Workshop with editors on application of Australian Rainfall and Runoff (ARR2016) in Urban Areas

Peter Coombes, Steve Roso & Mark Babister

Outline

- Overview of ARR and relationship to Urban Book
- Philosophy and objectives of ARR Urban Book (Ch 1, 2 & 3)
- Volume management and conveyance (Ch 4 & 5)
- Afternoon tea with Q & A
- Modelling guidance and approaches (Ch 6)
- Losses, pre-burst rainfall, rainfall ensembles, storm losses and climate change
- Worked examples and discussion

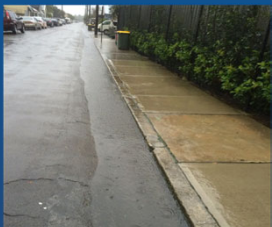ARR Urban Book: Coombes, Roso, Babister   7/01/2019

ARR History

- 1958 (version 1)
- 1977 (version 2)
- 1987 (version 3)
- 1999 (version 3.1 update for extreme floods)
- 2016 (version 4)

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Background

- Guideline not a standard as Australia is too diverse
- ARR is a 8 year project that commenced in 2008 with $9.15 Million government funding
  - Over $30 million in-kind effort
- Project has involved:
  - BoM, Geoscience Australia, CSIRO, state agencies
  - UTS, UWS, UNSW, Uni of Newcastle, Uni of Adelaide, Melbourne Uni
  - Most consulting firms

ARR Urban Book Coombes, Roso, Babister

WHAT IS ARR?

- Guideline for calculation of stormwater runoff, flows and flood behaviour
- ARR is not prescriptive
- ARR is a guideline document as the nature of hydrologic problems vary everywhere

ARR Urban Book Coombes, Roso, Babister

Development objectives for ARR 2016

- Use Australian data
- Practitioners are the primary audience
- To better represent real systems
- Scientific evidence based approaches
- Fit with and complement the broader set of tools used to manage the water cycle
- Where possible provide the uncertainty of methods and inputs
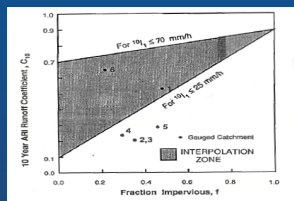
ARR Urban Book Coombes, Roso, Babister

Evidence Based

Evidence based:

30 years additional data, science and knowledge

From slide rule to computer age

ARR Urban Book Coombes, Roso, Babister

New supporting data for Australian Rainfall and Runoff

600 / **2280** Pluviographs

Pluviographs measure the amount of rainfall which fell and are critical to flood estimation. The 1987 version of ARR used 600 pluviographs and ARR 2016 used 2280 pluviographs.

7500 / **8074** Rainfall Gauges

The 1987 version of ARR accessed 7500 daily rainfall gauges and ARR 2016 used 8074 daily rainfall gauges from a range of sources.

/ **30** Years of Data

ARR 2016 uses an additional 30 years of data.

2000 / **100 000** Storm Events

The 1987 version of ARR analysed 2000 storm events for temporal patterns. ARR 2016 analysed 100 000 storm events.

ARR Urban Book Coombes, Roso, Babister

Application Objectives

- Computerise simple tasks
- Design inputs should be easy to use
- Minimise human errors in map/figure/table reading
- Reproducible
- Easily updated

ARR Urban Book Coombes, Roso, Babister
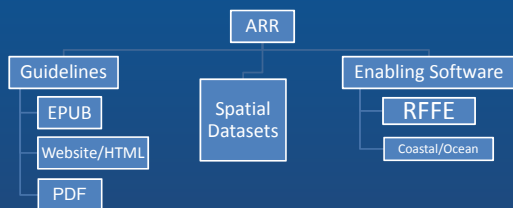
Big Changes in Practice

- Ensemble and Monte Carlo approaches to better capture variability
- Move away from simple burst approaches
- Less reliance on the rational method
- More data
- New IFD data
- Better flow estimates of ungauged catchments

ARR Urban Book Coombes, Roso, Babister

What does the new ARR look like?

ARR
- Guidelines
  - EPUB
  - Website/HTML
  - PDF
- Spatial Datasets
- Enabling Software
  - RFFE
  - Coastal/Ocean

ARR Urban Book Coombes, Roso, Babister

Terminology

- ARI no longer recommended
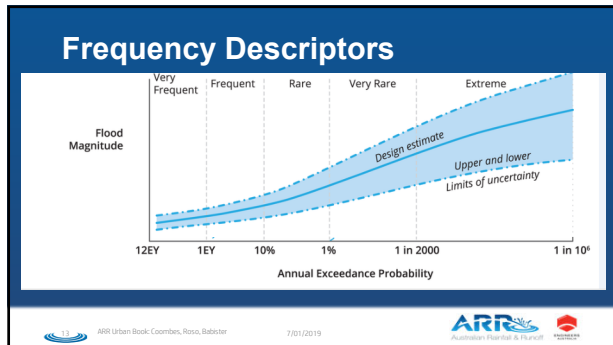- EY for frequent events to deal with seasonality

ARR Urban Book Coombes, Roso, Babister   7/01/2019

Frequency Descriptors

Changes in design modelling techniques

Design modelling techniques

Section 3.2 of Book 4

Data online

http://data.arr-software.org/

Other data is being added to the datahub including GSAM temporal patterns

Data on the data hub

Data	Use
ARF	recommended
Temporal Patterns	recommended
Pre burst	recommended
Losses	In the absence of local data
Climate change factors	In the absence of location specific studies
Baseflow	In the absence of local data

New enabling software

What is currently happening

Document is currently being updated
- PDF of document
- PDF by Book
- Glossary
- Web interface to include section referencing
- Examples
- Book 9 updated and almost complete

All the work is by volunteers

19   ARR Urban Book: Coombes, Roso, Babister

Ongoing work

- Climate change versus flood behaviour
- Spatial loss models
- Complete storms
- Urban flood frequency estimation
- Improved regional flood frequency estimations for rural catchments – improved rating curves for gauges
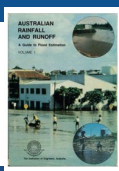- Need more urban streamflow data

20   ARR Urban Book: Coombes, Roso, Babister

Can I keep using ARR87 ?
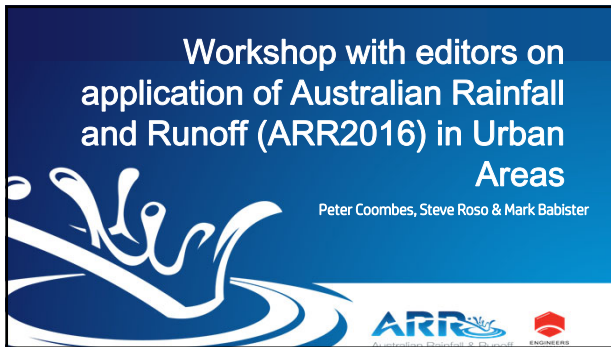## ARR 2016 is still draft

The use of new or improved procedures is encouraged, especially where these are more appropriate than the methods described in this publication. It is certain that within the effective life of the document, new procedures and design information will be developed.   ARR 87 Chapter 1, page 1 paragraph 6
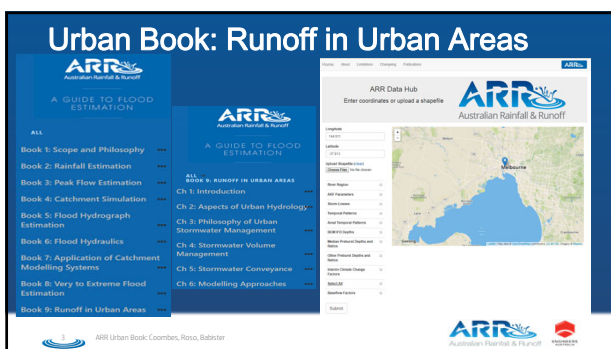
Workshop with editors on application of Australian Rainfall and Runoff (ARR2016) in Urban Areas

Peter Coombes, Steve Roso & Mark Babister

Book 9: Runoff in Urban Areas

ARR Urban Book Coombes, Roso, Babister   7/01/2019

Urban Book: Runoff in Urban Areas

Book 1: Scope and Philosophy
Book 2: Rainfall Estimation
Book 3: Peak Flow Estimation
Book 4: Catchment Simulation
Book 5: Flood Hydrograph Estimation
Book 6: Flood Hydraulics
Book 7: Application of Catchment Modelling Systems
Book 8: Very to Extreme Flood Estimation
Book 9: Runoff in Urban Areas

BOOK 9: RUNOFF IN URBAN AREAS
Ch 1: Introduction
Ch 2: Aspects of Urban Hydrology
Ch 3: Philosophy of Urban Stormwater Management
Ch 4: Stormwater Volume Management
Ch 5: Stormwater Conveyance
Ch 6: Modelling Approaches

ARR Data Hub
Enter coordinates or upload a shapefile

ARR Urban Book Coombes, Roso, Babister

Editorial process

Improve accessibility for non-specialist audiences

Reduce wordiness and length of draft book

Ensure technical rigor – evidence based

Achieve a cohesive document

Provide modern and up-to-date perspective on urban stormwater management

Avoid normative assumptions and values

4 ARR Urban Book Coombes, Roso, Babister

Introduction

Book 9 Ch 1

5 ARR Urban Book Coombes, Roso, Babister

Key principles of the Urban Book

- Evidence based using 30 years of additional Australian data and science
- Focus on entire spectrum of runoff events and potential flooding outcomes
- Stormwater management is part of linked water cycle systems which includes stormwater quantity and quality, water supply, urban form and waterways
- Built around Chapters 4 & 5: key elements of conveyance and storage
- Volume management is a key element of stormwater management and flood control – this will increase in future
- Stormwater volume controls have increased research effort since 1987
- There are substantial gaps in knowledge about urban hydrology
- Urban stormwater management is primarily about surface flows

6 ARR Urban Book Coombes, Roso, Babister

Aspects of Urban Hydrology

Book 9 Ch 2

Dr Tony Ladson

ARR Urban Book: Coombes, Roso, Babister

The Urban Water Cycle

Urban Water Cycle
A complex system that modifies the natural water cycle – increased impervious areas, imported water

Urban stormwater runoff processes
Urban is different and more complex than rural

Stormwater is part of urban water balance and cycle

Water Balances in cities
Average annual volumes of stormwater runoff from properties similar or greater than water use

Timelines of water balances in a city
Dependent on water collected from local rivers
Reduced flows in local rivers supplemented by groundwater and importing water from other regions
Significant urban stormwater runoff
Halved water demand using water efficiency and rainwater harvesting
Cumulative impacts on surrounding communities

ARR Urban Book: Coombes, Roso, Babister

Philosophy of Urban Stormwater Management

Book 9 Ch 3
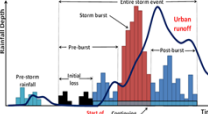
Dr Peter Coombes
Steve Roso

10 ARR Urban Book Coombes, Roso, Babister
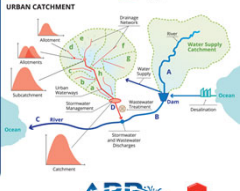
Traditional cumulative scale issues

- Water demanded, stormwater and wastewater generated, hydrology altered at distributed scales
- Runoff from almost all rainfall – cumulative response
- Urban areas alter hydrology and stormwater quality:
  - Water demands (B)
  - Within urban areas (a-h)
  - Downstream of urban areas (C)
- Flow management at bottom of urban catchment (D)
- Does not account for changes in catchments (increased density, aging infrastructure, climate issues)
- Water, wastewater and stormwater impacts are linked
  - Analysed separately

11 ARR Urban Book Coombes, Roso, Babister
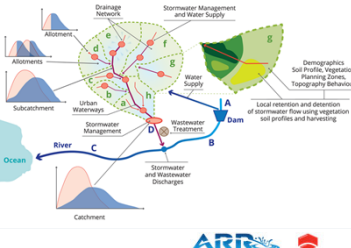
Systems Issues & Integrated Solutions
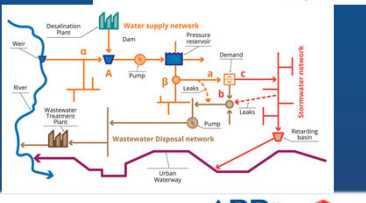
- Multiple physical and ecosystem responses within catchments
- Solutions at multiple scales
- Distributed "within catchment" solutions for whole of system benefits
  - Cannot be realised by analysis at bottom of catchment (D) and assumed runoff coefficients

Need to deconstruct peak flows into volumes, patterns and timing.

12 ARR Urban Book Coombes, Roso, Babister

Connectivity & variability

- History
- Evolution and Innovation
- Opportunities and challenges
- Urban flooding processes
- Market mechanisms

13   ARR Urban Book: Coombes, Roso, Babister

ARR
Australian Rainfall & Runoff

Stormwater offsets

Market mechanisms, tradeable permits, water markets, development control schemes:

- Analysis from perspective of entire catchment
- Equivalent and measurable changes in flow (and quality) from infrastructure or strategies within the same catchment
- The funds from stormwater off-sets tied to measurable and timely deliverables in the catchment

14   ARR Urban Book: Coombes, Roso, Babister

ARR
Australian Rainfall & Runoff

Legal insights

State Supreme Courts, High Court of Australia

- Professionals must use the latest data and science
- Default to local codes is not defence against liability
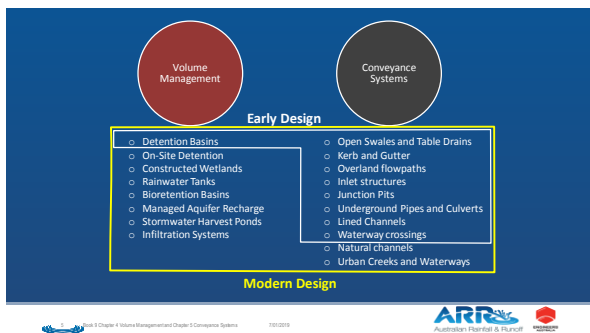- Must account for climate change
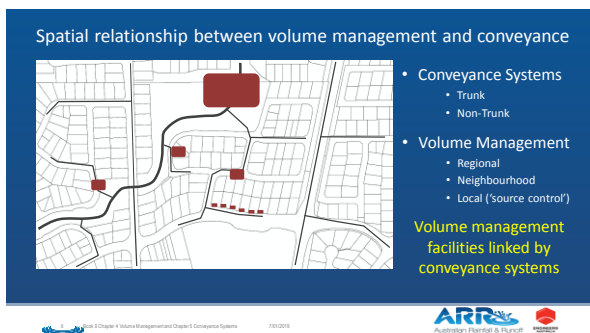
15   ARR Urban Book: Coombes, Roso, Babister

ARR
Australian Rainfall & Runoff

RUNOFF IN URBAN AREAS

Volume Management & Conveyance Systems

Peter Coombes, Steve Roso & Mark Babister

ARR
Australian Rainfall & Runoff

Session Outline

- Stormwater network and infrastructure overview

- Volume Management (ARR Book 9 Chapter 4)

- Conveyance Systems (ARR Book 9 Chapter 5)

ARR Urban Book, Coombes, Ross, Babister   7/01/2019

Urban Water Networks

Coombes 2018

ARR Urban Book, Coombes, Ross, Babister   7/01/2019

Slide 1

Urban Stormwater Network

Volume Management — Book 9 Chapter 4

Conveyance Systems — Book 9 Chapter 5

Two classes of infrastructure for the purpose of discussion in ARR Book 9

ARR Urban Book: Coombes, Roso, Babister

Slide 2

Volume Management

Conveyance Systems

Early Design

- Detention Basins
- On-Site Detention
- Constructed Wetlands
- Rainwater Tanks
- Bioretention Basins
- Managed Aquifer Recharge
- Stormwater Harvest Ponds
- Infiltration Systems

- Open Swales and Table Drains
- Kerb and Gutter
- Overland flowpaths
- Inlet structures
- Junction Pits
- Underground Pipes and Culverts
- Lined Channels
- Waterway crossings
- Natural channels
- Urban Creeks and Waterways

Modern Design

Slide 3

Spatial relationship between volume management and conveyance

- Conveyance Systems
  - Trunk
  - Non-Trunk
- Volume Management
  - Regional
  - Neighbourhood
  - Local ('source control')

Volume management facilities linked by conveyance systems

Volume Management

Book 9 Ch 4

Authors:
Steve Roso
Marlene van de Sterren

Contributors:
John Argue
Brett Phillips
Peter Coombes

| HIGH RAINFALL INFILTRATION | MODERATE RAINFALL INFILTRATION | LOW RAINFALL INFILTRATION |
| LOW RUNOFF CONCENTRATION | LOW RUNOFF CONCENTRATION | HIGH RUNOFF CONCENTRATION |

Urbanisation increases speed and volume of runoff
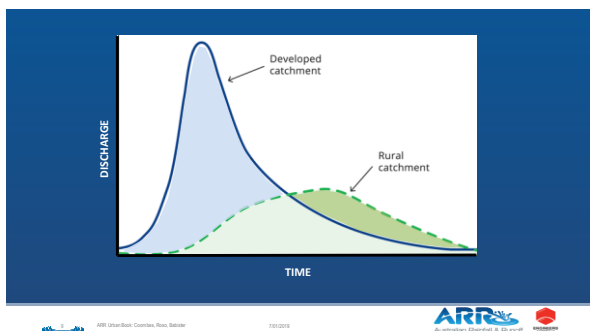
Decreased water quality due to urban runoff
- Lawns
- Gardens
- Roadways
- Commercial areas

Decline in aquatic health

www.northgeorgiawater.org 2018

Urbanisation increases speed and volume of runoff and reduces aquatic health

Volume Management

Problem   Solution

Volume Management Objectives

- Reduce flood and infrastructure damage
- Flood safety
- Reduce capacity requirements for downstream conveyance

Control Peak Discharge

Harvest or Infiltrate Stormwater

Improve Water Quality

- Maintain hydrologic behaviour
- Waterway stability and health
- Increased availability of water for harvesting and use
- Decrease demand on water supply network

- Maintain aquatic health
- Maintain visual amenity
- Pre-treatment of runoff before harvest

Volume Management Objectives

Ideally a single facility should target multiple objectives

- Control Peak Discharge
- Harvest or Infiltrate Stormwater
- Improve Water Quality

Design of a Volume Management Facility

Inlet Structure
connects the upstream conveyance network to the storage

Storage
storage structure that contains water after rain

Treatment Process
Filter zone, filter media, settlement process for improving water quality

Outlet structure
controls outflow from the facility and connects the storage to the downstream conveyance

Hydrologic performance is a function of these two components

Volume Management Facility

Volume Management Facility 'Components'

Example 1:   Water quality and minor flood control
- Inlet Structure
- Storage
- Treatment Process
- Outlet Structure

Example 2:   Large flood control only
- Inlet Structure
- Storage
- Treatment Process
- Outlet Structure

Components are designed for performance against different objectives

Slide 1

bio-retentionbasin   bio-swale
biobasin   constructedwetland
detention   filterstrip   infiltrationbasin   infiltrationsystem
infiltrationtrench
managedaquiferrecharge   on-
sitedetention on-siteretention osd osr
permeablepavement   porouspavement
raingarden rainwatertank retarding
retention   soakpit   soakwell
stormwaterharvestpond   swale
wetland

ARR
Australian Rainfall & Runoff

Slide 2
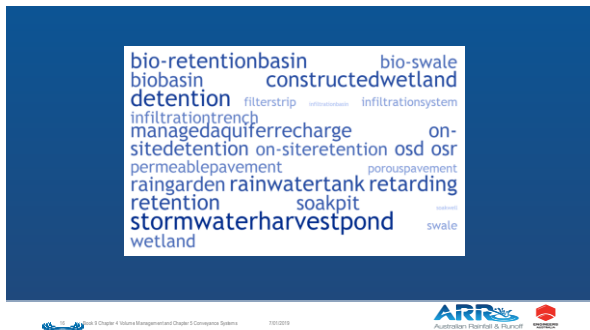
Common Configurations in Australian Practice

o Detention Basins
o On-site detention
o Constructed Wetlands
o Rainwater Tanks
o Bioretention Basins
o Managed Aquifer Recharge
o Stormwater Harvest Ponds
o Infiltration Systems

ARR 25 Urban Book. Coombes, Roso, Babister   7/01/2019

ARR
Australian Rainfall & Runoff

Slide 3

Table 9.4.4. Indicative Suitability of Common Volume Management Design Solutions

Solution	Control Peak Discharge	Improve Water Quality	Harvest or Infiltrate Stormwater
Detention (Retarding) Basin (see Section 5.1)	Suitable	Not suitable	Not suitable
On-Site Detention (OSD) (see Section 5.2)	Suitable	Not suitable	Not suitable
Rainwater Harvesting (see Section 5.3)	Suitable with limitations	Suitable	Suitable
Bioretention Basin (see Section 5.4)	Suitable with limitations	Suitable	Suitable with limitations
Constructed Wetland (see Section 5.5)	Suitable with limitations	Suitable	Suitable with limitations
Managed Aquifer Recharge (see Section 5.6)	Suitable with limitations	Suitable with limitations	Suitable
Infiltration System (see Section 5.7)	Suitable with limitations	Suitable with limitations	Suitable
Stormwater Harvest Pond (see Section 5.8)	Suitable with limitations	Suitable with limitations	Suitable

ARR
Australian Rainfall & Runoff

Volume Management Objectives

Control Peak
Discharge

Harvest or
Infiltrate
Stormwater

Improve
Water
Quality

- Detention Basins
- On-site Detention
- Constructed Wetlands
- Rainwater Tanks
- Bioretention Basins
- Managed Aquifer Recharge
- Stormwater Harvest Ponds
- Infiltration Systems

- Detention Basins
- Constructed Wetlands

- On-site Detention
- Rainwater Tanks
- Infiltration Systems

- Detention Basins
- Bioretention Basins

- Constructed Wetlands
- Managed Aquifer Recharge

In modern best practice
objectives often overlap

Look for co-location
opportunities or hybrid designs

ARR Urban Book: Coombes, Ross, Babister

Hybrid Design Example

Control Peak
Discharge

Harvest or
Infiltrate
Stormwater

Improve
Water
Quality

Key Features:
- 115ML Detention Basin for up to 1% AEP
- 1.4 Hectare Constructed Wetland
- Future Harvesting Option
- Design prepared by DesignFlow

ARR Urban Book: Coombes, Ross, Babister
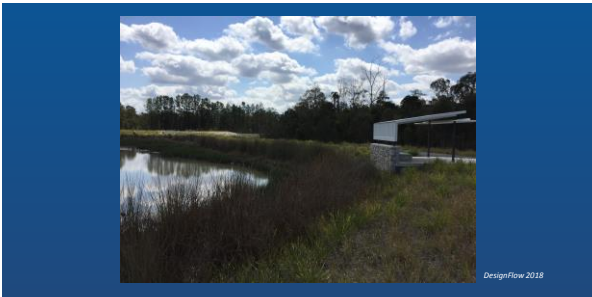
DesignFlow 2018

DesignFlow 2018

DesignFlow 2018

DesignFlow 2018

DesignFlow 2018

DesignFlow 2018

Catchment Volume Strategy (Ch 3.6)

CONSIDERATION

What are the volume management objectives for the Catchment?

Catchment Volume Strategy (Ch 3.6) cont'd

CONSIDERATION

Should the objectives be achieved in combined or separate facilities?

Catchment Volume Strategy (Ch 3.6) cont'd

CONSIDERATION

What is the performance level that is sought?

- Peak discharge
- Volume
- Timing
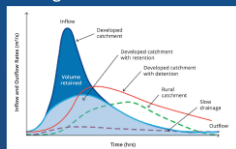
Catchment Volume Strategy (Ch 3.6) cont'd

CONSIDERATION

Where should volume management be achieved?

- 'at source'
- 'neighbourhood' scale
- 'regional' scale
- combinations

Catchment Volume Strategy (Ch 3.6) cont'd

CONSIDERATION

How does existing urban development influence the strategy?

- Future growth areas
- Highly urbanised catchments
- Over-developed catchments

Catchment Volume Strategy (Ch 3.6) cont'd

CONSIDERATION

Other constraints?

- Environmentally sensitive riparian land
- Land ownership and development patterns
- Local asset management policies

Volume Management - Summary

- Urbanisation results in much larger and faster runoff volumes
- Three typical volume management objectives
- Best practice seeks to achieve multiple objectives in a single facility
- Four components of a facility designed for performance against different objectives
- Number of considerations when devising a catchment strategy (See Ch 3.6)
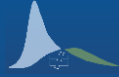
Conveyance Systems

Book 9 Ch 5

Author:
Benjamin Kus

Editors:
Peter Coombes
Steve Roso

Conveyance objectives:
- Maximise utilisation of land
- Minimise nuisance
- Pedestrian and road safety
- Manage disasters

For larger systems:
- Recreational use (in dry)
- Natural amenity/habitat
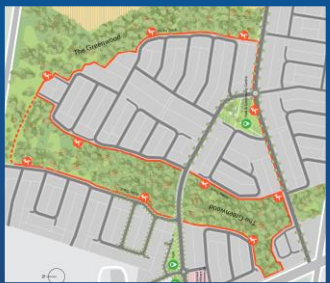
Conveyance Systems – Minor vs Major Systems

In residential areas

In commercial areas

In park areas
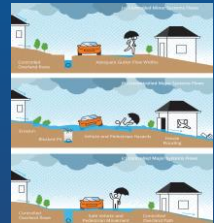
- Minor system – to manage nuisance (often underground and lined)

- Major System – to manage disaster (often above ground. Can be lined or unlined)

Balance Between Minor and Major Capacity

- Influenced by a number of factors:
  - Land availability
  - Rainfall patterns
  - Human exposure
  - Physical constraints
  - Erosion susceptibility
  - Blockage potential
  - Climate change
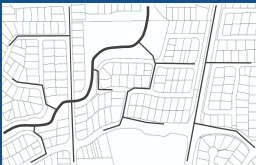
Conveyance Systems – underground vs surface systems

Underground
- Inlet Structures
- Junction Pits
- Underground Pipes and Culverts
- Waterway Crossings

Surface
- Open Swales and Table Drains
- Kerb and Gutter
- Overland flowpaths
- Lined Channels
- Natural channels
- Urban Creeks and Waterways

Extent of each will depend on hydrology, landuse, urban design objectives

Conveyance Systems – Alignment

- Generally lowest point
- Influenced by urban form
- Co-locate underground and surface systems
- Co-locate with open space, habitat, volume facilities
- Early planning and innovation can yield better outcomes

ARR Urban Book, Coombes, Ross, Babister   7/01/2019

ARR Australian Rainfall & Runoff
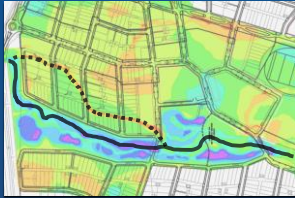
Underground Systems

Issues to consider:
- Location, type and capacity of inlets
- Likelihood of inlet blockage
- Location and config of junctions
- Head loss through pit structures
- Freeboard, surcharge and bypass flows
- Flow Pressurisation
- Alignment and size of pipes/culverts
- Outlet positioning
- Energy dissipation
- Downstream conditions

ARR Urban Book, Coombes, Ross, Babister   7/01/2019

ARR Australian Rainfall & Runoff
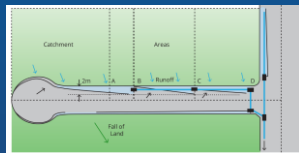
Surface Systems

Issues to consider:
- Alignment to public roads and open space
- Cross-sectional shape
- Velocity and depth of flow
- Gutter flow widths
- Exposure of pedestrians and vehicles
- Diversions and 2D flow behaviour
- Trapped sags
- Fences and obstructions

A well designed surface system is critical

ARR Urban Book, Coombes, Ross, Babister   7/01/2019

ARR Australian Rainfall & Runoff

Analysis

Issues to consider:
- Steady vs unsteady flow
- Complexity of surface hydraulics (1d/2d)
- 'Greenfields' vs 'Brownfields'
- Significance of storage to solution
- Energy loss co-efficients
- Blockage of inlets
- Can the underground system be ignored
- Climate change scenarios
- Temporal pattern ensembles

Iterative process, computer-based analysis now essential (see Chapter 6)

Conveyance Systems - Summary

- Conveyance objectives are:
  - Maximise utilisation of land
  - Minimise nuisance
  - Pedestrian and road safety
  - Manage disasters
- Best achieved through application of a minor/major system approach
- Underground and surface system options. Surface system critical.
- Analysis is complex and iterative therefore computers essential
- Little research and advance in this area since 1987 except for improved software

Thankyou

Workshop with editors on application of Australian Rainfall and Runoff (ARR2016) in Urban Areas
Examples

Peter Coombes, Steve Roso & Mark Babister

With
Mikayla Ward & Sophia Buchanan

Greenfield example
Collaboration with Sophia Buchanan
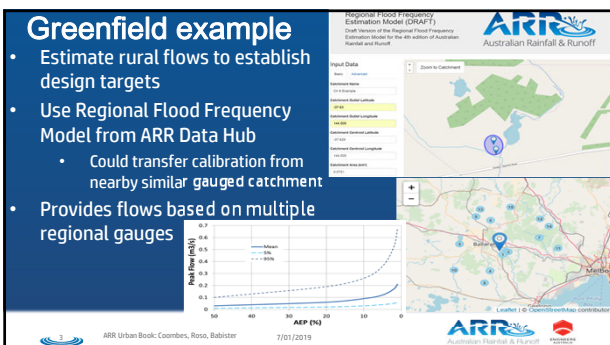
- Design of a new development near Ballarat
- Include conveyance and basin infrastructure
- Do not increase peak flows in downstream natural waterway
- Only stage 1 included in basin catchment

ARR Urban Book: Coombes, Roso, Babister

Greenfield example

- Estimate rural flows to establish design targets
- Use Regional Flood Frequency Model from ARR Data Hub
  - Could transfer calibration from nearby similar *gauged catchment*
- Provides flows based on multiple regional gauges

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Greenfield example

- Majority of hydrology and rainfall information sourced from Data Hub
- Rainfall ensembles
  - Proprietary models download this information
- Estimated rural losses
  - IL: 25 mm
  - CL: 4.3 mm/hr
- Pre-burst rainfall

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Greenfield example

- Used hydrology model to estimate local rural losses
  - Critical duration: 1.5 hours
- Median pre-burst rainfall
  - 50% AEP: 4.1 mm; 10% AEP: 3.3 mm; 1% AEP: 1.1 mm
  - Spread over hour prior to burst
  - burst loss = storm loss – pre-bust rainfall
- Calibrated rural losses:
  - IL: 18 mm; CL: 7 mm/hr (n = 0.075)

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Greenfield example

- Use hydrology model to evaluate catchment with urban development
- Urban losses
  - Impervious area: IL =1.5 mm, CL = 0 mm/hr
  - Pervious area = rural losses
- Critical duration: 10 minutes
  - Determine storm closest to mean peak flow for design of conveyance infrastructure

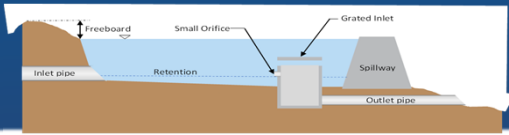ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Greenfield example

- Preliminary conveyance network (Ch. 5, Book 9) sized using storm 2 for 10% AEP
- Apply pit inlet relationships from Section 5.5, Book 9
  - Inlet capacities
  - Design blockage
  - Energy losses
- Sized pipes using software
  - 150 mm freeboard to grate
  - < 2 metre flow width on roads
- Check design using ensembles for 10% AEP
  - 10 min, 15 min, 20 min & 30 min
  - Pre-burst for 10% AEP: 2.1 mm

- Check major flows using ensembles for 1% AEP
  - 10 min, 15 min, 20 min & 30 min
  - Max flow depth < 200 mm & < 50 mm at road crown
  - Depth velocity < 0.4
  - Freeboard to floor levels > 300 mm

7   ARR Urban Book: Coombes, Roso, Babister   7/01/2019   ARR

Greenfield example
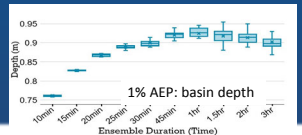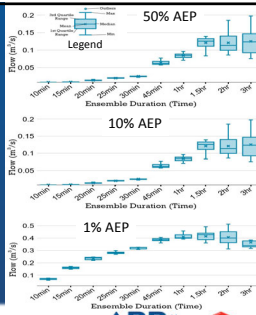
- Basin designed to manage flooding and impacts on downstream waterway (see Chapter 4, Book 9)
  - Mitigate 50%, 10%, 1% AEP flows to rural target
- Use storage volume and outflow arrangements to achieve this (retention & detention)
- Freeboard of 300 mm from 1% AEP maximum depth
- Emergency spillway designed for full blockage and 1% AEP events
  - See Ch. 6, Book 6 for blockage discussions

8   ARR Urban Book: Coombes, Roso, Babister   7/01/2019   ARR

Greenfield example

- Trial basin design using ensembles of 1.5 hour duration from rural analysis
- Design tested and modified using full ensembles
  - Meet rural flows
  - Not exceed maximum basin depth

9   ARR Urban Book: Coombes, Roso, Babister   7/01/2019   ARR

Greenfield example

- Test designs using climate change impacts
  - See Ch. 6 of Book 1; Section 7.7 of Book 8
- Select design life and consequence level
  - 100 years for the basin and medium consequence for impacts on waterway and surrounding rural properties
- Extract data from Data Hub
  - Used RCP 8.5 value for 2090
  - 16.1% increase in rainfall
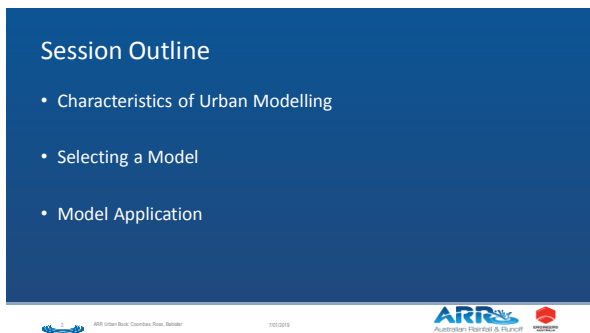- Test climate change impacts using ensembles

50% AEP

10% AEP

1% AEP

10 · ARR Urban Book: Coombes, Roso, Babister · 7/01/2019

Greenfield example

- Test designs using climate change
  - Basin depth
  - Road depth
- See emerging research
  - Wasko & Sharma
  - Increased rainfall intensities in urban areas

Basin depth

Road depth

11 · ARR Urban Book: Coombes, Roso, Babister · 7/01/2019

RUNOFF IN URBAN AREAS

Urban Catchment Modelling

Authors:
Peter Coombes
Steve Roso

ARR
Australian Rainfall & Runoff

Session Outline

- Characteristics of Urban Modelling

- Selecting a Model

- Model Application

Why Model?

- Rapid calculation across large spatial and temporal domains
- Testing of multiple suites of parameters and inputs
- Better calibration to best represent the real world conditions
- Readily documented and reviewed
- Better assessments and design outcomes

Characteristics of Urban Modelling

- Impervious Cover
- Conveyance Systems
- Hydraulic Structures (including volume management facilities)

Also
- Complex landuse patterns (changes spatially and temporally)
- Data intensity
- Stakeholders

Impervious Cover

- Imp% is basic hydrologic model parameter
- Reduces infiltration and decreases lag
- Two types of impervious cover described in ARR
  - Directly connected
  - Indirectly connected
- Effective Impervious Area (EIA) as a proportion of Total Impervious Area (TIA)
- EIA/TIA between 50% and 70% (refer Book 5)
- TIA may be more suitable in some circumstances
- Importance of a quality Imp % estimate not the same in every application
- A well constructed model with adequate spatial scale should account for effective impervious area and connectivity effects

Conveyance Systems

- Artificial linings support steeper than natural slope resulting in decreased lag
- Alters flow characteristics
- Physical processes are explicitly modelled by most hydraulic models
- Requires detailed schematisation
- Conduit type, Cross-sectional dimensions, Length, Slope, Hydraulic parameters

Hydraulic Structures

- Localised Afflux
- Floodplain storage and hydrograph attenuation
- Tail water levels for upstream drainage
- Cross-catchment diversion of flow
- Bed scour and local stream morphology
- Blockage scenarios
- Model requires detailed physical description: dimensions, elevations etc

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Selecting a Model

Book 8 Chapter 4 Volume Management and Chapter 5 Conveyance Systems   7/01/2019

Selecting a Model - Common Urban Model Types

Hydrology	Rational Method Time Area Method, Extended Rational Method Runoff Routing Continuous Simulation
Hydrology and Hydraulics	Hydrology coupled to 1D hydraulic model Direct Rainfall ('Rain on Grid') Runoff routing coupled to 2D hydraulic model
Hydraulics	One-dimensional hydraulic model Two-dimensional hydraulic model Pipe network models
Water Quality	Water quality models

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Slide 1 — Selecting a Model

Selecting a Model

Question 1: What capabilities do you need?

- Runoff generation and surface routing
- Channel and storage routing
- Structure hydraulics

Tables 9.6.1 and 9.6.2 assign a capability (limited, moderate, strong) to each type of model across these key areas.

Flood process	Limited Capability	Moderate Capability	Strong Capability
Runoff generation and surface routing	average intensity or burst Cursory treatment of infiltration losses Surface characteristics not fully represented	More complete storm Infiltration losses Surface characteristics partially represented	Full storm or rainfall sequence Infiltration losses Spatial distribution of rainfall Surface characteristics well represented (including surface wave speed)
Channel and storage routing	Channel characteristics not represented No explicit calculation of flood storage and its attenuation effects	Channel characteristics partially represented Storage behaviour partially represented including attenuation effects and spatial influences	Channel characteristics and flood wave speed well represented Storage behaviour well described including complex hydraulic behaviour and attenuation effects
Structure hydraulics	Basic hydraulic structures only Rating tables Manning's formula for open channels.	Small range of hydraulic structures Basic topographic representation	Wide range of hydraulic structures Resolves shallow water equations (1D or 2D or both)

ARR Urban Book: Coombes, Roso, Babister — 7/01/2019

Slide 2 — Hydrology

Hydrology

Urban Model Type	Estimation Capabilities				Example Model Platforms (where relevant)
	Runoff Generation and Surface Routing	Channel and Storage Routing	Structure Hydraulics	Other specific capabilities or limitations	
Rational Method	Limited	None	None	Peak flow only – scalar quantity, single lumped catchment, requires 'Time of Concentration' assumption, only suitable for small catchments. It has best capabilities where there is no storage present.	RATHGL, PCdrain
Time Area Method, Extended Rational Method	Moderate	None	None	Suitable for small catchments only. Can be extended as a collection of linked sub-catchments.	ILSAX, DRAINS,
Runoff Routing	Strong	Moderate	Limited	Full event hydrograph, empirically derived lag parameters, non-linear routing capabilities. Structure hydraulics can be moderately capable for discrete structures but not for continuous conveyance networks.	RORB, RAFTS, WBNM, URBS, HEC-HMS
Continuous Simulation	Strong	Moderate	Limited	Continuous multi-year runoff sequence, comprehensive infiltration loss models. Limited capability for rare to very rare floods unless utilised with replicates of conditioned synthetic continuous rainfall (such as DRIP)	XP-RAFTS, MUSIC, PURRS, Systems Framework

ARR Urban Book: Coombes, Roso, Babister — 7/01/2019

Slide 3 — Hydrology and Hydraulics

Hydrology and Hydraulics

Urban Model Type	Estimation Capabilities				Example Model Platforms (where relevant)
	Runoff Generation and Surface Routing	Channel and Storage Routing	Structure Hydraulics	Other specific capabilities or limitations	
Hydrology coupled to 1D hydraulic model	Moderate	Moderate	Strong	Not always emulating full capability of the underlying hydrologic model	DRAINS, Pcdrain, XP-SWMM
Direct Rainfall ('Rain on Grid')	Limited	Moderate	Strong	Does not require pre-defined flow paths. Sensitive to topographic data pre-processing and surface roughness assumptions. Not suitable for 'greenfield' subdivision drainage design.	TUFLOW, MIKE21, SOBEK, ANUGA
Runoff routing coupled to two-dimensional hydraulic model	Moderate	Strong	Strong	Requires pre-defined understanding of flow paths in order to establish initial model. Requires input and output procedure between two model software packages.	RAFTS with MIKE21, WBNM with TUFLOW, XP STORM with TUFLOW, DRAINS with TUFLOW

ARR Urban Book: Coombes, Roso, Babister — 7/01/2019

Hydraulics

Urban Model Type	Estimation Capabilities				Example Model Platforms (where relevant)
	Runoff Generation and Surface Routing	Channel and Storage Routing	Structure Hydraulics	Other specific capabilities or limitations	
One-dimensional hydraulic model	None	Moderate	Strong	Simple channel or pipe behaviour only. Limited where complex flood storages exist.	HEC-RAS, MIKE11, SOBEK
Two-dimensional hydraulic model	None	Strong	Strong	Complex flow behaviour including breakout and diversion. Flow transitions and hydraulic jumps. Principally surface flow.	TUFLOW, SOBEK, ANUGA, MIKE21, HEC-RAS 2D, RMA, RiverFlow2D
Pipe network models	None	Moderate	Strong	Specialist models for underground drainage networks, storage routing performance best where flow is contained within the minor system.	SWMM, XP-STORM, DRAINS, PCdrain, MIKE URBAN

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Selecting a Model
Question 2: What is your model's spatial scale?

Lot	Site	Neighbourhood	Precinct
A small parcel of land with 1 or 2 buildings.	A large parcel of land with multiple buildings. Sometimes a small number of 'lots' combined.	Many parcels of land each with at least one building. Many 'lots' and potentially some multi-building complexes.	Hundreds of parcels of land each with at least one building. A large number of 'lots' and multi-building complexes combined. Several neighbourhoods.
e.g. single detached dwelling or duplex up to say 1,000m² in area	e.g. large townhouse complex covering an area up to say 1 hectare	e.g. a residential subdivision stage or a neighbourhood covering an area up to say 10 hectares	e.g. a small suburb covering an area of say 100 hectares

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Number of flood generation processes increase with scale (Table 9.6.4)

More model capability required for larger catchments

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Selecting a Model
Question 3: What is your flood magnitude of interest?
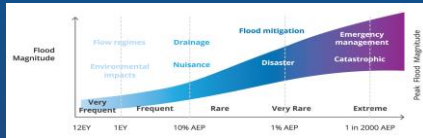
Not all hydrologic models capable across range of flood magnitudes
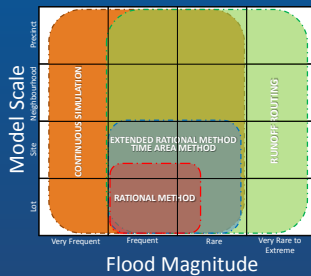

Question 2 and 3 lead to Figure 9.6.1

Not all hydrologic models are capable across range of flood magnitudes AND model scales

---

Selecting a Model
Question 4: What hydraulic model is suitable?

- Is flow behaviour 1D or 2D
- Proportion of flow underground
- Importance of storage

Selecting a Model

Other factors:

- simplest model, capable of the necessary calculations
- availability of sufficient input data
- parameter research
- output data capabilities
- cost
- user familiarity with the model

Book 8 Chapter 4 Volume Management and Chapter 5 Conveyance Systems   7/01/2019

Model Application

Book 8 Chapter 4 Volume Management and Chapter 5 Conveyance Systems   7/01/2019

Model Application - Rainfall

- Design rainfall depths from BOM

- Temporal patterns, ARF, climate change factors, pre-burst from ARR Datahub

Input	ARR 1987	Pre Update	ARR 2016
IFD	Paper maps	BoM web page	Updated BoM web page. Book 2 Chapter 2 Design Rainfall.
ARF	Figure 2.7 from US data	FORGE work (except NSW)	New equations derived using Australian data. Book 2 Chapter 4: Areal Reduction Factors.
Temporal patterns	Single temporal pattern of design burst rainfall based on average variability method (AVM)	AVM, filtered for embedded burst	Ensemble of real storms. Book 2 Chapter 5: Temporal Patterns.
Spatial pattern	Centroid	Spatially distributed IFD	Spatially distributed IFD
Climate change			Factors available from the Datahub. Book 1 Chapter 6 Climate change considerations
Losses	State based advice, sometimes based on data	Calibrated in the hydrologic Model.	Calibrated losses. Uncalibrated models use losses available from the datahub. Book 5 Chapter 3: Losses.
Pre burst	Allegedly incorporated into advice	mixed	Estimates provided on Datahub. Use 60 minute pre-burst rainfall with burst rainfall ensembles of durations less than 60 minutes

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

7

Model Application - Losses

- 'Initial Loss/Continuing Loss' Loss model recommended
- For urban catchments apply the following hierarchy:
  1) Locally derived data
  2) Regional losses as per Book 5 Ch 3.5 i.e. for:

Effective Impervious Area	IL = 1 to 2mm	CLR = 0mm/hr
Indirectly connected Area	IL = 60% to 80% of rural losses	CLR = 1 to 3 mm/hr (for South East)
Pervious Area	IL = Rural loss (from data hub)	CLR = Rural loss (from data hub)

- Datahub provides storm loss. Burst Loss = Storm Loss – Preburst

---

Model Application - Property Runoff

- Basic 'building block' of most urban models.
- Limited number of flood generation processes
- Physical definition should be sufficient to allow local effects to be determined
- Deemed to comply and Rational Method solutions can be considered for property drainage on simple sites e.g. AS/NZS 3500.3
- Continuous simulation may become important for volume harvesting and water quality design (resolve joint probability problems)
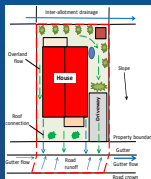
Model Application - Sub-catchment runoff

- Second 'building block' for urban models
- Landuse complexity, storage effects, variations in rainfall temporal patterns and pre-burst rainfall become more important
- Runoff routing or continuous simulation models more relevant (volume or joint probability)
- May be some opportunity for simplified definition of catchment

8
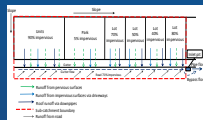
Model Application – Inlet to Outlet

- Third 'building block'
- Multiple sub-catchment flows accumulate at junctions.
- Some simplification of catchment necessary.
- Coupled 1D or 2D hydrology and hydraulic models suggested.
- Ensemble of patterns in hydrology with at least one pattern taken through to hydraulic model.
- Refer 'Brownfields' case study

Urban Catchment Modelling Summary

- Models have become necessary tools in modern practice
- Urban modelling has a number of special characteristics (impervious cover, conveyance systems and structures)
- To select a model identify:
  - Capabilities required
  - Model spatial scale
  - Flood magnitudes of interest
- When applying models consider the amount of physical simplification that is suitable for each model building block

Thankyou

Applying a hierarchy of losses, pre-burst rainfall, rainfall ensembles, storm losses and climate change

Mark Babister, Peter Coombes, Steve Roso

ARR
Australian Rainfall & Runoff
ENGINEERS
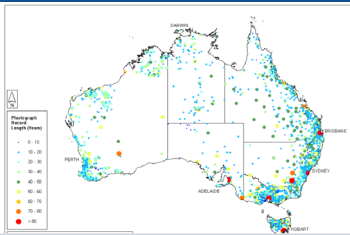
Storms and Losses becoming more realistic and defendable

aspect	ARR 1987	ARR 2016	Future
Storms volumes	Bursts only	Quasi-storms	Complete storms
Number	1	10	Large ensembles
Patterns	AVM - unrealistic	observed	observed
Pre-burst rainfall	NA	Estimated from nearby data	Complete storms include pre-burst
Post burst rainfall	NA	NA	Complete storms include post burst
Interaction of pre-burst and IFD	NA	Medium pre-burst	Can be calculated
Losses	No data	Scant data	Some data ?

2   Book 9 Chapter 4 Volume Management and Chapter 5 Conveyance Systems   7/01/2019

ARR
Australian Rainfall & Runoff
ENGINEERS AUSTRALIA

IFD 2016

- Significantly more continuous rainfall gauges
- Robust pooling of data

3   Book 9 Storms and Losses   7/01/2019

ARR
Australian Rainfall & Runoff
ENGINEERS AUSTRALIA

Storms becoming more complete

- Storm volumes more realistic
- Approach is closer to real system

All data sampled for IFD, Patterns and Pre-burst

Region	Number of Gauges	Number of Station Years	Number of Events	Average Number of Events per Station Year
Southern Slopes (Tasmania)	110	2,954	3,477	1.18
Southern Slopes (mainland)	356	8,536	20,581	2.41
Murray Basin	233	6,316	18,399	2.91
Central Slopes	118	2,767	7,167	2.59
East Coast South	331	8,067	19,856	2.46
East Coast North	210	5,187	12,123	2.34
Wet Tropics	99	2,474	5,437	2.20
Monsoonal North	211	5,054	12,287	2.43
Rangelands West	93	2,334	5,391	2.31
Rangelands	226	5,561	12,618	2.27
Flatlands West	349	9,113	26,402	2.90
Flatlands East	56	1,401	3,450	2.46

Temporal Patterns

- 10 temporal patterns are provided for each of the four categories of severity
- Temporal patterns should be used to derive floods in similar

Pre-burst

- Only an issue in some locations
- Generally medium pre-burst is a reasonable value
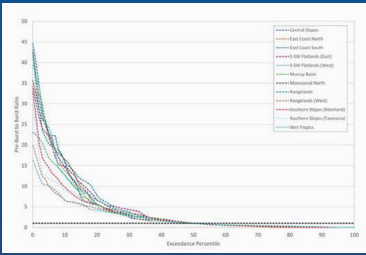- Sampling from distribution is a good idea when ratio of 90% to 50% is high

Pre-burst

Medium preburst is not representitive when
- 90% /50% ratio is high
- 50% value is significant

Pre-burst Rainfall and Loss Equation Ch. 6

- Use median pre-burst rainfall from ARR Data Hub
- Burst loss = storm losses – pre-burst rainfall (Burst Loss ≥ 0)
- Use one hour pre-bust rainfall for storm burst durations of less than one hour
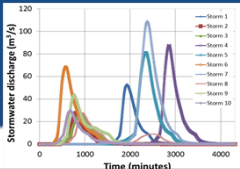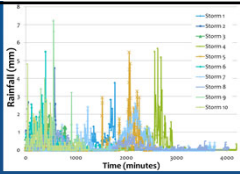
Hierarchy of Assumptions about Urban Losses and Connectivity Ch. 6

- ***Rural and regional loss assumptions should not be a default assumption for urban areas!***
- Hierarchy of Urban Loss assumptions:
  1. Use local losses based on GIS investigations, local knowledge and observations (Losses derived at a regional scale are not local losses – use local losses in small scale models)
     a) Note that a well constructed model with adequate spatial scale should account for effective impervious area and connectivity effects
  2. Regional losses (Book 5, Ch 3.4, 3.5):
     a) Impervious area: IL <1 mm, CL: 0 mm/hr; EIA: IL: 1 -2 mm, CL: 0 mm/hr; Pervious area ≈ rural losses etc
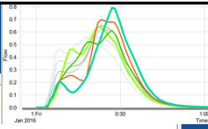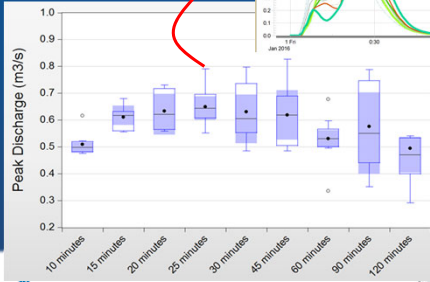 3. Rural losses: 60% - 80% of rural IL losses etc

"New" tools Ch. 6

- Ensembles of rainfall and temporal patterns
  - Storm bursts
  - Quasi- Complete storms
  - Based on local reality
- New IFDs
- Pre-burst
- RFFE
- Monte Carlo testing
- Continuous simulation and rainfall

Hydrology Ch. 6

Climate Change

- Five factors vulnerable to change:
  – IFD Rainfalls
  – Temporal & spatial patterns
  – Continuous rainfall sequences
  – Antecedent conditions and baseflows
  – Compound extremes
- Climate futures exploration tool provides useful summary of impact on selected factors:

https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/projections/

Climate Change

- Currently, GCMs provide robust estimates of the impacts on temperatures, but impacts on rainfalls, particularly rainfall intensities, is far more uncertain.
- Evidence for impacts on temporal and spatial patterns of rainfall is emerging, and indicates that these patterns will intensify
- In practice, the only factors that are easiest to quantify at present are the impacts of climate change on rainfall IFDs and sea levels.
- Other factors need careful thought and investigation

Climate Change

- Book 1 Ch 6 provides guidance on decision process to be used for assessing the impacts of climate change on floods:
  – Effective service life of the asset
  – Consequence of failure and costs of retrofitting
  – Assess impacts on IFD:

$$I_p = I_{ARR} \times 1.05^T$$

- See worked example in Section 6.4

Interim Climate Change Factors

Values are of the format temperature increase in degrees Celcius (% increase in rainfall)

	RCP 4.5	RCP6	**RCP 8.5**
2030	**0.719 (3.6%)**	0.739 (3.7%)	**0.822 (4.1%)**
2040	**0.925 (4.6%)**	0.915 (4.6%)	**1.119 (5.6%)**
2050	**1.123 (5.6%)**	1.085 (5.4%)	**1.449 (7.2%)**
2060	**1.271 (6.4%)**	1.294 (6.5%)	**1.865 (9.3%)**
2070	**1.394 (7.0%)**	1.526 (7.6%)	**2.333 (11.7%)**
2080	**1.477 (7.4%)**	1.778 (8.9%)	**2.776 (13.9%)**
2090	**1.527 (7.6%)**	2.009 (10.0%)	**3.21 (16.1%)**

Book 9 Chapter 4 Volume Management and Chapter 5 Conveyance Systems   7/01/2019

Climate Change

- Need to carefully consider the latest research on climate change
- For example; latest research shows links between urban heat island effects and increased rainfall intensity

Wasko, C. and A., Sharma, (2015), Steeper temporal distribution of rain intensity at higher temperatures within Australian storms. Nature Geosciences. 8, 527–529
Guerreiro S.B., H.J., Fowler, R., Barbero, S., Westra,G., Lenderink, S., Blenkinsop, E., Lewis and X., Li, (2018), Detection of continental-scale intensification of hourly rainfall extremes, Nature Climate Change, 1-5

Book 9 Chapter 4 Volume Management and Chapter 5 Conveyance Systems   7/01/2019

6

Workshop with editors on application of Australian Rainfall and Runoff (ARR2016) in Urban Areas Examples

Peter Coombes, Steve Roso & Mark Babister

With
Mikayla Ward & Sophia Buchanan

ARR Australian Rainfall & Runoff ENGINEERS
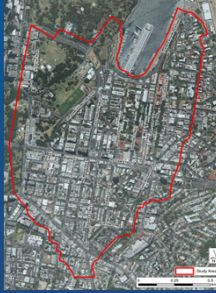
Brownfield example
Collaboration with Mikayla Ward

- Highly urbanised catchment in the Sydney CBD – 1.6 km^2
- Pit and pipe network with overland flow conveyed on roads
- Evaluating distributed flooding
- Use coupled 1D/2D hydaulic model
- Combined hydrology and hydraulic models

ARR Urban Book: Coombes, Roso, Babister   7/01/2019   **ARR** Australian Rainfall & Runoff

---

Brownfield example

- Overland flow is a major hazard that needs to be managed

7/01/2019   **ARR** Australian Rainfall & Runoff
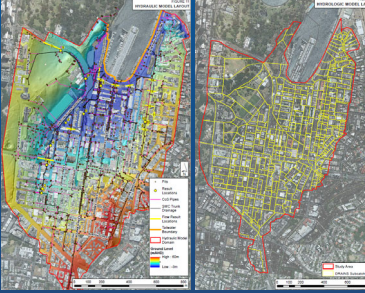
Brownfield example

Tested 3 methods
1. Hydrology model for small catchments – inflow to 1D/2D hydraulic model
2. Concentrated direct rain applied to polygons of different land surfaces with losses – inflow to 1D/2D hydraulic model
3. Direct rain less losses on grid (2 m X 2 m)

ARR Urban Book: Coombes, Roso, Babister · 7/01/2019

Brownfield example

- Data Hub
  - Rural IL = 28 mm, CL = 1.6 mm/hr, median 1% AEP 1 hr pre-burst = 1.1 mm
- Surfaces
  - 75% EIS, 20% pervious, 5% indirectly connected impervious surfaces
- Urban Burst losses (Ch. 3, Book 5 & local data less pre-burst rain)
  - EIA: IL = 0.4 mm, CL = 0 mm/hr
  - ICIA: IL = 16.1 mm, CL = 2.5 mm/hr
  - Pervious: IL = 26.8 mm, CL = 1.6 mm/hr
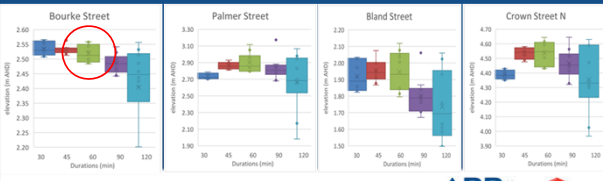- Pit blockage factors from Section 5.5, Book 9

Sag Inlet Pit	
Kerb Inlet	80%
Grated Inlet	50%
Combination	Assume Grate 100% blocked
On-grade Inlet Pit	
Kerb Inlet	80%
Grated Inlet	60%
Combination	90%

ARR Urban Book: Coombes, Roso, Babister · 7/01/2019
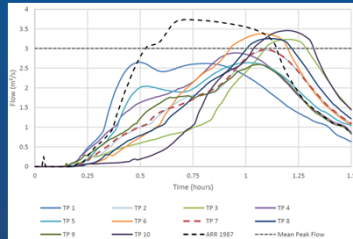

Brownfield example

- Rainfall ensembles used in combined hydrology and hydraulic model to select critical duration
  - Based on mean flood elevations
  - Spatial variation in critical duration – chose 60 minutes as best fit

ARR Urban Book: Coombes, Roso, Babister · 7/01/2019

Brownfield example

- Hydrographs from 1% AEP 60 minute rainfall ensembles compared to ARR87 single pattern at Bourke Street
  - Different runoff patterns and peak to ARR87
  - Chose Temporal Pattern 7 as the design storm

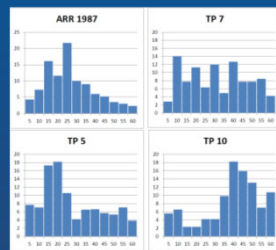

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Brownfield example

Temporal Pattern Comparison

TP5 below median discharge at Bourke St
TP10 above median discharge at Bourke St
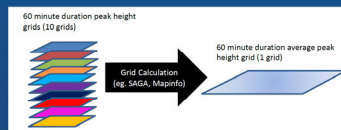

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Brownfield example

Average (mean) Grid Calculation

Tip: make sure you account for edge grids that are only wet in a some ensembles

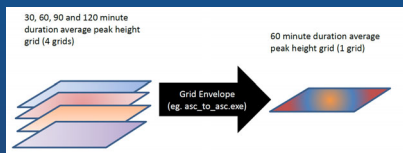ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Envelope grids

Brownfield example

Difference in level between the selected temporal pattern (TP7) and the average grid

Less than -0.25	0.0%
-0.25 to -0.1	0.0%
-0.1 to -0.05	0.8%
-0.05 to 0.05	99.1%
0.05 to 0.1	0.0%
0.1 to 0.25	0.0%
Greater than 0.25	0.0%
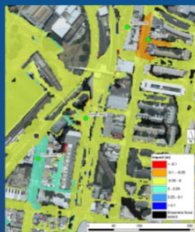
Brownfield example

- Buildings were nulled in the direct rain on grid method
  - Elevation raised by 2 m with n = 0.015
- Buildings were separate polygons in concentrated direct rain model
- Volume check undertaken in upper catchment to define catchment storage
  - Total rain + inflows – losses – outflows
  - 18% (15.4 mm) retained on grid due to topography

Type	Catchment Area (m²)	IL (mm)	CL (mm/hr)
100% Pervious	22,508	26.9	1.6
100% Impervious	102,607	0.4	0.0
EIA	133,909	0.4	0.0
ICIA	34,549	16.14	1.6
ICIA (Buildings)	234,630	16.14	1.6
AVERAGE LOSS		9.6	0.9
TOTAL (m²)	528,202		
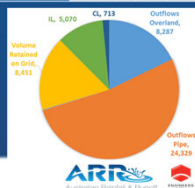
Brownfield example

- Need to correct direct rain model by reducing assumed losses
  - 5% acceptable error
  - This will increase pipe and surface flows
- Decrease assumed Initial losses
  - Outflows changed from 62 mm to 74 mm for concentrated direct rain
  - Outflows changed from 64 mm to 74 mm for direct rain on grid
- Total catchment storage (Initial losses) was 16 mm using direct rain methods with volume check
  - 15 mm storage (IL) in traditional hydrology and hydraulic model
  - Thus corrected direct rain model is OK

13   ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Brownfield example

Should also use sensitivity tests:
- No accounting for rainfall lost to depression storage
- Accounting for depression storage loss by reducing the initial loss. Apply direct rainfall with initial loss, less the average depth on grid
- Accounting for depression storage using a restart file, which reapplied the conditions from the last time step to the model. Direct rainfall applied with the initial conditions adopted from the final time step of the initial simulation

Direct rain models should also be compared to traditional hydrology and hydraulic models

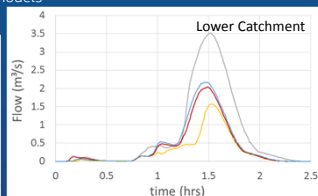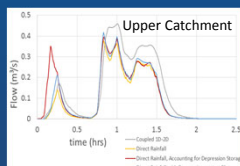14   ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Brownfield example

Uncorrected direct rain methods under-estimate surface flows
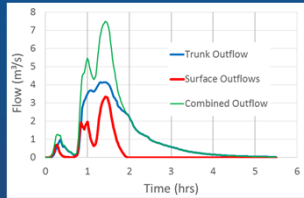- Improved results for corrected models

15   ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Brownfield example

Surface flows are a significant proportion of urban hydrology

ARR Urban Book: Coombes, Roso, Babister   7/01/2019

Tips

- Running ensembles through hydraulic model
- Make sure you account for grid cells not wet in some ensembles when taking average
- Check volume of runoff
- Find an event close to average grid results for simple development assessments

7/01/2019