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# Watershed Delineation and Cross-section Extraction from DEM for Flood Modelling

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## Abstract

Hydrological and hydrodynamic models are the practical tool for flood modelling. Watershed delineation is a prime step for hydrological model development. Two types of delineation techniques; manual and automatic are available. Manual watershed delineation is far more difficult and time consuming than automatic delineation. On the other hand, river cross-sections are the most important input to any river hydrodynamic model. Measured cross-sections are scarce in most of the large river basin or catchment. Field survey is very expensive and labour intensive to get the measured cross-section. Therefore, automatic cross-section extraction from Digital Elevation Model (DEM) is the easiest and cheapest option. Nowadays due to availability of DEM worldwide and several software packages, automatic delineation of catchment and automatic extraction of cross-section have become very popular. In this paper, watershed delineation and cross-section extraction from DEM for lower Fitzroy river basin are presented. Besides, the usefulness of using the watershed delineation and cross-section extraction from DEM under the scarcity of watershed information and measured cross-section data are demonastrated and discussed.

## Introduction

Flood risk is increasing in many urban regions due to growing population and economic activities near the rivers [1-4]. Considering severe impact of flood on lives and infrastructure and upcoming impact of climate change on flood, scientists are giving effort to develop techniques for more accurate and cost-efficient flood modelling approaches [3]. Slope–area method was used earlier for discharge estimation. Hydrological and hydrodynamic models have been developed and tested for flood modelling purpose after the evolution of fast computers [5-6]. So, flood model comprises a hydrological model and a hydrodynamic model. The hydrological model calculates the runoff generated from rainfall occurred in the area along with other parameters using historical climate and hydrologic time series data [7]. The output of hydrological model is used as input of hydrodynamic model. The hydrodynamic flood model identifies peak flood level, duration of inundation, peak flow rate and velocities across the inundated area [8].

Hydrological model estimates lateral inflows to a river or river system from rainfall occurred in the area [9-10]. It is important for the hydrological model to delineate a watershed into smaller-sized model areas or catchments where variables can be considered homogeneous. So, watershed delineation is a prime role of hydrological model that represents the model boundary [11]. A catchment is the smallest spatial unit of the delineated area in a watershed where integrated water management can be accomplished [11]. Watershed delineation can be done manually or automatically. But manual watershed delineation technique for large basin is very time consuming and required good quality topographic maps. After the development of reliable DEM, automatic watershed delineation has become very popular and has proved advantageous over manual method when study area are large and numerous.

Hydrodynamic river flow modelling became easier due to well developed 1D hydrodynamic modelling system like MIKE 11, HEC-RAS. These models use the Saint Venant equations, based on conservation of mass and momentum equations, to calculate the time-space variation of river water level, discharge and flow velocity at the un-gauged locations of the river [12-13]. These equations are capable of simulating the unsteady flow of channel with considerable accuracy. Accurate description of model parameters is important for accurate representation of the river channel, creeks and floodplain geometries. Accurate model parameters are also required for a successful flood model which can predict the water level and flow magnitude accurately along the river reach [6]. In One-dimensional hydrodynamic model river channel and floodplain is represented by river cross-sections. Therefore, river cross-section is the prime input of hydrodynamic model. Detailed field measurement survey is the traditional approach for getting the river cross-sections. However, detailed topographic survey is expensive and involves laborious work of post processing of survey data [12]. Hence, measured cross-sections are scanty in most of the large river. In these cases, the most suitable alternative approach would be the extraction of cross-sections from the DEM data. The Geographic Information System (GIS) based cross-section extraction approach has been used recently in some river systems and proved suitable for large scale application [14-15].

This study presents watershed delineation and cross-sections extraction for the lower Fitzroy River, Queensland, Australia. The methodology proposed here can be used for any other catchment.

## Data

The 3sec (90m x 90m) DEM data of HydroSHEDS were collected and used for the derivation of catchment and drainage flow direction. The high resolution elevation data of HydroSHEDS were collected during Shuttle Radar Topography Mission (SRTM) of NASA. This data is freely available electronically from the EROS (Earth Resources Observation and Science) data centre at http://hydrosheds.cr.usgs.gov. The downloaded grid data files were merged together (mosaic) for the lower Fitzroy sub-catchments and process using ArcGIS software to convert those into Raster formats.

For better understanding of the study, 25m x 25m resolution data were collected from the Queensland Government Information Service (QGIS). ArcGIS 10.1 software was used for DEM data processing and catchment delineation. MIKE 11 GIS and ArcGIS 10 softwares were used for the extraction of cross-sections from DEM data.

## Geo-referencing and Projection

Geo-referencing and projection is the first step of data processing. Geo-referencing is required to place the images on the exact location on earth for mapping and modelling purpose. Location is represented by longitude (X) and latitude (Y) based on a sphere (or spheroid) in Geographic coordinate systems (GCS), while projected coordinate systems use easting (X) and northing (Y) based on a plane. When a spherical earth is represented as a flat map, then distortion is usual. The distortion of map is managed by projections. Different GCS such as Australian Geodetic Datum 1984 (AGD84), GDA94 and WGS84 have been used in the collected vector and raster topographic data. The GCS, GDA94, has been used in the collected rainfall, evaporation, cross-section, water level and discharge data. The GCS is required to transfer into projected coordinate systems. The study area is situated in the Universal Transverse Mercator (UTM) zone 56. Therefore GCS data have been transferred to projected coordinate system for the hydrological and hydrodynamic modelling. In addition, satellite images were geo-referenced using the software package ArcGIS 10 to acquire bank lines (left bank and right bank) of the Fitzroy river where the projected coordinate system of the output data was GDA94 for UTM zone 56.

## DEM Data Processing

DEM data was used in this study for watershed delineation and cross-sections extraction. Therefore quality of DEM data is very vital. Before extracting data from DEM, it needs to be analysis to know the quality. For this study DEM data were collected from two sources: QGIS (25m x 25m) and HydroSHEDS (90m x 90m). The quality of DEM data was assessed from the computed Root Mean Square Error (RMSE) values for different elevation ranges. The RMSE of DEM data was determined using equation 1.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(E_{Si} - E_{DEMi})^2}{N}} \quad (1)$$

Where, $E_{Si}$, $E_{DEMi}$ and N represent the spot height elevation data, DEM elevation data and total number of reference data points used for this error analysis respectively.

Eight groups were made among the elevation ranges from 0m to 750m to calculate the RMSE values of DEM data collected from two sources. The RMSE values are presented in table 1. It is observed from this table that RMSE value is lower in the QGIS DEM data which indicates that the quality of QGIS DEM data is better than the SRTM DEM data. Therefore QGIS DEM has been used for all the analysis and data extraction.

There are 84 spot height points around the study area which were collected from the Geoscience Australia as a point shape file. The elevation values of the DEM and their respective spot heights are plotted around the 1:1 line and shown in figure 1. It is observed that the values are scattered closely around the 1:1 line which indicates the quality of DEM data.

Table 1: RMSE values at different elevation ranges.

| Elevation (m) | RMSE of QGIS DEM (m) | RMSE of HydroSHEDS DEM (m) |
|---|---|---|
| 0-10 | 0.98 | 1.53 |
| 11-20 | 1.12 | 1.68 |
| 21-30 | 1.43 | 1.93 |
| 31-40 | 1.61 | 2.09 |
| 41-50 | 2.94 | 3.60 |
| 51-100 | 4.23 | 5.52 |
| 101-200 | 9.11 | 14.33 |
| 201-750 | 12.39 | 16.92 |

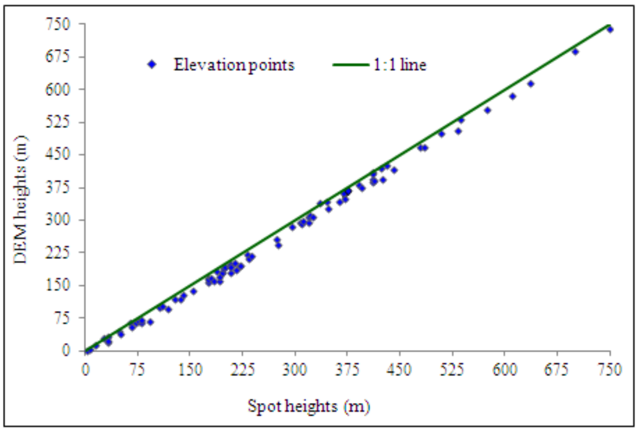


Figure 1: Spot height and corresponding DEM (QGIS) grids elevation comparison.

Besides, an error analysis of DEM data was performed by comparing the elevation of spot heights with corresponding DEM data points. The DEM data error was calculated by subtracting the DEM values from the spot heights. The propagation of the magnitudes of the errors with the increase in the elevations is presented in figure 2. The deviation between DEM and spot heights is found to be higher in case of higher elevation values. It is further observed that a majority of the 84 error values are negative, which indicates that the elevations of HydroSHEDS DEM points are higher than that of the spot heights. Pramanik et al. [5] got similar result in their study.

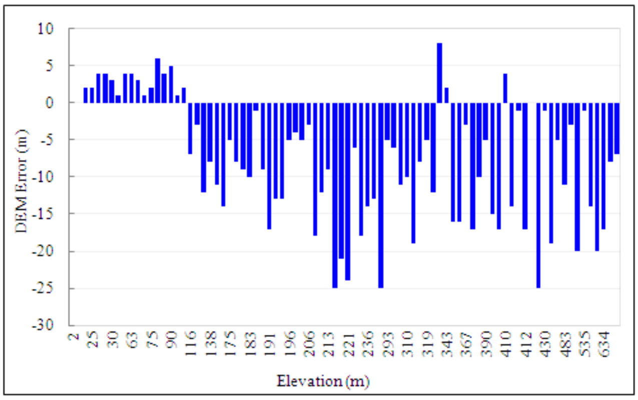


Figure 2: Propagation of error with respect to elevation

There were few voids in the DEM data and the voids were filled out using the ArcGIS software to extract better data from DEM. In this study the DEM data was processed to make a depression less elevation model. Here sinks in the original DEM were identified using the Sink tool of ArcGIS software. A sink is usually an incorrect value lower than the values of its surroundings. These depressions points create problem as any water that flows into them cannot flow out. To ensure proper drainage mapping, these depressions were filled up using the 'Fill' tool. Sinks are removed from DEMs using the standard flooding approach. Depressions are filled by increasing elevations of depression points to their lowest outflow point.

### Methodology

## Watershed Delineation

In this study, watershed was delineated using DEM data. The flowchart of watershed delineation following some sequential steps of GIS techniques is presented in figure 3. Firstly, the direction of flow was calculated using the 'Flow Direction' tool of ArcGIS using the depression less DEM data. Flow directions were calculated using the eight-direction (D8) flow model which assigns flow from each grid cell to one of its eight adjacent cells, in the direction with a steepest downward slope. O'Callaghan and Mark introduced the D8 method which is widely used nowadays [16]. Then using the Flow Accumulation tool, the number of upslope cells flowing to a location was calculated. The next step is to define stream network. The most common method of extracting channel networks from DEM is to specify a critical support area that defines the minimum drainage area required to initiate a channel using a threshold value [11]. In practice this threshold value is often selected on the basis of visual similarity between the extracted network and the lines depicted on topographic maps. The threshold value has been specified on the raster of flow accumulation that derived from the previous step. This task has been accomplished with the Con tool of spatial analyst tools. As a result, all cells with more than 'threshold value' cell flowing into them have been part of the stream network. An analytical method for determining an appropriate threshold value for stream network delineation can be found in Tarboton and Daniel [17]. After derivation of stream network, a unique value was assigned for each section of the stream raster line, associated with a flow direction using the stream Link tool. Then using the Watershed tool, the watersheds have been delineated for the lower Fitzroy river.

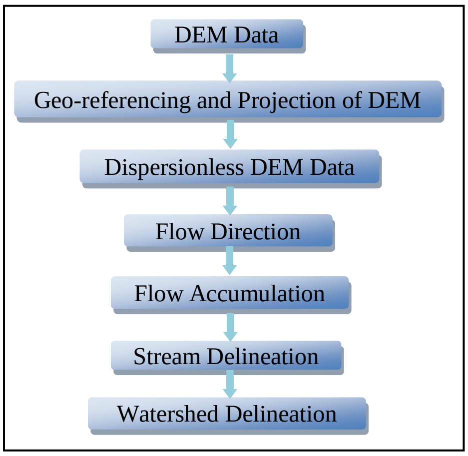


Figure 3: Flowchart of watershed delineation process.

## Cross-section Extraction and Modification

This section describes the generation of cross-sections and extraction of these cross-section data from the DEM. The flowchart of cross-section extraction process is presented in figure 4. First of all the geographic coordinate system of the DEM was converted to a projected coordinate system using the software package ArcGIS 10. River banks of the study area were extracted from Google$^{TM}$ Earth and the extracted points were converted to shape file using the software DNRGarmin 5.4.1. The river branch was digitised along the centre of the left and right bank. The cross-sections were automatically extracted along the river branch from the DEM data using the software package MIKE GIS. The interval between two consecutive cross-sections was 1 km. The cross-section digitization point spacing along the length was 25 m as resolution of the DEM data was 25 m.

## Results and Discussion

The watershed delineation and cross-section extraction was carried out using DEM data which was used to develop an integrated hydrologic and hydrodynamic model development. Threshold value selection was viewed important for watershed delineation. For this study, many trials were run with different threshold value and tried to match the DEM extracted channel with a reference channel of Geoscience Australia. A total of 21 watersheds were delineated by automatic process from the DEM data and presented in figure 5. The area of the delineated watersheds is shown in table 2. These delineated watershed areas can be used as input parameters of hydrological model.

Similarly, 81 cross-sections were extracted for hydrodynamic modelling purposes at 1km interval. The extracted cross-sections were verified with the measured one before use these in the HD modelling purpose for the accuracy of the model results. There were three available measured cross-sections in the lower Fitzroy River area which were compared with the extracted cross-sections. It was found that the bed level of the extracted cross-sections was higher than the measured cross-sections. Therefore, the bed level of the extracted cross-sections was modified from the measured longitudinal river profile. Besides hydraulic parameter, conveyance was used to modify the extracted cross-section for the true representation of the river using the cross-sections module of MIKE 11. A comparison plot of measured and modified cross-section at Gap station is presented in figure 6. These extracted cross-sections are the vital input parameter of hydrodynamic modelling and represents the river channel and floodplain of the study area.

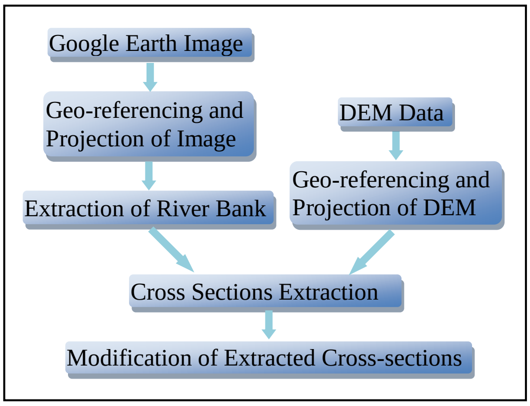


Figure 4: Flowchart of cross-section extraction process.

## Conclusion

It is very difficult to develop hydrological and hydrodynamic model especially for flood studies due to lack of sufficient catchment's information and measured cross-sections data. A GIS based automatic watershed delineation and cross-section extraction approach is presented in this study. However, it is viewed important to check the accuracy of DEM and automatic approaches before used those in the hydrological and hydrodynamic models. The adopted methodology can be used for the other catchments which have limited data for flood modelling.

## Acknowledgments

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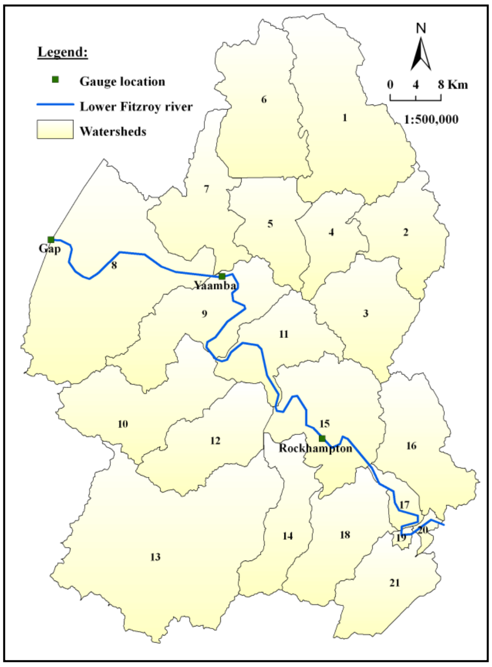


Figure 5: Watershed delineation for lower Fitzroy river.

| Watershed ID | Area (km²) | Watershed ID | Area (km²) |
|---|---|---|---|
| 1 | 370.09 | 12 | 201.49 |
| 2 | 170.41 | 13 | 667.94 |
| 3 | 201.88 | 14 | 164.37 |
| 4 | 117.29 | 15 | 271.49 |
| 5 | 154.90 | 16 | 211.02 |
| 6 | 276.01 | 17 | 41.58 |
| 7 | 194.19 | 18 | 200.81 |
| 8 | 553.00 | 19 | 8.35 |
| 9 | 250.22 | 20 | 14.25 |
| 10 | 261.10 | 21 | 165.91 |
| 11 | 170.59 | | |

Table 2: Area of delineated watershed.

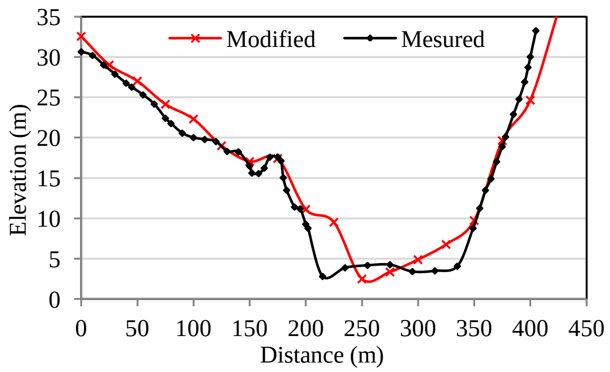


Figure 6: Comparison between measured and modified cross-section at Gap station.

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