2009 and 2010.

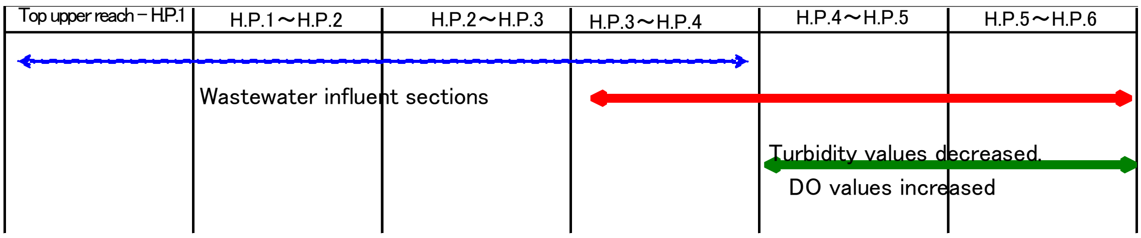


Fig. 2.8.4 Main Characteristics of the Hong Pasak for Water Quality Parameters

2.8.4 Indoor Experiment

(1) Objective of Indoor Experiment

In order to confirm quantitatively the basic water purification effects of N and P absorption by the plants, especially, wild water spinach (*Ipomoea aquatica Forsk*), indoor experiments were conducted from 30 July to 08 August 2010. For the experiment, it was necessary to confirm the water purification effect indoors, where the system is closed and no effect by other influences is caused.

The places of experiment were set in indoor locations beside a window where sunlight is able to reach the location, because the plant needs sunlight for is growth and the elimination of any impact by rainfall should be considered.

(2) Analysis Items (Pre-Experiment and Main Experiment)

The analysis items of water quality were BOD, NH_4, NO_2, NO_3, PO_4, pH, EC, Turbidity, DO water temperature, TDS, ORP, wet weight, temperature, and humidity. These parameters except BOD were measured by the JICA Study Team with a portable detector and used as analysis values. BOD was analyzed by a laboratory in Thailand from the samples taken by the JICA Study Team.

(3) Experiment Methods

The analysis was divided into 2 types. One was Pre-Experiment, the other was Main Experiment.

The Pre-Experiment analysis was conducted to confirm the volume of wild water spinach and the length of time needed to clarify any purification effect by N and P, as well as any difference of water purification effect between water spinach with roots and that without roots. The Main Experiment was conducted to estimate the basic water purification effects quantitatively based on the results of the Pre-Experiment.

For both the Pre and Main experiments, 5 stems of wild water spinach collected near the sites were floated in large-sized tubs (around 50 cm in diameter). By observing the changes in water quality values of N and P in the tubs before and after floating the water spinach, any water purification effect due to the absorption of N and P by the water spinach could be confirmed.

Any water purification effect could be confirmed by comparing the case of wastewater only and the case of wastewater with water spinach. Images of the two cases are shown in **Photo 2.8.2**. The wastewater for the experiment was sampled at the H.P. 5 survey point along the Hong Pasak Canal.

	
Wastewater only (Control Box)	Wastewater with Water Spinach

Photo 2.8.2 Images of Floating Water Spinach in Indoor Experiment

2.8.5 Main Findings of the Indoor Experiment

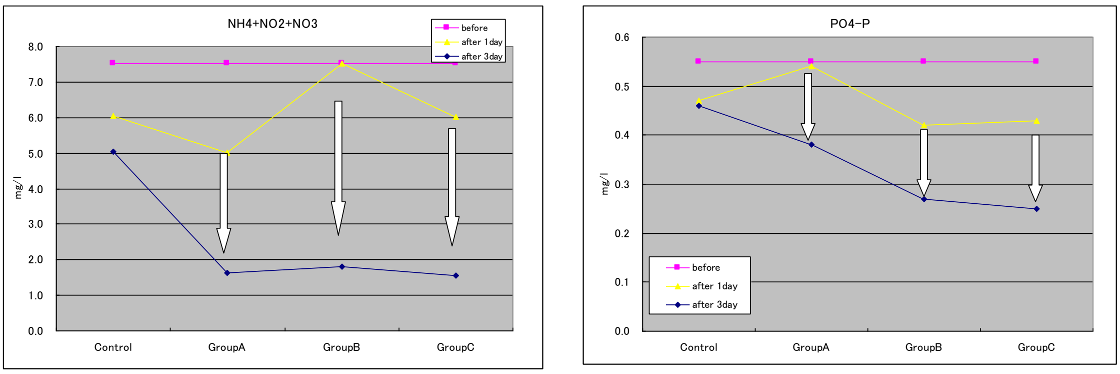
The following are the main findings in the indoor experiment.

(1) Pre-Experiment

- The case of water spinach with roots showed lower P and inorganic N (NO2-N, NO3-N and NH4-N) compared with the control and the case of ―without roots," and the wet weight of the case ―with roots" increased during the 3 days of experiment.
- The case of water spinach without roots showed lower inorganic N compared with the control, and wet weight increased after one day, which could be due to the new roots that came out after one day.
- The case of water spinach with roots showed lower values of Nitrogen and Phosphorous compared with the case of water spinach without roots. Water spinach shows different absorption rates of both Nitrogen and Phosphorous due to the roots.
- It was confirmed that water spinach can absorb Nitrogen and Phosphorous.
- It can be said that 5 stems of water spinach were enough to see the effect of water purification in the tub.
- It was better to use water spinach with roots than that without roots to gain stable data during 3 days.

(2) Main Experiment

- It was confirmed that 100 g of water spinach (three samples: each contains about five water spinach randomly selected) can absorb about 3 to 5 mg/l of inorganic nitrogen (NO2-N, NO3-N and NH4-N) and about 0.15 mg/l of phosphorous (PO4-P) during 48 hours (after 1 day to after 3 days). See Fig. 2.8.5.
- It was confirmed that all three samples have higher absorption effect for both Nitrogen and Phosphorous after three days although the effect is different among the samples and the reason is not clear.
- BOD values in the tub with water spinach were 2 to 3 mg/l lower than control, and relevant to the change of inorganic nitrogen value.
- It was confirmed that water spinach can contribute water purification by absorbing N and P, and the effect was higher in absorbing N than P.



Note: Group A, Group B, and Group C are sample names, where five stems of wild water spinach were floated in wastewater. ―Control" means wastewater only.

Fig. 2.8.5 Results of Main Experiment Measurements (Inorganic N, P)

2.8.6 Outdoor Experiment

(1) Objective of Outdoor Experiment

In order to confirm quantitatively any water purification effect of Suspended Solid filtration and sedimentation by plants, especially wild water spinach (*Ipomoea aquatica Forsk*), outdoor experiments were conducted conducted in 5 days from 2 to 6 August 2010. The two experiment sites were selected from the downstream of the Hong Pasak based on the present water quality and vegetation conditions in the canal, under the following conditions (see **Fig. 2.8.6**):

- Wild water spinaches are broadly grown in or on surface water along the canal;
- There are few inflows from drainage system; and
- The site is located in some straight alignment where no morphological effect of water purification might be caused.
- Analysis Items

The analysis items of water quality were BOD, SS, NH_4, NO_2, NO_3, PO_4, pH, EC, Turbidity, DO, water temperature, TDS, ORP, velocity, depth and area of vegetation. Water quality was measured in the same way as described in Subsection 2.8.4(4). Velocity, depth and area of vegetation were measured by simple current meter, sounding rod and measuring tape respectively.

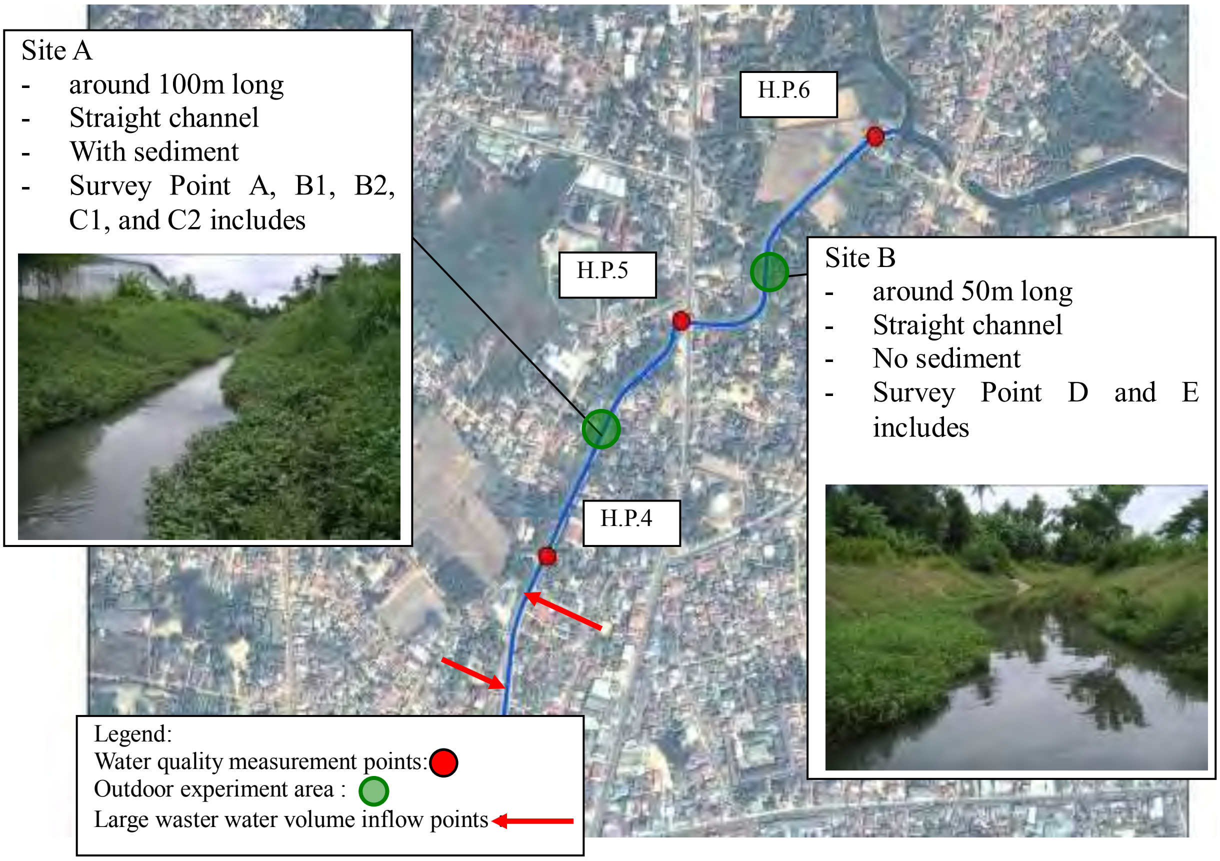


Fig. 2.8.6 Outdoor Experiment Area

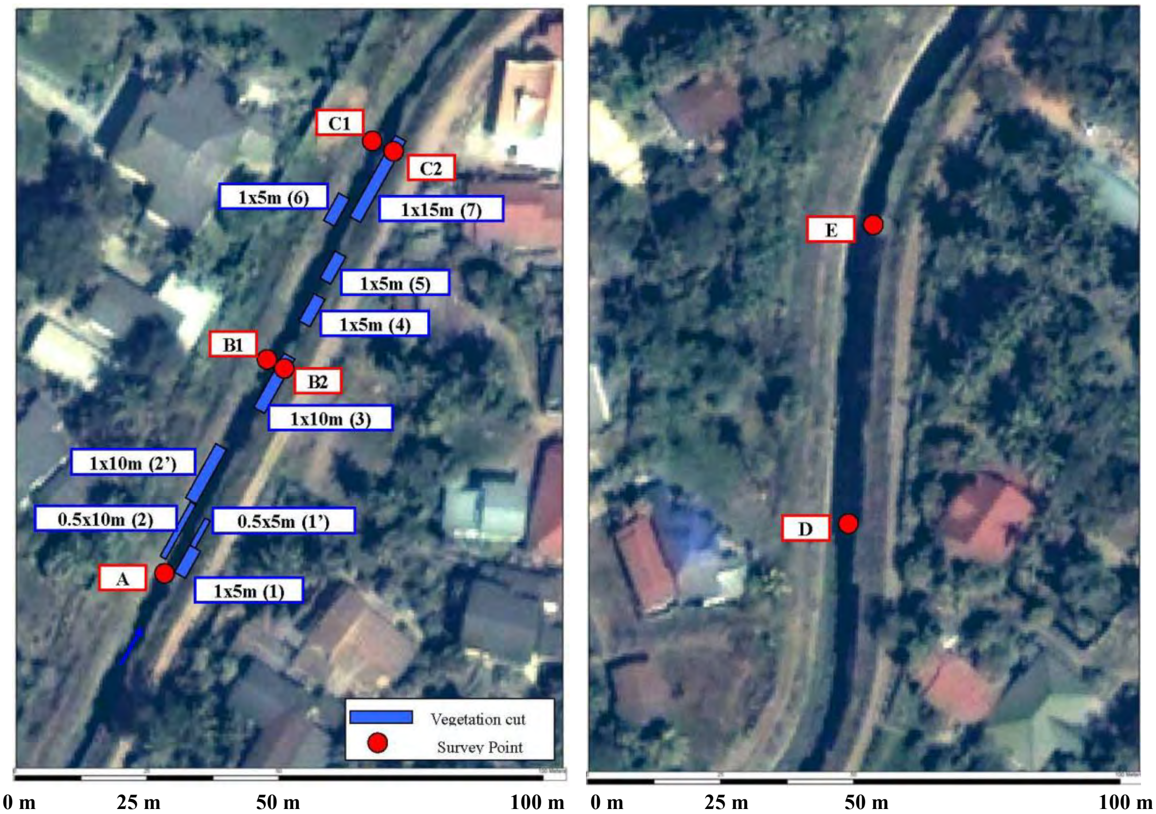
(2) Experiment Methods

Water quality values such as SS values in the upstream- and downstream ends were measured in each case before cutting the natural vegetation including water spinach and after cutting the natural vegetation. For Experiment Site B, the vegetation was not cut in order to compare the conditions of –with bottom sediment” and the –without bottom sediment” only. The images of the above analyses methods for SS are shown in **Photo 2.8.3**.

As the additional measurement items, depth and velocity were measured to calculate the flow discharge. Also, the area of the vegetation cut was measured as shown in **Fig. 2.8.7**.

Before cutting natural vegetation	After cutting natural vegetation

Photo 2.8.3 Images for Quantitative Analysis in Outdoor Experiment



Site A

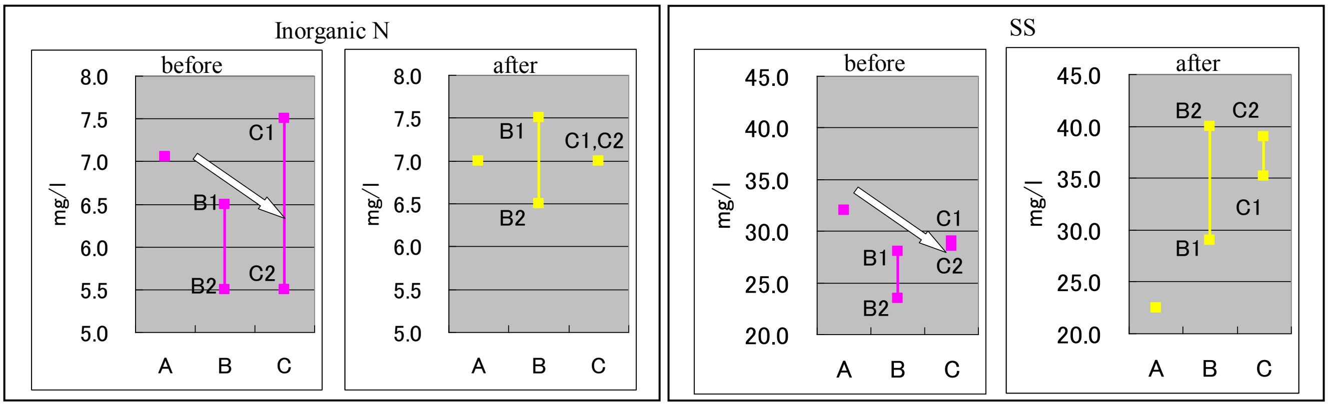
Site B

Fig. 2.8.7 Survey Points of the Outdoor Experiment and the Area Vegetation Cut

2.8.7 Main Findings of the Outdoor Experiment

The findings from the outdoor experiment are as follows:

- Comparing the conditions before cutting vegetation with after it, it was evident that inorganic N values were decreased by the vegetation. For example, before cutting, the inorganic N value decreased by 0.5 mg/l between point A and point B1, and showed the trend of decreasing inorganic N from point A to point C. Also, after cutting, inorganic N increased between point A and point B1 and showed no decreasing trend (refer to Fig. 2.8.8).
- Comparing the conditions before cutting vegetation with after it, it was evident that SS values were decreased by the vegetation. For example, before cutting, the SS value decreased by 4.0 mg/l between point A and point B1, and showed the trend of decreasing SS values from point A to point C. Also, after cutting, SS values increased between point A and point C and showed no decreasing trend (refer to Fig. 2.8.8)
- Comparing the conditions before cutting vegetation with after it, it was evident that the flow velocity was decreased by the vegetation. For example, after cutting vegetation, the velocity increased by 15 cm/s at point B2 (refer to Fig. 2.8.9), and almost the same at point C2. It was confirmed that the vegetation contributed to the decrease of velocity.
- Comparing the conditions before cutting vegetation with after it, it was found that water quality values of inorganic N, SS, and BOD inside the vegetation (B2) were less than the balues outside the vegetation (B1).
- There were no major differences of P value before and after cutting vegetation. It may be because the amount of P value was rather smaller than the other values such as BOD, SS or inorganic N, and thus the change of the P value would be difficult to recognize.
- Comparing point D with point E, no clear decreasing/increasing trend of inorganic N, SS and BOD value was observed.



Note: A, B, and C are cross section points within the A site of Fig. 2.8.7.

Fig. 2.8.8 Results of Outside Experiment (inorganic N, SS)

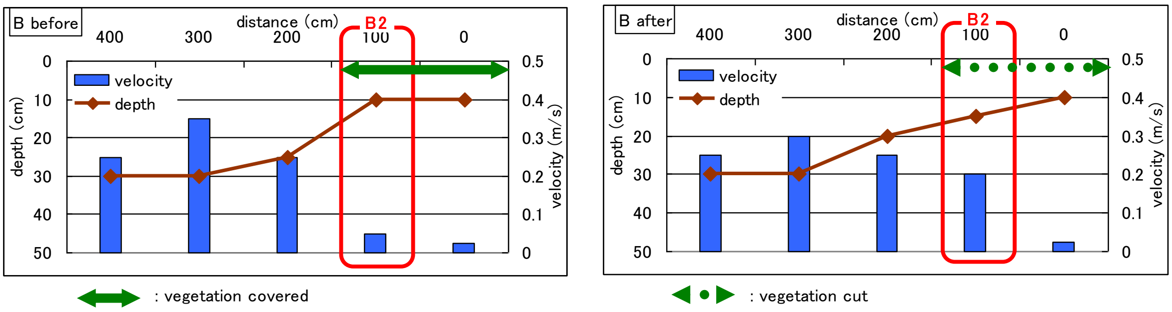


Fig. 2.8.9 Results of Outside Experiment (Velocity and Depth)

2.8.8 Considerations

(1) Calculation of BOD Reduction in the Hong Pasak Canal

Based on the results of the experiments mentioned above, the amount of BOD reduction could be calculated as follows:

- Comparing point A with point B1 before cutting vegetation, the reduction of BOD load was calculated as 1.5 kg/day for 50 m long. The BOD load reduction for 50 m long could be 169.1 kg/day to 167.6 kg/day (see Table 2.8.1).
- Comparing point B1 with point B2 before cutting vegetation, the reduction of BOD load was calculated by the quantity of vegetation area as 1.8 kg/day/30 m2 (for 50 m long). The calculation method is explained as follows:

i) Flow discharge (Q) in vegetation area (point B2) was calculated as below since the vegetation area was separated from the open water area:

*0.005 m^3/s = 0.1 m (water depth) * 1 m (vegetation width) * 0.05 m/s (average velocity)*

These values were measured by the Outdoor Experiment.

ii) The daily volume of stream water flowing through a unit vegetation area of 1 m^2 was calculated as below:

*43.2 m^3/m^2/day = 0.005 m^3/s (Q) / 10 m^2 (Area) * 86,400 (seconds)*

iii) The daily BOD reduction rate in unit vegetation area could be calculated as below:

*60.5 g/m^2/day = (43.2 m^3/m^2/day * ((BOD at Point B1 - BOD at Point B2 = 1.4 g/m^3)))*

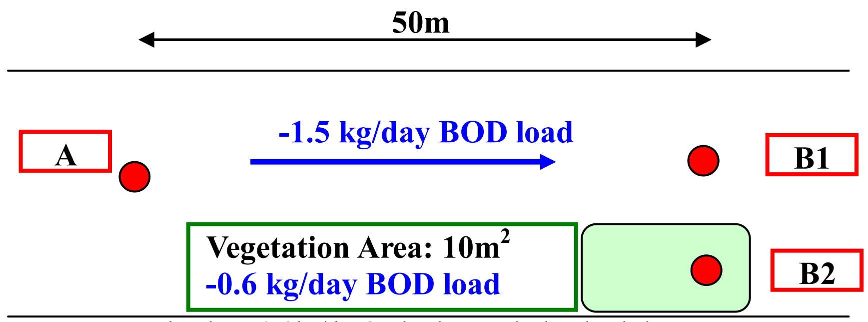
iv) The amount of vegetation area between A and B1 was measured as approximately 30 m^2 by the outdoor experiment.

v) The BOD reduction rate could be estimated at 1.8 kg/day (= 60.5 g/m^2/day * 30 m^2)

Table 2.8.1 Main Results of the BOD Reduction Calculation for Point A, B1 and B2

Item	Point A	Point B1	Point B2
Q (m^3/s)	0.2	0.2	-
BOD (mg/l)	10.3	9.7	8.3
BOD Load (kg/day)	169.1	167.6	-

Note: The above Q and BOD values are the results of the Outdoor Experiment.



Note: The above 0.6 kg/d BOD load was calculated as below:
0.6 kg/day = 1.8 kg/day * $10m^2$ / 30 m^2

Fig. 2.8.10 Image of BOD Load Reduction between Point A and Point B

(a) Calculation of BOD Reduction Rate in the Downstream of the Hong Pasak Canal

According to the result of Longitudinal Water Quality Monitoring Survey conducted by the JICA Study in July 2009 with point LB7 showing the BOD of 37.6 mg/l and flow rate of 0.02 m^3/s, and point LB8 showing the BOD of 10.1 mg/l and flow rate of 0.07 m^3/s, the amount of reduced BOD for 2 km (between point LB7 and point LB8) was estimated at 166.4 kg/day. This reduction amount was computed by estimating daily BOD loads at both points and adjusting with flow rate difference (0.07/0.02). Point LB7 was the same location as point HP2, and point LB8 was the same location as point HP3 of this field survey of the verification.

Applying the result of the Outdoor Experiment, the amount of reduction of BOD load between LB7 and LB8 could be estimated as about 60 kg/day (1.5 kg/day × 2,000 m / 50 m), and thus the reduction rate by the effect of vegetation would be estimated as 36% (60 kg/day / 166.4 kg/day ×100).

If it was calculated by the area of vegetation, the amount of reduction of BOD load between LB7 and LB8 was calculated as about 72 kg/day (1.8 kg/day × 2,000 m / 50 m) and thus, the reduction rate by the effect of vegetation would be estimated as 43% (72 kg/day / 166.4 kg/day × 100).

(2) Calculation of SS Reduction in the Hong Pasak Canal

Based on the results of the experiments mentioned above, the amount of SS reduction could be calculated as follows:

- Comparing point A with point B1 before cutting vegetation, the reduction of SS load was calculated as 42 kg/day for 50 m long. The SS load reduction for 50 m long could be estimated as 525.0 kg/day to -483.0 kg/day (see Table 2.8.2).
- Comparing point B1 with point B2 before cutting vegetation, the reduction of SS load was calculated by the quantity of vegetation area as 5.8 kg/day/30 m2 (for 50 m long). The calculation method is explained as follows:

i) Flow discharge (Q) of 0.005 m^3/s in vegetation area (point B2) was calculated as described in the previous section.

0.005 m^3/s (Q) = 0.1 m (water depth) × 1 m (area of vegetation) × 0.05 m/s (average velocity in the area of vegetation)

ii) The daily volume of stream water of 43.2 m^3/m^2/day which flows through a unit vegetation area of $1m^2$ was calculated as described in the previous section.

43.2 m^3/m^2/day = 0.005 m^3/s (Q) / 10 m^2 (area) × 60 (seconds) × 60 (minutes) × 24 (hours)

iii) The daily SS reduction in unit vegetation area per day could be calculated as below:
194.4 g/m^2/day = (43.2 m^3/m^2/day × ((SS at Point B1 - SS at Point B2 =4.5 g/m^3)))

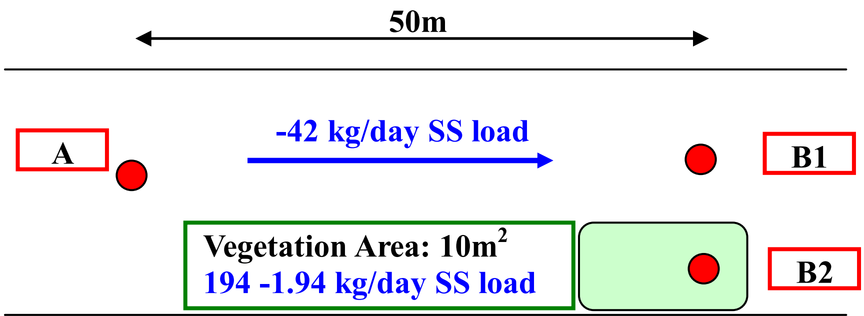
iv) The amount of vegetation area between A and B1 was measured as approximately 30 m^2 by the outdoor experiment.

v) The SS reduction rate could be estimated at 5.8 kg/day (194.4 g/m^2/day × 30 m^2)

Table 2.8.2 Main Results of the SS Reduction at Point A, B1 and B2

Item	Point A	Point B1	Point B2
Q (m^3/s)	0.2	0.2	-
SS (mg/l)	32.0	28.0	23.5
SS Load (kg/day)	525.0	483.0	-

Note: The above Q and SS values are the results of the Outdoor Experiment.



Note: The above 1.9 kg/day SS load was calculated below:
1.9 kg/day = 5.8 kg/day × 10 m^2 / 30 m^2

Fig. 2.8.11 Image of SS Load Reduction between Point A and Point B

(a) Calculation on Inorganic N Reduction in the Hong Pasak Canal

Based on the results of the experiments mentioned above, the amount of inorganic N reduction could be calculated as follows:

- It was confirmed by the indoor experiment that about 100 g of water spinach could absorb about 3 to 5 mg/l of inorganic N (NO2-N, NO3-N and NH4-N) in 48 hours.
- By applying this finding to the real canal, it was calculated that inorganic N could be absorbed by 1 to 2 mg/l through 10 m2 vegetation area. The calculation method is explained as follows:

i) Retention time in the vegetation area was as calculated below since the vegetation area was separate from the open water area:
200 seconds = 0.1 m (water depth) × 1 m (vegetation width) × 10 m (length)/0.005 m^3/s
These values were measured by the outdoor experiment and calculated value in the previous section.

ii) The average wet weight of water spinach per 0.25 m^2 in the vegetation area was estimated as 822 g/0.25 m^2.
This value was calculated based on the average wet weight of wild water spinach which was taken at three points near Survey Point A in the outdoor experiment along the Hong Pasak Canal.

iii) The amount of absorbed inorganic N by 10 m^2 vegetation area was as calculated below:

1 to 2 mg/l/10m^2 = 3 to 5 mg/l × (200 seconds /48 hours × 60 minutes 60 seconds) × 822 g/100g x 10m^2 /0.25m^2

It was found that the amount of inorganic N absorbed by vegetation was very much smaller than the amount of SS reduced by vegetation.

(b) Considerations of Water Purification Mechanism by Water Spinach

Based on the results of this verification, including the outdoor experiment and the others, the mechanism of water purification by water spinach could be explained as follows:

- It has been confirmed by the outdoor experiment that, at first, the velocity of stream flow is reduced by vegetation, and then SS concentration is decreased by filtration and sedimentation effects. Moreover, it has been reported that the stalks and roots of water plants can cultivate a layer of micro-organisms on them. This layer is called microbial biofilm and it could contribute to trapping SS. Photo 2.8.4 shows that the color roots of water spinach in the canal is brown but the one grown inside the tub is white. This difference in color may suggest that SS is trapped in the canal by the roots.
- It has been confirmed by the outdoor experiment that inorganic N was decreased by the vegetation. However, it was estimated that the amount of absorption of inorganic N by plants in the canal was quite small based on the results of indoor experiment. Therefore, the reduction of inorganic N could be consistent with the reduction of organic matters of SS which leads to the reduction of BOD value as well.
- From the above consideration, the BOD reduction could occur mainly by filtration and sedimentation of organic matters of SS. However, in some sections the values of SS and BOD were not consistent. This is because SS consists of organic and inorganic matters and sometimes inorganic matters such as soil flow into the canal, so that some results showed increasing SS concentration but not increasing BOD concentration.

Roots of water spinach (outdoor)

Roots of water spinach (indoor)

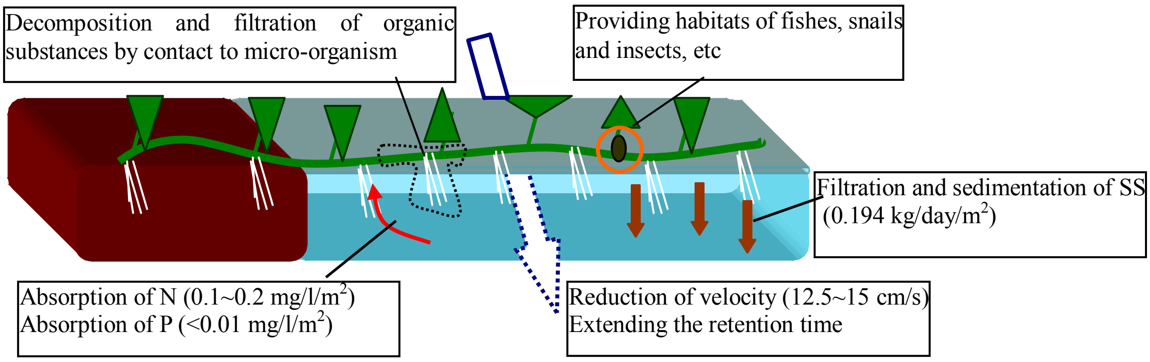
Photo 2.8.4 Conditions of the Roots of Water Spinach as observed in the Experiments

2.8.9 Considerations of Water Quality Improvement Using Water Spinach

(1) Effects for Water Purification by Water Spinach

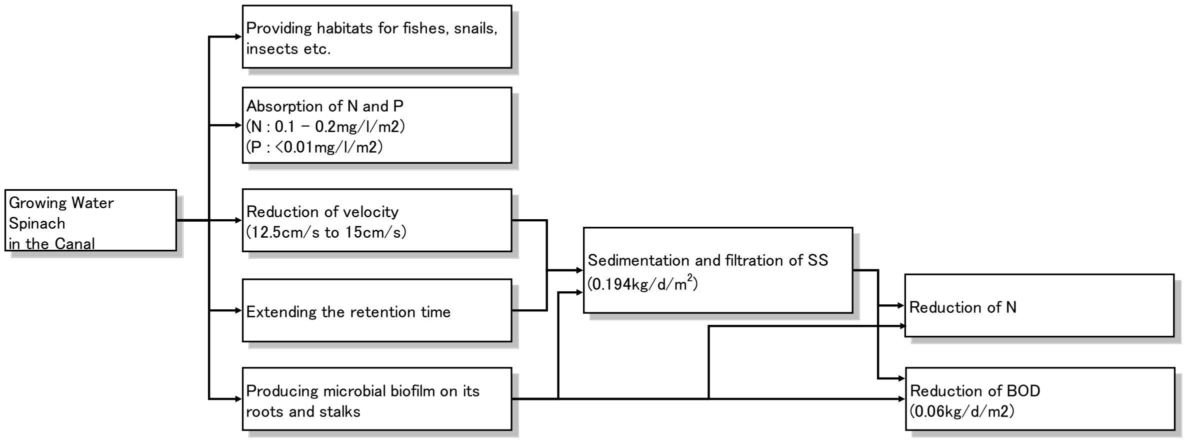
Based on the findings and the results of this verification and the other relevant studies, water quality in the canal could be improved to some extent through the water purification functions of water spinach. The image and mechanism of water purification in Hong Pasak is shown in **Figs. 2.8.12** and **2.8.13**.

It is summarized by the former findings that water purification effects by water spinach could be featured mainly by reducing SS including suspended organic matters which leads to the reduction of the BOD and N in the vegetation area in Hong Pasak.



Note: The above values are preliminary calculations based on the survey and experiment results.
Source: Shokusei Joka-shisetsu No Gijutsu Shiryo (Japanese), 2007. Foundation of River & Watershed Environment Management, modified by JICA Study Team

Fig. 2.8.12 Image of Water Purification Mechanism by Water Spinach in Hong Pasak



Note: The above values are preliminary calculations based on the survey and experiment results.

Fig. 2.8.13 Flow of Water Purification Mechanism by Water Spinach in Hong Pasak

(2) Suitability of Water Spinach as a Vegetative Measure of Water Purification

Based on the relevant findings and the interview with a botanical specialist in the National University of Lao PDR, water spinach could be suitable as a plant for the vegetative measure of water purification in the survey area due to the following reasons:

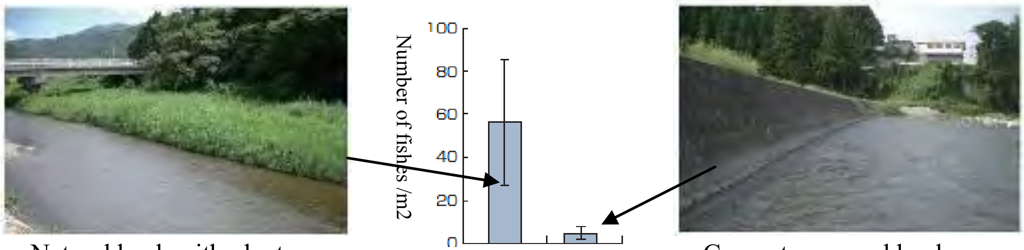
- There are few seasonal fluctuations of purification effects by water spinach, because water spinach is grown throughout a year without defoliation. On the other hand, water spinach is not so much grown in the dry season due to low rainfall.
- Water spinach is applicable to fluctuations of water volume between the dry season and the wet season because water spinach is grown by floating the stalks and leaves on a water

surface. On the other hand, the other plants, which are grown with roots on the ground such as sessile joyweed, might be flooded in the rainy season and then withered.

- Water spinach is used for feed of pigs or used for food in Lao PDR. Therefore, water spinach has other usage values.

(3) Consideration of the Effect of Providing Habitats by Water Plants

It is reported that the water plants can contribute providing habitat for aquatic organisms. As an example, **Fig. 2.8.14** shows comparison of the bank type and the number of fishes. From the result, it was confirmed that water plants provide important habitat for the fishes.



Natural bank with plants

Concrete covered bank

Cited from ARRC activity report 2004

Fig. 2.8.14 Comparison of Bank Type and Number of Fishes

It was found that many snails stuck to the water spinach in Hong Pasak and several species of dragonfly flew and rested among the vegetation area in the canal. Thus, water spinach can contribute to providing habitat for fishes, snails and some species of insects.

Snails stick to the roots and stalks

A species of dragonfly flies in the canal

Photo 2.8.5 Snails in Roots of Plant and Dragonfly in Canal

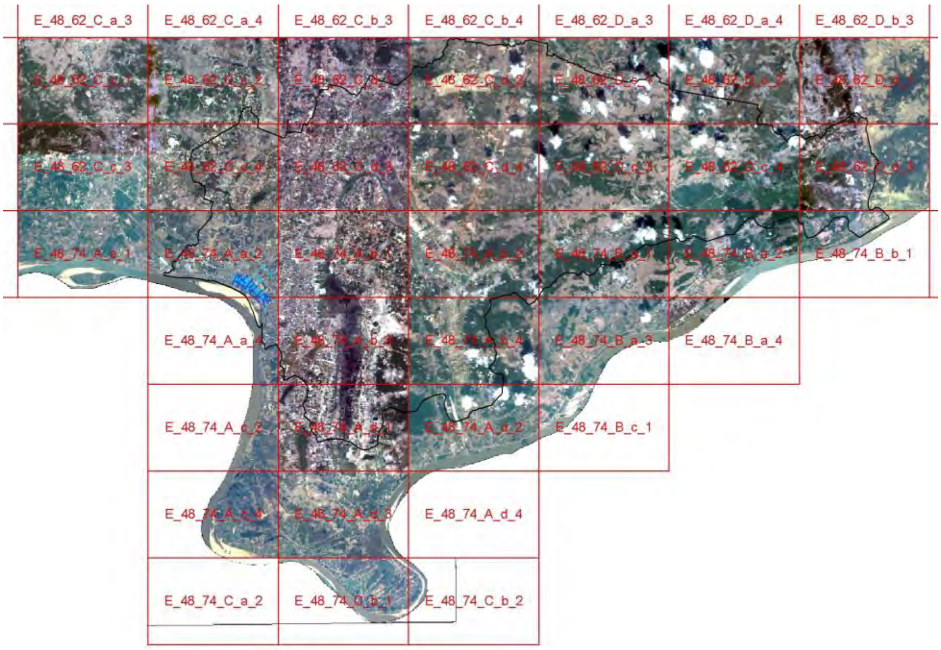
2.9 GIS

2.9.1 Policy on Systems Management and Existing GIS Data Collection

The GIS system has been constructed in cooperation with the Laotian counterparts, intending to provide data for the basic study. This system is to be granted finally to the counterpart agency (PTI) in order to be used continuously and developed in the future. PTI has been utilizing a lot of GIS data so far and holds many GIS specialists. Thus, it will be able to continue to manage this GIS system. Through the study, many GIS source data and satellite image data have been collected.

(1) Quickbird Satellite Image

Quickbird Satellite Image Data with 3 bands and 61 cm resolution have been collected from the counterpart organization (PTI). The satellite images were taken in December 2007 and February 2008, and formatted in ERDAS Imaging format. The data is also clipped by 1:10000 scale map index with WGS84 coordinate system. The data is very clear with less clouds because it was taken in dry season. It was used as a basic or background data in this study.

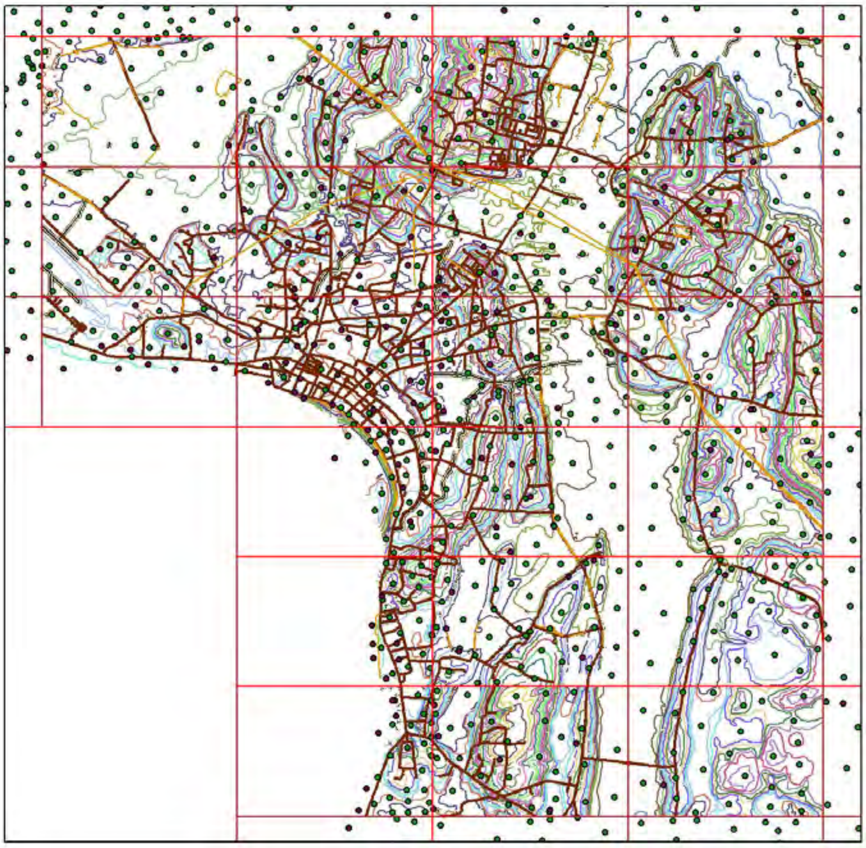


Source: PTI

Fig. 2.9.1 QuickBird Satellite Image Data Index Map

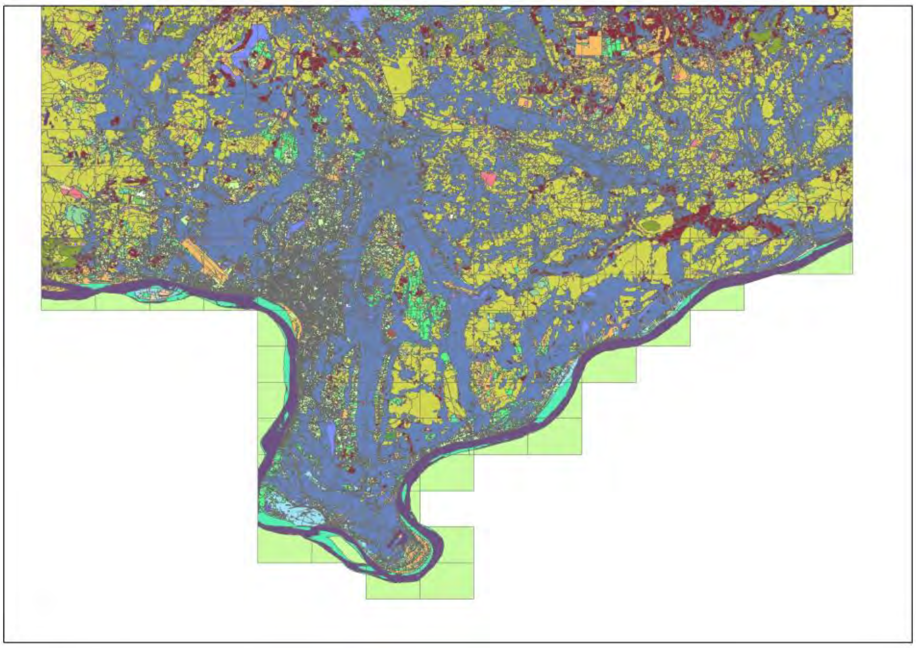
(2) Topographic and Land Cover Data in 1:5000 Scale

Topographic as well as land cover data in 1:5000 scale have been collected from the National Geographic Department, Lao PDR. The topographic data covers the inner Vientiane area and includes 21 map sheets. The land cover data covers the whole study area and includes 116 map sheets. The data were taken from the aerial photos taken in February 1999, and formatted into the LaoDatum 1997, UTM 48N Zone coordinate system.



Source: National Geographic Department

Fig. 2.9.2 1:5000 Topographic Index Map



Source: National Geographic Department

Fig. 2.9.3 1:5000 Land Cover Index Map

(3) Hydrology Data

Hydrology data have been created through the study. The data includes sub-basin boundary, sewage drainages, marsh ponds, and catchment area data covering Mak Hiao River Basin. All of these data were digitized from high quality satellite image and formatted into 1:5000 in scale.

(4) Current River Status Data

Through the study, a huge volume of data associated with the current river status has been collected. For good management of these data, they are all linked to the GIS database and managed by a viewer system. The data includes river environment, river facilities, river ecology monitor, and river water quality monitor. The data are formatted in documents, photos and drawings, and linked to the GIS viewer system.

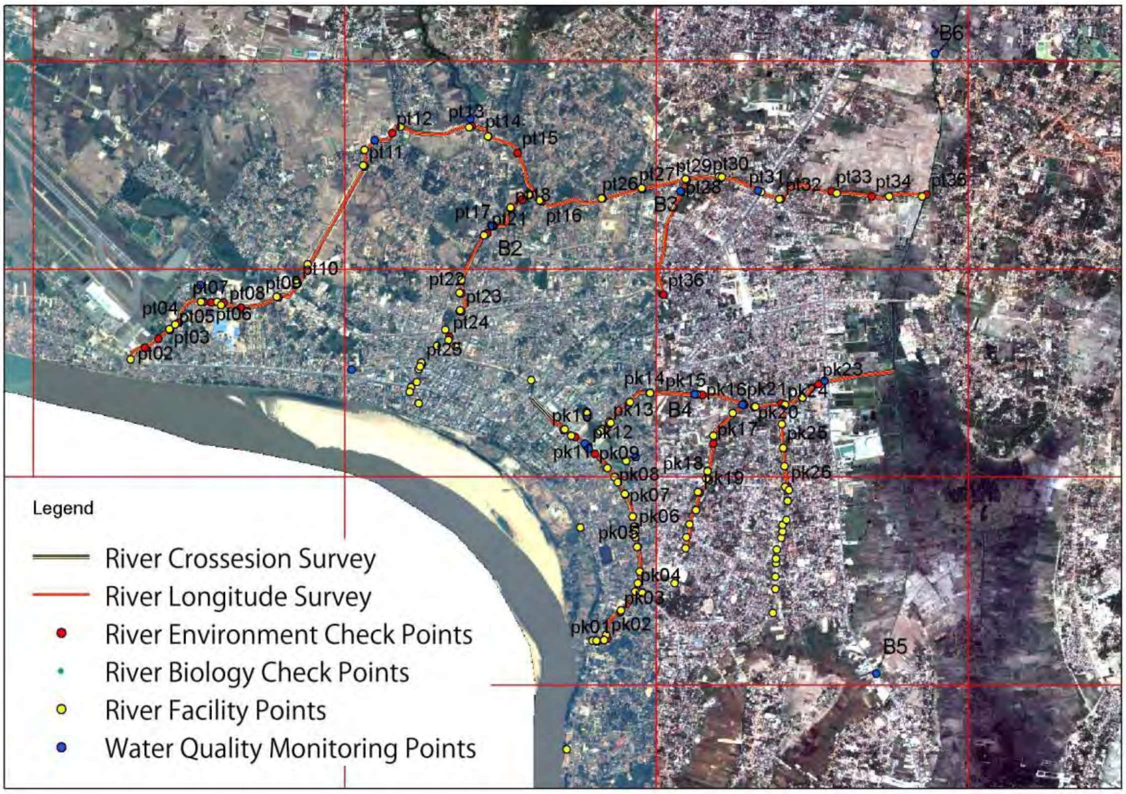


Fig. 2.9.4 Image Map of Current River Status

(5) Other Data

In addition to the data mentioned above, the social environment data such as the population data linked to the administration boundary had been created through the study. Also, the natural environmental data such as the forest reserve area data in the study area were created into the GIS database.

2.9.2 GIS Database Establishment

(1) Unification of GIS Database Coordination System

The GIS data collected from different data sourcesand generators vary. Hence the data cannot be overlain and matched with each other without converting them to a unification coordination system. The original data coordination systems are as tabulated below.

Table 2.9.1 List of Coordination System of GIS Data Sources

Data Source	Coordination	Projection	Unit	Provider
Quick Bird Satellite Image	Geographic Coordination	WGS84	Decimal Degree	PTI
Topographic Map Data in 1:5K scale	UTM 48N	Datum of Lao 1997	Meter	National Geographic Department
Statistical Population Data	Geographic Coordination	North American 1927	Decimal Degree	National Statistic Department
Catchment Distribution	Geographic Coordination	WGS84	Decimal Degree	JICA Study Team
Field Survey Data	Geographic Coordination	WGS84	Decimal Degree	GPS
New Town	No Info	No Info	Meter	CAD data

The unification coordination system decided was the UTM_48N_LAO97, because it is the standard coordination system in the National Geographic Department. The CAD data without any coordination information was also converted through the Rubber Sheeting Tool. The Parameters of the unification coordination system is as tabulated below.

Table 2.9.2 Parameters of Standard Coordination System UTM_48N_LAO97

Project Parameters	Projection	Transverse_Mercator
	False_Easting	500000.000000
	False_Northing	0.000000
	Central_Meridian	105.000000
	Scale_Factor	0.999600
	Latitude_Of_Origin	0.000000
	Linear Unit	Meter
Datum Parameters	Datum Name	The Lao National Datum 1997
	Angular Unit	Degree (0.017453292519943299)
	Prime Meridian	Greenwich (0.000000000000000000)
	Spheroid	Krasovsky_1940
	Semimajor Axis	6378245.000000000000000000
	Semiminor Axis	6356863.018773047300000000
	Inverse Flattening	298.300000000000010000

(2) GIS Database Structure

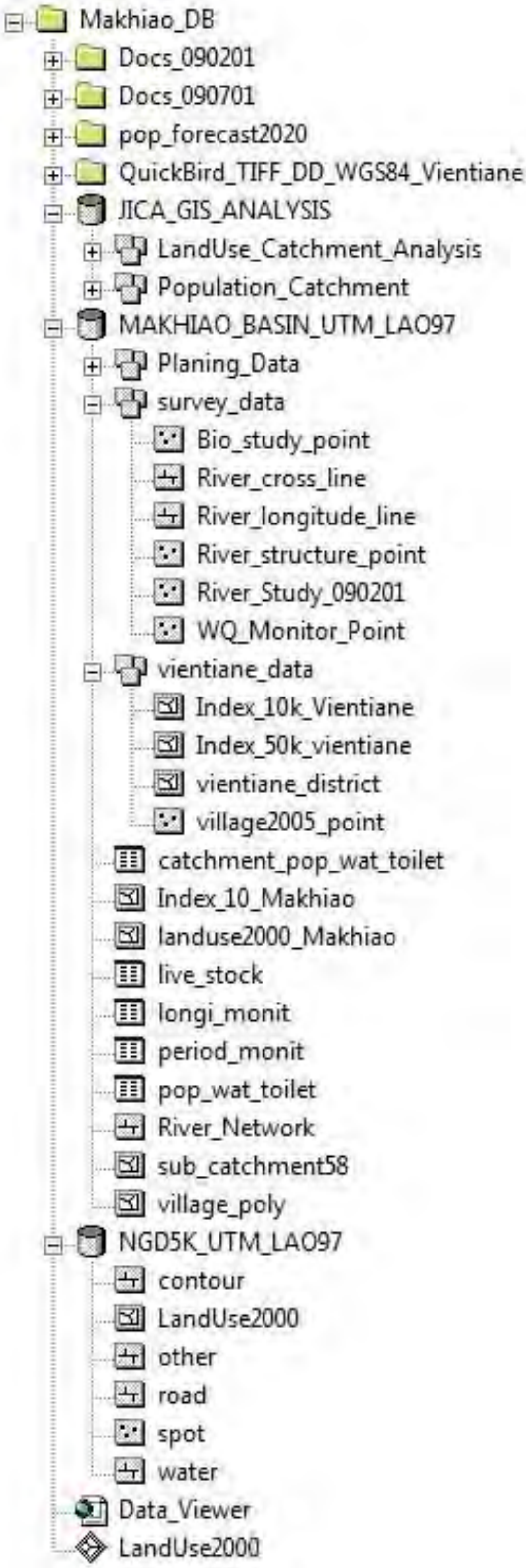


Fig. 2.9.5 Structure of GIS Database

The database has been installed in the Makhiao_DB folder. The documents data of photos and CAD drawings collected through previous study in February 2009 have been saved in DOCS_090201 subfolder. The photos show drainage conditions in dry season. The rainy season photos and docs have been saved in DOCS_090701 subfolder. Pop_forecast2020 and JICA GIS ANALYSIS Folder have been saved in the GIS analysis data. QuickBird_TIFF_DD_WGS84 folder stores the Quick Bird satellite image data. MAKHIAO_BASIN_UTM_LAO97 personal database stores a group GPS field survey data named as DOC_VIEW, and also linked to the photos and docs stored in the DOCS folder. Therefore, the docs and photos are easy to be viewed in GIS software. Other data, sort of Industrial park, New Town, and New Road which shows the development plan in the catchment area are also stored in this personal database. NGD5K_UTM_LAO97 personal database stores the 1:5K topographic map data which were collected from the National Geographic Department.

Data_Viewer is an ARCGIS9.2 View File, with which the above database can be viewed easily.

2.9.3 GIS Database Viewer System

For simple browsing of the above GIS database, a GIS data viewer system was created. The functions of the viewer system are as described below.

(1) River Environment GIS Viewer

According to the study, two main sewerage drainages, Hong Xeng and Hong Ke, were examined through a walking survey. There are up to 62 main points of river environment along with the drainages surveyed and a photo database linked to those points was created. The photo database is linked to the GIS database, and can be displayed easily in the viewer system background with a high resolution satellite image.

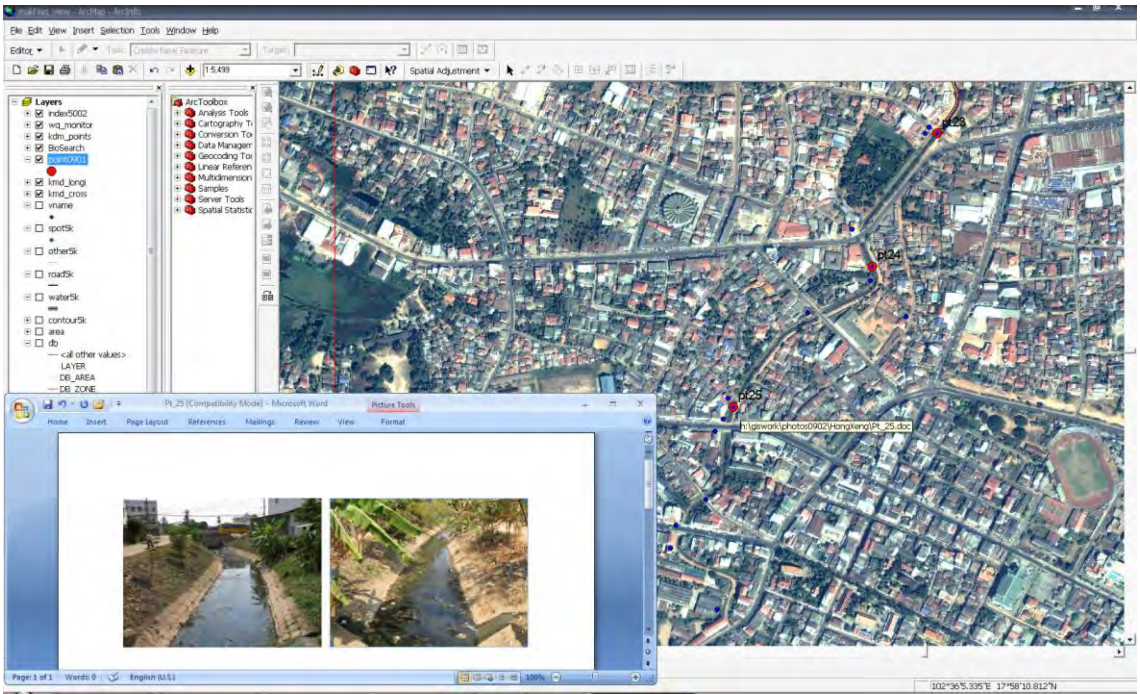


Fig. 2.9.6 River Environment Viewer

Explanation of the viewer system:

1. Opening the viewer from ARCMAP software, the map with satellite image background will be displayed. The river environment survey points will be shown as red circle symbols.

2. Moving the mouse point over the river environment survey points, a file name linked to photos will be displayed.

3. By clicking the file name, a photo file will be opened.

(2) Ecology and Water Quality Monitoring GIS Viewer

In this study, 6 ecology monitoring points and 14 water quality monitoring points were selected. The point position information and the photos showing the status of monitoring are linked together, and saved in GIS database. The operation of viewer system is the same as the river environment viewer. By clicking the point, the photos will beopened.

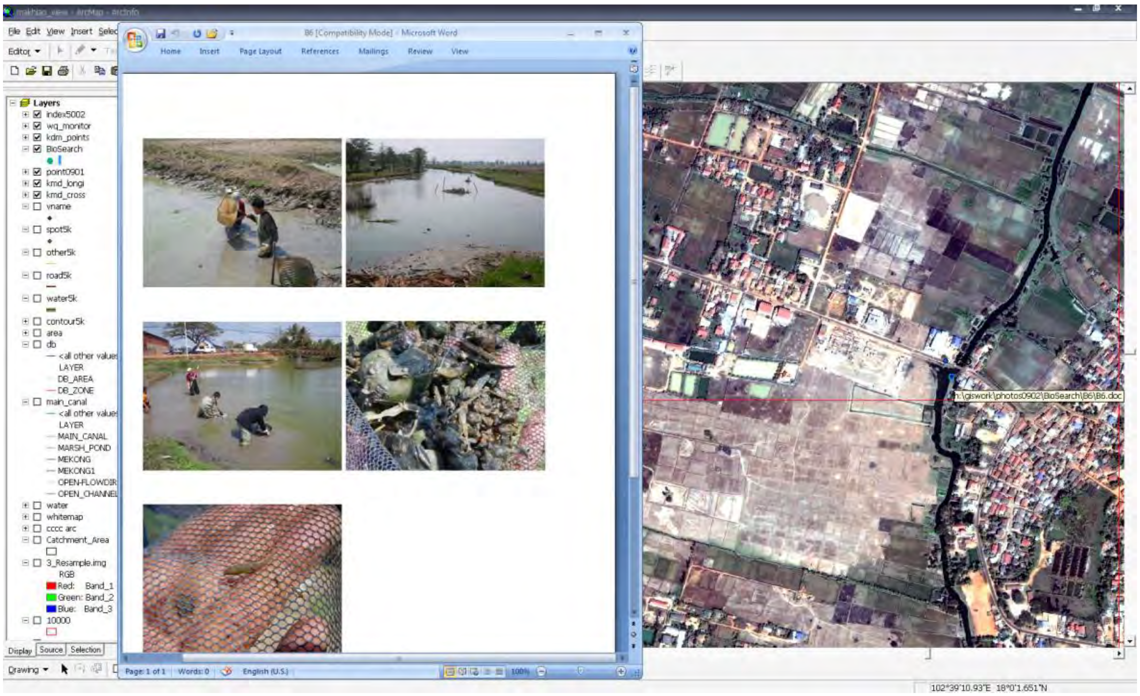


Fig. 2.9.7 Ecology and Water Quality Monitoring Viewer

(3) River Facility GIS Viewer

Up to 117 river facility points, 89 river longitudinal survey lines, and 139 river cross-section survey line information have been collected in this study. The information includes facility photos and survey drawings. The points and line positions linked with photos and drawings have been saved into the GIS database. The operation of the viewer system is the same as the river environment viewer. By clicking the point or line, the linked photos or drawings will be displayed.

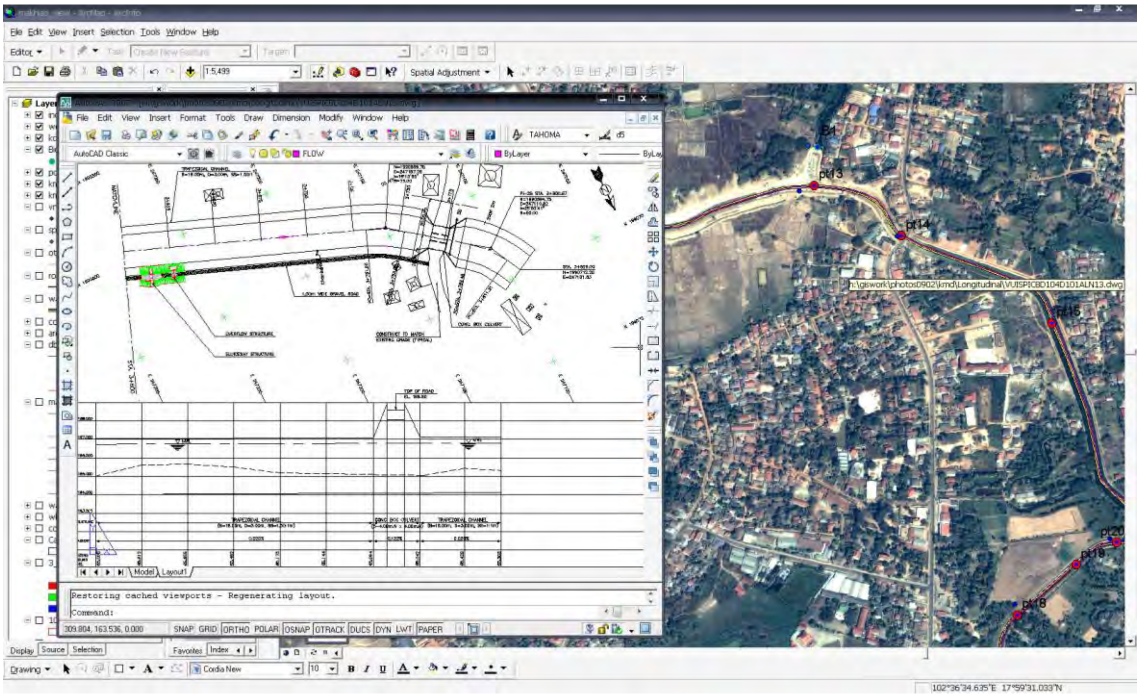


Fig. 2.9.8 River Facility Viewer

2.9.4 GIS Analysis

(1) Basic Data

(a) Statistical Population Data at Village Level

In this analysis, the primary data is the population data in 1995 and 2005 at village level, which was collected from the National Statistic Department. The data includes village code and name, population in 1995 and 2005, supply water type in 1995 and 2005, toilet type in 1995 and 2005. The table items are as follows.

Table 2.9.3 Item Lists of Statistic Data

Key Index Item	Village Code, Village Name
Population in 2005	House Holds, Male, Female, Total Populations
Supply Water Type in 2005	Pipe Water, Well Borehole Protected, Well Borehole Unprotected, River Stream Dam, Mountain Source, Rain Water, Other, Not Stated
Toilet Type in 2005	Type0, Type1, Type2, Type3, Type4
Population in 1995	House Holds, Male, Female, Total Populations
Supply Water Type in 1995	Pipe Water, Well Borehole Protected, Well Borehole Unprotected, River Stream Dam, Rain Water, Other
Toilet Type in 1995	Modern Toilet, Normal Toilet, Soak Pit, Other, None

(b) Village Administration Boundary GIS Data

The secondary data for this analysis is the village boundary GIS data which was surveyed through a PTI project in 2009. The data covers all the study area. Therefore, the statistical population data can be linked to this village boundary data and the population density can be easily calculated by using the boundary area value.

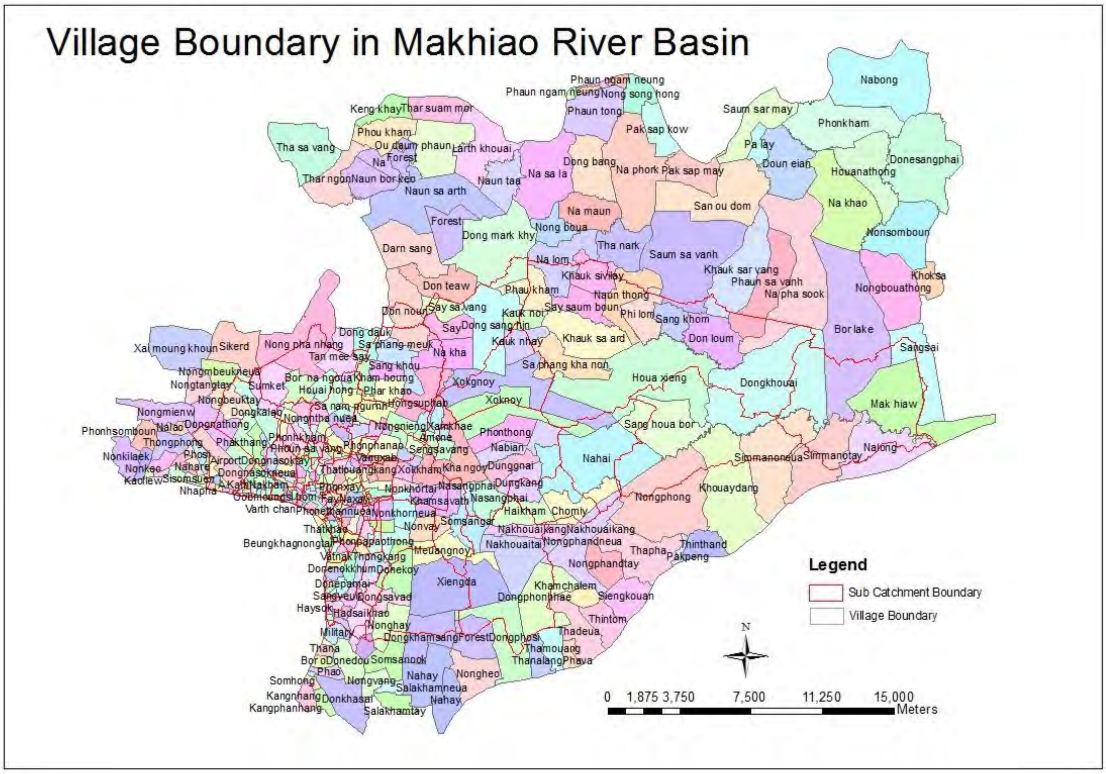
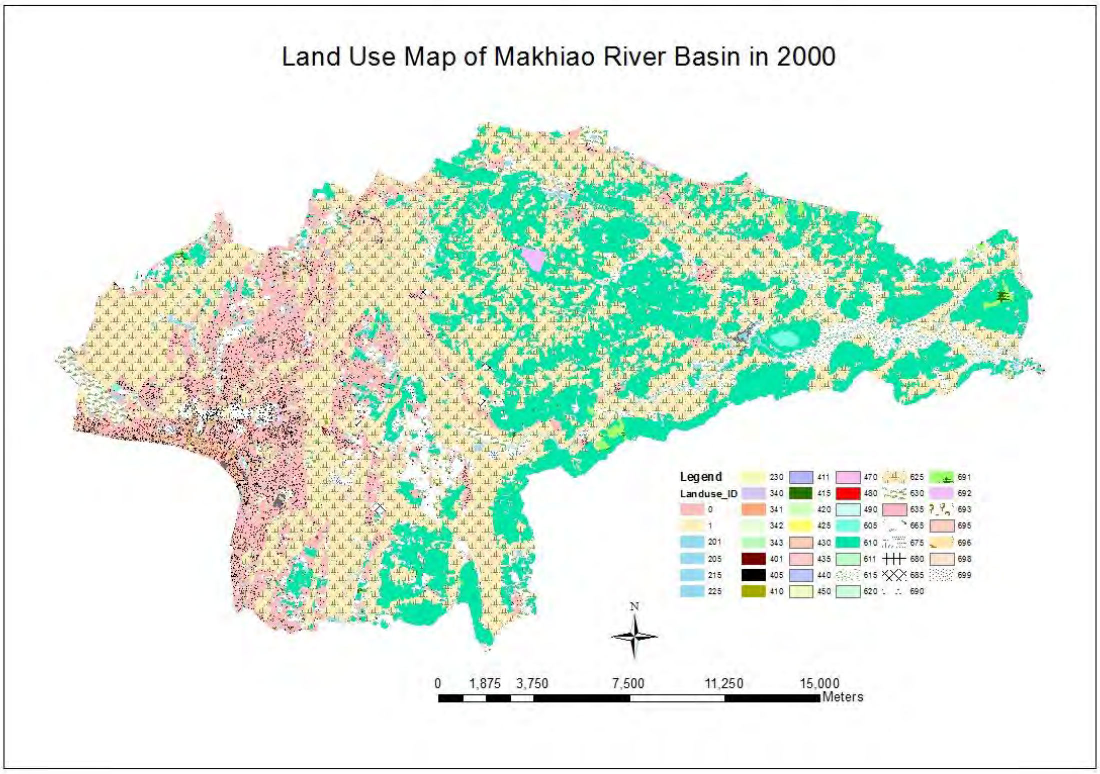


Fig. 2.9.9 Village Map in Mak Hiao River Basin

(2) Sub-Catchment Land Use Analysis

(a) Land Use Data in 2000

The land use data has been collected from the National Geographic Department. Although it is an old data in 2000, it is a 1:5000 scaled data. Therefore, the information can be easily updated with Quick Bird Satellite Image. The data has been clipped by catchment boundary.



Source: National Geographic Department

Fig. 2.9.10 Land Use Map of Mak Hiao River Basin in 2000

Table 2.9.3 Table of Land Use Description

Land Use ID	Land Use Description	Land Use ID	Land Use Description
0	Inner City	490	Christian Church
201	River, Stream	605	Dense Forest
205	Intermittent River or Stream	610	Sparse Forest
215	Water Canal (Width lt 10m)	615	Bush
225	Water, Pool, Pond	620	Bamboo
230	Basin, Swimming Pool	625	Rice Field
340	Road Edge (Paved)	630	Grass
401	Public/Office House	665	Orchard
405	Private House	675	Perennial Swamp
410	Commercial Building	680	Park
415	Industrial Building	685	Cemetery
420	School(University)	690	Other Plantation
425	Temple	691	Teak
435	Monument	692	Eucalyptus
440	Water Tower, Tank	693	Banana
450	Power Substation	696	Sugar
470	Gasoline	698	Papaya
480	Hospital	699	Sand

(b) Reclassification for Better Analysis

For easier analysis in this study, Land Use ID has been reclassified to Class ID as shown in the following table.

Table 2.9.4 Table of Land Use Reclassification

Land Use ID	Land Use Description	Class ID	Class Description
0	Inner City	1	Built-up Area
340	Road Edge (Paved)		
401	Public/Office House		
405	Private House		
410	Commercial Building		
415	Industrial Building		
420	School (University)		
425	Temple		
435	Monument		
440	Water Tower, Tank		
450	Power Substation		
470	Gasoline		
480	Hospital		
490	Christian Church		
201	River, Stream	2	River
205	Intermittent River or Stream		
215	Water Canal (Width lt 10m)		
225	Water Pool, Pond	3	Marsh
230	Basin, Swimming Pool		
675	Perennial Swamp		
605	Dense Forest	4	Forest
610	Sparse Forest		
615	Bush		
620	Bamboo		
625	Ricefield	5	Ricefield
630	Grass	6	Natural Field
665	Orchard		
699	Sand		
680	Park	7	Park
685	Cemetery		
690	Other Plantation	8	Farmland
691	Teak		
692	Eucalyptus		
693	Banana		
696	Sugar		
698	Papaya		

(c) Analysis of Sub-Catchment Land Use by GIS Overlay

Finally, to overlay the Land Use and sub-catchment area data, the GIS software generates a new land use classification data. In this data, the Land Use is also divided into small polygons by sub-catchment boundary.

In order that the data can be used with spread sheet software or statistical tools, the Land Use distribution area in every sub-catchment area is calculated.

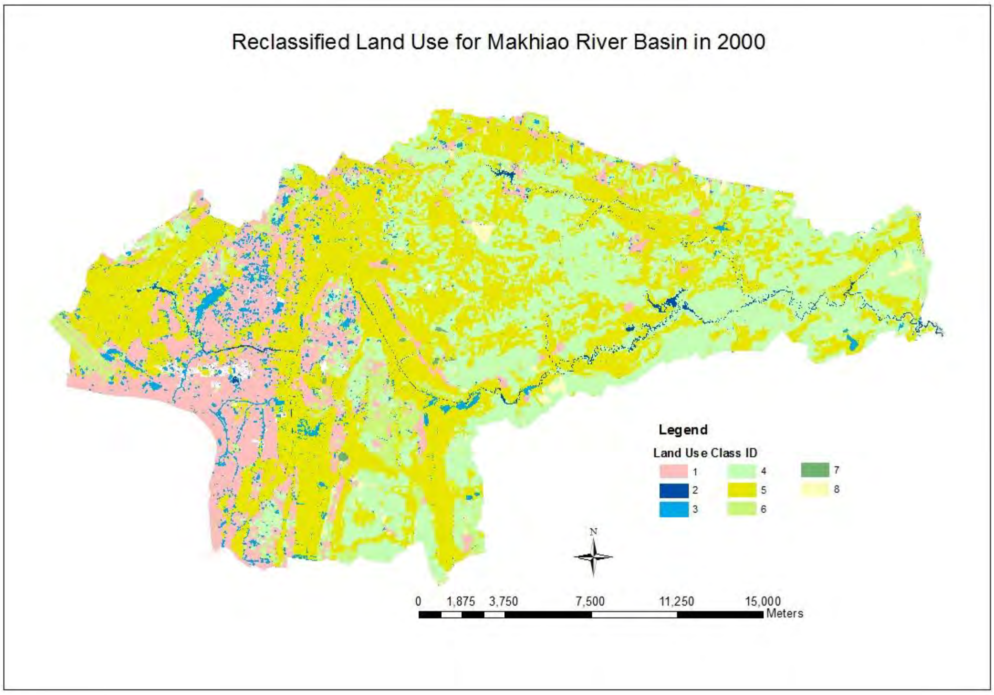


Fig. 2.9.11 Land Use Classification Map of Mak Hiao River Basin in 2000