Hotspots of Pathogens in Drinking Water Catchments: Case Study of Googong Catchment

Report Prepared for ECOWISE Environmental Pty. Ltd.

Ivan Hanigan,

Ph: 61253503
E-mail: ivan.hanigan@anu.edu.au

June 2003

TABLE OF CONTENTS

Appendices:

Methods and Metadata

ACKNOWLEDGMENTS

The Author would like to thank Tanya Whiteway, twhiteway@ecowise.com.au; Isabelle Balzer, ibalzer@ecowise.com.au; Stuart Hay, shay@ecowise.com.au; Alan Wade, Alan.Wade@actewagl.com.au; Declan Page, dpage@envirochimica.com; Ken Johnson Ken.Johnson@anu.edu.au; The Cooperative Research Centre for Water Quality and Treatment, www.crcwqt.com; ECOWISE Environmental Pty. Ltd., www.ecowise.com and *Actew*AGL, www.actewagl.com for support.

EXECUTIVE SUMMARY

It is vital to the protection of public water supplies that sources of pathogen contamination be identified, enabling the strategic management of catchments to reduce water pollution. Geographical Information System (GIS) based analysis was used in a test case study to develop a method identifying hotspots of pathogen contamination in the Googong catchment, New South Wales. Pathogen hotspots were defined as areas with optimal conditions for the **occurrence**, **survival** and **transport** of pathogens.

The spatial data layers used for this analysis were created by collecting information from land managers in the Googong catchment as well as drawing on existing data archives (ECOWISE 2002). This information was assessed qualitatively and classified to represent risk factors identified from the literature. The mapping process aims to highlight areas in the landscape with the highest potential for contamination. Hotspots can be characterised as grazing land on steep slopes with south-easterly aspect, impermeable soils, and low vegetative groundcover within 50 metres of a perennial watercourse and well connected to the reservoir via the fluvial network.

The output of this GIS model must then be checked against data from fieldwork and monitoring. Ground-truthing fieldwork was conducted at several sites identified in the analysis. The conceptual model guiding GIS analysis will be refined over time and guide further data collection and modelling.

The identification of hotspots allows them to be systematically assessed and management options investigated. Decisions about changes to the system must be made, focusing on desirable and feasible outcomes. Management experiments will inform decisions about which actions may be applied for proactive catchment management to reduce contamination potential. Monitoring these actions to evaluate outcomes also refines the conceptual model of the system. The GIS modelling process enables scenarios to be generated, assumptions may be altered and hypotheses tested. This process forms a system for active research, management and reflection for controlling pollution in drinking water catchments.

Key Words: Pathogens, Geographical Information Systems (GIS), drinking water catchments, adaptive management.

INTRODUCTION

The Cotter and Googong Catchments provide drinking water to approximately 350,000 people living in the Australian Capital Territory (ACT) and Queanbeyan (2001 Australian Census of Population and Housing). The majority of water is derived from the near-pristine Cotter system. However, during extended periods of high demand, drought or disturbance the Cotter system alone is unable to fully sustain water supplies to the ACT and Queanbeyan and the Googong system is used as a supplementary source of drinking water. Unfortunately, use of the Googong Reservoir and Catchment for recreation, rural-residential development and agriculture has increased the potential for drinking water contamination. Therefore the cost of treating and pumping water from the Googong reservoir is approximately ten fold the cost of water from the Cotter system (Moloney 2002).

To date, pathogens have not posed a serious threat to public health in the Canberra water supply. However, there is always potential for contamination particularly where pathogens occur at high levels, and can be transported rapidly to the reservoir. Currently, the standard pathogen monitoring and subsequent management is often inadequate and reactive, occurring only after a contamination event has been detected (Fullerton 2001). The proactive monitoring and management of pathogens, before they become a public health problem, is an important issue that needs to be addressed. The development of new decision support tools such as spatial data analysis (as undertaken in this work) and an adaptive catchment management system will be necessary to deal with the threat of pathogen contamination.

AIM

The aim of this study was to produce and test a conceptual framework for the rapid analysis of spatial data using GIS to identify hotspots of pathogens in the Googong catchment. The output of this analysis is discussed in the context of integrated catchment management. It is acknowledged that an iterative process of modelling, monitoring and experimental intervention will be required to refine the conceptual and GIS models.

BACKGROUND

Pathogens include any "virus, micro-organism, or other substance that causes disease; an infecting agent" (Academic Press 2002). In public water supply catchments, pathogens from infected animals can cause widespread disease downstream, particularly if distributed to urban populations through the reticulated water system. Even though the water from the Googong Reservoir is filtered and treated before distribution it is wise to implement a multi-barrier approach to pro-actively manage the catchment and thus reduce the risk of contamination.

The scope of this analysis is focused on microbial pathogens excreted in the faeces of infected humans and animals. These include bacteria (such as *Escherichia coli)* and protozoa (such as *Cryptosporidium parvum)* (Mawdsley et al. 1995). Microbial pathogens are important because some have the ability to survive in the environment for long periods and can be transported large distances (Robertson et al. 1992, Robertson and Edberg 1997, Walker et al. 1998, Walker et al. 2001). Because of several recent high profile contamination events there is plentiful literature available for *C. parvum*. This literature was reviewed to gain insight to its ecology. It is assumed that other pathogens may be similarly characterised (particularly other protozoa like *Giardia lamblia*).

C. parvum is a pathogen for immunocompetent as well as immunocompromised humans (Dillingham et al. 2002). The infective stage of the complex lifecycle is a thick-walled, chlorine and acid resistant oocyst, shed in the faeces of infected humans and animals. These oocysts may survive up to 12 months in cold water and are filtered only by <1um filters (Dillingham et al. 2002). They can be killed by boiling or freezing. There are many animals implicated as possible zoonotic sources of *C. parvum* but this analysis focuses only on humans and cattle.

Cattle have been strongly linked to *C. parvum*. Clinical infections are found more often in calves (aged < 1.5 years), who can shed up to 10,000,000 oocysts/gram of faeces and exceed 10,000,000,000 oocysts in daily output (Anderson 1981 cited in Graczyk et al. 2000). Adult cattle represent a lower risk than calves because of the higher prevalence of oocyst positive samples, and higher oocyst concentrations, found in calf manure (Graczyk et al. 2000). Some time series studies document peak concentrations coinciding with calving activity (Mawdsley et al. 1995, Ong et al. 1996, Bodley-Tickell et al. 2002).

The Googong Catchment

The Googong River Catchment lies to the southeast of Canberra in the Southern Tablelands of New South Wales (Figure 1). The headwaters are in the Gourock Range bounded to the east by the Tinderry Range and to the west by the Great Dividing Range. The river flows north west crossing an "undulating granite plateau and then flows through mountainous country formed mainly on metasedimentary rocks" (Starr et al. 1999). The river flows originally through sparsely populated high cold areas with slightly higher rainfall than the land to the north and west (Jenkins 1993). The southern portion of the catchment has areas of forest, lightly stocked grazing land and rural residential blocks. The growing season is very short and soils fertility low, which limits agricultural intensity.

The southern half of the catchment is administered by the Cooma Monaro Shire Council and the northern half by the Yarrowlumla Shire Council, the border crossing Ballinifad Creek. As the river approaches this border it passes through a highly circuitous stretch running through more densely populated rural residential and agricultural land. The river takes a sharp turn to the west and meets Urila creek. The Urila creek catchment contains some relatively intensive cattle grazing land and residential development (Urila Landholder Pers. Comm. 2003). The river then runs northwest again to discharge into the Googong reservoir at Washpen Crossing.

The southern end of the reservoir has two arms, one fed by the Queanbeyan River and the other by the Burra Creek. The headwaters of Burra Creek are in the Tinderry Mountains. The creek flows north through dense native forests on steep slopes. As it descends from the range it passes through land supporting agricultural properties, hobby farms and residential blocks. The major tributary of Burra Creek is Holden's Creek, which has numerous small properties stocking grazing animals like cattle, horses sheep and goats (Burra Landholder Pers. Comm. 2003). This part of the catchment has scattered underlying limestone and occasional outcrops that controls groundwater movement and discharge in the Burra valley (Page et al. 2001b). This is especially evident on the western side of the valley with a tributary Limestone Creek and an underground limestone channel called London Bridge.

A 1-2 km wide foreshores exclusion zone surrounds the Googong reservoir. The Parks and Conservation branch of Environment ACT manage this area aiming to protect water quality, allow recreational activity, conserve native biodiversity and control invasive pests.

There are approximately 1,900 people living in the Googong catchment (Australian Bureau of Statistics 2001). There are 287 dwellings, nearly two thirds of which are in the Burra and Urila Valleys or adjoin the Googong reservoir exclusion zone (Starr 2001).

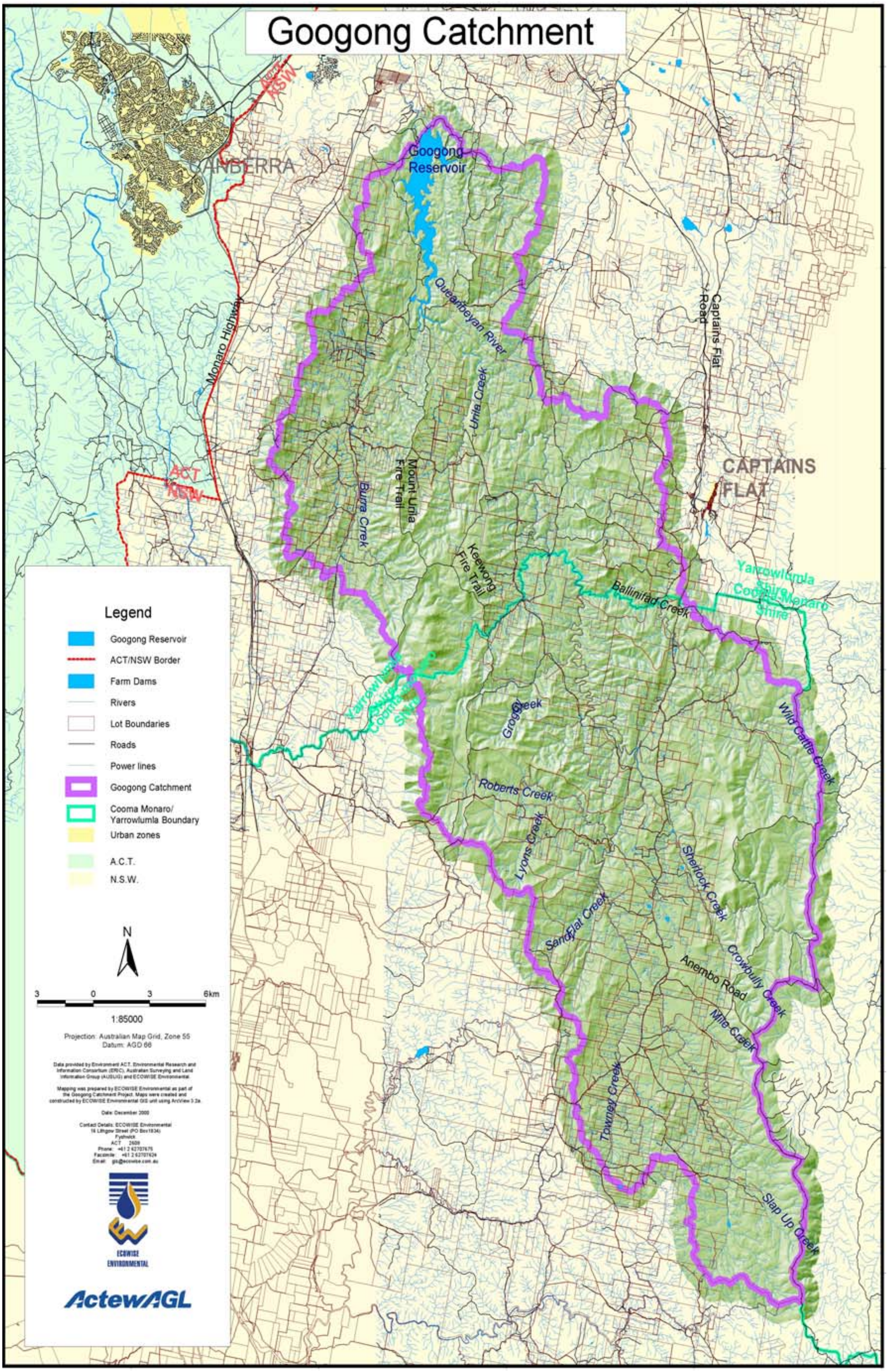


Figure 1: The Googong catchment

Conceptual model

The conceptual model motivating this analysis is shown in Figure 2. The model assumes that if infected animals are present pathogenic organisms will: be deposited in faecal material; die before moving; move through the fluvial network to the reservoir; or be intercepted on their way to the catchment, remain static and die.

Pathogenic organisms are deposited in faecal material onto the soil surface in the form of manure or as effluent from a septic tank. The pathogens must survive until a precipitation event occurs releasing them onto the soil surface. When rainfall intensity exceeds the infiltration capacity of the site, the pathogens are entrained into the prevailing surface or shallow subsurface flow (either separately or adsorbed to particles). They are then transported down-slope to the channel and then to the reservoir. The movement of pathogens may be slowed or halted by flow interruptions such as: vegetative filter-strips; dams; wetlands; and floodplains (Khaleel et al. 1980, Page et al. 2001a, Wasson et al. 2001, Atwill et al. 2002)

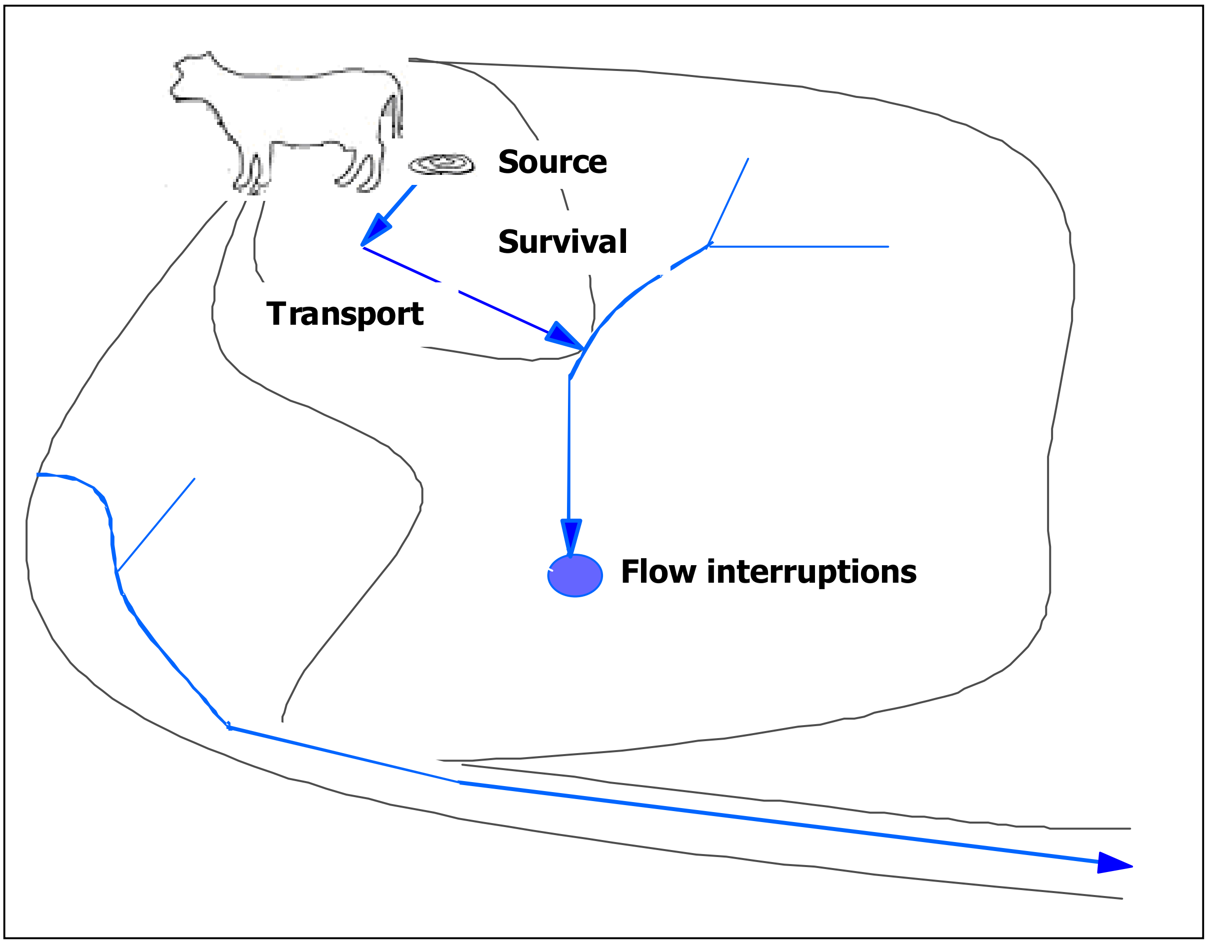


Figure 2: Conceptual model of the system

For the purposes of this study the important ecological processes are crudely separated into three domains (source, survival and transport). These processes operate at a number of scales, ranging from the small and fast dynamics of microbes and viruses, to the large and slow processes of society and climate. Setting the scale of the analysis makes data collection and analysis feasible, but it is important to recognise interdependence and feedback loops operating at and between multiple scales. The primary scale of focus for this analysis is the headwaters, hillslopes and drainage paths of a subcatchment.

GIS Analysis

In the GIS analysis, primary input layers representing **source**, **survival** and **transport** factors were created from secondary layers reflecting specific attributes of the pathogen system. These were intersected to identify hotspots. The resultant map shows the areas where there is a coincidence of high pathogen potential. The process is described visually in Figure 3.

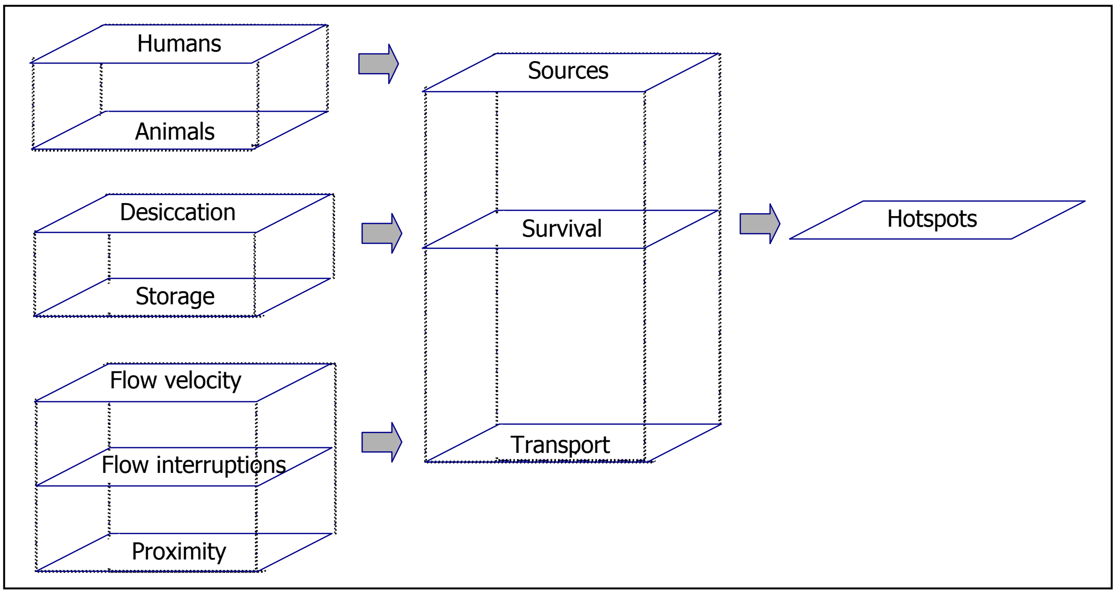


Figure 3: GIS analysis

METHODS

Sources of Pathogen Contamination

Information regarding grazing animals in the Burra and Urila valleys was collected from local landholders. Burra valley data was collected during several visits to a farmer (Appendix 1). This farmer is one of three in the valley running cattle on large blocks (800-1000 acres) (Burra creek landholder 2003). There are numerous smaller rural residential or hobby farm blocks in the neighbourhood, some stocking cattle, horses and sheep. Over a cup of coffee we discussed the human and ecological characteristics of the local landscape. Topics of conversation included: stocking regimes; climate; vegetation; topography; geology; and fire management. Elements of this information about the Burra catchment were mapped. A GIS layer of the stocking rate was created for this farm only. A layer of stock type was created for the neighbourhood. The surrounding farms were included in the analysis only if they had cattle. Stocking rates and other aspects of the stocking regime could be applied to the neighbouring land after collecting this data through similar interviews to determine actual presence and density of animals. This data will need to deal with spatial and temporal variation in both animal distributions, infection and excreta patterns (White et al. 2001).

To identify areas of grazing land on residential blocks without conducting interviews it was decided that vegetation could be used as a proxy for grazing animal occurrence. A grazing vegetation layer was intersected with a layer for property boundaries covering the entire Googong catchment (Appendix 2). Grazing vegetation was defined as improved pasture, pasture and open woodland. The layer was created by re-classifying the existing 17 vegetation classes into 2: grazing land and non-grazing land (woodland and forest areas) (see Meta Data 4). Areas of grazing vegetation inside property boundaries were assumed to have a high potential for the occurrence of livestock and hence pathogens. However this layer only gives a general idea of the source areas.

Human waste is generally treated by a septic tank or an intermittent aeration wastewater treatment system. Effluent absorption beds or land irrigation are employed for effluent disposal. Inadequately treated effluent represents a potential source of pathogens and need to be identified and assessed (Miller et al. 2003). In 2001 a survey was conducted of septic tanks in the Googong Catchment (Starr 2001). Septic tanks were mapped and inspected. At one site effluent was detected 50 metres away from the tank. A GIS septic tank layer was created from the survey (ECOWISE 2002). A circular buffer with a 50 metre radius was used to represent the area of possible contamination around each septic system (Appendix 3). In reality only those areas down slope of the tank are potential source zones.

The information about paddock boundaries, land-use, vegetation type and septic tanks were then combined to identify areas that are potential sources of pathogens. This information then became the **source** input layer for the GIS analysis (Figure 4).

Survival of Pathogens in a Landscape

The survival of pathogens in soil and water is influenced by diverse factors such as; nutrients, predation, natural die-off rate, temperature, solar radiation, soil moisture and water chemistry. A review of the literature reveals that dominant factors in survival are; moisture, temperature and ultraviolet radiation (Robertson et al. 1992, Mawdsley et al. 1995, Rose 1997, Walker et al. 1998, Walker et al. 2001, Wasson et al. 2001, Jenkins et al. 2002).

Spatial and temporal variation of incident solar radiation was considered the major driving force in pathogen survival. Two radiation scenarios were created for the current analysis. These scenarios were for winter and summer. The sun rises earlier and travels higher in the sky during summer and thus the hillslope areas with aspect from north, east and west will receive large amounts of solar radiation. The southerly slopes will be in shade for the longest and are thus high survival zones. During winter the sun rises later and travels lower and thus the slopes to the southeast and southwest will be in shade for longer. These slopes were included for the winter scenario.

This analysis concentrated on shaded hillslopes with a southerly aspect (Appendix 4) and topographically wet areas (Appendix 5). The topographic wetness was crudely defined as an area within 50 metres of a drainage path. This was deemed adequate for a first pass, although more refined models for calculating soil moisture were identified in the literature (Grayson et al. 1997, Woods et al. 1997, Western et al. 1999, Mackey 2002, Aryal et al. 2003).

These factors were combined into a single **survival** layer that identified zones sharing a coincidence of high moisture, low temperature or low solar radiation risk factors. Waterlogged areas or areas with low temperature and low solar radiation were assumed to be areas with high pathogen survival potential.

Transport of Pathogens

Transport of pathogens occurs when a rainfall event of sufficient intensity erodes the upper layer of the faecal material or soil in which the pathogen is embedded. The pathogens then move off the hillslope drainage areas and enter the channel network, eventually leaving the subcatchment. Pathogen transport occurs mainly by adsorption onto otherwise harmless mobile colloidal clay particles or soil organic matter (Walker et al. 1998, McGechan and Lewis

2002). The three influences on transport of pathogens considered here are flow velocity, flow interruption and distance to travel. Where flow velocity is high and uninterrupted, pathogens may be transported long distances through the landscape.

Transportation of pathogens may occur in overland flow (water flowing across soil) or in subsurface and groundwater flow (through the soil) (Walker et al. 1998). Transportation has been detected more often via overland flow, due to higher flow velocity, lower potential for adsorption and mechanical attenuation of the pathogen compared to movement through soil (Mawdsley et al. 1996a, Walker et al. 1998). Subsurface and groundwater flow processes were excluded from this analysis.

Flow velocity

Soils with low permeability produce more overland flow and thus present higher potential for transportation. The existing geological soil classifications were reclassified into low and high permeability classes using soil data from the Department of Land and Water Conservation (Jenkins 1993, 2000, see Meta data 8).

An important factor determining overland flow velocity is slope. Land with a high gradient will increase the flow velocity and produce more overland flow. Mawdsley *et al* (1996b) investigated the movement of *C. parvum* and found that a gradient of 7.5% was sufficient to effectively mobilise this pathogen in overland flow. For this analysis a gradient of 10% or greater was considered the threshold of potential pathogen transport. Data from a Digital Elevation Model (DEM) was used to identify these areas (Meta data 9 + 10).

Areas with dense ground cover will slow down the flow velocity of the water moving across it. Vegetative roughness was classified from the existing vegetation classes to identify areas with sparse ground cover (Meta data 4).

Flow interruptions

Particles entrained in flow may slow down or stop completely when they encounter such obstacles as dams, contour banks, vegetative filter-strips, wetlands, ephemeral ponds, and floodplains.

A layer of dams in the catchment was used with a DEM to identify the catchment areas. These were included in this analysis as areas where the flow will be interrupted before reaching the reservoir (ECOWISE 2002). Hotspots upstream of a dam were assumed to be safer than those with no such barrier.

There can be filtration of the water as it travels to a watercourse via overland flow. The local vegetation type and ground cover may have considerable impact on the amount and speed of pathogen transport. Long grasses and dense ground cover are considered effective filters of pathogens (Delgado et al. 1995, Clark 1998, Entry et al. 2000, Atwill et al. 2002). In order to account for vegetative filtration, a buffer was applied to the map of permanent watercourses and the vegetation within this boundary was assessed for its filtrative capacity. Hotspots upslope of an effective riparian vegetation buffer were assumed to be safer than those with none (Appendix 9).

Proximity

Some hotspots may be poorly connected to streams or only effectively connected to main streams during extreme events and therefore pose no immediate high risk. By identifying the connectivity of each hotspot to the nearest watercourse, an indicator of the probability of pathogen contamination could be generated. Connectivity between slopes and channels is generally greatest in headwater catchments with no intervening alluvial flats, fans, floodplains and river terraces that intercept or attenuate flows from hillslopes (Wasson 1998).

For this analysis each hotspot was ranked according to its proximity to the nearest watercourse. Hotspots were crudely ranked into 2 groups: less than 50m and greater than 50 metres from a perennial watercourse. Each hotspot was then assigned a risk value on an index of 1-5 with those closer than 50m given the highest value. This value represents the potential for pathogens to be transported from the hillslope to a watercourse. A different approach considered was that of (Fraser et al. 1998) where proximity is characterised by a negative exponential relationship to distance. This could be achieved by creating a raster layer around the watercourses and calculating proximity values for each grid cell.

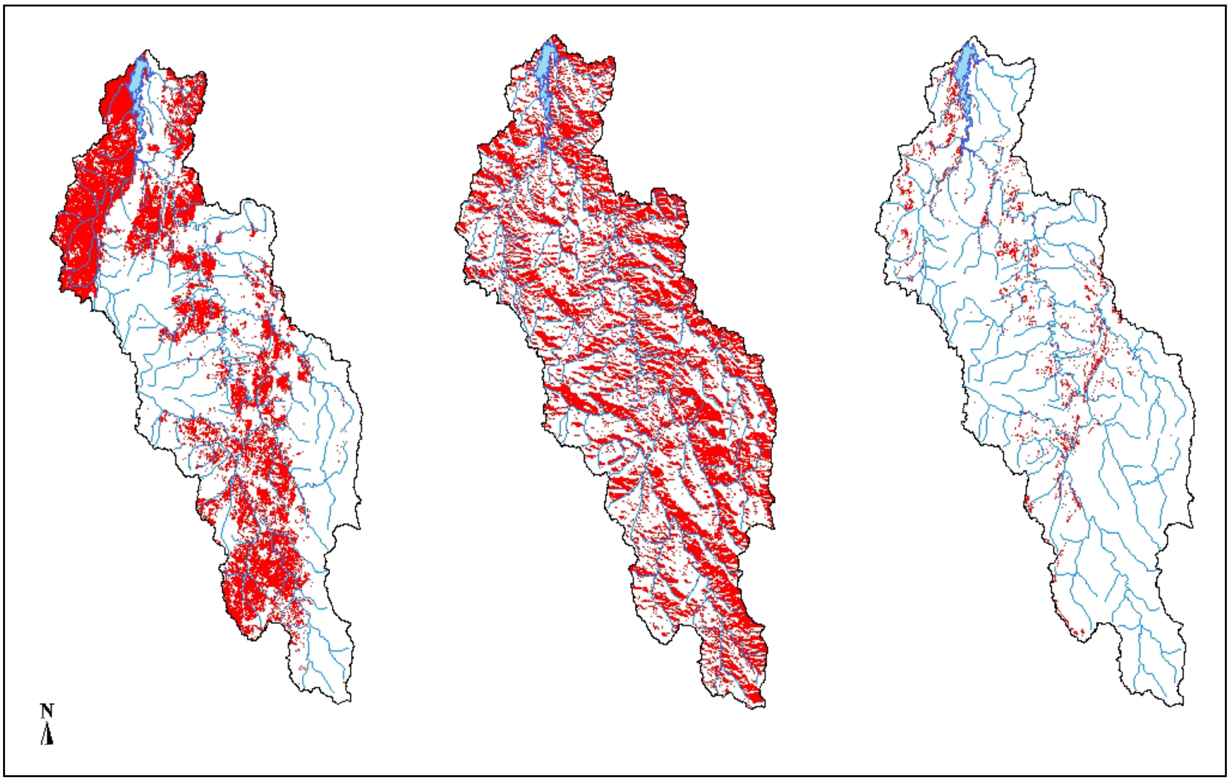
These transport factors (flow velocity, interruptions and proximity) were combined to create a layer representing areas of highest transport potential.

Final Combinations

The GIS layers described above were merged into the three primary model inputs: source (septic tanks and grazing land); survival (southerly aspect and moist soil); and transport (flow velocity, interception and proximity). These layers were intersected to find the area with optimal conditions for hotspots.

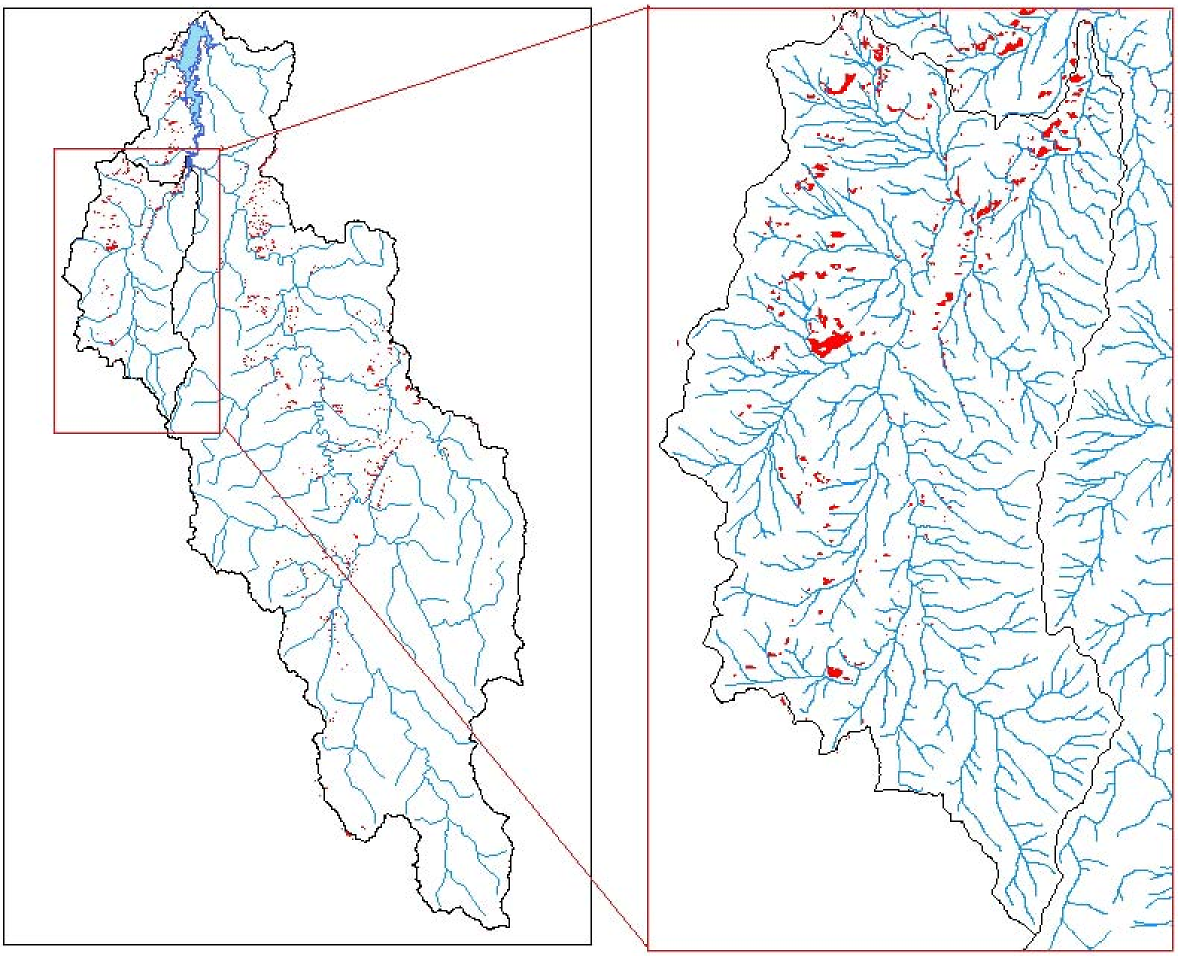
RESULTS

Figure 4: The primary GIS model input layers.



The three primary GIS model input layers were intersected to find the areas of the catchment that share high potential for the source, survival and transport of pathogens (Figure 4). The red areas in the layer on the left represent the areas with high potential for the occurrence of pathogens, the next layer shows areas with high survival potential, on the right is a layer which displays the areas with high transport potential.

Figure 5: The combination of source, survival and transport layers gives hotspots.



The final output of the GIS model shows potential hotspots (Figure 5). These hotspots only represent potential for the occurrence, survival and transport of pathogens and need to be investigated to ascertain their actual risk. The approach taken here was to select several subcatchments that appeared to have the highest risk because of proximity to the reservoir and land use. The Burra creek catchment was selected because of its relatively intensive use for grazing, as well as rural residential land. A subcatchment focused on for ground-truthing is presented in Figures 6, 7 and 8 (detailed maps of this subcatchment are included as Appendices 2-14).

Figure 6: Limestone creek catchment was selected as an area for closer inspection.

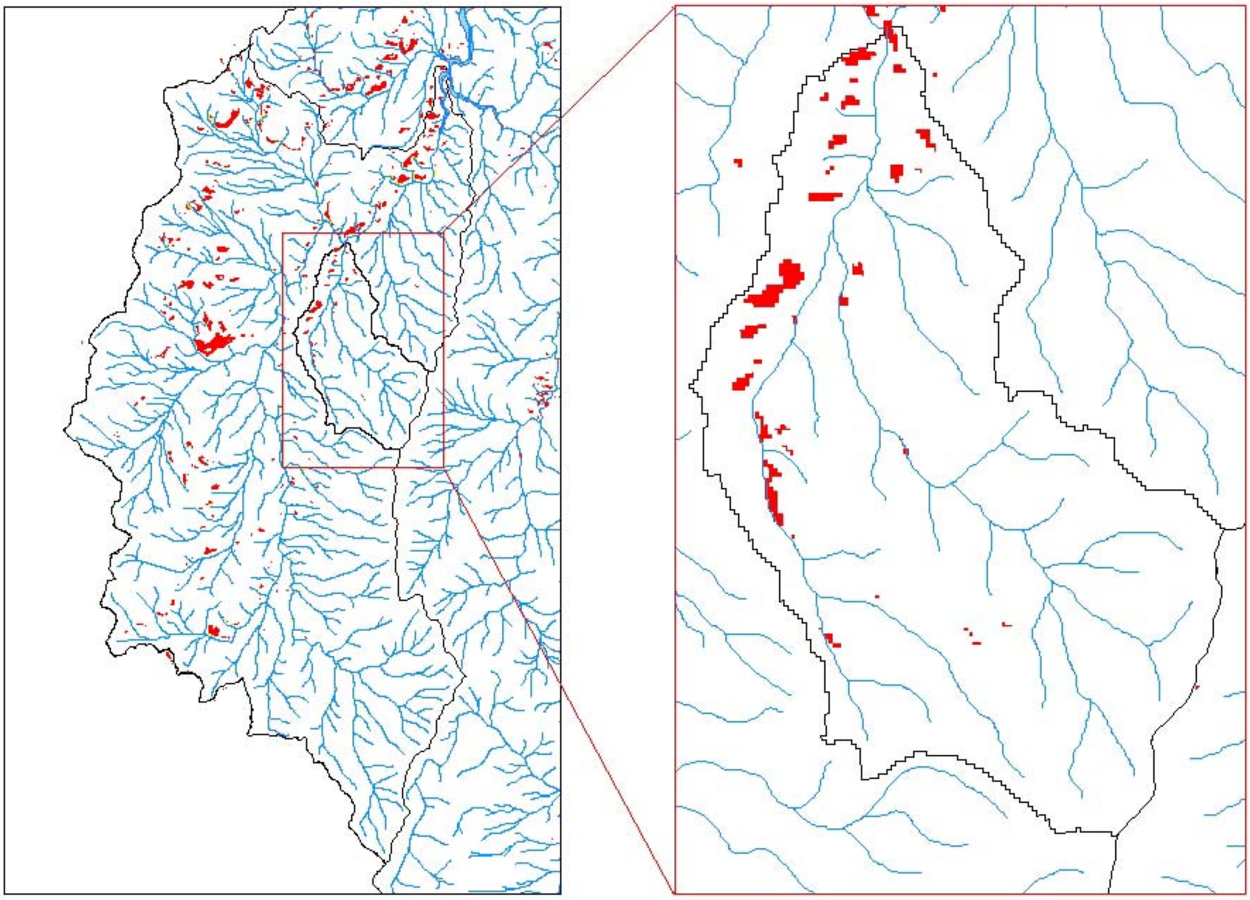
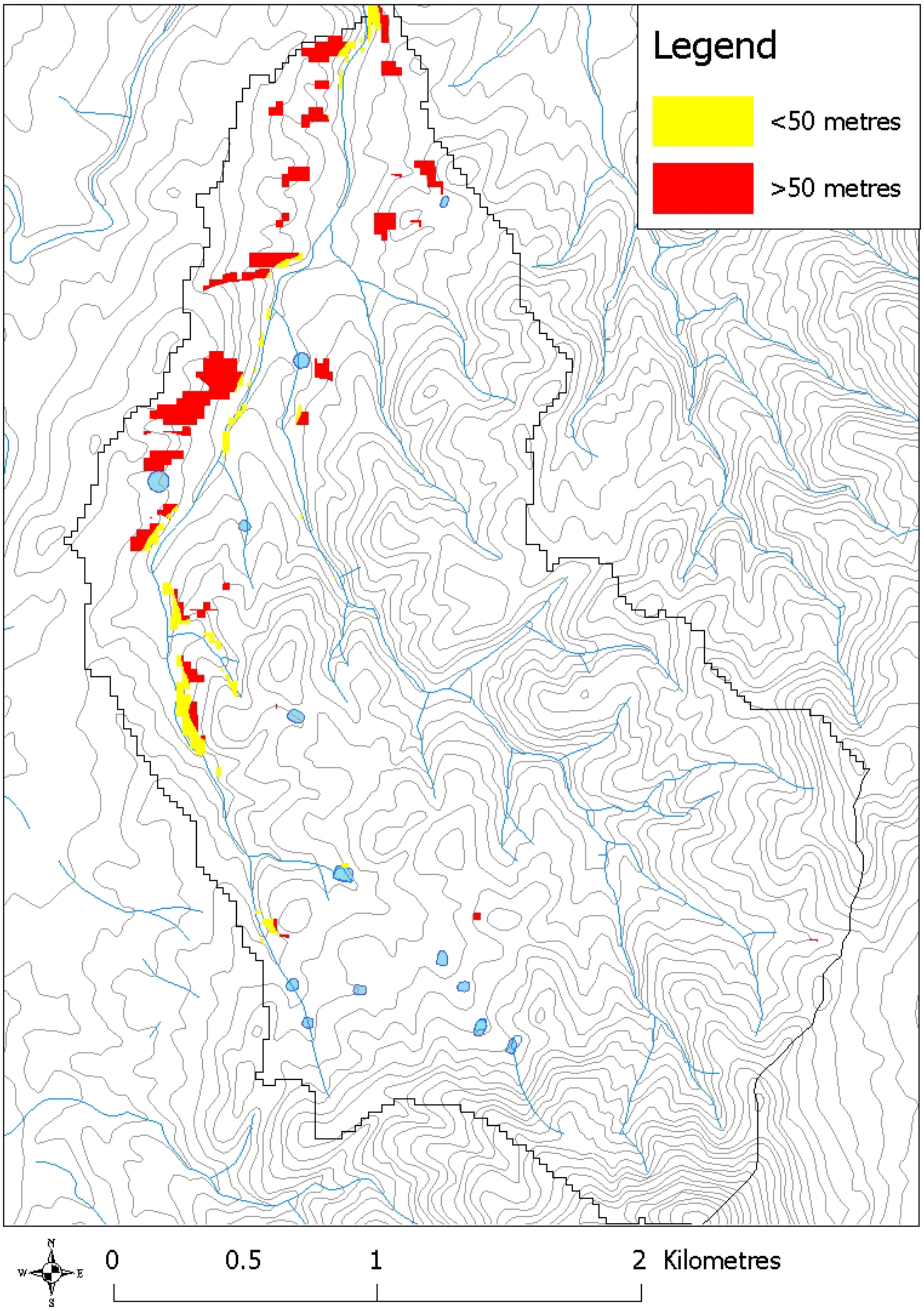


Figure 7: Limestone creek catchment hotspots



Maps were made of this catchment to aid ground-truthing fieldwork. Note: Yellow represents the areas within 50 metres of a perennial channel. These areas are assumed to have the highest connectivity to the channel.

Figure 8: Limestone creek – A hotspot identified by the GIS model and visited in subsequent ground-truthing.

Ground-truthing

Ground-truthing refers to testing the results of a GIS analysis in the field. Ground-truthing was performed at several identified hotspots and one of these is described below. Initial hotspot selection was performed by analysing the GIS output and selecting a subcatchment. Maps were made with the necessary roads, contours and property boundaries to aid navigation. A visit to the hotspot was conducted with permission from the landholder. The area was qualitatively checked to test if the appropriate attributes were identified in the model. Figure 8 shows that the area identified is indeed a spot where the grazed south-easterly slope is well connected to a major watercourse. The areas considered hotspots in the field were outlined using a Global Positioning System (GPS) and then overlayed on the hotspots layer. This showed a good correlation between the area identified in the field and by the GIS model.

DISCUSSION

Action research and catchment management

Action Research is a combination of research and action through a series of processes by which issues are defined, addressed and reconsidered (Ison and Ampt 1992, Parkes and Panelli 2001). This discussion describes an adaptive management system that moves through the following sequence: define the system; describe the system; develop a rich picture of the system; construct models of the system; identify management issues; debate actions; act; and monitor.

Define the system

As discussed above, the system may be defined at a number of scales. This needs to range from the micro to the macro scale. Micro scale subcatchments have areas in the order of hundreds of square metres. The time frame important at this scale is in the order of days, weeks and months. At the large scale of a catchment with an area in the order of hundreds of thousands of square metres, analysed at a time frame in the order of years-decades the important processes are different.

Developing a rich picture of the system

The conceptual model of the system was created from a review of the literature relevant to water-borne pathogens in general and *C. parvum* specifically. Fieldwork was conducted in the Googong catchment to develop an understanding of the landscape and land-uses. These methods allow the researcher to create a picture of the system that then needs to be refined (making a rich picture). As the modelling proceeds, the picture of the system becomes richer and this to guide further investigation of the system in an iterative process.

Integrated pollutant models

It is argued that the conceptual framework applied in this report can be used for a wide variety of contaminants and eventually aid the construction of risk-based targeting models or quantitative materials budgets (such as those described in Fraser et al. 1998, Casman et al. 2000, Caruso 2001, Leon et al. 2001, Merritt et al. 2001, Wasson et al. 2001, Letcher et al. 2002, Whiteway et al. 2002). However, this would require extensive research and data in order to make assumptions regarding the ecological dynamics relevant to each type of contaminant.

There are distinct classes of water-borne pathogens ranging from bacteria, protozoa, viruses, agricultural chemicals and even the biogeochemical context of the landscape . These distinct classes of pathogens behave differently to each other in their source, survival and transport characteristics. Incorporating many different types of pathogen introduces methodological problems and interdisciplinary tensions. Theories and assumptions will need to be integrated to adequately represent the factors and processes important for each class of pathogen.

Hotspot Modelling

Modelling is ideally a part of an ongoing process of refinement. The capability of this particular analysis to identify hotspots of pathogens is limited by some of the assumptions made and data used. The following discussion will highlight a few of these issues and identify areas that require further work.

Sources

The method for identifying sources used here was based on the assumption that grassland within a fenced boundary is a proxy for livestock. This may wrongly identify land that is not used for grazing as a potential source area. This would be overcome by conducting interviews to collect detailed information of stocking rates and regimes as well as animal types.

Wildlife also act as sources and stocks of pathogens (Chilvers et al. 1998, Heitman et al. 2002). They may contaminate areas of the catchment as well as transmit infection. These animals were excluded from this analysis because of difficulty characterising their habitat. Some methods for this may be gained from veterinary epidemiology (Davis et al. 2002) and landscape ecology (Mackey and Lyndenmayer 2001). Wild animals may be deemed unnecessary to the analysis however, if it is assumed that cattle are the dominant sources of pathogens. The health and immune status of cattle should be monitored to guide the modelling and management processes.

Another source zone excluded from this analysis was roadside reserves. These are sometimes used by graziers and may be easily included in the GIS analysis. It was discovered from the interviews that grazing the sides of roads does not happen often in the Burra or Urila valleys.

Survival

Survival of pathogens varies with climate through time. Scenarios of important climatic processes represent seasonal and inter annual variations in pathogen occurrence, survival and transport. These can be constructed although climatic modelling is very uncertain, a function of both small and large scale variability and change.

The climatic scenarios generated for this analysis represented seasonal flux of shade on southerly hillslopes. The lower radiation on southerly slopes, especially in winter makes this an optimal place and time for pathogen survival. In this region, slopes are generally warmer than their surrounds because the very cold air from the mountain tops drains into valley depressions such as frost hollows (Jenkins 1993). Areas that get colder than pathogens can survive were not identified in this report due to time constraints but may be identified using a digital elevation model.

Another survival factor identified in the literature but excluded from this analysis is effluent retention and treatment. Retention ponds are commonly used to store effluent from feedlots and abattoirs. These ponds may provide survival areas where some pathogens might multiply given appropriate conditions (Khaleel et al. 1980). There are no feedlots or abattoirs in the Googong Catchment. For the purposes of other surveys these could be mapped easily given adequate land use data. Sometimes treatment measures are taken to purify and decontaminate the effluent (Stott et al. 2001). This would have to be taken into consideration if investigating retention ponds.

Transport

There are many ways of modelling hydrological connectivity, soil moisture and runoff. These are often complex mathematical models that take into account soil infiltrative capacity, slope, shape and land cover (Grayson et al. 1997, Woods et al. 1997, Fan and Bras 1998, Aryal et al. 2003). These models may be incorporated in an analysis such as this in a future iteration that focuses in on particularly high risk catchments, but as they are data intensive they were not included in this stage of the modelling.

Flow interruptions of many kinds may intervene in pathogen transport through the catchment and reservoir to ultimately contaminate the drinking water supply. These include: deposition zones in the channel network; surface flow interception structures; and reservoir sedimentation, dilution or mixing processes. These factors were not considered in the analysis presented in this report but are briefly discussed below.

Sedimentation processes may be mapped and included in a future analysis. Characteristics of the channel such as width, depth and slope may be easily mapped to identify points where flow is slow enough for sedimentation. Other factors in sedimentation are flotation characteristics of the pathogen or the particle they are adsorbed to. Flocculation of pathogens (where particles bind together to form clumps that fall out of suspension) may occur at certain calcium concentrations (Page et al. 2001b). Geological controls on stream water quality may be a considerable factor in transport of pathogens, especially through limestone (calcium carbonate) dominated country such as the Burra valley. Previous investigations of the Burra valley have found that groundwater concentrations of calcium regularly exceed 300 mg/L (Page et al. 2001b). Areas of limestone may constitute a form of flow interruption during low to medium flow.

This beneficial influence of limestone may be counteracted during periods of high flow because of the increased subsurface flow rates. Limestone often forms karstic regions that are characterised by underground caves and channels. This presents a challenge for the modelling of transport processes. This area of study was excluded from this analysis due to time constraints but is considered very important because "in the Burra valley much of the flow is in karstic aquifers, particularly on the western side of the valley" (Page et al. 2001b, Page et al. 2001c). Karstic geology contains soluble rocks dominated by interconnected caves and conduits dissolved from the host rock (Huntoon 1995). These conduits evolved to connect high hydraulic heads to low heads and facilitate the movement of fluid through the permeable structure. Networks of conduits may form during high flow events and move high volumes of water large distances and at fast rates (Sidle et al. 2001) The presence of cattle in groundwater recharge zones has been shown to lead to high levels of contamination in springs, lasting several months after the departure of the cattle (Schaffter and Parriaux 2002). The priority of this influence is deemed lower than that for surface flow because water that flows through subsurface pathways may be filtered more than surface water in its journey to channel transport systems.

A few conditions influencing the survival and transport of pathogens in groundwater and subsurface flow systems include; size and shape of pathogen; surface electrostatic properties; other physicochemical adsorption characteristics; specific gravity or density; water flow velocity; aquifer attributes (grain size, micropore and macropore connectivity); and presence of colloidal particles (Robertson and Edberg 1997, Sidle et al. 2001, McGechan and Lewis 2002). Smaller pathogens like viruses may be transported large distances via subsurface and groundwater flow (Yates and Gerba 1984, Redman et al. 1997, Robertson and Edberg 1997) while larger pathogens may be filtered out.

Identify, Prioritise and Investigate

Rapid analysis of catchment attributes enables identification, prioritisation, monitoring and further investigation. Participation of stakeholders is necessary for identification of desirable and feasible management strategies, as well as previously undetected management issues (Ison and Ampt 1992).

Initial model outputs identified the Burra valley as an area of concern for hotspots. Several brief fieldtrips were conducted in the Burra valley, focussing on assessing the hotspot model output. The Limestone creek, Warm Corner creek and Holden's creek catchments were judged to be areas to focus on in future research. This stage of the management loop should focus on engaging with a wide range of stakeholders.

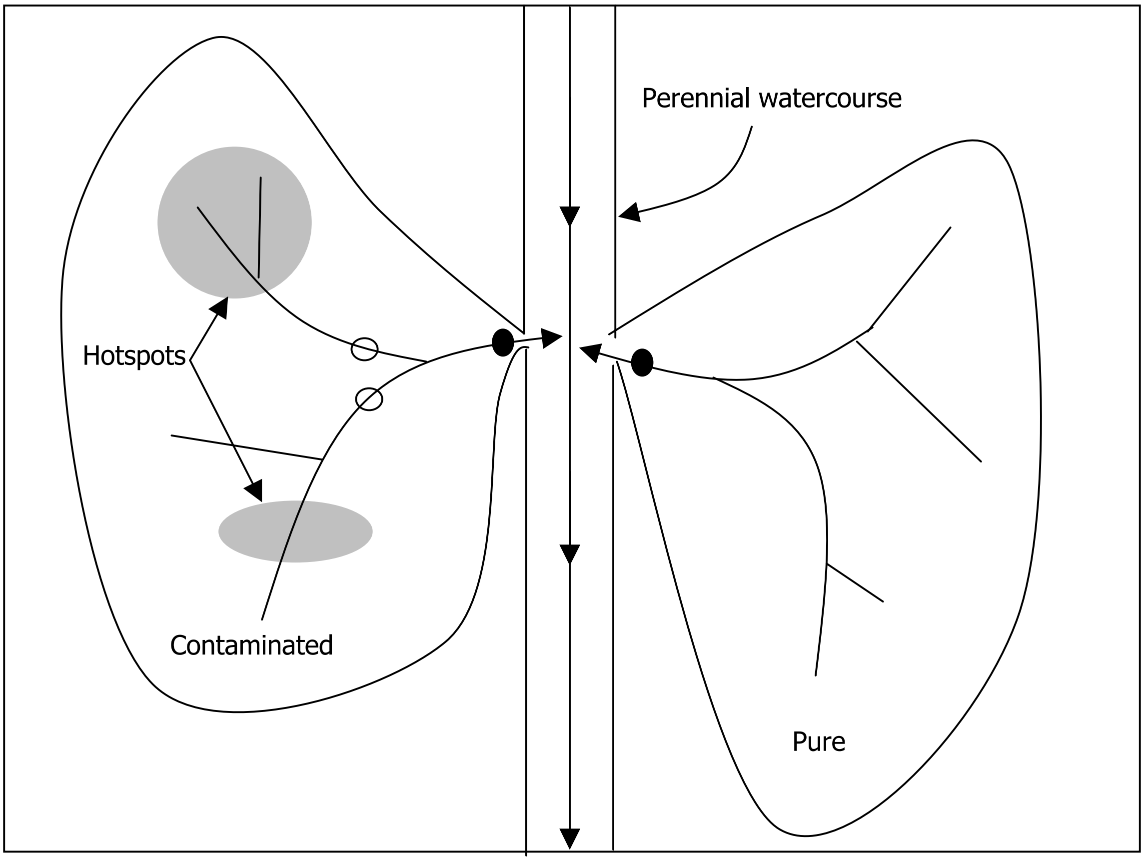


Figure 9: Water sampling strategy for verifying hotspots (grey circles). The small black circles represent initial sampling sites. Clear circles represent sampling points for subsequent investigation.

Another important management strategy is the collection of baseline and time series data of water quality and flow regimes. Sampling sites should be targeted to compare catchments with similar topographical features. The sites represented by the small black circles in Figure 9 enable comparisons to be made between these two catchments. Parasitological methods could be applied to these samples to ascertain pathogen presence, concentration and source (Jagals et al. 1995, Bajer et al. 2002, Davis et al. 2002, Heitman et al. 2002, Kistemann et al. 2002) . If testing finds that the GIS model accurately discriminates between contaminated <u>and</u> pure catchments, the monitoring regime could then focus on subcatchment scale analysis of hotspot characteristics, aiming to refine the conceptual model. The refinement of the conceptual and GIS models will enable management strategies to be tested and assessed.

The clear circles represent a possible sampling regime for comparison of hotspot management strategies.

Debate

The management strategies need to be selected by taking into account both their effectiveness and feasibility. A major constraint on feasibility of implementing an otherwise effective management option is the engagement and mobilisation of stakeholders. If the management strategy does not take into account stakeholder's values, attitudes and capacities, the strategy may not be implemented effectively (if at all).

The stakeholders in this catchment include: farmers, rural residents, local governments, Landcare groups, Googong Foreshores managers, ACT government departments, ActewAGL and recreational users. These groups of stakeholders should be contacted in conjunction with investigation of specific hotspots and included in discussions of management options.

Management options were discussed with a farmer from the Burra valley (Burra creek landholder 2003). These included:

- Vegetation management on slopes and riparian zone;
- Dams and retention ponds;
- Increasing soil infiltration capacity; and
- Drainage of water logged areas.

As these options were discussed, vegetation management emerged as a favoured strategy. This approach would ideally integrate pasture management, stocking regime and vegetation buffer strips in the riparian zone. Strategically planting riparian buffer strips of thick vegetation would be appropriate for filtration (Entry et al. 2000, Endreny 2002) as well as reduce stock access to the drainage path.

This farm is underlain by limestone karst geology as discussed above, therefore subsurface flows may also contribute pathogens. Management strategies geared to getting the water into the soil are not as important as slowing it down and filtering it. Ploughing with a chisel plough on the alluvial floodplain area is currently practiced and decreases runoff.

Act and monitor

The final phase of the action research process is to implement desirable and feasible changes to the system and monitor their effects. This would follow the approach outlined in the "identify, prioritise and investigate" section above. This integrated research, act and reflect loop enables the management system to be adaptive and strategic, focusing on specific problems, applying effective solutions and monitoring for new or unrecognised problems.

CONCLUSIONS

GIS analysis was used to identify potential 'hotspots' of contamination in the Googong reservoir catchment. Ground-truthing these 'hotspots' found that most were located on grazing land with a south-easterly aspect, within 50 meters of a watercourse and greater than ten degrees in slope. This is an alternative to current empirical methods of detecting pathogen and contaminant sources. GIS tools could potentially be used to strategically manage hotspots, thus enabling catchment managers to be proactive, rather than reactive.

In the future, management tools such as this may be essential for the maintenance of drinking water quality. It is commonly argued that global climate variability and change may be producing an enhanced hydrological cycle with more frequent high-intensity rainfall events, increasing the potential mobility of pathogens (Arnell 1999, Graczyk et al. 2000, Casman et al. 2001, Curriero et al. 2001, Rose et al. 2001, McMichael et al. 2002). To protect public water supplies, understanding the stocks and flows of pathogens through catchment areas is vital. The development of methodologies to aid strategic management of catchments will be imperative to minimise the risk of contaminating drinking water.

REFERENCES

Academic Press. 2002. http://www.academicpress.com.

Arnell, N. W. 1999. Climate change and global water resources. Global Environmental Change-Human and Policy Dimensions **9**:S31-S49.

Aryal, S. K., Main, R. G., and O'Loughlin, E. M. 2003. The concept of effective length in hillslopes: assessing the influence of climate and topography on the contributing areas of catchments. Hydrological Processes **17**:131-151.

Atwill, E., Hou, L., Karle, B., Harter, T., Tate, K., and Dahlgren, R. 2002. Transport of *Cryptosporidium parvum* Oocysts through Vegetated Buffer Strips and Estimated Filtration Efficiency. Applied and Environmental Microbiology **68**.

Australian Bureau of Statistics. 2001. Australian Census of Population and Housing. http://www.abs.gov.au/ausstats/abs@.nsf/ausstatshome?openview.

Bajer, A., Bednarska, M., Pawelczyk, A., Behnke, J. M., Gilbert, F. S., and Sinski, E. 2002. Prevalence and abundance of Cryptosporidium parvum and Giardia spp. in wild rural rodents from the Mazury Lake District region of Poland. Parasitology **125**:21-34.

Bodley-Tickell, A. T., Kitchen, S. E., and Sturdee, A. P. 2002. Occurrence of Cryptosporidium in agricultural surface waters during an annual farming cycle in lowland UK. Water Research **36**:1880-1886.

Burra creek landholder. 2003. Pers. Comm.

Caruso, B. S. 2001. Risk-based targeting of diffuse contaminant sources at variable spatial scales in a New Zealand high country catchment. Journal of Environmental Management **63**:249-268.

Casman, E., Fischhoff, B., Palmgren, C., Small, M. J., and Wu, F. 2000. An Integrated Risk Model of a Drinking-Water-Borne Cryptosporidiosis Outbreak. Risk Analysis **20**:495-511.

Casman, E., Fischhoff, B., Small, M., Dowlatabadi, H., Rose, J., and Morgan, M. G. 2001. Climate change and cryptosporidiosis: A qualitative analysis. Climatic Change **50**:219-249.

Chilvers, B. L., Cowan, P. E., Waddington, D. C., Kelly, P. J., and Brown, T. J. 1998. The prevalence of infection of *Giardia* spp. and *Cryptosporidium* spp. in wild animals on farmland, southeastern North Island, New Zealand. International Journal of Environmental Health Research **8**:59-64.

Clark, E. A. 1998. Landscape variables affecting livestock impacts on water quality in the humid temperate zone. Canadian Journal of Plant Science **78**:181-190.

Curriero, F. C., Patz, J. A., Rose, J. B., and Lele, S. 2001. The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948-1994. American Journal of Public Health **91**:1194-1199.

Davis, G. M., Wu, W.-P., CHen, H.-G., Liu, H.-Y., Guo, J.-G., Lin, D.-D., Lu, S.-B., Williams, G., Sleigh, A., Feng, Z., and McManus, D. P. 2002. A Baseline Study of Importance of Bovines for Human *Shistosoma Japonicum* Infections around Poyang Lake, China: Villages Studied and Snail Sampling Strategy. American Journal of Tropical Medicine and Hygene **66**:359-371.

Delgado, A. N., Periago, E. K., and Viqueira, F. S. F. 1995. Vegetated Filter Strips for Waste Water Purification: A Review. Bioresource Technology **51**:13-22.

Dillingham, R. A., Lima, A. A., and Guerrant, R. L. 2002. Cryptosporidiosis: epidemiology and impact. Microbes and Infection **4**:1059-1066.

ECOWISE. 2002. Environmental land use map based on ground truthed remote imaging. *in*. ECOWISE Environmental Pty. Ltd., Canberra.

Endreny, T. A. 2002. Forest buffer strips - Mapping the water quality benefits. Journal of Forestry **100**:35-40.

Entry, J. A., Hubbard, R. K., Thies, J. E., and Fuhrmann, J. J. 2000. The influence of vegetation in riparian filterstrips on coliform bacteria: I. Movement and survival in water. Journal of Environmental Quality **29**:1206-1214.

Fan, Y., and Bras, R. L. 1998. Analytical solutions to hillslope subsurface storm flow and saturation overland flow. Water Resources Research **34**:921-927.

Fraser, R. H., Barten, P. K., and Pinney, D. A. K. 1998. Predicting stream pathogen loading from livestock using a geographical information system-based delivery model. Journal of Environmental Quality **27**:935-945.

Fullerton, T. 2001. Watershed. Australian Broadcasting Commission, Sydney.

Graczyk, T. K., Evans, B. M., Shiff, C. J., Karreman, H. J., and Patz, J. A. 2000. Environmental and geographical factors contributing to watershed contamination with *Cryptosporidium parvum* oocysts. Environmental Research **82**:263-271.

Grayson, R. B., Western, A. W., and Chiew, F. H. S. 1997. Prefered states in spatial soil moisture patterns: Local and nonlocal controls. Water Resources Research **33**:2897-2908.

Heitman, T. L., Frederick, L. M., Viste, J. R., Guselle, N. J., Morgan, U. M., Thompson, R. C. A., and Olson, M. E. 2002. Prevalence of Giardia and Cryptosporidium and characterization of Cryptosporidium spp. isolated from wildlife, human, and agricultural sources in the North Saskatchewan River Basin in Alberta, Canada. Canadian Journal of Microbiology **48**:530-541.

Huntoon, P. W. 1995. Chapter 19 Is it Appropriate to Apply Porous Media Groundwater Circulation Models to Karstic Aquifers *in* Groundwater Models for Resource Analysis and Management. CRC Press.

Ison, R. L., and Ampt, P. R. 1992. Rapid Rural Appraisal: A Participatory Problem Formulation Method Relevant to Australian Agriculture. Agricultural Systems **38**:363-386.

Jagals, P., Grabow, W. O. K., and Devilliers, J. C. 1995. Evaluation of Indicators for Assessment of Human and Animal Fecal Pollution of Surface Run-Off. Water Science and Technology **31**:235-241.

Jenkins, B. R. 1993. Soil Landscapes of the Michelago 1:100 000 Sheet Map. Department of Conservation and Land Management, Sydney.

Jenkins, B. R. 2000. Soil Landscapes of the Canberra 1:100 000 Sheet Report. Department of Land and Water Conservation, Sydney.

Jenkins, M. B., Bowman, D. D., Fogarty, E. A., and Ghiorse, W. C. 2002. Cryptosporidium parvum oocyst inactivation in three soil types at various temperatures and water potentials. Soil Biology & Biochemistry **34**:1101-1109.

Khaleel, R., Reddy, K. R., and Overcash, M. R. 1980. Transport of Potential Pollutants in Run-off Water from Land Areas Recieving Animal Wastes. Water Research **14**:421-436.

Kistemann, T., Classen, T., Koch, C., Dangendorf, F., Fischeder, R., Gebel, J., Vacata, V., and Exner, M. 2002. Microbial load of drinking water reservoir tributaries during extreme rainfall and runoff. Applied and Environmental Microbiology **68**:2188-2197.

Leon, L. F., Soulis, E. D., Kouwen, N., and Farquhar, G. J. 2001. Nonpoint source pollution: A distributed water quality modeling approach. Water Research **35**:997-1007.

Letcher, R. A., Jakeman, A. J., Calfas, M., Linforth, S., Baginska, B., and Lawrence, I. 2002. A comparison of catchment water quality models and direct estimation techniques. Environmental Monitoring & Software **17**:77-85.

Mackey, B. 2002. Pers. Comm.

Mackey, B. G., and Lyndenmayer, D. B. 2001. Toward a hierarchical framework for modelling the spatial distribution of animals. Journal of Biogeography **28**:1147-1166.

Mawdsley, J. L., Bardgett, R. D., Merry, R. J., Pain, B. F., and Theodorou, M. K. 1995. Pathogens in livestock waste, their potential for movement through soil and environmental pollution [Review]. Applied Soil Ecology **2**:1-15.

Mawdsley, J. L., Brooks, A. E., and Merry, R. J. 1996a. Movement of the protozoan pathogen *Cryptosporidium parvum* through three contrasting soil types. Biology & Fertility of Soils **21**:30-36.

Mawdsley, J. L., Brooks, A. E., Merry, R. J., and Pain, B. F. 1996b. Use of a novel soil tilting table apparatus to demonstrate the horizontal and vertical movement of the protozoan pathogen *Cryptosporidium parvum* in soil. Biology & Fertility of Soils **23**:215-220.

McGechan, M., and Lewis, D. 2002. Transport of Particulate and Colloid-sorbed Contaminants through Soil part 1: General Principles. Biosystems Engineering **83**.

McMichael, A., Woodruff, R., Whetton, P., Hennessy, K., Nicholls, N., Hales, S., Woodward, A., and Kjellstrom, T. 2003. Risk Assessment Regarding Human Health and Climate Change in Australasia. National Centre for Epidemiology and Population Health, ANU, Canberra. Published by the Commonwealth Department of Health and Aging.

Merritt, W. S., Croke, B. F. W., and Jakeman, A. J. 2001. Tools for Assessing the Nutrient and Sediment Components of Water Quality: A Review. Sydney Catchment Authority, Sydney.

Miller, R., Engler, P., and Hillis, J. 2003. Spot the Micro Risk ! *in* OzWater 2003 Conference. The Australian Water Association, Perth.

Moloney, J. 13/8/2002. Googong water 10 times Cotter cost. *in* The Canberra Times, Canberra.

Ong, C., Moorehead, W., Ross, A., and Isaac-Renton, J. 1996. Studies of *Giardia* spp. and *Cryptosporidium* spp. in Two Adjacent Watersheds. Applied and Environmental Microbiology **62**:2798-2805.

Page, D., Benjamin, R., Olley, J., Wallbrink, P., Wasson, R., Croke, B., Wade, A., Ferguson, C., and Deere, D. 2001a. Tracing and Tracking of Water Pollution: A Practical Guide. Sydney Catchment Authority Internal Report, Sydney.

Page, D., Huett, D., and Wade, A. 2001b. Base Flow and Groundwater Investigation of Burra Valley and Implications for Runoff Water Quality. ECOWISE Environmental, Canberra.

Page, D., Starr, B., and Wade, A. 2001c. Interim Report on Baseflow and Groundwater Investigation of Burra Valley and Implications for Runoff Water Quality. ActewAGL, Canberra.

Parkes, M., and Panelli, R. 2001. Integrating Catchment Ecosystems and Community Health:The Value of Participatory Action Research. Ecosystem Health **7**:85-106.

Redman, J. A., Grant, S. B., Olson, T. M., Hardy, M. E., and Estes, M. K. 1997. Filtration of recombinant Norwalk virus particles and bacteriophage MS2 in quartz sand: Importance of electrostatic interactions. Environmental Science & Technology **31**:3378-3383.

Robertson, J. B., and Edberg, S. C. 1997. Natural protection of spring and well drinking water against surface microbial contamination .1. Hydrogeological Parameters [Review]. Critical Reviews in Microbiology **23**:143-178.

Robertson, L. J., Campbell, A. T., and Smith, H. V. 1992. Survival of *Cryptosporidium parvum* oocysts under various environmental pressures. Applied and Environmental Microbiology **58**:3494-3500.

Rose, J. B. 1997. Environmental ecology of *Cryptosporidium* and public health implications. Annual Review of Public Health **18**:135-161.

Rose, J. B., Epstein, P. R., Lipp, E. K., Sherman, B. H., Bernard, S. M., and Patz, J. A. 2001. Climate variability and change in the United States: Potential impacts on water- and foodborne diseases caused by microbiologic agents [Review]. Environmental Health Perspectives **109**:211-221.

Schaffter, N., and Parriaux, A. 2002. Pathogenic-bacterial water contamination in mountainous catchments. Water Research **36**:131-139.

Sidle, R. C., Noguchi, S., Tsuboyama, Y., and Laursen, K. 2001. A conceptual model of preferential flow systems in forested hillslopes: evidence of self-organisation. Hydrological Processes **15**:1675-1692.

Starr, B. 2001. Googong Dam and Upper Cotter River Catchments; potential point sources of pollution and pesticide use. ActewAGL, ACT.

Starr, B., Wasson, R., and Caitcheon, G. 1999. Soil Erosion, Phosphorous and Dryland Salinity in the Upper Murrumbidge. Murrumbidgee Catchment Management Committee, Wagga Wagga, NSW.

Stott, R., May, E., Matsushita, E., and Warren, A. 2001. Protozoan predation as a mechanism for the removal of cryptosporidium oocysts from wastewaters in constructed wetlands. Water Science and Technology **44**:191-198.

Walker, M., Leddy, K., and Hagar, E. 2001. Effects of combined water potential and temperature stresses on *Cryptosporidium parvum* oocysts. Applied and Environmental Microbiology **67**:5526-5529.

Walker, M. J., Montemagno, C. D., and Jenkins, M. B. 1998. Source water assessment and nonpoint sources of acutely toxic contaminants: A review of research related to survival and transport of *Cryptosporidium parvum*. Water Resources Research **34**:3383-3392.

Wasson, R. 1998. Dryland Farming, Erosion and Stream Sediments - the Problem of Catchment Scale. *in* J. Williams, R. A. Hook, and H. L. Gascoigne, editors. Farming Action, Catchment Reaction: the Effect of Dryland Farming on the Natural Environment. CSIRO Publishing, Canberra.

Wasson, R., Fergusson, C., Page, D., and Bales, M. 2001. Contaminant Budget Construction for Sydney Catchment Authority Catchments. Sydney Catchment Authority Internal Report.

Western, A. W., Grayson, R. B., Bloschl, G., Willgoose, G. R., and McMahon, T. A. 1999. Observed spatial organisation of soil moisture and its relation to terrain indices. Water Resources Research **35**:797-810.

White, S. L., Sheffield, R. E., Washburn, S. P., King, L. D., and Green, J. T. 2001. Spatial and Time Distribution of Dairy Cattle Excreta in and Intensive Pasture System. Journal of Environmental Quality:2180-2187.

Whiteway, T., Page, D., and Wasson, R. 2002. Materials budgets as a tool for integrated catchment management. Ecowise Environmental Pty. Ltd., Canberra.

Woods, R., Sivapalan, M., and Robinson, J. S. 1997. Modeling the spatial variability of subsurface runoff using a topographic index. Water Resources Research **33**:1061-1073.

Yates, M. V., and Gerba, C. P. 1984. Factors Controlling the Survival of Viruses in Groundwater. Water Science and Technology **17**:681-687.

Appendices:

1. **Stocking regime information collected from landholders**
2. **Maps of each layer at subcatchment scale**
3. **Methods and Metadata**

Appendix 1: Stocking regime information

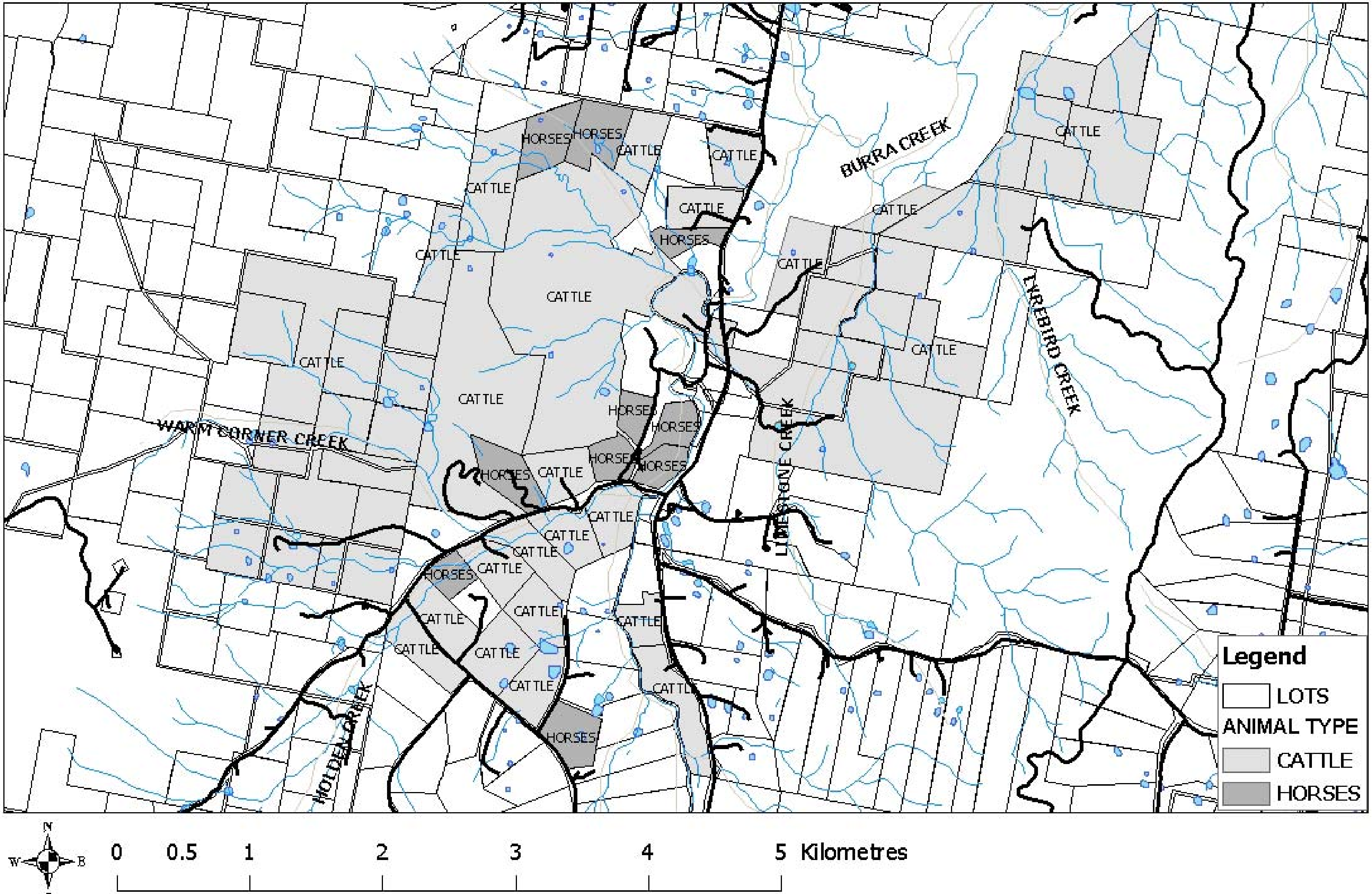
Landholder contacts in the Burra+ and Urila* valleys: See next page for map of the Burra catchment.

Property Name	Stock	Contact
Lagoon Station+	Cattle 110 head/320 hectares (~1/3) ~50 calves	Tom and Therese Moore 62363119
Burravale+	Sheep, Cattle and Goats	Scattergood 62363219
Burra Station+	Cattle and horses	Sidhu 62363150
Unknown*	Cattle ~400 head/810 hectares ~1/2	Tom Henshall 886 Urila Road 2620
Sunnybrae*	No stock	Mervyn and Sandy Lloyd 62363322

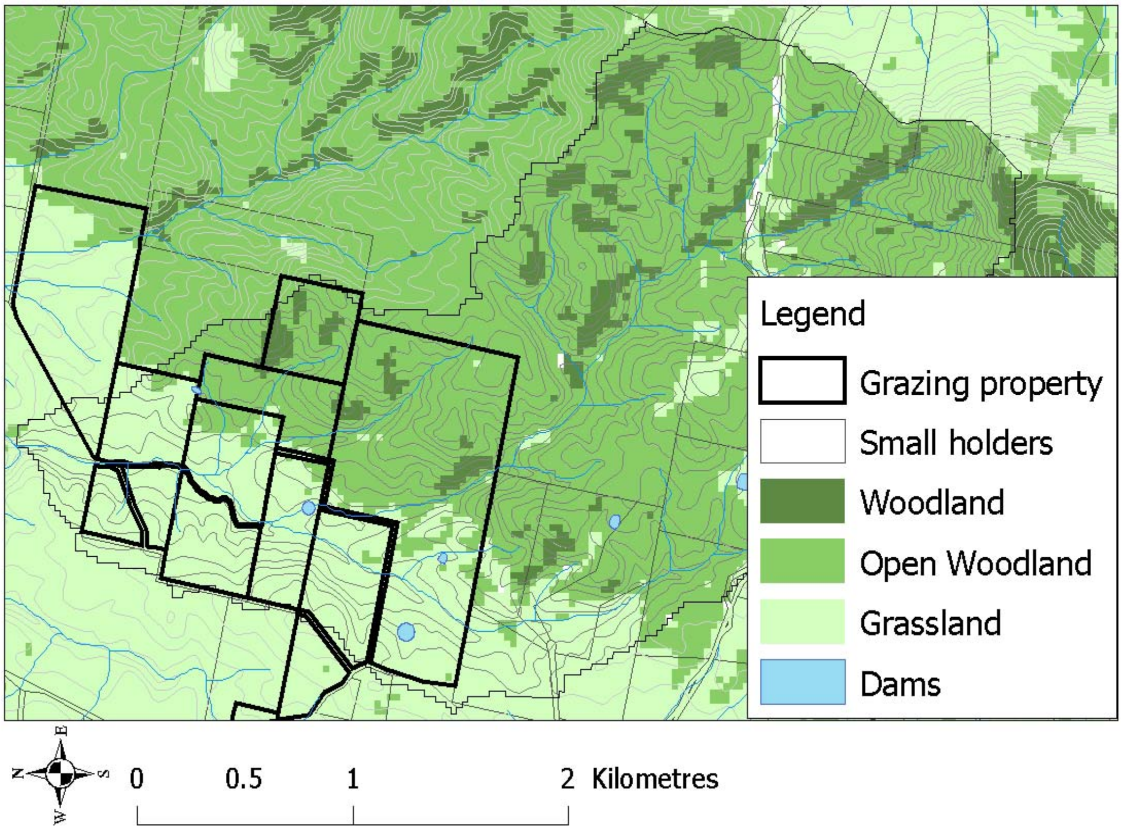
Landholder contacts adjoining the Googong Foreshores Boundary:

Name	Address	Postcode
Mr B Ballard	1028 Burra Road Queanbeyan	2620
Mr P Bell	Po Box 775 Queanbeyan	2620
Ms R Bush	1088 Burra Road Burra Creek	2620
Mr A Butlin	352 Wanna Wanna Road Queanbeyan	2620
CEC Martin Motors Pty Ltd	Po Box 391 Fyshwick	2609
Mr D Charman	6 Kinsella Street Queanbeyan	2609
Mr M Cumberland	17 Spowers Circuit Holder	2000
Mr M Deveau	25 Balala Place Isabella Plains	2611
Mr G Flanagan	1167 Burra Road Queanbeyan	2905
Googong Pty Ltd	Googong Po Box 316 Queanbeyan	2620
Ms S Hill	1169 Burra Road Queanbeyan	2620
Ms S Hill	"London Bridge" Rmb 87a Burra Road	2620
Maxsons Pty Ltd	C/- Woolcara Station 525 Woolcara Lane Bungendore	2620
Mr R Moore	C/- Mr Caj Willoughby 129 La Perouse Street	2620
Mrs P Murphy	"Glenola" Rmb 89 Burra Road	2620
Mr A Padovan	13 Abbott Street Yarralumla Act	2620
Ms K Rae	Po Box 3052 Manuka	2620
Mr P Rowley	Rmb 874 Hardy Road Burra Creek	2621
Mr A Smith	10 Collins Street Queanbeyan	2621

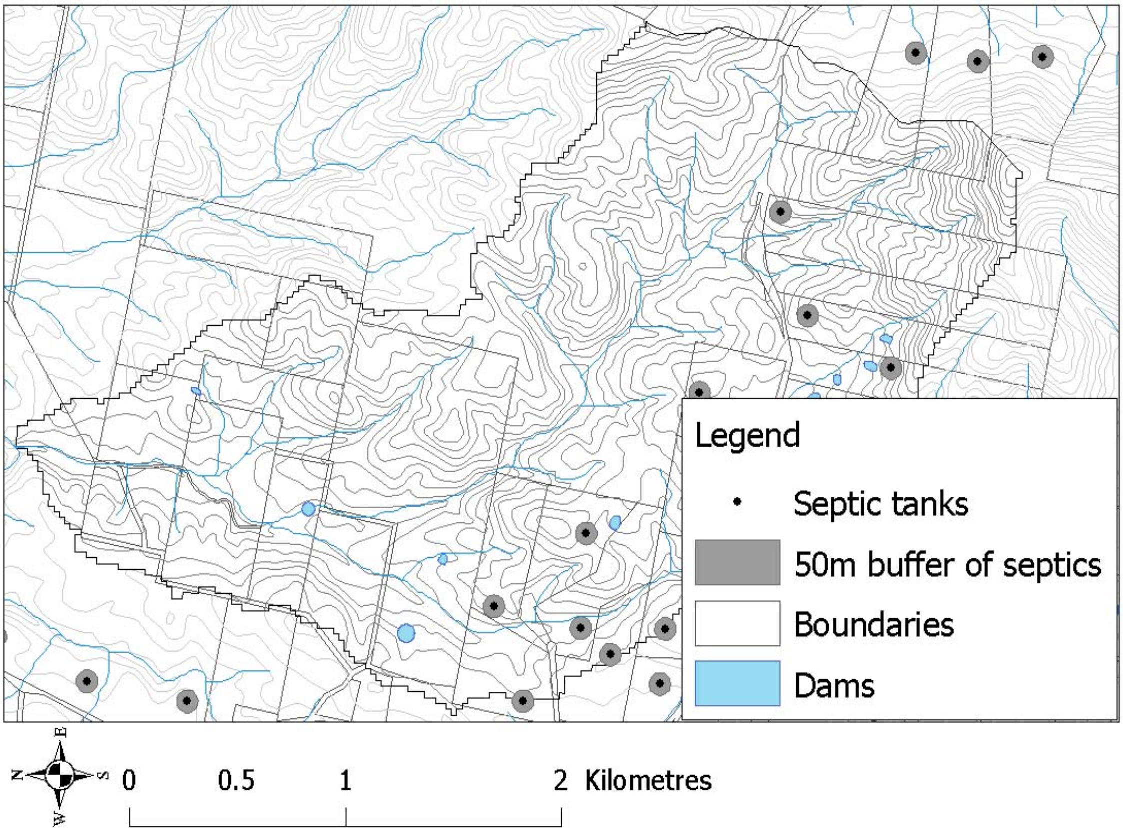
Grazing animals in the Burra Creek Catchment



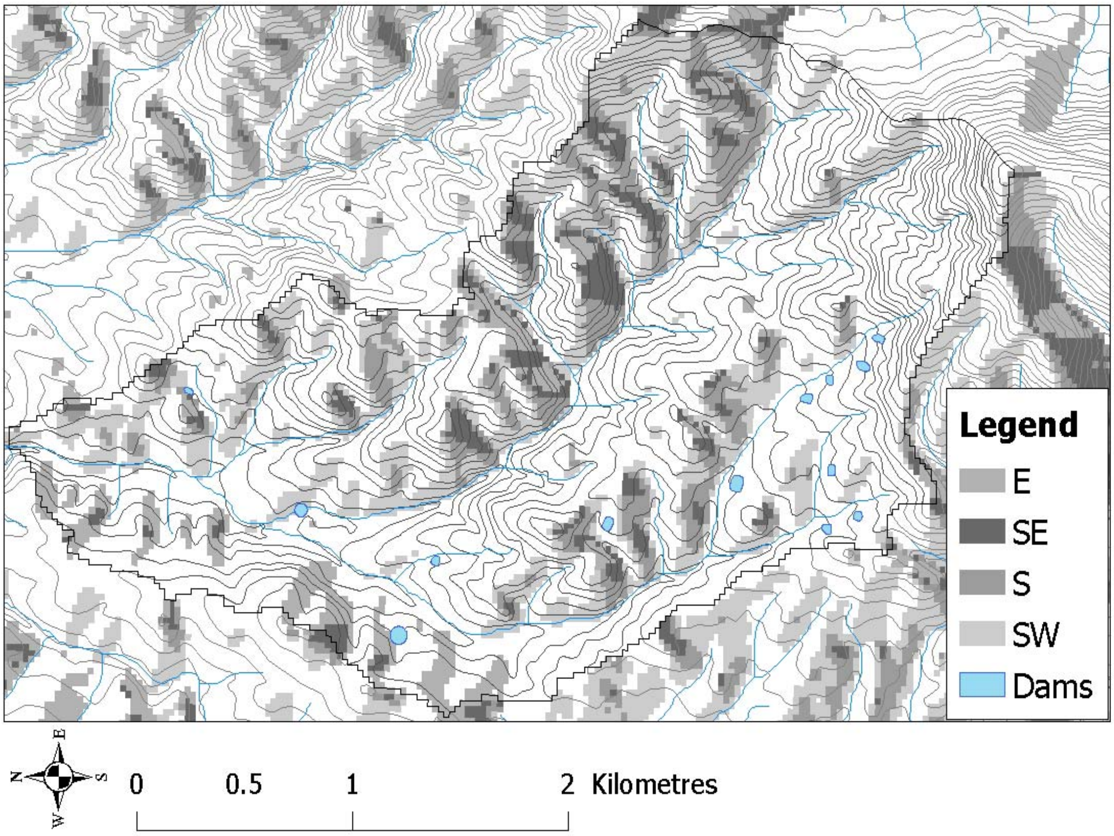
Maps of each layer at subcatchment scale: Limestone Creek



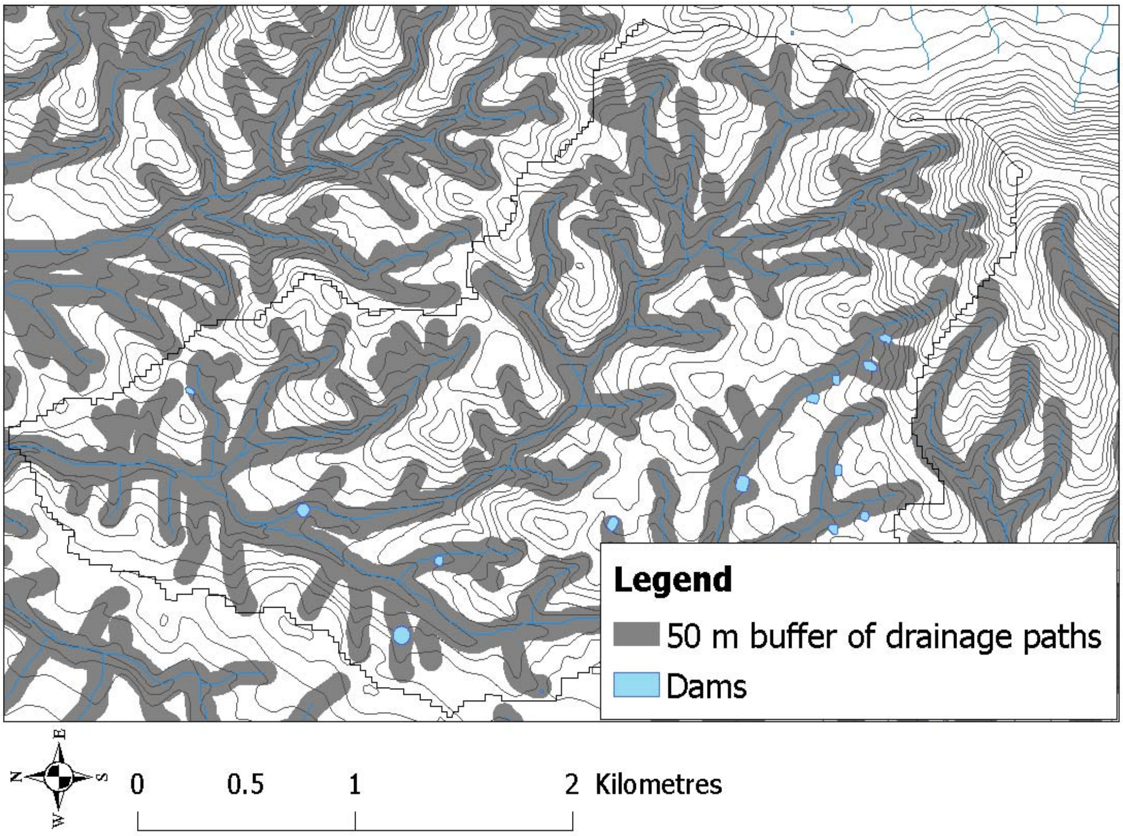
Appendix 2: Grazing vegetation



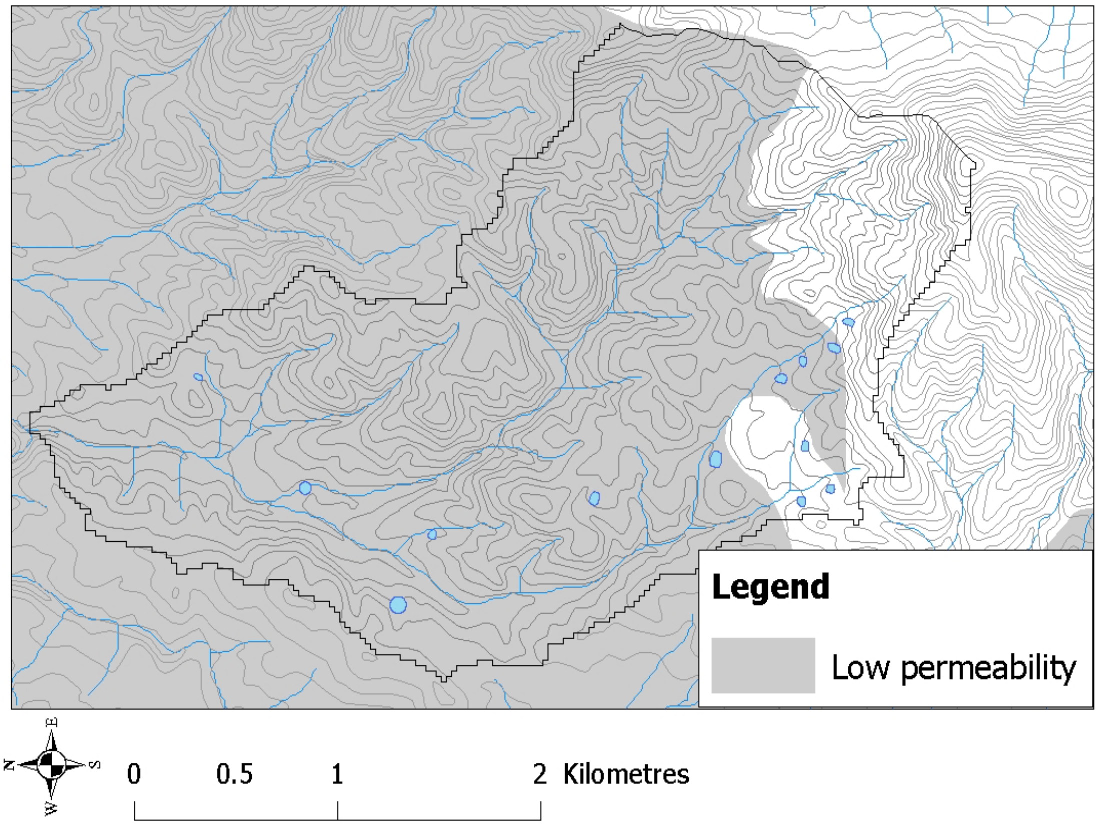
Appendix 3: Septic tanks



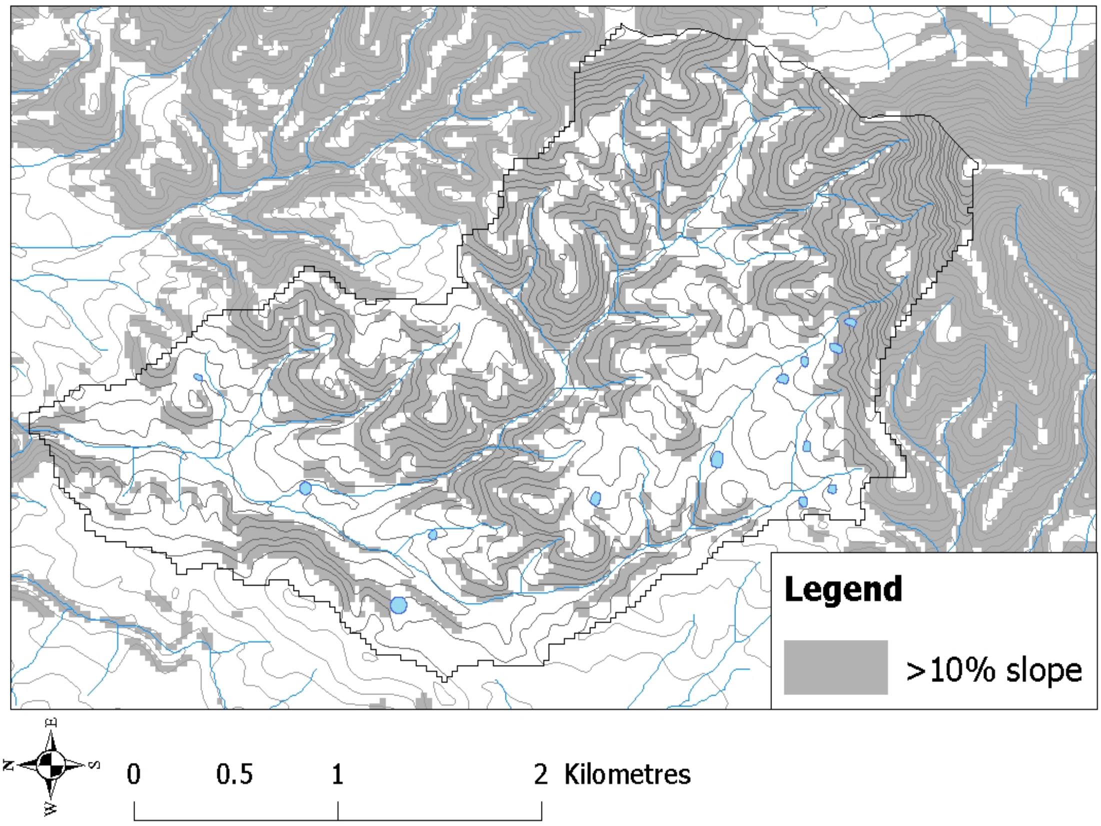
Appendix 4: Radiation and temperature



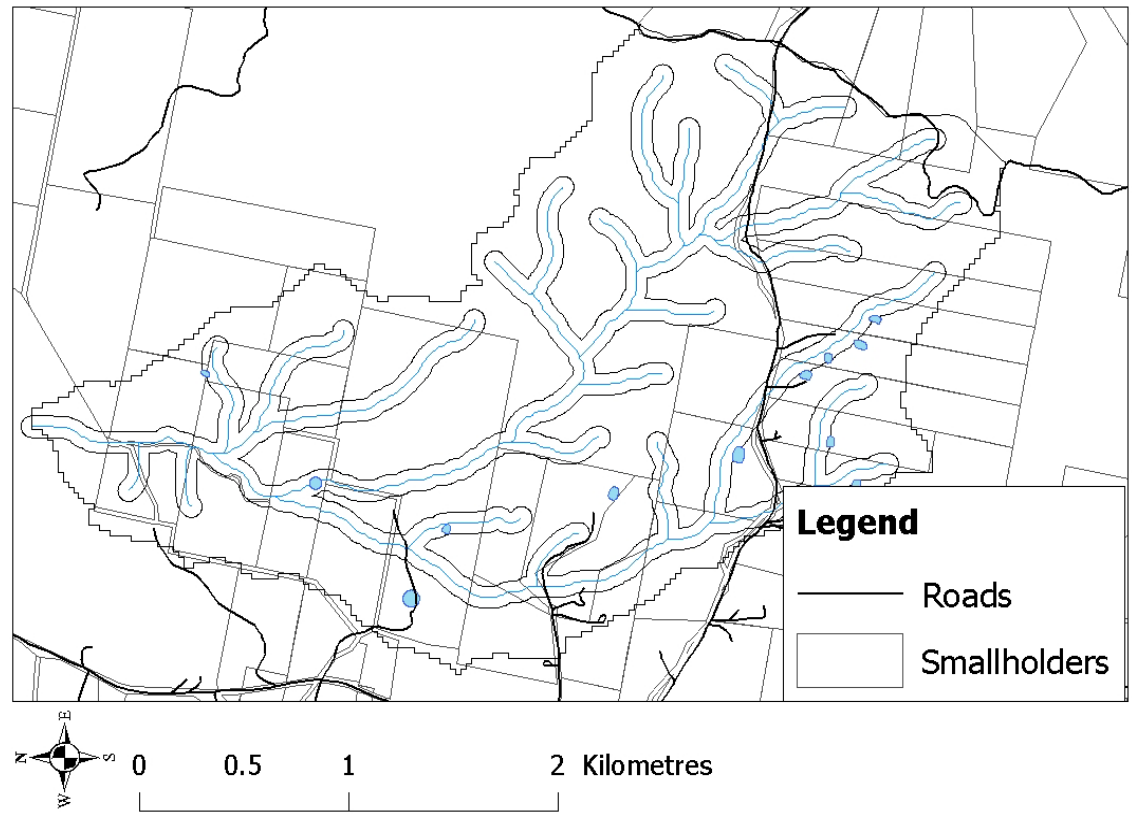
Appendix 5: Soil moisture



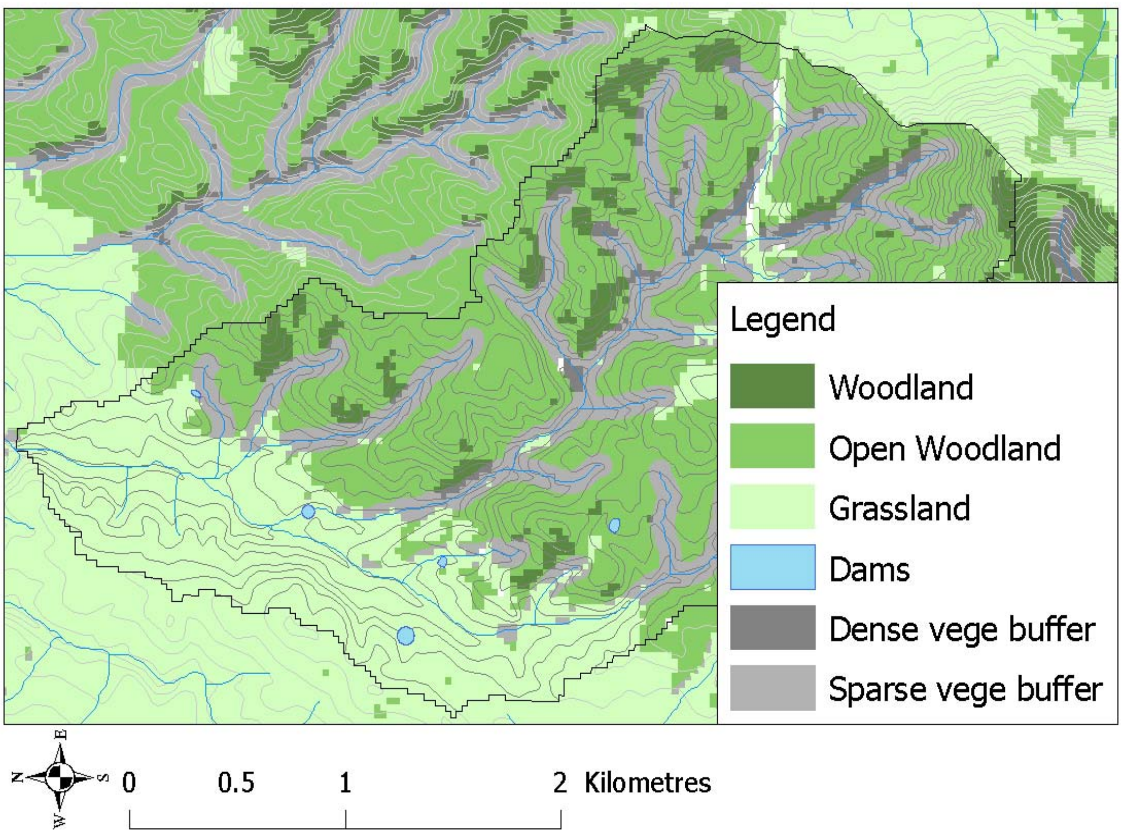
Appendix 6: Soil permeability



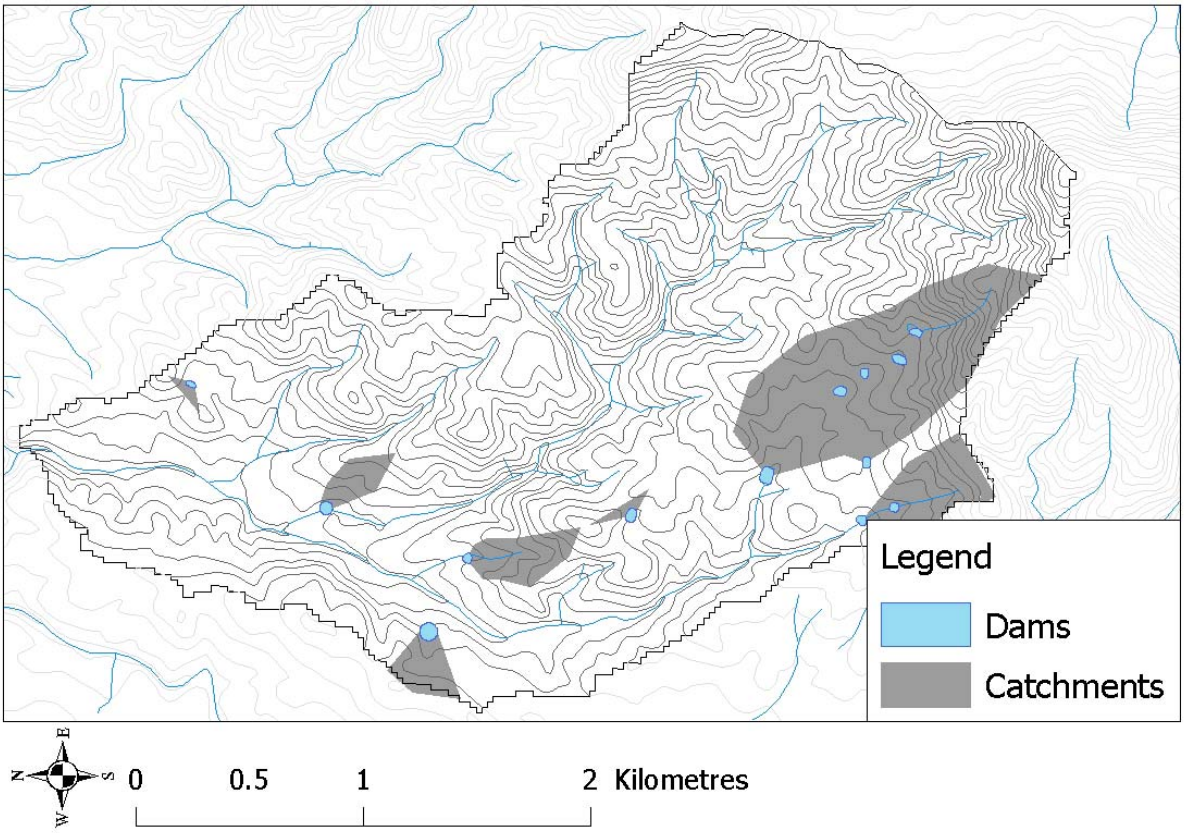
Appendix 7: Slope gradient



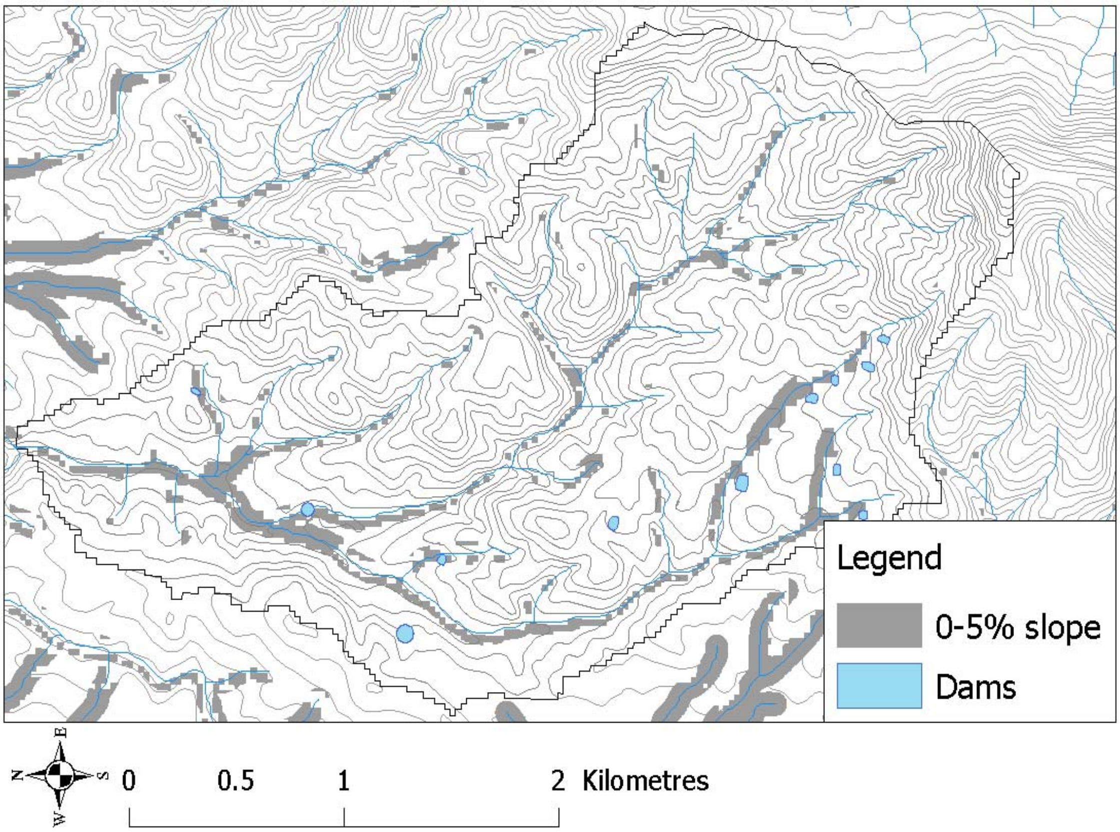
Appendix 8: Roads



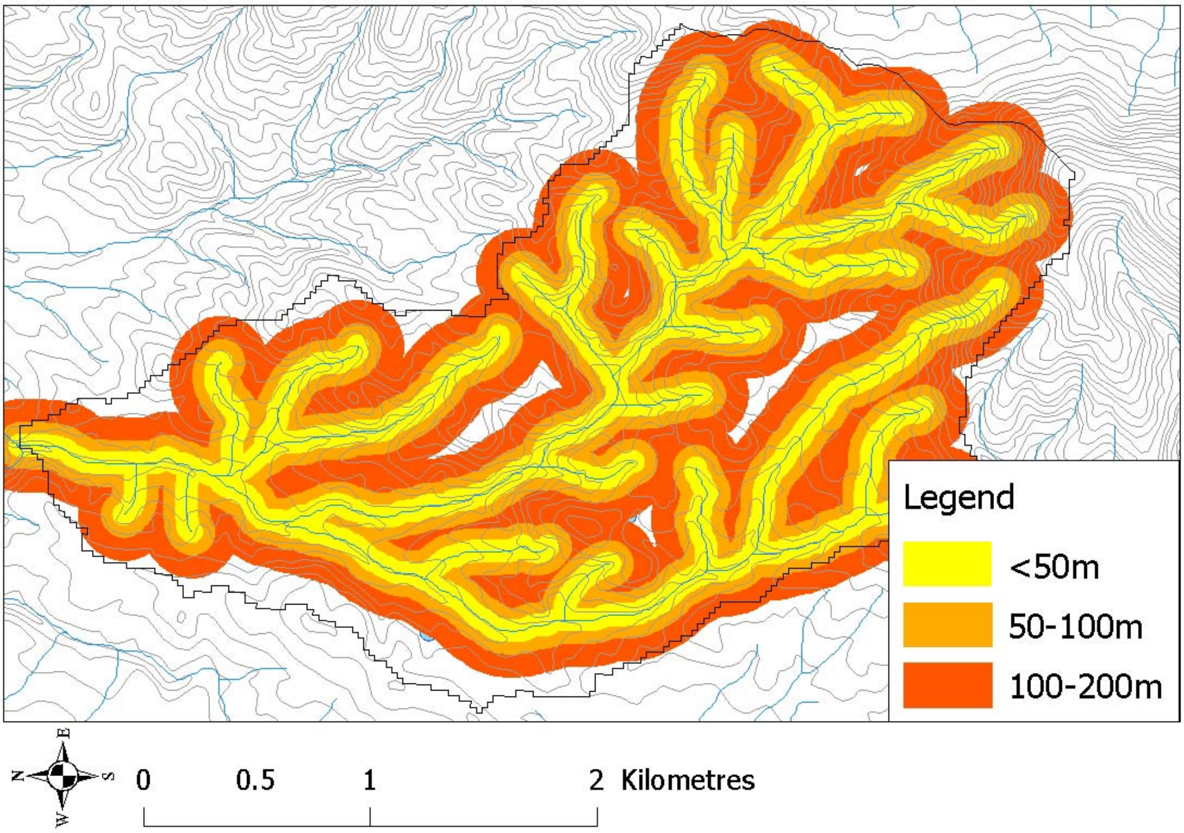
Appendix 9: Vegetation type



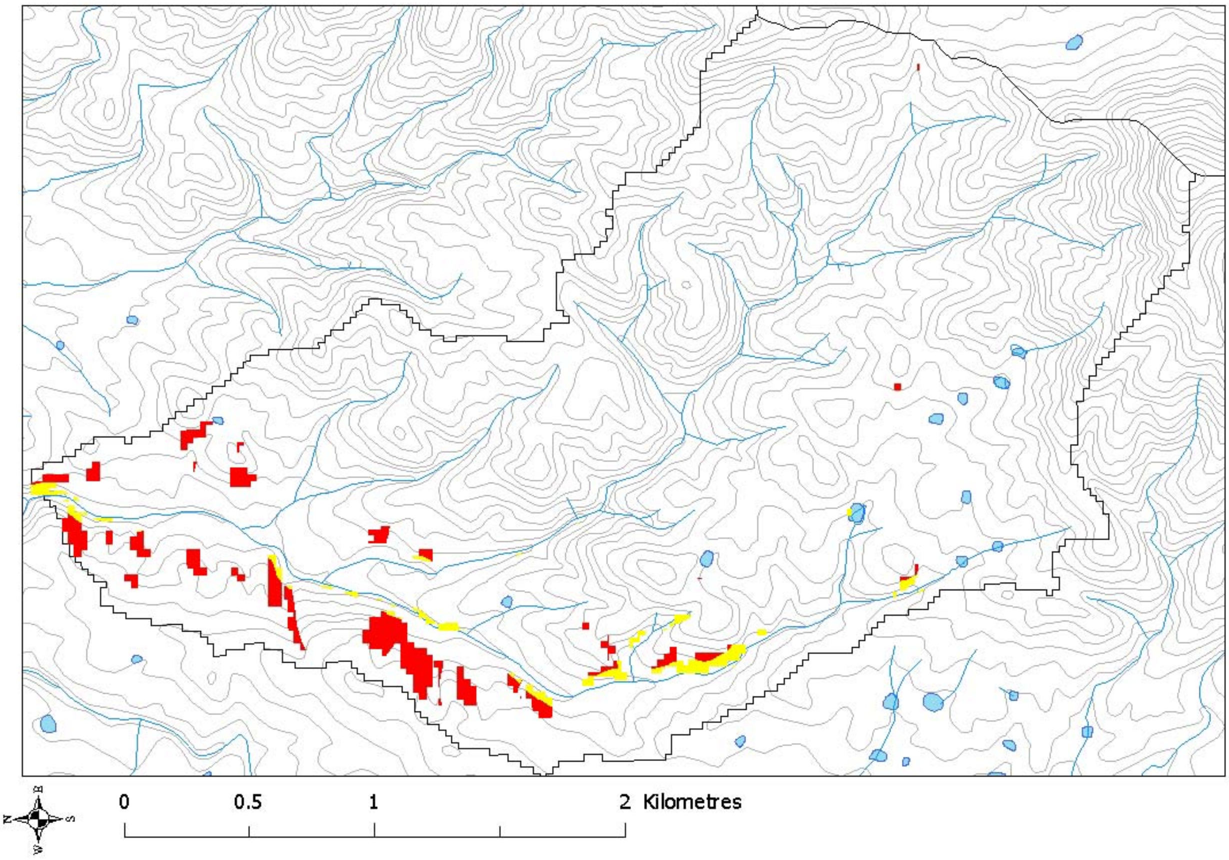
Appendix 10: Dams



Appendix 11: Flood plains



Appendix 12: Proximity to perennial water course



Appendix 13: Final combination

Methods and Metadata

Meta data 1: Googong lot boundaries

Method: Cooma Monaro and Yarrowlumla shires data was merged and clipped to the Googong catchment

Named: goog_lots

Cooma Monaro shire lots:

Category	Element	Comment
Dataset	Title/path	lots
	Custodian	NSWLIC
	Jurisdiction	NSW
Description	Abstract	Lot boundaries, includes owner names and addresses
	Type	Shapefile (polygon)
	Search Word(s)	Lot boundaries
	Geographic Extent Name(s)	Cooma Monaro shire
	Geographic Extent Polygon(s)	AMG Zone 55, AGD 66
Data Currency	Beginning Date	1987
	Ending Date	1999
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	Irregular
Access	Stored Data Format	Arc shapefile
	Available Format Type	- Vector Coverage - ARC/INFO - MapInfo
	Access Constraint	As per NSWLIC license agreements for Cooma Monaro shire and ECOWISE Environmental. Further access would require license agreements and fees.
Data Quality	Lineage	Compiled by private sub-contractors for NSWLIC
	Positional Accuracy	Not Documented
	Attribute Accuracy	1:1000 to 1:4000 - urban 1: 25,000 to 1:100000 - rural
	Logical Consistency	Not Documented
	Completeness	Complete to 1997 information
Contact Information	Contact Organisation	New South Wales Land Information Centre (NSWLIC)
	Mail Address	Land Information Centre PO Box 143 Bathurst NSW
	Suburb	Bathurst

	State	NSW
	Country	Australia
	Postcode	2795
	Telephone	02 6332 8200
	Facsimile	02 6331 8095
Metadata Data	Metadata Date	29/6/2000
Additional Metadata	Additional Metadata	NSWLIC

Yarrowlumla shire lots:

Category	Element	Comment
Dataset	Title/path	lots
	Custodian	NSWLIC
	Jurisdiction	NSW
Description	Abstract	Lot boundaries includes owners name and address
	Type	Shapefile (polygon)
	Search Word(s)	Lot boundaries
	Geographic Extent Name(s)	Yarrowlumla shire
	Geographic Extent Polygon(s)	AMG Zone 55, AGD 66
Data Currency	Beginning Date	1987
	Ending Date	1999
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	Irregular
Access	Stored Data Format	Arc shapefile
	Available Format Type	- Vector Coverage - ARC/INFO - MapInfo
	Access Constraint	As per NSWLIC license agreements for Yarrowlumla shire and ECOWISE Environmental. Further access would require license agreements and fees.
Data Quality	Lineage	Compiled by private sub-contractors for NSWLIC
	Positional Accuracy	Not Documented

	Attribute Accuracy	1:1000 to 1:4000 - urban 1: 25,000 to 1:100000 - rural
	Logical Consistency	Not Documented
	Completeness	Complete to 1997 information
Contact Information	Contact Organisation	New South Wales Land Information Centre (NSWLIC)
	Mail Address	Land Information Centre PO Box 143 Bathurst NSW
	Suburb	Bathurst
	State	NSW
	Country	Australia
	Postcode	2795
	Telephone	02 6332 8200
	Facsimile	02 6331 8095
Metadata Data	Metadata Date	29/6/2000
Additional Metadata	Additional Metadata	NSWLIC

Meta data 2: Septic tanks

Category	Element	Comment
Dataset	Title/path	Goog_septics.shp
	Custodian	
	Jurisdiction	
Description	Abstract	Location of septic tanks in the Googong Catchment. Divided into septic tanks pre 1976 and post 1976 (in age field).
	Type	Points
	Search Word(s)	septics
	Geographic Extent Name(s)	Googong Catchment
	Geographic Extent Polygon(s)	AMG Zone 55, AGD 66
Data Currency	Beginning Date	2/3/2001
	Ending Date	-
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	-
Access	Stored Data Format	
	Available Format Type	- ARC/INFO - MapInfo
	Access Constraint	ECOWISE Environmental.
Data Quality	Lineage	Data heads up digitised from maps created by Barry Starr, recording locations of all known septic tanks (original scale 1:40000).
	Positional Accuracy	Accurate to Barry Starr's extent of knowledge and original map scale.
	Attribute Accuracy	
	Logical Consistency	
	Completeness	
Contact Information	Contact Organisation	ECOWISE Environmental.
	Mail Address	
	Suburb	
	State	
	Country	
	Postcode	
	Telephone	
	Facsimile	
Metadata Data	Metadata Date	
Additional Metadata	Additional Metadata	

Meta data 3: Cattle stocking rates

Category	Element	Comment
Dataset	Title/path	Goog_cattle.shp
	Custodian	
	Jurisdiction	
Description	Abstract	Information about animal type and density was gathered by informal visits to landholders in the Burra and Urila creek subcatchments. Added to goog_lots.
	Type	Shapefile
	Search Word(s)	Cattle
	Geographic Extent Name(s)	
	Geographic Extent Polygon(s)	AMG Zone 55, AGD 66
Data Currency	Beginning Date	January 2003
	Ending Date	-
Dataset Status	Progress	Incomplete
	Maintenance and Update Frequency	-
Access	Stored Data Format	Shapefile
	Available Format Type	- ARC/INFO - MapInfo
	Access Constraint	ECOWISE Environmental.
Data Quality	Lineage	
	Positional Accuracy	Paddock boundaries are from shire cadastral data (see goog_lots)
	Attribute Accuracy	
	Logical Consistency	
	Completeness	
Contact Information	Contact Organisation	ECOWISE Environmental.
	Mail Address	
	Suburb	
	State	
	Country	
	Postcode	
	Telephone	
	Facsimile	
Metadata Data	Metadata Date	
Additional Metadata	Additional Metadata	

Meta data 4: Vegetation

Category	Element	Comment
Dataset	Title/path	landcover
	Custodian	ERIC
	Jurisdiction	ACT
Description	Abstract	Land cover and vegetation from satellite imagery
	Type	Bil image file
	Search Word(s)	Land cover, vegetation
	Geographic Extent Name(s)	Googong Catchment
	Geographic Extent Projection	System: AMG Zone:55 Projection: Transverse Mercator Datum: AGD 66 Ellipsoid: IUGG 1976
Data Currency	Beginning Date	Image from Dec 1998
	Ending Date	Current
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	Currently no updates, may be updated in the future
Access	Stored Data Format	BIL Raster image ArcView shapefile MapInfo Table
	Available Format Type	BIL Raster image ArcView shapefile MapInfo Table BIL Raster image
	Access Constraint	As per ECOWISE Environmental license agreements for Yarrowlumla and Cooma Monaro shires. Further access would require license agreements and fees.
Data Quality	Lineage	SPOT panchromatic data (10 meter pixel size), combined with Landsat TM imagery (30 m pixel size) Referenced to ECOWISE Data
	Positional Accuracy	Within 5km to within 60m, or better, after specialised processing.
	Attribute Accuracy	Not applicable
	Logical Consistency	Extents are confined to one satellite run, therefore there is likely to be

		good consistency
	Completeness	Complete
Contact Information	Contact Organisation	Environmental Research and Information Consortium (ERIC)
	Mail Address	PO Box 179, Deakin, West ACT,
	Suburb	Deakin
	State	ACT
	Country	Australia
	Postcode	2600
	Telephone	(02) 62605161
	Facsimile	(02) 62605162
Metadata Data	Metadata Date	16/8/2000
Additional Metadata	Additional Metadata	

Creating grazing vegetation layer:

Method:

1. Using the vegetation classes below decide which will be included and which excluded.
2. Using the "Select by attributes" function select the appropriate grid codes.
3. Export the grassland class.
4. Intersect this with goog_lots to identify grazing vegetation on private land.

Vegetation Classification:

Class	Grid code	Risk
1. Exposed Soil or Rock Little or no vegetation cover Cultivated land	37	High
2. Pasture Sparse to very sparse pasture (non-tussock) Interspersed rock outcrops	29	High
3. Improved Pasture Sparse pasture (non-tussock)	27	High
4. Mixed Pasture (Improved Pasture and Native mix) Moderate to sparse pasture (non-tussock) Dominantly improved pasture with native species interspersed	125	High

5. Mixed Pasture (Improved Pasture and Native mix) Improved pasture interspersed with grassland and meadow communities In the upper catchment; moderate pasture In the lower catchment (Lower slopes and broad drainage channels); mainly tussock grassland	111	High
6. Open Grasslands and Meadows Predominantly native grassland and meadow species interspersed with improved pasture In the upper catchment; moderate to dense pasture In the lower catchment (Lower slopes and broad drainage channels); mainly tussock grassland	108	High
7. Native Tussock Grassland Sparse tussock grassland Some areas of improved pasture	35	High
8. Native Tussock Grassland Moderate tussock grassland	32	High
9. Native Tussock Grassland Dense tussock grassland Mainly associated with drainage lines	31	High
10. Open Savannah woodland Fringing open woodland Widely spaced trees with grassy understorey Transitional area from woodland to open grassland Transitional area from frost hollows (grassland species) to woodland	65	High
11. Open Woodland medium spaced trees Moderate understorey Sparse ground cover Associated with drier soils and aspects	62	High
12. Woodland Medium spaced trees Moderate understorey Dense ground cover	16	Low
13. Woodland/ Sclerophyll Closed woodland/ open forest Moderate understorey Dense ground cover	13	Low

14. Dry Sclerophyll Forest - open Open forest Moderate understorey Sparse ground cover	3	Low
15. Dry Sclerophyll Forest Moderate forest Moderate understorey Sparse ground cover Usually associated with wet, sheltered aspects	1	Low
16. Pine Plantations Immature or raised pine plantations	44	Low
17. Pine Plantations Semi – mature or mature pine plantations	41	Low
18. Water / water bodies	9	None
19. Cloud	60	None

Glossary

Woodland: A woodland in this instance is defined by a Eucalypt community with varied understory density and species composition. The dominant tree species must however conform to; "Vegetation where the projected foliage cover is sparse." (Boland et al.1984.)

There are two possible types of woodland, shrub-woodland and savannah woodland (dominant grassy understory). (Hall et al., 1970)
In this case woodland is taken to refer to those areas where there are both
an understory of shrubby material and,
also a grassy level.
These in turn have been divided into different levels of density based on the understorey density, the crown density and the intermediate level of cover.

Savannah Woodland: Is characterised by an open woodland type of community, widely spaced trees, with moderate to dense grassy understorey commonly with large areas of (*Poa caespitosa*) Tussock.

The dominant species in this type of woodland, include Candlebark (*E. rubida*),Snow Gum *(E. pauciflora*), and Black Sallee (*E. stellulata*) and Blakely's Red Gum (*E. blakelyi*). There are also a range of co-dominant species including, Yellow Box (*Eucalyptus melliodora*) and Apple Box (*E. bridgesiana*). (Pryor, 1968).

Dry Sclerophyll forest: In sclerophyll forests, the trees are generally positioned closer together than in Savannah woodland Forests. The tree size in a dry sclerophyll forests is also comparatively smaller than those in a wet sclerophyll forest.

This community is often found on the more exposed, dryer aspects and on areas with low fertility or thin soils. A thin, scrubby understorey is a common characteristic comprising hardy, sparce species. The dominant tree species in these forests include, White Gum (*E. maculosa*), Scribbly Gum (*E. rossii*), Red Stringy Bark (*E. macrorrhyncha*) (Pryor, 1968), *E. dives* and *E. mannifera* (Gunn et al., 1969)

Native Tussock grassland: The most common tussock species in the Googong catchment is *Poa caespitosa*. This species is interspersed with native pastures and in some areas it has reclaimed land with improved pastures and has formed a 'patchwork' pattern.

Open Grasslands and Meadows: Often found in valley floors in frost hollows throughout the ACT and Googong catchment. As suggested by Pryor, (1968), the influence of grazing and pasture improvement to native grasses in the last 100 years, has changed the native grassland species composition, which is now dominated by tussock grasses.

In the Googong region these species include *Poa caespitosa,* Wallaby Grass (*Danthonia*) and Spear Grass (*Stipa*). In area where grazing has not been as intensive, there still remains large patches of Kangaroo Grasses (*Themeda australis*) (Gunn et al., 1969).

Mixed Pasture: Combination of both native pasture species such as Kangaroo Grass, Plume grass species (*Dicheiachne*), Spear Grass, Wallaby grass and introduced species.

References

Boland, D. J. et al. (1984). *Forest Trees of Australia*, Australian Government Publishing Service CSIRO, Canberra.

Gunn, R, H. et al. (1969). *Lands of the Queanbeyan – Shoalhaven Area, ACT and NSW*, Land Research Series, No. 24, Commonwealth Scientific and Industrial Organization.

Hall, N. et al. (1970). *Forest Trees of Australia*, Australian Government Publishing Service, Canberra.

Pryor, L. D. (1968). Trees in Canberra, The Department of the Interior, Canberra.

Arthur, A. J (ed.) (1957). Handbook on Forestry in the Australian Capital Territory, Prepared for the seventh British Commonwealth Forestry Conference, Australia and New Zealand, Commonwealth Government Printer, Canberra.

Meta data 5: Radiation and temperature

Method: Select classes to reflect radiation in summer vs winter.

Goog_aspect

Category	Element	Comment
Dataset	Title/path	Goog_aspect
	Custodian	ECOWISE Environmental
	Jurisdiction	ACT
Description	Abstract	Slope of the Googong Catchment, with 10 slope classes: Class: aspect 1: Flat 2: North 3: North east 4: East 5: South east 6: South 7: South west 8: West 9: North west
	Type	ArcView shapefile
	Search Word(s)	aspect
	Geographic Extent Name(s)	Googong Catchment
	Geographic Extent Projection	AMG, UTM Zone 55
Data Currency	Beginning Date	Not documented
	Ending Date	Not documented
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	No updates required
Access	Stored Data Format	Grid, Arc coverage and shapefile and tiff format
	Available Format Type	Grid, Arc coverage and shapefile and tiff format
	Access Constraint	Permission from ECOWISE Environmental
Data Quality	Lineage	Created from Googong DEM using ArcView spatial analyst
	Positional Accuracy	Not Documented
	Attribute Accuracy	Not Documented
	Logical Consistency	Aligned to AUSLIG rivers and catchment data
	Completeness	Complete

Contact Information	Contact Organisation	ECOWISE Environmental
	Mail Address	16 Lithgow St (PO Box 1834) Fyshwick
	Suburb	Fyshwick
	State	ACT
	Country	Australia
	Postcode	2609
	Telephone	(O2) 62707675
	Facsimile	(02) 62707624
Metadata Data	Metadata Date	5/12/2000
Additional Metadata	Additional Metadata	

Meta data 6: Soil moisture

<u>Waterlogging</u>

Category	Element	Comment
Dataset	Title/path	waterlogging
	Custodian	ERIC
	Jurisdiction	ACT
Description	Abstract	Areas with saturated soils, Waterlogging
	Type	ArcView shapefile, polygon
	Search Word(s)	Saturated soils, waterlogging
	Geographic Extent Name(s)	Googong Catchment
	Geographic Extent Projection	System: AMG Zone:55 Projection: Transverse Mercator Datum: AGD 66 Ellipsoid: IUGG 1976
Data Currency	Beginning Date	Image from Dec 1998
	Ending Date	Current
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	Currently no updates, may be updated in the future
Access	Stored Data Format	BIL Raster image MapInfo Table ArcView Shapefile
	Available Format Type	BIL Raster image MapInfo Table ArcView Shapefile

	Access Constraint	
Data Quality	Lineage	Processed SPOT panchromatic data (10 meter pixel size), combined with Landsat TM imagery (30 m pixel size). Areas around creeks, associated with high density Poa tussock.Converted to shapefile Referenced to ECOWISE Data
	Positional Accuracy	Within 5km to within 60m, or better, after specialised processing.
	Attribute Accuracy	Not applicable
	Logical Consistency	Extents are confined to one satellite run, therefore there is likely to be good consistency
	Completeness	Complete
Contact Information	Contact Organisation	Environmental Research and Information Consortium (ERIC)
	Mail Address	PO Box 179, Deakin, West ACT,
	Suburb	Deakin
	State	ACT
	Country	Australia
	Postcode	2600
	Telephone	(02) 62605161
	Facsimile	(02) 62605162
Metadata Data	Metadata Date	16/8/2000
Additional Metadata	Additional Metadata	

Meta data 7a: Topographic wetness and proximity to watercourse

Goog_flowpaths is not accurate enough, rivers_25k is too accurate. Buffer goog flow paths at 100m. Select all features from rivers_25k with their centre in this buffer. This gives accurate layer of the perrenial creeks.

Category	Element	Comment
Dataset	Title/path	Goog_flowpaths
	Custodian	ERIC
	Jurisdiction	ACT
Description	Abstract	Flow paths, creeks, rivers
	Type	Shapefile (line)
	Search Word(s)	Flow paths, creeks, rivers
	Geographic Extent Name(s)	Googong Catchment
	Geographic Extent Projection	AMG Zone 55, AGD 66
Data Currency	Beginning Date	Dec 1989
	Ending Date	Current
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	Updates not required
Access	Stored Data Format	ArcInfo coverage; tic, and arc
	Available Format Type	- ArcInfo - Arc shapefile - MapInfo
	Access Constraint	As per ECOWISE Environmental license agreements for Yarrowlumla and Cooma Monaro shires. Further access would require license agreements and fees.
Data Quality	Lineage	Not documented
	Positional Accuracy	- flowpaths renamed SPOT panchromatic data (10 meter pixel size), combined with Landsat TM imagery (30 m pixel size) Filtered Referenced to ECOWISE Data
	Attribute Accuracy	Within 5km to within 60m, or better, after specialised processing.
	Logical Consistency	Not applicable
	Completeness	Extents are confined to one satellite run, therefore there is likely to be good consistency
Contact Information	Contact Organisation	Complete
	Mail Address	PO Box 179, Deakin, West ACT,

	Suburb	Deakin
	State	ACT
	Country	Australia
	Postcode	2600
	Telephone	(02) 62605161
	Facsimile	(02) 62605162
Metadata Data	Metadata Date	16/8/2000
Additional Metadata	Additional Metadata	

Meta data 7b: Topographic wetness and proximity to watercourse

Category	Element	Comment
Dataset	Title/path	river_25k
	Custodian	NSWLIC
	Jurisdiction	NSW
Description	Abstract	Rivers, flow paths
	Type	Shapefile (line)
	Search Word(s)	Flow paths, rivers, streams
	Geographic Extent Name(s)	Yarrowlumla and Cooma Monaro shire councils
	Geographic Extent Polygon(s)	AMG Zone 55, AGD 66
Data Currency	Beginning Date	1987
	Ending Date	1999
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	Irregular
Access	Stored Data Format	Arc shapefile
	Available Format Type	- Vector Coverage - ARC/INFO - MapInfo
	Access Constraint	As per NSWLIC license agreements for Yarrowlumla and Cooma Monaro shires and ECOWISE Environmental. Further access would require license agreements and fees.
Data Quality	Lineage	Joined layers from local district data. Includes data from Bungendore, Snowball, Tinderry, Whinstone, Williamsdale, Michelago, Canberra, Captains Flat, Hoskinstown, Jerangle, Kain, Krawarree and Tuggeranong.

		Compiled by private sub-contractors for NSWLIC. Data sourced from digital cadastral data base. 1:1000, 1:2000 and 1:4000 scale maps in urban areas and 1:25,000, 1:50,000 and 1:100,000 scale in rural areas
	Positional Accuracy	Accuracy dependent on original mapping procedures. Currently this is not documented.
	Attribute Accuracy	Accuracy dependent on original mapping procedures. Currently this is not documented.
	Logical Consistency	Not documented
	Completeness	Complete
Contact Information	Contact Organisation	New South Wales Land Information Centre (NSWLIC)
	Mail Address	Land Information Centre PO Box 143 Bathurst NSW
	Suburb	Bathurst
	State	NSW
	Country	Australia
	Postcode	2795
	Telephone	02 6332 8200
	Facsimile	02 6331 8095
Metadata Data	Metadata Date	29/6/2000
Additional Metadata	Additional Metadata	NSWLIC

Meta data 8a: Soil permeability

Method: Soil landscape layers of the Michelago (michsoila) and Canberra (cansoila) 1:100,000 sheets were merged. Slivers were rectified and the layer was dissolved (ie one feature class per landscape). Clipped to the Googong Catchment and named Goog_soil. Using the soil classes described below it was decided which would be included and which excluded. (Moderate to High permeability = low risk, Moderate to low permeability = high risk). These were selected in the same manner as for vegetation classes.

Soil landscape	Risk	Permeability	Page *	Page+	Notes
Celeys Creek	Low	High	89	56	Coarse sandy loam.
Round Hill	Low	High	63	122	Loamy sand.
Big Badja	Low	Moderate - High	80	-	Sandy loam.
Anembo	Low	Moderate – High	24	140	Coarse sandy loam (however some subsoils have low permeability).
Campbell	Low	Moderate – high	39	52	Sandy loam.
Foxlow	Low	Moderate – high	47	65	Gravelly loam.
Tharwa	Low	Moderate –High	128	128	Sandy Loam.
Burra	High	Moderate	139	44	Sandy loam.
Bennison	High	Moderate	76	32	Loam.
Bollara	High	Moderate	85	35	Loam.
Brothers (c)	High	Moderate	171	-	Clay loam. A variant of br found at higher altitude and moister climate
Bywong	High	Moderate	-	48	Loam.
Captains Flat	High	Moderate	163	146	Clay loam at top of slope, sandy loam at the bottom.
Lyons Creek	High	Moderate	29	-	Loam.
Maneroo (a)	High	Moderate	182	-	Clay loam. Shallow, moderately well drained Chocolate soils. Above 1000 m.
Macanally Mountain (a)	High	Moderate	105	99	Loam. Variant a is slightly deeper and receives higher rainfall.
Nundora (a)	High	Moderate	147	164	Loam. Variant a is extensively pasture, less surface rock and gentler slopes.
Tallaganda	High	Moderate	67	-	Loam.
Tinderry	High	Moderate	71	-	Sandy loam, high in organics. Also high decomposing organic matter on surface
Williamsdale	High	Moderate	154	132	Loam
Bendembeer	High	Moderate – low	159	-	Sandy loam at top of slope, clay loam at the bottom.

* Jenkins, B. R. 1993. Soil Landscapes of the Michelago 1:100 000 Sheet Map. Department of Conservation and Land Management, Sydney.

+ Jenkins, B. R. 2000. Soil Landscapes of the Canberra 1:100 000 Sheet Report. Department of Land and Water Conservation, Sydney.

Meta data 8b: Soil permeability

Category	Element	Comment
Dataset	Title/path	michsoila
	Custodian	DLWC
	Jurisdiction	NSW
Description	Abstract	Soils regions based on 1:100000 mapping
	Type	Shapefile (polygon)
	Search Word(s)	Soils, Michelago Soils
	Geographic Extent Name(s)	Michelago region
	Geographic Extent Projection	AMG Zone 55, AGD 66
Data Currency	Beginning Date	1999
	Ending Date	Current
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	Not documented
Access	Stored Data Format	ArcINFO; tic, polygon, label and arc
	Available Format Type	- ArcInfo - Arc shapefile - MapInfo
	Access Constraint	As per DLWC license agreements for Yarrowlumla and Cooma Monaro shires and ECOWISE Environmental. Further access would require license agreements and fees.
Data Quality	Lineage	- michsoil_poly renamed Created from 1:100000 map sheets, converted to coverage from h8726a.shp projected from h8726a coverage
	Positional Accuracy	Not documented
	Attribute Accuracy	Not documented
	Logical Consistency	Not Documented
	Completeness	Complete
Contact Information	Contact Organisation	Department of land and water conservation (DLWC)
	Mail Address	P.O. Box 3720 Parramatta NSW

	Suburb	Parramatta
	State	NSW
	Country	Australia
	Postcode	2124
	Telephone	(+61) 2 9895 6211
	Facsimile	(+61) 2 9895 7086
Metadata Data	Metadata Date	17/8/2000
Additional Metadata	Additional Metadata	

Meta data 8c: Soil permeability

Category	Element	Comment
Dataset	Title/path	cansoila
	Custodian	DLWC
	Jurisdiction	NSW
Description	Abstract	Soils regions based on 1:100000 mapping
	Type	Shapefile (polygon)
	Search Word(s)	Soils, Canberra Soils
	Geographic Extent Name(s)	Canberra region
	Geographic Extent Projection	AMG Zone 55, AGD 66
Data Currency	Beginning Date	1999
	Ending Date	Current
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	Not documented
Access	Stored Data Format	ArcINFO; tic, polygon, label and arc
	Available Format Type	- ArcInfo - Arc shapefile - MapInfo
	Access Constraint	As per DLWC license agreements for Yarrowlumla and Cooma Monaro shires and ECOWISE Environmental. Further access would require license agreements and fees.
Data Quality	Lineage	- cansoil_poly renamed Created from 1:100000 map sheets, converted to coverage from h8727a.shp projected from h8727a

		coverage
	Positional Accuracy	Not documented
	Attribute Accuracy	Not documented
	Logical Consistency	Not Documented
	Completeness	Complete
Contact Information	Contact Organisation	Department of land and water conservation (DLWC)
	Mail Address	P.O. Box 3720 Parramatta NSW
	Suburb	Parramatta
	State	NSW
	Country	Australia
	Postcode	2124
	Telephone	(+61) 2 9895 6211
	Facsimile	(+61) 2 9895 7086
Metadata Data	Metadata Date	17/8/2000
Additional Metadata	Additional Metadata	

Meta data 9: Slope gradient

After Mawdsley et al. (1996b) greater than 10% slope was assumed as high transport potential.

Category	Element	Comment
Dataset	Title/path	Goog_slope
	Custodian	ECOWISE Environmental
	Jurisdiction	ACT
Description	Abstract	Slope of the Googong Catchment, with 10 slope classes: Class: slope 1: 0 – 5 2: 5 - 10 3: 10 – 15 4: 15 – 20 5: 20 – 25 6: 25 – 30 7: 30 – 35 8: 35 – 40 9: 40 – 45 10: 45 - 50

	Type	ArcView shapefile
	Search Word(s)	Slope, hillslope
	Geographic Extent Name(s)	Googong Catchment
	Geographic Extent Projection	AMG, UTM Zone 55
Data Currency	Beginning Date	Not documented
	Ending Date	Not documented
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	No updates required
Access	Stored Data Format	Grid, Arc coverage and shapefile and tiff format
	Available Format Type	Grid, Arc coverage and shapefile and tiff format
	Access Constraint	Permission from ECOWISE Environmental
Data Quality	Lineage	Created from Googong DEM using ArcView spatial analyst
	Positional Accuracy	Not Documented
	Attribute Accuracy	Not Documented
	Logical Consistency	Aligned to AUSLIG rivers and catchment data
	Completeness	Complete
Contact Information	Contact Organisation	ECOWISE Environmental
	Mail Address	16 Lithgow St (PO Box 1834) Fyshwick
	Suburb	Fyshwick
	State	ACT
	Country	Australia
	Postcode	2609
	Telephone	(O2) 62707675
	Facsimile	(02) 62707624
Metadata Data	Metadata Date	5/12/2000
Additional Metadata	Additional Metadata	

Meta data 10: Digital Elevation Model

Category	Element	Comment
Dataset	Title/path	googdem
	Custodian	NSWLIC, NSW Surveyor Generals Department
	Jurisdiction	NSW
Description	Abstract	Didgital elevation model
	Type	TIFF Image file
	Search Word(s)	Elevation, DEM Digital elevation
	Geographic Extent Name(s)	Googong catchment
	Geographic Extent Projection	AMG Zone 55, AGD 66
Data Currency	Beginning Date	Not documented
	Ending Date	Not documented
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	No updates required
Access	Stored Data Format	Image only
	Available Format Type	Image only
	Access Constraint	As per NSWLIC license agreements for Yarrowlumla and Cooma Monaro shires and ECOWISE Environmental. Further access would require license agreements and fees.
Data Quality	Lineage	Created from clipped and joined aralgrid and cangrid. In this data aralgrid and cangrid overlap. Where they are overlapping, values from aralgrid take precedence over cangrid values.
	Positional Accuracy	Not Documented
	Attribute Accuracy	Not Documented
	Logical Consistency	Aligned to AUSLIG rivers and catchment data
	Completeness	Complete
Contact Information	Contact Organisation	New South Wales Land Information Centre (NSWLIC)
	Mail Address	Land Information Centre PO Box 143

		Bathurst NSW
	Suburb	Bathurst
	State	NSW
	Country	Australia
	Postcode	2795
	Telephone	02 6332 8200
	Facsimile	02 6331 8095
Metadata Data	Metadata Date	29/6/2000
Additional Metadata	Additional Metadata	Digital products and services, Surveyor-Generals Department.

Meta data 11: Roads

Category	Element	Comment
Dataset	Title/path	roads_25k
	Custodian	NSWLIC
	Jurisdiction	NSW
Description	Abstract	Roads
	Type	Shapefile (line)
	Search Word(s)	Roads
	Geographic Extent Name(s)	Yarrowlumla and Cooma Monaro shire councils
	Geographic Extent Polygon(s)	AMG Zone 55, AGD 66
Data Currency	Beginning Date	1987
	Ending Date	1999
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	Irregular
Access	Stored Data Format	Arc shapefile
	Available Format Type	- Vector Coverage - ARC/INFO - MapInfo
	Access Constraint	As per NSWLIC license agreements for Yarrowlumla and Cooma Monaro shires and ECOWISE Environmental. Further access would require license agreements and fees.
Data Quality	Lineage	Joined layers from local district data. Includes data from Bungendore, Snowball, Tinderry, Whinstone,

		Williamsdale, Michelago, Canberra, Captains Flat, Hoskinstown, Jerangle, Kain, Krawarree and Tuggeranong. Compiled by private sub-contractors for NSWLIC. Data sourced from digital cadastral data base. 1:1000, 1:2000 and 1:4000 scale maps in urban areas and 1:25,000, 1:50,000 and 1:100,000 scale in rural areas
	Positional Accuracy	Accuracy dependent on original mapping procedures. Currently this is not documented.
	Attribute Accuracy	Accuracy dependent on original mapping procedures. Currently this is not documented.
	Logical Consistency	Not documented
	Completeness	Complete
Contact Information	Contact Organisation	New South Wales Land Information Centre (NSWLIC)
	Mail Address	Land Information Centre PO Box 143 Bathurst NSW
	Suburb	Bathurst
	State	NSW
	Country	Australia
	Postcode	2795
	Telephone	02 6332 8200
	Facsimile	02 6331 8095
Metadata Data	Metadata Date	29/6/2000
Additional Metadata	Additional Metadata	NSWLIC

Meta data 12: Dams

Dams appear to be in the order of 100 m southwest of where they should be. Moved manually using Editor menu bar.

Method: Creating Catchment Boundaries

To create catchments (upstream from points) to calculate catchment area, define catchment boundaries etc. from Grid:

1. From the original input grid create a flow direction grid with the fill command then flow direction to specify the direction of flow

- Grid tools\analysis\new\step manager\new
- Identifyer = fill
- Output grid = fill
- Tool categories = hydrologic analysis
- Tools = fill
- Input surface grid = original input grid
- Optional output flow direction grid = flowdir (creates the flow direction grid)
- ok

OR specify no optional output flow direction grid, and instead run the flow direction tool (Described below)

- Grid tools\analysis\step manager
- Identifyer = flow direction
- Output grid = flowdir
- Tool categories = hydrologic analysis
- Tools = flow direction
- Input surface grid = fill
- ok

3. From the flow direction grid create a flow accumulation grid

- Still in step manager
- Identifyer = flow accumulation
- Output grid = flowac
- Tool categories = hydrologic analysis
- Tools = flow accumulation
- Flow direction grid = flowdir
- Ok

3. From the flow accumulation grid create a stream network grid (For the Canberra region, try a cell accumulation of about 500 grid squares)

- Still in step manager
- Identifyer = stream_net
- Output grid = streamnet
- Tool categories = hydrologic analysis
- Tools = stream network
- Flow accumulation grid = flowac
- Minimum cell value = (about 500 in this area)
- Ok

Based on this grid, place the point locations on the stream network (above the river confluence if the site is directly at the confluence). Convert the shapefile (riverpts) to a coverage (riverpts) and then coverage to point grid (pourpts) coverpoint command in arc. In this process specify that the cell size is 25.

4. Run the Define watershed tool to delineate the watershed area.

- Still in step manager
- Identifyer = watershed
- Output grid = watershed
- Tool categories = hydrologic analysis
- Tools = Define Watersheds
- Flow direction grid = flowdir
- Pour point grid = pourpts
- Ok

Category	Element	Comment
Dataset	Title/path	Goog_dams
	Custodian	ERIC
	Jurisdiction	ACT
Description	Abstract	Farm Dams
	Type	Shapefile (polygon)
	Search Word(s)	Farm Dams, dams
	Geographic Extent Name(s)	Googong Catchment
	Geographic Extent Projection	AMG Zone 55, AGD 66

Data Currency	Beginning Date	Dec 1989
	Ending Date	Current
Dataset Status	Progress	Complete
	Maintenance and Update Frequency	Updates will occur when new satellite imagery is available
Access	Stored Data Format	ArcInfo coverage; tic, polygon, label and arc
	Available Format Type	- ArcInfo - Arc shapefile - MapInfo
	Access Constraint	As per ECOWISE Environmental license agreements for Yarrowlumla and Cooma Monaro shires. Further access would require license agreements and fees.
Data Quality	Lineage	- splindam_exp renamed Dam layer created from combined Landsat TM and SPOT panchromatic satellite imagery
	Positional Accuracy	Within 5km to within 60m, or better, after specialised processing.
	Attribute Accuracy	Field checking has been carried out, but some shadows may have been recorded as dams. Also some small dams may not have registered in the imagery.
	Logical Consistency	Not documented
	Completeness	Complete
Contact Information	Contact Organisation	Environmental Research and Information Consortium (ERIC)
	Mail Address	PO Box 179, Deakin, West ACT,
	Suburb	Deakin
	State	ACT
	Country	Australia
	Postcode	2600
	Telephone	(02) 62605161
	Facsimile	(02) 62605162
Metadata Data	Metadata Date	16/8/2000
Additional Metadata	Additional Metadata	