DEVELOPMENT OF A METHOD FOR TWO-DIMENSIONAL PLANE REPRESENTATION OF ONE-DIMENSIONAL ANALYSIS RESULTS BY CONSIDERING LAND FORM SHAPE USING LASER PROFILER DATA

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ABSTRACT

In recent years, hydraulic analysis has required, in addition to analytical precision, prompt and explanatory presentation of results. The results of one-dimensional analysis have been conventionally represented as longitudinal river beds. In response to the abovementioned needs however, this study developed a method of plane two-dimensional representation, considering the landform shapes of mountainous regions. Further, a program that outputs GIS data was also developed. An example of the application of this program to a torrent revealed that it is possible to rapidly and easily understand hydraulic phenomena in mountainous regions by displaying the rate of change of hydraulic quantities such as water depth and flow speed, or sediment deposition and erosion quantities, in plane two dimensions. The proposed method allows experts as well as members of the public who are unfamiliar with riverbed longitudinal graphs to easily understand the results of hydraulic analysis.

1. INTRODUCTION

In Japan, there has been an increasing number of opportunities to explain hydraulic phenomena to members of the Japanese public through information disclosure and resident participation seminars. Disasters are becoming more unpredictable and devastating, so it is increasingly necessary to be able to rapidly and accurately analyze hydraulic phenomena during disasters and inform governmental agencies and residents. However, traditional methods of presentation prove insufficient to present hydraulic analysis results with promptness and clarity. A method to display the results of a plane two-dimensional analysis of flood plains has been established to present flood behavior from the starting point of inundation to the flood plains. Analytical results can be displayed while being compared to planar positions using software. The software that is able to display one-dimensional analysis results on a map, Hyper-KANAKO (Horiuchi *et al*. 2012) was developed as a method to use color to represent "linear" data along the river centerline, allowing for more intuitive understanding compared to the traditional longitudinal profile. In addition, Kajiyama *et al.* (2018) developed a method to apply color to the river centerline while also considering the river channel width. In this manner, positional information, river channel width, and analytical results could be understood simultaneously. However, because this method applied color to the river channel width relative to the river centerline, accurate representation was difficult to achieve for strongly asymmetrical settings, such as river channels in mountainous regions.

In this study, we have developed a plane two-dimensional representation method that is able to display the area of the water surface, depositional areas, and erosional areas with high precision, while accurately reflecting river channel morphology from results of one-dimensional analysis performed for mountainous regions. We have also developed a program that maintains the analytical results from this method and outputs GIS data that can be overlapped on landform data, etc. Finally, we have developed a method for displaying one-dimensional analysis results on a plane two-dimensional space and have provided an example application of the method.

2. INPUT/OUTPUT DATA AND DATA PROCESSING INFORMATION

Input/output data and data processing information for the program is given below.

(1) Input data

(a) Positional information for a mountain stream: X and Y coordinates in a Cartesian coordinate system for the starting point, inflection point, and end point of the river channel centerline in the interval where one-dimensional analysis was performed.

(b) Elevation data: Planar landform data obtained from airborne laser measurements.

(c) One-dimensional analysis results: One-dimensional analysis results such as river bed elevation, water surface elevation, river channel width, water flow speed, and sediment concentration.

(2) Data processing method

Information on data processing with the program is given below. Figure 1 shows the processed information.

(a) Input positional data of the river channel, elevation data and analytical results (Figure 1a).

(b) Based on the positional data of the river channel, values of the one-dimensional analysis results along the river channel are interpolated using an interval smaller than the grid size of the elevation data (Figure 1b).

(c) Along the river channel, positions are determined to calculate landform cross-sections at intervals smaller than the grid size referred to in the elevation data (Figure 1c).

(d) Using the above defined cross-section positions, the cross-sectional landform shapes are extracted from the elevation data (Figure 1d).

(e) The landform shapes from step (d) are compared with analytical results. Then, plane two-

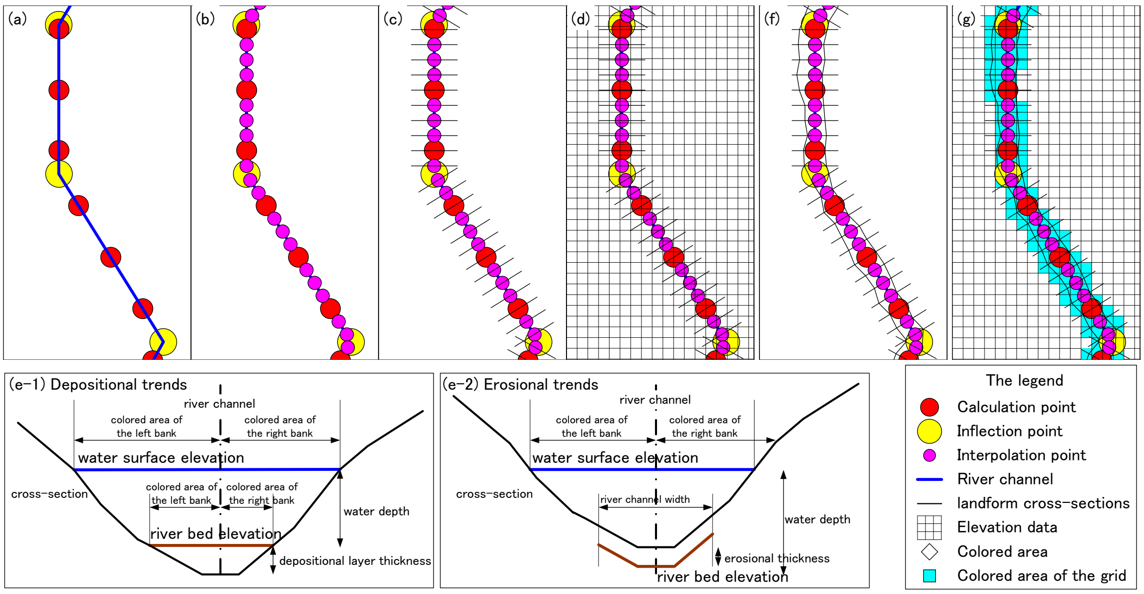


Figure 1. Plane two-dimensional display image for one-dimensional analysis results that considers landform shape using LP data

dimensional information (river channel width, water depth, and depositional layer thickness) is extracted from these results. For a depositional environment where the river bed elevation is higher than the landform shape, the process shown in Figure 1e is performed. For an erosional environment, where the river bed elevation is lower than the landform shape, the process shown in Figure 1e was added. For numerical values that are unrelated to landform information, such as flow speed and sediment concentration, the same values as those in the colored river channel width of water depth were applied.

(f) Based on the colored river channel width extracted in step (e), the colored range of the plane two-dimensional display (Figure 1f) is defined.

(g) Using the colored river channel width information from step (f), the numerical results are applied to the target grid as plane two-dimensional information (Figure 1g).

(3) Output data

We used ESRI ASCII raster format data so that the output data could be displayed in as text format. This data format can be processed using ArcGIS by ESRI and is highly versatile, allowing data to be displayed with free open software QGIS and shareware SIS by simply changing the file extension.

3. EXAMPLE APPLICATION OF THE PROGRAM

An example application of the developed program is presented in the next section:

(1) Definition of the target site

The target site is a stream in a mountainous region north of Kiyomizu Temple in Kiyomizu, Higashiyama-ku, Kyoto (Japan), where detailed LP data already exists (Figure 2). The stream has a surface area of 0.04 km^2 and a length of about 200 m.

(2) Input data

Three sets of data were used in the program:

(a) Position of the river channel centerline defined by the Cartesian coordinates for the starting point, inflection point, and end point (Table 1 shows a subset of the data). A contour map was prepared from the elevation data shown in Figure 2, and the river channel data were calculated through interpretation.

(b) Elevation data: Data at the grid size of 1 m, 2 m, and 5 m were calculated based on the previously known LP data (provided by Nakanihon Air Services).

(c) One-dimensional analysis results: Data for river bed elevation, water surface elevation, flow speed, and sediment concentration at each landform cross-section calculation point was extracted from the results of the one-dimensional analysis (Table 2 shows a subset of the data). In this study, the one-dimensional analysis simulation program KANAKO 1D (Nakatani *et al.* 2008) was used to perform an unsteady flow analysis using the parameters shown in Table 3. Influx conditions are shown as a hydrograph in Figure 3, and calculations

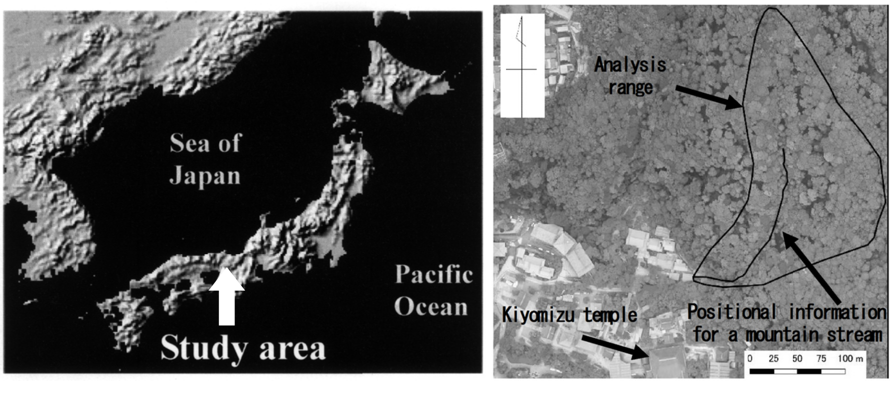


Figure 2. Area and range for which the analytical data were prepared.

were performed using a sediment concentration of 0.3. In this study, we chose to present a case where the one-dimensional analysis results were applied to the unsteady flow calculation. However, any type of analytical method could be used as long as that it is able to output river bed and water surface elevation.

(3) Display options

(a) Display of the maximum values of each result

In order to display the maximum water depth, maximum river bed elevation, and flow speed at each calculation point of the one-dimensional analysis, the plane two-dimensional

Table 1. An example of positional data for the mountain stream.

id	X coordinate (m)	Y coordinate (m)
1	−19505.4	−111267.1
2	−19504.3	−111272.9
3	−19504.0	−111278.9
4	−19504.4	−111281.2
5	−19505.0	−111282.3
6	−19504.4	−111284.6
7	−19501.4	−111291.2
8	−19500.8	−111301.3
9	−19505.4	−111310.1
10	−19506.0	−111317.9

Table 2. An example of one-dimensional analysis.

id	Distance (m)	River bed elevation (m)	Water surface elevation (m)	River channel width (m)	Sediment concentration	Flow rate (m/s)
1	0	146.1	146.7	3.0	0.30	1.27
2	5	144.9	145.5	3.0	0.30	1.20
3	10	143.8	144.2	3.4	0.31	1.15
4	15	142.6	143.1	3.3	0.31	1.18
5	20	141.5	142.1	2.8	0.30	1.22
6	25	140.5	141.1	3.0	0.30	1.21
7	30	139.5	140.0	2.9	0.30	1.16
8	35	138.4	139.0	3.4	0.30	1.11
9	40	137.4	138.0	3.4	0.30	1.14
10	45	136.4	137.0	3.1	0.30	1.10

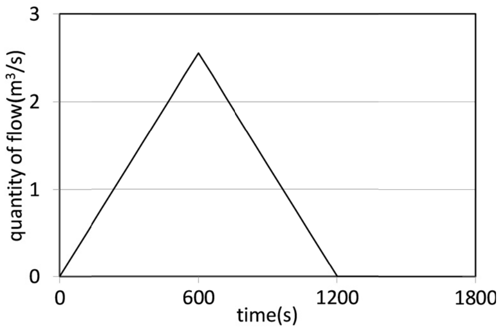
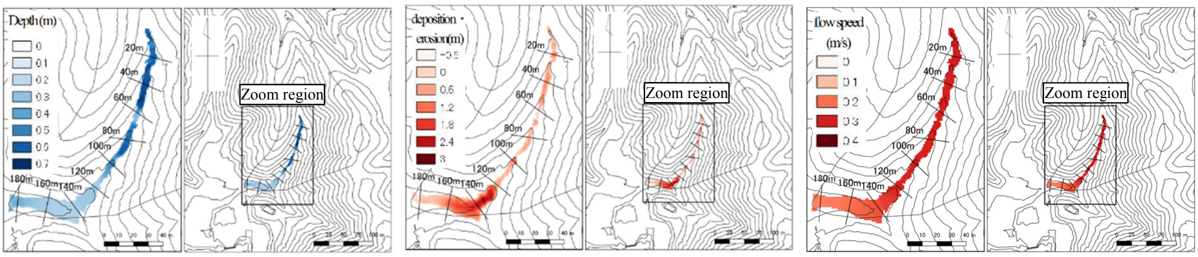


Figure 3. Hydrograph (Nawate *et al.*) used for one-dimensional analysis

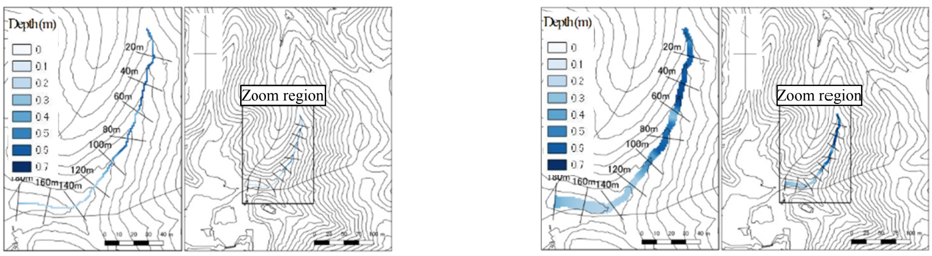
Table 3. Analytical parameters.

Prameters/Variables	Value	Unit
Simulation time	1800	s
Time step	0.01	s
Mass densty of bed material	2650	kg/m^3
Mass density of fluid(water and mud, silt) phase	1000	kg/m^3
Acceleration of gravity	9.8	kg/s^2
Concentration of movable bed	0.65	
Manning's coefficient	0.03	$s/m^{1/3}$
Coefficient of erosion rate	0.0007	deg.
Coefficient of deposition rate	0.05	m/s^2
Diameter of material	0.2	m/s2
Internal friction angle	37	deg.



(a) Maximum water depth (b) Maximum river bed elevation (c) Maximum flow speed

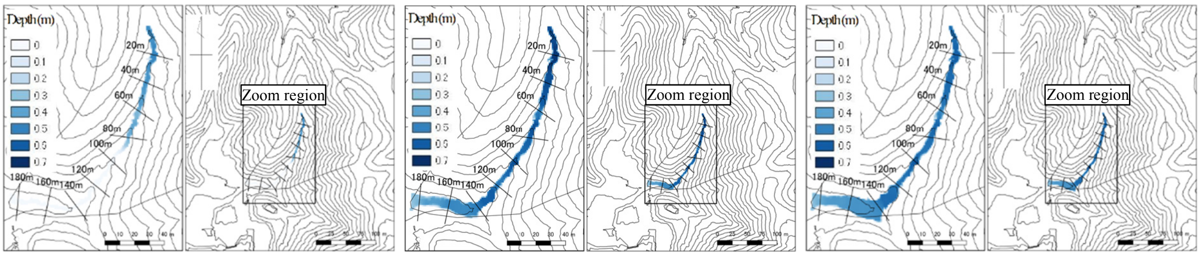
Figure 4. Display of one-dimensional analysis results using the new method



(a) Display using Hyper-KANAKO (b) Display method used by Kajiyama et al. (2018)

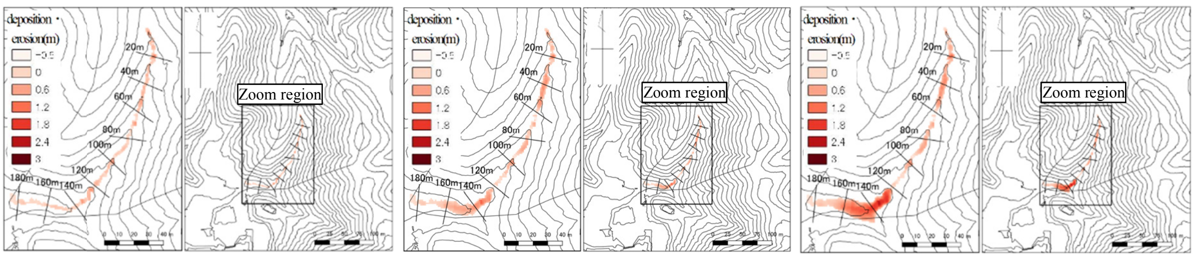
Figure 5. Display of the results of a typical one-dimensional analysis

representation method was used (Figure 4). For comparison with traditional methods, the one-dimensional analysis results by Hyper-KANAKO were mapped (Fig. 5a) along with the results of the display method used by Kajiyama *et al.* (2018) (Fig. 5b) . As shown in Figure 4, the plane two-dimensional representation method presents straightforward information regarding water depth distribution, similar to the traditional methods (Figures 6a and 6b). However, Figure 4a shows that the colored river channel width can be displayed with the additional landform cross-sectional shapes on the plane two-dimensional representation, unlike in the traditional method. For river channels in mountainous regions that have a high degree of asymmetry in their cross-sectional shapes (for example, at points 140 m and 160 m), an accurate representation of the colored river channel width that considers landform shape is now possible. Furthermore, as shown in Figure 4b, fluctuations in the depositional area, erosional area, and river beds can also be displayed accurately through the landform cross-sectional shape. Looking at the output results of water depth and flow speed, it is easy to understand that the depositional layer thickness increases and flow speed decreases at the point where the river channel width increases and the gradient decreases (for example, between 120 m and 140 m). By visualizing the hydraulic phenomena analysis results through the plane two-dimensional representation, anyone can quickly and easily understand information about the river channel width, location, and river channel width where critical hydraulic phenomena occur. In addition, when a colored area deviates greatly from the expected river channel width, it could be used to determine the necessity to verify the river channel width, and detailed analysis such as plane two-dimensional analysis can be conducted.



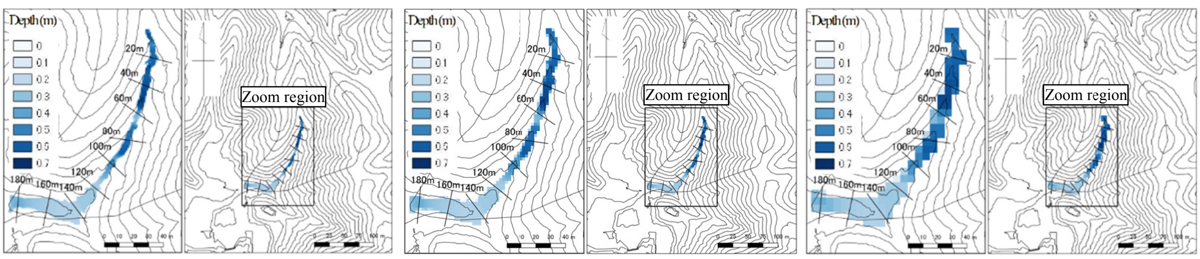
(a) 300 minutes (b) 600 minutes (c) 900 minutes

Figure 6. Display of temporal changes in water depth



(a) 300 minutes (b) 600 minutes (c) 900 minutes

Figure 7. Display of temporal changes in depositional layer thickness



(a) 1 m grid (b) 2 m grid (c) 5 m grid

Figure 8. Apparent differences due to change in grid size

(b) Display of temporal variations in water depth and river bed depositional layer thickness.

Figure 6 shows an example of water depth data for three-time ranges—300 minutes, 600 minutes, and 900 minutes—using one-dimensional analysis. Figure 7 shows an example of a display of depositional layer thickness. By displaying the temporal changes in the water depth, one can easily understand the amount of time it takes for the flood water to move from upstream to the mouth of the valley, and the time it takes for flood water to flow from upstream to an arbitrary position downstream. By displaying changes in the depositional layer thickness, temporal changes in sediment can also be easily understood. In addition, a video can be prepared from output analytical data at small intervals, allowing for more effective presentations at information disclosure and resident participation seminars.

(c) Display for various grid intervals

Elevation data during the GIS data output for 1 m, 2 m, and 5 m are shown in Figure 8. The representation for a 1 m (Figure 8a) and a 2 m grid interval (Figure 8b) are similar, illustrating the relationship between the river channel width and water depth. On the other hand, in the representation for a 5 m grid interval (Figure 8c), the relationship between the river channel width and water depth is unclear due to the restricted grid size of the display. This is because the width of the target stream in this study was about 3 to 10 m, and some of the data calculated in the analysis used a grid interval larger than the actual river channel width. Therefore, in this case, grid should have been 3 m or less.

4. CONCLUSION

In this study, we developed a method that can quickly and easily display one-dimensional analysis results from three aspects of hydraulic phenomena: positional information for a river channel, water elevation, and river channel width, taking landform shape into consideration. We also developed an output program which was able to effectively present: water depth, depositional layer thickness, and flow speed, temporal changes in water depth and depositional layer thickness, and elevation output data using different grid intervals for a mountain stream north of Kiyomizu Temple in Kyoto-shi. In addition, the plane two-dimensional representation in this method was able to quickly display one-dimensional analysis results, such as hydraulic phenomena and river bed fluctuations (deposition and erosion), with clarity.

5. REFERENCES

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