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APPENDIX B

Drainage and Groundwater Management Study

FEILMAN PLANNING CONSULTANTS

THE ELLENBROOK DEVELOPMENT

DRAINAGE AND GROUNDWATER MANAGEMENT STUDY

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EXECUTIVE SUMMARY

The Drainage and Groundwater Management Study has shown that the urbanization at Ellenbrook can be developed and managed to protect and enhance the environment. The management practices proposed to manage the groundwater and surface runoff from the urban catchment can result in many benefits. These practices can:

- increase the amount of groundwater available for public and private bore abstraction;
- ensure that the water quality of the Lexia and Mirrabooka borefields will not be compromised by urbanization and can be maintained at a standard suitable for public water supply;
- minimise changes to the water regime of the natural wetlands proposed for conservation within the proposed urban area;
- reduce nutrient loads entering Ellen Brook and the Swan River.

The impacts of the proposed urbanization on the groundwater and surface waters of the area have been investigated. The study evaluates the effects of groundwater abstraction within the development area and also the impacts on the groundwater table of the proposed Lexia borefield.

Design of the urban development will incorporate principles of water sensitive design to minimise water usage and maximise recharge within the development. Water conservation will be actively promoted in the urban zone where recharge of stormwater to the groundwater will occur by various methods including the use of recharge basins.

Optimization of recharge and reuse within the proposed development, rather than disposal of all stormwater runoff, forms an important component of the trend towards an ecologically sustainable development.

It is proposed to treat the water from storm runoff using sedimentation and biological nutrient removal processes within artificial wetlands (detention basins) throughout the urban zone. These basins will be multifunctional - providing the following benefits:

- compensating storage for storm runoff to reduce the magnitude of flow peaks;
- detention time to allow settling processes to remove silt and other suspended solids from the water;
- detention time for biological uptake processes to act to remove dissolved nutrients and other contaminants from the water; and
- storage to provide additional opportunity for recharge of water to the ground.

The larger, vegetated basins will also provide water bodies for educational and recreational public use. Appropriate soil amendment techniques within the basins will enhance contaminant uptake within the base sediments of the recharge and detention basins. Summer drying of the smaller basins will allow oxidation of the base sediments. This process will assist in removing contaminants from the drainage system.

A monitoring programme will be put in place to assess base line water conditions and monitor the progressive development of the urban area. Adaptive management of the development in response to the results of the monitoring programme will ensure protection of the water resources of the area.

1.0 INTRODUCTION

1.1 General

The purpose of this report is to present the results of groundwater and surface water studies carried out on the proposed urban development at Ellenbrook. These studies were initiated to identify the management strategy for drainage in the development and to predict the likely impacts of the proposed urbanization on the groundwater table in the area.

The report considers the effects on the water table of groundwater abstraction both within the proposed development area and within the overall Lexia borefield proposed by the Water Authority of Western Australia.

In relation to the overall Lexia Scheme, this report does not consider the consequential effects of groundwater table changes outside of the Ellenbrook area. These effects are considered to be beyond the scope of this study and will be more appropriately investigated as part of the Water Authority's environmental assessment for the Lexia Groundwater Scheme.

The report outlines the proposed drainage management strategy for the Ellenbrook development and presents estimates of the water loads transported from the site via the surface drainage system. Impacts of urbanization on the regional groundwater table are identified and quantified.

Various options for land use and water management were investigated in this study and results are presented in this report. Options included:

- Inclusion or exclusion of Lexia borefield operation;
- 90 hectare or 410 hectare wetland conservation area;
- Inclusion or exclusion of State Forest areas proposed for development; and
- Inclusion or exclusion of a stormwater pumpback scheme to enhance recharge.

1.2 Background to the Urban Proposal

In the mid-80's, an Independent Review Group was commissioned by the Government to review the Metropolitan Region Scheme (MRS) and the Perth Corridor Plan. The resulting report (State Planning Commission, 1987), released for public comment in 1987 included a "preferred strategy" for development. This report included part of the Ellenbrook land.

The Department of Planning and Urban Development (DPUD) carried out a detailed assessment of the responses received on the 1987 report. In May 1990, DPUD released a draft policy statement for land development within the Perth Metropolitan Area (DPUD, 1990). This Policy Statement, the Perth Urban Expansion Policy, reflected the wide consultation following the earlier report and considered the emerging pressures on land availability for urban residential development. The Policy Statement identified several future urban areas which were classified as:

- Category A - relatively unconstrained for development; and
- Category B - constraints to development.

Included under the Category A proposals, within the North-West corridor, was the land at Ellenbrook which is the subject of this report.

This study has been commissioned by Ellenbrook Management Pty Ltd proposing development of a large portion of the land at Ellenbrook and includes land currently owned by SANWA Vines and Homeswest. The land being proposed for urban development is shown in Figure 1.1a. Ellenbrook Management Pty Ltd have proposed rezoning of the land to Urban and Urban Deferred zones under the Metropolitan Region Scheme. The Environmental Protection Authority

(EPA) have determined a Public Environmental Review (PER) be prepared to examine this proposed zoning.

G B Hill & Partners Pty Ltd was engaged by Ellenbrook Management Pty Ltd, on behalf of the Ellenbrook owners, to prepare this study report. The study was carried out by G B Hill & Partners Pty Ltd and by Mackie Martin and Associates, who provided specialist groundwater modelling expertise. Dr Rod Lukatelich was engaged to provide specialist environmental expertise.

The principal objectives of this study were as follows:

- to formulate a drainage management strategy for the development;
- to determine the effects of the proposed urban development on the groundwater in the adjacent portions of the Lexia and Mirrabooka Public Water Supply Areas;
- to examine the effects of urbanization on the water regime of existing wetlands within and adjacent to the development area;
- to estimate the surface drainage water loadings that will be transported from the area; and
- to estimate the likely nutrient loads exported from the proposed urban area to Ellenbrook and the Swan River.

In examining the potential effects of urbanization on the water regimes in the area, a drainage strategy is presented herein. With respect to changes resulting from urbanization at Ellenbrook, this strategy has as its goals:

- minimization of adverse changes to water levels and water quality within the Lexia and Mirrabooka Public Water Supply Areas;
- minimization of changes to the water regime of specific wetlands within the urban area;
- optimization of recharge within the urban area;
- optimization of groundwater abstraction within the urban area;
- minimization of changes to storm runoff peak flows entering Ellen Brook and the Swan River;
- minimization of pollutant loads transported from the urban area by the drainage system.

The strategy has been formulated with measures to conserve water where possible and has assumed the planning and design of the urban development will incorporate principles of water sensitive design and management practices for stormwater quality control.

2.0 OUTLINE OF THE DRAINAGE STRATEGY

The drainage strategy for the area acknowledges the benefits of water sensitive design and the need to conserve water. To minimise the effects of drainage discharges from the site, the strategy aims to reduce the magnitude of storm runoff peak flows emanating from the urban area and to minimise the transport of pollutants to the Swan River and its tributaries.

The effects of urbanization on the groundwater levels in the area have been predicted using a computer model. Urbanization tends to increase water table levels as a result of lower evapotranspiration losses and importation of scheme water for domestic use within the urban area. To minimise these changes, the proposed drainage system includes strategically placed subsoil drainage and recharge sites.

In areas where the depth from the natural surface to the groundwater table is less than 1.5 metres, a combination of sand filling and subsoil drainage is proposed to provide ground conditions suitable for urban residential development. The subsoil drains will reduce the magnitude of the potential water table rises typically associated with clearing and urbanization. The subsoil drainage will generally be installed to restrict the rise of groundwater to the winter levels observed in an average rainfall year. The groundwater in this region normally peaks in the September/October period as a result of recharge from winter rains. The numerical modelling conducted for this study utilised observed data for October 1989 for calibration.

The urban area may be separated into three main surface water catchments, described as the Southern, Northern and Eastern Catchments as shown in Figures 1.1a and 1.1b.

The characteristics of the Southern catchment are such that there are few areas which will require subsoil drainage. In the higher land, considerable recharge of drainage water is feasible.

The Southern area also contains an existing quarry which is proposed, in the Draft Structure Plan, to be redeveloped as a lake. This lake will act as a major detention basin to reduce the magnitude of drainage flow rates and enable improvement of the drainage water quality. Water quality improvement will be achieved by providing detention time to reduce suspended solids by sedimentation and to optimize biological uptake of nutrients and other pollutants from the drainage water.

The Northern urban catchment is generally of lower elevation with less freeboard between the natural ground surface and the groundwater table. The area contains specific wetlands which may need to be protected (Dames & Moore, 1991). The greatest effect on the water regime of the wetlands is likely to be due to groundwater abstraction from the adjacent Lexia borefield. Careful management of the borefield by the Water Authority of WA will enable this effect to be minimized. Although no urban drainage water will enter the wetlands located to the north west of the urban area, the trunk drainage system will be designed to accommodate overflows from the wetlands (excess water flows) to prevent excessive flooding of the wetlands in abnormally wet years. These flows will pass through the urban drainage system for discharge to Ellen Brook. The control level of the overflow from the wetlands to the drainage system will be set to operate above the peak level of the 10% annual exceedence probability event. This will ensure that there is no direct transfer of water from the wetlands in the majority of years.

The Eastern catchment is also of lower elevation, lying between the sand ridges of the Southern catchment to the west and Ellen Brook in the east. Urban residential development within this catchment will again require subsoil drainage to limit groundwater rise in the area. Drainage discharge from the Eastern catchment will pass through detention basins prior to entering Ellen Brook and the Swan River.

The basic drainage strategy has been incorporated into the groundwater modelling to provide a predictive model of the effects of the urbanization including the proposed drainage system.

3.0 GROUNDWATER MANAGEMENT

Detailed evaluation of the groundwater environment was initiated to assess groundwater/surface water management options for urban development at Ellenbrook. This follows previous Geological Survey and Water Authority review investigations of the aquifer systems within the south eastern section of the regional superficial aquifer, known as the Gnangara Groundwater Mound. These studies, in conjunction with regional numerical modelling completed during the Perth Urban Water Balance Study (PUWBS) have provided a basis for establishing a more detailed numerical model of the shallow groundwater system in the Ellenbrook area. The incorporation of landuse changes and groundwater development and management strategies within the model have provided an assessment of potential impacts of the proposed developments. The effects on the regional groundwater, as a result of urbanization and development of the Lexia Groundwater Scheme, have been minimized by optimization of water level controls which include subsoil drainage and groundwater abstraction.

3.1 Hydrogeological Background

3.1.1 Geological Environment

The Ellenbrook area covers part of the eastern onshore margin of the Perth Basin and is underlain by more than 7500 metres of sediments. The sequence of formations underlying the site is outlined in Table 3.1 and presented in section in Figure 3.1 (after Davidson, 1987)

AGE	FORMATION		THICKNESS	DESCRIPTION
QUATENARY	Superficial Formations	Bassendean sand	10m	Sand: fine to coarse, mainly fine
		Guildford Formation	60m	Sand: Fine to very coarse, feldspathic, containing beds and lenses of clay.
TERTIARY		Ascot Beds	17m	Calcarenite: sand, clay, shells. Glauconitic.
EARLY-LATE CRETACEOUS	Osborne Formation	Mirrabooka Sand Member	105m	Sand: fine to medium, slightly clayey grading downwards into fine to coarse clayey sand. Glauconitic
			80m	Shale: grey to black, silty. Glauconitic.
		Henley Sand Member	50m	Sand: Dark green fine to very coarse clayey. Glauconitic.
EARLY CRETACEOUS	Leederville Formation		390m	Sandstone, siltstone, shale, interbedded.

Table 3.1: Stratigraphic Sequence of Near Surface Units

3.1.2 Hydrogeology

Groundwater contained within the superficial formations originates from direct infiltration of rainfall. This forms part of the regional shallow aquifer system referred to as the Gnangara Mound. The water table which exists at the surface of the unconfined groundwater system is defined mainly by topography. The water table fluctuates seasonally by about 1 to 1.5 metres. Peak groundwater levels are observed in September- October, with minimum levels in April-May.

The base of the superficial aquifer ranges from +4 mAHD to -10 mAHD across the Ellenbrook area. The corresponding saturated aquifer thickness ranges from approximately 10 metres to the east (in the vicinity of Ellen Brook) to over 50 metres in the west.

Groundwater gradients are generally towards the south east, with natural groundwater discharge to Ellen Brook or to drainages which discharge to Ellen Brook. Vertical head gradients suggest that there is also leakage from the superficial formations into the underlying "Marine Sands", with downwards gradients present over most of the Ellenbrook area.

Flow net calculations (Davidson, 1987) undertaken using both hydraulic gradient and chloride balance techniques suggest groundwater throughflow beneath the proposed urban area of the order of 10,000 kL/day or 4 x 10^6 kL/annum. The water balance for the entire Lexia area (extending northward to Cooper Road) is estimated as follows:

- Discharge to Ellen Brook 12,000 kL/day
- Leakage from superficial formation downwards to Marine Sand 2,750 kL/day
- Leakage from Marine Sand upwards to superficial formation 4,800 kL/day
- Discharge from groundwater system via surface drainages 7,500 kL/day

The Marine Sand (also referred to as the "Mirrabooka Sand Member") appears to be in hydraulic continuity with the superficial formations and is thought to be semi-confined (Davidson, 1987). Water balance calculations indicate little regional throughflow within this formation and that groundwater recharge to the Marine Sand occurs within the Lexia area as a result of downwards leakage from the superficial formation. Shale present at the base of the Marine Sand prevents further downward leakage to underlying units (Henley Sand Member and Leederville Formation).

3.2 Criteria For Groundwater Management

The need to allocate water resources to future developments has highlighted the potential conflict between various water users. Groundwater resources contained within the Gnangara Mound represent a significant source which has a key role in Perth's water supply. Developments on the fringes of the Wanneroo Public Water Supply Area are required by the Water Authority to be compatible with the protection of the resource.

In addition to public and private demand for groundwater, there are wetland areas in the vicinity of the Ellenbrook project which rely on the shallow groundwater system for their existence. Groundwater and surface water management strategies within the Mirrabooka PWSA, Wanneroo PWSA and Swan Groundwater Area are required by the Water Authority to be evaluated on the basis of the regional impact on the groundwater system and the environment.

3.2.1 Environmental Constraints

Changes to the water regime outside of the development area must be minimised. Wetlands in the north west of the proposed development area have been identified as being of potential conservation value (Dames & Moore, 1991). The water management strategy has been analyzed to determine the effects of both urbanization and groundwater abstaction. The tolerance of the wetland flora and fauna to water table change should be determined to enable implementation of appropriate methods of groundwater control.

3.2.2 Public Water Supply Requirements

A portion of the development area lies within the Mirrabooka Public Water Supply Area (PWSA), with the remainder of the site located in the Swan Groundwater Area, immediately to the west of the Wanneroo PWSA (Figure 3.2). The Lexia region, identified by the Water Authority as an important groundwater source area, is located within the Wanneroo PWSA and Swan Groundwater Area, to the north and west of the development.

The Wanneroo and Mirrabooka PWSA were proclaimed in 1975, identifying the utility of these areas for public water supplies for Perth. The Wanneroo PWSA extends southwards from the crest of the Gnangara mound and is coincident with State Forest No.65. Consequently, groundwater abstraction within the Wanneroo PWSA is limited to public water supply schemes. The extension of the Gnangara mound south of Gnangara Road is incorporated within the Mirrabooka PWSA. At present this area includes frontal development and industrial sectors in the south west, rural and special rural activities. Approximately 25% of the Mirrabooka PWSA is set aside for parkland.

Current annual yields from the Wanneroo and Mirrabooka Groundwater Schemes are approximately 21 x 10^6 kL and 22 x 10^6 kL, respectively. Proposed groundwater schemes in the vicinity of the Ellenbrook urban area include the East Mirrabooka Stage 3 (yielding an additional 1.5 x 10^6 kL/annum) and the Lexia Groundwater Scheme (yielding 6.9 x 10^6 kL/annum).

Private groundwater abstraction within the development area is limited to properties within the south east corner and that associated with the Vines development. Excluding the Vines usage (discussed below), the current licensed abstraction north of Gnangara Road totals 44,000 kL/annum. Private bore abstraction to the south of Gnangara Road in the Henley/Henley Brook areas within the Mirrabooka PWSA is estimated at 900,000 kL/annum.

3.2.3 Optimization of Groundwater Recharge

To maximize groundwater availability for public, private and environmental purposes, an appropriate balance between water levels and environmental impact must be sought. In regions of high depth to water table the opportunity exists to increase recharge and therefore groundwater levels with minimal impact upon the environment. Across the southwestern portion of the proposed urban area, existing groundwater levels vary from approximately 39 to 45 mAHD, with surface elevations ranging up to 70 mAHD. This presents an opportunity to increase groundwater recharge and therefore groundwater availability over this section of the development. Assessment of the regional impact of increasing local recharge is required to delineate potential adverse impacts in lower lying areas down gradient from the recharge site.

3.2.4 Subsoil Drainage Requirements

Where shallow depth to groundwater is present under existing land use conditions, groundwater level control will be required for urban development. A minimum depth to groundwater of 1.2 metres is required to meet building codes, which in practice necessitates groundwater level control (subsoil drains) at 1.5 metres below the finished surface level. To minimise the adverse impact upon groundwater availability, subsoil drainage levels should be located no lower than the existing average winter groundwater levels. This approach limits the impact of subsoil drains to winter periods but may require the importation of sand fill to provide the 1.2 metres of freeboard.

The resultant drainage requirements must accommodate peak flow events associated with extreme groundwater levels. An assessment of annual catchment discharges may be required to optimize extent and final invert levels for subsoil drains.

3.3 Numerical Modelling Methodology

The management of the groundwater resources within the Lexia area is governed by the amount that the water table can be varied without having an unacceptable affect on the environment and groundwater resources. Management is also governed by the impact of land use changes on groundwater quality. Modelling results presented in this report address groundwater quantities and the predicted impact of development upon water quality.

3.3.1 Application of Numerical Modelling

A numerical model allows the evaluation of the likely impact on regional water table levels arising from the numerous factors influencing water table variation. These include climate, groundwater abstraction, land use and surface and subsoil drainage.

A suitably calibrated model enables:

- The individual impacts of various factors currently influencing the groundwater system to be isolated from the total observed response, as recorded at monitoring bores. This provides a much improved understanding of the system response and the factors producing the major impacts.
- The prediction of future water levels under various climatic, land use and abstraction scenarios, which assists in establishing preferred management strategies for the area.

Within this framework, data obtained from Water Authority monitoring bores, climate records and Geological Survey of WA investigations have been integrated to establish a regional groundwater model which is capable of simulating changing abstraction patterns and urban drainage installations, and incorporates climatic and land use characteristics (as compared with historical data). Application of this model to future changes in parameters influencing the groundwater system has allowed possible management options to be investigated.

3.3.2 Numerical Model Description

Numerical modelling undertaken during this study has employed the Water Authority model developed during the Perth Urban Water Balance Study (PUWBS). The PUWBS model was established to amalgamate all the components of the water budget for superficial aquifer systems on a scale compatible with available data and modelling capabilities. The model is comprised of two coupled components; the 'Vertical Flux Model' which calculates a net flux for input into a regional hydraulic model (the Golder package) which solves the groundwater flow equations.

The structure of the model is illustrated in Figure 3.3 and a summary of major components is provided in the following section. A detailed description of the PUWBS model is presented in Volume 2 of the Perth Urban Water Balance Study Report (Water Authority of WA, 1987b).

3.3.2.1 Vertical Flux Model

The Vertical Flux Model (VFM), illustrated schematically in Figure 3.3, is a soil moisture accounting model for the unsaturated zone (above the water table). For each time step, all the processes impacting local recharge are quantified and a single flux to or from the saturated zone is determined. The VFM operates on a regular grid of cells of dimension 500 by 500 metres and calculates the net vertical flux for each cell every time step. This flux is distributed between the nodes of the underlying triangular element of the hydraulic model containing that cell. A comprehensive overview of the Vertical Flux Model is provided in Appendix A.

In summary, the VFM contains a total of 21 "parameters" that may be varied in the input data. This includes three for definition of the soil profile, nine for calculation of inputs, seven for calculation of evapotranspiration and three for the percolation algorithm. In addition there are five numerical constants which can not be changed between runs, four for capillary rise and one for evaporation from open water bodies.

Of the 21 parameters, only a few are generally modified during model calibration. The majority are based upon independent evidence and experience with previous modelling studies. The fact that these parameters can have constant values in space over a large region partially justifies the concept of the VFM. In addition, the results of the modelling studies completed using the VFM have confirmed the applicability of this approach for the Swan Coastal Plain.

3.3.2.2 Regional Hydraulic Model

Regional flow modelling may be undertaken via a number of techniques. One of the more common approaches is via the application of finite element numerical models. In 1982, the WAWA and GSWA jointly purchased the Golder package for simulation of regional groundwater systems. The Golder package consists of a number of separate Fortran codes (Marlon-Lambert et al, 1979) including a multi-layered flow code (AFPM). This code has been coupled to the VFM to provide hydraulic response to net recharge supplied by the VFM.

Besides having a multi-layered capability, other advantages of the Golder package include:

- the ability to conveniently model regions of arbitrary shape, using triangular or quadrilateral finite elements;
- a swamping capability, in which groundwater levels are constrained to be at or below the land surface elevation, with any resulting groundwater outflow being redirected to another location as potential recharge.

The governing groundwater flow equations solved within the Golder model correspond to a particular form of the general water balance equation:

change of storage = net lateral groundwater flow + net vertical flux

The partial differential water balance equation is mildly nonlinear for an unconfined aquifer, since aquifer transmissivity varies as a function of saturated thickness. Consequently, an iterative approach to the solution is required, particularly if water level changes are large between time steps.

The Golder package solves transient problems by stepping forward in time, using a "fully implicit" algorithm which, at least for linear problems, is unconditionally stable. Initial values of heads are required at all nodes, together with distributions of aquifer properties, definitions of boundary conditions on all boundaries and spatial and temporal distributions of net inputs. These net inputs are provided by the VFM.

3.3.2.3 Data Requirements

The determination of model inputs is based on numerous data sets briefly outlined below. Most of the input data may be estimated (measured) with reasonable confidence over the whole study area. The Water Authority spatial database established during the Perth Urban Water Balance Study has a 100 metre cell basis. That is, where continuous type spatial data is available (e.g., canopy cover, land use, topography etc.) information is stored on a 100 x 100 metre 'cell'. Raw data has been obtained from the following sources;

◦ Geological Survey of WA	- geological data
◦ Lands and Survey	- topographical data
	- Landsat bands 5 & 7 (land use)
◦ Bureau of Meteorology	- temporal and spatial rainfall/evaporation
◦ State Energy Commission	- urban land use (aerial photography)
◦ CALM	- pine plantation history
◦ Water Authority	- water consumption
	- public & private groundwater pumpage
	- sewerage & drainage data
◦ Local Authorities	- local authority groundwater pumpage

Compilation of all relevant parameters results in an enormous database. In modelling exercises undertaken to date, this database has been reduced to 500 x 500 metre size cells for input to the VFM. For the Ellenbrook study, the database employed for the Water Authority's Pinjar Study was utilized.

Using the Pinjar base, additional information was added to update parameters to match existing conditions. This included extensive review of land use and canopy cover from recent aerial photography and private and public groundwater abstraction from the WAWA database. In addition, 2 metre contour maps for the development area were used to refine cell averaged surface elevations. This parameter is critical in determining the net vertical flux.

Geological data compiled by the Geological Survey of WA (Davidson,1987) has provided the basis for numerical modelling. Discussion with officers of the GSWA and WAWA has confirmed the modelling approach employed to represent hydrogeological conditions.

At each time step (each month) temporal parameters are defined, including rainfall, evaporation and water usage (i.e. pumpage and irrigation). Two temporal data sequences were used to cover the calibration period (April 1983 to March 1990) and predictive period. Figure 3.10 provides available historical rainfall data for Perth, along with a three year moving average. To gauge likely response to extreme climatic conditions, a synthetic rainfall/evaporation sequence was constructed, consisting of the period April 1941 to March 1948 (the wettest period on record) and April 1981 to December 1989 (containing average rainfall years).

3.3.3 Development of a Groundwater Model for the Ellenbrook Area

The key aspects in defining model extent and parameters for the Ellenbrook Urban Study were surface drainage features and existing/proposed land uses. The numerical model grid comprises 1580 triangular elements defined by 836 nodes (Figure 3.4). The model extends northward to Bulls Brook and is bounded to the east by Ellen Brook and the Swan River. To ensure adequate representation of Lexia borefield, the western model boundary extends to the 65 metre average groundwater contour and follows a streamline southwards to the 48 metre contour. This approach is required to eliminate insignificant sections of 'streamtubes' well removed from the areas of importance.

Finite element mesh density has also been varied across the model, reflecting increased detail within the Ellenbrook area which grades to much larger element sizes at boundaries distant from the development area.

Nodes have been aligned with surface drainage features where possible to implement groundwater 'swamping' within the Golder model. These nodes provide groundwater controls, which fix the maximum water table elevation whilst permitting water level decline during dry periods. In addition, monitoring of the predicted discharge from these nodes is compared with both regional calculation of aquifer discharge to surface drainages (Davidson, 1987) and available stream gauging data to assist with model calibration.

3.4 Calibration And Model Verification

Calibration of the model is based upon matching the spatial water table levels, seasonal water table fluctuations, bulk groundwater throughflows and groundwater discharges to surface drainages. Parameters defining each of these aspects must show reasonable agreement with available data. The initial matching of regional hydraulic parameters (permeability and specific yield) was based upon regional water table contours and seasonal fluctuations (defined by more than 60 shallow monitoring bores). These observed field data represent the most accurate information available and effectively integrate hydraulic parameters and the prevailing seasonal net recharge. Refinements to the regional adjustment of the permeability and water balance parameters are then undertaken at the local scale in areas of specific interest.

The calibrated permeability distribution, specified on an element basis, is presented in Figure 3.5.

Calibration of the model across the proposed urban area is complicated by an apparent geological transition associated with the change in land form running through the centre of the Ellenbrook area. This feature appears as a region of steeper hydraulic gradients in observed groundwater level data (Figure 3.6). Immediately upstream of this transition, hydraulic gradients are much flatter, suggesting significantly higher permeability and/or water level control resulting from topographical features.

Topographical data was reassessed across the Ellenbrook area on a cell by cell basis for input to the Vertical Flux Model. In the case of significant topographical variations across the 500 x 500 metre cell a judgement was made to obtain the appropriate average land elevation. For instance, in cells containing low lying drainage features and areas of high depth to water, the dominating constraint will be the drainage for calculation of final water level. However, the net recharge to the unconfined aquifer for the cell may be impacted more by the areas of greater depth to water.

Predicted groundwater levels for October 1989 are presented in Figure 3.7. These predictions indicate excellent agreement with observed data presented in Figure 3.6. Selected hydrographs for shallow monitoring bores are presented in Figure 3.8, and include both observed data and predicted groundwater levels. General trends in water levels and seasonal fluctuations should exhibit good agreement for most bores across the proposed development area. Minor differences are attributed to the interpolation of grid data to observed data points and the limitations of the planar representation of the water table obtained with triangular finite elements.

Surface drainage nodes (swamping nodes) within the modelled area, along the lines of existing drainages were matched with the invert levels of these drains. A total of 125 nodes across the model were defined as swamping nodes. Monthly predicted discharge for each surface drainage within the proposed urban area is presented in Figure 3.9. Total annual discharges are calculated at 4×10^6 kL (cf. Davidson.)

In summary, it is considered that the model reliably simulates the water balance and the trend in observed groundwater response over the 7 year calibration period and therefore may be applied with some confidence to assess the cause and effect response of various land use and water management strategies on future water levels.

The model has been employed to estimate the impact of current land use conditions on water table levels, and future impact on the groundwater system for predicted water use and land use development associated with the Ellenbrook project. Results of these simulations and their implications for management in the area are discussed in the following sections.

3.5 Incorporation Of Ellenbrook Urban Development

3.5.1 Urban Development

Incorporation of future land use changes associated with the Ellenbrook Urban Development is facilitated by adjusting the appropriate parameters in the Vertical Flux Model. Typical parameters relating to recharge and water usage have been estimated from existing urban development areas and are similar to those used in the Thomsons Lake Study (G B Hill & Partners, 1990). Within the proposed urban area, allowance is made for domestic bores, surface runoff, subsoil drainage and Water Authority abstraction. A summary of urbanization parameters corresponding to the expected average urban development is provided in Table 3.2, along with typical parameters for undeveloped areas.

PARAMETER	ASSIGNED VALUE
Compensating basins	Calculated for each basin
Land use	6
Canopy cover	5%
Water supplied to properties with bores	188 bore equivalents
Water supplied to properties without bores	780 bore equivalents
Domestic bores:	
High depth to water	11 bore equivalents
Low depth to water	19 bore equivalents
Council bores	2 bore equivalents
Institutional bores	1bore equivalents

Table 3.2: Urbanization Parameters for the Vertical Flux Model

Groundwater usage within urban areas has been shown to be a function of depth to water (Domestic Water Use Study, MWA, 1985). A bore density of 25% (i.e., one house in four) has been adopted in shallow depth to water areas with a reduction to 15% in areas of high depth to water, corresponding to 1875 m^3/ha/annum and 1125 m^3/ha/annum, respectively.

Management of surface runoff (rainfall) is also assumed to be a function of depth to water. In regions of high depth to water sufficient storage capacity exists within the unsaturated zone for local disposal of surface runoff. In these areas it is anticipated that runoff will be directed to standard type compensating basins within the urban area. In low lying areas it is assumed that runoff is directed to local drainage works and ultimately exported from the area. Figure 4.2 illustrates proposed compensating basin locations and the associated catchment areas.

3.5.2 Sub-Soil Drainage

Development within the Ellenbrook area will require either sand fill or permanent subsoil drainage at some locations to ensure that sufficient depth to water is maintained for dwelling construction.

Minimum impact of such subsoil drainage will be achieved with the maximum possible elevation of drains. However, if the drains are set too high they will not act to control groundwater rise. Modelling has retained existing surface drainage features and located subsoil drains at the maximum groundwater table levels observed in an average rainfall year. It is assumed that the freeboard requirement for urban development will then met by importing fill to the areas of low depth to water table.

If the subsoil drainage is installed at a level higher than the average year maximum groundwater levels, then the groundwater table will tend to rise in winter to the level set by the subsoil drainage system. This could have serious consequences on the wetlands and associated native vegetation. Installation of the subsoil drainage system at the average winter peak level will help maintain the existing water regime in the conservation area. Setting the drains at a higher level will not only result in higher water levels in the wetlands but also greater potential for contamination of the wetlands as hydraulic gradients towards the wetlands could develop.

Discharges from subsoil drains within the catchment areas (Figure 3.12) are summarized by the model on a monthly basis. The monthly base flows, in response to seasonal variations, allow the assessment of the impact of subsoil drainage on the receiving water bodies.

3.5.3 Existing Vines Development

Development at the Vines has resulted in noticeable changes to the shallow groundwater system. Summer decline in groundwater levels have been observed at monitoring bore L80C and rising groundwater levels are noted in the vicinity of compensating lakes. Changes to land use include:

- the reduction of canopy cover;
- establishment and irrigation of the golf course;
- installation of a temporary effluent treatment facility;
- substantial drainage works and the development of compensating basins; and
- groundwater abstraction for irrigation purposes.

Each of these components have been incorporated into the model for future predictive simulations.

3.5.4 Lexia Borefield

The Lexia area has been identified as having potential for groundwater development for Public Water Supply. The Water Authority submitted a Notice of Intent for the Lexia Groundwater Scheme to the Environmental Protection Authority in April 1985. This groundwater scheme proposal comprises a total of 12 shallow groundwater bores located within the Wanneroo PWSA (Figure 3.3) drawing an average of 420,000 kL/annum/bore and three deep bores (intersecting the Marine Sands) to the east of the Wanneroo PWSA drawing an average of 500,000 kL/annum/bore. This corresponds to an annual abstraction of 6.5×10^6 kL.

Preliminary modelling of the Lexia scheme as proposed by the Water Authority and recommended variations to minimise the impact upon environmentally sensitive areas are presented below.

3.6 Peak Runoff/Groundwater Discharge Events

As noted above, a critical aspect of urban development at Ellenbrook is the management of excess surface water and groundwater. Clearly, both of these components are likely to peak during sustained wet periods. Although surface runoff corresponds directly to storm events, groundwater discharge (via subsoil drainage and upwards seepage) has a response time ranging from months to years. Therefore, in considering the appropriate design catchment discharge events both short and longer term rainfall events must be evaluated.

Long term climatic data for Perth indicates significant cycles in annual rainfall (Figure 3.10) Comparison of these data and water levels recorded in the Ellenbrook area, (Figure 3.8) demonstrates the short term responses superimposed upon longer term trends. For instance, the above average rainfall received in 1978 produced a corresponding net annual rise in groundwater levels (i.e. an increase in stored groundwater) however 1978 was preceded by a sequence of three below average rainfall years. Conversely, it is anticipated that a combination of rainfall events similar to those observed in the 1940's will result in maximum groundwater levels. The period 1945 - 1948 has the highest recorded four year average rainfall (1095 mm), followed by the 1926 - 1929 period (1064 mm).

Figure 3.11 presents the predicted variation in water levels at key locations across the development area for historical climatic conditions with current land use parameters. This figure illustrates the impact of the 1940's with respect to peak groundwater levels. The regional rise in water levels is also presented as a difference plot between simulated 1989 peak levels and predicted 1947 peak groundwater levels.

3.7 Impact of Development within the Ellenbrook Urban Area

Incorporation of urbanization parameters, including subsoil drainage at the current maximum groundwater levels results in a net water table rise over the southwestern region, a minor decline north of Henley Brook and little change over the remainder of the modelled area. These impacts are summarized in Figure 3.13, showing the difference between predicted average water levels and current groundwater levels for October. Local mounding within the southern area is associated predominantly with compensating basins, which are treated as point inputs.

A reduction in water levels is predicted to the north of Gnangara Road in the vicinity of Henley Brook. This area currently is impacted by clearing and pine plantation areas immediately upgradient. During initial establishment of the pine trees a high recharge will occur over the cleared areas. The water level declines depicted in Figure 3.13 suggest that this recharge exceeds that achievable in urban areas.

3.7.1 Predicted Impact at Ellenbrook Wetlands

Environmental considerations (Dames & Moore, 1991) suggest a maximum acceptable long term water level variation from current conditions of 200 mm. Available data from nearby WAWA monitoring bores indicate seasonal groundwater levels variations of the order of 1.0 to 1.2 metres. Over the period 1984 to 1990 some long term trends are evident at monitoring bore L140C (Figure 3.2). However immediately downgradient, at bore L150C, the annual variation between maximum water levels is less than 0.5 metres. This suggests some topographical control or smoothing of long term water levels variations due to the wetlands.

The predicted response at the wetlands due to urbanization (Figure 3.13) is less than ± 0.1 metres under average rainfall conditions. The reduced impact over the north western region of urban development corresponds to the area of subsoil drainage, where maximum groundwater levels are restricted. During extreme rainfall event periods the subsoil drainage in the adjacent urban areas will restrict the water level rise in the wetlands resulting in increased discharge. Under peak rainfall conditions a rise of the order of 0.8 metres is predicted on the western side of the wetlands.

3.7.2 Water Balance for Northern/Southern Drainage Catchments

Output from the Vertical Flux Model was summarized for the Ellenbrook area to quantify the impact of urbanization upon local water balance components. The major components are presented, as a percentage of the annual rainfall for the northern and southern areas of the development in Table 3.3. These areas have been chosen on the basis of regional topography and reflect areas of low depth to water and high depth to water, respectively. Data are presented for average rainfall (1986) and peak rainfall (1945) periods.

AREA	Rainfall Period	Urban/Lexia	Net Recharge	Direct Evaporation	Transpiration Interception	Pumpage
North	Average	-	9.2	12.8	67.2	10.6
	Wet	-	16.2	12.0	64.4	7.4
South	Average	-	19.7	20.6	56.6	2.9
	Wet	-	25.0	15.1	57.6	2.0
North	Average	Urban	11.6	12.5	50.6	25.2
	Wet	Urban	18.3	11.1	53.0	17.5
South	Average	Urban	32.8	15.6	32.6	18.8
	Wet	Urban	32.6	15.0	39.2	13.0
North	Average	Urban + Lexia	14.1	6.0	50.6	29.2
	Wet	Urban + Lexia	19.7	7.7	52.3	20.3
South	Average	Urban + Lexia	33.4	15.1	32.5	18.8

Table 3.3: Vertical Flux Components

The increase in groundwater availability due to urbanization is clearly demonstrated in Table 3.3. Under average climatic conditions, the volume of water input to the aquifer flow model (net recharge) or abstracted totals approximately 20% of rainfall with existing land use. Typical urbanization, incorporating a significant increase in groundwater abstraction, increases the apparent net recharge to up to 33% of rainfall in areas of high depth to water. The combined total of net recharge and abstracted groundwater totals up to 50% of rainfall.

Changing land use modifies vegetation type and distribution, which is reflected in the phreatophytic losses. In addition, the increased pumpage lowers groundwater levels and thus the availability of groundwater for the vegetation.

3.7.3 Subsoil Drainage Requirements

Predicted subsoil drainage from the northern catchment is presented in Figure 3.12. Urbanization of the Ellenbrook area, without abstraction from the proposed Lexia scheme, suggests peak discharges of 380 L/s during extreme rainfall events, with a corresponding total annual discharge from subsoil drainage of 4.81×10^6 kL. Under average rainfall conditions the peak winter discharge reduced to approximately 150 L/s and the annual discharge is estimated at 1.02×10^6 kL.

Incorporation of the Lexia scheme results in a reduction in peak monthly discharge rates to less than 300 L/s during extreme rainfall periods. For average climatic conditions the peak subsoil drainage requirement is less than 50 L/s. Calculated annual drainage volumes for peak and average conditions are 3.16 x 10^6 kL and 0.22 x 10^6 kL, respectively. These predictions are based upon the Lexia Groundwater Scheme defined in the WAWA Notice of Intent to EPA (MWA, 1985). Refinements to this scheme to meet perceived environmental criteria and maximize the scheme yield adjacent to and within the proposed urban area is discussed in the following section.

3.7.4 Impact and Optimization of Lexia Borefield

Preliminary simulations were carried out incorporating the Lexia Groundwater Scheme, as defined by the Water Authority, and including urbanization. These simulations indicate a decline in water levels at the wetlands in northwest of the Ellenbrook area ranging from 0.5 to 1.2 metres (Figure 3.14). This impact is a result of pumping from proposed bores on either side of the wetlands (Figure 3.2). Optimization of the borefield has been considered to define a preferred configuration and yield of the borefield. This approach permits the maximization of borefield yield while reducing the predicted impact in key locations to acceptable levels.

Figure 3.15 presents the predicted impact of relocating of the Marine Sand bore adjacent to the wetlands (previously near L140C) and bore L130C. These bores, which were repositioned within the model, as indicated on Figure 3.15, lie on either side of the mounding due to urbanization over the southern section of the proposed development. The impact at the wetlands under this scenario is of the order of 0.2 to 0.4 metres.

Re-evaluation of existing groundwater schemes by the Water Authority has indicated that the sustainable yield of the Lexia bores may be up to 80% above the initially proposed rates. The revised annual borefield capacity is estimated at 11.1 x 10^6 kL, compared with 6.5 x 10^6 kL used in the scenarios discussed above. Increasing borefield production results in a predicted decline exceeding 1.0 metre in the vicinity of the wetlands. Implementation of this option would require further optimization of bore locations and yields.

Impacts presented for long term response to urbanization and groundwater development strategies have assumed that the wetland areas are managed remotely. The effect of land use and water use changes adjacent to the wetlands are assumed to be controlled to the extent that an acceptable impact at the wetlands is obtained. It is apparent that to achieve the optimal groundwater development scenario for the full Lexia Borefield and ensure no effect upon water levels within the wetlands, artificial maintenance of the wetlands could be considered. The requirement for artificial maintenance of the wetlands may be determined by an appropriate monitoring programme in conjunction with Lexia Borefield development and operation.

Analysis has demonstrated that there are several alternative strategies for provision of a water supply to the Ellenbrook development. The following scenarios proved to be feasible and consistent with the objectives for environmental protection of the groundwater and surface waters of the area.

- 1. Initially supply water from three Marine Sand bores (shown indicatively on Figure 3.15), augmented at the appropriate time with a supply piped from Mirrabooka;
- 2. Provide all water supplies for Ellenbrook from Mirrabooka;
- 3. Provide an initial supply from three Marine Sands bores, augmented at the appropriate time with a further supply from the Lexia Borefield.

Any of these alternatives can be achieved:

- without adverse effects on the Lexia wetlands;
- without adverse effects on groundwater levels beyond the site; and
- without adverse effects on source water quality.

Supply from the Lexia borefield would be subject to future environmental assessment and approval of the Lexia Borefield Scheme.

4.0 STORMWATER RUNOFF MANAGEMENT

4.1 Description Of Approach

Drainage flows within the development catchment will be generated from stormwater runoff and from subsoil drainage discharge. As the development will be fully sewered, there will be no sewerage flows associated with the drainage system. Surface runoff flows generated from rain falling on impervious areas, such as roads and pavements will be collected by a formal drainage system and transported to detention basins. In the detention basins, the flows will be compensated to reduce the magnitude of outflow hydrographs. Water quality improvement will occur by processes of sedimentation and biological nutrient uptake within the basins. Outflow from the detention basins will be transported to the receiving water bodies via open channels and/or piped systems.

The engineering design of drainage works within the area will be carried out in accordance with the recommendations of "Australian Rainfall and Runoff" (The Institution of Engineers, Australia, 1987 – ARR87). The strategy includes implementation of water sensitive design principles (WA Water Resources Council, 1991) and optimization of water conservation features within the urban development. Stormwater quality will be optimized by using the best management practices commensurate with urban development.

A major-minor design approach (ARR87) is to be adopted for drainage design within the development. The major design will provide safe escape routes for flood waters generated by the 100 year Average Recurrence Interval (ARI) design rainfall event.

4.1.1 Subsoil Drainage

Subsoil drainage will be installed in residential areas where the peak groundwater level (based on the 1989 winter) occurs within 1.5 metres of the finished surface level. The ultimate spacing of subsoil drainage pipes will be determined from measured soil parameters, including permeability and aquifer thickness. Development of the strategy for the subsoil drainage, has been based on results obtained from the groundwater component of this study. The subsoil drainage system will be installed to prevent groundwater rise to levels higher than the existing peak level in an average winter.

The detailed design of the subsoil drainage system will be based on maintaining a minimum freeboard of at least 0.8 metres between the Finished Surface Level (FSL) of the residential lot and the **transient** water table rise resulting from the 2 year ARI design rainfall event.

4.1.2 Road and Pavement Drainage

Road and Pavement Drainage will be collected in gully or side entry pits and transported via a piped drainage system to detention basins in accordance with requirements of the Swan Shire Council. To encourage recharge, roof drainage will be connected to on-site seepage/overflow wells, Dutch drains and/or seepage beds (Argue, 1986) prior to connection to the formal drainage system.

4.1.3 Trunk Drainage

The trunk drainage system will consist of detention basins interconnected by pipes or channels. The basins will comprise two types of storage, base storage for water quality control and surcharge storage for water quantity control.

The base storage will consist of a semi-permanent water body (in areas where there is shallow depth to the water table) and will provide reduced velocities within the basin to optimize the effects of sedimentation and biological contact for the lower flows. Nutrient reduction will be achieved by providing detention times exceeding 7 days for base flows.

The base storage will comprise volumes located below the invert level of the outlet piped drain as shown in Figure 4.1. The outlet invert level will be generally set to conform to the maximum winter water levels recorded in 1989. The basin depth, below the outlet invert will be dependent on the size and location of the basin, but will generally be in the range 0.8 to 2 metres. The major basin in the Southern Catchment (to be located in the existing quarry) will exceed 15 hectares in area and would contain a lake of several metres depth.

The detention basins will be designed to provide surcharge storage to attenuate the flood peaks. This zone of storage will lie above the invert level of the outlet pipe as shown in Figure 4.1. The design Top Water Level (TWL) will be based on the ten year ARI design storm, in accordance with Water Authority compensating basin design requirements for Main Drainage.

4.2 Modelling Methodology

4.2.1 Objectives of the Modelling

The RORB runoff routing programme was used to model the catchment to address the following objectives:

- Estimate the outflow drainage water volumes from the development area as a result of storm runoff events;
- Determine detention basin parameters for quantity control including basin and outlet pipe sizes;
- Predict design peak flows within the catchment;
- Determine the location of suitable drainage routes.

A spreadsheet based water quality model was used to:

- Estimate the annual drainage water loads passing through the development area;
- Estimate the likely annual phosphorus load transported through the system;
- Predict the overall effectiveness of the modelled detention basins in terms of water quality improvement.

The water quality aspects of this study are presented in Chapter 5 of this report.

4.2.1.1 Estimation of Detention Basin Parameters

For the drainage strategy, the detention basin sizes were initially based on the associated subcatchment area. The minimum surface area of the basin, at the 10 year ARI design TWL, was set equivalent to 1.6 percent of the total sub-catchment area. The basin depth is dependent the depth to water table, but is generally restricted to a maximum of 2 metres.

The runoff routing model was run for numerous storm durations at an average recurrence interval of 10 years to determine the critical duration. The outlet pipe sizes were adjusted to maintain a reasonable storage level in each basin. With the detention basin sizes determined, the runoff routing model was run with various ARI storms to determine catchment responses for storms of varying magnitudes.

4.2.1.2 Estimation of Outflows to Receiving Water Bodies

Estimation of annual outflows was determined as two separate components:

- groundwater seepage to the subsoil drainage system and basins obtained from the groundwater modelling; and
- surface runoff based on a loss model applied to monthly rainfall for an average year.

Groundwater seepages, summarized by the groundwater model on a monthly basis, are presented in in Figure 3.12.

Surface water runoff was estimated for each land use type defined, using a simple loss model applied to the monthly rainfall for an average year. Table 4.1 shows the monthly rainfall distribution adopted for the average year.

MONTH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall (mm)	8.4	12.3	18.9	45.3	123.0	182.5	173.1	135.4	80.0	54.5	21.3	13.6	**868.3**

Table 4.1: Adopted Annual Rainfall Distribution

4.2.1.3 Estimation of Peak Design Flows

The runoff routing model was run with the adopted detention basin sizes to determine the 1, 10 and 100 year ARI peak flows at various locations throughout the catchment. These are summarised in Section 4.3.

4.2.2 Description of the Runoff Model

The surface drainage study utilized a runoff routing model to produce the outlet volumes, peak flows and detention basin design requirements for storm flow compensation.

Runoff routing is the process of routing rainfall excess through a model of catchment storage to produce an estimate of the runoff hydrograph for the catchment. The following factors are considered:

- areal and temporal variations in rainfall;
- non-linear catchment response; and
- the distributed nature of catchment storage.

The RORB runoff routing model (Laurenson and Mein, 1988) used for this study is one of the most widely used runoff routing techniques in Australia.

The method of approach involved dividing the catchment into several sub-catchments. A loss model was used to calculate rainfall excess hyetographs for each subcatchment. These hyetographs were then routed through a conceptual storage model to produce surface runoff hydrographs. The storage model was assumed to have a storage- discharge relationship of the form:

$$S = 3{,}600\ KQ^{m}$$

where S = storage in m^3
Q = discharge in m^3/s
m = constant relating catchment non-linearity
K = constant relating catchment storage effects, and

$$K = k_c\, k_r$$

where k_c = empirical coefficient
k_r = relative delay time

The parameters k_c and m were determined by regional formulae. Design rainfall excesses were used with the adopted valves of k_c and m to produce design flood estimates of direct runoff. Base flows were not included in the model. The proposed detention basins were modelled as special storages.

4.2.3 Model Data

4.2.3.1 Catchment Data

The Ellenbrook drainage catchment is approximately 27 square kilometres in area, of which about ninety percent is proposed as urban (Figure 1.1). The land is predominately Bassendean Sand Formation. A large dune ridge runs north-south through the centre of the development area. West of this dune, the existing drainage is internal with numerous wetland areas to the north west. The land grades gently down to Ellen Brook on the eastern side of the dune.

Three distinct drainage catchments form the total catchment area (Figure 4.2a). The Southern Catchment bounded by the ridge running through the centre of the proposed urban area, is largely urban (75%) with the balance being forest. This catchment is proposed to outlet via a 15 hectare lake (existing quarry site) adjacent to Gnangara Road. Compensated outflow is then to be piped to the Swan River along Gnangara Road.

The Northern Catchment is bounded by the central ridge in the south and an east-west ridge near Maralla Road in the north. This catchment is mainly urban (80%) with the balance being forest. This catchment is proposed to flow into the Ellen Brook tributary, Saw Pit Gully Creek, which passes through the north eastern corner of the proposed development area.

The creek itself has a substantial rural catchment which is located to the north of the development area. This catchment comprises 70% forest and 30% active rural land.

An option to reduce the water loads exported to Ellen Brook is the proposal to divert some of the base flows from the Northern Catchment to the Southern Catchment where there is greater potential for detention treatment of the water and greater capacity to recharge. A pump station of 30 L/s capacity has been modelled which will transfer a proportion of the Northern Catchment flows to the Southern catchment. Flows exceeding the capacity of the pump station will continue to flow into Saw Pit Gully. Based on the groundwater seepage flows, this proposal can reduce the outflow to Saw Pit Gully by as much as 700,000 m^3/annum (typically 300,000 m^3/annum).

4.2.3.2 Design Rainfall Data

The design rainfall totals and temporal patterns used in the RORB analysis were derived from ARR-87. The design rainfalls were calculated for various durations and ARI's to enable determination of the critical durations for various catchments within the study area.

4.2.3.3 Annual Rainfall

The annual rainfall records for Perth were examined to determine values for the 10%, 50% and 90% annual rainfall values, representing dry, average and wet years. The monthly records were also examined to determine typical rainfall patterns for those years.

A simple loss model approach was adopted to estimate monthly surface drainage volumes for each of the catchments examined. The loss rates adopted were varied seasonally to reflect differing loss rates between dry and wet seasons. The weighted average runoff coefficient generated was 13% which is consistent with values used for urban residential land use in the Perth Urban Water Balance Study (WAWA, 1987)

The monthly surface runoff values were combined with the monthly groundwater seepage volumes, determined from the groundwater model, to estimate annual outflows from each catchment for an average rainfall year. This technique provided a means of estimating the total water loads discharged from the catchments along the outlet drainage lines.

4.2.3.4 Parameter Values

As there was no stream gauging data available on the catchment, regional techniques were used to predict the RORB parameters. From Australian Rainfall and Runoff 1987, the regional values of the parameters for the south west region of Western Australia were determined as follows:

$$m = 0.8 \quad \text{and} \quad k_c = 1.49L^{0.91}$$

For the Southern Catchment:

$$L = 6.1\ \text{km} \quad \& \quad k_c = 7.7$$

For the Northern Catchment:

$$L = 7.0\ \text{km} \quad \& \quad k_c = 8.8$$

For the Eastern Catchment:

$$L = 2.7\ \text{km} \quad \& \quad k_c = 3.7$$

For the combined Catchments:

$$L = 14\ \text{km} \quad \& \quad k_c = 16.5$$

4.2.3.5 Loss Model

4.2.3.5.1 Urban Area

The loss model adopted for the urban area assumes that 25 percent of the total rainfall falls on impervious areas and 75 percent on pervious areas (Figure 4.3). RORB assumes the coefficient of runoff for impervious areas is 0.9 resulting in direct runoff of 22.5 percent. From the Water Authority publication "Ellen Brook Flood Study" (WAWA, 1987a) the pervious area runoff coefficient was adopted as 0.12. Only 9 percent of the total rainfall therefore runs off from the pervious areas.

For areas with no subsoil drainage, the remaining 66 percent of design storm rainfall is lost due mainly to evaporation, transpiration and infiltration. However, in areas where subsoil drainage exists, 52.5 percent is assumed to be collected by the subsoil drains (70% of the pervious area) and losses are reduced to 13.5% (WAWA, 1989). Refer to Figure 4.4.

4.2.3.5.2 Rural Area

The rural areas were classified as either "natural" (including bushland and forests) or active (i.e. developed pasture, horticulture, etc). The natural rural was assumed to have no impervious areas and the active rural 5 percent impervious areas (Figures 4.5 and 4.6). The loss model was structured similar to the urban loss model.

4.3 Modelling Results

4.3.1 Summary of Peak Design Flows and Detention Basins Following Urbanization

The following tables summarize the peak design flows and modelled detention basins assuming urbanization for the Northern and Southern Drainage Catchments.

Table 4.2 shows the modelled basin parameters for the Northern and Southern Catchments.

PRELIMINARY DETENTION BASIN DESIGN PARAMETERS

Pervious Runoff Coefficient: 0.12, kc = 16.5

BASIN	Catchment Area ha	Nom. Basin Area ha	Surcharge Depth m	Surcharge Volume m3	Max. GWL m AHD	Outlet IL m AHD	NSL m AHD
2	105	1.2	0.8	8,440	48.5	48.5	49.5
4	178	3.0	1.4	38,200	47.1	47.1	48.0
5	167	3.5	1.8	55,400	43.6	44.5	44.0
11	39	0.6	1.2	5,850	45.8	46.5	47.0
9	94	2.5	1.2	28,000	43.5	43.5	44.0
12	69	2.0	1.4	23,900	33.0	33.0	33.5
14	88	2.0	1.4	24,422	35.5	35.5	38.0
45	180	3.0	1.8	46,900	19.0	19.0	20.0
16	78	1.5	1.4	18,000	40.5	41.8	42.0
17	39	0.6	1.2	6,900	40.3	40.4	44.0
21	156	2.5	1.5	31,700	44.0	45.8	46.0
23	28	0.5	1.9	7,110	44.0	44.0	48.0
24	87	1.5	1.5	19,300	41.8	42.8	46.0
27	44	0.7	1.3	6,870	43.3	46.0	48.0
26	64	1.0	1.8	14,600	41.5	41.5	44.0
29	94	2.0	1.9	32,500	39.8	40.5	43.5
36	113	15.0	1.0	139,000	39.0	39.0	41.0
39	71	1.1	0.9	9,270	30.5	31.0	32.0

Note: Surcharge Water Depth and Volume are based on the 10 year ARI rainfall event.

Max GWL = the maximum observed Ground-Water Level in an average rainfall year.

Outlet IL = the Invert Level of the lowest outlet pipe or channel.

Table 4.2: Detention Basin Design Parameters

These are indicative of the final basin parameters although some modifications can be expected in conjunction with refinement of the structure plan and development of more detailed subdivision plans following rezoning.

Table 4.3 shows the peak design flow characteristics of the detention basins proposed for the Northern and Southern Catchments, for a 1 year ARI event. Tables 4.4 and 4.5 show similar characteristics for the 10 year and 100 year ARI events. Estimates for Peak Flow, Peak Depth, Peak Volume and Critical Duration are tabulated for both 'wet' and 'dry' conditions.

1 YEAR ARI DESIGN EVENT

Pervious runoff Coefficient: 0.12 k_c = 16.5 I_c = 0 mm

Basin	"WET" CONDITION — Subsoils Included				"DRY" CONDITION — Subsoils Excluded			
	Outflow L/s	Surcharge Depth m	Surcharge Volume m³	Critical Duration days	Outflow L/s	Surcharge Depth m	Surcharge Volume m³	Critical Duration days
2	95	0.40	4,190	1	95	0.39	4,090	1
4	275	0.66	17,900	3	195	0.57	15,300	1
5	330	0.74	22,800	3	220	0.59	18,200	3
11	55	0.48	2,170	1	55	0.47	2,150	1
9	425	0.80	17,900	3	260	0.51	11,400	3
12	470	0.82	14,000	3	270	0.54	9,020	3
14	440	0.80	13,700	3	255	0.50	8,350	3
45	510	0.84	2,220	3	285	0.64	16,700	7
16	60	0.56	7,240	1	60	0.56	7,240	1
17	80	0.44	4,500	3	80	0.44	4,500	3
21	60	0.54	11,500	1	60	0.54	11,500	1
23	70	0.67	2,390	1	70	0.67	2,390	1
24	110	0.60	7,360	1	110	0.60	7,360	1
27	55	0.49	2,580	1	55	0.49	2,580	1
26	195	0.71	5,800	1	195	0.71	5,800	1
29	195	0.72	12,100	3	195	0.72	12,100	3
36	180	0.59	83,800	7	180	0.59	83,800	7
39	90	0.42	4,270	1	90	0.42	4,270	1

Table 4.3: Estimated 1yr ARI Design Flows

10 YEAR ARI DESIGN EVENT

Pervious Runoff Coefficient = 0.12 k_c = 16.5 I_l = 0 mm

Basin	"WET" CONDITION — Subsoils Included				"DRY" CONDITION — Subsoils Excluded			
	Outflow L/s	Surcharge Depth m	Surcharge Volume m³	Critical Duration days	Outflow L/s	Surcharge Depth m	Surcharge Volume m³	Critical Duration days
2	300	0.80	8,440	2	295	0.79	8,370	2
4	635	1.40	38,200	3	575	1.23	33,600	1
5	760	1.78	55,400	3	670	1.49	46,500	3
11	100	1.24	5,850	1	100	1.22	5,790	1
9	1040	1.24	28,000	3	860	1.08	24,300	3
12	1180	1.40	23,900	3	930	1.14	19,600	3
14	1200	1.42	24,400	3	980	1.19	20,300	3
45	1470	1.77	46,900	3	1130	1.34	35,500	3
16	110	1.37	18,000	3	110	1.37	18,000	3
17	185	1.18	6,900	1	185	1.18	6,900	1
21	115	1.45	31,700	3	115	1.45	31,700	3
23	130	1.92	7,110	3	130	1.92	7,110	3
24	220	1.53	19,300	3	220	1.53	19,300	3
27	105	1.27	6,870	1	105	1.27	6,870	1
26	380	1.77	14,600	3	380	1.77	14,600	3
29	400	1.89	32,500	3	400	1.89	32,500	3
36	580	0.98	139,000	7	580	0.98	139,000	7
39	240	0.90	9,270	1	240	0.90	9,270	1

Table 4.4: Estimated 10yr ARI Design Flows

100 YEAR ARI DESIGN EVENT								
Pervious Runoff Coefficient = 0.12			kc = 16.5				Il = 0 mm	
	"WET" CONDITION — Subsoils Included				"DRY" CONDITION — Subsoils Excluded			
Basin	Outflow L/s	Surcharge Depth m	Surcharge Volume m3	Critical Duration days	Outflow L/s	Surcharge Depth m	Surcharge Volume m3	Critical Duration days
2	480	1.02	10,800	1	460	1.01	10,800	1
4	1395	1.60	44,700	1	1230	1.58	44,000	1
5	1760	2.12	67,700	3	1355	2.08	65,900	1
11	130	1.89	9,020	1	130	1.86	8,870	1
9	2370	1.63	37,800	3	1570	1.54	35,100	1
12	2530	2.12	37,400	3	1430	1.71	29,300	1
14	2700	2.13	37,800	3	1440	1.73	29,700	3
45	3275	2.18	59,600	3	1685	2.01	53,400	2
16	380	1.54	20,500	1	380	1.54	20,500	1
17	545	2.05	9,990	1	545	2.05	9,990	1
21	300	2.03	44,500	2	300	2.03	44,500	2
23	345	2.03	7,700	2	345	2.03	7,700	2
24	520	2.04	26,000	3	520	2.04	26,000	3
27	135	1.94	10,600	1	135	1.94	10,600	1
26	830	2.07	17,500	1	830	2.07	17,500	1
29	1040	2.10	36,900	1	1040	2.10	36,900	1
36	915	1.62	230,000	7	915	1.62	230,000	7
39	500	1.04	10,800	2	500	1.04	10,800	2

Table 4.5: Estimated 100yr ARI Design Flows

The critical duration for peak outflows from the detention basins varies depending on the size and characteristics of the contributing subcatchments. The basins located towards the catchment outlets have critical times of concentration exceeding 1 day whereas the critical durations of the upstream basins are 1 day or less. The 100, 10 and 1 year ARI design outflows at the Northern Catchment outlet are estimated as 3.3, 1.5 and 0.5 m^3/s respectively. The peak outflows for the Southern Catchment are 1.0, 0.6 and 0.2 m^3/s respectively. Estimates for the Eastern Catchment yield 1.8, 0.8 and 0.3 m^3/s respectively.

The markedly lower flows from the Southern Catchment are due to the relatively large detention storage within the Southern Catchment. This catchment also has greater potential for recharge than the Northern Catchment due to greater freeboard to the water table. Utilization of the exsiting quarry site in the Southern Catchment as a large detention basin and lake will provide considerable compensating storage enabling outlet drainage works to be reduced in scale.

Overall the proposed size of the trunk drains in the Southern Catchment are smaller than those in the Northern Catchment because of the dendritic pattern of the Southern drainage system and the greater effectiveness of compensating storage in the catchment.

The modelled detention basins generally vary in depth from one to two metres. The basins in the Southern Catchment are typically deeper reflecting the greater depth to the water table and the increased opportunity to recharge water. The detention basin surface areas are between 0.5 and 3.5 hectares with the exception of the large lake proposed at the existing quarry. This was modelled with a surface area of 15 hectares. The surcharge storage capacities of the basins are generally between 10,000 and 50,000 m^3. The quarry site lake provides a storage volume exceeding 280,000 m^3.

Subsoil drainage does not appear to be required in the Southern Catchment due to the greater depth to water table. The Northern Catchment requires significant subsoil drainage to prevent water table rise following urbanization. Flows generated in the Northern Catchment were calculated for direct runoff alone and for runoff with transient subsoil runoff included. The former case, defined as the "dry" case, represents storm runoff when the water table is low (i.e. runoff occurring in the January to June period of the year). The latter, or "wet" case, applies to runoff events occurring when the water table is higher (typically July to December). The water table has a tendency to peak at the end of September and reach a minimum level in April of each year.

4.3.2 Estimated Outflow Volumes

The total annual flow volumes at the development outlets were estimated from the groundwater model (seepage flows) and from the loss model (surface flows). These results are based on monthly flows in an average year. Numerical modelling was carried out for a number of options including:

- for urbanization WITHOUT Lexia borefield operation;
- for urbanization WITH Lexia borefield operation;
- for urbanization with a 90 hectare conservation area; and
- for urbanization with a 410 hectare conservation area.

The development proposed includes the option for urbanization of a portion of the Sate Forest to the west (180 hectares). If this area is excluded from the development, there is a reduction in the outflow of water from the Southern Catchment commensurate with the reduced urbanized area.

The effect of intercatchment pumping of base flows from the Northern to the Southern Catchment was also quantified. If intercatchment pumping is not implemented, then outflows from the Northern Catchment will increase. A summary of the estimated annual outflows from the catchments following development is presented in Table 4.6.

Lexia Scheme	Groundwater Scheme INCLUDED		Groundwater Scheme EXCLUDED	
Conservation Area	90 ha	410ha	90 ha	410 ha
CATCHMENT:				
NORTHERN	0.9×10^6 m^3	0.7×10^6 m^3	1.3×10^6 m^3	1.0×10^6 m^3
SOUTHERN	1.4×10^6 m^3	1.4 x 106 m^3	1.4 x 106 m^3	1.4 x 106 m^3
EASTERN	0.8×10^6 m^3	0.8 x 106 m^3	0.8 x 106 m^3	0.8 x 106 m^3
INCREASED outflow if NO intercatchment pumping	0.2×10^6 m^3	0.2 x 106 m^3	0.3 x 106 m^3	0.3 x 106 m^3
DECREASED outflow if area of State Forest is EXCLUDED from development	0.1×10^6 m^3		0.2 x 106 m^3	

Table 4.6: Estimated Annual Drainage Outflows

The average annual flow of groundwater entering Ellen Brook and the Swan River after passing under the development area has also been estimated. This flow, passing through the superficial aquifer was assessed at 4×10^6 m^3 per year. The change in annual groundwater flow following development is not expected to be significant.

5.0 WATER QUALITY MANAGEMENT

5.1 Objectives

The water quality studies carried out as part of the overall study had as their main objectives:

- determination of strategies to minimise pollutant loads exported from the site by the drainage system;
- optimisation of flow routing and detention basin design to enhance discharge water quality;
- estimation of the water loads discharged to receiving water bodies by the drainage system;
- estimation of the nutrient loads exported from the urban areas by the drainage system.

5.2 Runoff Water Quality

The quality of the subsurface (subsoil) and surface runoff waters was initially assessed based on data used in previous studies (G B Hill & Partners and Sinclair Knight & Partners, 1987 and G B Hill & Partners Pty Ltd 1990 and 1991). In particular the loadings of phosphorus (P) in the drainage flows were estimated and applied over each subcatchment in the drainage model. The urban area will be fully sewered.

The following basic assumptions were adopted for the preliminary estimates of P entering the drainage system:

- Catchment Population:

  Urban 36 persons/hectare

  Active Rural 1 persons/hectare

  Forest and Natural Bushland 0 persons/hectare

- Phosphorous loads transported to the drainage system:

  Urban Areas 0.019 kg P/capita/annum;

  Active Rural Areas 0.019 kg P/capita/annum plus 4 kg P/hectare/annum;

  Forest and Natural Bushland 0 kg P/hectare/annum.

The population based P loading rate assumed for the drainage from the urban development in the preliminary estimation represented an areal loading of 0.68 kg P/ha/annum. By comparison, observed data in the Kardinya catchment has indicated typical urban drainage loading rates of 0.5 kg P/ha/annum. The values adopted for this study are considered to be conservative.

Subsequently, data obtained by the Water Authority (H T H Tan, 1992) were incorporated into the nutrient modelling. This data was obtained from monitoring of urban runoff in selected catchments within the Perth Metropolitan Area. Obtained from first flush sampling (event first flush) in the autumn, winter and spring of 1991, the data set is not ideal, but is the best field data currently available for Perth Urban conditions.

The Water Authority data, presented as seasonal loads, was discretized to suit the monthly time step used in the nutrient model. The values used are shown in Figure 5.1.

The monthly water loads for each subcatchment were determined for the average rainfall year. Water loads comprised a combination of base flows and runoff flows. The base flows were assessed as seepage into the subsoil drainage system and detention basins intersecting the groundwater table. These flows were estimated from the groundwater modelling. Monthly runoff flows were determined from a loss model applied to average monthly rainfall for Perth.

An annual distribution of transported P was adopted to reflect first flush effects in the preliminary study. These figures are shown in Table 5.1. The more recent analysis has been based on the Water Authority data.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Distribution	5%	5%	55	10%	25%	15%	10%	5%	5%	5%	5%	5%

Table 5.1: Adopted Distribution of Annual P Load

5.3 Detention Basins

The estimated water flows and pollutant loads were applied to a simple routing model which incorporated phosphorus reduction calculations based on detention time. Two processes were modelled, sedimentation and biological nutrient removal (BNR).

Estimation of the extent of P reduction by sedimentation was based on the Vollenweider/OECD nutrient budget model (OECD, 1982). This model is known to overestimate in-lake concentrations (OECD, 1982) so the predicted retentions of P can be assumed to be conservative.

It is proposed that the detention basins will be substantially vegetated to enable significant BNR to occur. Nutrient uptake by emergent macrophytes, algae and bacteria in the sediments of the basins will all contribute to the reduction process. Where possible, the detention basins will be designed to dry out in the summer, to allow the sediments to oxidise. The oxidation process will effectively remove a proportion of the P and N thereby reducing the amount of nutrients available for remobilisation. By ensuring correct hydraulic design of the basin, so that low velocities (<0.3 m/s) are maintained within the basins, the probability of remobilisation by resuspension of the sediments is remote.

For the 20 basins modelled, individual residence times varied from 2 days to over 30 days. A summary of the detention basin data is included in Table 4.2. Overall, the volumes of the basins modelled provide in excess of 7 days detention for runoff from a 10 year ARI design storm.

The detention basins will need to be properly managed if they are to remain effective in treating the drainage waters. Vegetation will require harvesting periodically to prevent a buildup of dead plants which would otherwise release nutrients and other pollutants back into the water body on decomposition. It is proposed that one third of the vegetation within each artificial basin be harvested each year to maintain effective stands of vegetation. Strip harvesting perpendicular to the major flow path is recommended to prevent short circuiting and provide abundant stock for regeneration.

To improve the ability of the basins to trap nutrients and other pollutants while allowing some infiltration to the groundwater, the bottom sediments of the major basins will be amended with neutralised red mud to improve the phosphorus absorption capacity of the basins. Reamendment of the sediments will need to be carried out every 20 years or longer as identifed by environmental monitoring.

5.4 Outflow Waters Quality

Based on the detention storage modelled, the overall reduction in P load was estimated as 85% in the Northern Catchment, 90% in the Southern Catchment and 78% in the Eastern Catchment. The estimated overall phosphorus loads exported and retained for the various options considered are shown in Table 5.2.

These loads represent export rates in the drainage water of only 0.03, 0.01 and 0.02 kg P/hectare/annum for the Northern, Southern and Eastern catchments respectively. For comparison, the Minister for the Environment's condition for drainage discharges in the Peel/Harvey Catchment is 0.375 kg P/hectare/annum (EPA Bulletin 482, 1990). It is evident that with the management practices proposed, the Ellenbrook development can surpass this requirement.

Lexia Scheme		Groundwater Scheme INCLUDED		Groundwater Scheme EXCLUDED	
Conservation Area		90 ha	410 ha	90 ha	410 ha
WATER LOAD (Mm³)					
Catchment:	Northern	0.9	0.7	1.3	1.0
	Southern	1.4	1.4	1.4	1.4
	Eastern	0.8	0.8	0.8	0.8
	TOTAL	3.1	2.9	3.5	3.2
If No Intercatchment Pumping Increase by		0.2	0.2	0.3	0.3
If State Forest Excluded Decrease Load by		0.1		0.2	
P EXPORTED (kg)					
Catchment:	Northern	20	19	46	44
	Southern	7	7	8	8
	Eastern	10	10	10	10
	TOTAL	37	36	64	62
If No Intercatchment Pumping Increase by		5	5	14	15
If State Forest Excluded Decrease P by		1		4	
P RETAINED (kg)					
Catchment:	Northern	105	98	339	316
	Southern	66	68	75	77
	Eastern	35	35	35	35
	TOTAL	206	201	449	428
If No Intercatchment Pumping Increase by		5	5	14	16
If State Forest Excluded Decrease P by		7		26	

Table 5.2: Estimated Water and Phosphorus Loads

5.5 Groundwater Quality In The Lexia Borefield

The majority of the proposed Lexia production bores are located upgradient from the development. The quality (and quantity) of groundwater abstracted from these bores will not be adversely affected by the urban development. Two bores, located within the development area, may be affected by the development. By adopting the management practices outlined, and with adaptive management of the scheme in response to monitoring, the groundwater abstracted from within the urban area can be maintained at a quality suitable for public water supply.

5.6 Groundwater Quality Entering the Swan River

The quality of the shallow groundwaters intercepted by the subsoil drainage system has been estimated and is included in the above assessment. So too has the shallow groundwater intercepted by the natural streams leading to Ellen Brook and the Swan River. An estimate of the P load in the deeper groundwater flowing through the proposed development has been inconclusive due to the absence of suitable groundwater quality data. The quantity of groundwater passing through the development area and flowing directly into Ellen Brook and the Swan River has been estimated as 4×10^6 m^3 per year. This flow would also pass through the "Vines" area, the Eastern Catchment area (Multiplex land) or the Henley Brook rural land to the south prior to entering the river. The existing land uses in each of these areas indicate a higher rate of P input to this groundwater flow than would be generated by the proposed development. This again indicates that adoption, throughout the North East Corridor, of the water and land management principles proposed for this development, would improve the quality of waters flowing to the Swan River.

6.0 CONCLUSIONS

The study has shown that with appropriate water management strategies for the proposed urban development, the following conclusions may be drawn:

- The quality and quantity of groundwater abstracted from the proposed Lexia bores to the west of the development area will not be adversely affected by the proposed urbanisation.
- Changes to the water quality of the Lexia and Mirrabooka borefields within and immediately adjacent to the development can be minimised and can be maintained at a standard suitable for public water supply.
- The quantity of water available for public and private abstraction can be increased by strategic placement of recharge sites.
- By using a combination of drainage (to relieve high water levels) and artificial recharge (to relieve low water levels), the existing water regime in the wetlands conservation area to the north west of the development may be maintained.
- The urban development can be managed to produce negligible changes to the water regime in the wetlands. A major effect, predicted by the groundwater model, was lowering of the water table as a result of groundwater abstraction from the proposed Lexia borefield. By optimising bore locations in the Lexia borefield and by providing some artificial recharge of the wetlands in the drier years, the impact of the Lexia Scheme can also be minimised.
- The bulk of the Southern Catchment may be developed without requiring subsoil drainage.
- Substantial subsoil drainage and sand fill will be required to develop the Northern and Eastern Catchments for urban development.
- Changes in groundwater levels in the existing Vines development will be minimised by installation of the subsoil drainage system.
- Adoption of intercatchment pumping of drainage base flows from the Northern Catchment to the Southern Catchment can significantly reduce the export of drainage water to the Swan River and Ellen Brook.
- By using appropriate techniques of water sensitive design within the development, the amount of drainage water flowing from the area can be reduced and accumulation of contaminants in the drainage system can also be minimised.
- The nutrient loads that will be exported from the development area by the drainage system may be minimised by the management principles outlined.
- An Environmental Management Programme (EMP) will need to be set up to monitor water quality exported from the development area. This programme should be carried out by the Authorities managing the drainage system and would be initially funded by the developers through headworks charges or rates.
- Adaptive management of the development would occur in response to the findings of the EMP, to ensure protection of the water resources in the area.
- Adoption of similar management principles throughout the North East Corridor would significantly reduce the contaminant loads entering Ellen Brook and the Swan River.

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APPENDIX A

THE VERTICAL FLUX MODEL

APPENDIX A: The Vertical Flux Model

The Vertical Flux Model (VFM), illustrated schematically in Figure 3.3, is a soil moisture accounting model for the unsaturated zone (above the water table). For each time step, all the processes impacting local recharge are quantified and a single flux to or from the saturated zone is determined. The VFM operates on a regular grid of cells of dimension 500 by 500 metres and calculates the net vertical flux for each cell every time step. This flux is distributed between the nodes of the underlying triangular element of the hydraulic model containing that cell.

As shown in Figure 3.3, the unsaturated zone is divided into three layers, with water movement permitted only in the vertical direction. At the start of each time step, the "state" of the system is summarised by a "wetness index" which indicates the depth of water stored in each layer.

Inputs to the net vertical flux model, which are derived from rainfall, imported and locally pumped water, are applied to the different layers. The natural processes of infiltration, evapotranspiration and percolation are then simulated in order to predict the resulting changes in wetness and the net vertical flux.

The VFM is based on the choice of three zones, each of which is conceptually associated with different transpiration processes.

The uppermost layer is associated with shallow rooted plants, the most common of which is grass. This layer is known as the "grass root zone" and has a maximum thickness of 2 metres. The second layer is associated with deeper rooted plants such as trees. The maximum thickness of the "tree root zone" is 5 metres, which implies a maximum rooting depth for trees of 7 metres. Although it is recognised that some trees have substantial rooting densities more than 7 metres below the surface, this depth is accepted as a reasonable average value for pines and native trees in the study area. The lowest layer, between the tree root zone and the water table, is assumed to be largely free of roots ("root free zone").

When the depth to water table is less than 2 metres, there is a shallow grass root zone less than 2 metres in thickness and no tree root or root free zones. Similarily, when the depth to water table is between 2 and 7 metres, there is a 2 metre grass root zone, a tree root zone less than 5 metres in thickness and no root free zone. Determination of this type are made for every time step as the water table rises and falls.

Plants whose root zones extend into the saturated zone are phreatophytes. Special algorithms are used for phreatophytic withdrawals when the water table is within the grass and tree root zones.

In addition to evapotranspiration processes, direct input of water to the tree or root free zones is possible to simulate the depth at which household sumps, septic tanks and road runoff infiltration basins actually discharge to the unsaturated zone.

The overall moisture storage of the unsaturated zone in any cell is summarised at any point in time by "wetness indices" for each zone, representing the volume of water stored (moisture content). These indices control evapotranspiration and percolation within each zone.

A.1 Vertical Flux Model Components

A.1.1 Rainfall

The primary source of water for the region is rainfall. The amount of rain reaching each cell in the VFM is calculated using the spatial pattern of annual rainfall and a pattern of monthly rainfalls within the year (historical data). The amount of rainfall which reaches the soil, however, depends on land use. A range of landuse variables representing the percentages of roofed, paved and vegetated areas forms part of the model input data. Interception losses for each of these areas is defined within the model.

For instance, for rainfall on the roofed part of the urban landscape, a fraction (0.85) is assumed to be caught by the roof, while the remainder overflows gutters and falls on the vegetated surface. Of the 85% caught by the roof, a further fraction (0.05) will be held in storage (ie, intercepted) and evaporated, while the remainder flows into sumps located approximately 2 metres below the land surface. The latter becomes an input to the tree root zone in the Vertical Flux Model.

The destination of road runoff depends on the local drainage system and in particular the presence of local infiltration (compensation) basins. Contributing areas of road runoff to compensating basins may be defined for each cell (the sum of all paved areas contributing to the basin). If this parameter is set to zero, then runoff from that cell is exported, either to a nearby cell where there is a compensating basin, or to a river or the ocean. Allowing for interception and storage the net paved area runoff becomes an input to the root free zone, which is at a depth equivalent to the depth of typical infiltration basins.

Rainfall which reaches non-roofed and non-paved surfaces in urban areas, (the vegetated areas) is derived from the percentage of vegetated area and the volumes which spill off roofs and paved surfaces. A canopy cover coefficient associated with the vegetated area of each cell is applied to calculate the canopy interception of rainfall with the remainder applied as an input to the grass root zone of the VFM.

A.1.2 Irrigation

Garden watering is the second largest input to the soil zone. Input consists of irrigation with both privately pumped groundwater and Scheme water supplied by the Water Authority.

It is assumed that all water pumped from bores other than those operated by the Water Authority is used for irrigation in the same cell. This includes bores installed in council parks and gardens, golf courses, schools, hospitals, private residences and market gardens. An exception in the Ellenbrook study has arisen in the case of the Vines project, where groundwater is abstracted to the west of the project and applied as golf course irrigation to the east. In this instance, abstraction is treated in a similar manner to the Water Authority schemes.

For all irrigation except that in market gardens, the water reaching the ground becomes an input to the grass root zone. The water not reaching the ground is assumed to evaporate, either before it reaches the ground (when the droplet size is small and potential evaporation is high) or after it lands on leaves or other surfaces.

A.1.3 Septic tank effluent

In-house water use and, as a result, septic tank effluent volumes have been shown to be almost constant throughout the year (Metropolitan Water Authority, 1985a). The calculated value for this parameter was 14.4m^3/month per septic tank, however this can be varied between simulations, to simulate changes in in-house water use habits, such as the installation of dual-flush toilets or more efficient dishwashers and washing machines. The number of septic tanks per cell, included in the model database, produces an input at a depth equivalent to the depth of most septic tanks, ie. into the tree root zone.

The Ellenbrook urban area will be fully sewered, so this component of the water balance will be exported from the area via the sewerage system. An allowance for septic tank effluent from the surrounding active rural areas has been included in the model.

A.1.4 Evapotranspiration

Different algorithms are used to calculate evapotranspiration (ET) by shallow-rooted and deep-rooted plants, and to calculate evaporation directly from the water table and open water bodies.

It is assumed that ET from the grass root zone can only occur in vegetated areas which are not sheltered by tree canopy. An equivalent grassed area is calculated from the vegetated area, less the canopy cover. Similarly, ET from the tree zone is calculated directly from the vegetated area times the canopy cover fraction.

Water balances for the three soil zones are performed sequentially, with flow between zones defined as a 'leaky bucket' function. Calculations for the grass and tree root zones are performed twice each at each time step, because of the dependence of evapotranspiration and percolation on soil wetness. Any error in convergence within this process does not cause a loss of water; its only effect is to modify the lag between climatic forcing and the resulting net vertical flux.

The final output from the lowest soil zone is the deep drainage or recharge to the aquifer. Where the unsaturated soil zone is thick (higher depths to water), the lowest zone is the root free zone. With thinner unsaturated zones, recharge may result from the grass or tree root zones. The net vertical flux to be applied to the regional aquifer system must also include a number of other vertical fluxes, directly into or out of the saturated zone. These are outlined below.

A.1.5 Evaporation directly from the water table (including lakes)

Cells may be defined as open water bodies such as lakes and wetlands. The evaporation from these cells is calculated as 90% of the class A pan evaporation for each time interval.

If the water table elevation rises above the land surface in any time step, a temporary wetland is assumed to have formed and evaporation is calculated as above. Evaporation from a shallow water table (i.e. just below the land surface) is included in earlier calculations for evapotranspiration from a grass root zone less than 2 metres thick.

A.1.6 Water Authority and private pumping

The total Water Authority and private groundwater abstraction is defined for each cell as a number of domestic bore equivalents (1 bore equivalent is 1,000 m^3/ha/annum). Seasonal variations in groundwater abstraction are defined separately for domestic, council, market garden and Water Authority on a monthly basis as part of the temporal model data. This allows abstractions to be increased gradually with time.

A.2 Summary of Vertical Flux Model

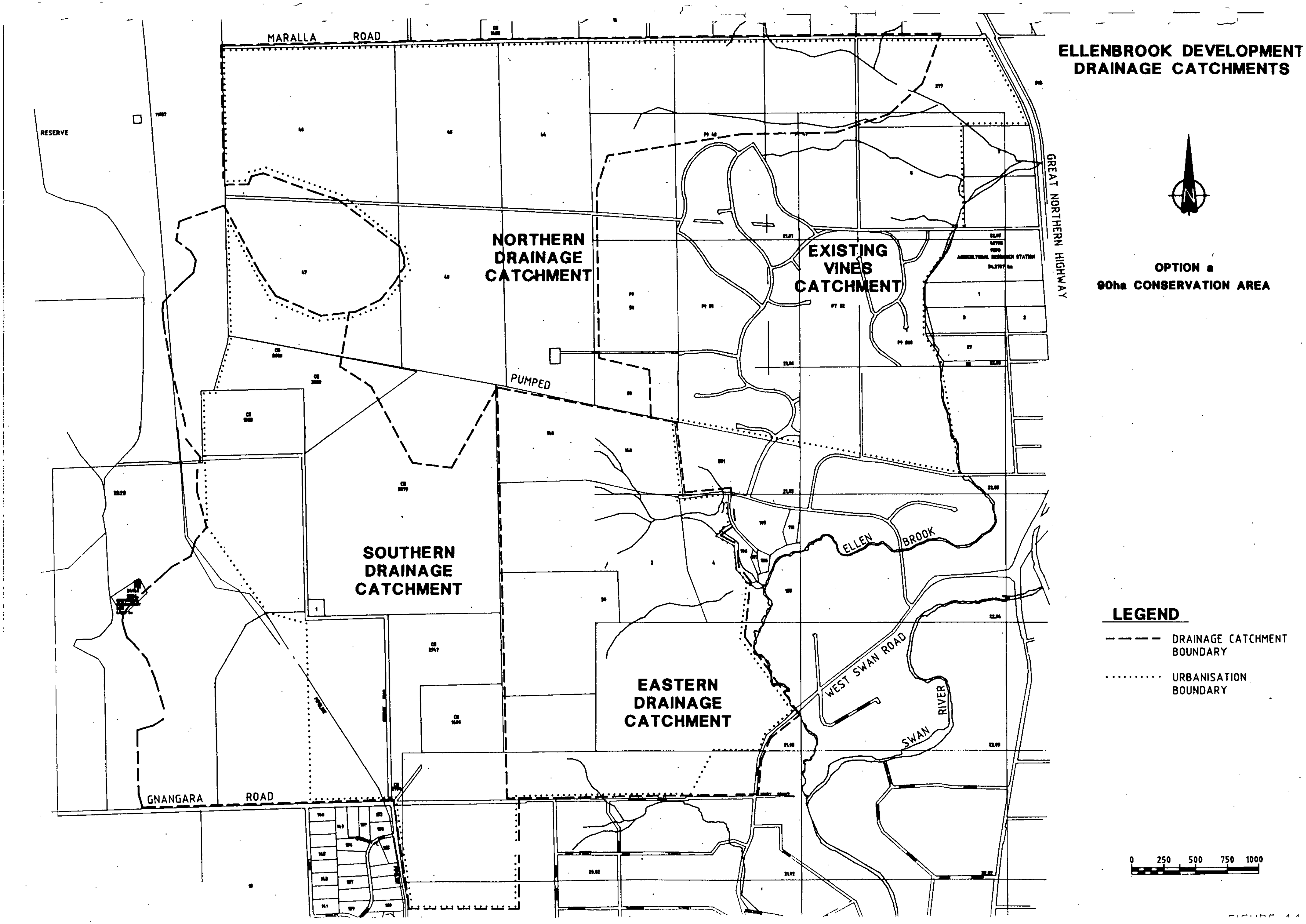
The total number of "parameters" that may be varied in the input data for the Vertical Flux Model is 21. This includes three for definition of the soil profile, nine for calculation of inputs, seven for calculation of evapotranspiration and three for the percolation algorithm. In addition there are five numerical constants which can not be changed between runs, four for capillary rise and one for evaporation from open water bodies.

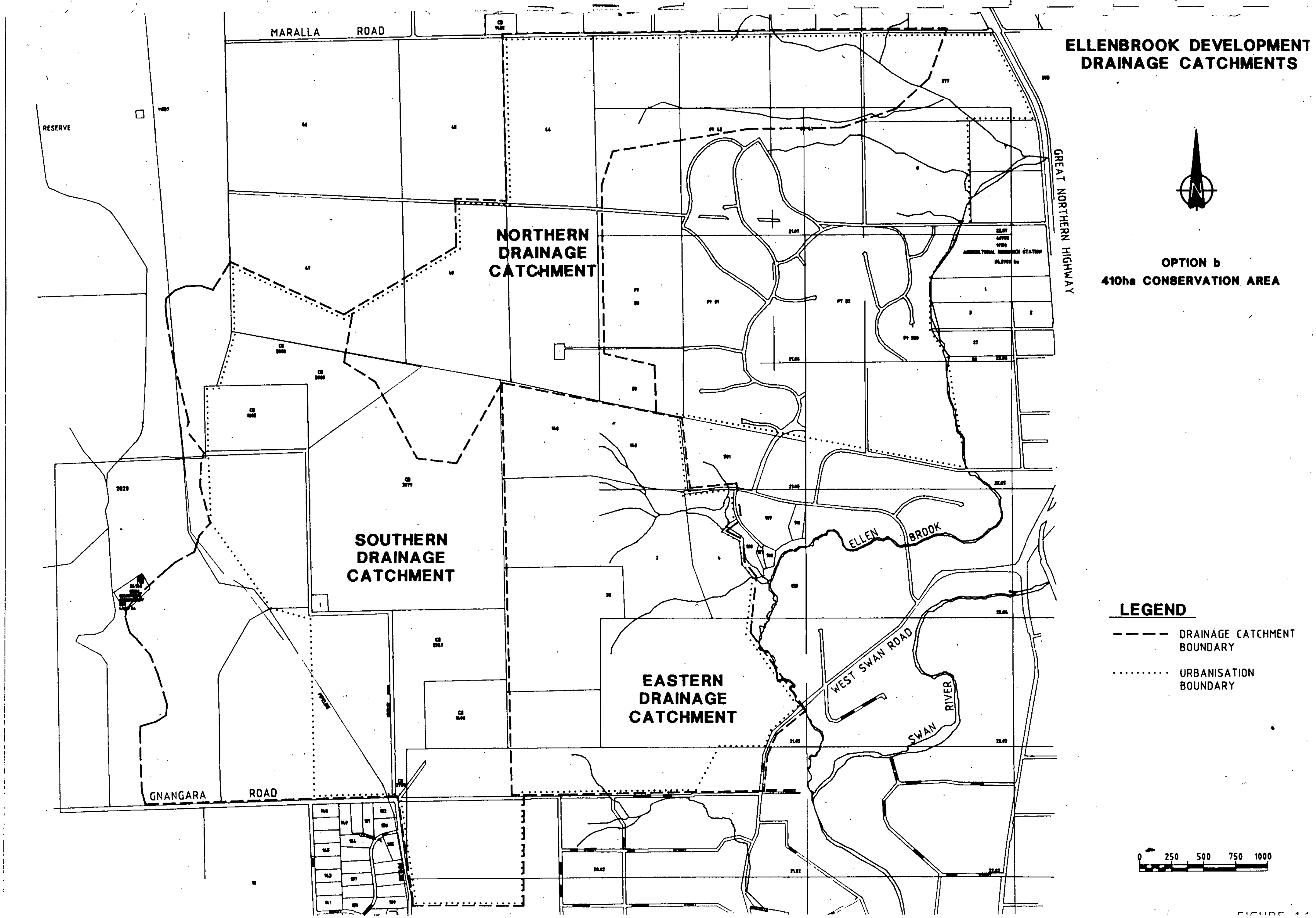
Of the 21 parameters, only a few are generally modified during model calibration. The majority are based upon independent evidence and experience with previous modelling studies. The fact that these parameters can have constant values in space over a large region partially justifies the concept of the VFM. If the structure or algorithms of the VFM were fundamentally in error, it would not be possible to match observed water levels over a range of land use types, without requiring these parameters to vary.

FIGURES

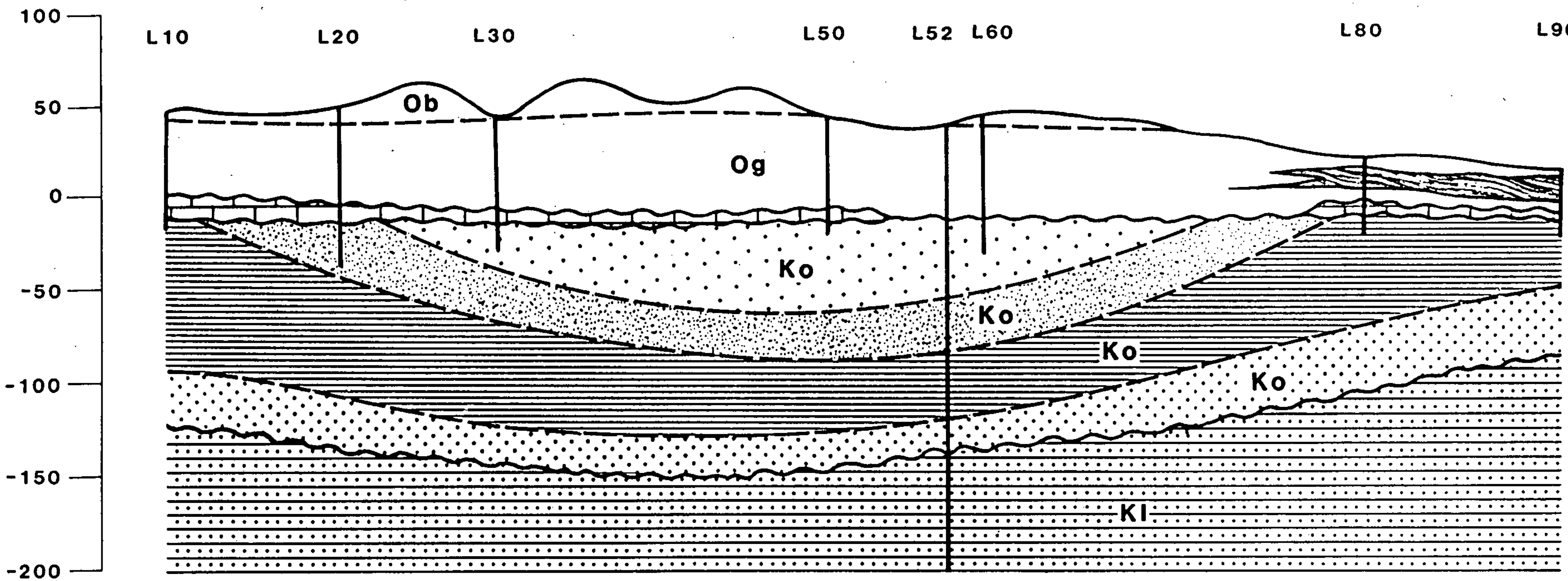
ELLENBROOK DEVELOPMENT DRAINAGE CATCHMENTS

OPTION a
90ha CONSERVATION AREA




ELLENBROOK DEVELOPMENT
DRAINAGE CATCHMENTS
OPTION b
410ha CONSERVATION AREA
NORTHERN DRAINAGE CATCHMENT
SOUTHERN DRAINAGE CATCHMENT
EASTERN DRAINAGE CATCHMENT
MARALLA ROAD
GNANGARA ROAD
GREAT NORTHERN HIGHWAY
WEST SWAN ROAD
ELLEN BROOK
SWAN RIVER
RESERVE
AGRICULTURAL RESEARCH STATION
LEGEND
DRAINAGE CATCHMENT BOUNDARY
URBANISATION BOUNDARY
0 250 500 750 1000

GEOLOGICAL CROSS-SECTION



Qb, Qg: Superficial Formations, Sand: fine to coarse

Clay

Limestone

Ko: Osborne Formations, Sand: fine - medium, clayey, 'marine sand'

Ko: Osborne Formations, Sand: fine - very coarse, very clayey

Ko: Osborne Formations, Shale

Ko: Osborne Formations, Sand: fine - very coarse, very clayey

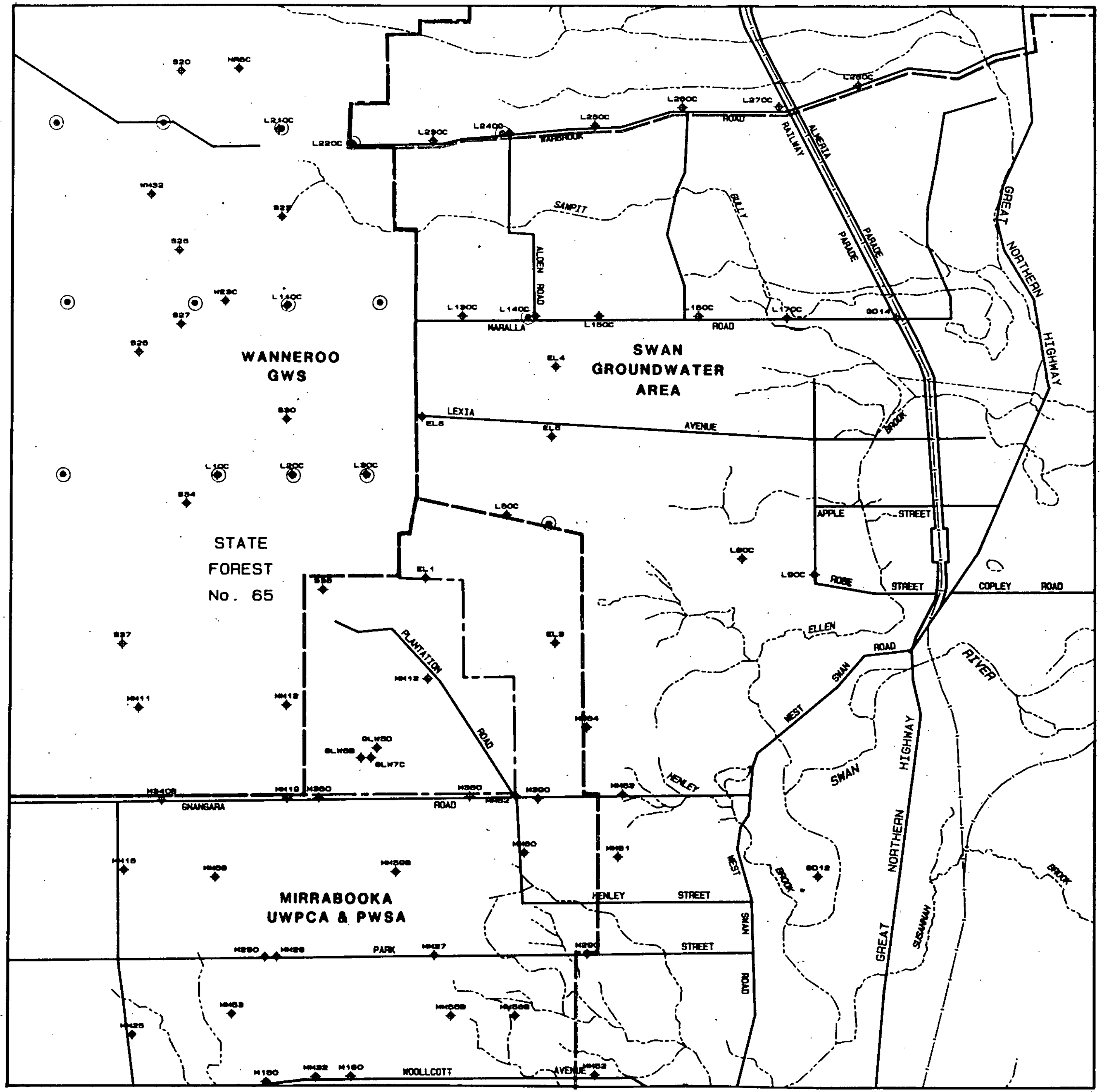
Kl: Leederville Formation, Interbedded sandstone, siltstone and shale

FIGURE 3.1

AFTER WAWA 1987

Mackie Martin & Associates PTY. LTD.
GROUNDWATER ENGINEERS & EARTH SCIENTISTS

ELLENBROOK
DRAINAGE AND GROUNDWATER
MANAGEMENT STUDY



LEGEND:

- Road
- Railway
- State Forest Boundary
- Surface Drainage
- Monitoring Bore
- Proposed Lexia Scheme Bore

NOTE:

Base map produced from GSWA 1:50000 Environmental Geology Maps.

0 500 1000 1500 2000 2500 3000 3500 M

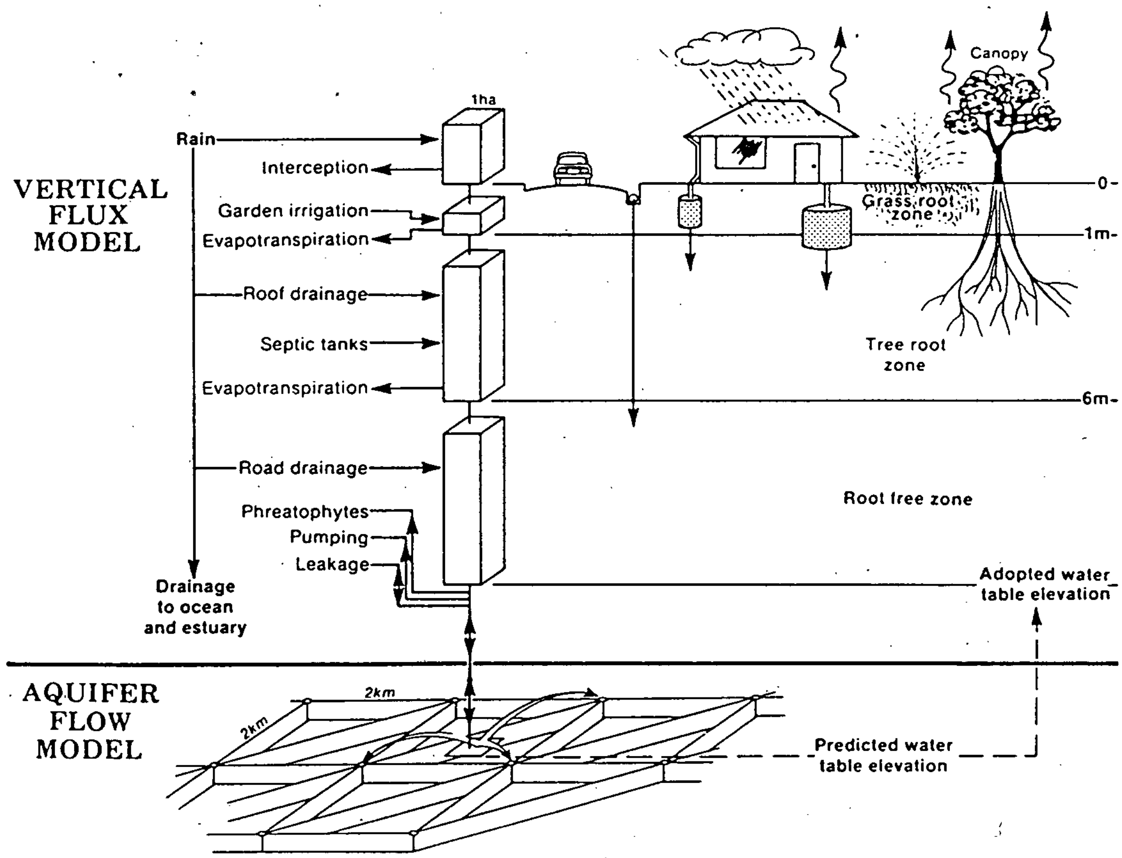
ORIGINAL SCALE 1:50000

PWSA BOUNDARIES AND WATER AUTHORITY BORE LOCATIONS

FIGURE 3.2

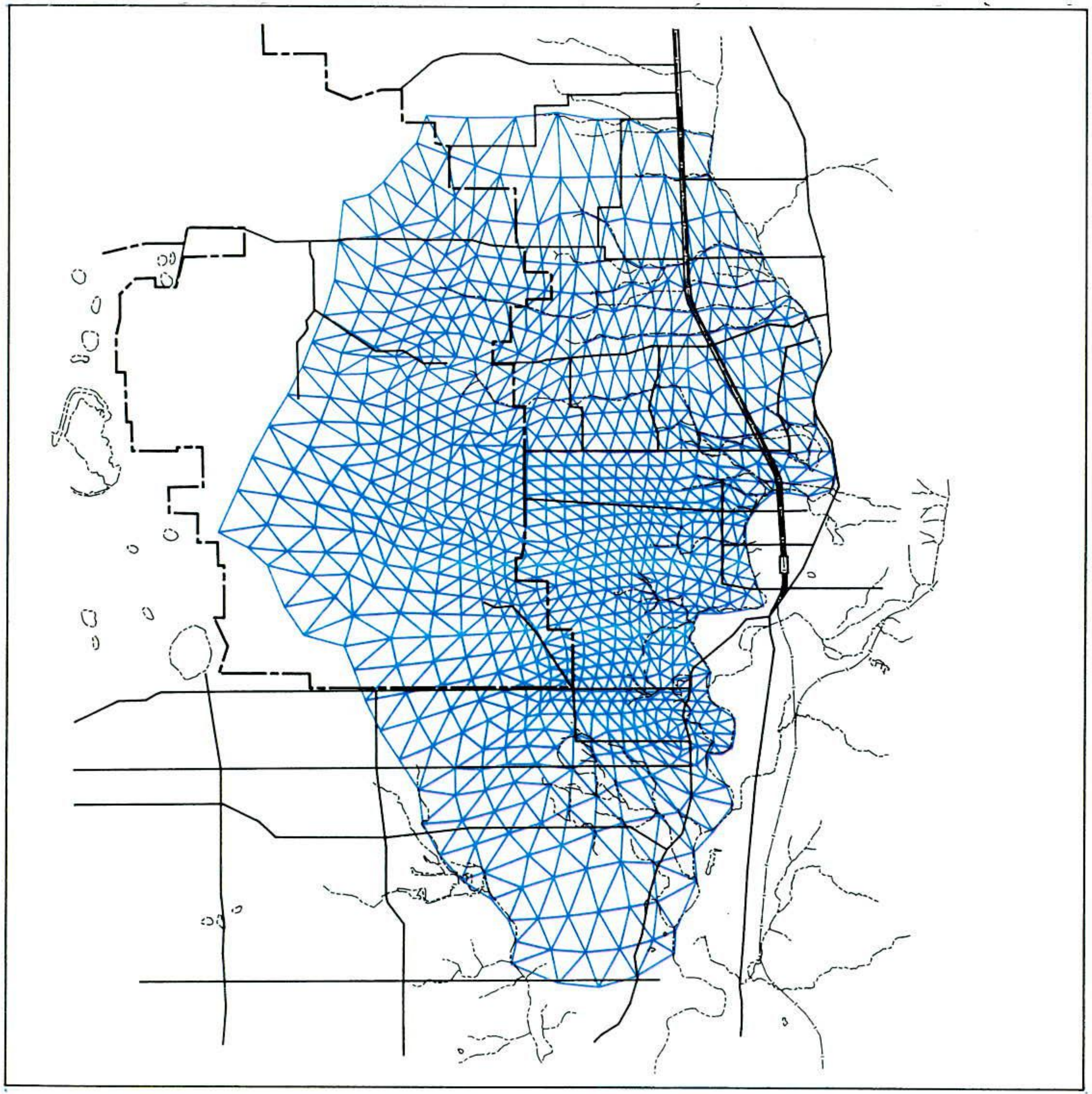
Mackie Martin & Associates
GROUNDWATER ENGINEERS

STRUCTURE OF THE PERTH URBAN WATER BALANCE MODEL



AFTER WAWA 1987

FIGURE 3.3



ELLENBROOK

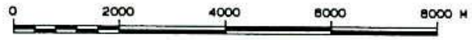
DRAINAGE AND GROUNDWATER MANAGEMENT STUDY

LEGEND:

- Road
- Railway
- State Forest Boundary
- Surface Drainage
- Triangular Element Mesh

NOTE:

Base map produced from GSWA 1: 50000 Enviromental Geology Maps.

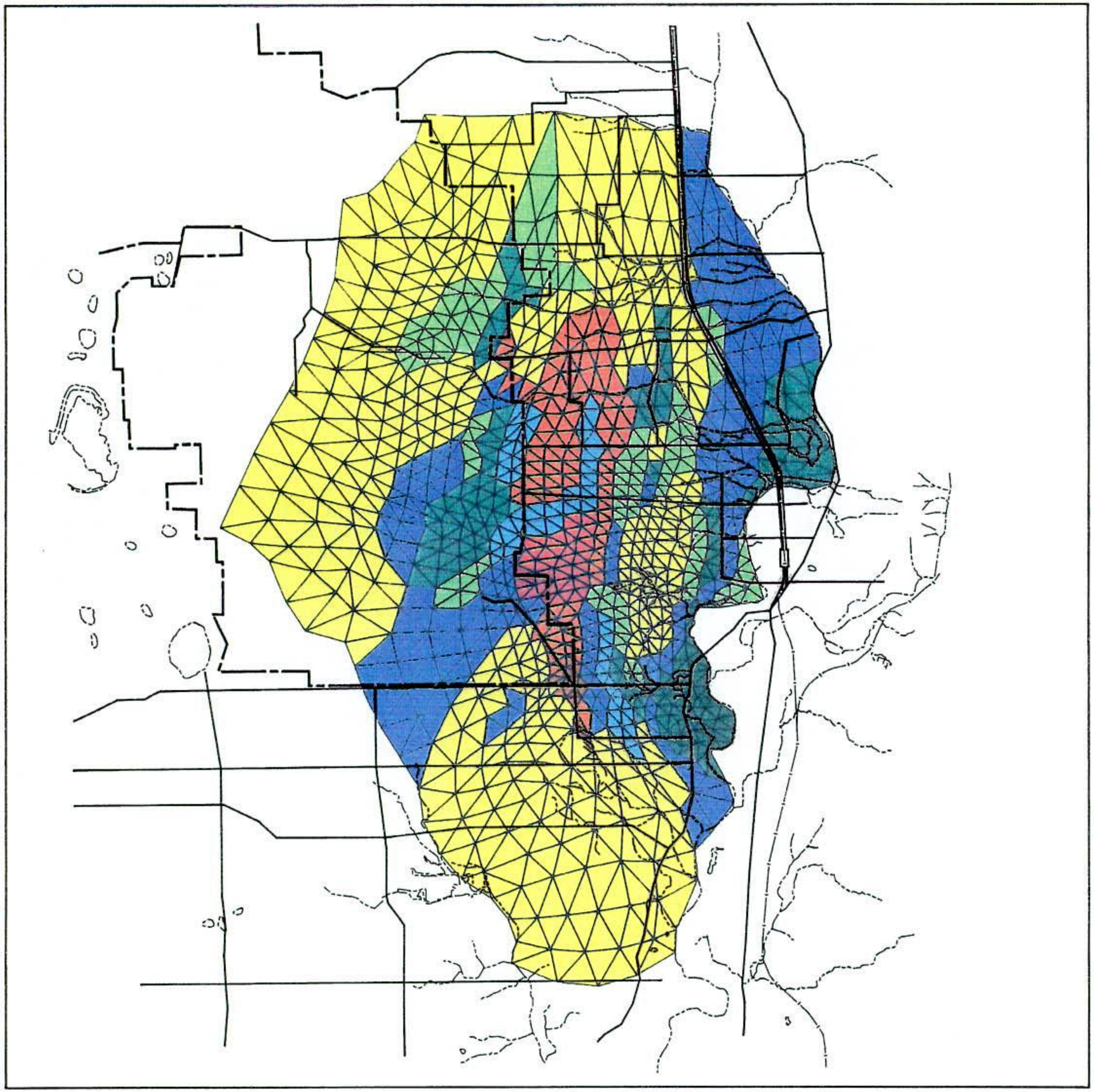


ORIGINAL SCALE 1: 100000

FINITE ELEMENT MESH

FIGURE 3.4

Mackie Martin & Associates
GROUNDWATER ENGINEERS



ELLENBROOK
DRAINAGE AND GROUNDWATER MANAGEMENT STUDY

LEGEND:

- Road
- Railway
- State Forest Boundary
- Surface Drainage
- Permeability 1m/day
- Permeability 2m/day
- Permeability 4m/day
- Permeability 5m/day
- Permeability 10m/day
- Permeability 15m/day
- Permeability 40m/day

NOTE:

Base map produced from GSWA 1: 50000 Enviromental Geology Maps.

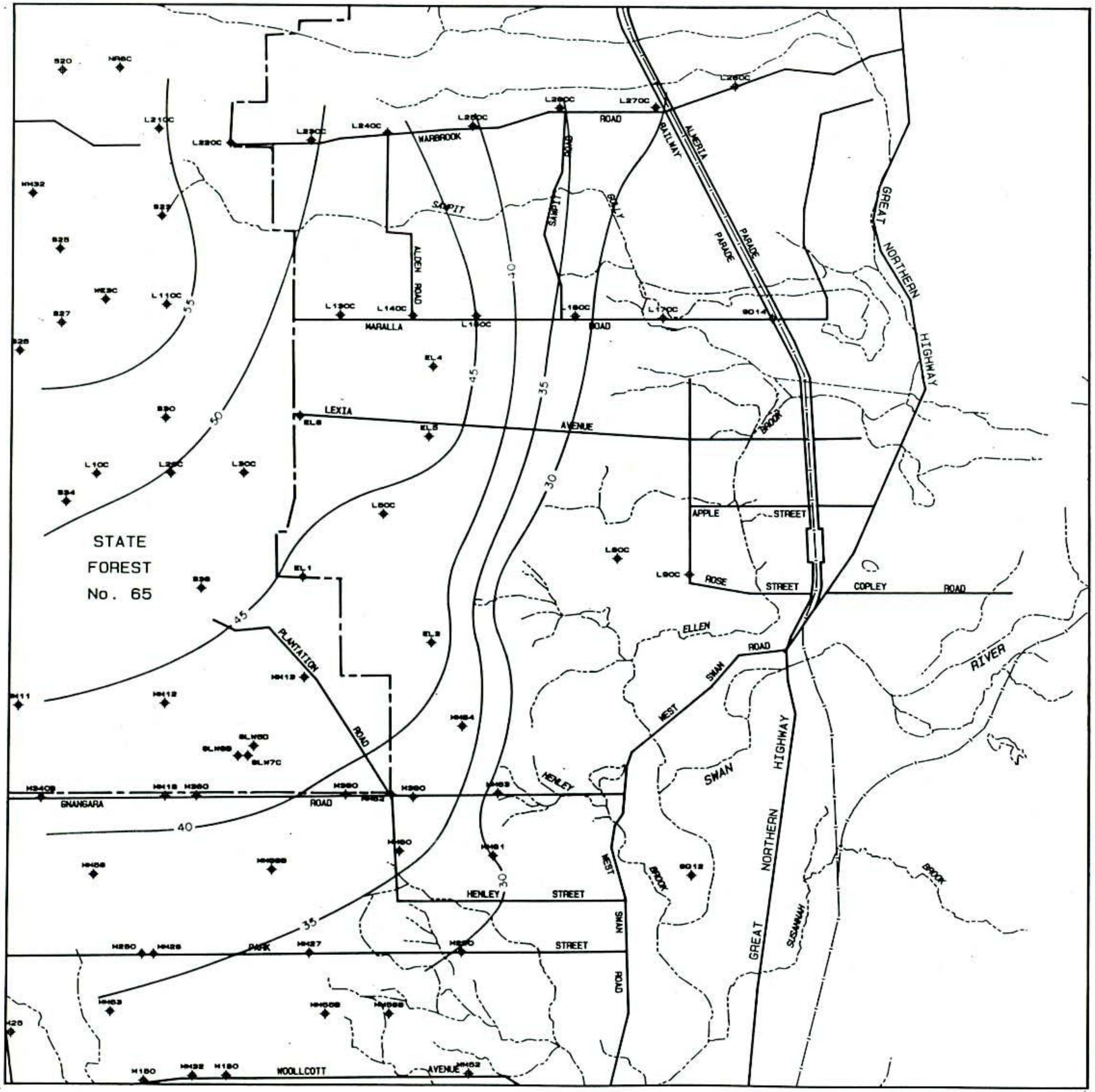
0 2000 4000 6000 8000 M

ORIGINAL SCALE 1: 100000

CALIBRATED PERMEABILITY DISTRIBUTION

FIGURE 3.5

Mackie Martin & Associates
GROUNDWATER ENGINEERS



ELLENBROOK
DRAINAGE AND GROUNDWATER MANAGEMENT STUDY

LEGEND:

- Road
- Railway
- State Forest Boundary
- Surface Drainage
- Monitoring Bore
- Groundwater Contour (mAHD)

NOTE:

Base map produced from GSWA 1: 50000 Enviromental Geology Maps.

N

0 500 1000 1500 2000 2500 3000 3500 M

ORIGINAL SCALE 1: 50000

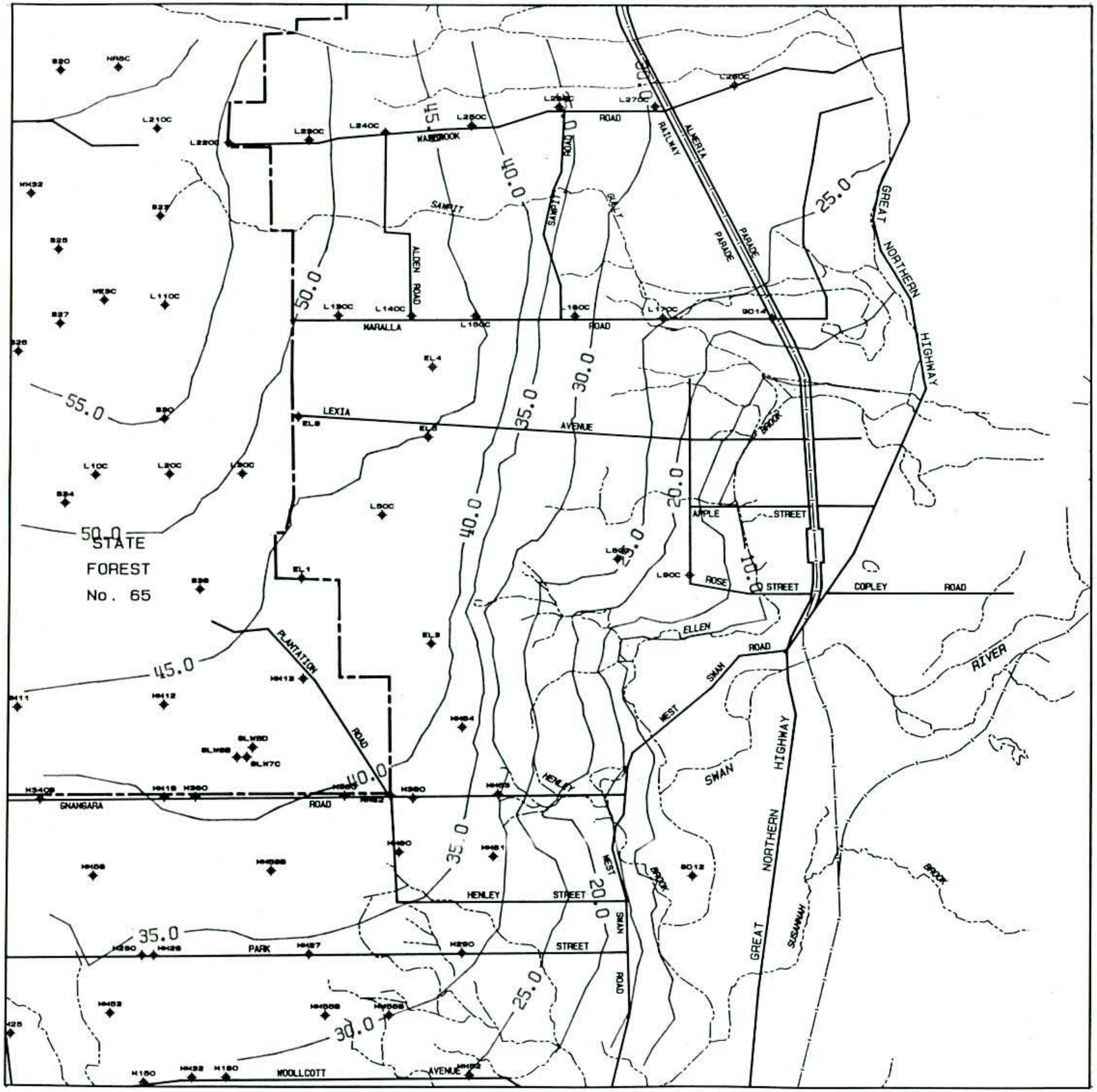
OBSERVED GROUNDWATER LEVELS OCTOBER 1989

FIGURE 3.6

Mackie Martin & Associates
GROUNDWATER ENGINEERS

ELLENBROOK

DRAINAGE AND GROUNDWATER MANAGEMENT STUDY



LEGEND:

- Road
- Railway
- State Forest Boundary
- Surface Drainage
- Monitoring Bore
- Groundwater Contour (mAHD)

NOTE:

Base map produced from GSWA 1: 50000 Enviromental Geology Maps.

0 500 1000 1500 2000 2500 3000 3500 M

ORIGINAL SCALE 1: 50000

PREDICTED GROUNDWATER LEVELS OCTOBER 1989

FIGURE 3.7

Mackie Martin & Associates
GROUNDWATER ENGINEERS

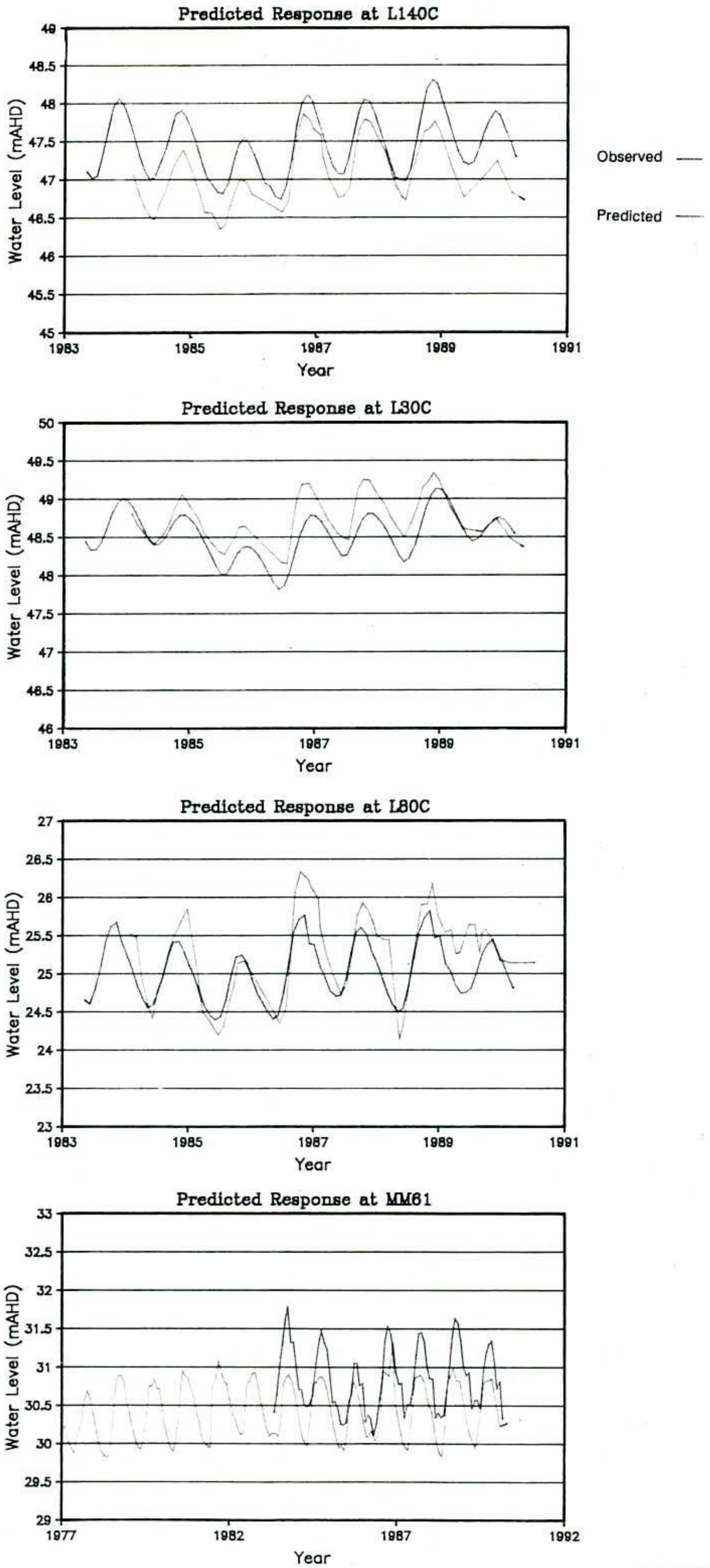

Predicted Response at L140C
Water Level (mAHD)
Year
Observed
Predicted
Predicted Response at L30C
Water Level (mAHD)
Year
Predicted Response at L80C
Water Level (mAHD)
Year
Predicted Response at MM61
Water Level (mAHD)
Year

FIGURE 3.8A

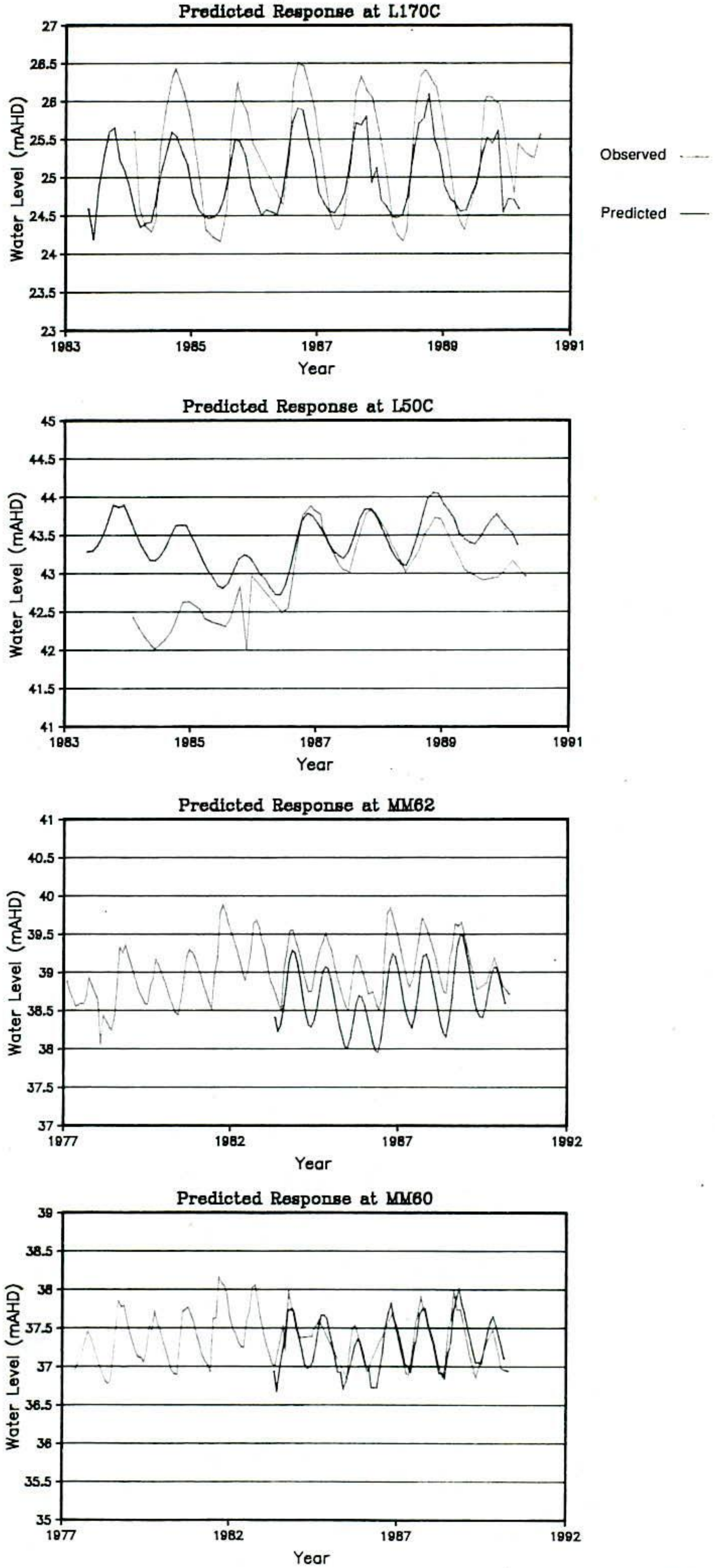

Predicted Response at L170C
Water Level (mAHD)
27
26.5
26
25.5
25
24.5
24
23.5
23
1983
1985
1987
1989
1991
Year
Observed
Predicted
Predicted Response at L50C
Water Level (mAHD)
45
44.5
44
43.5
43
42.5
42
41.5
41
1983
1985
1987
1989
1991
Year
Predicted Response at MM62
Water Level (mAHD)
41
40.5
40
39.5
39
38.5
38
37.5
37
1977
1982
1987
1992
Year
Predicted Response at MM60
Water Level (mAHD)
39
38.5
38
37.5
37
36.5
36
35.5
35
1977
1982
1987
1992
Year

FIGURE 3.8B

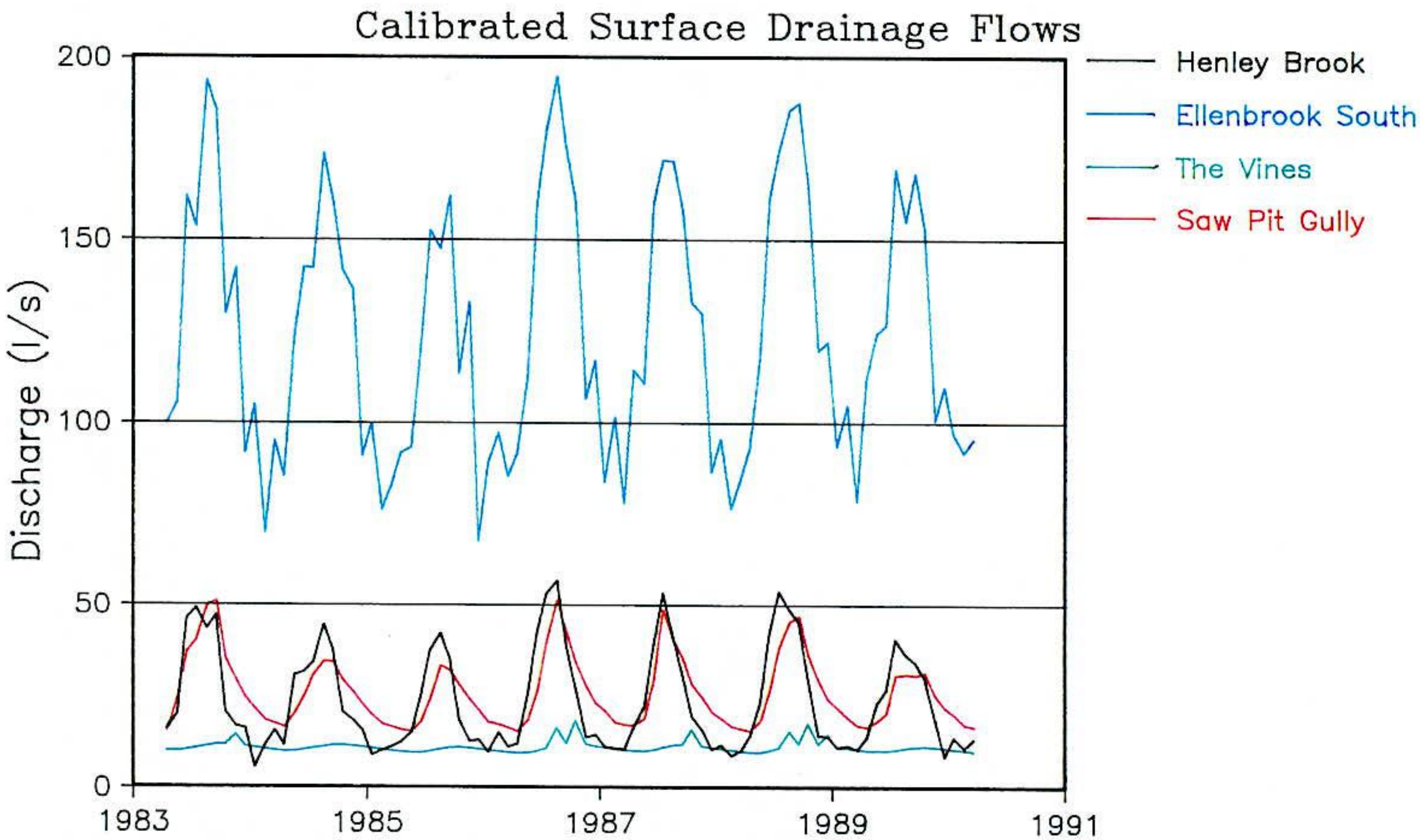

Calibrated Surface Drainage Flows
Henley Brook
Ellenbrook South
The Vines
Saw Pit Gully
Discharge (l/s)
200
150
100
50
0
1983
1985
1987
1989
1991

FIGURE 3.9

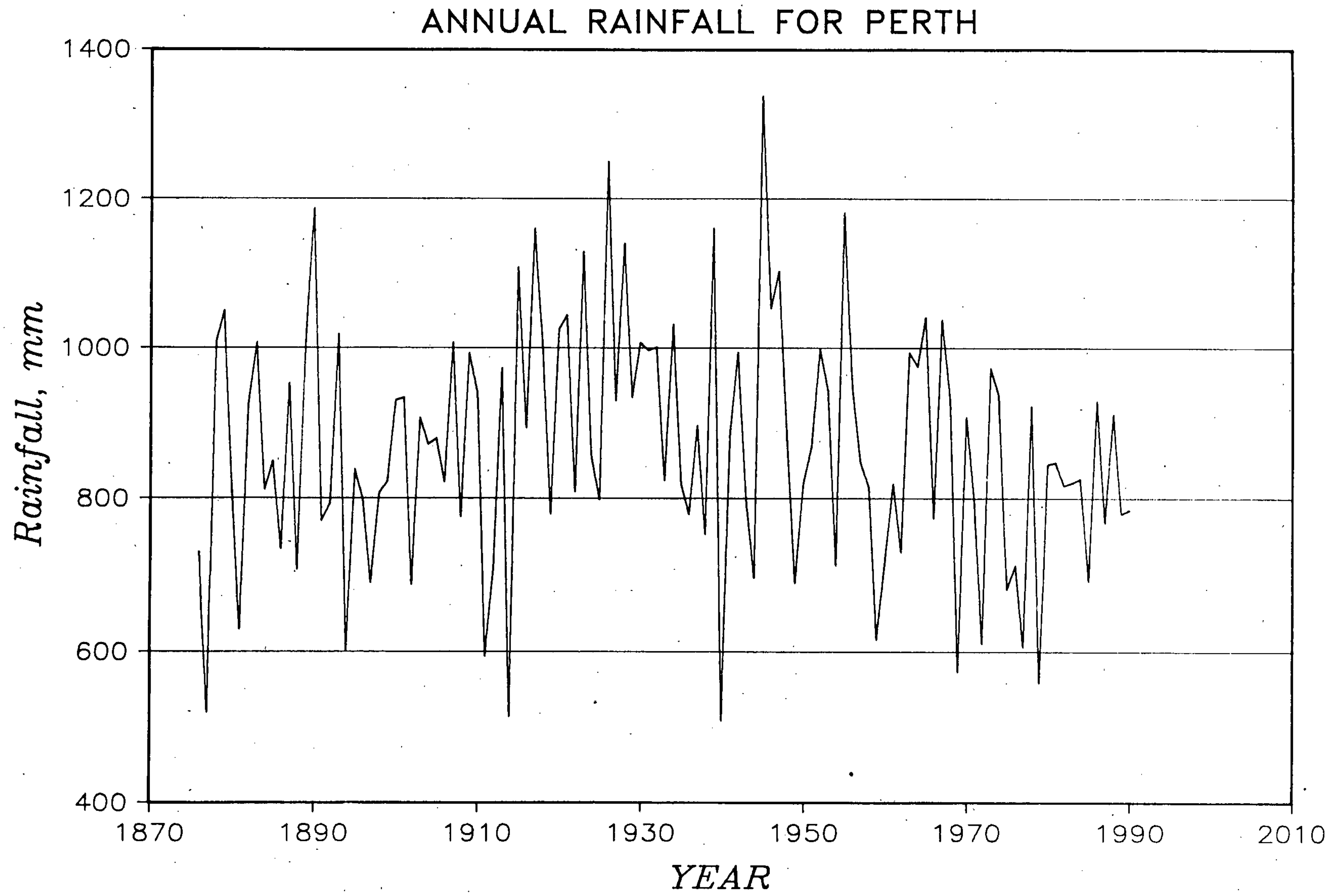
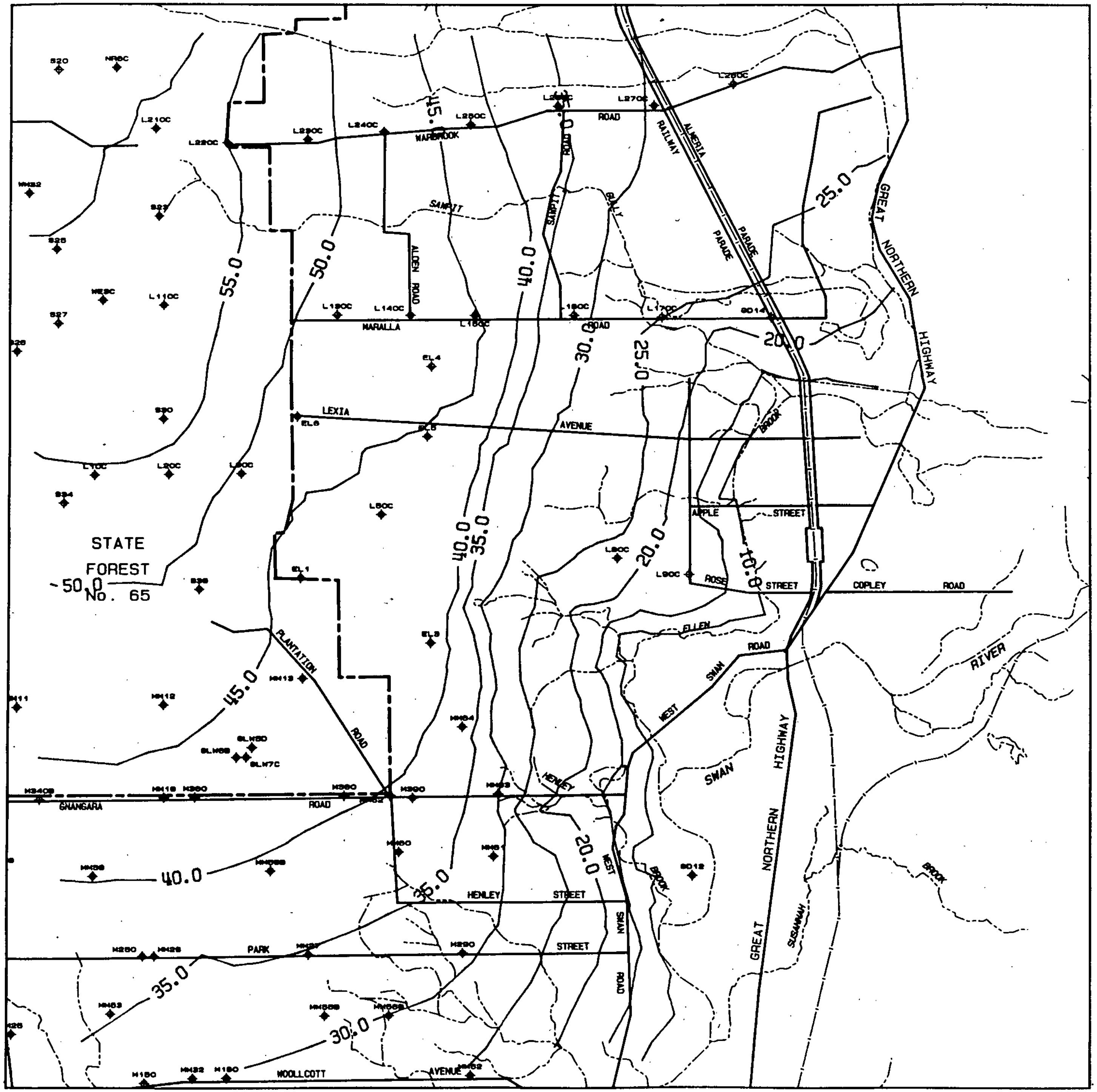

ANNUAL RAINFALL FOR PERTH
1400
1200
1000
800
600
400
Rainfall, mm
1870
1890
1910
1930
1950
1970
1990
2010
YEAR

FIGURE 3.10



ELLENBROOK
DRAINAGE AND GROUNDWATER MANAGEMENT STUDY

LEGEND:

- Road
- Railway
- State Forest Boundary
- Surface Drainage
- Monitoring Bore
- Groundwater Contour (mAHD)

NOTE:

Base map produced from GSWA 1:50000 Enviromental Geology Maps.

0 500 1000 1500 2000 2500 3000 3500 M

ORIGINAL SCALE 1:50000

PREDICTED FUTURE WATER LEVEL FOR CURRENT LAND USE (OCTOBER)

FIGURE 3.11

Mackie Martin & Associates
GROUNDWATER ENGINEERS

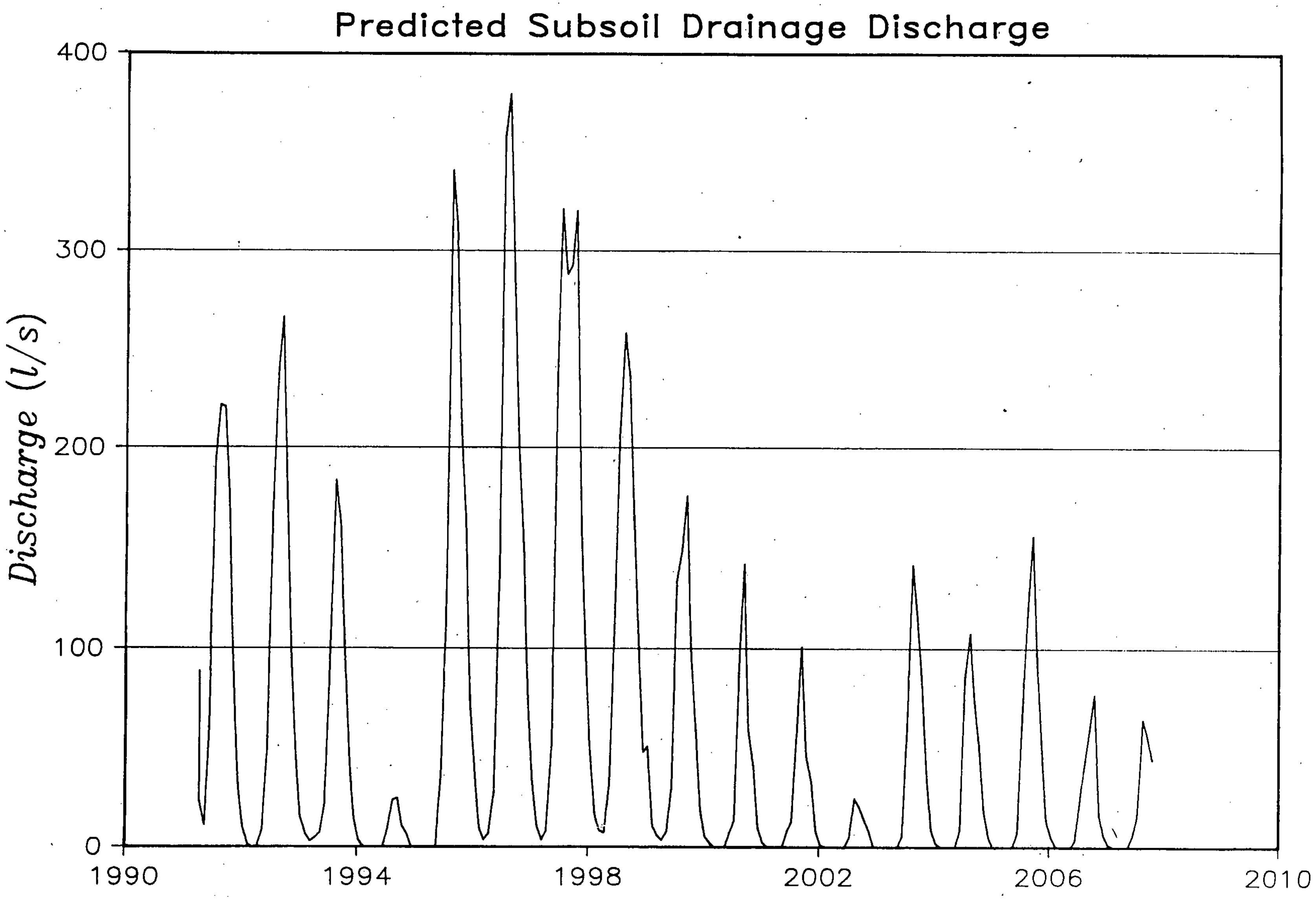
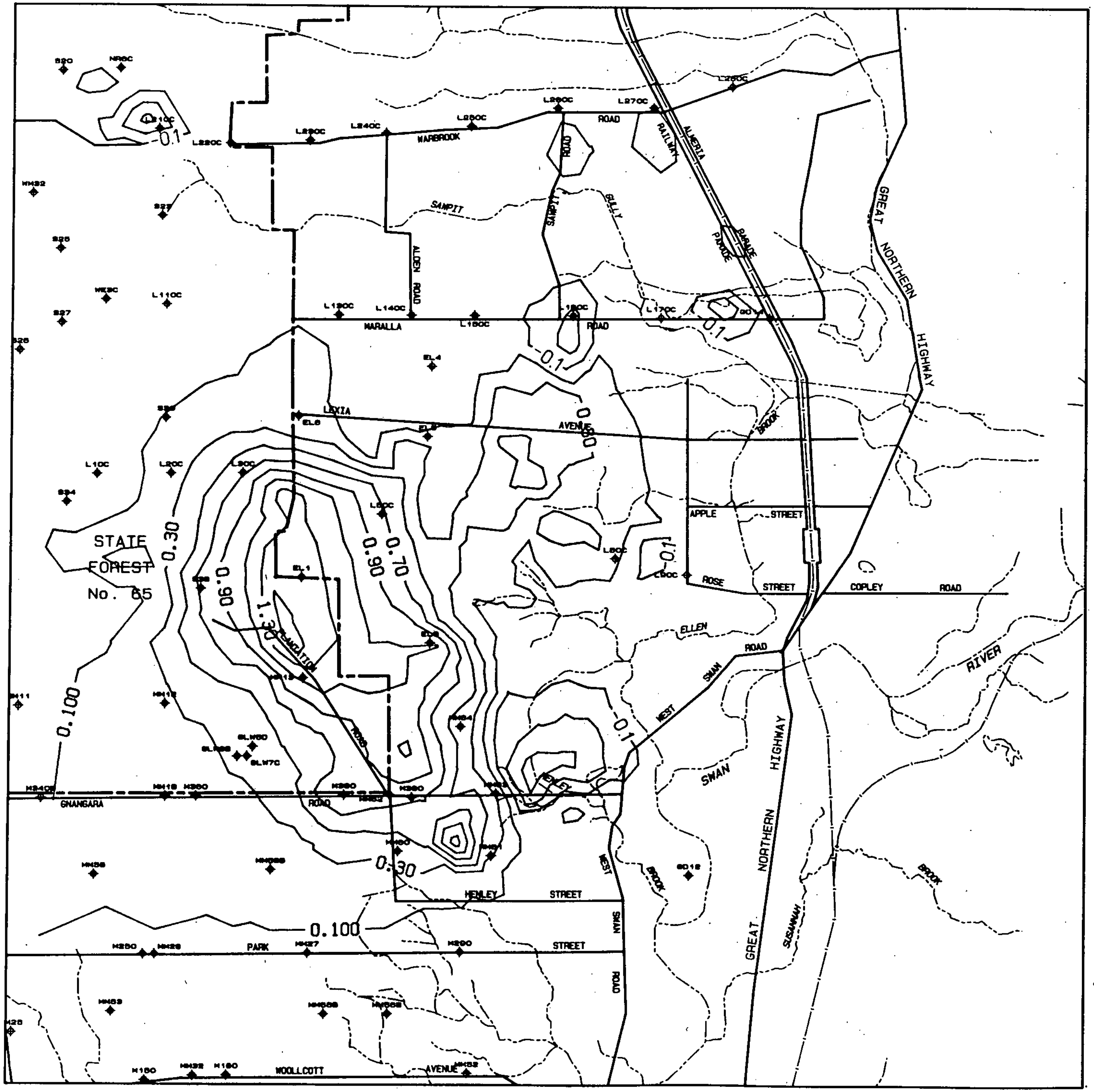

Predicted Subsoil Drainage Discharge
Discharge (l/s)
400
300
200
100
0
1990
1994
1998
2002
2006
2010

FIGURE 3.12



ELLENBROOK

DRAINAGE AND GROUNDWATER MANAGEMENT STUDY

LEGEND:

- Road
- Railway
- State Forest Boundary
- Surface Drainage
- Monitoring Bore
- Groundwater Contour (mAHD)

NOTE:

Base map produced from GSWA 1: 50000 Enviromental Geology Maps.

N

0 500 1000 1500 2000 2500 3000 3500 M

ORIGINAL SCALE 1: 50000

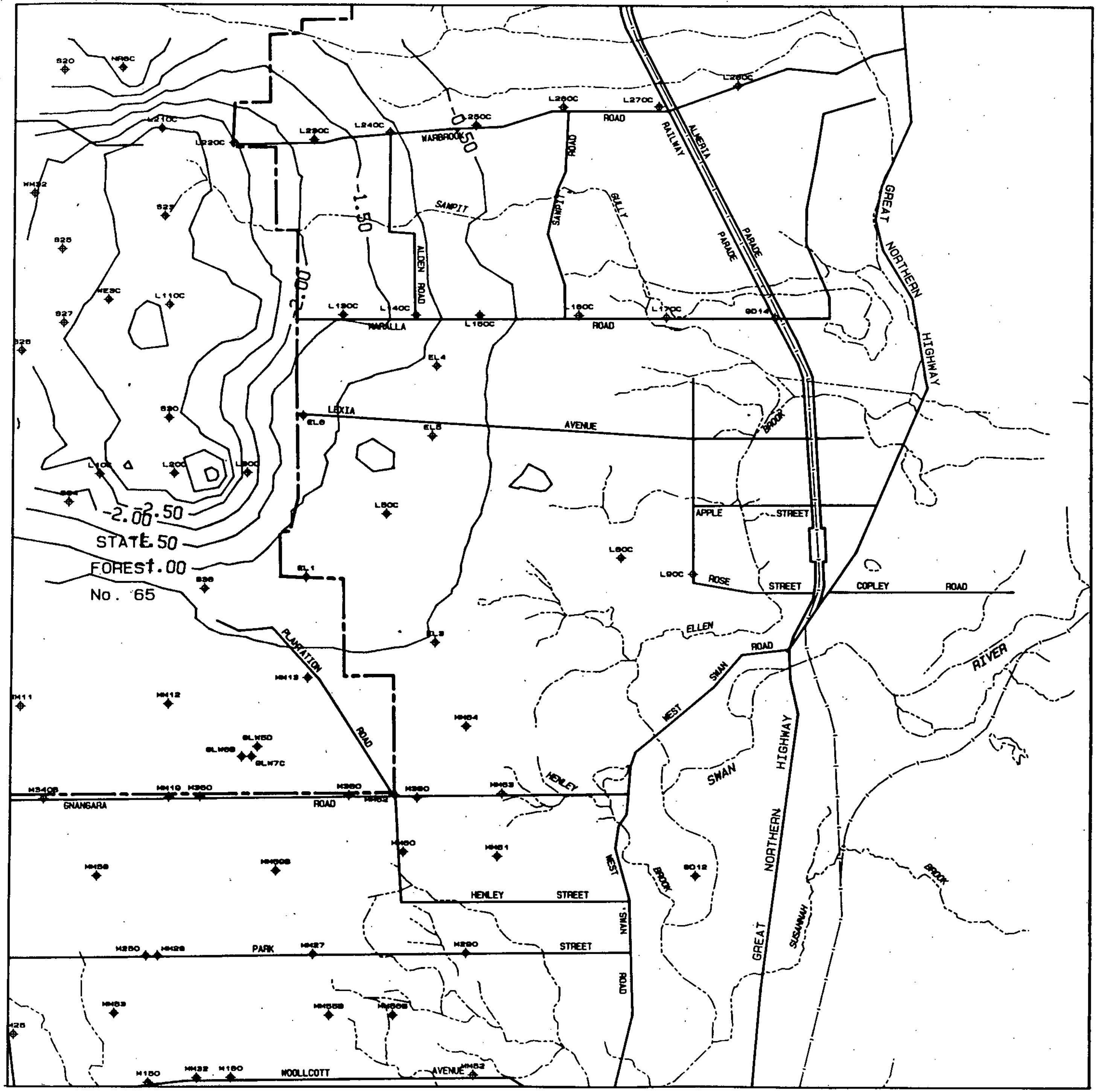
IMPACT OF URBANISATION

FIGURE 3.13

Mackie Martin & Associates
GROUNDWATER ENGINEERS

ELLENBROOK

DRAINAGE AND GROUNDWATER MANAGEMENT STUDY



LEGEND:

- Road
- Railway
- State Forest Boundary
- Surface Drainage
- Monitoring Bore
- Groundwater Contour (mAHD)

NOTE:

Base map produced from GSWA 1: 50000 Envirometal Geology Maps.

0 500 1000 1500 2000 2500 3000 3500 M

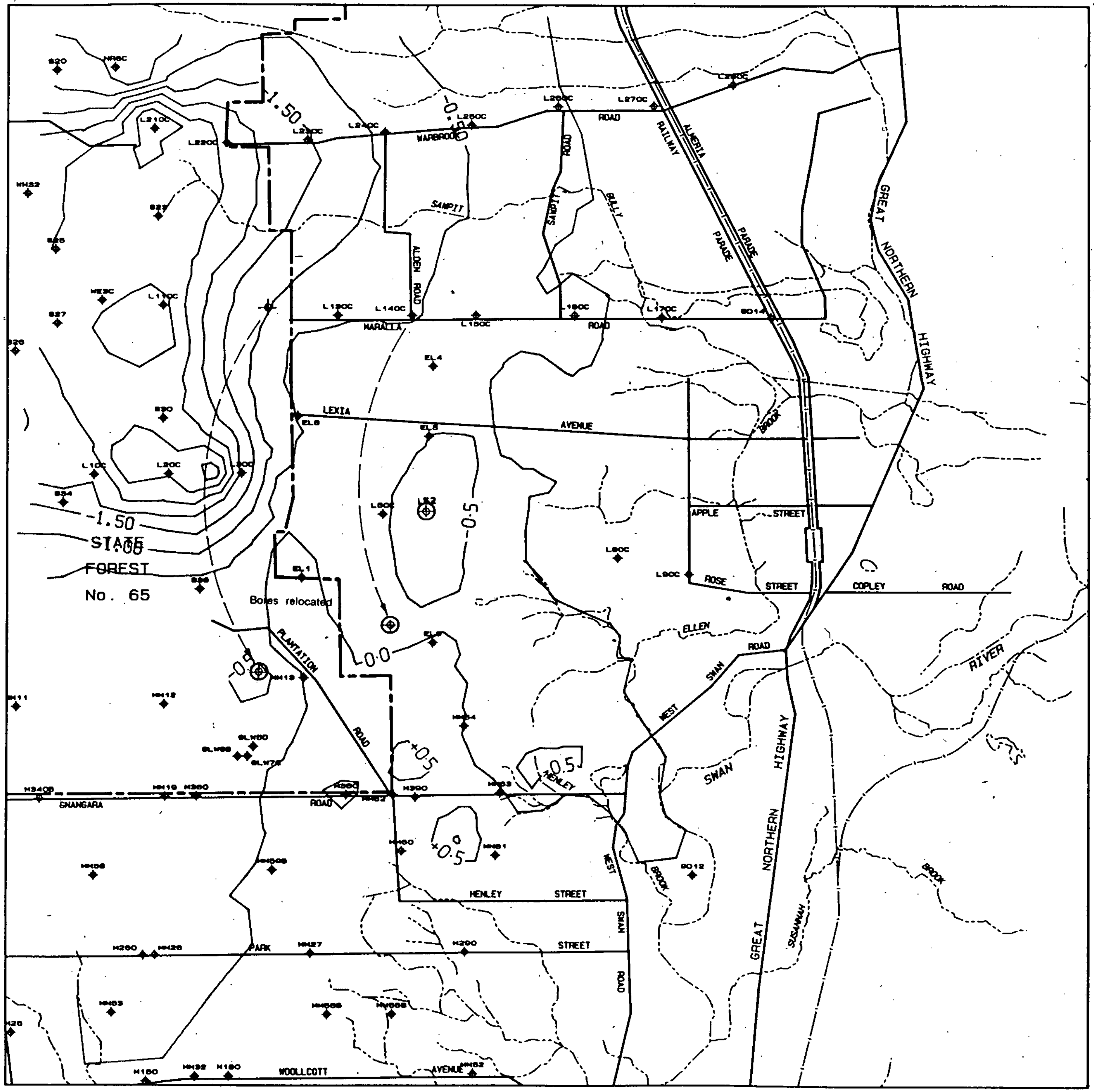
ORIGINAL SCALE 1: 50000

IMPACT OF LEXIA SCHEME WITH URBANISATION

FIGURE 3.14

Mackie Martin & Associates
GROUNDWATER ENGINEERS

ELLENBROOK
DRAINAGE AND GROUNDWATER MANAGEMENT STUDY



LEGEND:

- Road
- Railway
- State Forest Boundary
- Surface Drainage
- Monitoring Bore
- Groundwater Contour (mAHD)
- Ellenbrook Supply Bore

NOTE:

Base map produced from GSWA 1:50000 Enviromental Geology Maps.

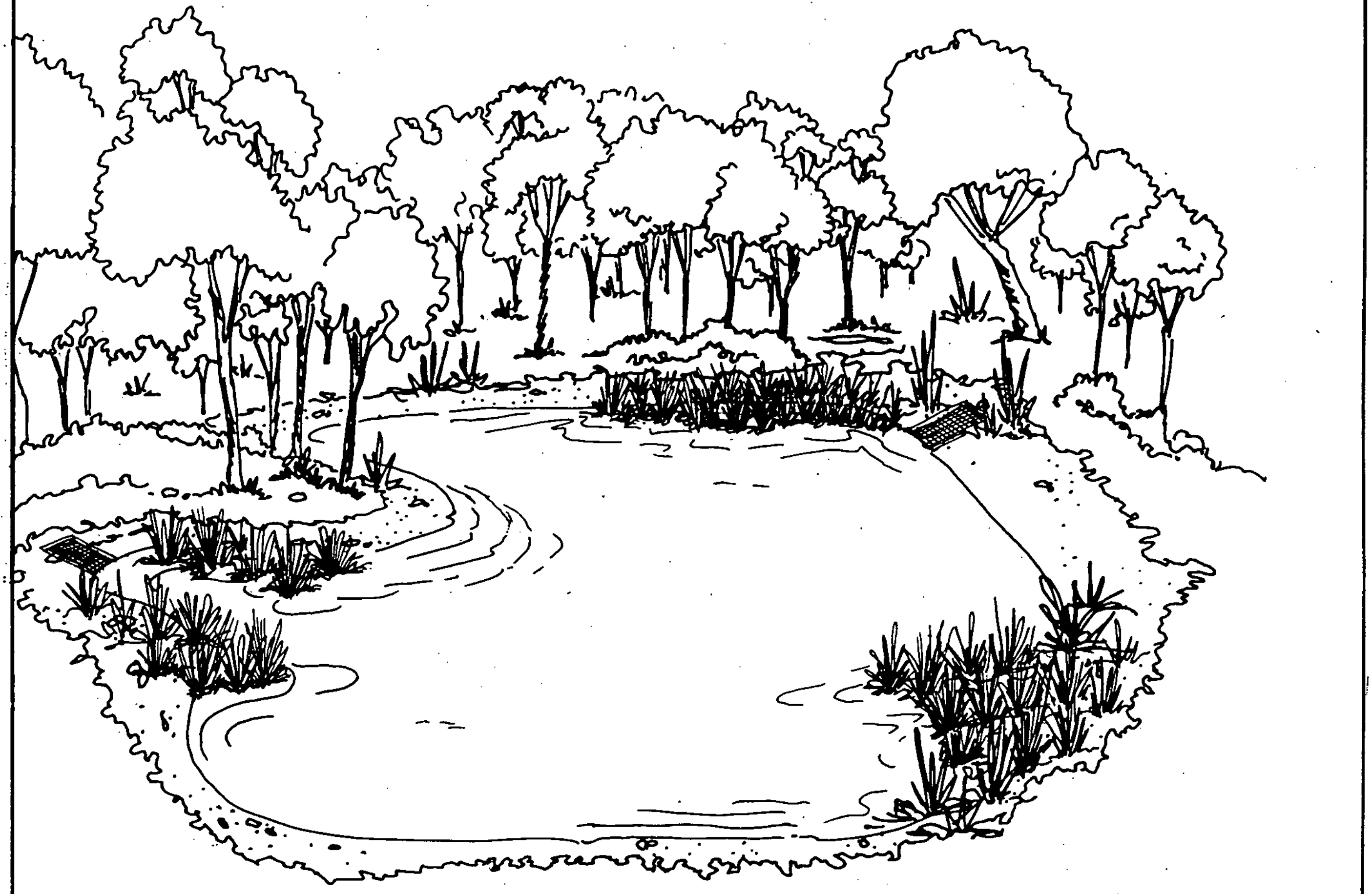
0 500 1000 1500 2000 2500 3000 3500 M

ORIGINAL SCALE 1:50000

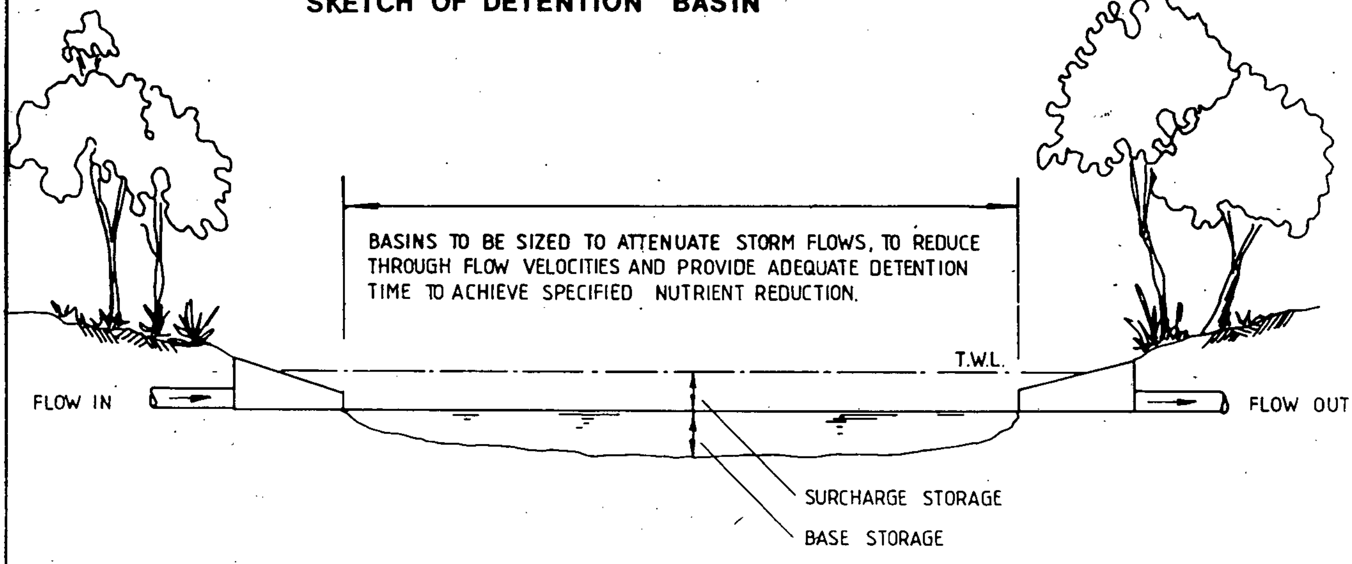
IMPACT OF URBANISATION AND OPTIMISED LEXIA SCHEME

FIGURE 3.15

Mackie Martin & Associates
GROUNDWATER ENGINEERS



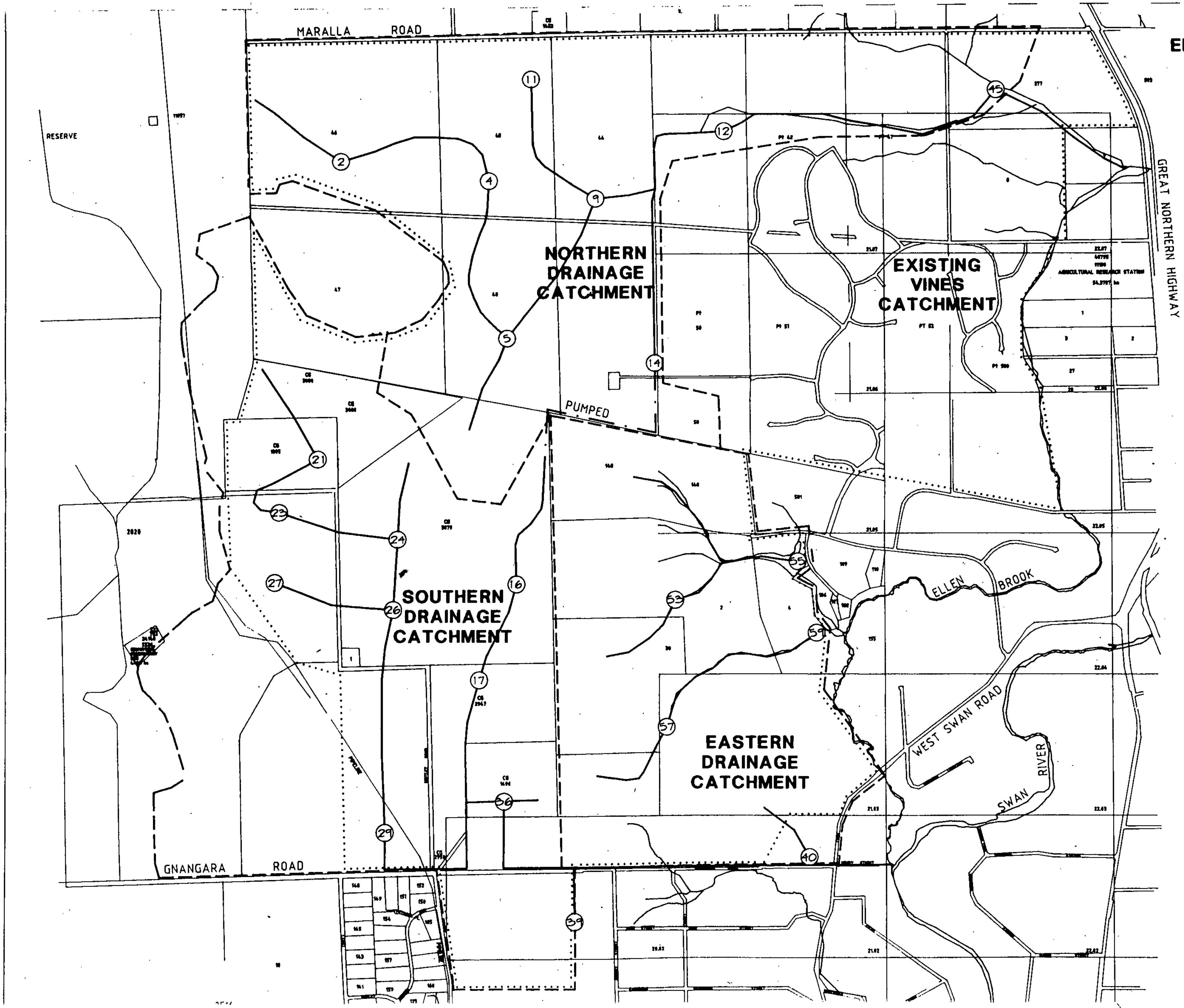
SKETCH OF DETENTION BASIN



SECTION THROUGH DETENTION BASIN

TYPICAL DETENTION BASIN

FIGURE 4.1



ELLENBROOK DEVELOPMENT TRUNK DRAINAGE STRATEGY

OPTION a
90ha CONSERVATION AREA

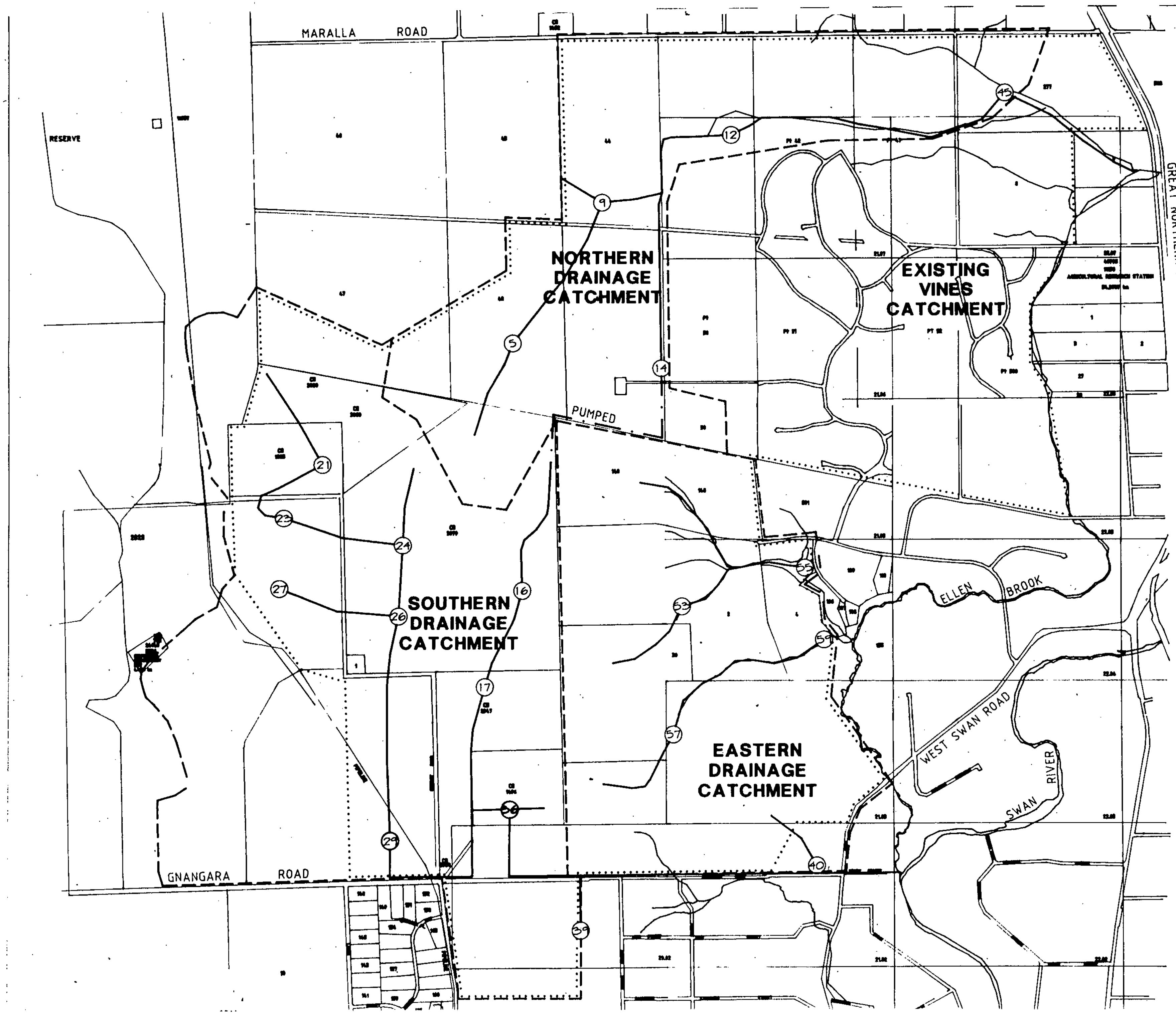
LEGEND

- (NO) PROPOSED DETENTION BASIN LOCATIONS
- DRAINAGE CATCHMENT BOUNDARY
- PROPOSED TRUNK DRAINAGE ROUTES
- URBANISATION BOUNDARY
- PUMPED MAIN
- REGIONAL OPEN SPACE

0 250 500 750 1000

FIGURE 4.2

ELLENBROOK DEVELOPMENT TRUNK DRAINAGE STRATEGY

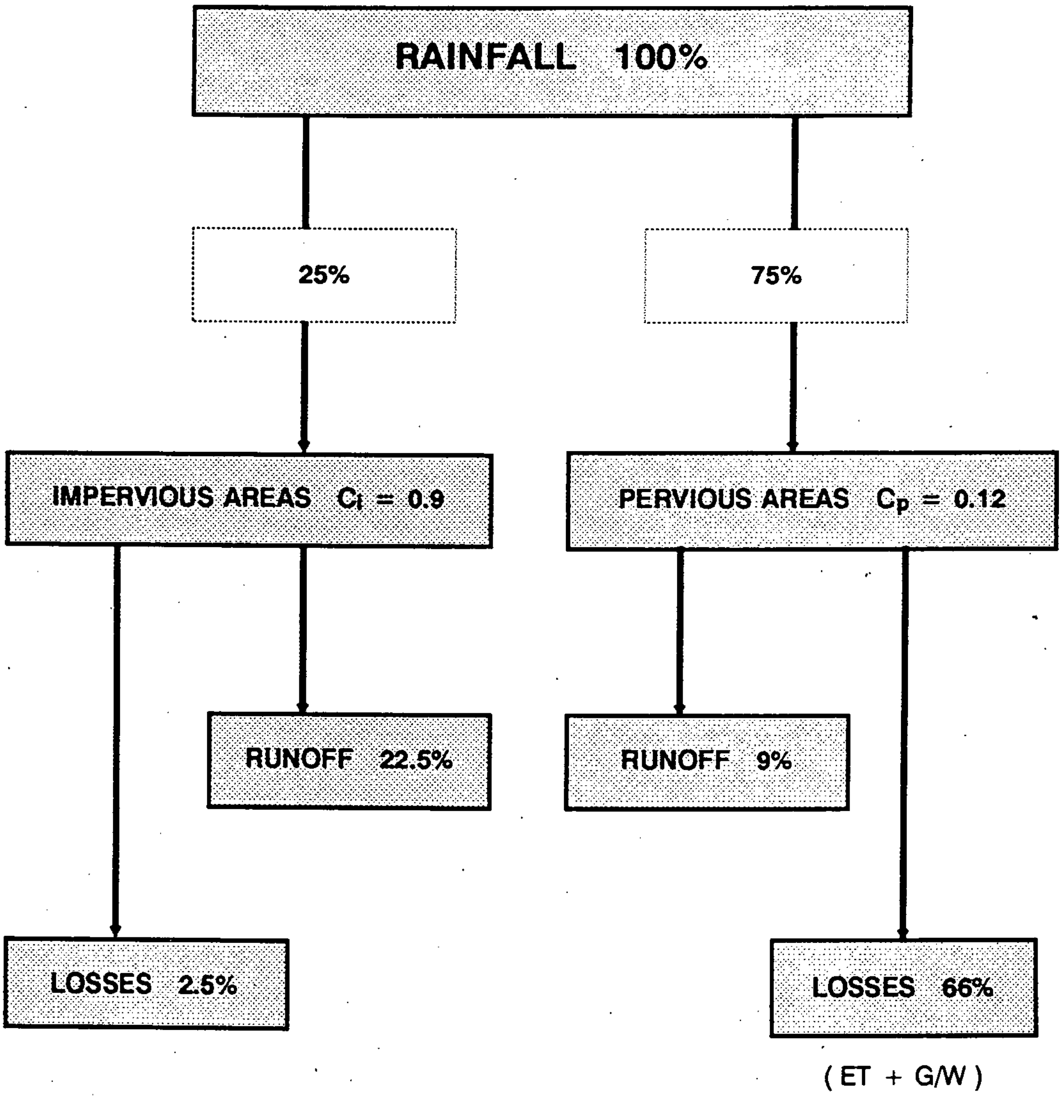


OPTION b
410ha CONSERVATION AREA

LEGEND

- (NO) PROPOSED DETENTION BASIN LOCATIONS
- DRAINAGE CATCHMENT BOUNDARY
- PROPOSED TRUNK DRAINAGE ROUTES
- URBANISATION BOUNDARY
- PUMPED MAIN
- REGIONAL OPEN SPACE

0 250 500 750 1000



WATER BALANCE:

RUNOFF FROM IMPERVIOUS AREAS	22.5%
LOSSES FROM IMPERVIOUS AREAS	2.5%
RUNOFF FROM PERVIOUS AREAS	9.0%
LOSSES FROM PERVIOUS AREAS	66.0%
TOTAL	100.0%

NOTE:

ET = Evapo-Transpiration

G/W = Losses to GroundWater

Coefficients of Runoff:

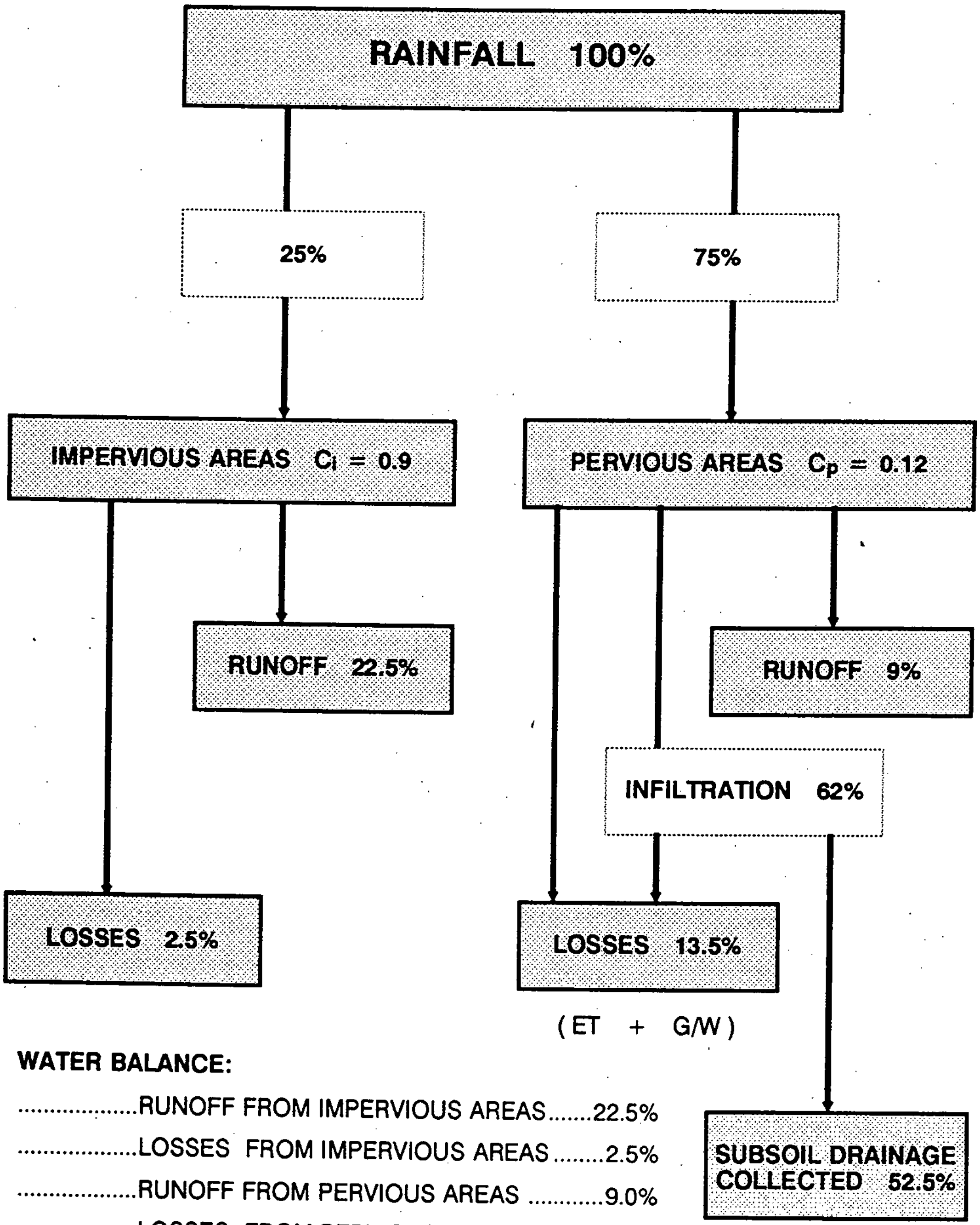
C_i = for Impervious Areas

C_p = for Pervious Areas

RAINFALL LOSS MODEL

URBANISATION WITH NO SUBSOIL DRAINAGE

FIGURE 4.3



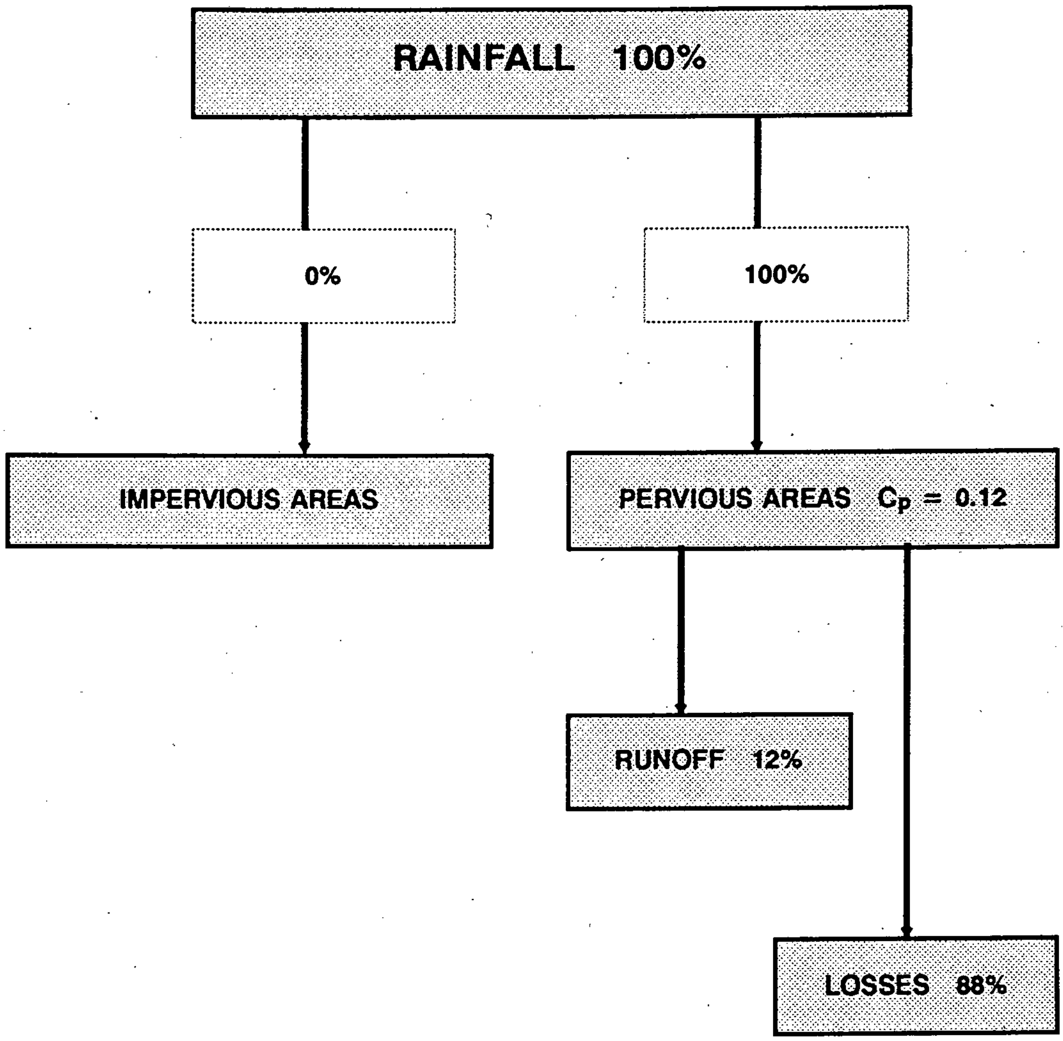
WATER BALANCE:

....................RUNOFF FROM IMPERVIOUS AREAS.......	22.5%
....................LOSSES FROM IMPERVIOUS AREAS........	2.5%
....................RUNOFF FROM PERVIOUS AREAS	9.0%
....................LOSSES FROM PERVIOUS AREAS	13.5%
....................SUBSOIL RUNOFF (PERVIOUS AREAS) ..	52.5%
....................TOTAL	100.0%

RAINFALL LOSS MODEL

URBANISATION WITH SUBSOIL DRAINAGE

FIGURE 4.4



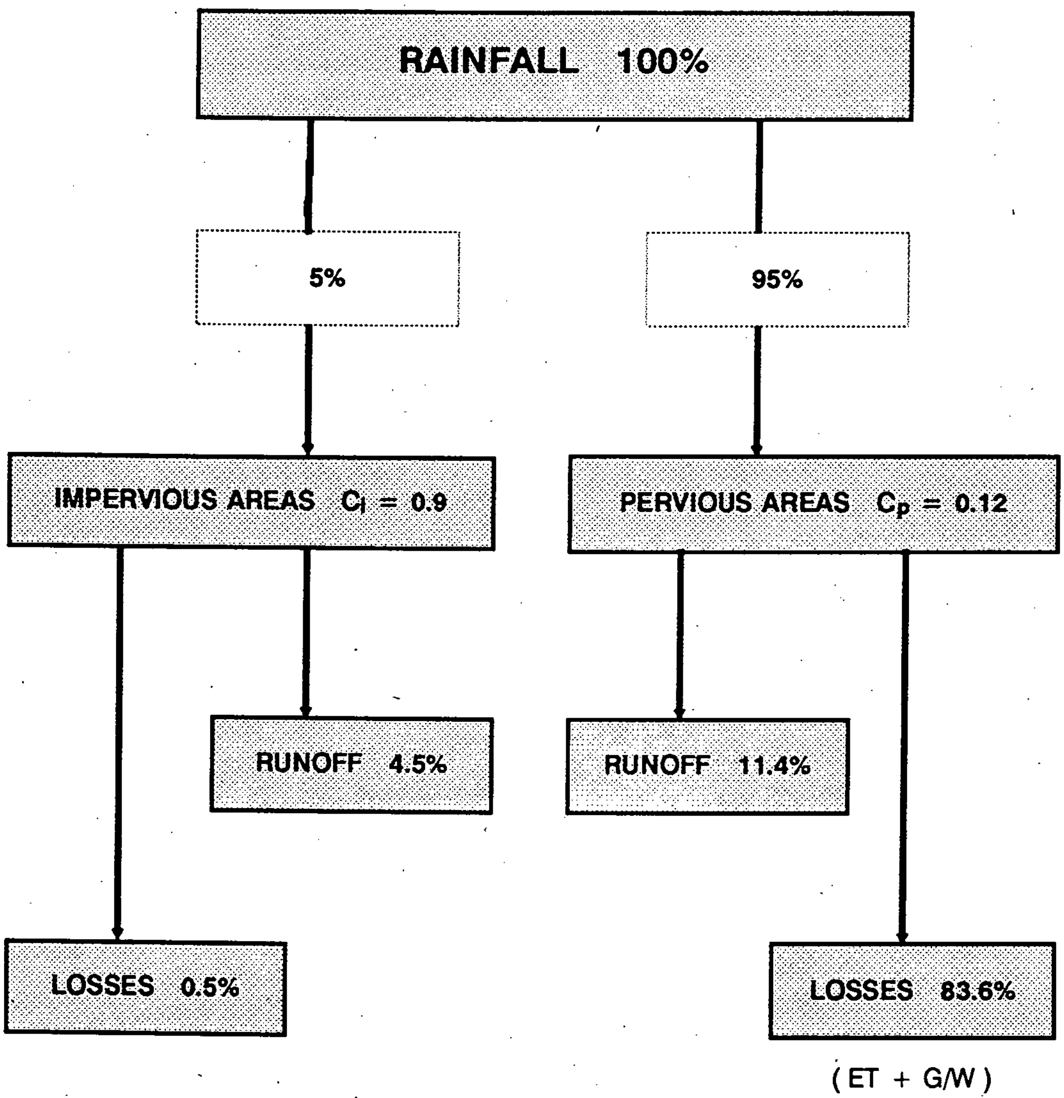
WATER BALANCE:

..................RUNOFF FROM IMPERVIOUS AREAS.........	0.0%
..................LOSSES FROM IMPERVIOUS AREAS......	12.0%
..................RUNOFF FROM PERVIOUS AREAS	88.0%
..................TOTAL	100.0%

RAINFALL LOSS MODEL

NATURAL RURAL
(including Forest)

FIGURE 4.5



WATER BALANCE:

..................RUNOFF FROM IMPERVIOUS AREAS.........	4.5%
..................LOSSES FROM IMPERVIOUS AREAS........	0.5%
..................RUNOFF FROM PERVIOUS AREAS	11.4%
..................LOSSES FROM PERVIOUS AREAS	83.6%
..................TOTAL	100.0%

RAINFALL LOSS MODEL

ACTIVE RURAL

FIGURE 4.6

Figure 5.1: Distribution of Annual P Load

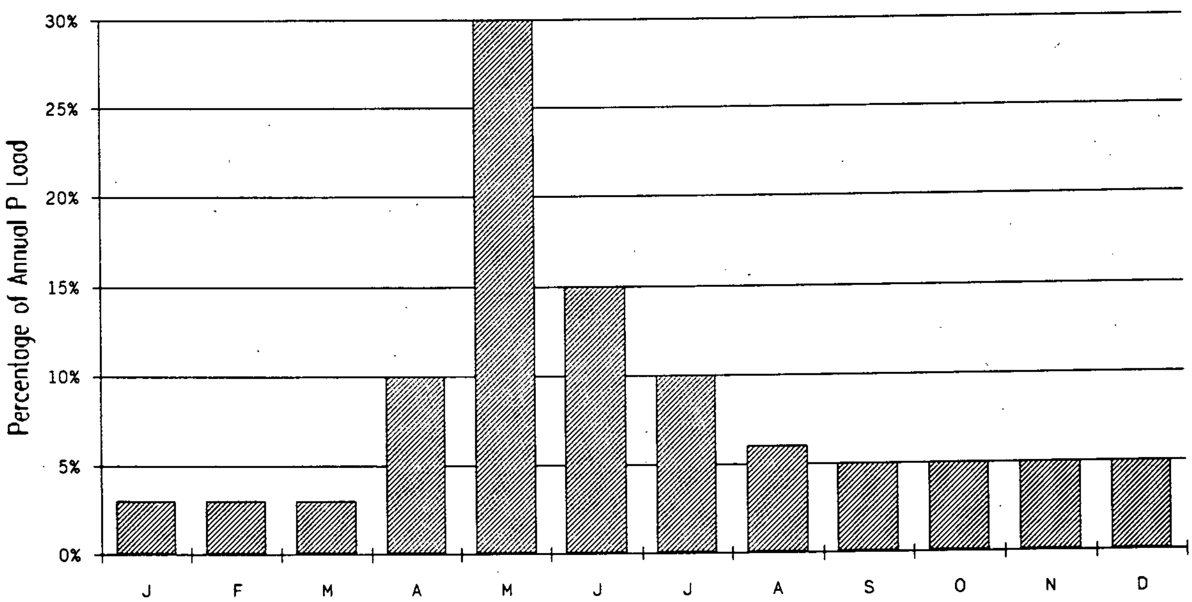


Figure 5.2: Monthly Rainfall Distribution

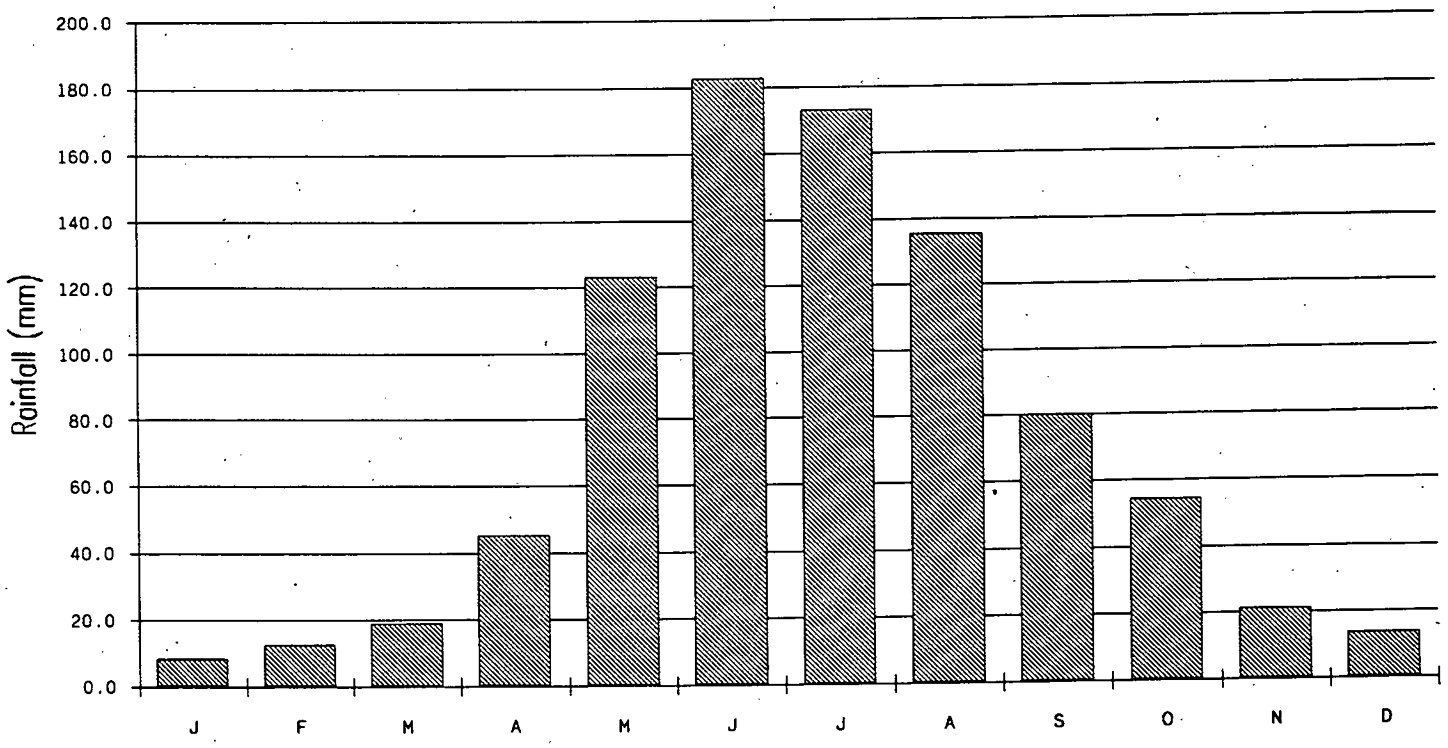


Figure 5.3: Proportional Loss Rate

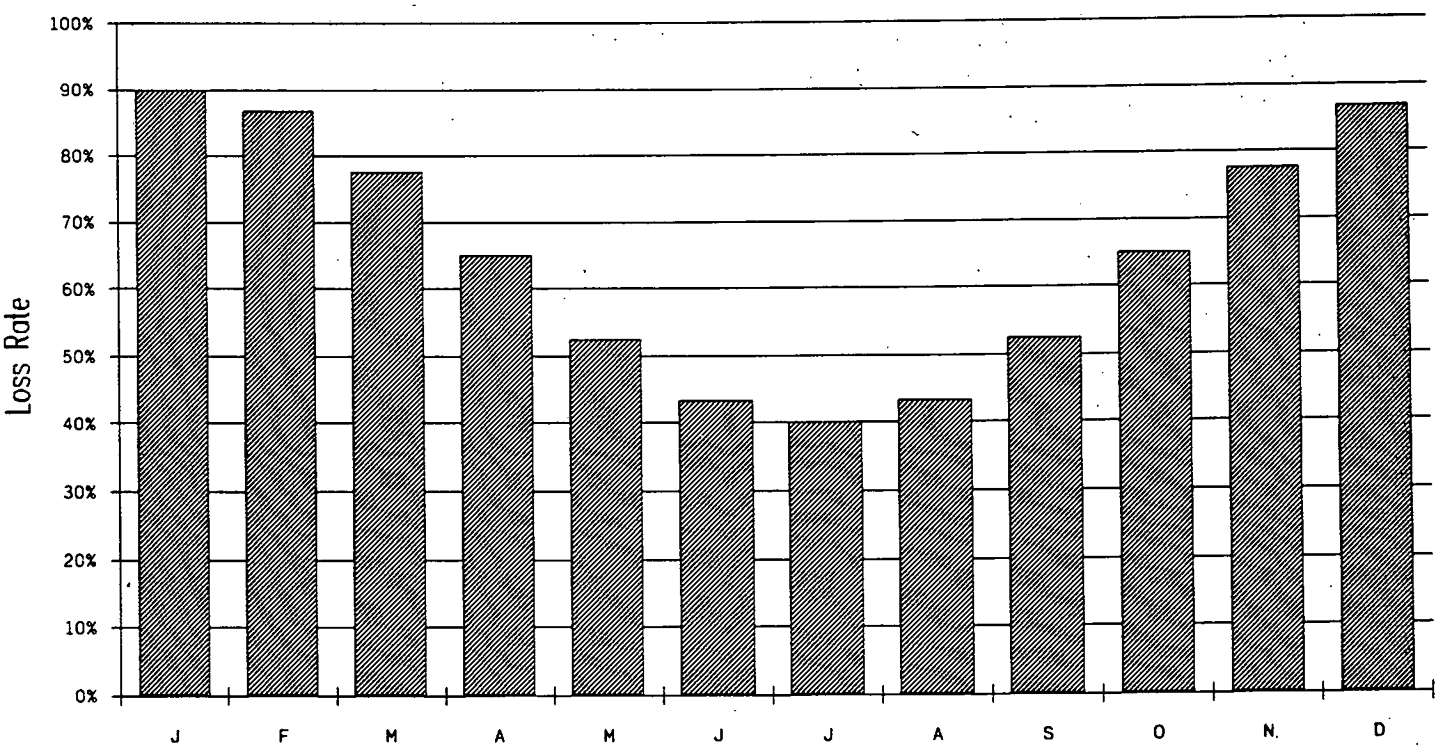


Figure 5.4: BNR vs Detention Time

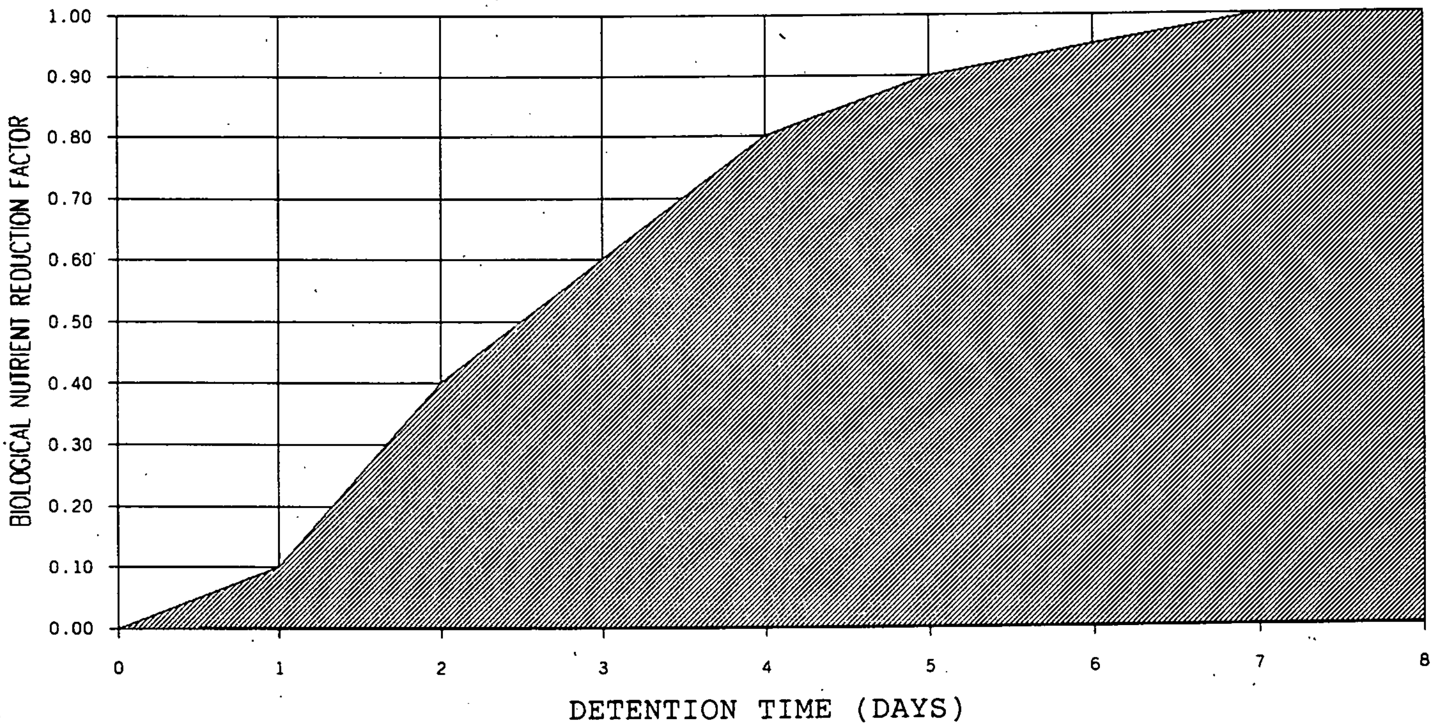


Figure 5.5: Seasonal Variation in BNR