Finding Areas at Risk from Floods in a Downpour Using the Lidar-Based Elevation Model

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Abstract: Climate change can impact coastal areas in different ways, including flooding, storm surges, and beach erosion. Of these, flooding has a major impact on the operation of coastal drainage systems. This paper develops a new flood screening model using a LiDAR based digital elevation model (DEM) to improve the implementation of Victorian’s coastal flooding risk assessment and management. Hydrological elevation models are directed towards protection from cloudbursts and applied to rising sea level. The aim is to simulate water flow on the ground and in streams, and the resulting accumulation of water in depressions of the blue spot using DEM. Due to the presence of pipes, watercourses, bridges and channels it was required that the DEM data to be lowered. The reservoirs of rain will prevent seawater from flowing across the stream channel into land. The rain drain will be open during normal sea levels to allow rain water in the river to move and flow in to the sea. Traditionally, geographic information system (GIS) assists with spatial data management, but lacks modelling capability for complex hydrology problems and cannot be relied upon by decision-makers in this sector. Functionality improvements are therefore required to improve the processing or analytical capabilities of GIS in hydrology. This research shows how the spatial data can be primarily processed by GIS adopting the spatial analysis routines associated with hydrology. The objective of this paper is to outline the importance of GIS technology for coastal flood management. Following a definition of the coastal flood, and, short description of its peculiarities and the urgency of its management, this paper describes the use of GIS technology in coastal flood management, its advantages and the consideration for accuracy. This is followed by the information and LiDAR data required for coastal flood management and the application area in coastal flood management. This paper method is presented to conduct a first high-resolution DEM screening to detect the degree and capacities of the sinks in the coastal landscape. When their capacities are established, the rain volumes received during a rainstorm from their coastal catchments are saved as attributes to the pour points. The conclusion emphases the importance of a geographical information system in coastal flood management for efficient data handling and analysis of geographically related data. Local governments at risk of coastal flooding that use the flood screening model can use to determine appropriate land use controls to manage long-term flood risk to human settlements.

Key words: LiDAR, flood-risk, model builder, blue spot model, ESRI, DEM.

1. Introduction

In this research, the procedure for conducting a pilot study for flood-risk awareness or focused coastal land use planning is described. To support new land development decision-making spatial models to estimate the flood risk for existing infrastructure in Bass Coast Shire Council (BCSC) were developed. Previous studies focused on different goals in the same study area. Previous research developed methods based on geographic information system (GIS)-embedded hydrological models to generate missing council GIS datasets.

The main aim of this research is to show where sinks are located, connected to the storm water system, and may cause infrastructure near the coast to be flooded.

Flood-risk awareness or focused planning policy to be put into practice requires a business workflow,
specific information products, and a spatial database. Moreover, to develop a comprehensive flood-risk digital elevation model (DEM), a dataset with an appropriate scale, with enough spatial detail and appropriate attribute information is required. GIS-embedded hydrological models should also be linked to the database. These matters are discussed to provide a framework for answering the research questions listed below:

- How can the current process for drainage analysis be improved?
- How does a spatial decision support system help to identify infrastructure at risk from sea level rise (SLR) induced flooding?

1.1 Background and Purpose

In this research the duty of local governments for floodplain management and especially for flood risk reduction in Victoria is outlined. Also, the reliance of the local governments on the flood mapping information created by CMAs, and on Melbourne water flood data is discussed [1]. The BCSC area faced heavy precipitation in May 2012 and higher than expected precipitation in August 2012. Phillip Island received over 90 mm of rain, including 55 mm in one day, nearly achieving the normal September precipitation in less than 24 hours [1]. This heavy downpour caused flooding over the district, including areas that are usually not prone to flood.

Precipitation is the main source of major floods in Australia [2, 3]. Floods caused by rainfall are either river floods or underground floods. Although flood behaviour varies with the topography, the approximate geographical extent and time of flooding can be predicted by utilizing precipitation-runoff models. Stormwater flash flooding happens during storms and causes an overflow as it surpasses the limit of the subsurface stormwater infrastructure [4]. Overland flash flooding also happens when runoff moves over the ground towards the closest topographic discouragement territory, ordinarily in developed or rural areas secured by impervious surfaces whose volume can be increased but not quickened. Although flash flooding occurs over small areas, its damage is frequently more severe than a riverine flood because of very little warning time [5]. For instance, in 2005 riverine floods compromised around 20,000 properties in Melbourne, while stormwater flooding in a similar area threatened 82,000 properties [5].

In recent years, Melbourne has experienced several sudden, extreme rainfall events. On 30th Dec. 2016, the State Emergency Service (Assessment) received more than 2,500 calls for assistance since the heavy rain hit. Melbourne’s north, north-east and south-east suffered the most flood damage [6]. At the height (peak) of the storm, about one millimeter of rain fell every minute, causing rivers to burst their banks. Claire Yeo from the Bureau of Meteorology Severe Weather Meteorologist reported that rain fell in a short time, with up to 70 millimetres recorded in the Dandenong Ranges in half an hour [7].

2. Theory and Analysis Methodology

This research project was designed to develop a screening method for buildings and roads in flood prone areas.

This method was selected to assess where infrastructure with a chance of getting flooded is located within a pour point area. This is an unfair categorization of infrastructure’s flood risk based on its terrain level within the sinks. Sheets of water flow downhill after heavy rain always finding a stream to flow into, and continue to engage in the natural water cycle. Water flows according to the steepest gradient and may get trapped in a sink. Every sink has a contributing catchment. As more water flows the lower sinks fill. Based on 1 m the hydrologically corrected digital elevation model (DEM), near the coast, features the class of road and buildings and easily identifies the sinks and their maximum water depth when filled to their pour point in heavy rainfall.

To do this using Blue Spot Model (BSM) a map of
Inverloch was developed which identifies low-lying areas that have no natural drainage. A blue spot is an area where there is a relatively high likelihood of flooding and the consequences are significant. In a cloudburst (extreme rainfall event), blue spots may fill and overflow, damaging buildings and roads that lie within and adjacent to them. BSM tools will support flood-risk sensitive land use planning at the local level and allow the usage of new forms of information to assist in the decision process.

The key aim of the BSM tool is to support local government in preparing for future cloudbursts. The following sections present a method for creating a BSM, the development of a screening method to assess buildings and roads in high flood risk areas, and a geoprocessing model. The geoprocessing model involves analysis, data management, editing, and other operations that use elevation data to find the locations of blue spots using a BSM. The study area is in Inverloch, but the models have international applicability because the criteria consist of the land surface, buildings and streets. An underlying hypothesis is that the DEM produces a very accurate flow direction surface; this hypothesis has been improved for DEMs with higher resolution [8].

Drainage flow models will not work in spots where the water will not flow. Flooding problems in low-lying regions such as sinks, depressions, or hollows are very common and come in all sizes and shapes. Landscapes appearing flat may contain low depressions that trap rainwater (Fig. 1).

Some residential areas are developed in low-lying areas where depressions are not noticed under dry conditions. Stormwater in coastal urban areas collects from roofs, sidewalks, driveways, footpaths and other impermeable or hard surfaces by rain runoff. The soil, organic matter, garbage, garden fertilizers and driveway oil residues that it carries can contaminate downstream waterways. The stormwater system in Victoria is different from the sewage network. It becomes evident during a downpour that the soil surface cannot naturally drain, and the stormwater system does not function effectively. Coastal buildings, streets, infrastructure, tram or railway tracks are also vulnerable [9].

Cultivated soil presents some risks in low lying areas. On agricultural land, there can be a threat to yields and equipment. Construction in built-up areas causes house flooding unless buildings are built on high ground. Even infrastructure not in depressions may still be at risk as, during heavy rain water flows towards the discharge points, and adjacent areas may be flooded.

Morris et al. [10] developed a DEM to provide overland flow paths and catchment boundaries. GIS and hydrological modelling can help assess the local nature of flood risk and identify areas where new residential housing may be at risk of flooding. Before

Fig. 1 (a) An orthophoto Inverloch map from 2010 which shows low-lying grasslands and a creek; (b) the same area in 2018 is now a residential development.
Source: Google Earth.
the residential development, the drainage was efficient as some water was able to drain through pastures into the underground water basins. However, in the BCSC region, several developments were located on land that was once swamps or ponds and was typically farmland. Today, some houses exist in low-lying areas where water accumulates during an event of extreme rain. Homeowners living in these low-lying areas that have been converted from agriculture to residential housing face the challenge of regular flooding.

Spatial data are fundamental to hydrological modelling of real-world hydrological forms [11]. Despite the complexity of stormwater management in urban catchments [12], as discussed site-specific and catchment-scale runoffs are assessed using the BCSC existing overland flow path model and catchment boundaries. Thus, existing catchment boundary and overland flow path datasets provide the basic information for implementing flood-risk informed land use planning. It does this through a GIS-embedded hydrological model, for which each land unit has its hydrological situation [13]. In the remainder of this article, the methods for developing the BSM-based map using the GIS-embedded hydrological model are also described. In describing the overland flow path model, rainfall information is used at a sample site as a pilot study. The following section concludes with the investigation results.

The BSM Fill Up Values are underpinned by a function for classifying basins and make a numerical calculation of flood risks to buildings in case of heavy rainfall. For example, two Danish companies, NIRAS (an international consulting group in Europe) and COWI (an international consulting group, specialising in engineering, environmental science and economics, based in Lyngby, Denmark) have developed BSM based maps for Denmark [14].

This research presents a comprehensive GIS-based decision support tool that integrates with BSM for effective management of coastal flooding. The BSM is customized and used in the pilot study area. This model is updated based on the current overland flow, the catchment and highlights blue spot areas—low lying areas and sinks where flooding risks are higher (see Fig. 2).

Fig. 2 shows the results of the assessment of overland flow in a heavy rainfall event. The houses shown as blue are the blue spot buildings which will be flooded first. The model uses ArcGIS geoprocessing to determine the flooded areas and their

Fig. 2  The BSM based map of the lowland area identified with the Future Coast LiDAR data 2009.
neighbouring watersheds. The DEM fill identifies the amount of rain that would be needed to fill the depressions, by partitioning the BSM based sink-filling volume according to the watershed. The impact of the drainage network on flooding can also be predicted.

It is worth considering here that the model results are enough to identify critical flood-risk thresholds for single buildings. In the absence of building attributes, the best way to do this is to create a worst-case scenario by calculating the critical level of flooding for a building based on ground floor level. In fact, this is true of many houses, storerooms, shops, and workplace facilities. Though, for all buildings, it is not true. The actual flood level can be higher than estimates for building raised on the above ground level. Equally, the standard for houses with basements can be lower than expected. The BCSC housing record includes information of the building but does not include that information in the housing feature table. It normally provides no evidence for the building’s base heights. The integration of building features into the model will be to improve results.

An additional component of vulnerability is that the water level for a building depends on the exact vertical location of the building within the blue spot area [9]. The other factors are equivalent, a building at or near the bottom of a blue spot will be flooded quicker than a higher house on its hillside.

Introducing this work, as discussed, in real life ideal runoff conditions are rare, but in an extreme rainfall event, the basic concept of hydrological behaviour could be relaxed. Ordinary flow levels that can be accommodated by the drainage networks may not have the required capacity during peak storms. At the point when this occurs, precipitation will create streams that, in part or totally, fill the blue spot. Notice that the models described here do not reflect the change of surface runoff by a storm drain and other infrastructure.

The risk assessment for individual buildings could be improved if an examination of the permeability of the surface, whether significant sections of the local river basins are paved or not, should be made. A bigger paved surface means a faster outflow. A raster data set indicating the percentage of the solid impervious surface for the Inverloch area should be added to the resource geodata. Measurements of slope and length of flows within river basins would also be relevant to determine which buildings would be hit first in a downpour.

2.1 Methodology for Blue Spot Modelling

This blue spot model (BSM) is implemented with ArcMap and the ArcGIS Spatial Analyst extension, four geodatabases including Inputs.gdb, outputs_bluestop.gdb, outputs_bluestopFillUP.gdb and resource.gdb and four toolboxes using model builders (Fig. 3). Conceptually, the BSM has three main purposes:

1. It determines blue spots on the Digital Elevation Model (DEM).
2. It manages this result and outlines the footprint of the building so that the data are in the appropriate format to make a spatial selection.
3. This selects the buildings situated within or adjacent to the blue spots on the map.

The main processes in the model builder are as follows:

- Blue spots are recognized by running the Fill geoprocessing tool on the DEM.
- The minus tool subtracts values in the true DEM (Small Sinks Filled) from values in the filled DEM (All Sinks Filled) on a cell-by-cell basis.
- Con (restrictive assessment) tool evaluates an expression as true or false for each cell.
- The expression “value > 0” is evaluated by the cell raster for a Bluespot depth cell, which is true for any cell in a blue spot. These cells are given an arbitrary value of 1.
- Group blue spot cells individually into numbered regions based on fluency. An alternative is set to define diagonally connected cells as coordinates.
The output raster dataset is Bluespot with IDs.

Dissolving the polygons on their grid code attribute merges the diagonally connected polygons with the bluespots they belong to. The final goal of this model is to find and select buildings within or adjacent to bluespots. The buildings are spatially compared to the bluespots using a specified relationship. In this case, the relationship is an intersection. Two features intersect if they touch, or partially overlap, or if one contains the other. Therefore, buildings will be selected if they are adjacent to bluespots, or if they are partly or completely within bluespots.

2.2 Models of Data Preparation

The toolbox contains the following two-geoprocessing models. The geodatabases and toolbox contents are listed in Table 1.

- The BSM identifies structures inside or adjoining the blue spots. The outcomes appear, with very coarse dimensions and illustrate which structures are at risk of a flood hazard in a storm. The model does not attempt to measure this hazard.

- The Bluespot Fill Up Values model investigates and determines the BSM volume of each BSM and its surrounding watershed area (the basin that channels water to the river). From these results, the model calculates how much rain it will take to fill the blue spot entirely. This model takes into consideration some positioning of flood hazard. The blue spot that requires less rainfall to overflow represents a higher risk flood hazard to buildings and infrastructure.

2.2.1 DEM-Based Characterisation of BSM

ArcGIS hydrology tools, the DEM can be analysed to determine the blue spot regions, calculate their volume, size and identify areas that contribute to the flow of water in a cloudburst.

In the pilot study area, it is important to analyse the DEM beyond the BCSC boundaries and include the nearby watersheds. To guarantee that all blue spot regions and watersheds are recognized accurately, the DEM for Inverloch was extended to include a 0.5 kilometre buffer. The Vicmap Elevation, Future coastal 1 m DEM & 0.5 m contours was derived from airborne LiDAR. Native Format: DEM-XYZ ASCII
Table 1  The contents of the blue spot model geodatabases.

| Name                        | Contents                                                                 |
|-----------------------------|---------------------------------------------------------------------------|
| Layers                      | Visualizing input spatial data.                                           |
| Inputs.gdb                  | Starting data for models (Inverloch_LiDAR_point, DEM, building, road).    |
| Outputs_the BSM.gdb         | Empty. Hold outputs to classify the BSM (Blue spots, Buildings Touch BSM, Road Touch BSM). |
| Outputs_BSM FillUp.gdb      | Outputs data to classify the BSM fill upvalues.                           |
| Resource Data. gdb          | Extra raster and feature data to explore and analyse.                    |
| BSM_Metric.tbx              | Geoprocessing tools in the Model Builder environment (see Fig. 3).       |
| BSM_Metric_NoBuildings      | Model versions for input datasets where no footprints are available to create. |

ESRI Grid ASCII Contours—ESRI Shapefiles, MapInfo TAB. The created DEM was inspected to identify the sinks and low-lying areas utilizing the cutting tool in the SAGA-GIS and assessing the impact of pit expulsion calculations on surface overflow reproduction. A DTM (Digital Topographic Model) with pits removed is a precondition for hydrologic analysis. Two pit removal methods, the carving method and the filling method, are investigated in this study for three different geomorphometric areas. The input data are photogrammetrically measured DEM with a resolution of $5 \times 5$ meters. Šamanović et al. [15] argued that choosing the correct calculation is critical, and suggested using a DEM without pits, including the minimum geomorphometric changes. The vertical precision of the DEM is critical for GIS-based hydrological modelling. The methods used in this research enables local organizations to evaluate the quality of the GIS databases, and use the GIS based hydrological models to improve flood risk management [13].

2.2.2 Blue Spot Model (BSM) and Affected Buildings

The limit of the examination region was constrained to areas covered by the LiDAR dataset. The DEM for the examination region was created based on the LiDAR data utilizing Inverse Distance Weighted (IDW) interpolation in the ArcGIS Geostatistical Analyst extension. In IDW only known $z$ values and distance weights are used to determine the unknown areas. IDW has the advantage that it is easy to define and therefore easy to understand the results.

These models examine the DEM using hydrological tools to discover the BSM. At that point, the location of the blue spot region is identified in relation to existing structures and highlights the structures that are inside or nearby the blue spot region. These structures are at greater risk of being flooded. The geoprocessing model includes input data, workflow tools and runs as a single operation. The model process involves an input dataset associated to a tool (yellow color) connected to an output dataset (blue color) (see Fig. 3). Components input and output variables because their properties can be accessed and thus their path names can be changed. Conceptually, the model functions include the following three main steps, which are then explained in the following section:

- Identify the BSM Fill Up Values from the DEM.
- Using the layer of buildings so that the information is in the best possible structure for a spatial decision.
- Spatial determination buildings layer on the guide that exists in or is contiguous to the BSM (i.e. identifying the blue spots).

2.2.3 Identify the Blue Spot Regions on the Digital Elevation Model

This stage of the process involves identifying the blue spot regions on a predetermined DEM. Once this is done it is possible to spatially identify the structures that are inside or adjoining the BSM. These structures are at risk of flooding in a storm.

The blue spot regions are distinguished by running the Blue Spot Model Fill Up Values geoprocessing process twice on the DEM. The process is run once to
fill sinks under 0.05 meters down, which are thought to be potential mistakes in the DEM. The output is the best DEM we can create. Next, the process is run a second time to fill all sinks to their pour levels. The output, a filled DEM without any sinks by any means, is vital for the following tasks.

The minus operation subtracts values for the genuine DEM (little sinks filled) from qualities in the filled DEM (all sinks filled) on a cell-by-cell basis. The outcome is a raster dataset (the BSM is identified cell by cell) demonstrating the areas and profundities of the substantial sink, or the BSM.

With raster image analysis there are two types of cells (BSM cells and non-BSM cells) derived using the Con (restrictive assessment) tool. This tool assesses whether this condition is evident or false for every cell and allots a value to the cell accordingly. When this “Value > 0” for the raster BSM cell heights, it is a Blue Spot and it is assigned a value of 1. Cells that have a “Value < 0” are not Blue Spot. The raster yield informational is collected using a cell by cell process.

The BSM cells have been identified, but they have not been grouped in an intuitively meaningful way. It is normal to think about a contiguous set of blue spot cells encompassed by non-blue spot cells as a blue spot region. A first raster pixel value is allocated in this cell by cell process, followed by determining the blue spot value for every cell to create blue spot and non-blue spot zones. Accordingly, the next stage is to group the blue spot cells into areas with the same number dependent on continuity. A choice is made whether to characterize cells diagonally associated corner to corner as adjacent.

The blue spot regions, which can be thought of as raster objects, are converted to a polygon feature class (the blue spot Polygons). The final output of the model includes data, which can be displayed and analysed with other feature classes (Fig. 4).

2.2.4 Using the ArcGIS Dissolve Tool

In the raster-to-polygon conversion that produces the blue spot polygons dataset, raster cells that are diagonally associated with the BSM, which ought to have a place with BSM, are made as isolated highlights. Dissolving the polygons based on their cell value consolidates the diagonally connected polygons with the blue spot region they are connected to.

3. Results of Blue Spot Modelling

The four important datasets are Buildings TouchBS (buildings touching blue spot) and Roads TouchRS (Roads Touching blue spot). Figs. 5 and 6 show the
Fig. 5  The BSM output for the Inverloch area.

Fig. 6  Building within the BSM in the Inverloch area—yellow denotes buildings, the blue spot areas are shown in dark blue, and the light blue are buildings that interest with the modelled blue spot areas.
location of the blue spot regions in the Inverloch area and affected buildings. In Fig. 6 some vertical stripes are evident in the results from the BSM, which highlight potential errors in the DEM. The following section assesses these potential errors to see Fig. 7.

As illustrated in Fig. 6, over 467 buildings lie within or adjacent to the blue spot regions. From the attributes in the buildings layer, Inverloch has approximately 6,165 buildings. This means that approximately 7.9% of buildings in a cloudburst have some degree of flood risk. The analysis was done again based on the DEM correction model vertical stripes in the results. After cleaning up the LiDAR data, different results were obtained. The updated results show that 345 buildings (14.4%) lie within or adjacent to the updated blue spot regions and will experience flood risk in a downpour.

As illustrated in Fig. 7, over 212 roads lie within or adjacent to the blue spot regions. From the attributes in the roads layer, there are about 1,034 roads in Inverloch. This means that approximately 20.5% of the roads have flood risk in a rainstorm. Analysis has been repeated based on the correction DEM model vertical stripes in the results. After cleaning up the LiDAR data, different results were obtained. The updated results show that 149 roads (14.4%) lie within or adjacent to the updated blue spot regions and will experience flood risk in a downpour.

3.1 Vertical Accuracy Validation Tools for LiDAR Data

LiDAR ground points were validated at various levels of the minimum distance around each survey permanent marks [16]. The methodology adopted in this study prevents the gridding effect in the final evaluation.

To understand the degree to which gridding would impact the vertical accuracy, a direct regular IDW
interpolation procedure and geo measurement IDW were utilized. The impact of the geo measurement IDW and basic IDW in inferred DEMs exactness were investigated. Moreover, the autocorrelation between LiDAR ground points and GCPs has been evaluated utilizing an Average Nearest Neighbour (ANN) investigation proposed strategies for this study, successive least separation. The contrast between the LiDAR measured height and the rise as dictated by the Permanent Marks (PMs) in the evaluated separation was around 0.5 m at a 95% certainty level.

The difference between the LiDAR height and the value in the PMs was around 0.5 m at a 95% confidence level. Therefore, the LiDAR ground point dataset can be utilized for flood mapping that does not require the vertical accuracy to be greater than 0.5 m. The LiDAR ground point dataset does not contain enough vertical accuracy for drainage calculations, as a vertical precision of 10 cm is required [13]. Fig. 8 shows the results of a process for deleting duplicate points and problematic points, (-999, -0). Clean the raster of these duplicate and error points to have a smooth uncovered earth DEM. After utilizing the IDW interpolation system and erasing blend devices, another BSM was created with the outcomes shown in Fig. 7.

3.2 The Blue Spot Model (BSM) Analysis Results

After data analysis, buildings that are in the BSM attribute table can be examined to determine how many roads and buildings in the Inverloch area risk of a flood. As illustrated in Fig. 6 there are many buildings within the BSM areas spread throughout the Inverloch area. However, floods may affect other infrastructure types, as well as buildings and highways. Using this model, it is possible to add other infrastructure datasets, such as trails, and railways, to determine where they are with the blue spot regions. Identifying the blue spot regions does not assess risk rates for buildings and does not pose the same risk to all blue spot areas. How quick the blue spot regions filling and overflowing in a rainfall depends on its depth, flood hazards and catchment size, or local watershed that contributes to it.

3.3 Assessing Flooding Risk to Buildings and Roads

This section discusses how flood hazard risk to buildings can be assessed, along with how much precipitation is needed to fill each Blue spot region to its pour point. These data will help improve the assessment of flooding risk to structures. This model has been developed for situations in which building footprints may be accessible or not accessible. The model identifies blue spot regions on a DEM and computes how much precipitation is needed to fill up a blue spot region in a downpour. This datum improves the assessment of flood risk for a building situated in a blue spot region. A building in a blue spot region that fills up rapidly has a higher level of flooding risk than a building in blue spot region that fills up gradually [9].

This is based on the hydrological assumption that

Fig. 8  (a) Delete duplicate and problematic points, merge LiDAR and create DEM; (b) the vertical stripes error and (c) the error-free model.
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Each blue spot region in the landscape has a catchment area in which this region contributes only to the flow of that blue spot region. It can be determined how much rainfall is needed to fill the blue spot region by calculating the capacity of the blue spot region and the area of its watershed. “For example, if a blue spot region’s volume is 500 m$^3$ and its watershed is 10,000 m$^2$, the rainfall needed to fill the blue spot region to its pour point is $500 \text{ m}^3/10,000 \text{ m}^2 = 0.05 \text{ m} = 50 \text{ mm}$” [9]. In fact, not all the rainfall that falls in the watershed streams into the blue spot region because ideal run-off situations do not exist. However, the run-off conditions in a storm are near perfect. The water balance condition $P = I + E + Ao + Au + M$ expresses that precipitation ($P$) is equivalent to the interception by vegetation ($I$) plus evapotranspiration ($E$) plus overland ($Ao$) plus surface run-off ($Au$) plus storage in soils ($M$). In this specific situation, a local store implies blue spot region [9].

For this process, the approach used by Balstrøm and Crawford [9] was implemented. In a rainstorm, blockages, dissipation and infiltration of soils were nominated as zero. The extreme capacity of the Victoria drainage system in local locations is around 40 millimeters of downpour per day [3]. Focusing on 1 hour of precipitation and if the day-to-day maximum is 60 minutes, the soil infiltration and sewerage ($Au$) value will be set at 40. Surplus runoff ($Ao$) in the situation will not be a concern until after the BSM fills in. “For the fill-up values, the equation can therefore be streamlined to $P = 40 + M$ or $M = P - 40$ millimeters for every hour” [9]. If 90 millimetres of downpour occurs in 60 minutes, the sewer frame will redirect 40 millimetres, while 50 millimetres will flow into the BSM—filling it up either slightly or entirely. If BSM is filled to the point where it pours, the overflow ($Ao$) will join the downstream drain, dam, waterway or ocean [9].

Although this model makes for an improvement assessment of flooding risk, there are limitations to this approach as overflow downstream of the blue spot region is not considered. Nor is the height of the structures inside the blue spot region. For instance, if a building is situated close to the base of the blue spot region, it could be flooded before the blue spot region fills. Further, underground structures such as basements are not considered [9].

The model identifies the blue spots in the BSM and it computes their volumes and watersheds. These data are useful in calculating the amount of precipitation expected to fill each blue spot region. Many of the workflow model procedures are operations for table

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Fig. 9 Left map assesses flood risk to buildings Inverloch west side and right map assessing flooding risk to buildings in Wreck Creek, Inverloch.
manipulations: including joining fields, adding fields and field values for calculation. The BSM analyses the amount of water that is needed to fill each blue spot, thus making it possible to assign relative degrees of flood risk (see Fig. 9).

The colours in the legend for the fill-up values start at 40 millimetres to represent the drainage network limit. If the fill-up area includes values of 0-20 mm, they will be classified as 40-60 mm when the symbology is associated. Add field to the BSM touching buildings as well and measure their values by [Fill-up] + 40 mm.

BCSC experienced large precipitation in August 2012, following previous storms. Phillip Island experienced over 90 mm rain, including 55 mm in one day, nearly achieving the normal September precipitation in less than 24 hours. It was likely that blue spot regions associated with the top 2-3 risk categories (colored as red, dark orange, orange in Fig. 9) would fill up. This heavy rain did cause flooding across the region.

Some buildings in Fig. 9 that appear susceptible to flooding are not highlighted. While there may be a blue spot region in those areas, they are not highlighted as being at risk as the blue spot region fill up volume is in excess of 140 millimeters rain balanced. It is very unlikely that these blue spot regions would flood. The calculations predict the whole blue spot region would not be filled, yet this is not generally the situation. Some blue spot regions are lasting water bodies, for example, Wreck Creek in Inverloch area.

Further analysis is required to find out how many buildings are within blue spot regions of different risk levels. Assuming perfect run-off conditions within the catchment area and no sewer system to drain the water, the Fill UP value can be estimated by dividing the individual sink volume by its catchment. BSM can be classified in the highest risk category with the BSM

Fig. 10  Roads and buildings touching blue spots in Ayr Creek, Inverloch.
buildings level attribute question “Fill Up ≥ 0 and Fill Up ≤ 20. Spatial building data are selected that intersect within the selected set of the BSM. The watersheds layer can be applied to analyse the relationship between the blue spot regions and the areas that contribute to their flow. Precipitation affects the lower parts of infrastructure such as buildings and roads. Flooding on the road networks should be avoided because it leads to traffic jams, making roads unsafe and damaging the road surface (Fig. 10).

Blue spot models can be used to perform accurate water flow calculations considering the cavities and dips as well as other surface conditions. These models produce a “blue spot map” that shows where and how intensely the road network will flood for a given flood. These models identify the location of the watercourse and develop guidelines for how to reduce flood exposure. The result is a screening method that the municipal environment department planners, road authorities and other interests can use. While the BSM has been incorporated into the computations, the variation in assessment of future flood risk is difficult due to climate variation.

This research shows a unique approach to the BSM to describing the urban overland runoff under a heavy rainfall scenario in an innovative way. The key finding from this case study is that a high-resolution modelling methodology is important. Furthermore, the distributed data model creates a feasible data schema for subdividing the scene data under basin from hydrology recognitions empowering it to fit into genuine hydrology conditions.

It is also integrated with coastal urban heterogeneity distribution models, opening an entryway to even more extensive inclusion of hydro-displaying related datasets to be included. Also, unlike a “one for all”-modelling approach, the modified sub-model group method makes it possible to produce diverse individual stormwater models depending on different modified target rainfall events and flooding objects. It provides a possible modelling approach to adapt to the dynamic world. Also, multiple hydrological examinations were connected in the model. Not all sub-models generated from the entire drainage basin provide a reliable boundary for hydrology modelling, the small-scale hydrological changes. Sub models may achieve improved flooding connectivity between coastal and mainland areas. The automatic process of the Blue Spot model with little manual input A programmed method in BSM with minimal manual information sources requires reduced analysis time when developing the input hydrological model.

4. Conclusions

In this research, the methodology for producing a blue spot map for Inverloch that identifies low-lying blue spot regions with no natural drainage was presented. In a cloudburst event, the blue spot regions may fill up and overflow, damaging buildings and roads that lie within and adjacent to them. BSM tools will support flood-risk land use planning at the local level and allow the usage of new forms of information to assist in the decision process.

The results presented in this research involved new applications of geoprocessing to derive the blue spot regions and their watersheds locally. The fill-up qualities are determined by partitioning the BSM volume by the local watersheds. It is then possible to assess how much floodwater the drainage network can accommodate. These results, however, need to be viewed with some caution. In Australia, when storms are heavy from a specific wind direction over a couple of days, many low-lying coastal areas are at risk of getting flooded. Thus, research focuses on which models are useful for coastal drainage connection to the main land drainage analysis. This flood screening model is useful for local government planners to understand areas that might be threatened due to a sudden or a long-term coastal flood impact.

Based on that analysis, the research model allowed assessment of flood-risk thresholds for infrastructure. However, the best thing that can be done without
building features is to create a worst-case scenario by ensuring that the crucial flood level for a building is at its base height. Flood levels might be higher than accepted for structures with high building levels or structures built above ground. On the other hand, the dimensions might be lower than expected for structures with storm cellars. The BCSC property department has data about whether structures have cellars, yet those data are excluded in the building feature table. It does not have building databases on basements. Including the features of the infrastructure inside the model will improve the outcome.

Since a hydrological model depends on characteristics of a given study area, no specific model of flow direction is universally applicable, which is the fundamental step in the hydrological models integrated into a GIS. The implicit assumption is that the DEM produces a consistent surface of the flow path and this hypothesis is very high-resolution digital elevation models. Another component of uncertainty is that the amount of water input to a building depends on the structure actual vertical position inside the blue spot region. Different factors are equivalent; a building at or near a blue spot region’s low point is going to be flooded before a building on its high point.

As discussed in the introduction to this study, ideal conditions for outflow are rare, but in a downpour, basic hydrological hypotheses change. Normal soil infiltration capacity is irrelevant, and the drainage systems will very easily exceed full capacity. When this happens, the rainfall transforms into rapid overland flows that fill blue spot regions partially or completely. BSM deployed in this study does not find surface runoff diverting by drainage ditches or other channels. The research also considered some improvements to the BSM’s Fill up module.

An examination of the permeability of the surface, whether the large sections of the river basins are lined, should enhance risk management for individual building. Faster outflow means more paved surface. It would be useful to set solid impermeable surface percentage raster data for the area of analysis at Inverloch. A study of the slope and length of flows within the river basins would also be relevant to determine which buildings in the downpour will be affected first.

This research assesses flood risks for residential areas caused by cloudbursts. The focus has been on developing models to estimate the flood risk for an existing building or planned new developments.

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