WATERSHED MANAGEMENT STRATEGIES FOR THE CHIANG-CHUN RIVER BASIN, TAIWAN

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ABSTRACT

The Chiang-Chun River is the largest and the most intensively used river basin in Tainan County, Taiwan. It is 24-km long, drains a catchment of more than 18 km^2. Based on the recent water quality analysis, the Chiang-Chun River is heavily polluted. Concern about the deteriorating condition of the river led the Government of Taiwan to amend the relevance legislations and strengthen the enforcement of the discharge regulations to effectively manage the river and control the pollution. Investigation results show that the hog farming is one particularly important activity in the watershed. Most of the untreated hog farm waste is indiscriminately discharged into the river. Moreover, municipal wastewater in the watershed is also discharged into the river without proper treatment. Thus, the hog farm and municipal wastewaters are the major causes of the deterioration of water quality of Chiang-Chun River. Currently, the percent of sewer system connection in the Er-Ren River watershed is less than 1%. Investigation results show that the daily wastewater, BOD, and NH_3-N loadings into the river are approximately 101,600 m^3, 15,800 kg, and 3,900 kg, respectively. Results also indicate that the domestic wastewater and hog farm waste contribute more than 50% of the daily BOD and NH_3-N loads to the river, respectively. In this study, the Enhanced Stream Water Quality Model (QUAL2E) was selected as a water quality-planning tool to perform the water quality evaluation and carrying capacity calculation. The calculated BOD and NH_3-N carrying capacities were 2,700 and 210 kg per day. A comprehensive strategy for Chiang-Chun River basin management has been proposed based on the results from water quality investigation and modeling. The strategy consists of short-term management and improvement measures, long-term structural measures (e.g., sewer system construction to achieve 30% of connection in the basin within 10 years), and land use management and legislation (e.g., river bank management and enforcement of wastewater discharge standards). After the implementation of the proposed measures, the water quality can be significantly improved. The developed watershed management strategies can also be applied to other similar watersheds.

Key Words: Water quality; carrying capacity; BOD, hog farm waste

INTRODUCTION

The Chiang-Chun River is the most intensively used river basin in Tainan County, Taiwan. It is 24-km long, drains a catchment of more than 170 km^2, and has a mean flow of 85 m^3/s. Although the mean annual rainfall in this river basin is close to 2,000 mm, over 90% of which appears in the wet season. The period of high flow rate in the stream usually occurs in the late spring and summer due to the impacts of monsoon and typhoon. The population is about 210,000 inside the Chiang-Chun River basin. Figure 1 shows the Chiang-Chun River, its catchment, and major reaches. Chiang-Chun River provides water to livestock industries, aquiculture, and farmlands in the basin. In the meantime, it also receives their treated and untreated wastewater. Taiwan Environmental Protection Administration (TEPA) has developed a three-part classification system (Classes A, B, and C) for the major rivers in Taiwan based on the purpose of water usage and degree of protection (Chiang et al., 2000). Table 1 presents the water quality criteria for the three classes. The Chiang-Chun River has been classified as Class C for the whole river section.

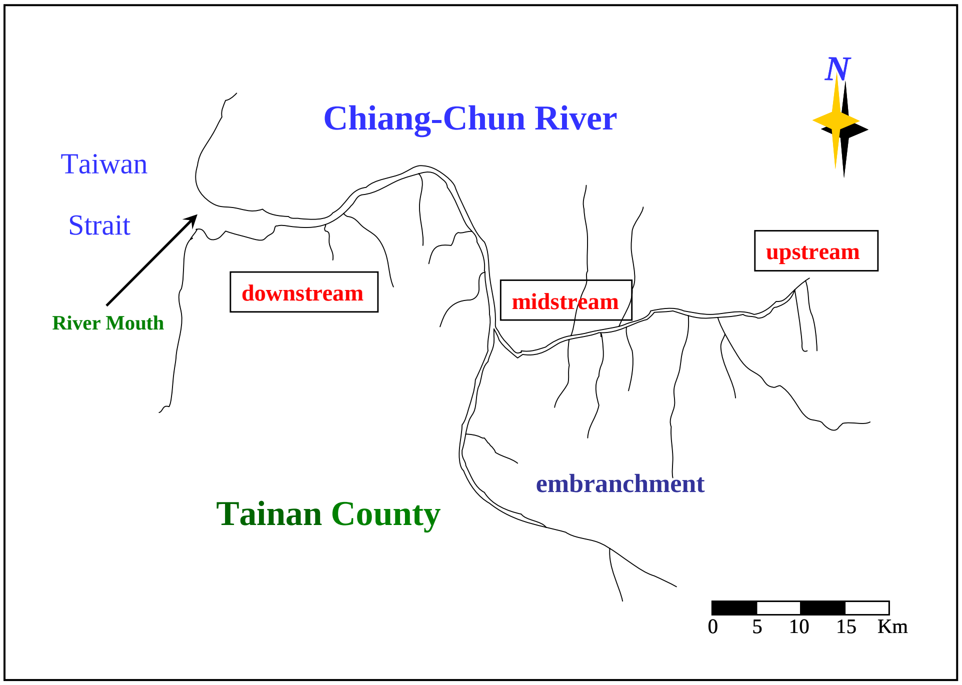

Figure 1. Chiang-Chun River basin and major reaches.

Recent water quality analysis by Taiwan Environmental Protection Administration (TEPA) indicates that the Chiang-Chun River is one of the most heavily polluted river in Taiwan. Results from previous studies indicate that the concentrations of all major water quality indicators [e.g., dissolved oxygen (DO), biochemical oxygen demand (BOD), suspended solid (SS), ammonia-nitrogen (NH_3-N), and Escherichia Coliform (E. Coli)] were much higher than the assigned water quality criteria for Chiang-Chun River (TEPA, 2000, 2001, and 2002). Concern about the deteriorating conditions of the Chiang-Chun River led the Government of Taiwan to amend the relevance legislations and strengthen the enforcement of the discharge regulations to effectively manage the river and control the pollution. The major objectives of this study were to (1) assess the water quality, (2) identify the current contributions of point and non-point source pollutants to the river pollution, (3) perform water quality simulation and carrying capacity calculation, and (4) develop river management protocols to improve the river water quality.

Table 1. The three-part classification system developed by TEPA.

Water Quality Item	Category A[1] Most upstream reach[1]	Category B Most midstream reach[1]	Category C Downstream reach[1]
DO (mg/L)	>=6.5	>=5.5	>=4.5
BOD (mg/L)	1	2	4
NH_3-N (mg/L)	0.1	0.3	0.3
NO_3-N (mg/L)	10	-[2]	-
Total Phosphorus (mg/L)	0.02	0.05	-
E. Coli (CFU/100 mL)	<50	<5,000	<10,000
Suspended Solid (mg/l)	<25	<25	<40

[1]Illustrated in Figure 1; [2]No criteria.

POINT AND NON-POINT SOURCE POLLUTION

Results from the review of recent information on the water usage and investigation of the water quality demonstrate that both point and non-point source (NPS) pollutants are now the causes of BOD, nutrients, and suspended solid (SS) in the river (TEPA, 2000). The main water pollution sources are livestock wastewater from hog farms, municipal wastewater, industrial wastewater, NPS pollutants from agricultural areas, and leachate from riverbank landfills. The amount of wastewater discharged into the river is approximately 101,600 m^3 per day. Of the total discharges, domestic sewage, wastewater from the livestock industry, industrial effluent, and landfill leach are responsible for 59.7%, 8.1%, 32%, and 0.2%, respectively. In the Chiang-Chun River basin, most of the upper catchment is used for agricultural activities including cropland and livestock farming. The dominant agricultural activities in the mid and downstream catchments are livestock industries and aquiculture, respectively. NPS pollutants mainly associated with stormwater runoff from agricultural land uses can be quite diffuse and difficult to treat. Nutrients, pesticides, and sediments are the main detrimental NPS constituents. Investigation results show that the NPS pollution contributes 5 to 10% of the overall pollution loads to the Chiang-Chun River (TEPA, 1998; CPA, 2001; TEPA, 2002). Hog farming is a particularly important activity in the rural area in the basin. The total hog population is estimated to be more than 100,000 in the whole catchment, and approximately half of the population is in the upper and mid catchments. Most of the untreated hog farm waste is indiscriminately discharged into the river. Thus, the hog farm waste is the major cause of the deterioration of the water quality of Chiang-Chun River.

Currently, the overall percentage of public sewer system (for collection and disposal of municipal wastewater) connection in Taiwan is only 10%. Due to the rapid urban and industrial expansion, the percent of sewer system connection in the Chiang-Chun River basin is less than 1%. Most of the municipal wastewater in the basin is discharged into the river without proper treatment. Moreover, there are 55 registered industrial factories discharge their wastewater into the river. However, illegal or expedient discharges are sometimes practiced feeding polluted industrial flows into the river. Therefore, the untreated municipal and industrial wastewaters are also two causes of the poor water quality. In the Chiang-Chun River basin, due to the shortage of available lands for landfill construction, the riverbank sites have been used as the domestic garbage dumping locations or have been converted to simple landfills. Those riverbank landfills (or garbage dumping sites) are neither well designed nor well maintained. Thus, landfill leachate could significantly deteriorate the downstream river water quality. There are three riverbank landfills within the floodplain. Moreover, there are more than five illegal waste/garbage dumping sites along the riverbank. Leachates from those landfills and dumping sites are currently polluting the Chiang-Chun River and might also cause the clogging problems during the flood season.

WATER QUALITY MODELING

In this study, the Enhanced Stream Water Quality Model (QUAL2E) was selected as a water quality-planning tool to perform the water quality evaluation and carrying capacity calculation (Brown and Barnwell, 1987). The QUAL2E Windows interface was developed by U.S. Environmental Protection Agency to assist the implementation of the Total Maximum Daily Load (TMDL) program. It can simulate up to 15 water quality constituents including BOD, nutrients, DO, temperature, algae as chlorophyll A, and coliforms. It uses a finite-difference solution of the advective-dispersive mass transport and reaction equations. A stream reach is divided into a number of computational elements, and for each computational element, a hydrologic balance in terms of stream flow, a heat balance in terms of temperature, and a material balance in terms of concentration are written. Both advective and dispersive transport processes are considered in the material balance. Mass is gained or lost from the computational element by transport processes, wastewater discharges, and withdrawals. Mass can also be gained or lost by internal processes such as release of mass from benthal sources or biological transformations. Hydraulically, QUAL2E is limited to the simulation of time periods during which both the stream flow in river basins and input waste loads are essentially constant. QUAL2E can operate as either a steady-state or a quasi-dynamic model, making it a very helpful water quality planning tool. When operated as a steady-state model, it can be used to study the impact of waste loads (magnitude, quality, and location) on instream water quality. By operating the model dynamically, the user can study the effects of diurnal variations in meteorological data on water quality (primarily dissolved oxygen and temperature) and also can study diurnal dissolved oxygen variations due to algal growth and respiration. However, the effects of dynamic forcing functions, such as headwater flows or point loads, cannot be modeled in QUAL2E.

Previous studies have been performed to obtain the input data for the QUAL2E model construction (TEPA, 1999; CTC, 1999). The input data include stream segmentation, locations of inflow and outflow, geological and meteorological conditions, hydrological parameters, decay rates, water quality parameters, dispersion coefficient, reaeration coefficient, BOD removal rate, and benthal oxygen demand. After the model construction, the recent water quality data were used for model calibration (TEPA, 2000; Kao et al., 2002; Chen, 2003). Figures 2 to 4 present the measured and simulated water quality results for DO, BOD, and NH_3-N in the Chiang-Chun River from the river mouth (0 km) to the 23 km upstream location. Results demonstrate that the simulated data had a good match with the analytical water quality results. Based on the investigation, the current daily BOD, and NH_3-N loadings to Chiang-Chun River are 15,800 and 3,900 kg, respectively. Among the BOD loadings, domestic sewage, livestock wastewater, industrial wastewater, NPS pollution, and landfill leachate contribute 50.8, 34.5, 9.2, 4.3, and 1.3% of the daily BOD loadings into the river. Among the ammonia loadings, domestic sewage, livestock wastewater, industrial wastewater, NPS pollution, and landfill leachate contribute 29.4, 56.8, 0.7, 10.2, and 2.9% of the daily BOD loadings into the river.

CARRYING CAPACITY CALCULATION

The carrying capacity calculations for BOD and NH_3-N were performed using the calibrated QUAL2E water quality model to obtain the maximum acceptable BOD and NH_3-N loadings per day without violating the water quality criteria for Chiang-Chun River (Table 1). The calculated BOD and NH_3-N carrying capacities were only 2,700 and 210 kg per day. However, the current BOD and NH_3-N loadings are almost 5.9 and 18.6 times higher than the calculated carrying capacities, respectively. To protect public health and improve the river water quality, six river management scenarios are proposed. Table 2 presents the proposed strategies and their achievements on BOD reduction and DO improvements after the completion of each proposed plan. The proposed six major plans include the following: (1) reduction of the produced domestic wastewater, (2) application of natural treatment system (constructed wetland and land application systems) on domestic wastewater treatment, (3) enforcement of industrial wastewater discharge standards, (4) livestock wastewater reduction and feces removal from hog farms, (5) removal of riverbank landfills and waste dumping sites, and (6) sewer system construction (achievement of 30% of connection in 10 years). Because domestic and livestock wastewaters are the two main causes of the impairment of water body, simulated results demonstrate that sewer system construction and livestock wastewater treatment and hog farm management are the most effective measures to improve the water quality.

CONCLUSIONS

The water quality of the Chiang-Chun River, particularly that of its mid and upstream section, has deteriorated markedly over the past 10 years. This has largely been due to (1) substantial increase of the hog population in the basin, (2) untreated municipal and industrial wastewater discharges due to urban and industrial expansion, (3) intensified agricultural development in the upper catchment, and (4) riverbank garbage dumping. Both point and non-point source pollutants are the major causes of the poor water quality. Thus, improvements of conventional wastewater collection and treatment, as well as reductions in the contaminant loads from point and non-point sources are required to improve the river water quality. A comprehensive strategy for Chiang-Chun River basin management has been proposed. The strategy consists of short-term management and improvement measures (e.g., riverbank landfills removal), long-term structural measures (e.g., sewer system construction), and land use management and legislation (e.g., hog farm management and enforcement of wastewater discharge standards). Moreover, the proposed NPS pollution management strategy for the Chiang-Chun River basin consists of the following measures: construction of the watershed geographical information system (GIS) and real time water quality monitoring systems, source (fertilizer) reduction, and construction of grassy buffer zone or other natural treatment systems. Recent water quality investigation results indicate that the BOD and nutrient loadings to the Chiang-Chun River have been significantly reduced and the water quality has been effectively improved after the implementation of the remedial strategies described above. Results and experience obtained from this study will be helpful in designing the watershed management strategies for other similar river basins.

Table 2. Simulated BOD reduction and DO improvement after the implementation of each proposed plan.

Scenario	Measure	BOD reduction (%)	DO increment (mg/L)
1	reduction of the domestic wastewater	10	0.5 (downstream section)
2	application of natural treatment system on domestic wastewater treatment	13	2 (downstream section)
3	enforcement of industrial wastewater discharge standards	8	0.5 (downstream section)
4	livestock wastewater reduction and feces removal from hog farms	45	1.5 (whole section)
5	removal of riverbank landfills and waste dumping sites	9	0.5 (whole section)
6	sewer system construction	61	2.5 to 3.5 (downstream section)

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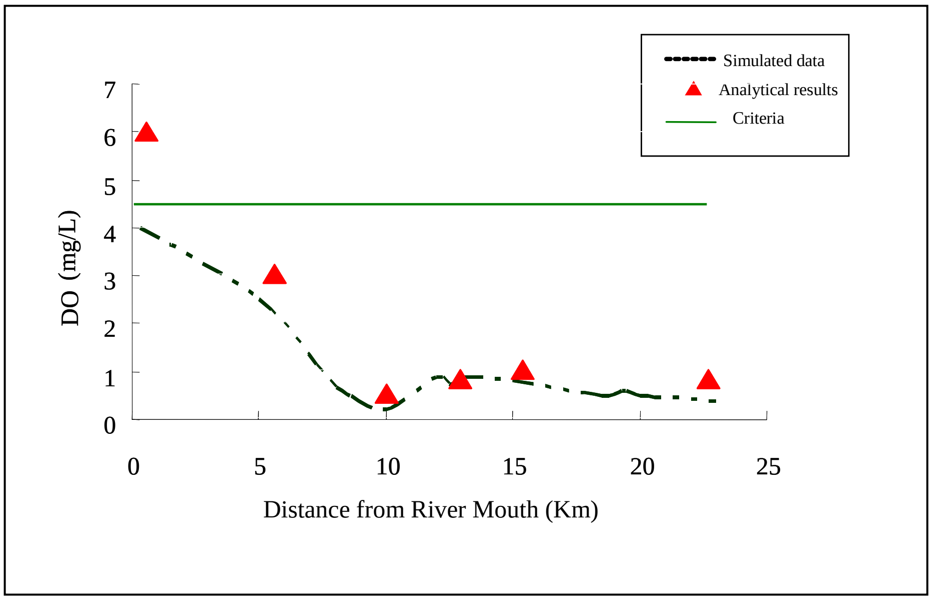

Figure 2. Measured and simulated DO concentrations and Class C water quality criteria from the river mouth (0 km) to the 23 km upstream location.

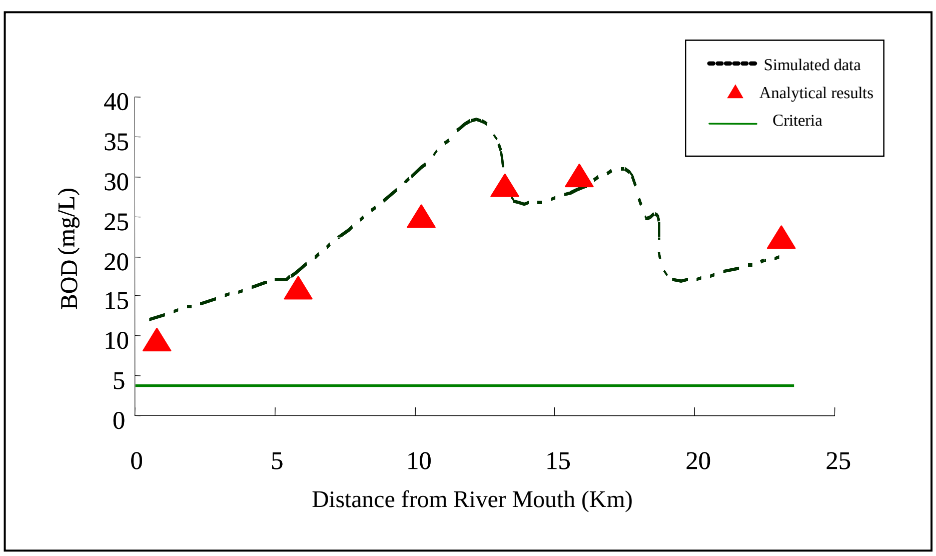

Figure 3. Measured and simulated BOD concentrations and Class C water quality criteria from the river mouth (0 km) to the 23 km upstream location.

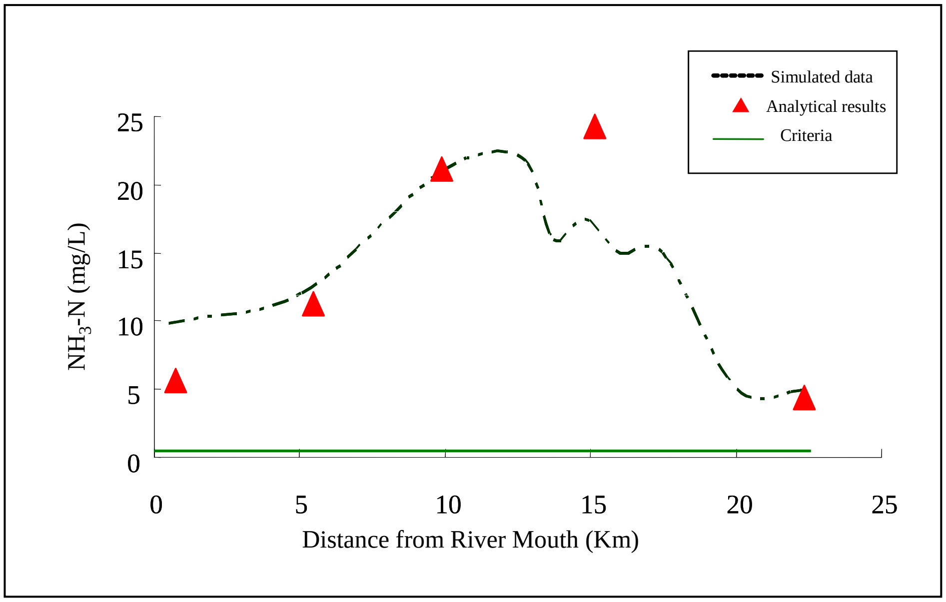

Figure 4. Measured and simulated NH_3-N concentrations and Class C water quality criteria from the river mouth (0 km) to the 23 km upstream location.