



<http://researchspace.auckland.ac.nz>

ResearchSpace@Auckland

Copyright Statement

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

This thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- Any use you make of these documents or images must be for research or private study purposes only, and you may not make them available to any other person.
- Authors control the copyright of their thesis. You will recognise the author's right to be identified as the author of this thesis, and due acknowledgement will be made to the author where appropriate.
- You will obtain the author's permission before publishing any material from their thesis.

To request permissions please use the Feedback form on our webpage.

<http://researchspace.auckland.ac.nz/feedback>

General copyright and disclaimer

In addition to the above conditions, authors give their consent for the digital copy of their work to be used subject to the conditions specified on the Library Thesis Consent Form.

HYDROLOGICAL IMPACTS OF URBAN DEVELOPMENT
IN THE ALBANY BASIN, AUCKLAND.

A thesis presented in fulfilment of requirements for the degree of
Doctor of Philosophy in Geography.

Department of Geography
University of Auckland

John R. Herald

January 1989

HAPPINESS

John had
 Great Big
 Waterproof
 Boots on;
 John had a
 Great Big
 Waterproof
 Hat;
 John had a
 Great Big
 Waterproof
 Mackintosh-
 And that
 (Said John)
 Is
 That.

A.A. Milne

ABSTRACT

In several areas of Auckland, urban development has resulted in flooding and siltation problems that have been both difficult and expensive to manage. This study investigates the fluvial processes of runoff and sediment generation with a pastoral catchment of the Albany Basin and assesses the potential hydrological impacts of urban development with its catchment area. During the study period this catchment was on the fringe of the urban development of Auckland's North Shore.

By examining the factors that control runoff and sediment generation within a pastoral catchment, site information that may be useful for controlling runoff and sediment generation within an urbanised Albany Basin is gained. To assess the impacts of urban development, streamflows and suspended sediment yields from catchments representative of three different land uses are compared: pastoral, urban construction and developed urban. Stream channel enlargement indices for a number of nearby catchments with different proportions of urban land cover are also determined and compared.

The study shows significant increases in stormflows and suspended sediment yields from catchments that are either fully developed or undergoing construction for urban use. But due to the relatively dry weather experienced during the study period these results are thought to underestimate the impact of urbanising the Albany Basin. The investigation of stream channel enlargement shows that for totally urban catchments stream channel cross-sectional areas may be nearly three times those for pastoral catchments.

Methods for controlling the impact of urban development on streamflows, sediment yields and channel enlargement are discussed. It is proposed that by developing techniques where by storm runoff is dispersed and stored within the considerable soil moisture storage capacity of an urban land cover, of the type planned for the Albany Basin, that a considerable reduction in stormflow and sediment generation may be achieved. The study concludes that through careful land use planning and the use of appropriate control structures the impacts of urban development may be reduced to acceptable levels.

ACKNOWLEDGEMENTS

I am sincerely grateful to Prof. Paul Williams for his guidance and encouragement as supervisor of this thesis.

The Water and Soil Division of Ministry of Works and Development provided financial support for which I am also very grateful.

To Catherine, my wife, I extend a very special thanks for her understanding and encouragement during the difficult times of this work and in particular I appreciated her methodical proof reading of the text.

I also wish to thank Dr. Peter Hosking for his interest and valuable comments; and the Department of Geography at Rhodes University for the use of computing and word processing facilities.

Finally, to my parents I am very grateful for their encouragement and support.

TABLE OF CONTENTS

	Page Number
Abstract	III
Acknowledgements	V
Table of Contents	VI
List of Figures	X
List of Tables	XVII
List of Plates	XXI
 CHAPTER ONE	
INTRODUCTION	1
1.1 Aims of Research	3
1.2 Research Procedure	5
1.3 The Albany Basin	5
Topography	5
Geology and Soils	7
Climate	7
Land Use	11
1.4 Significance of Research Theme	12
 CHAPTER TWO	
THEORETICAL BACKGROUND	20
2.1 Development of the Runoff Generation Theory	20
Horton's Model	21
The Variable Source Area Model	23
2.2 Hillslope Erosion	30
2.3 The Impact of Urban Development	38

CHAPTER THREE

RESEARCH DESIGN	44
3.1 Conceptual Framework	45
3.2 Research Design	49
3.3 The Experimental Basins	55
Grassland Catchment	56
Developing Catchment	63
Chartwell Catchment	65
3.4 Representativeness of the Study Period	66

CHAPTER FOUR

METHODS OF DATA COLLECTION AND ANALYSIS	72
4.1 Methods of Data Collection	72
Precipitation	72
Streamflow Measurement	77
Water Quality Sampling and Analyses	82
Groundwater Level	83
Saturated Hydraulic Conductivity	
Measurement	84
Soil Moisture Tension	86
Grass Cover Index	90
4.2 Analytical Techniques	90
Computer Processing	90
Double Mass Curve Analysis	92
Antecedent Precipitation Index	92
Flow Duration Curves	93
Hydrograph Separation	94
Stream Channel Ordering	96

CHAPTER FIVE

4	RUNOFF GENERATION IN THE GRASSLAND BASIN	98
5.1	Variations in Hydrological Response	102
	Streamflow Yield	102
	Variations of Runoff Regimes	109
	Variations in Stormflow Response	110
5.2	Factors Controlling Runoff Generation	114
	Rainfall Characteristics	115
	Physiographic Characteristics	123
5.3	Mechanisms of Runoff Generation	136

CHAPTER SIX

	SUSPENDED SEDIMENT GENERATION WITHIN THE	
6	EXPERIMENTAL GRASSLAND CATCHMENT	143
6.1	Suspended Sediment Concentrations	144
6.2	Suspended Sediment Loads	169
6.3	Processes of Suspended Sediment	
	Generation	179

CHAPTER SEVEN

7	THE IMPACT OF URBAN DEVELOPMENT ON STREAMFLOW	183
7.1	Changes to Specific Water Yield	185
7.2	Changes to Streamflow Regimes	200
7.3	Changes to the Storm Hydrograph	204
7.4	Impact on Streamflow Magnitude and	
	Frequency	209
7.5	Lessening the Impact of Urban	
	Development	212

CHAPTER EIGHT

IMPACT OF URBAN DEVELOPMENT ON EROSION AND SEDIMENT GENERATION	219
8.1 Suspended Sediment Concentrations	220
8.2 Suspended Sediment Yields	239
8.3 Stream Channel Erosion	247
8.4 Lessening the Impact of Urban Development	259

CHAPTER NINE

CONCLUSION	267
9.1 Streamflow Generation within Pastoral Catchments	268
9.2 Sediment Generation within Pastoral Catchments	272
9.3 Impacts of Urban Development on Streamflow	274
9.4 Impacts of Urban Development on Sediment Generation	277
9.5 Lessening the Impact of Urban Development	279

APPENDICES

APPENDIX A

APPENDIX B

APPENDIX C

REFERENCES

LIST OF FIGURES

Figure Number	Title	Page Number
Fig. 1:1	Location of the Albany Basin and Wairau valley.	2
Fig. 1:2	Topography of the Albany Basin.	6
Fig. 1:3	Physiography of the Albany Basin.	8
Fig. 1:4	Geology of the Albany Basin.	9
Fig. 1:5	Soils of the Albany Basin.	10
Fig. 1:6	Mean monthly rainfall at Whenuapai from 1951 to 1980.	11
Fig. 1:7	Land cover of the Albany Basin in 1980.	13
Fig. 1:8	Sediment yields and channel responses to an hypothetical sequence of land use change.	14
Fig. 1:9	Changing land use of the Wairau valley from 1940 to 1977.	15
Fig. 1:10	Projected land cover of the Albany Basin.	17
Fig. 2:1	The downslope accumulation of overland flow by the Horton method of generation.	22
Fig. 2:2	The variable source area model.	23
Fig. 2:3	Moisture content versus depth profiles and models of overland flow generation.	26
Fig. 2:4	A schematic representation of the sub-area model of Beven and Kirkby's physically based contributing area runoff model.	29

Figure Number	Title	Page Number
Fig. 2:5	Curves of erosion and deposition for uniform material according to Hjulstrom.	34
Fig. 2:6	Equilibrium of a spherical particle on a bed of similar particles beneath a fluid stream.	35
Fig. 3:1	Research framework of the current study.	46
Fig. 3:2	The drainage basin as a functionally significant unit with many subsystems.	47
Fig. 3:3	Location of the catchments monitored for this study.	51
Fig. 3:4	Topography and instrumentation of the Grassland and Developing catchments.	52
✓ Fig. 3:5	The Alexandra catchment.	57
✓ Fig. 3:6	The Alexandra experimental catchments.	60
Fig. 3:7	Slope angles within the Experimental Grassland catchment as calculated from a 5 metre square grid of elevation data.	61
Fig. 3:8	Slope categories for percentage areas of the Experimental Grassland, Grassland North and Grassland South catchments.	62
Fig. 3:9	Chartwell catchment	64
Fig. 3:10	Cumulative double-mass curve of annual rainfall recorded at Albert Park and Whenuapai for the period 1951 to 1980.	66
Fig. 3:11	Summary of Whenuapai monthly rainfall for period 1951 to 1980.	68

Figure Number	Title	Page Number
Fig. 3:12	Variations from the mean monthly rainfall recorded at Whenuapai for the period January 1981 to May 1983.	69
Fig. 4:1	Cumulative double-mass curve of monthly rainfall for the Alexandra master rainfall record and that for Whenuapai during the study period.	75
Fig. 4:2	Cumulative double-mass curve of monthly rainfall for the Alexandra master rainfall record and that for the Santa Maria gauge.	76
Fig. 4:3	Design of permeameter used for measuring hydraulic conductivity.	85
Fig. 4:4	Design of tensiometer used for measuring soil moisture tension.	87
Fig. 4:5	Definition of Hewlett and Hibbert's hydrograph separation technique.	94
Fig. 4:6	An hypothetical stream network ordered according to Graf's cumulative system.	97
Fig. 5:1	Topography and instrumentation of the Experimental Grassland catchment.	101
Fig. 5:2	Streamflow yields from sub-areas of the Experimental Grassland catchment.	103
Fig. 5:3	Variations in the level of the ground-water table near the outlet of the Experimental Grassland catchment.	106

Figure Number	Title	Page Number
Fig. 5:4	Flow duration curves for sub-basins of the Experimental Grassland catchment.	108
Fig. 5:5	Comparison of stage hydrographs for Grassland North and Grassland South for the period 28-7-82 to 3-8-82.	111
Fig. 5:6	Comparison of soil water pressures as recorded by tensiometers in the Experimental Grassland catchment.	126
Fig. 5:7	Flow paths and the accumulation of drainage areas within Grassland North and Grassland South.	132
Fig. 5:8	Mean dry weight of grasses in the Experimental Grassland catchment	135
Fig. 6:1	Suspended sediment rating curves developed for streamflow from Grassland North	147
Fig. 6:2	Suspended sediment rating curves developed for Grassland South	150
Fig. 6:3	Suspended sediment rating curves developed for the Experimental Grassland catchment.	152
Fig. 6:4	Variations in total and organic suspended sediment concentrations during the stormflow event from Grassland North on 14 July, 1982.	158

Figure Number	Title	Page Number
Fig. 6:5	Variations in total and organic suspended sediment concentrations during the stormflow event from Grassland South on 14 July, 1982.	159
Fig. 6:6	Variations in total and organic suspended sediment concentrations during the stormflow event from the Experimental Grassland catchment on 8 December, 1981.	162
Fig. 6:7	Variations in total and organic suspended sediment concentrations during the stormflow event from Grassland North on 8 December, 1981.	164
Fig. 6:8	Variations in total and organic suspended sediment concentrations during the stormflow event from Grassland South on 8 December, 1981.	165
Fig. 6:9	Conceptual model of relationships between stormflows, suspended sediment concentrations and soil moisture status.	181
Fig. 7:1	Monthly water balance for the Grassland catchment.	188
Fig. 7:2	Monthly water balance for the Alexandra catchment.	189
Fig. 7:3	Monthly water balance for the Developing catchment.	190

Figure Number	Title	Page Number
Fig. 7:4	Monthly water balance for the Chartwell catchment.	191
Fig. 7:5	Percentage of rainfall discharged as streamflow for the Grassland, Alexandra, Developing and Chartwell catchments.	196
Fig. 7:6	Flow duration curves for streamflow from Alexandra, Grassland, Developing and Chartwell catchments.	201
Fig. 7:7	Unit hydrographs determined for Briar Creek under different percentages of impermeable surface.	208
Fig. 7:8	Effects on flood magnitude of paving twenty percent of a basin.	211
Fig. 8:1	Suspended sediment rating curves for the Grassland catchment.	222
Fig. 8:2	Suspended sediment rating curves for the Developing catchment.	225
Fig. 8:3	Suspended sediment rating curves for the Chartwell catchment.	228
Fig. 8:4	Comparison of suspended sediment rating curves for the Grassland, Developing and Chartwell catchments.	230
Fig. 8:5	Variations in suspended sediment concentrations of streamflow from the Grassland catchment on 22 June, 1982.	233

Figure Number	Title	Page Number
Fig. 8:6	Variations in suspended sediment concentrations of streamflow from the Developing catchment on 22 June, 1982.	236
Fig. 8:7	Variations in suspended sediment concentrations of streamflow from the Chartwell catchment on 30 April, 1982.	238
Fig. 8:8	Effect of construction and drainage area on sediment yield.	242
Fig. 8:9	Definitions for channel cross-sections and their measurement.	249
Fig. 8:10	Location of channel cross-sections surveyed for this study.	250
Fig. 8:11	Variations in channel enlargement ratio with increasing percentage of urban land cover.	255

LIST OF TABLES

Table Number	Title	Page Number
Table 2:1	Channel enlargement effects of land use in a one square mile basin.	42
Table 3:1	Area and dominant land use of catchments monitored for the current study.	58
Table 4:1	Regression equations relating event rainfall in mm recorded by the Grassland Weir raingauge to that recorded by the State Highway 1 , Tomlinson's Farm and Santa Maria raingauges respectively.	74
Table 4:2	Control structures and stage recorders used to measure streamflow in the study catchments.	78
Table 5:1	Regression models relating rainfall catch, mean and maximum ten minute rainfall intensities and antecedent precipitation to rapid runoff generated in sub-areas of the Experimental Grassland catchment.	117
Table 5:2	Regression models relating stormflows from the Experimental Grassland catchment and the Grassland Sideslopes to rainfall totals, intensities and antecedent precipitation index values.	119

Table Number	Title	Page Number
Table 5:3	Regression models relating index values for the area contributing to storm runoff to values of antecedent precipitation and rainfall intensity.	122
Table 5:4	Description of tensiometer locations.	125
Table 5:5	Saturated hydraulic conductivity measurements for sites in the Experimental Grassland catchment.	134
Table 6:1	Coefficients of determination and F statistics of the suspended sediment rating curve equations developed for Grassland North, Grassland South and the Experimental Grassland catchment	146
Table 6:2	Suspended sediment loads generated from the Experimental Grassland catchment and from the Grassland South and Grassland North sub-basins for the period November 1981 to October 1982.	171
Table 6:3	Suspended sediment loads generated from the Experimental Grassland catchment and from the Grassland South and Grassland North sub-basins during twenty-five stormflow events.	172

Table Number	Title	Page Number
Table 6:4	Regression models relating variations of rainfall catch, rainfall duration, mean and maximum ten minute rainfall intensity and antecedent rainfall to storm event sediment loads from Grassland South, Grassland North and the Experimental Grassland catchment.	176
Table 7:1	Regression models relating rainfall catch, mean and maximum rainfall intensities and antecedent precipitation to the rapid runoff generated from the Grassland, Developing and Chartwell catchments.	206
Table 8:1	Coefficients of determination and F statistics of suspended sediment rating curves for the Grassland, Developing <i>and</i> Chartwell catchments	221
Table 8:2	Suspended sediment yields from the Grassland, Developing and Chartwell catchments for the period November 1981 to November 1982.	240

Table Number	Title	Page Number
Table 8:3	Regression models relating variations in rainfall catch, rainfall duration, mean and maximum ten minute rainfall intensity and antecedent rainfall to storm event sediment loads from the Grassland, Developing and Chartwell catchments.	244
Table 8:4	Statistics for student T-test comparison of means of areas, length/width ratios, elevation range and stream channel gradients of the two sets of catchment data.	252
Table 8:5	Multiple regression model developed for predicting channel cross-sectional areas for rural streams using catchment physiographic parameters.	253
Table 8:6	Comparison of surveyed urban and estimated pre-urban stream channel cross-sectional areas.	254
Table 8:7	Channel enlargement ratios due to urban development.	258

LIST OF PLATES

Plate Number	Title	Page Number
Plate 1:1	An area of pastoral land cover on the urban fringe of Auckland's North Shore.	4
Plate 1:2	Sections of the Wairau Creek are contained within concrete lined channels.	19
Plate 3:1	View looking north from the top of the Experimental Grassland catchment towards the Developing catchment.	59
Plate 3:2	The disturbed clay surface of the Developing catchment.	59
Plate 3:3	The discharge rated concrete lined channel at the outlet of the urbanized Chartwell catchment.	71
Plate 4:1	The 1.5 Ft. H flume used for measuring streamflow from the Experimental Grassland catchment.	79
Plate 4:2	The fibre glass 1.0 Ft. HS flume used for measuring streamflow from Grassland North.	81
Plate 4:3	Ceramic pot tensiometer used for monitoring soil moisture tension within the Experimental Grassland catchment.	88

Plate Number	Title	Page Number
Plate 5:1	A view looking up the Experimental Grassland catchment with the Grassland Weir concealed by the scrub in the foreground.	100
Plate 8:1	Temporary suspended sediment retention dam on a construction site within the Wairau valley.	261