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ASSESSMENT OF HYDRO-ENVIRONMENTAL CONDITION USING NUMERICAL MODELING IN DIBAWAH LAKE, WESTERN SUMATRA, INDONESIA

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Abstract: This study investigates the hydro-environmental condition of Dibawah Lake, Province of Western Sumatra, Indonesia, using a finite element model called the Surface-water Modeling System (SMS). The aim is to present the parameters distribution in the existing condition and a year later. Field measurements are carried out to supply data for the domain input, boundary conditions, and model validation. The field measurements are lake-bed elevation, water level, current flow, and contaminant quantity measurements. The contaminant measurements are carried out to collect biochemical oxygen demand (BOD), sulfide, and total suspended sediment (TSS). The existing flow model is validated by current flow and water elevation field data. The validation shows a decent agreement. The result of water quality modeling, using the water quality module of SMS called RMA4, shows that after a year the BOD content is still in an acceptable proportion, which is less than 2 mg/liter. However, it is found that the sulfide content exceeds the limit defined by the government regulation, at over 0.002 mg/liter. In the sedimentation model generated by the module in SMS called SED2D, the maximum bed change obtained is around 15 cm, located at the inlet of two rivers connected to the lake. The proposed mitigation of the current research findings is to control the use of fertilizer around the lake watershed area with the aim of lowering the sulfide content and to maintain the lake bed elevation by routine dredging, particularly in the river inlets.

Keywords: Finite element, BOD, Sulfide, Bed Change, Dibawah Lake.

1. INTRODUCTION

Reviewing the status of lake conditions in Indonesia, there are 15 lakes included in the Mid Term National Development Plan year 2015–2019. The lakes require special attention to their sustainability [1]. Four of these 15 lakes, namely Maninjau, Toba, Limboto, and Rawapening Lake, is in critical condition. These lakes have various problems such as vast sedimentation and high sulfide content [2].

The research was conducted in Maninjau Lake, which is located in the Province of Western Sumatra, Indonesia. Evidence of a very high phosphorus content and very low brightness level were obtained [3]. Syandri et al. (2015) also studied the condition of Maninjau Lake by investigating the number of heavy metals contained in the water column, sediment, and fish [4]. It was found that the heavy metal concentration is in acceptable values according to World Health Organization (WHO) standard.

The aim of this research is to present the distribution of parameters in Dibawah Lake, Province of Western Sumatra. Field measurement and numerical modeling are conducted. The modeling is carried out to result in the distribution for one year. The investigated parameters are total suspended sediment, biochemical oxygen demand, and sulfide.

2. FIELD MEASUREMENT

Field measurements are lake-bed elevation bathymetry using single beam echosounder, water level observation using staff-gauge, current velocity measurement using the current meter and contaminant quantity trough water sampling is carried out as the part of the research. Climatology is also collected, and hydrology analysis is conducted. The aim is to provide data for the model input and validation. The location of Dibawah Lake is given in Fig.1a. The field measurement locations are shown in Fig.1b.

2.1 Lake-bed Elevation Bathymetry

Dibawah Lake is one of five lakes in West Sumatra with an area of more than 1,400 hectares [5]. Dibawah Lake is located at 1,462 meters above sea water level and has a maximum depth of 309 meters [6]. This study conducts bathymetry survey to obtain detailed lake-bed elevation data using a single beam echosounder. The area of measurement is 1,099.89 hectares. The documentation of the bathymetry survey is given in Fig.2. The base map of lake-floor is processed with the data from the Indonesian Geospatial Reference System 2013

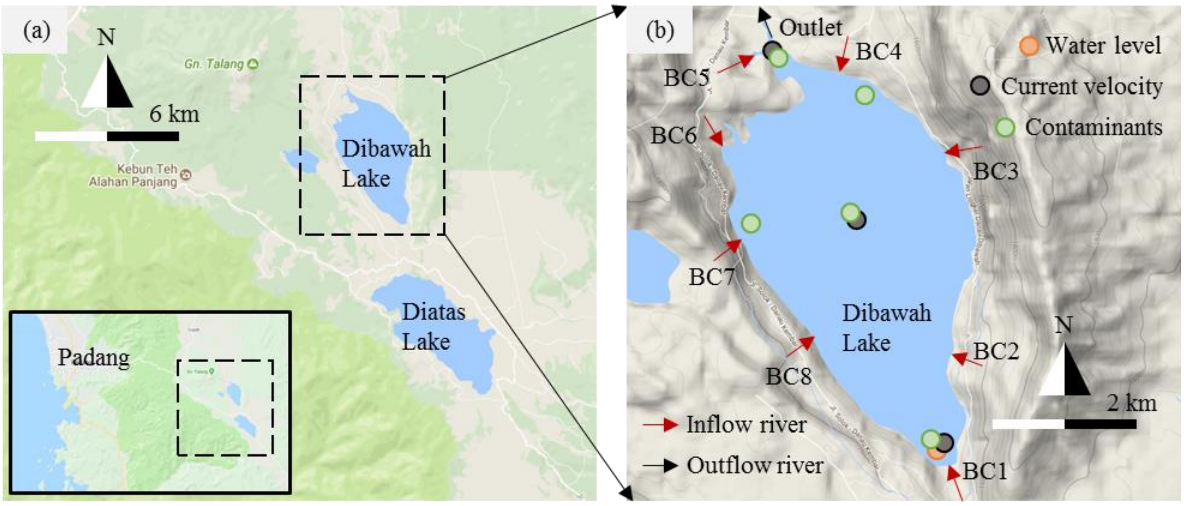

Fig.1 (a) The location of Dibawah Lake and (b) its surrounding rivers.

Fig.2 Documentation of lake-bed elevation field survey.

(SRGI2013). The resulting lake-bed elevation and model grid will be given in the modeling chapter.

2.2 Water Level Observation

Water level observation is carried out to provide the fluctuation of surface water elevation data for model reference and validation. A staff gauge is fixed at the lake at the location as given in Fig.3. The water levels are recorded hourly. The location of the staff gauge can be seen in Fig.1b. The water level data are taken for 15 days from 7th to 22nd of July, 2017. The field data and their comparison with the model result are given in the model validation chapter.

2.3 Current Velocity Measurement

The three locations of current velocity data measurement are seen in Fig.1b as black circles. The points are located at the center, northernmost point and southernmost point of the lake for representing the general lake conditions.

The Valeport current meter was used to measure magnitudes and directions of lake current velocity at the depths of 0.2d, 0.6d and 0.8d where d is the lake depth. The documentation can be seen in Fig.4. At every point, the data are collected hourly for 2 days. The resulting data and the comparison with the model results are presented in the model validation chapter.

Fig.3 Documentation of water level survey.

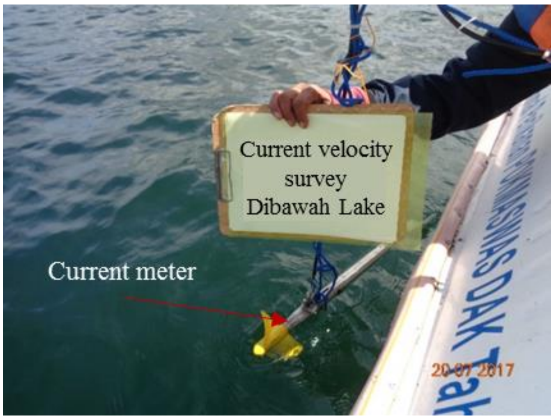

Fig.4 Documentation of current velocity survey.

2.4 Water Sampling

The contaminant quality field measurement is carried out by taking water samples using a water sampler at the 5 points given as green circles in Fig.1b. The documentation is given Fig.4. The samples are examined in the Water Laboratory at Bandung Institute of Technology, Indonesia. The resulting values of the investigated parameters are total suspended sediment (TSS), biochemical oxygen demand (BOD), and sulfide. The obtained data are used to determine the initial and boundary conditions of contaminant values in the numerical model.

Fig.5 Documentation of water samplings.

2.5 Hydrology Analysis

Hydrology analysis is carried out to determine the discharge of rivers which connect to Dibawah Lake. The rivers are shown in Fig.1b. There are 8 rivers supplying water into the lake (red arrows) and an outlet river (black arrow). The rainfall data are processed, and the land topography map is also delineated to obtain the region of each river watershed. The rainfall data are obtained from Diatas Lake Rainfall Station, Western Sumatra, Indonesia. Open source topography data are obtained from Shuttle Radar Topography Mission (SRTM) and processed to result in the topographical map. The mock analysis is carried out to obtain monthly river discharges as given in Fig.6. The monthly river discharges are shown in Fig.6. The inflow river discharges are denoted by Q1 to Q8, respectively. The outflow river discharge is denoted by O1.

3. NUMERICAL MODEL

In this research, the finite element model is the main part which shows the distribution of parameters after one-year simulation. The finite

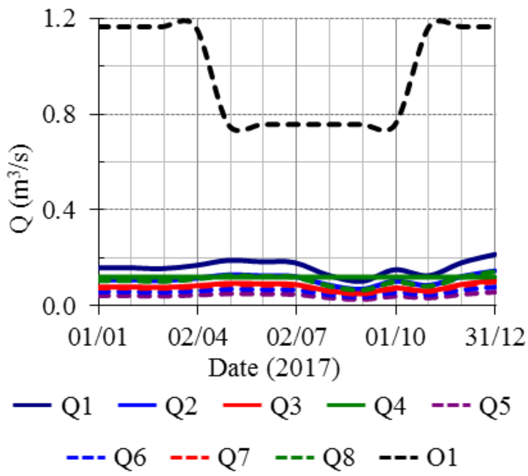

Fig.6 The resulting monthly river discharge

element model is licensed under the name Surface-water Modeling System (SMS). The software is developed by the US Army Corps of Engineers. This tool had been widely used in the world for various applications. Ajiwibowo and Pratama (2017) [7, 8] and Ajiwibowo (2018) [9] used the tools in the study of Ancol of Indonesia reclamation in Jakarta Bay and Muan river modeling in East Kalimantan, respectively.

3.1 Governing Equations

RMA2 of Surface-water Modeling System (SMS) is a tool for hydrodynamic modeling. RMA2 solves the depth-integrated equations of fluid mass as given in Eq. (1), while the momentum conservation in two horizontal directions is given in Eqs. (2) and (3) [10].

$$\frac{\partial h}{\partial t}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}=0 \quad (1)$$

$$h\frac{\partial u}{\partial t}+hu\frac{\partial u}{\partial x}+hv\frac{\partial u}{\partial y}-\frac{h}{\rho}\left[E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right]$$
$$+gh\left[\frac{\partial a}{\partial x}+\frac{\partial h}{\partial x}\right]+\frac{gun^2}{\left(1.486h^{1/6}\right)^2}\left(u^2+v^2\right)^{1/2}$$
$$-\zeta V_a^2\cos\psi-2hv\omega\sin\Phi=0 \quad (2)$$

$$h\frac{\partial v}{\partial t}+hu\frac{\partial v}{\partial x}+hv\frac{\partial v}{\partial y}-\frac{h}{\rho}\left[E_{yx}\frac{\partial^2 v}{\partial x^2}+E_{yy}\frac{\partial^2 v}{\partial y^2}\right]$$
$$+gh\left[\frac{\partial a}{\partial y}+\frac{\partial h}{\partial y}\right]+\frac{gvn^2}{\left(1.486h^{1/6}\right)^2}\left(u^2+v^2\right)^{1/2}$$
$$-\zeta V_a^2\sin\psi+2hu\omega\sin\Phi=0 \quad (3)$$

where h is the water depth, and x, y are the Cartesian coordinates, t is time, u and v are the velocities in the Cartesian coordinates, ρ is the fluid density, E is the eddy viscosity coefficient, g is the acceleration due to gravity, a is the elevation of the bottom, n is Manning's roughness n-value, 1.486 provides the conversion from SI to non-SI units, ζ is the empirical wind shear coefficient, V_a is the wind speed, ψ is the wind direction, ω is the rate of angular rotation of the Earth, and Φ is the local latitude.

3.2 Model Setup and Validation

The numerical model domain covers the water area of Dibawah Lake and also includes 9 rivers surrounding the lake. Fig.7 shows the bathymetrical map and the model's grids. The elements are generated varying to adjust to the lake geometry. The model is only forced by the monthly river discharge which the data obtained from hydrology analysis. The tidal effect is assumed to be very small and negligible.

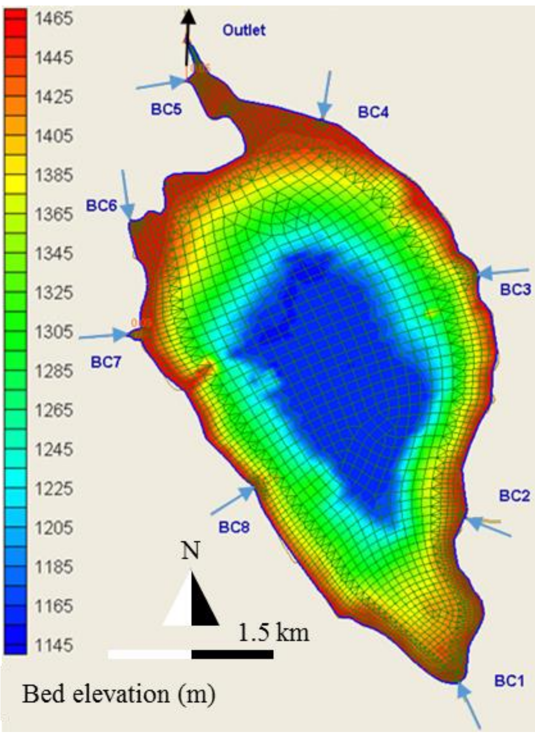

Fig.7 The bed elevation and mesh of model domain

RMA2 is executed to simulate water elevation and water currents in the lake. The resulting simulation is then validated with field data, which are the water level and current velocity data. The validation shows good agreement. The validation results are given in Figs.8 and 9, respectively.

Using the flow from the RMA2 model, the

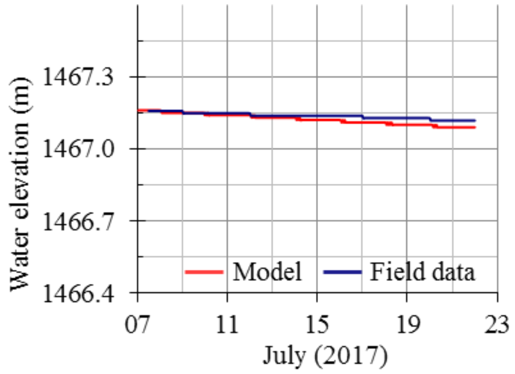

Fig.8 Water level validation result

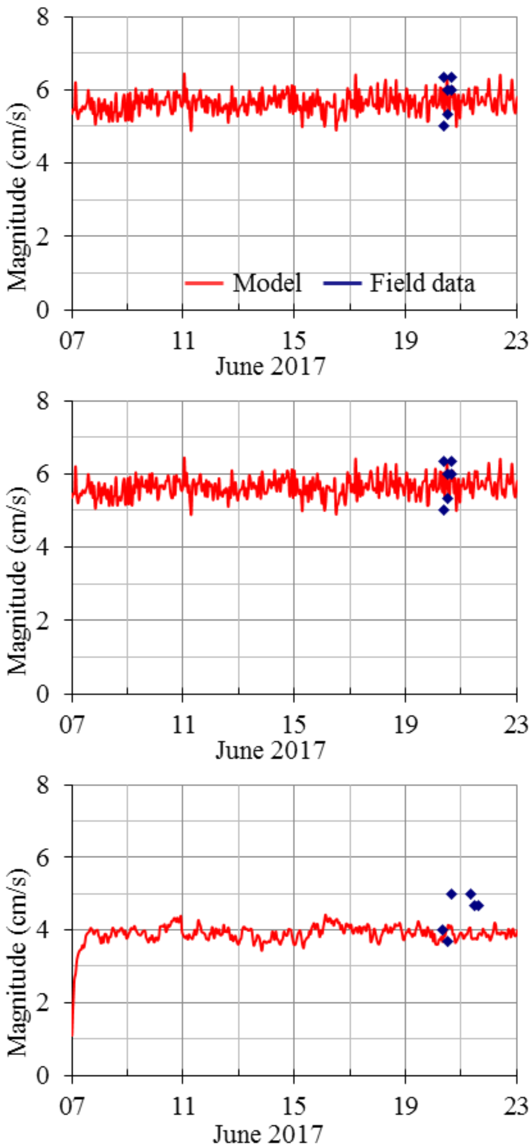

Fig.9 Current velocity validation result. Top to bottom show the validation results at the north, center, and south of the lakes as black circles in Fig.1b. The field data are magnitudes of current at top layer near the lake water surface.

simulation is expanded into sedimentation and contaminant simulation modeling using SED2D for sediment model and RMA4 for water quality, respectively. An additional boundary condition needs to be included to proceed with the simulation. The values of TSS and other contaminant boundary conditions are given in Table 1.

Table 1 The values of TSS, BOD, and sulfide at the initial and boundary conditions

BC	TSS	BOD	Sulfide
		mg/l	
BC1	4	2.210	0.015
BC2	4	1.100	0.001
BC3	6	2.210	0.060
BC4	6	2.210	0.060
BC5	6	1.100	0.053
BC6	4	1.470	0.060
BC7	4	1.470	0.060
BC8	4	1.470	0.060
Initial	4	1.100	0.001

4. RESULTS AND ANALYSIS

The resulting model of three investigated parameters, BOD, sulfide, and TSS, is given in a spatial distribution. And particularly for the most significant changes, the specific values are given in Table 2. The values are then compared to the contaminant standard from the local government regulation. This analysis is carried out to determine in which class Dibawah Lake is situated.

4.1 Biochemical Oxygen Demand

The result of BOD change after one year of simulation from RMA4 is given in Fig.10. The figure shows that the highest BOD value is situated in the estuary of the only outlet river, with a value of 1.6 mg/l. Although the BC5 river, which is the nearest river to the estuary, contains a normal level of BOD, the estuary is expected to have the highest BOD because the contaminant from all rivers converges into and accumulates at the mouth of Lembang river outflowing from the lake. Referring to the Governor Regulations number 24 the year 2010 of West Sumatra [11], the standard of BOD content in a lake should be below 3 mg/l. Dibawah Lake's BOD content still satisfies the condition.

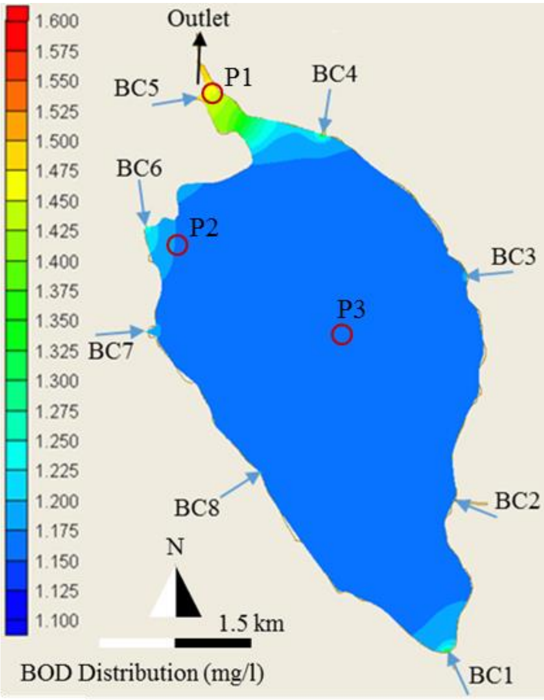

Fig.10 The resulting BOD distribution

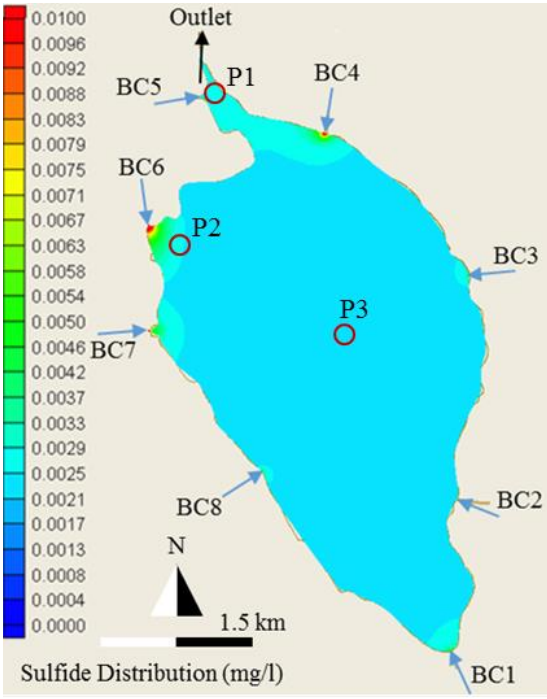

Fig.11 The resulting sulfide distribution

Table 2 The resulting value of BOD and sulfide at three investigated points

Value	BOD (mg/l)			Sulfide (mg/l)		
	P1	P2	P3	P1	P2	P3
Maximum	1.682	1.337	1.332	0.0057	0.0057	0.0056
Average	1.527	1.223	1.218	0.0035	0.0035	0.0034
Minimum	1.100	1.100	1.100	0.0010	0.0010	0.0010

4.2 Sulfide

Fig.11 presents the distribution of sulfide contaminant after a year simulation generated by RMA4. The figure shows that the highest sulfide content is located at the inlets of BC4 and BC6, which is nearly 0.009 mg/l. The area around the outlet river estuary also contains a relatively higher sulfide, approximately around 0.003 mg/l. The values of three selected points show that the average and maximum values are ranging from 0.0034–0.0035 and 0.0056–0.0057 mg/l, respectively. Referring to the Governor Regulations of Western Sumatra number 24 the year 2010 [11], the standard of sulfide content in a lake shall be below 0.002 mg/l. Dibawah Lake does not satisfy the condition.

4.3 Total Suspended Sediment and Bed Change

The simulation of TSS movement generated using SED2D results in the lake-bed change. Similar to BOD and sulfide analysis, the bed change is presented after a year simulation as given in Fig.12. It is shown that the most notable change is at the inlets of BC3 and BC4 rivers, which is around 15 cm within one year. This is anticipated because of the high concentration of TSS flowing out from these rivers.

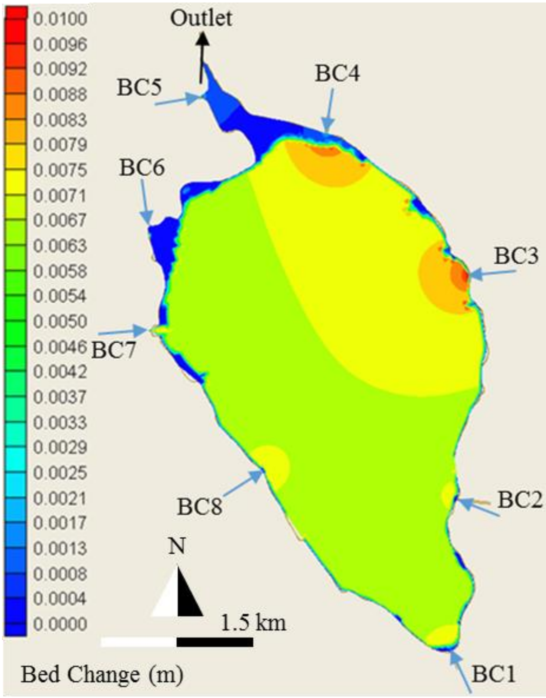

Fig.12 The resulting bed change

5. CONCLUSION

The resulting flow model using RMA2 of SMS showed a good agreement with the field data. The contaminant model using RMA4 showed that BC4 and BC6 rivers had the highest value of sulfide, exceeding the standard referring to the Governor Regulations of Western Sumatra number 24 in the year 2010. The BOD model showed that the highest value is still in the acceptable proportion, referring to the same regulation. From these findings, a measure to manage the utilization of fertilizer on farming activity was proposed to be taken, to decrease the accumulation of sulfide content coming into the lake.

For the bed change, the SED2D model showed that the maximum bed change, around 15 cm within one year, is located at BC3. A routine maintenance dredging every 6 years on the lake water area was advised to maintain the lake capacity, assuming that the 1-meter bed change is considered deteriorating to the lake volume capacity. All 5 inflow river-mouths should also be maintained by dredging since the higher depositions are mostly found there.

6. ACKNOWLEDGMENTS

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