IMPACT OF URBANIZATION ON THE HYDROLOGY OF WAIRAU CREEK, NORTH SHORE, AUCKLAND

P. W. Williams*

ABSTRACT

Hydrological changes that have occurred as a consequence of the urbanization of a small catchment of 11.4 km² on the North Shore of Auckland are examined. The catchment is mainly developed on relatively impermeable siltstones and fine sandstones. It originally had a cover of subtropical evergreen rain forest but by 1940 was predominantly grassland and scrub. In 1959 almost three-quarters of the catchment was covered in bush, scrub and grassland, but by 1975 almost three-quarters of the basin was in urban uses. Hydrological records that commenced in 1962 indicate that up to the present the number of small floods contained within the channel have increased five times and that the number of larger floods has also increased, especially since the channel was lined with concrete. In general there appears to be an inverse relationship between flood frequency increase and flood magnitude. Flood hydrographs have also changed over the period, becoming much more peaked. Floods now strike more swiftly, rise higher and run off more rapidly than before urbanization. Sedimentation has also increased. Suspended sediment concentration in storm drainage from a neighbouring East Coast Bays residential subdivision attained 59 000 mg/l, which is as high as any concentration ever recorded in New Zealand. In the Wairau Creek catchment, preliminary sediment rating curves were constructed for tributary streams draining areas of different land use. It was concluded that, even when residential areas become established, sediment yield remains unexpectedly high. Silt discharge from the Wairau basin contributes to sedimentation of the estuary at Milford and incurs considerable costs for de-silting the marina. Environmental costs arising from flooding and siltation are estimated, and it is concluded that the costs are not being borne by those that produce them, but are being transferred to the community.

INTRODUCTION

The twentieth century has been marked not only by a rapidly increasing population, but also by a rural-to-urban migration. One result of this population growth and movement has been the vigorous expansion of built-up areas – a process that implies the urbanization of previously rural river catchments. The extension of

* Department of Geography, University of Auckland, Auckland.

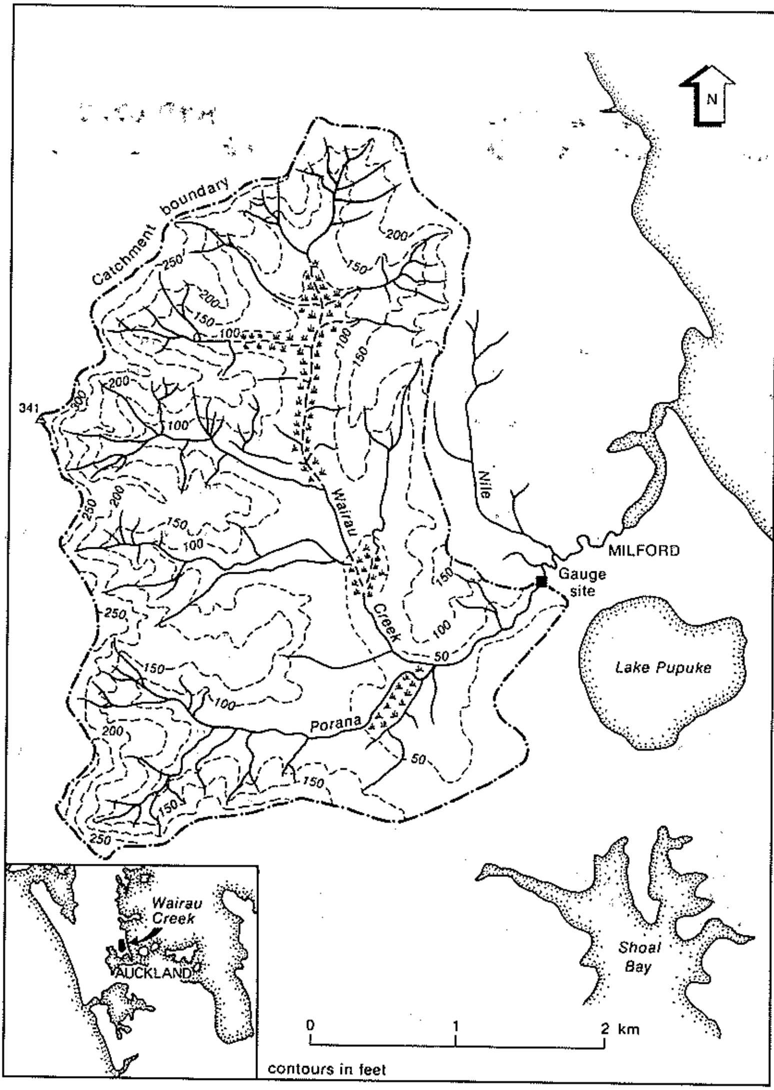

FIG. 1 — Basin of the Wairau Creek.

city boundaries and the conversion of agricultural land to urban uses is not new, but the rapidity of land-use change is a novel feature of our times. The speed and style of conversion of land to urban uses renders the consequences of change more noticeable than before, and in an environmentally conscious era the unnecessary and unpleasant impacts of urbanization are not lightly tolerated. Planning guidelines are required to reduce the environmental cost of catchment urbanization, but before these can be established it is necessary to identify and explain the changes that occur. Thus it is the purpose of this paper to examine the impact of urbanization on the hydrology of a small previously rural catchment on Auckland's North Shore and to consider some of the monetary consequences of the process. A large number of studies on urban hydrology have recently been completed overseas (e.g. Leopold, 1968; Walling and Gregory, 1970; Hollis, 1974, 1975), although this is the first detailed case study in New Zealand and the first to consider the financial implications. Howe and Waugh (1972) provided a preliminary analysis of local data up to 1971.

CATCHMENT CHARACTERISTICS

Geology and Relief

The area examined is the 11.4 km² basin of the Wairau Creek (Fig. 1). The catchment is incised into a low plateau that attains 104 m on the highest part of the watershed. Slopes rarely exceed 15°, being steepest on the valleysides of headwater tributaries. The creek initially drained southwards into Shoal Bay, but following the volcanic eruption at the site of Lake Pupuke some 40 000 years ago (Searle, 1964) it was diverted eastwards to its present estuary at Milford (Fig. 1). The impediment to drainage caused by volcanic deposits resulted in a marshy valley floor that was a characteristic of the creek system before urbanization. Although Quaternary basalts outcrop in the lower reaches of the basin, volcanics are not areally important in the catchment, which is mainly underlain by mudstone, siltstone and sandstone of the Miocene Waitemata Formation (Ballance, 1965; Schofield, 1967). Weathering of the Waitemata rocks commonly extends downwards for at least 10 metres, resulting in a rather impermeable regolith of silty clay upon which yellow-brown podzolic soils are developed (Pohlen, 1965). The Wairau Creek system is thus located on rocks and soils that are intrinsically relatively impermeable and have little groundwater storage capacity.

Climatic Water Balance

When investigating the magnitude of hydrological changes perhaps attributable to urbanization, it is necessary first to consider the possibility that all or part of the observed changes may be ascribable to some other independent causes such as climatic variation. Long-term climatic records are not available for the Wairau basin, but since short-term rainfall records for the basin and for Lake Pupuke correlate highly with data for Albert Park, Auckland, the Albert Park information was used for long-term analysis.

The 1941–1970 mean annual rainfall at Albert Park was 1268 mm. Average runoff from this is estimated to have been equivalent to 539 mm per annum (N.Z. Meteorological Service, 1973). Rainfall, runoff and water deficit are highly seasonal (Fig. 2a), the water surplus being ten times greater in July than in January. Meteorological Service estimates indicate a mean annual water deficit of 87 mm in total between December and April, the maximum monthly deficits occurring in January and February. The data from Riverhead and Whenuapai stations show a similar pattern.

Five-year running means of rainfall and runoff at Albert Park suggest that the period since 1953 has been significantly wetter than the previous two decades, with on average perhaps 50 mm more runoff per annum. But over the main period of urbanization of the Wairau basin since 1960, there appears to have been no systematic trend or change in the climatic water balance that could account for any progressive shifts in the runoff pattern of the Wairau Creek (Fig. 2b). Variations in the incidence of rainfalls of particular intensities could influence flooding frequencies, although there is no reason to suspect such rainfall changes.

Vegetation and Land Use

Before the arrival of Polynesians and Europeans, most of the Auckland region was covered with subtropical evergreen rain forest. The mild almost frost-free habitat of the Wairau basin would have supported a podocarp/broadleaf forest association dominated by kauri, but with kahikatea more prominent in the marshy valley bottoms. Tidal mangrove swamp occupied the estuary at Milford.

Many of the large trees had already been felled or burnt by the mid-nineteenth century (Millener, 1965), when the Wairau basin would have been vegetated by patches of the original forest, manuka bush and swamp. These were gradually cleared for farm land during the first few decades of this century, so that by 1940 just over half the basin had been converted to grassland, but still only 6 percent of the land was used for roads and residential sites, and this was mainly near the coast.

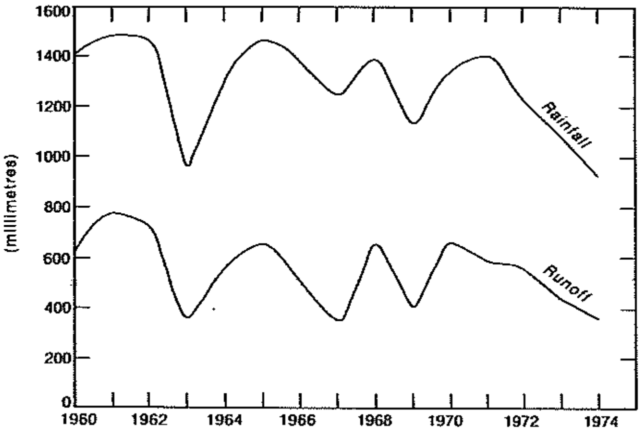

FIG. 2b — Auckland (Albert Park) : annual rainfall and runoff 1960–1974. *Source: N.Z. Meteorological Service.*

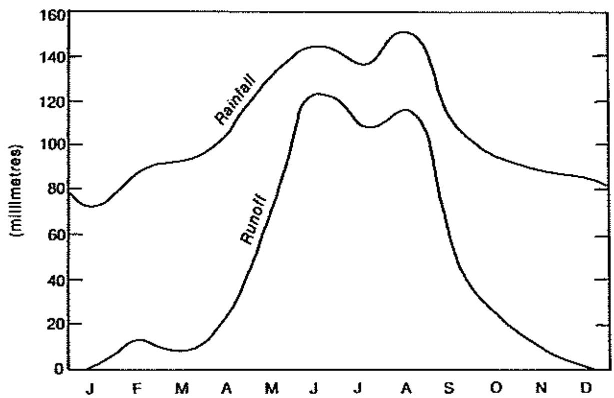

FIG. 2a — Auckland (Albert Park) : mean monthly rainfall and runoff 1960–1974. *Source: N.Z. Meteorological Service.*

The spur to urbanization was provided by the opening of the Auckland harbour bridge in 1959. Rapid communication to the North Shore resulted in a surge of suburban and industrial development into the Wairau basin, such that the 10 years following the opening of the harbour bridge saw twice the number of new buildings erected in the basin than the previous decade. In 1959 almost three-quarters of the catchment was covered in bush, scrub and grassland, but by 1969 less than half the basin remained under this vegetation, and by 1974 it had been reduced by urban inroads to

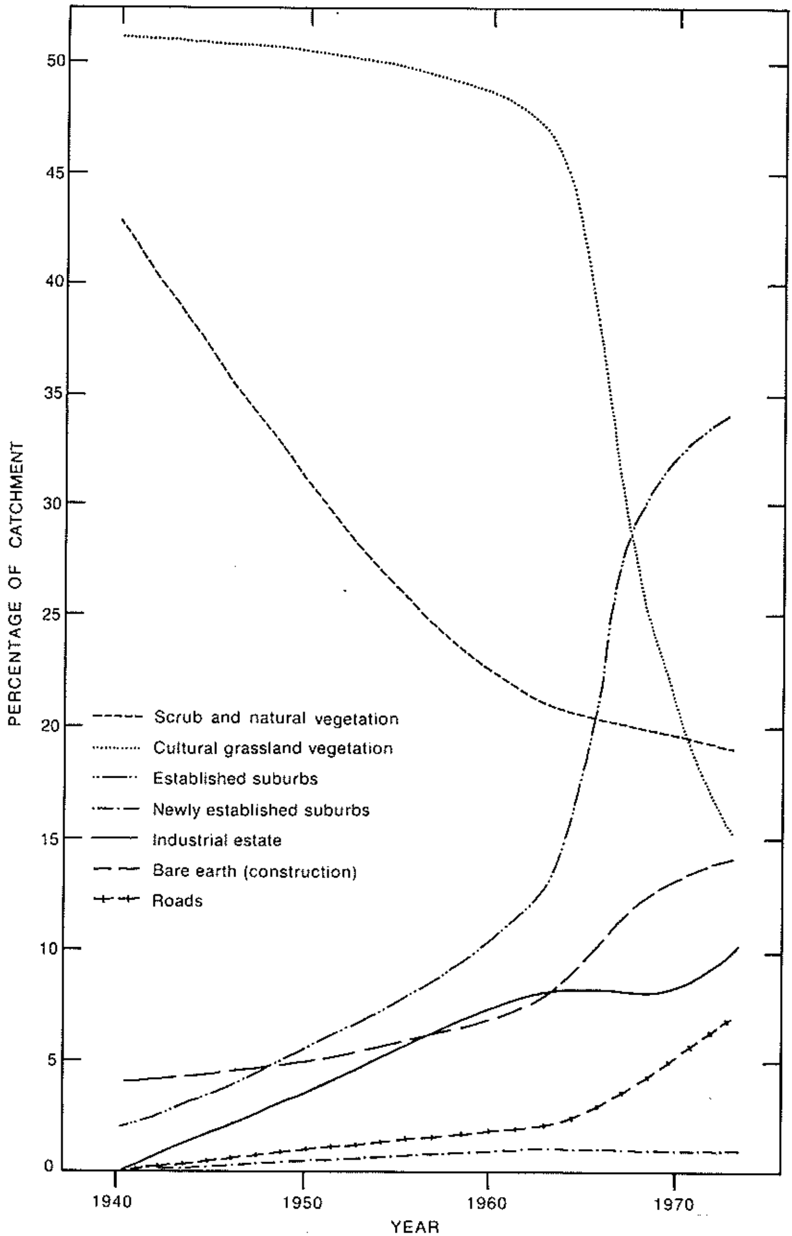

FIG. 3 — Changes in land use: Wairau basin 1940–1973.

only one-third of the catchment area (Fig. 3). Although the effect of the opening of the harbour bridge on land use in the basin is quite clear, the reaction was slightly delayed. The turning point appears to have been in 1962. Up until that time suburban growth had consumed only 12 percent of the catchment, whereas in the next decade it expanded to 34 percent along with additional parallel growth in roading and new industrial sites, with the result that by 1972 approximately 65 percent of the basin was in urban uses. 'Urban' land in this context is taken to include suburban housing sites, roads, industrial and construction sites and public buildings. 'Non-urban' land consists of remaining patches of bush and scrub, and large areas of grassland such as fields and parks. Urban land has approximately 15 percent impervious cover and is extensively storm-sewered.

HYDROLOGICAL RESPONSES TO URBANIZATION

Hydrological monitoring of the Wairau Creek by the Ministry of Works commenced in 1962. Thus the effects on streamflow of the major land-use change from predominantly rural to urban conditions are recorded. Channel works in 1972–73 resulted in a temporary break in the streamflow record. Re-rating the new situation is not yet completed.

Flooding Frequency

An investigation of flooding frequency was stimulated because of many local complaints that the incidence of flooding had markedly increased. In order first to establish if the increased flooding was real or perceived, the numbers of floods per annum exceeding three heights were noted and plotted for each year of record (Fig. 4). The three heights were selected to include bankfull and two arbitrary lower levels as follows: (1) bankfull (2.90 m old channel stage, approximately 10 m^3/s discharge), (2) 1.98 m old channel stage (2.7 m^3/s) and (3) 1.52 m (just over 1 m^3/s). For comparison, mean annual discharge is approximately 0.21 m^3/s, which was represented by an old channel stage of 1.01 m.

The conclusions that may be drawn from this simple analysis are (1) that flooding frequency undoubtedly increased during the period, although overbank flooding only increased after 1968 (by which time 53 percent of the basin was urbanized), and (2) that there is an inverse relationship between flood frequency increase and flood magnitude. The number of small (>1 m^3/s) floods contained within the channel increased five times, whereas larger floods were until recently progressively less influenced. Since 1972, how-

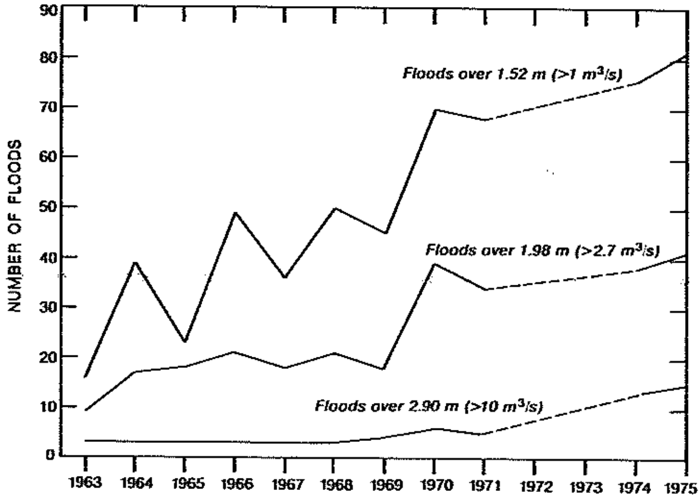

FIG. 4 — Wairau Creek: number of floods.

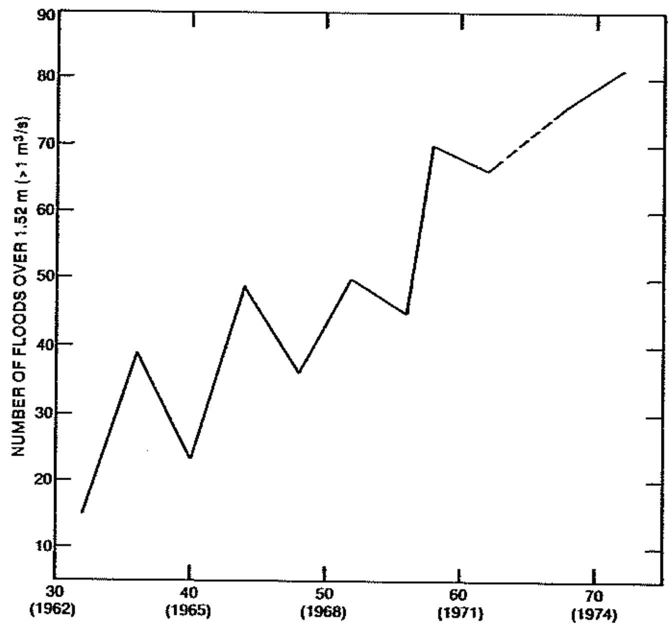

FIG. 5 — Wairau Creek: number of floods versus built-up area.

ever, the frequency of larger floods ($>10\ m^3/s$) has markedly increased, and it is probably significant that the commencement of this increase coincided with the beginning of drainage works that have involved channel enlargement and concrete lining.

The increase in flooding is most unlikely to be attributable to climatic changes, for reasons noted earlier. The direct relationship between the number of floods (of the three magnitudes noted above) and the percentage of built-up or 'urbanized' area in the Wairau basin (Fig. 5) is taken to be a causal one, particularly since overseas work points strongly to this conclusion. Only individual annual deviations from the trend depicted in Fig. 5 are ascribable to climatic variations, and these can be taken to operate on a random basis for the short period involved.

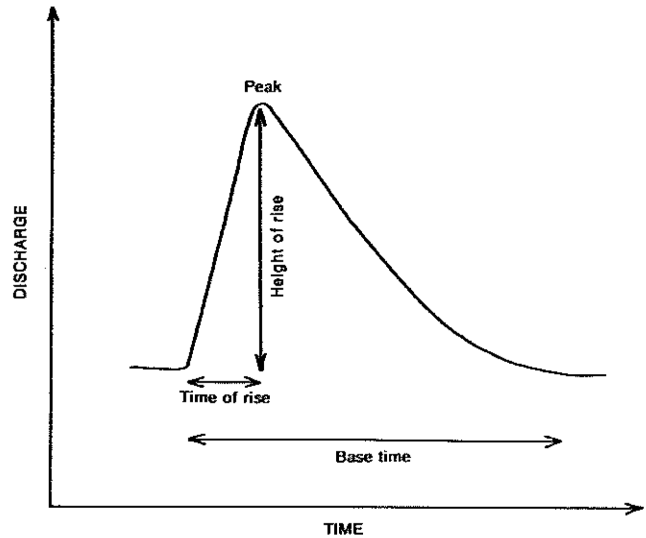

FIG. 6 — Flood hydrograph.

Detailed examination of flood hydrographs (Fig. 6) reveals further changes to have occurred. The mean height of rise of floods was found to increase directly with the percentage of urban land use (Fig. 7). Simultaneously, the mean time of rise of these floods decreased steadily from about 7 hours in 1963 to 5.5 hours in 1971. The floods also ran off more rapidly, the mean duration of a flood (the base time) more than halving from 70.6 hours in 1963 to 32.7 hours in 1971. Thus the general effect of urbanization has been for floods to strike more swiftly, rise higher and to run off more rapidly than before. Floods are thus more peaked (Fig. 8), with the

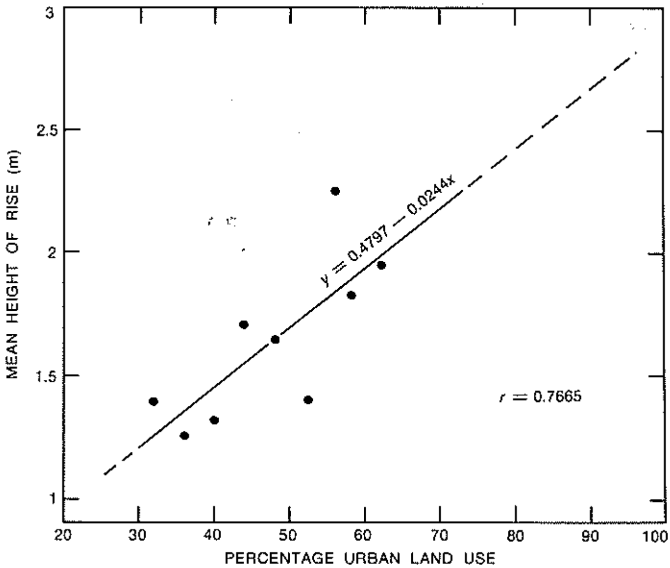

FIG. 7 — Wairau Creek: flood height increase.

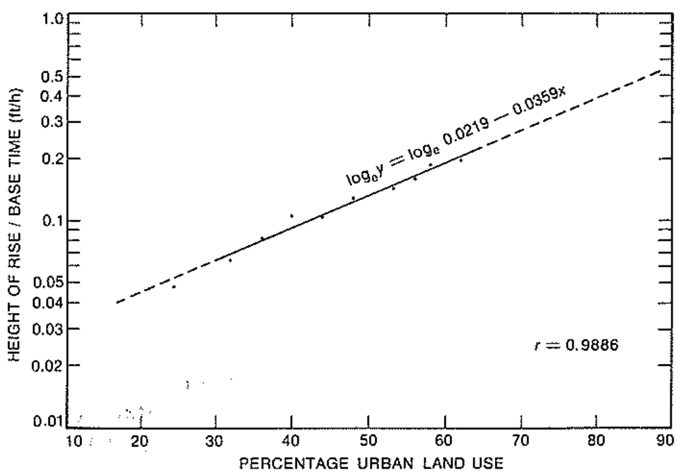

FIG. 8 — Wairau Creek: flood peakedness.

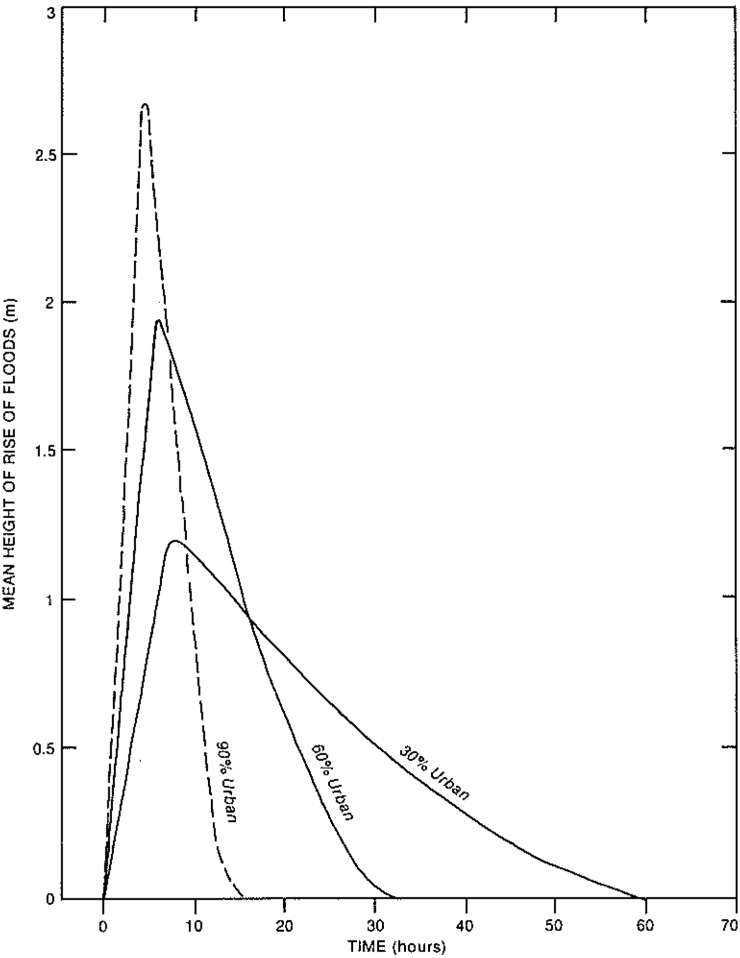

FIG. 9 — Wairau Creek: changing flood hydrograph shape.

response to rainfall being more rapid than under rural conditions (Fig. 9). Whereas extended rain was necessary to produce a flood of overbank magnitude, storms of much shorter duration can now produce significant floods, because the dense network of storm sewers in the basin efficiently concentrates the runoff in a very short period. If present trends continue, the mean height of rise of floods when 90 percent of the basin is urbanized will be 2.67 m (old channel stage), implying a peak discharge of about 9 m^3/s, which is not much less than the old bankfull flow. The new concrete-lined channel fortunately has a much increased bankfull discharge capa-

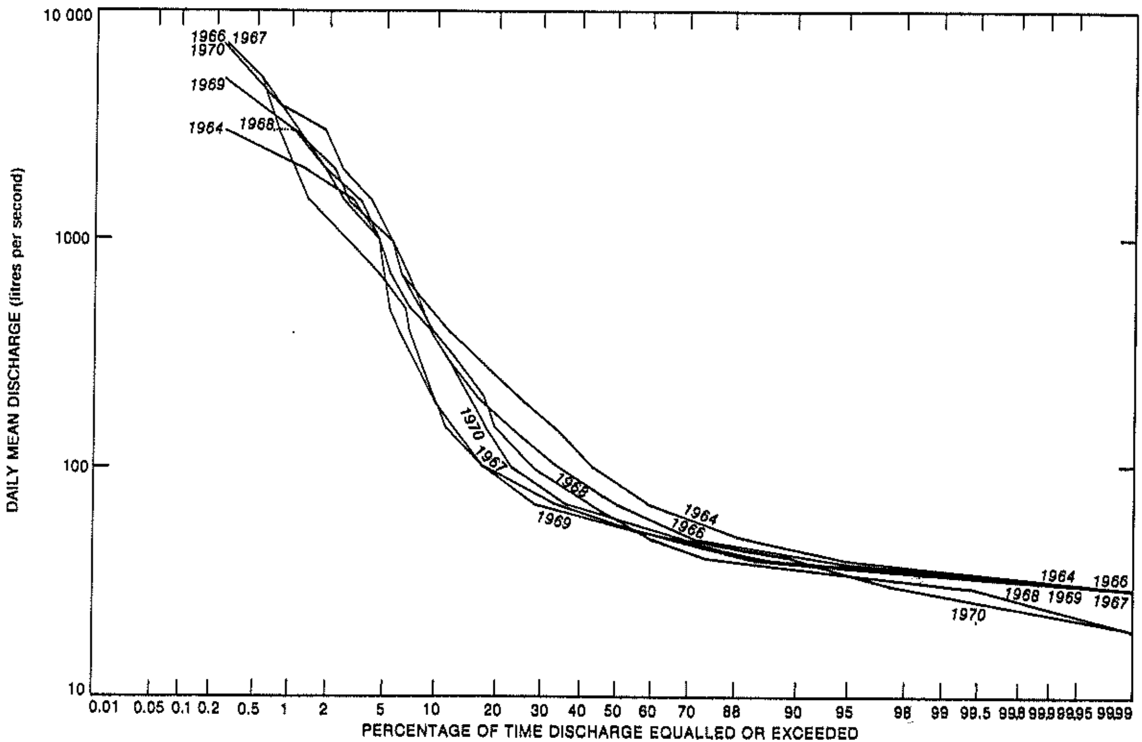

FIG. 10 — Wairau Creek: flow-duration curves (Alma Road).

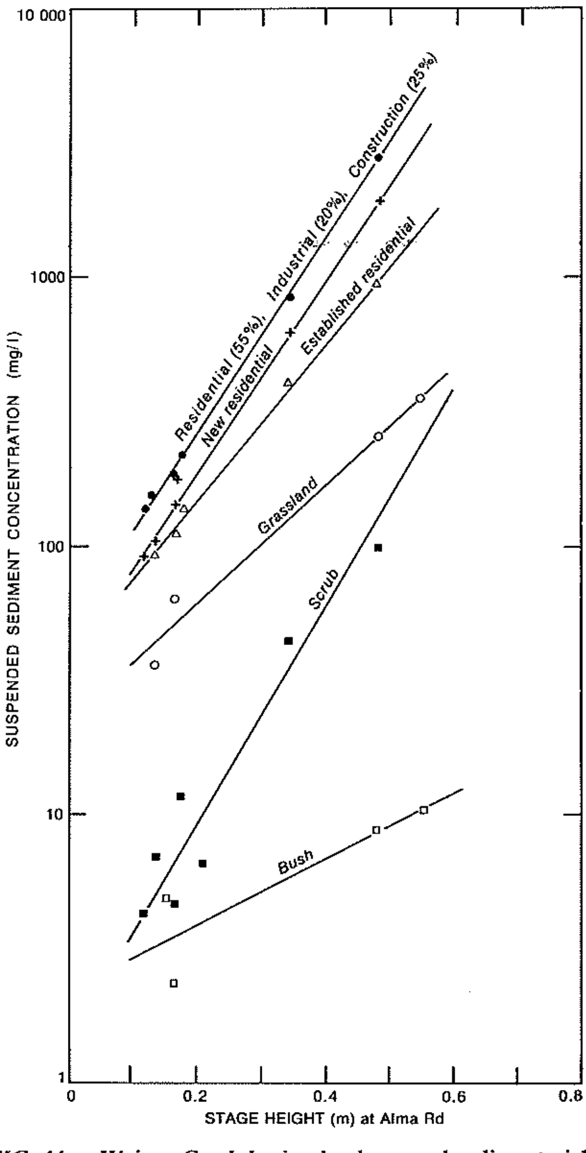

FIG. 11 — Wairau Creek basin: land use and sediment yield.

city, probably of about 50–60 m^3/s, so most future flooding should be contained within the enlarged channel.

In a natural catchment, bankfull discharge is expected in theory to occur once every 1.5 to 2 years. By the time hydrological measurements had commenced in the Wairau Creek, when urbanization had already reached 30 percent, bankfull discharge was being recorded three times every year. And by 1970–71, with 62 percent urbanized, it was occurring five times per year, i.e. eight to ten times more frequently than under assumed natural conditions.

Flow Duration

With the expansion of the impervious area and with more rapid runoff via a high-density network of stormwater drains, there is less opportunity for percolation to groundwater storage than under natural conditions. Hence the flow-duration characteristics of an urbanized stream could be expected to change with time as building advanced. High flows should become more extreme and low flows less well sustained. However, the Wairau data are inconclusive on this point, mainly because there is no information from the natural catchment. Flow-duration curves for 1964 to 1970 as urbanization increased from 37 to 58 percent show no successive modification (Fig. 10), although more detailed analysis of the extremities of the curves might reveal subtle modifications.

Sediment Yield

The vegetation cover acts as a control mechanism in the fluvial erosion system. Thus streams draining different land-use categories with contrasting vegetation types can be expected to yield different sediment loads. Assuming slope and lithologic factors to be essentially constant, small streams draining subcatchments of different land use in and around the Wairau basin were sampled in order to establish comparative suspended-sediment rating curves. These are illustrated in Fig. 11. The curves are based on few data points and so are clearly only provisional inaccurate guides to the situation. However, the contrasts are sufficiently great as to merit much more work on the subject. The information suggests that during low flows construction, industrial and new residential localities yield 30–40 times more suspended sediment than bushed sites, a difference that increases to 300–500 times more during high flows. Since high flows are also more frequent during urbanization than before, the output of suspended sediment from a built-up catchment with development still in progress is likely to be many hundreds of times greater than under natural conditions. It is noteworthy that a sample (taken on 15 June 1974) of stormwater drainage from a major East

Coast Bays residential subdivision yielded a suspended-sediment concentration of over 59 000 mg/l, which is as high as any concentration ever recorded in New Zealand. The greatest concentration measured in the Wairau Creek was 9800 mg/l from the surface layer of the water when the discharge was about 18 m^3/s.

On the basis of provisional data collected thus far, one large flood such as that produced by Cyclone Dinah in February 1967 would result in the discharge from the Wairau basin of at least 7000 m^3 of sediment. Since a significant proportion of this – depending on the state of the tide – would be deposited in the marina at Milford, such flood events are very costly to the community. Nor does it seem possible to look too optimistically towards very much reduced sediment transport in the future. The provisional data suggest that sediment concentrations from established suburbs remain quite high, though not as extreme as during construction, probably because of the many small patches of bare ground that exist in suburban areas and because of the very high flood-flow velocities that promote scouring of tributary stream channels.

ENVIRONMENTAL COSTS

Many social and economic benefits are gained from urbanization, but there are also many costs. Some of these arise from hydrological impacts culminating in flooding and siltation.

FIG. 12 — Wairau Creek in the Wairau Road industrial and commercial estate, showing the original stream channel and building development to the edge of the floodplain.

FIG 13 — The enlarged and concrete-lined channel of the Wairau Creek immediately downstream of the Alma Road gauging site.

FIG. 14 — The Wairau Creek at the site shown in Fig. 13 in flood in June 1975 (discharge approximately 40–50 m^3/s).

Overbank flooding in the Wairau Creek before major channel improvements commenced occurred four to six times annually instead of perhaps twice every three years under natural conditions. These floods resulted in damage to property and in loss of industrial production, which by 1974 amounted to at least $132,000. An irate business community, having been permitted to build on a naturally flood-prone, previously swampy floodplain (Fig. 12), eventually persuaded the local authorities to initiate a flood-alleviation scheme. By 1976, this project will have cost the local community approximately $1,500,000, and pressure is mounting for still further work. Even more serious was the drowning of a youth in the flood of June 1975 (Figs. 13 and 14).

Downstream in the estuary at Milford, huge quantities of sediment are deposited in a pleasure-boat marina, approximately 15 000 m^3 of silt having accumulated in the small estuary in six to eight years. This is now being excavated at a cost of $\$1.80/m^3$. The silt that is not trapped there is deposited in shallow coastal waters

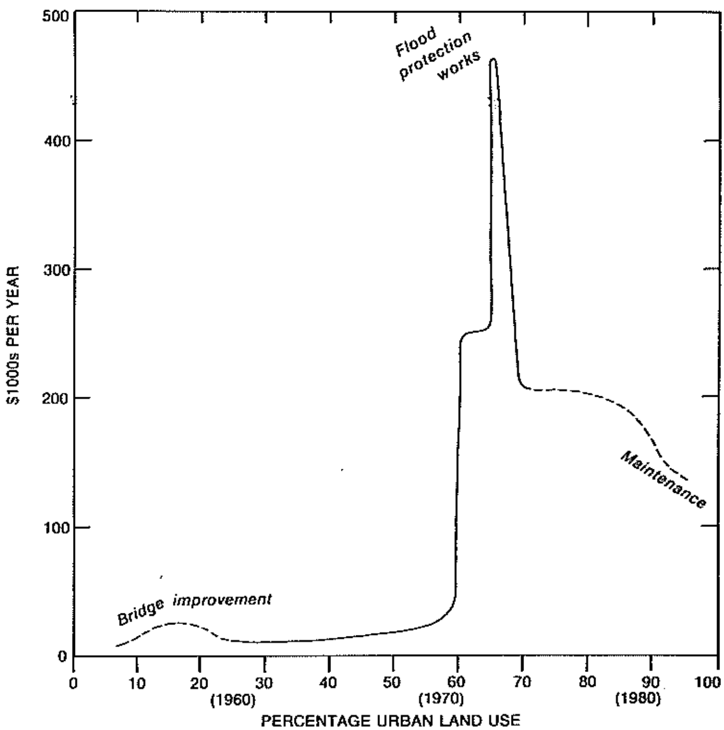

FIG. 15 — Wairau Creek basin: costs of flooding.

and distributed along the beaches to the detriment of a recreational resource and the invertebrate fauna.

Estimation of the costs of flooding and siltation in the basin is difficult because of the intangible elements. Nevertheless, average annual costs incurred by the community, mainly because of channel-improvement works and flood damage, are illustrated in Fig. 15. It is also evident that these costs are not being borne by those that produce them and that they have been made unnecessarily large by inadequate planning. The problem of transferred environmental costs from developers to a community with insufficient protection is thus clearly illustrated.

Across the watershed from the Wairau Creek is the Albany basin, now on the brink of development into a new town. Its catchment drains to the vulnerable headwaters of the Waitemata Harbour, Auckland's greatest recreational resource. With the abundant overseas and local knowledge of the hydrological problems associated with urbanization, there is now no excuse for mismanagement of this part of the environment.

ACKNOWLEDGMENTS

I wish to thank J. Waugh and R. Coates of the Hydrological Survey, Ministry of Works, for their interest and co-operation in the course of this investigation, and also a group of enthusiastic graduate students whose capable research provided some of the data reported on here.

REFERENCES

Ballance, P. F. 1965: The geology and physiography of the Auckland district. In: *Science in Auckland.* Proceedings of the 11th New Zealand Science Congress. pp. 8–19.

Hollis, G. E. 1974: The effect of urbanisation on floods in the Cannon's Brook, Harlow, Essex. In: Gregory, K. J., and Walling, D. E. *Fluvial Processes in Instrumented Watersheds.* Institute of British Geographers. Special Publication 6. pp. 123–139.

Hollis, G. E. 1975: The effect of urbanisation on floods of different recurrence interval. *Water Resources Research 11*(3): 431–435.

Howe, J. M.; Waugh, J. R. 1972: Urban hydrology to 1971. *N.Z. Ministry of Works, Hydrological Research Annual Report 24.* 21 p.

Leopold, L. B. 1968: Hydrology for urban land planning – a guidebook on the hydrologic effects of urban land use. *U.S. Geological Survey Circular 554.* 18 p.

Millener, L. 1965: Forest, scrub and fresh-water communities. In: *Science in Auckland.* Proceedings of the 11th New Zealand Science Congress. pp. 36–48.

New Zealand Meteorological Service 1973: Summaries of climatological observations to 1970. *N.Z. Meteorological Service Miscellaneous Publication 143.* 77 p.

Pohlen, I. J. 1965: Soils of the Auckland district. In: *Science in Auckland.* Proceedings of the 11th New Zealand Science Congress. pp. 28–30.

Schofield J. C. 1967: Sheet 3. Auckland (1st ed.). *Geological Map of New Zealand 1:250,000*. N.Z. Department of Scientific and Industrial Research. Wellington.
Searle, E. J. 1964: *City of Volcanoes: a Geology of Auckland*. Longman Paul. Auckland. 112 p.
Walling, D. E.; Gregory, K. J. 1970: The measurement of the effects of building construction on drainage basin dynamics. *Journal of Hydrology (Netherlands) 11*: 129–144.