UNDERGRADUATE THESIS

HYDRAULIC SIMULATIONS USING DIGITAL ELEVATION MODELS WITH DIFFERENT FLOW CONDITIONS AND VARYING SPATIAL RESOLUTIONS

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PERNYATAAN

Yang bertandatangan di bawah ini, saya dengan data diri sebagai berikut:

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Menyatakan bahwa skripsi dengan judul:

HYDRAULIC SIMULATIONS USING DIGITAL ELEVATION MODELS WITH DIFFERENT FLOW CONDITIONS AND VARYING SPATIAL RESOLUTIONS

adalah benar-benar karya saya sendiri di bawah bimbingan dosen pembimbing. Saya tidak melakukan penjiplakan atau pengutipan dengan cara-cara yang tidak sesuai dengan etika keilmuan yang berlaku dalam masyarakat keilmuan. Apabila di kemudian hari ditemukan adanya pelanggaran terhadap etika keilmuan dalam karya saya, atau jika ada tuntutan formal atau non formal dari pihak lain berkaitan dengan keaslian karya saya ini, saya siap menanggung segala resiko, akibat, dan/atau sanksi yang dijatuhkan kepada saya, termasuk pembatalan gelar akademik yang saya peroleh dari Universitas Katolik Parahyangan.

Dinyatakan: di Tangerang

Tanggal: 2 Februari 2021

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ABSTRACT

To reduce the impacts of flood disaster, flood mapping becomes very important in providing information about areas prone to flooding. Such information can be used to prevent loss of life as well as property. Utilizing computer programs, flood mapping can be carried out for a reasonably accurate result with a relatively short time. In the process of flood mapping, grids were created to discretise the computational area investigated. This study aims to find the optimal grid size to ensure the flood mapping results being reasonably accurate without suffering from high computational cost. To this regard, HEC-RAS software was used to map the floods of the hypothetical breaching case of Parangjoho dam, located in Central Java, Indonesia. The topography map used in this study is of DEM (Digital Elevation Model), i.e. ALOS and MERIT-Hydro, which are open-access. Grid sizes of 10 m, 20 m, 30 m, 50 m, 90 m, 120 m, and 200 m were employed for the flood simulations. Two types of flood flows, i.e. Gradually Varying Unsteady Flow (GVUF) and Rapidly Varying Unsteady Flow (RVUF) were considered. The results indicate that floods caused by GVUF exhibit a larger inundation area than the ones caused by RVUF. Another finding in this study relates to the trade-off between efficiency and accuracy, where using smaller grid sizes, the computational cost rises exponentially, whereas using larger grid sizes reduces the accuracy. It was found that using the 30 m grid size, the results were reasonably accurate without having high computational cost.

Keywords: Dam, Dam Break, Flood Mapping, HEC-RAS, DEM, Grid, Grid Size, Numerical Simulation, Shallow Water

SIMULASI HIDRAULIK MENGGUNAKAN DIGITAL ELEVATION MODEL DENGAN BERAGAM KONDISI ALIRAN DAN BERBAGAI RESOLUSI DATA TOPOGRAFI

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ABSTRAK

Untuk mengurangi dampak dari bencana banjir, pemetaan banjir menjadi sangat penting dalam memberikan informasi tentang area yang rentan terhadap banjir. Informasi tersebut dapat digunakan untuk mengurangi korban jiwa dan juga kerugian material. Dengan memanfaatkan program komputer, pemetaan banjir dapat dilakukan dengan hasil yang cukup akurat dalam waktu yang cukup singkat. Dalam proses pemetaan banjir, dibuat grid untuk mendiskretisasi area komputasi yang ditinjau. Studi ini bertujuan untuk menemukan ukuran grid size yang optimal untuk memastikan hasil dari pemetaan banjir memiliki hasil yang cukup akurat tanpa memerlukan biaya komputasi yang terlalu tinggi. Dalam hal ini, software HEC-RAS dipakai untuk memetakan banjir dalam kasus hipotetikal keruntuhan bendungan Parangjoho yang terletak di Jawa Tengah, Indonesia. Peta topografi yang digunakan dalam studi ini berupa DEM (*Digital Elevation Model*), seperti ALOS dan MERIT-Hydro, yang bersifat *open-access*. Ukuran grid 10 m, 20 m, 30 m, 50 m, 90 m, 120 m, dan 200 m digunakan dalam simulasi banjir. Dua jenis aliran banjir, Aliran Tidak Langgeng Berubah Lambat Laun (GVUF) dan Aliran Tidak Langgeng Tiba-Tiba (RVUF) digunakan. Hasil menunjukkan bahwa banjir akibat GVUF menggenangkan area yang lebih besar daripada banjir akibat RVUF. Penemuan lain dari studi ini adalah tentang hubungan antara efisiensi dengan akurasi, dimana dengan menggunakan ukuran grid yang lebih kecil, biaya komputasi naik secara eksponensial, sementara dengan menggunakan ukuran grid lebih besar mengurangi akurasi. Ditemukan bahwa dengan menggunakan ukuran grid 30 m, didapat hasil yang cukup akurat tanpa biaya komputasi yang terlalu tinggi.

Kata kunci: Bendungan, Keruntuhan Bendungan, Pemetaan Banjir, HEC-RAS, DEM, Grid, Ukuran Grid, Simulasi Numerik, Air Dangkal

PREFACE

This thesis was written as a requirement to complete a bachelor's degree in Civil Engineering from Parahyangan Catholic University. During the process of writing this thesis, I have received many supports in various forms. Therefore, I would like to acknowledge:

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While acknowledging the many limitations in this thesis, it is with great hope that any reader can find this thesis to be useful.

Bandung, 2 February 2021

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CHAPTER 1
INTRODUCTION

1.1 Background

Using computer models has helped ease the implementations of simulations for various problems in water resources such as dam-break, tsunami, water distribution, water quality, sedimentation, runoff discharge, etc. The method of using computers to solve flow equations is called Computational Fluid Dynamics (CFD) (Çengel & Cimbala, 2010), and specifically as Computational Hydraulics for open-channel flow equations. Using less efforts, difficult flow problems can now be solved using computers models achieving accurate results. The fast progress of technology has allowed one to carry out computer models for complex simulations without having to build physical models.

One of several common computer models used for free-surface flow modelling is HEC-RAS 5.0.7. HEC-RAS has been used by many engineers and scientists for various flow applications, e.g. 1D open channel flow simulations, 2D urban flood modelling, etc. HEC-RAS was developed by USACE's Hydraulic Engineering Centre (HEC) with a development team led by Gary W. Brunner (U.S. Army Corps of Engineers (USACE), 2002). This model is a free software and has been proven accurate. In general, one can solve using HEC-RAS the flow properties such as depth and velocity, if the input data are available: bed topography including main channel and channel bank, discharge, and Manning coefficient (Dyhouse, Hatchett, & Benn, 2007).

In this study, the author focuses on numerical simulations of flood modelling at the downstream area of Parangjoho dam, located in Central Java (Indonesia). The simulations are carried out using HEC-RAS 5.0.7 utilizing several open-access digital elevation models (DEMs) from low to high resolutions. A DEM represents a gridded terrain data with each pixel value in the grid indicating a certain height above a datum (Hawker, Bates, Jeffrey, & Rougier, 2018). Meanwhile, the resolution represents the number of pixels in a grid size. Yet, the author is interested in investigating the grid size effects on both the accuracy and computational cost of the numerical simulations.

It is known that using (very) fine grids can in general increase the accuracy of numerical free-surface flow simulations, including the one simulated using HEC-RAS 5.0.7. However, refining the grid size increases the computational cost. This means that the computer used to run the simulation has to process more computations, requiring more energy and time. According to (Versteeg & Malalasekera, 2007), the accuracy of the solution and the computational cost depend on the fineness of the grid but another finding of (Çengel & Cimbala, 2010) indicated that using finer grids does not necessarily mean that a more accurate solution is produced. Therefore, it is of importance to find a balance between the accuracy and the computational cost, or in other words, to find the coarsest grid size that can still give reasonable accurate results.

In conjunction with the computational cost, the author also investigates in this work the accuracy of numerical results for various flow conditions, i.e. gradually varying unsteady flow (GVUF) and rapidly varying unsteady flow (RVUF). Hypothetically, the grid size will have different effects on the numerical accuracy when dealing with different characteristics of flood hydrograph. Furthermore, the author also investigates the accuracy of numerical results for various resolutions of topographical data. The quality of the map of the flooded areas depends on the accuracy of a digital terrain model (DTM) (Zhang, et al., 2019). This is because the different resolutions of topographical data produce different flood inundation areas, for which finer scale resolutions increase computational cost. It is therefore of interest to study the effect of grid size on the accuracy and the computational cost with different flow conditions and different resolutions of topography data.

Currently, there are several DEM sources ranging from fine-resolution and accurate with a high cost to low-resolution and low-cost, such as ASTER, ALOS, TanDEM-X, SRTM, and GTOPO30 (Azizian & Brocca, 2019). Such DEMs are available at (NASA JPL, 2004), (JAXA, 1997), (German Aerospace Center (DLR), 2006), (NASA JPL, 2015), and (USGS, 2018), respectively. Other (open-access) sources for DEM are DEMNAS (Badan Informasi Geospasial, 2018) and MERIT Hydro (Yamazaki, 2019). As previously mentioned, hydraulic simulations can include simulations of dam-break, tsunami, water distribution, water quality, sedimentation, runoff discharge, etc. Such simulations require a lot of data to be processed by the computer. It is expected that by the findings of this study, one may know the optimum grid size for accurate hydraulic simulations without suffering from high computational cost, thus saving energy and time.

Similar studies focusing on the use of DEMs and various grid sizes for dam-break flood simulation are already conducted numerous times in the past. In (Ginting, Yudianto, Willy, & Ginting, 2021), a set of numerical simulations for dam-break flow was carried out using DEMNAS, ALOS, and MERIT Hydro. It was found that using 50 m computational grid size will no longer produce significant differences of numerical results, i.e. maximum inundation boundary, maximum depth, maximum velocity, and average depth. In (Lodhi & Agrawal, 2012) a dam-break flood case in India was simulated using DAMBRK model with a DEM. Another study of (Pilotti, 2016) focused only on a one-dimensional solution of dam-break wave propagation by extracting cross sections of a DEM. In (Azizian & Brocca, 2019), various DEM data were directly used for flood inundation mapping without interpolating them to various grid sizes. The use of various grid sizes to simulate dam-break flow were studied by utilizing a quadrilateral unstructured mesh with average side-lengths of 350, 300, 200, and 150 m in (Zhang, Xia, Yuan, & Jiang, 2014) and by utilizing adaptive grids in (Rahman & Chaudhry, 1998) (Rai & Anderson, 1981). In this current study, the author will compare the use of DEM maps and utilizing various grid sizes for simulating two different flow types, in order to determine the most cost-effective grid size.

1.2 Aim and Objective

This thesis aims to find the coarsest grid size for hydraulic simulations with different hydrograph values and different resolutions of topography data in order to maintain the reasonable accuracy and computational cost.

The objectives are formulated as follows:

1. To perform hydraulic simulations with different values of hydrograph using different grid sizes
2. To perform hydraulic simulations with different resolutions of topographical data using different grid sizes
3. To determine the level of accuracy of each hydraulic simulation performed

4. To determine the computational cost of each hydraulic simulation performed
5. To analyse and compare the results of all the hydraulic simulations performed
6. To determine the optimum grid size to be used in hydraulic simulations

1.3 Scope of Study

This study focuses on hydraulic simulations performed using the computer software HEC-RAS 5.0.7 with GVUF and RVUF floods. The topographical data used in this study are the DEMs for Parangjoho dam, Central Java (Indonesia), which are obtained from various open-access sources with the resolutions of 30 m and 90 m. These DEMs will then be used in the simulations using several computational grid sizes of 10 m, 20 m, 30 m, 50 m, 90 m, 120 m, and 200 m. The computational cost will be determined by measuring the time required to perform each hydraulic simulation. The accuracy level of these simulations will be assessed by comparing each flood inundation area with the one computed using the 10 m grid size. Note that as no measurement data are available for the validation purpose, the results produced using 10 m grid size are assumed to be the most accurate results among the others (as a benchmark).

In this study, all hydraulic simulations will be carried out using a computer with specifications shown in Table 1.1

Table 1.1 Computer Specifications

Processor	Intel® Core™ i7-6700HQ CPU @ 2.60GHz
RAM Capacity	16 GB
Operating System	Windows 10 Pro v1909

1.4 Research Methodology

The research methodology for this thesis consists of:

1. Literature Study

   This step is carried out to understand the basic principles of the topic based on various sources.

2. Data Collection and Analysis

   This step is carried out to collect and to process the raw data such as topographical data, hydrograph data, etc., as input for the preparation of the computer modelling process.

3. Computer Modelling

   This step is carried out to determine the accuracy level and the computational cost of all hydraulic simulations performed using HEC-RAS 5.0.7

4. Result Analysis

   This step is carried out to analyse the data obtained from the previous steps.

The flow chart of the research methodology is presented in Figure 1.1

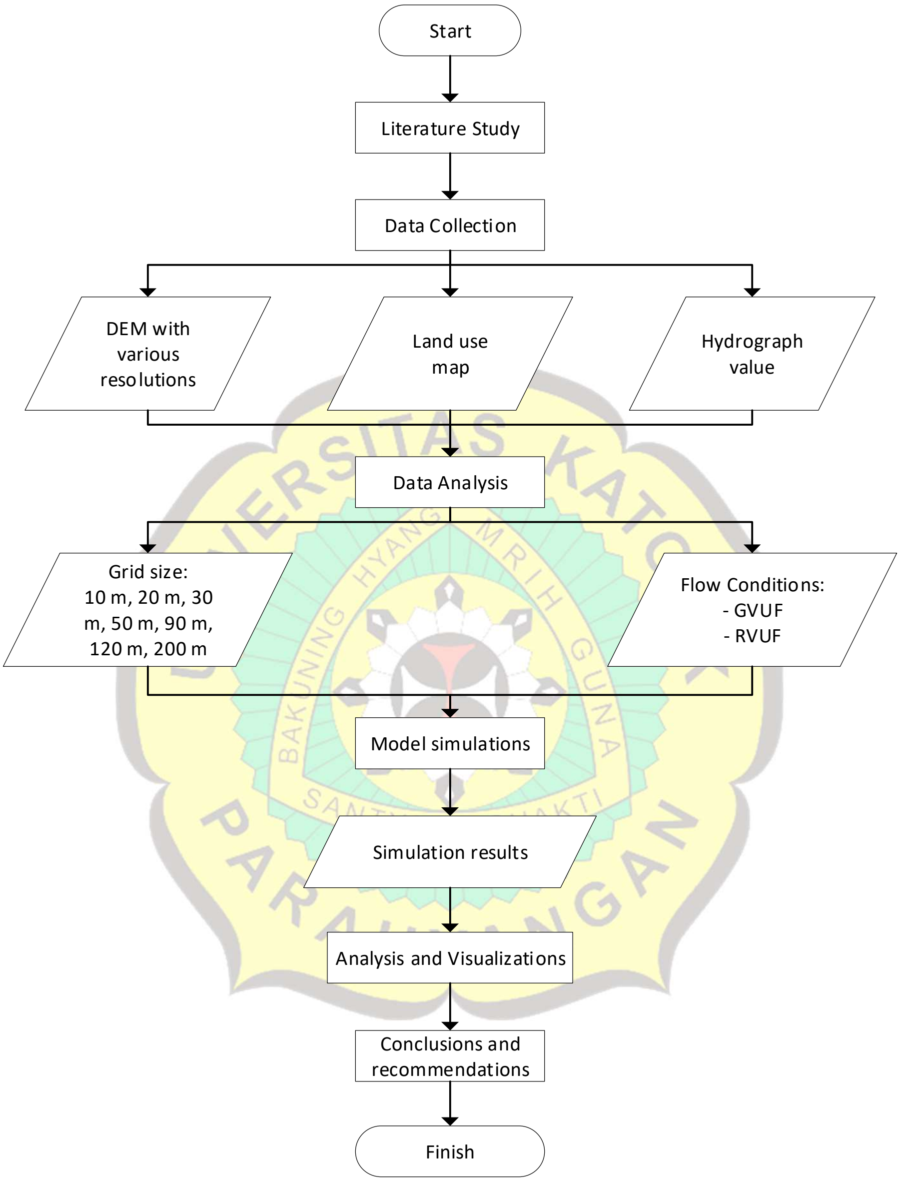

Figure 1.1 Flow Chart