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Potential capture of surface run-off for reliable water supplies in the 500-825 mm rainfall zone of south Western Australia

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Summary

Annual run-off likely to occur in 90 per cent of years was calculated for 3,651 farm-scale catchments within the 500-825 millimetre rainfall zone of the SWCC area. This was done using a novel GIS-based method of run-off calculation that incorporates average annual rainfall, vegetation cover, soil type and landforms. When compared with historical flow measurements from 13 catchments, this method was found to be accurate (or conservative) in 85% of all measured years, indicating its usefulness for predicting reliable annual flows, essential if the water is to be captured and used for more intensive agricultural industries.

The study determined that 1,151 catchments have potential to generate more than 75 ML annually, at 90% exceedence probability. The average area for these catchments was approximately 700 ha. Most of these catchments fall entirely within land tenured by the Department of Environment and Conservation (DEC). Of catchments identified that contain privately-tenured land, 152 have annual (90 percentile exceedence) flows of 75-100 ML, 203 could yield 100-200 ML, 58 have 200-400 ML, and three have more than 400 ML of flow.

This shows that there is good potential to develop large, reliable water supplies to support new agricultural development with the ‘cells’ of best potential including areas around Boddington, Boyup Brook, Bridgetown and East Manjimup. Generally, the potential reduces rapidly to the east within the study area so that below 550 mm rainfall no catchments are likely to generate more than 75 ML of reliable run-off. If large reliable water supplies are to be developed in these areas, linked multiple catchments, run-off improvement structures and over-sized water storages will be necessary.

Salinity, expanding blue gum plantations and competition for run-off from existing users, were identified as the major threats to development of water supplies in the study area. All except two of the 14 ground-truthed catchments would require salinity management to maintain water quality. Salinity is likely to be more readily managed where defined point-source seepage or minor individual streams are the major contributors of total salt load.

Soil types within the study area have been identified as largely suitable for a range of perennial horticulture or irrigated agriculture.

Because this study is strategic in scope, the next logical step is to demonstrate that large supplies can be established (and threats ameliorated) and used to sustain more profitable and environmentally acceptable intensive agricultural enterprises in the ‘new’ areas. This requires strong industry involvement, and would require research and development geared toward determining suitably scaled enterprises to make better use of the available water supplies.

Contents

Acknowledgments

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1. Introduction

1.1 Background

Reduction in wool prices since the early 1990s has resulted in increasing challenges for farmers in the woolbelt of Western Australia to operate profitable production enterprises. Though some farmers are still able to turn a healthy profit, there is enormous variation in net returns. Flock structures have changed and there has been an increase in cropping. Some farmers that have struggled to make money out of wool have turned to alternative land uses such as prime lamb production and agro-forestry. (Ian McFarland, pers comm.). The plantation forestry industry has provided economic benefits to landholders, but the social impact of reducing permanent population due to the proliferation of agro-forestry has caused concern in local communities.

There is a need for initiatives that aid diversification and development in this region to increase environmentally sustainable productivity, local employment opportunities and social capital. The development of irrigated agriculture (and other water requiring enterprises such as dryland dairying or aquaculture) in the 500–825 mm rainfall zone will create employment opportunities and help to maintain the social integrity of these rural communities, encourage external investment and offer an alternative, high value, productive land use.

A major limitation to the development of alternative agriculture (and other industries) in these areas is the availability of reliable fresh water supplies. As well as receiving lower rainfall than areas closer to the coast where most intensive agriculture is currently located, the Woolbelt has limited fresh water aquifers and the development of dryland salinity reduces the potential for harvesting surface run-off.

This study aims to identify areas where there are water resources and suitable land for intensive agricultural production in the medium rainfall zone of the South West Natural Resource Management (SW NRM) region. The focus is on catchments where there is the potential to harvest sufficient amounts of fresh run-off, on farms.

Table 1 indicates the volumes of water that a range of agricultural enterprises, potentially suitable for the region, are likely to require annually.

Four parts to the project are documented in this report:

- identifying soil-landscape mapping units within the study area, and assigning reliable run-off values to these soil-landscape mapping units
- delineating the boundaries of catchments of up to 2,500 ha in size and estimating run-off, which should be exceeded in 9 out of 10 years, from these catchments
- assessing the capacity of soils in the study area to support a variety of intensified land uses
- on-ground assessment of a number of catchments to verify assumptions and assess characteristics not covered by the modelling such as suitability for dam sites and salinity management potential.

Table 1: Indicative water requirements (volume and quality) for intensive agricultural industries in the study area

Intensive agricultural industry	Annual water requirements (ML)*[3]	Maximum salinity before production is reduced[4]
Dryland dairy (500 cows)	60-75	550 mS/m [1]
Feedlot beef (1000 head)	29–30	1550 mS/m [1]
Feedlot sheep (10,000 head)	40–50	1100-2200 mS/m (depending on lambs, weaners, breeders or adult sheep) [1]
Centre pivot irrigated pasture (40 ha)	240–340	80-550 mS/m (depending on species of pasture) [2]
Vineyard vines (20 ha)	44–75	100 mS/m [2]
Vineyard table grapes (2 ha)	12–17	100 mS/m [2]
Fruit orchard (10 ha)	57–75	90-250 mS/m (depending on species) [2]
Olives (10 ha)	41-50	250 mS/m [2]
Vegetables (10 ha)	130-160 (2-3 crops)	70–340 mS/m (depending on crop) [2]

* Water requirements depend on evapotranspiration demand and soil type, and do not include evaporation and other losses associated with storage.

1. Chemistry Centre, Western Australia (2004)
2. Lantzke and Calder (2004)
3. Lantzke and Dee (2004)
4. Westrup (2007)

While this is an initial scoping project, with the results based on broad-scale modelling and some ground-truthing, the results can be used to target investment in further research. The results will also be useful for guiding on-ground works that help realise the potential of these water supplies by managing the risks of salinity and other threats that may reduce the quantity or quality of this run-off. As such it is an important preliminary study to determine where further work is warranted.

Two separate studies associated with this report are: *Options for improving the quality of surface water through managing saline seepage* (Westrup, in prep); and *Determining environmental flow requirements* (Prasser-Jones 2006).

1.2 Study area

The area investigated lies between the 500 and 825 mm long-term average annual rainfall isohyets within the area covered by the South West Catchments Council (SWCC). The study area covers approximately 1,600,000 ha, and is bounded by longitude 116:00:00 and 117:10:10 degrees east and latitude 32:25:00 and 34:40:00 degrees south. Figure 1 shows the location of the study area relative to the local government authorities and major towns.

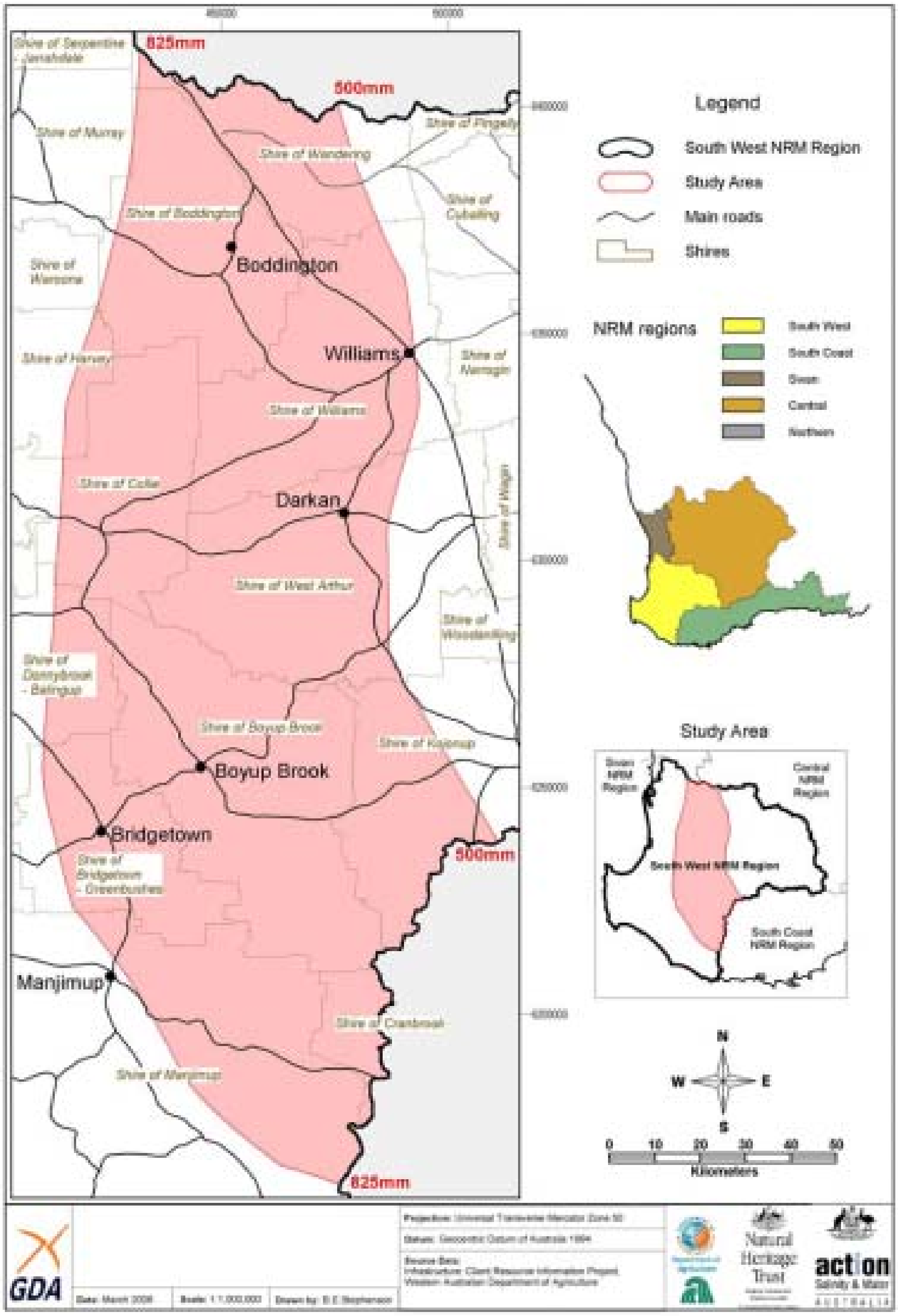

Figure 1: Location of the study area

Local government authorities include the shires of Wandering, Boddington, Williams, Harvey, Collie, West Arthur, Donnybrook-Balingup, Boyup Brook, Kojonup, Bridgetown-Greenbushes, Manjimup and Cranbrook.

The area encompasses from North Bannister in the north-west to Lake Muir in the south-east, west of the Albany Highway. It includes sections of the Warren, Donnelly, Blackwood, Preston, Harris, Murray, Hillman, Arthur, Beaufort, Williams, Hotham and Bannister River catchments. Large public water supply reservoirs include the Glen Mervyn and Harris dams on the western margins.

Uncleared native vegetation covers approximately 870,500 hectares, or 55% of the study area, with 601,600 ha (38%) under management of the Department of Environment and Conservation (DEC). The DEC estate falls predominantly in the western half. There are some additional small areas (less than 5%) under a variety of government tenures, with the remainder of the land privately owned.

The land use in cleared parts to the east is primarily broadscale sheep grazing and cropping. Cattle and sheep grazing, together with isolated areas of perennial and annual horticulture, occur on cleared land in western areas. Timber plantations, mainly Tasmanian blue gum (*Eucalyptus globulus*), occupy approximately 10% of private land and are located predominantly in the west where annual average rainfall exceeds 600 mm.

2. Methods

Catchment boundaries within the study area were identified using a GIS package to estimate how much reliable run-off is likely to be generated from those catchments annually and assess the capability of soils to support a range of intensified agricultural enterprises that might use the potential water supplies. Some of the modelled catchments were also surveyed in the field to ensure aspects of the GIS modelling reflected the catchment on the ground.

The four major steps documented in this report are:

- 2.1: Soil-landscape mapping units within the study area identified and assigned reliable run-off values.
- 2.2: Catchment delineation, and run-off modelling using the South-West Run-Off Estimator (SWROE, Westrup and Tille, *in prep*) to estimate 90% exceedence run-off (i.e. run-off volumes exceeded in 9 out 10 years on average). A digital elevation model was used to identify the boundaries of catchments up to 2,500 ha. Run-off from these catchments was modelled using the South-West Run-Off Estimator (SWROE, Tille and Westrup, *in prep*) to estimate 90% exceedence run-off (i.e. run-off volumes exceeded in 9 out 10 years on average). The yearly run-off estimates were based on soil types (soil-landscapes), vegetation extent and long-term average rainfall and used to identify catchments with potential to generate more than 75 ML annually. The estimates were verified against historical data collected from Department of Water gauging stations. This modelling was used to identify catchments with high potential for improved water harvesting and storage.
- 2.3: On-ground assessment of 14 catchments to validate some assumptions (extent of salinity, suitable dam sites, catchment boundaries, interference with downstream water supplies, potential to manage salinity for high quality run-off, and the risk that land use change may result in reduced run-off feeding the supply).
- 2.4: Soil-landscape capability assessment for potential intensified land use (annual and perennial horticulture, grazing (irrigated pasture) and viticulture) was conducted over the study area to ensure that the soils were capable of sustainably supporting intensified agriculture that might utilise new water supplies.

2.1 Attribution of run-off rates to soil-landscape units

Temporal variables such as the amount, duration and intensity of rainfall (with the spatial variability of that rainfall) have major impacts on run-off generation. Other climatic variables that affect evapotranspiration (such as humidity, solar radiation, temperature and wind velocity) also impact on run-off that can be generated by any given catchment, but to a lesser extent (Coles and Moore 1998). Catchment-specific factors (which remain relatively unchanged from year to year) that affect run-off include perennial vegetation cover, underlying geology and hydrogeology, topography, surficial geology and soils (Coles and Moore 1998). Of these, perennial vegetation cover has the largest effect, followed by landscape characteristics.

Coles and Moore (1998) published a series of tables estimating run-off (at varying probabilities of exceedence) on the basis of average annual rainfall, vegetation coverage and land type. Three land types were identified based on soil and geomorphological features:

- land type A produces the highest volumes of run-off;
- land type B produces moderate amounts of run-off; and

- land type C produces the lowest amounts of run-off.

Tille and Westrup used these tables to develop the South-West Run-Off Estimator model (SWROE *in prep*.). This can be used to generate estimates of the amount of run-off from a catchment that can expect to be exceeded in 9 out of 10 years (90% exceedence).

In the SWROE model long-term average annual 25 mm rainfall isohyets were used to represent climatic variability. Data from the National Land and Water Resources Audit (NLWRA) provided the extent of perennial vegetation cover for each of the catchments identified. The Department of Agriculture and Food's soil-landscape mapping provided the spatial description of soil and landform factors affecting run-off. These mapping units are made up of a number of unmapped land units that are assigned to the map unit on a proportional basis.

In the SWROE model each of the soil-landscape mapping units is assigned a weighted index for infiltration excess run-off and saturation excess run-off, based on a number of characteristics attributed to the land units in the Department's map unit database (Schoknecht *et al.* 2004). These characteristics include soil permeability, water repellence, surface condition, slope gradient and degree of waterlogging.

The values for saturation and infiltration excess are then added together, and based on this value the land unit is assigned to one of five land types. These are the three land types of Coles and Moore (1998) with two additional intermediate land types. In order of decreasing run-off these land types are A, AB, B, BC and C.

For any given average annual rainfall on a particular land unit, a vegetated and cleared 90% exceedence run-off in millimetres was then generated. This was multiplied by the percentage area which that land unit occupies within the soil-landscape map unit. The values for the individual land units can then be added to produce the average run-off value across the entire soil-landscape map unit.

Given the extent of dryland salinity across the study area, it cannot be assumed that the calculated run-off will necessarily be of suitable quality for intensive agriculture. Many streams will have saline flows, and valleys that are currently saline or likely to be affected by rising saline watertables will be unsuitable sites to capture and store fresh run-off.

In the Department's Map Unit Database there is assessment of the existing and potential future salinity of each soil-landscape unit. Run-off from these units was excluded from the calculations to provide a separate estimate of fresh run-off generated in the catchment.

An example of two of the soil-landscape mapping units, 253Bo_1s (Boscabel sand) and 253Bo_4 (Boscabel valley) is in Table 2. The valley floor unit produces more run-off from cleared land (2.8-61.9 mm) than sandy soil (0.6–41.7 mm). However, much of the Boscabel valley floor unit has a high risk of salinity while Boscabel sand is considered to have low risk. This results in the fresh run-off (0.1–6.4 mm) from the Boscabel valley floor unit being much less than from the Boscabel sandy unit (0.6–41.7 mm). If the area is vegetated, no run-off is expected at 550 mm annual rainfall or less. For all soil-landscapes, expected run-off is much less from uncleared than cleared areas.

Within the 500-825 mm rainfall zone, the total variation in values assigned to all soil-landscape units was 0 to 78 mm. For any given location, rainfall can account for up to 68 mm of this variation (87% or most impact), vegetation to 50 mm (64% or second greatest impact) and soil-landscape type to 38 mm (48% or third most important). If a greater range in rainfall values (i.e. higher rainfall) was used, the weighting of rainfall would be greater (Tille and Westrup, *in prep*.).

Table 2: Example of soil-landscape map unit run-off values (for 90% exceedence) assigned to SWROE model (Tille and Westrup, *in prep.*)

		Annual rainfall (mm)						
Unit type	**Map unit symbol**	**500**	**550**	**600**	**650**	**700**	**750**	**800**
Cleared	253Bo_1s	0.6	2.8	5.9	13.1	21.9	31.1	41.7
Non-saline cleared	253Bo_1s	0.6	2.8	5.9	13.1	21.9	31.1	41.7
Vegetated	253Bo_1s	0.0	0.0	0.3	1.3	2.5	4.1	5.7
Cleared	253Bo_4	2.8	9.2	17.2	26.8	38.8	50.1	61.9
Non-saline cleared	253Bo_4	0.1	0.4	0.9	2.0	3.4	4.8	6.4
Vegetated	253Bo_4	0.0	0.0	2.3	4.5	7.3	10.4	13.9

Land management practices such as tillage, stubble retention, crop type, pasture cover and earthworks, as well as seasonal impacts on groundcover also impact on volumes of run-off generated from any given area (Coles and Moore 1998). Because these factors are highly variable and therefore difficult to model in the long-term, or at the scales required for catchment assessment, they were not considered in this study. They are, however, important and should be included in any detailed analysis undertaken at the site scale.

2.2 Catchment delineation and run-off modelling

The run-off values assigned to the soil-landscape units enable estimation of reliable run-off from any portion of land within the study area. Run-off from various portions of land contributing to a dam site was then totalled to identify how much water is likely to be available for harvest. This required catchment areas to be identified, and land to be identified as vegetated or cleared. The combination of these datasets then provided an estimate of reliable run-off available for harvest from various catchments in the study area.

The workflow diagram (Figure 2) illustrates the stages of the run-off modelling phase of this project. The existing datasets used for the analysis include:

- a Digital Elevation Model (DEM)
- spatial distribution of Department of Environment and Conservation (DEC) tenure
- NLWRA dataset indicating the distribution of vegetation (Shepherd *et al.* 2001)
- distribution of Department of Water (DOW) gauged catchments
- Map Unit Database (Schoknecht *et al.* 2004).

During the project a number of new datasets were constructed:

- sub-catchments to 2,500 hectares size (limited to allow for farm-scale development, and to maximise the chances of identifying catchments high in the landscape, clear of regional groundwater tables and associated salinity)
- soil map unit run-off values (differentiating between cleared and vegetated areas) assigned to units in the soil-landscape Map Unit Database
- total run-off for each of the sub-catchments in the dataset mentioned above.

The datasets were interrogated using Intergraph GeoMedia^{TM} Version 5.2 software to produce the maps and figures included in the results and discussion below. Detailed description of methodology used to construct these datasets is contained in the Appendix.

The sub-catchments able to produce 75 ML of run-off or more might be capable of supplying the volumes of water required to support some of the enterprises listed in Table 1. Enterprises such as centre pivot irrigation (a minimum of 240 ML for 40 ha) require significantly more water than others, e.g. a sheep feedlot (minimum of 5 ML/1000 head). For these reasons, catchments with estimated reliable run-off of 75–100 ML, 100–200 ML, 200-400 ML and >400 ML were identified and grouped separately.

Those catchments that are entirely within DEC land do not offer any development potential for private water supplies. For this reason, catchments were grouped on whether they contained any private land, or were entirely under DEC tenure.

Historical flow data was sourced from the DoW from 52 gauging stations that were located within the study area (Figure 3). A dataset delineating contributing areas to the relevant gauging stations was also sourced from DoW. Modelled run-off values were then calculated using the values assigned for the relevant soil-landscapes contained within the catchment areas (example in Table 2). Although each of gauging stations had several years of run-off data attributed to them, only data recorded as being actual measurements were used for the comparison (extrapolated, and estimated data was removed from the dataset), resulting in 13 catchments being used. Measured volumes were then compared to modelled volumes.

Modelled run-off rates were also compared against a broad scaled water allocation model, REG 6 (Muirden 1996). This model is used by the DoW for water allocation in south-west WA. From the SWROE modelling, four of the higher yielding catchments were selected (on the basis of geographical spread) and analysed using REG 6 to compare predictions of run-off from both models.

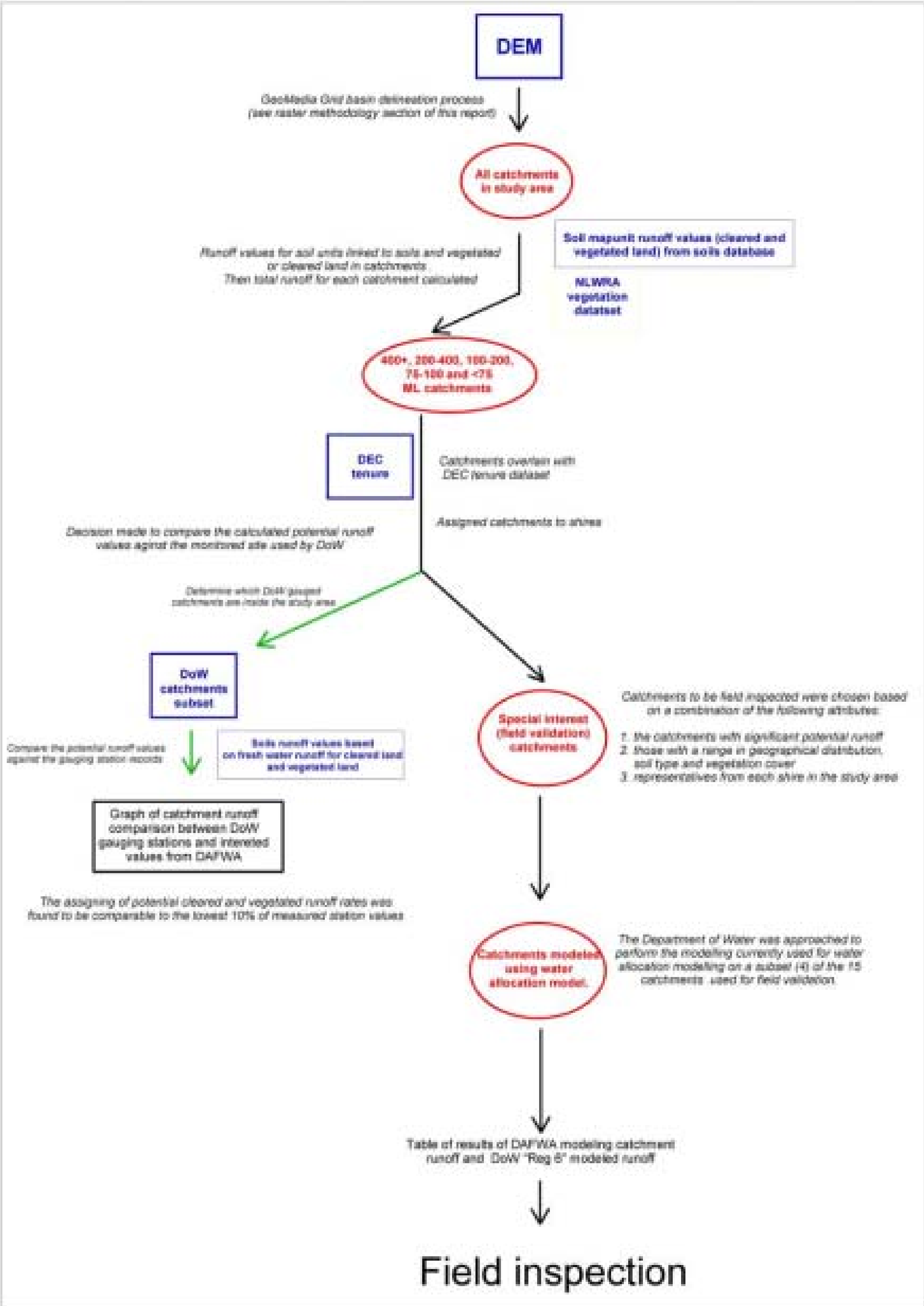

Figure 2: The project workflow

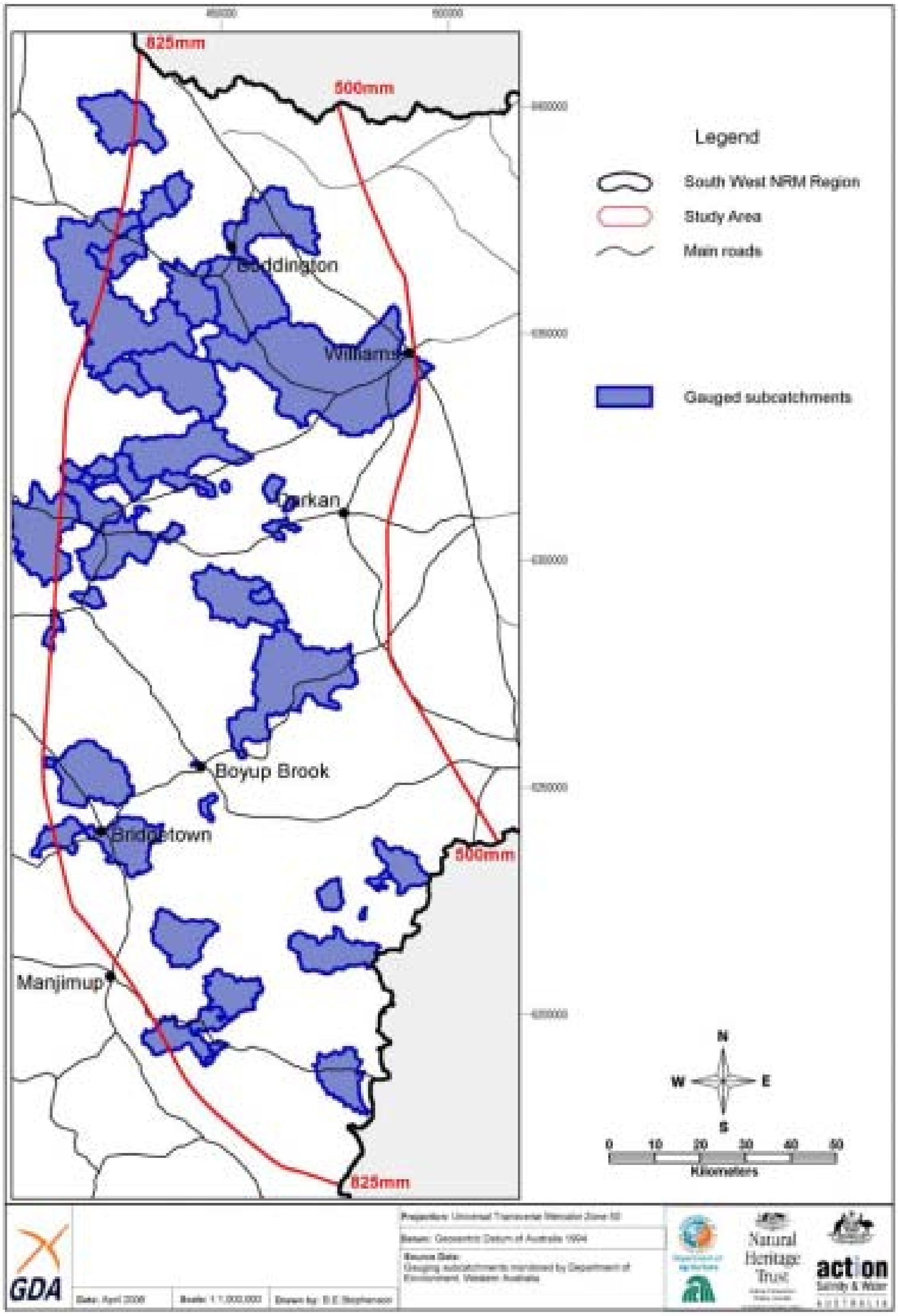

Figure 3: Location of DoW gauged catchments used to compare modelled and recorded stream flow

2.3 *Catchment survey*

Reliable run-off estimates for the catchments in the study area provided a means to compare catchments and identify those of interest. Field surveying of a number of these catchments was undertaken to provide information on accuracy of some of the model parameters, and the risks and opportunities for water to be harvested in these catchments. Fourteen catchments throughout the study area (with large modelled annual run-off volumes) were assessed to determine the accuracy of catchment boundaries, vegetation data sets and drainage lines used for run-off modelling.

Existing land use, potential dam sites, risks to water quantity and quality, and potential to manage salinity risk were rated in each catchment. Table 3 lists the catchment characteristics assessed and the methodology used to make the assessments.

Table 3: Field survey methodology

Catchment characteristic	Rating given	Comments	Datasets/survey method used
Boundary accuracy	1-5 1 = inaccurate 5 = accurate	25 m DEM was used to delineate catchment boundaries; some errors are expected, particularly in flat areas with poorly defined drainage.	Visual inspection of road/ catchment boundary intersections 2 m contours Sub-catchments dataset Automatic level
Salinity risk	1-5 1 = widespread 5 = no salt expression	The amount of salinity expression in the catchment will indicate the potential for salt to compromise water quality. Salt scalds, saline seepage and water salinity give the best indications.	Aerial photography Visual inspection Water samples collected and EC measurements
Salinity management potential	1-5 1 = no impact 5 = complete recovery	A subjective assessment of the potential to manage or recover salinity in the catchment.	Aerial photography Visual inspection Topographic assessment Water samples collected and EC measurements
Run-off risk rating	1-5 1 = high risk 5 = no risk of reduction	Commercial forestry greatly reduces run-off volume. Subdivision of property is an issue in some areas. Industries competing for water resources pose a risk.	Cadastre Visual inspection Aerial photography Current extent of agroforestry
Downstream risk rating	1-5 1 = high risk 5 = no risk	Development of water supplies may impact on downstream users. High risk was assigned where the catchment flow is already utilised by downstream parties, e.g. water supply catchments and irrigators.	Aerial photography Cadastre
Suitability for dam sites	1-5 1 = no suitable sites 5 = several potential sites	Some catchments are more suited to gully wall dams than others. Those with topographic relief, suitable gullies, deep loam or clay soil, were given a high rating. Those risking flooding roads, with low relief and shallow basement rock gained a low rating.	Visual inspection Aerial photography

2.4 Land capability assessment

Once catchments with good potential to harvest water were identified, it was important to assess whether the land resources in, or near those catchments could support a range of intensive industries that had the potential to utilise the water supplies.

Land capability assessment was conducted for annual horticulture, viticulture, perennial horticulture and grazing. The assessment used land qualities that had been previously assigned proportionally to the soil-landscape mapping units contained within the study area (Schoknecht *et al.* 2004). These land qualities were then compared to land ratings tables to produce a proportional capability rating for each map unit using the methodology described by van Gool *et al.* (2005).

Under the ratings assessment:

- Class 1 indicates that the soil-landscape mapping units have very high capacity for the associated land use, with very few physical limitations which are easily overcome, and there is negligible risk of land degradation.
- Class 2 indicates that the soil-landscape mapping units have a high capacity for the associated land use, with minor physical limitations affecting either productivity and/or causing risk of land degradation. These limitations can be overcome by careful planning.
- Class 3 indicates that the soil-landscape units have fair capacity for the associated land use, and moderate physical limitations significantly affecting productivity and/or causing risk of land degradation. Careful planning and conservation measures required.
- Class 4 indicates that the soil-landscape mapping units have a low capacity for the associated land use, with a high degree of physical limitations not easily overcome by standard development techniques and/or resulting in high risk of degradation. Extensive conservation measures are required.
- Class 5 indicates that the soil-landscape mapping units have a very low capacity and severe limitations for the associated land use. Use is usually prohibitive in terms of development costs or risk of degradation (Schoknecht *et al*. 2004).

Generally, classes 1 or 2 indicates that the land is suitable for the particular enterprise; class 3 may be suitable with some management intervention to control risks; and classes 4 or 5 require high level of management or are unsuitable.

3. Results

3.1 Catchment delineation and modelling

A total of 3,651 sub-catchments with area to 2,500 ha were delineated and are shown in Figure 4, with areas of uncleared land under DEC tenure.

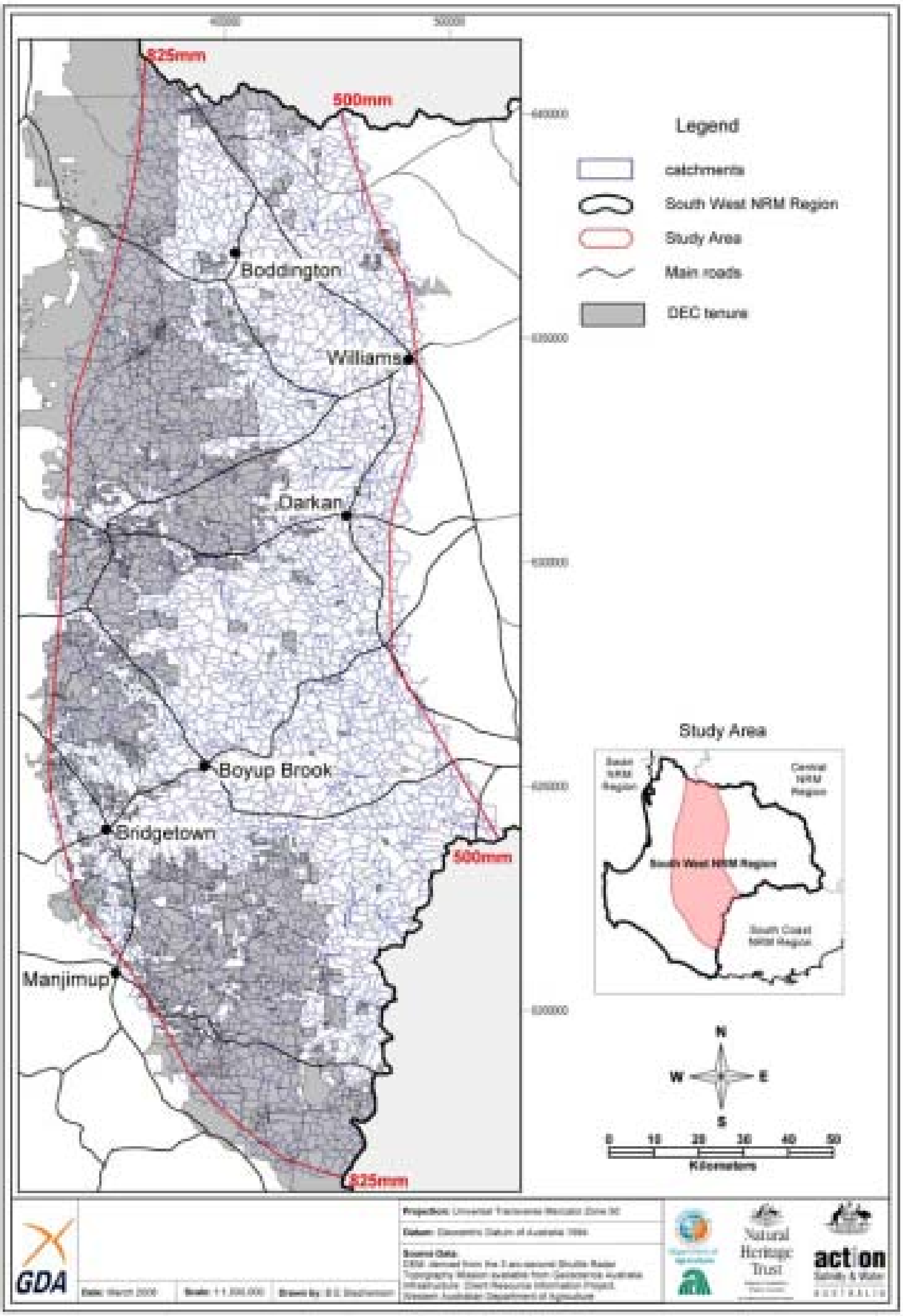

Figure 4: Catchments delineated using the DEM with additional analysis

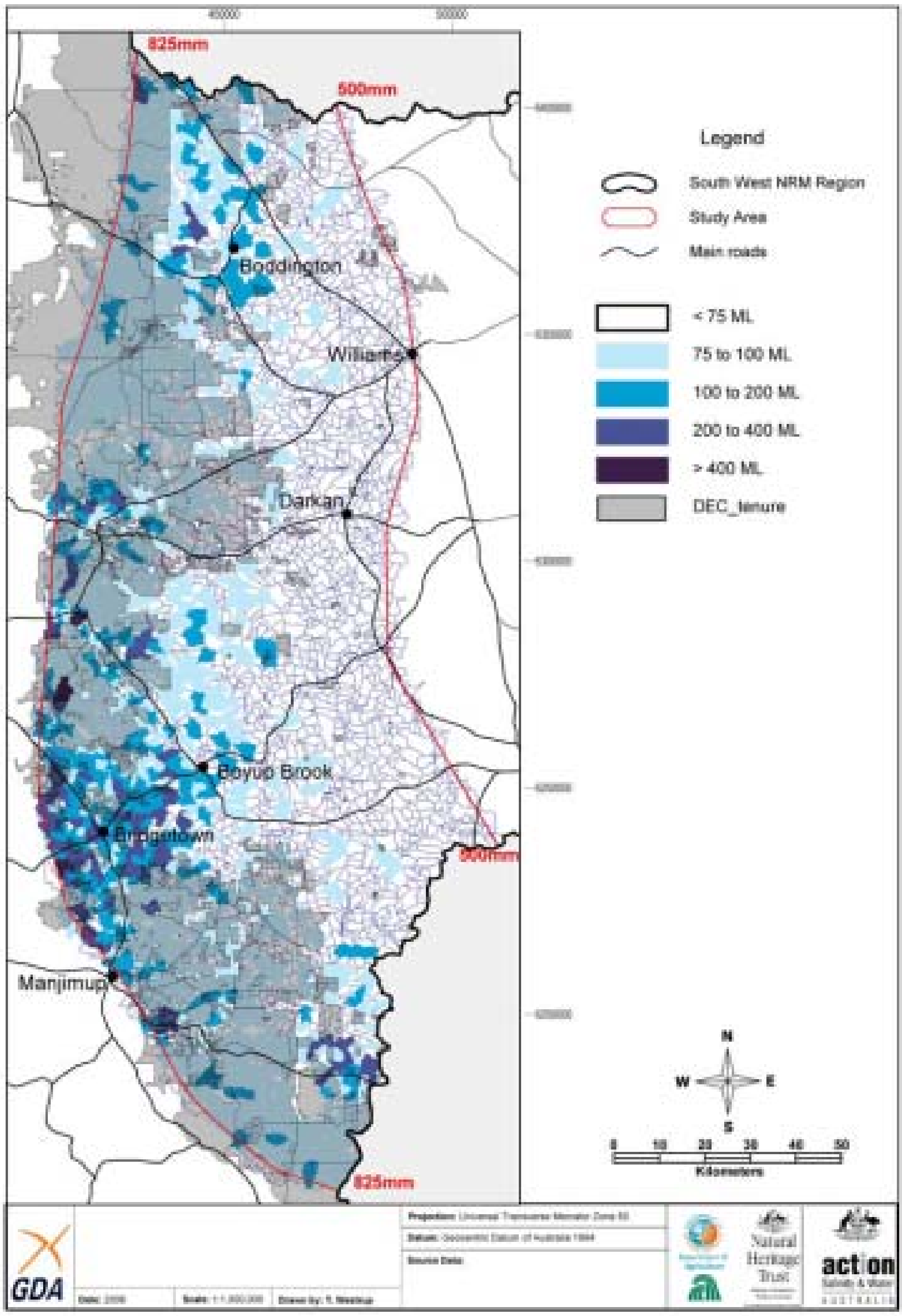

Figure 5: Catchments with potential to generate more than 75 ML of annual flow

There are 416 catchments containing some private land that have the potential to generate more than 75 ML of annual flow, as identified using the 90% exceedence run-off modelling. Table 4 indicates that 264 of these were identified as having a total run-off of 100 ML or more, 61 as having 200 ML or more, and three as generating at least 400 ML. These statistics take into account the reduced run-off from vegetated areas and include DEC tenured land. The run-off from soil-landscape units noted to be currently saline or at high risk of becoming saline was removed from this analysis.

Table 4: Catchment run-off estimates and tenure details

Calculated volume (ML)	Total catchments in study area	Number of catchments entirely DEC tenured	Catchments with some land not under DEC tenure
75-100	879	727	152
100-200	210	7	203
200–400	59	1	58
>400	3	0	3
TOTAL	**1,151**	**735**	**416**

In total (including catchments entirely under DEC tenure), 1,151 catchments have potential to generate more than 75 ML of annual flow, as identified using the 90% exceedence run-off modelling. Of these, 272 were identified as having a total run-off of 100 ML or more, 62 as having 200 ML or more, and three greater than 400 ML.

Generally, the higher yielding catchments are concentrated to the west of the study area, coinciding with higher average rainfall. The potential for large storage tapers from west to east, so that at the 550 mm rainfall isohyet, there are no 'farm scale' catchments that have the potential to generate more than 75 ML of surface flow annually.

The highest yielding catchments also tended to have the largest portions of cleared land. Seven hundred and twenty seven catchments entirely under DEC tenure had the potential to produce between 75 and 100 ML, with most of these being entirely vegetated. This meant that only 17% of the 75–100 ML catchments contained private land. Within the higher yielding catchments however, 96% of the 100–200 ML catchments, 98% of the 200–400 ML catchments, and all of the >400 ML catchments contained some private land, and this was partially or entirely cleared in most cases.

Table 5 shows the spread of catchments within each shire. Bridgetown-Greenbushes has the largest concentration of high yielding catchments (>200 ML), and also the most low yielding catchments. Boyup Brook also had a high number of low yielding catchments, but few high yielding ones. This is not surprising given the lower average annual rainfall experienced in this shire.

Table 5: Number of high volume catchments in each shire* within the study area

Shire	Potential numbers of high run-off volume catchments by shire (ML)			
	>400	**200-400**	**100-200**	**75-100**
Boddington	0	2	30	24
Boyup Brook	0	8	42	43
Bridgetown-Greenbushes	1	34	74	28
Collie	0	4	15	10
Cranbrook	0	6	3	9
Donnybrook-Balingup	2	4	20	11
Harvey	0	0	0	0
Kojonup	0	0	0	1
Manjimup	0	9	32	23
Wandering	0	0	8	4
West Arthur	0	1	4	7
Williams	0	0	1	9

* Catchments that cross shire boundaries are counted in each shire.

3.2 Validation of modelled run-off values against measured data

Measured run-off data from 13 catchments with multiple years of measurement are shown in Figure 6 (totalling 205 gauged years) together with the calculated 90% exceedence values. Points plotted in a horizontal line represent the flows measured in individual catchments over a number of years, and where the solid line crosses the horizontally plotted points represents the modelled 90% exceedence for that particular catchment. If 90% of the plotted points are to the right of the solid line, this would suggest that 90% exceedence was accurately modelled. Eleven catchments had more than 90% of the measured values higher than the predicted 90% exceedence value. Of the two other catchments, one had more than 80% of the measured annual run-off volumes above the predicted 90% exceedence volume and the other above 50%. This shows that the SWROE model tended to underestimate the actual run-off values for 85% of all available measurements, indicating that it is a conservative predictor of run-off.

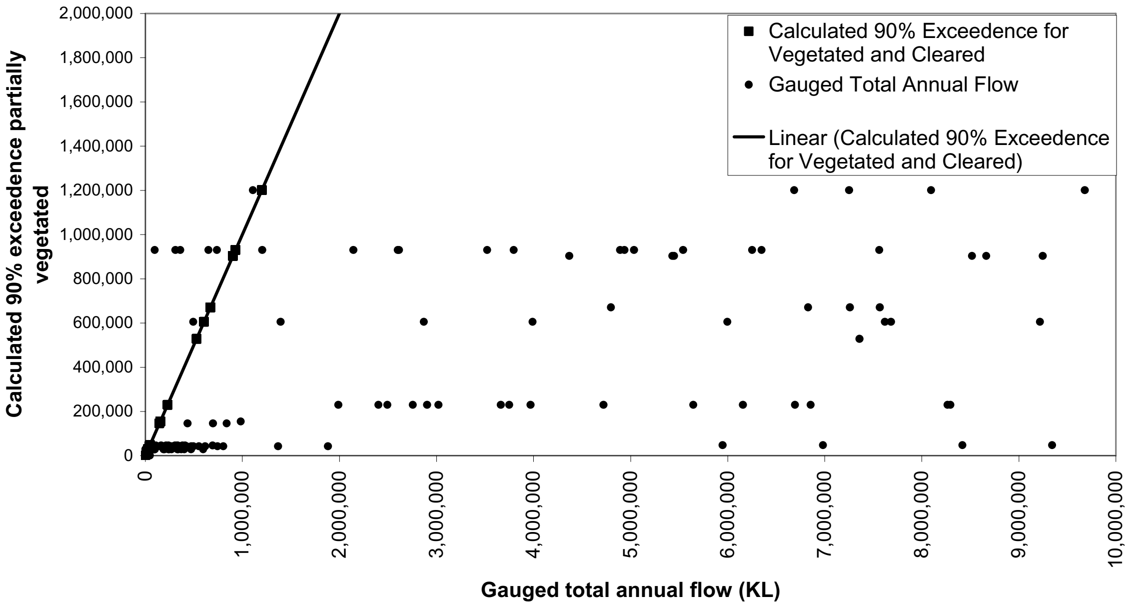

Figure 6: Calculated 90% exceedence run-off values (incorporating reduced values for uncleared areas) plotted against measured volumes

This validation used available records of complete measured annual flow volumes (i.e. only those results that were actually complete and measured were used). While this reduced the amount of available data, it ensured that estimated volumes were not used for modelled comparisons. While the number of gauges with some data within the study area was 65, only 13 could be used because of lack of continuity of data (a wide range in the number of years) and several had contributing catchments that extended well beyond the study area.

3.3 Comparison with REG 6 modelling

The four catchments selected for comparison to the REG 6 model were located just north-west of Boddington, near Moodiarrup, just west of Bridgetown, and near Lake Muir. Table 6 indicates that the difference between REG 6 and the SWROE model becomes greater to the north and east of the study area, with the REG 6 predictions being more conservative. Predictions of reliable run-off in the south and west (Lake Muir and Bridgetown) were similar for both models.

The results for Moodiarrup show the greatest difference. This catchment contained 425 ha (19% of total area) of blue gum plantations, which was not included in the NLWRA vegetation dataset, and therefore treated as cleared land by the SWROE model. However, the REG 6 model treated the blue gum plantation as vegetated. Additionally, the REG 6 result was based on a single rainfall value for this catchment (550 mm) while the SWROE model assigned rainfall based on the 550-575 mm and 575-600 mm bands. These factors could account for some difference between the models.

The coefficient of variance (CV) is used as an input to REG 6 to estimate variation in low and high flows (related to rainfall consistency). A run-off factor (RO) or 'catchment factor' is also used to estimate the impact of the catchment-specific factors of percentage vegetated, area and mean annual rainfall (Muirden 1996). The CV of 1.1 and RO of 1.2 were used for Moodiarrup (Henry Sieradzki, *pers. comm*.). Both these coefficients were greater for Moodiarrup than for Lake Muir (CV=0.75, RO=0.9). This resulted in REG 6 assigning proportionally greater variation in run-off for Moodiarrup, resulting in the Q10 value (or 90% exceedence) being proportionately lower than average annual flow at Lake Muir. This highlights the importance of accurately ascribing these factors in REG 6 and suggests that they may additionally account for some difference between the REG 6 and SWROE results for the Moodiarrup catchment.

There was also large difference in the Boddington catchment. The REG 6 result here was also based on a single rainfall value (700 mm) while the SWROE model assigned rainfall based on the 700-725 mm, 675-700 and 650-675 mm bands which covered the catchment. The catchment also contains 65 ha of blue gum plantation, accounting for only 3% of the area but 16% of the 'cleared' area. Like Moodiarrup, the impact of the blue gum plantation not being taken into account by the SWROE model could account for some of the difference. The CV and RO values used in REG 6 for Boddington were 1.0 and 0.9 respectively (Henry Sieradzki, *pers. comm.*), also indicating that some difference between the models can be attributed to these input factors used in the REG 6 analysis.

Table 6: 90% reliable run-off model comparison

Catchment	Modelled 90% exceedence (kL)	REG 6 Model Q10 (kL)
Boddington	223,000	60,000
Moodiarrup	110,000	20,000
Bridgetown	388,000	322,000
Lake Muir	201,000	183,000

3.4 Catchment survey

The locations of the 14 catchments selected for field assessment are shown in Figure 7, with the summary of results of the surveys included in Table 7. Only two catchments, McAlindon (catchment 5) and Lake Muir (10), had errors with boundary delineation. Both of these are very flat, and this error was likely to be from the DEM dataset.

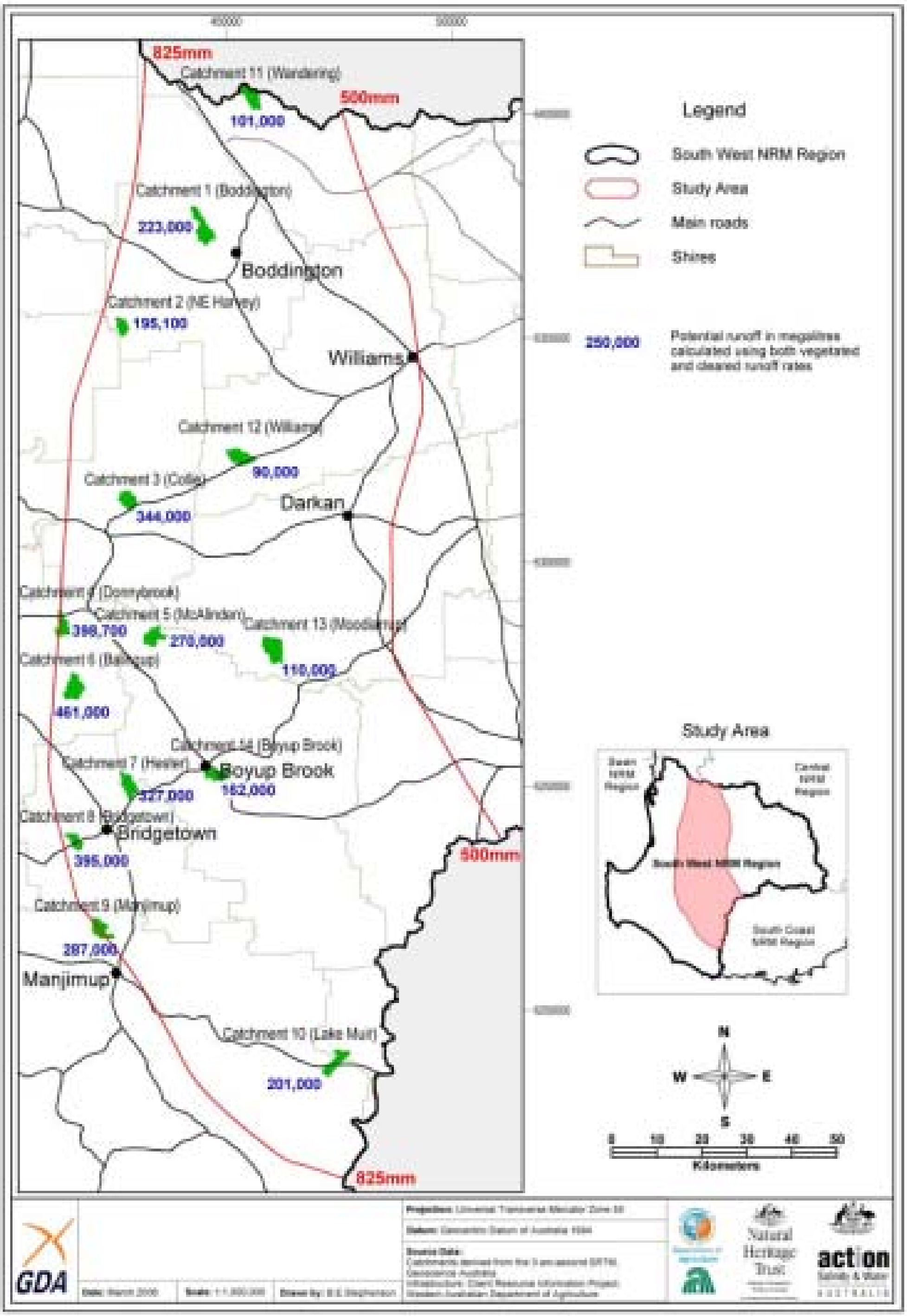

Figure 7: Catchments selected for ground-truth survey

Table 7: Field survey results

Catchment	Calculated 90% exceedence run-off (ML)	Individual catchment scores					
		Catchment boundary	Salinity risk	Salinity management potential	Run-off reduction risk	Downstream impact risk	Suitability for dam sites
1	223	5	1	2	4	3	2
2	195	5	5	5	1	4	4
3	344	5	4	4	2	1	3
4	398	5	4	5	2	3	4
5	260	3	2	3	4	5	2
6	461	5	4	3	1	5	3
7	327	5	2	4	1	5	4
8	395	5	4	5	3	5	3
9	286	5	2	5	3	4	4
10	201	2	4	5	4	5	2
11	101	4	2	3	4	5	3
12	193	NA	5	5	4	5	NA
13	110	5	1	2	3	5	2
14	162	5	1	2	3	5	2

Catchments 5 and 10 have low scores for boundary accuracy because they have extensive flat sections.

Catchments 2, 3, 4, 6, 7, 8, 9, 13 and 14 have low score for run-off reduction risk because of large areas of tree plantation.

Catchment 3 has a low score for downstream impact risk because it is in Wellington Dam catchment area.

Thirteen catchments had some salinity risk, either from current or potential salinity. Catchments 7 and 9 had high salt risks but also good potential to manage the salt because most salinity was contributed by ‘point sources’ in the form of individual saline streams or isolated saline seepage. Catchments 1, 11, 13 (see Figure 8) and 14 have similar or higher salinity risks, but in these cases the source appears to be diffuse (large areas of salt crusting on the surface, expression of salinity in vegetation across the valley), or the catchment shape would make it difficult to isolate or manage the salt because of low gradients, wide valleys or other geomorphological factors preventing isolation and diversion of water from the saline areas.

Figure 8: Salinity in broad valley floors (catchment 13) may prove difficult to manage, and broad valleys do not provide good gully wall dam sites

Catchment 12 is entirely forested, and vested in Water Authority tenure. There were no visible signs of salinity, and the catchment was judged to have a low risk of salinity. Because catchment 2 (North-east Harvey) is entirely vegetated (blue gum and native forest) and highly dissected, it was attributed a low salinity risk rating.

Catchments 3, 4, 6, 8, and 10 had either opportunities to site dams well clear of the salt or had slight expressions of salinity (<5% of catchment area), exhibiting features such as vegetation decline in streamlines or valleys attributed to salinity.

Generally, catchments in the north and east have higher salinity risk, with those in the east also having lowest opportunity for management intervention to reduce impact on surface water supplies.

Several catchments had high run-off reduction risks, including catchments 2 (North-east Harvey), 3 (Collie), 4 (East Donnybrook), 6 (East Balingup), 7 (Hester), 8 (Bridgetown), 9 (Manjimup), 13, (Moodiarrup) and 14 (Boyup Brook). This was because they had significant proportions planted to, or about to be planted to, blue gum or pine plantations. This is likely to severely reduce the run-off potential.

Catchment 3 scored poorly with downstream impact risk as it contributes to Wellington Dam. Catchment 4 also scored poorly as it contributes to the Preston River, which is used to recharge irrigation dams during winter.

Those judged to have sites well suited to dam construction included catchments 2, 3, 4, 6, 7 (Figure 9), 8, 9, 11 and 12. These catchments were incised and potential sites were likely to comprise heavy deep soils, free of rocks. Those catchments with broad valleys (catchments

1, 5, 10, 13 and 14), sandy soils (catchment 10) or rocky areas located near potential dam sites were judged as unsuitable for dam construction.

Figure 9: Incised valleys with loamy or heavy soils provide ideal sites for gully wall dams

3.5 Land capability

3.5.1 Capability assessment for annual horticulture

Figure 10 indicates that most of the study area has a fair capability rating indicating that annual horticulture may be a suitable land use in most areas. However, significant management interventions such as working across the slope, surface water management, and wind breaks will be required to prevent land degradation, and irrigation and fertiliser application will be required to ensure water and fertiliser requirements are met. There are few areas which are unsuitable for this land use (classes 4 and 5), largely because of steep slopes, shallow soil, and waterlogging or salinity constraints.

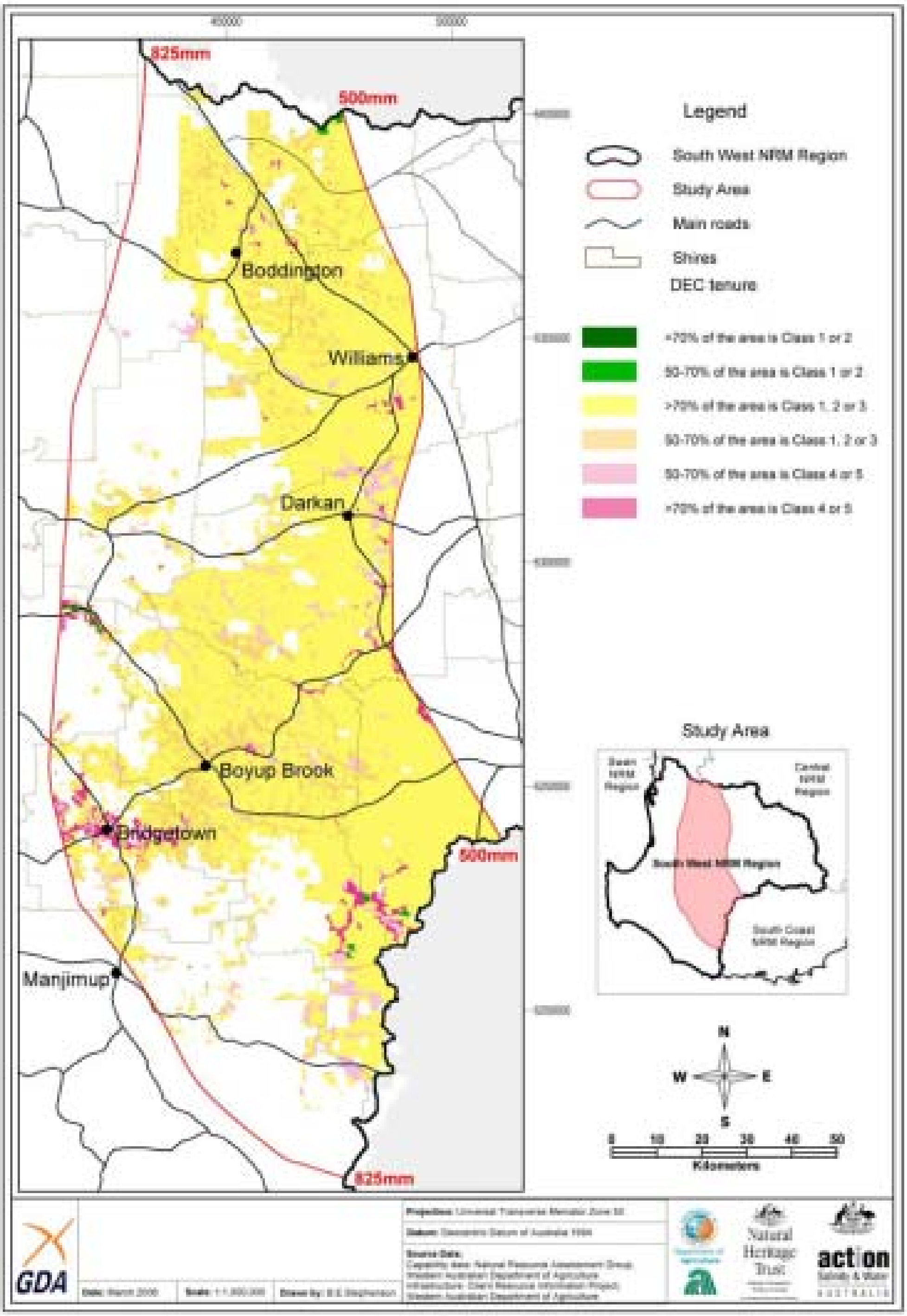

Figure 10: Land capability for annual horticulture

3.5.2 Capability assessment for viticulture

Figure 11 indicates that much of the area has high suitability for viticulture (classes 1 and 2). A large portion has good capability, and isolated areas are unlikely to be suitable because of steep slopes, shallow rock, salinity or waterlogging.

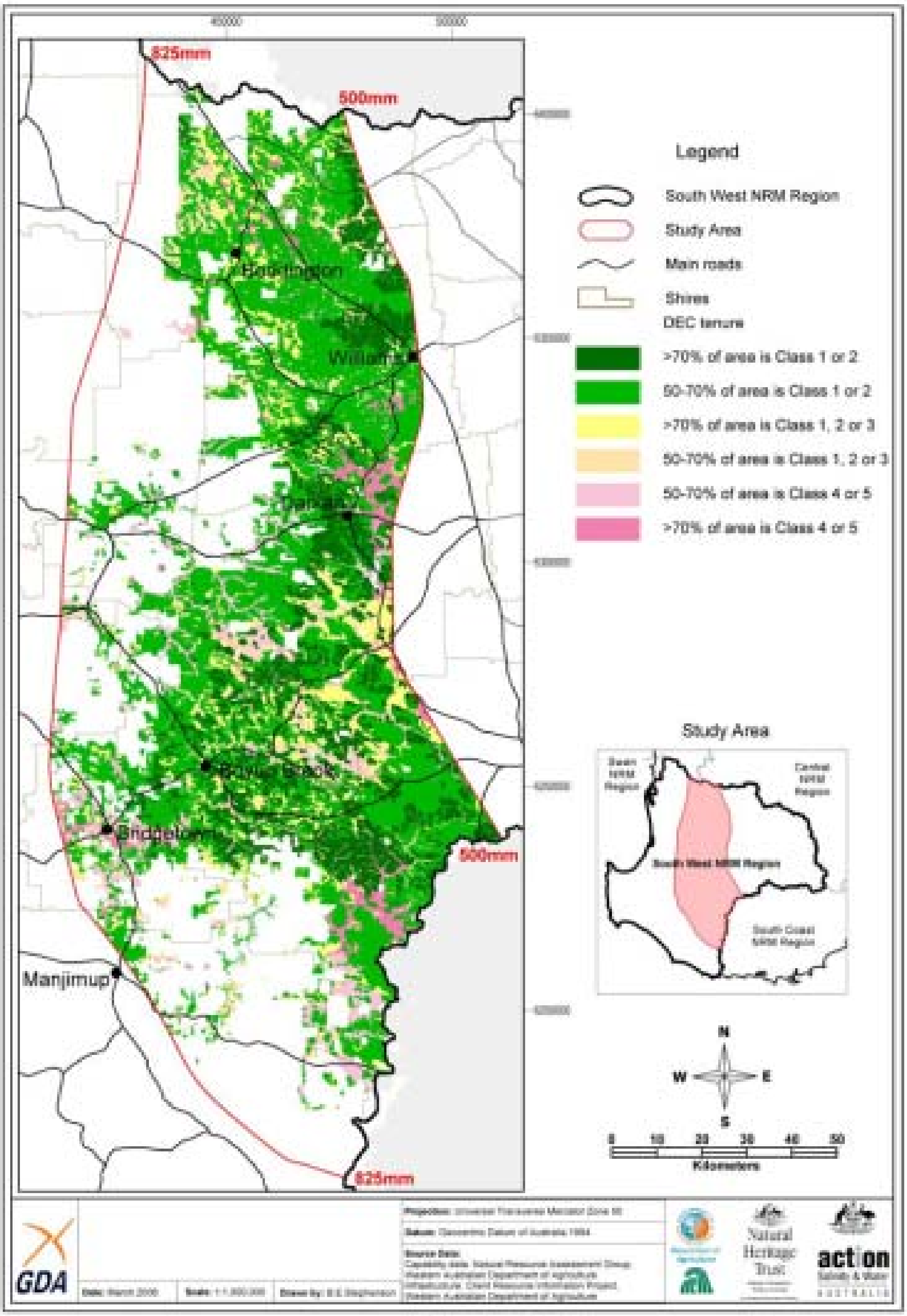

Figure 11: Land capability for viticulture

3.5.3 Capability assessment for perennial horticulture

Figure 12 indicates that most of the study area has good capacity to support perennial horticulture, and pockets of soils to the east of Darkan and Boyup Brook have very high capacity to support this land use. Some of the land classified as class 3 might otherwise be very productive land, but steep slopes result in a requirement to manage erosion. Constraints in unsuitable areas (classes 4 and 5) are mainly due to waterlogging and salinity, and areas where steep slopes result in severe erosion risk.

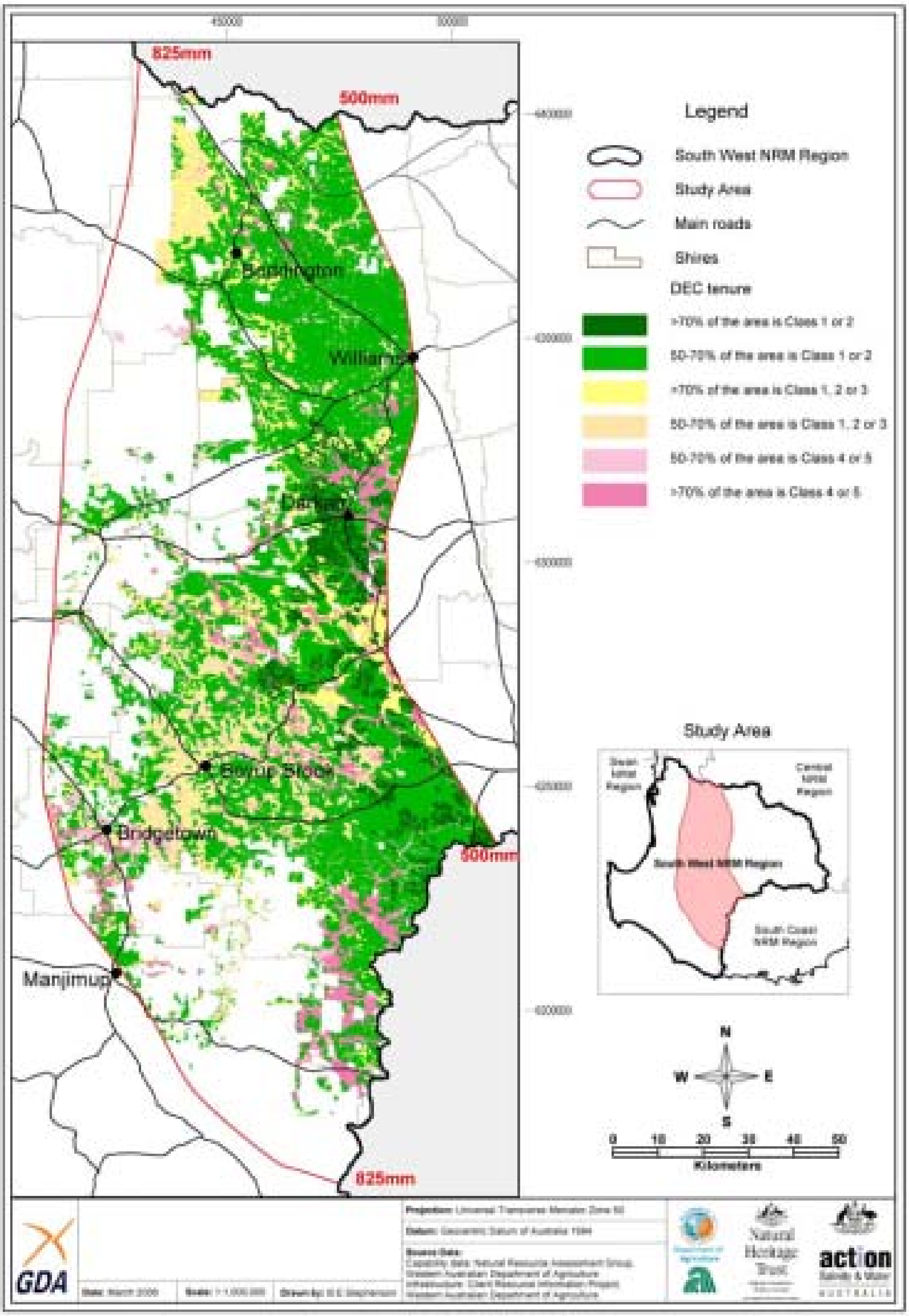

Figure 12: Land capability for perennial horticulture

3.5.4 Capability assessment for grazing

An assessment of land capability for grazing was included as a surrogate to indicate potential for irrigated pasture. Figure 13 shows that most of the area has high capacity to support grazing, with some having a fair capacity.

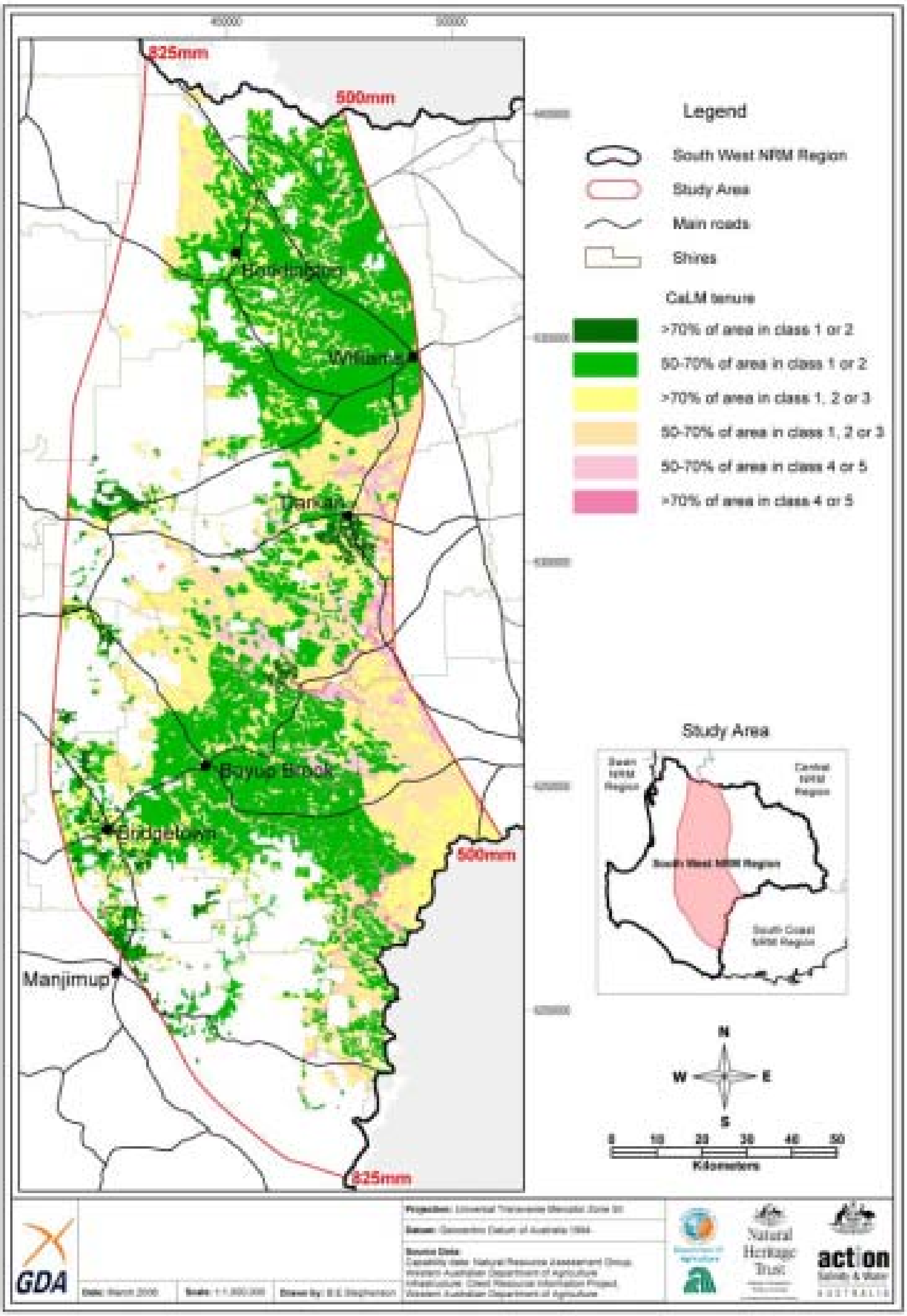

Figure 13: Land capability for grazing

While the figure indicates that some areas have low capacity it is important to note that many grazing enterprises cover a range of soils with different capabilities, and managers successfully stock land with lower capacity as part of a larger farming strategy.

For example, those areas with deep, gutless sandy soils are classed as having low capacity, and production is limited due to poor water and nutrient retention and high wind erosion risk, but they can be successfully managed within a grazing rotation system incorporating other soils. Similarly, waterlogged land may have very poor grazing capacity during the wetter months, but these areas may provide good feed later in the season as pastures in other areas senesce.

3.6 Summary of datasets created

New datasets created include:

- Sub-catchments to 2,500 hectares in size generated using a 25 m DEM
- Soil map unit run-off values (differentiating between cleared and vegetated portions) assigned to units in the Map Unit Database
- Total SWROE estimated run-off for 90% exceedence for each sub-catchment, including the total generated from vegetated and cleared sections of the catchment.

4. Discussion

4.1 Run-off modelling

During catchment run-off modelling, 1,151 catchments were identified (416 of which had some land in private ownership) with potential to generate at least 75 ML of run-off in 9 out of 10 years. Subsets of catchments that had the potential to generate at least 200 ML (62 catchments, 61 of them with some private land) and at least 400 ML (three catchments, all with private land) were also identified. Most were in the higher rainfall areas. The 75-100 ML catchments extend nearly as far east as Darkan and 30 km east of Boyup Brook.

As this study aimed to scope the potential of catchments for developing private water supplies, catchments entirely under DEC tenure were excluded from analysis. The field assessment indicated that some catchments such as North-east Harvey (catchment 2), and Williams (catchment 7) had other land tenure issues preventing them being suitable sites for developing private water supplies, as they were under Forest Products Commission and Water Corporation tenure respectively.

The position of the private land in catchments was not qualified and this land was not necessarily in the ideal position for water harvesting from that catchment. If the lower two thirds of a catchment is under DEC tenure, for example, the contributing area to a dam on private land would be limited to the top third of the catchment, and this would limit the water harvesting potential.

The SWROE model adds all the fresh run-off generated in the catchment. A catchment generating 100 ML of run-off does not necessarily produce enough run-off to fill a 100 ML dam because the run-off figures do not account for losses to evaporation, leakage, environmental flow requirements, effluent, water detained in dams upstream, and other surface water which for catchment specific purposes may not be harvestable. It is difficult to estimate these losses strategically, as they are catchment specific, however as a general rule of thumb, between 50 and 75% of the estimated run-off may be available for harvest.

The results presented in this paper are based on long-term annual average rainfall. They do not take into account the decrease in average annual rainfall that has been observed since the mid-1970s (Tille *et al*. 2001). Using post-1975 average annual rainfall isohyets is likely to reduce the estimates of potential volumes across all catchments. SWROE modelling using post-1975 rainfall data is ongoing.

When the modelled run-off was compared with historical measured annual flows, in nearly all cases it conservatively estimated likely flow. Inaccuracies in the model estimates may arise from limitations in the way that rainfall characteristics are applied to the run-off equation. Variability in temporal rainfall patterns, evaporation and intensity of rainfall are not accounted for and so the model may be improved by accounting for temporal variability in rainfall rather than utilizing annual averages. However, currently temporal factors are not utilized by any local model, as sufficient data is unlikely to be available for calibration.

The application of soil and landscape factors is where the SWROE modelling has great potential - especially for agricultural purposes at farm scales. Other currently available models calibrated for this area such as REG 6 apply climactic factors very well and consider broad landscape type as a weighting factor, but do not account for site specific soil conditions or landscape. The best comparisons between the two models were for high run-off generating catchments in the south, where the REG 6 landscape and rainfall variability weighting factor was smallest. There is considerable potential for combining models which would incorporate the climatic factor strengths of the REG 6 model with better site-specific soil-landscape effects. Investigations are being undertaken by the Department of Water and Department of Agriculture and Food to determine if the two models can be combined.

It is important to note that this modelling was done at a large scale, and it is recommended that site specific investigation and modelling be done prior to committing to works program with a large investment.

4.2 Soil-landscape capability assessment

Soil-landscape capability assessment can be used as broadscale planning tool, to highlight areas which may be generally highly suited to certain land uses.

Overall, viticulture was the land use with the highest portion of land classified as very high capability, and smallest area classified as very low capability. This is primarily due to the suitability of grapevines to well drained gravelly soils which have a wide distribution throughout the study area.

Annual horticulture was the land use with the smallest portion of land assessed as class 1. Most of the land had a class 3, with fair capacity for annual horticulture, but it is the erosion risk associated with steep slopes and requirement for regular cultivation that is the primary limitation for this land use in the area. Climatic extremes such as frost and other non-landscape related issues such as distance from market and economics are not covered by this assessment, but are also extremely important.

The capability assessment for grazing was primarily an assessment of the soil's capacity for maintaining pasture, and for resisting erosion resulting from stock traffic. Much of the study area has good capacity to support grazing, and forms part of the traditional "wool belt", that has an extensive grazing history. Areas that are saline, steep and areas with deep sands have a low capacity for grazing. For intensified (irrigated) grazing, land use capability is likely to be similar, though a separate assessment for the type of pasture or fodder crop being irrigated would be required. If the livestock production system was to be centred around feedlots and irrigated fodder crops, separate assessments for the type of fodder crop being irrigated and the lands suitability for feedlots is also recommended.

The capability assessment for perennial horticulture is selective toward deep, well structured soils on gentle slopes or flats that are not at risk of waterlogging or salinity. Much of the study area has a good capacity for this land use, with areas around Darkan and east of Boyup Brook having very high capacity for perennial horticulture. These areas have deep loamy or gravelly soils associated with gentle relief, which are well suited to this land use.

The soil-landscape capability assessment indicates that large areas within the study area are likely to be very well suited to supporting development of a variety of intensive agricultural industries. Aside from economic factors (such as distance to market) and climatic requirements (such as frost susceptibility and chilling requirements), the major limitation to the development of these industries is the availability of reliable, good quality water supplies.

4.3 Catchment survey

The likelihood of salinity having an impact on freshwater supplies generally increases with distance north and east in the study area. This is largely due to increased rainfall in the southwest of the study area having the ability to dilute, leach and flush the salt out of the landscape in history. In the north and east of the study area the impact of evaporation is more pronounced, and this combined with an increase in the proportion of catchments cleared results in the higher salinity risks. Most of the salt expression in the north and east is in the broader valley floors, while in the west and south it appears that hillside seepage makes a more significant contribution. There are examples such as catchment 14 (Boyup Brook), where the bottom two-thirds of the catchment are saline, but the top third may still generate enough water to fill a 50 ML dam.

The run-off reduction risk is higher in the higher rainfall western areas of the study area, mainly because run-off from blue gum and pine plantations is likely to be greatly reduced. Most of the catchments that scored poorly in this area already had large proportions of the catchment in plantation, or undergoing establishment. This is likely to be an ongoing risk in higher rainfall (>600 mm) areas targeted for broad scale forestry. Blue gum plantations may be seen as the main competing land use with water harvesting, as very few catchments generating 75 ML or greater were identified in the area that do not suit blue gum establishment. However there are catchments in the higher rainfall areas which will still produce significant run-off (up to 200 ML) despite the increase in vegetative cover from plantations (assuming a similar reduction in run-off to native vegetation). The potential and impact that the reduced run-off capacity will have on a catchment will need to be assessed on an individual catchment basis, however it is likely to be substantial.

Another run-off reduction risk is the likelihood of land subdivision for rural residential lots. While the resultant increase in the proportion of hard surfaces (e.g. roads and roofs) has the potential to increase run-off (Horner *et al.* 1994), it is more likely that owners will construct tanks and small dams to store water for their own use, effectively removing it from the catchment. This (and the plantation) risk will require increased consideration by shire planners in the future.

The dam site suitability was variable throughout the study area with many aspects impacting on the appropriateness of sites. The features that could be readily assessed included valley profile, likelihood of suitable soil (absence of rock) for dam wall construction, and potential to flood upstream of the dam without affecting established infrastructure such as roads, houses, sheds and pipelines. The most suitable valley profiles are in the highly dissected catchments in the west, and least suitable to the east, where valley floors are generally wider and flatter. Additionally, suitability generally decreased with distance down the catchment as the valley floors broadened and the likelihood and severity of salinity increased towards the east of the study area. The potential for impact on infrastructure was variable, probably because it is linked to local population density, as the higher the density the greater the likelihood of infrastructure.

Soil engineering properties for dam wall construction were not assessed as they are likely to vary considerably on a site by site basis. However these are an extremely important consideration, with extensive investigation and testing required at site scale prior to considering construction.

4.4 Sub-catchment delineation

Field assessment indicates that the sub-catchment boundaries delineated using the DEM method are accurate except in areas with poorly defined drainage and or low topographical relief. There does not seem to be a clear cut-off in terms of land slope, and most problems appear where the DEM appears to misinterpret the canopies of belts of trees as the land surface. Lake chains and upland plateau areas are most problematic using this approach. The errors are also likely to be the result of the coarseness of the 25 m DEM which was used for this process. A smoothing process was used to correct some of the errors (see Appendix 1), but the effectiveness of this was limited. The large variety in landscape morphology meant that the level of smoothing was appropriate for most of the area, however catchment boundaries were lost in areas with low relief. On-ground assessment to enable modification of DEM delineated boundaries using the current methodology is likely to be always required in areas of low gradient.

The segmentation and sub-basin delineation process used to define boundaries resulted in some inaccuracies, such as some areas defined as single catchments actually being part of larger catchments and receiving water from upstream catchments. This occurred near Donnybrook (catchment 4) and Collie (catchment 3) where field assessment showed that the identified catchments were actually part of much larger systems, namely the south branches of the Preston and Collie Rivers respectively. This is important in terms of design of capture and storage infrastructure and highlights the requirement for on-ground verification during planning for construction of large storages.

Overall, the sub-catchments dataset is accurate enough for strategic planning purposes, as no errors were found in the boundary delineation in 12 of the 14 catchments surveyed.

5. Conclusion

There is good potential to develop large, reliable water supplies in many catchments identified in this study. The ‘cells’ of best potential include areas around Boddington, Boyup Brook, Bridgetown and East Manjimup, with sites around Donnybrook and Collie also good. Generally, potential reduces rapidly to the east of the study area to almost no potential (for >75 ML reliable storage) in areas below 550 mm rainfall. If large reliable water supplies are to be developed in these areas, linked multiple catchments, run-off improvement structures and over-size water storages are likely to be necessary.

The results presented should only be used to prioritise catchments, and indicate total potential capturable run-off but do not take into account losses associated with evaporation and temporary storage. Licensing and environmental flow requirements mean that not all water is available for capture. However, in general terms within the study area, the licensable flow available for capture is approximately 40% of the 50 percentile annual flow, which generally equals the 90% exceedence flows used in this modelling.

Soil types have been identified as largely suitable for a range of perennial horticulture or irrigated agriculture. Land in the ‘cell’ near Bridgetown is steep (over 15% in some areas), which has resulted in some limitation to the potential for annual and perennial horticulture, and viticulture, even though this area has some of the greatest potential for developing water supplies.

Most land around Boyup Brook has good capacity to support grazing and viticulture, and fair capacity to support perennial and annual horticulture. The main limitation is the risk of water erosion on valley slopes, and small areas of waterlogging. Steep slopes are not as much of an issue around Darkan, and most of the land there has high capacity to support viticulture, annual and perennial horticulture; and grazing is good to fair, except north-east of Darkan, which has areas prone to waterlogging and salinity.

The area near Boddington is well suited to grazing (and therefore irrigated pasture), but also has good capacity for viticulture and perennial horticulture, as well as fair capacity for annual horticulture. Salinity and waterlogging in valley floors are the major limitations.

Salinity, expanding blue gum plantations and competition for run-off with existing users were identified as major threats to development of water supplies. These threats can be managed to various degrees depending on severity and individual circumstances. The threat of salinity can be more readily managed in those catchments where defined point-source seepage or minor individual streams is a major contributor of total salt load. Salinity will be difficult and expensive to manage in catchments with diffuse sources such as regional watertable rise or many hillside seeps. All except two of the ground-truthed test catchments required some salinity management, and even those that had no current risk may develop salinity in the water supply over time if basic management practices such as dam flushing are not done.

It is intended that SWROE will be re-run using post-1975 rainfall, to determine if catchment volumes still provide potential given the climatic shift observed since the mid-1970s.

The next logical step is to demonstrate that large supplies can be established (and threats ameliorated) and used to sustain more profitable and better environmentally managed, intensive agricultural enterprises in the ‘new’ areas. If successful, it will prove the potential for setting up large water supplies. Associated opportunities such as water trading across farms could be investigated. This step requires strong agricultural industry involvement, and would require research and development geared toward determining suitably scaled enterprises to make better use of the available water supplies.

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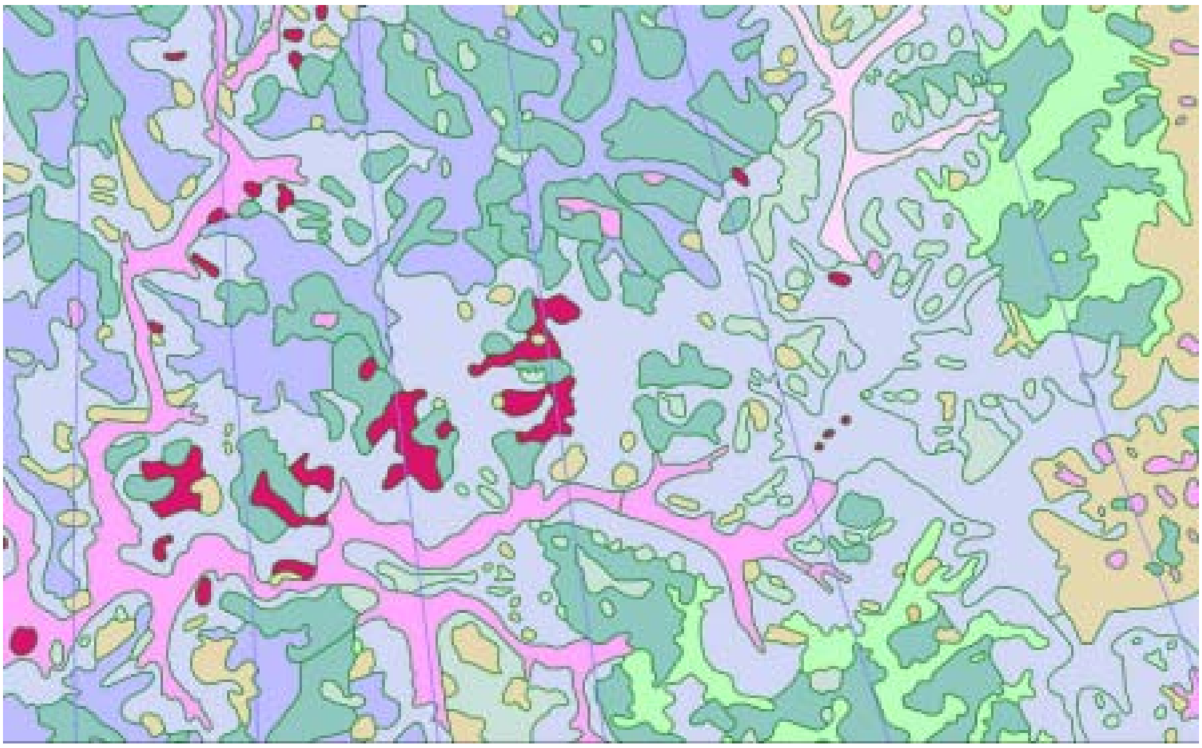
7. Appendix

7.1 Detailed spatial methods

A detailed description of the methods used during the spatial analysis and modelling phase of this project follows. Vector analysis was used to spatially represent 90% exceedence run-off values over the study area. Raster analysis was then used for catchment boundary delineation. Vector analysis was again used to identify catchments with greater than 75 ML.

Step 1 – intersecting the soil map units with the isohyets

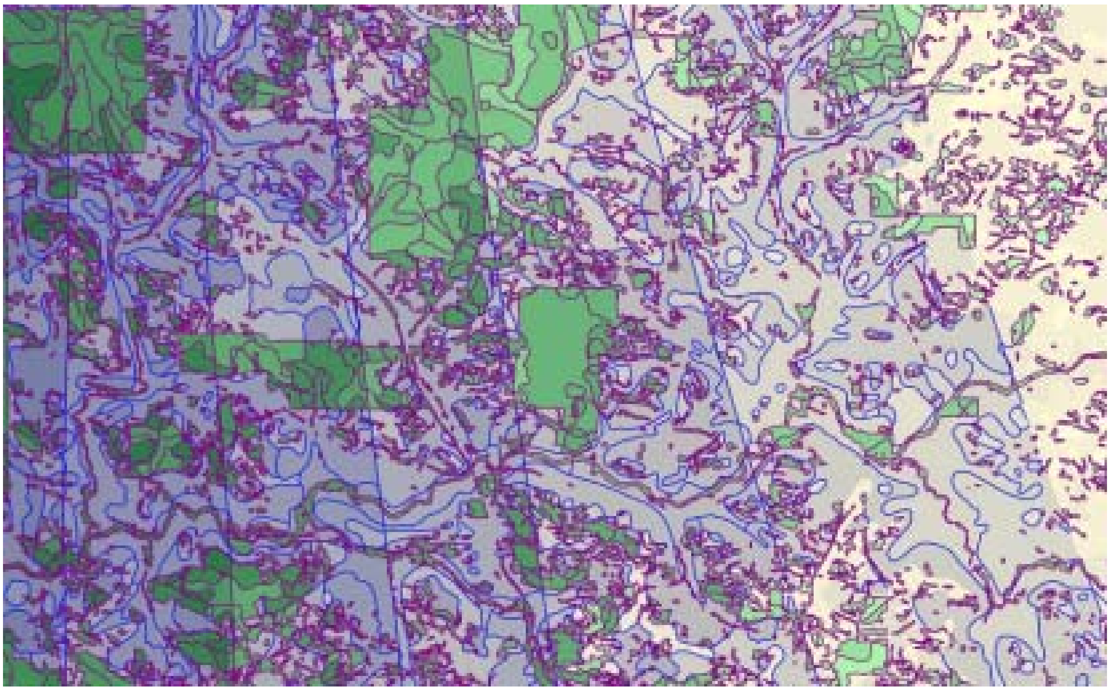
For each map unit there is a different run-off rate depending on the rainfall and vegetation status. To assign run-off rates to the map unit polygons two principal processes were necessary. The first step was to perform a spatial intersection between the map unit theme and the rainfall theme. This produced a theme that contained map-units cut into discrete polygons based on intersections with the rainfall bands.



Example of soil map units with the isohyets overlaid prior to cutting the map units polygons

Step 2 – assigning run-off rates to the cut map units

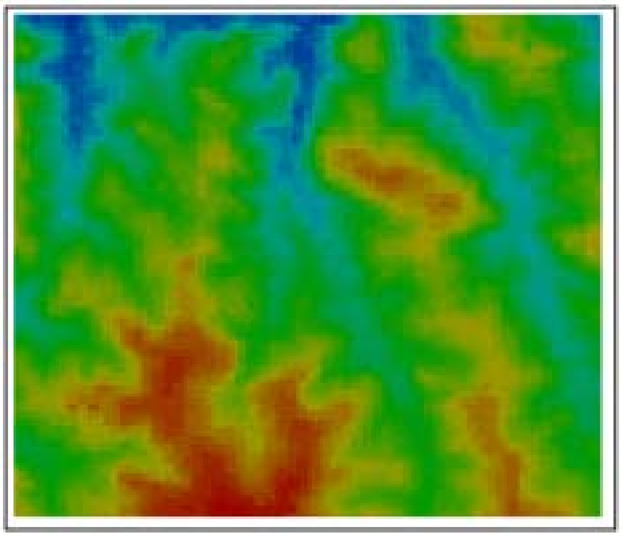
This required a correlation to be calculated between the product of step 1, differentiating between vegetated and cleared portions, and assigning run-off rates according to the run-off tables presented in Tille and Westrup (in prep).



Example of soil map units with run-off rates based on rainfall and vegetation status

Step 3 – DEM processing

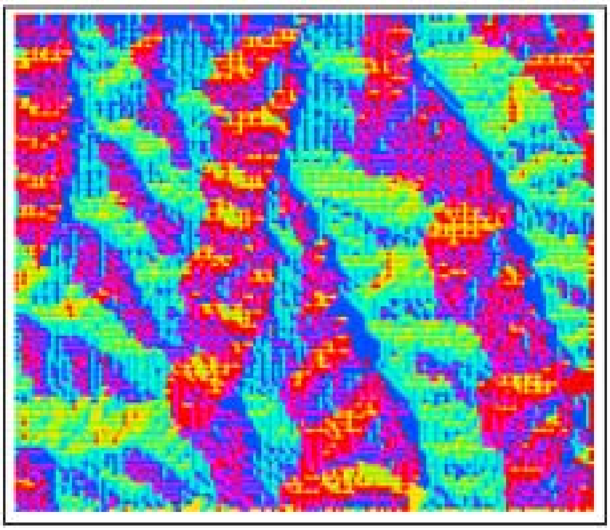
The surface of the Digital Elevation Model (DEM) required correction (or smoothing) for hydrological flow analysis. The *Fill Pits* process and the *Fill Depressions* process in GeoMedia™ Grid were used to correct anomalies. The *Fill Pits* process compares each cell value against the immediate surrounding cells and assigns the lowest surrounding cell value if the centre cell is less than the surrounding cells. The *Fill Depressions* process is used for dealing with depressions that are larger than a single cell, by comparing all the cells in a basin with the elevation value at the basin outlet. If the value is lower than the elevation value at the basin outlet it gets 'filled'.



Example of corrected DEM showing that landscape features such as ridges (red) and flow lines (blue) are clearly evident when ranges of elevation are assigned colours

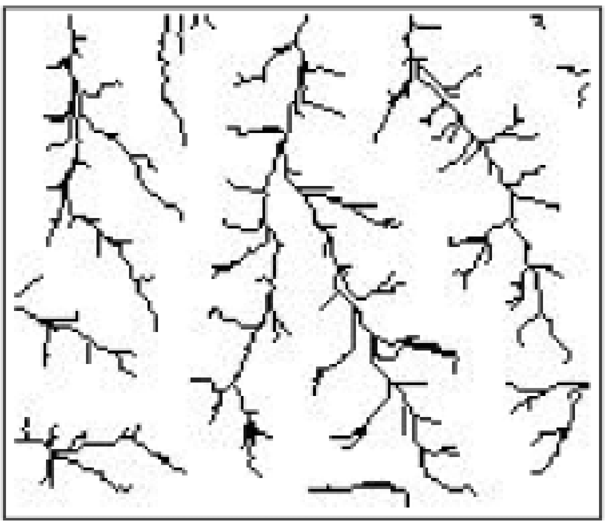
Step 4 – creating flow paths

To be able to delineate drainage lines, and subsequently, their surrounding drainage basins, a flow path grid was required to be created from the DEM. The *Downhill Path* process in Geomedia is used to create a grid of downhill flow directions from the corrected DEM, which was made in step three. The *Downhill Path* process assigns each cell with one of eight possible cardinal values, i.e. 1 = east, 2 = southeast, 4 = south, 8 = southwest, 16 = west, 32 = northwest, 64 = north, 128 = northeast.



Example of the flow path grid

To create drainage lines from the flow path grid it is necessary to perform the *Downhill Accumulation* process analysis. The *Downhill Accumulation* process sums the number of cells up hill from any particular cell to which run-off would drain. Because most cells have a value (except those with a value of 0 which represent stream outlets), the *Downhill Accumulation* grid needs to be recoded before the drainage lines become clear. The *Recode* process, if run with assigned values of VOID to any cells from 0 to 25, and I to any cells with values of 26 upwards, creates a drainage grid such as shown below.

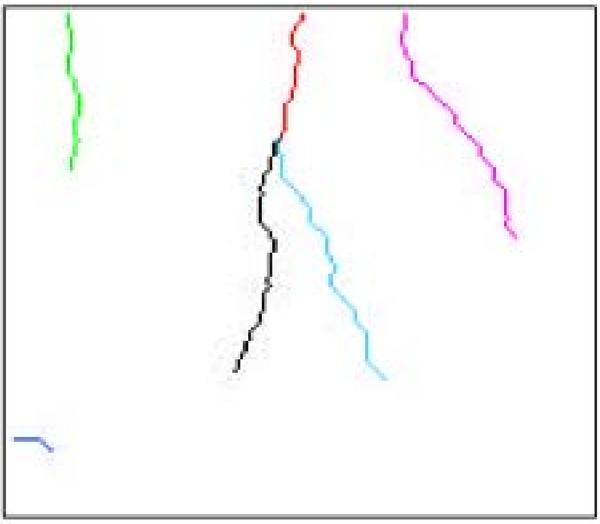


Example of Downhill Accumulation grid after recoding with a 25 cell cut-off

Because the drainage grid would produce an unmanageable number of sub-basins if used over the entire study area, a *Recode* process using a value of 999 as the cut-off was used. This resulted in only those stream segments that were a minimum of 2.5 km in length (999 x 25 m cells) being assigned a sub-basin.

Step 5 – segmentation

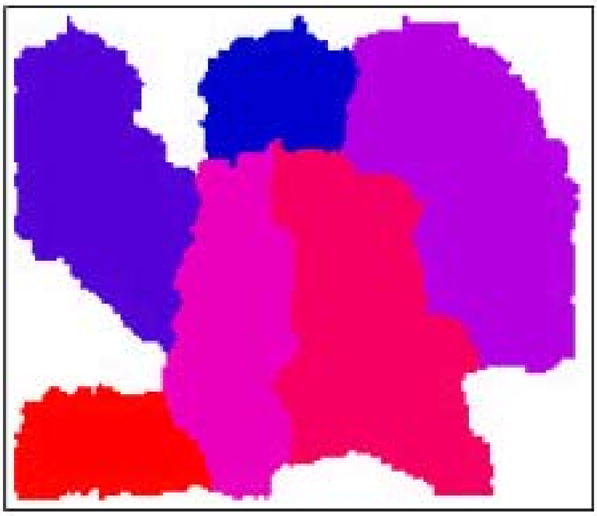
Once the downhill accumulation is recoded, the cells need to be combined into discrete segments that represent a drainage basin. The *Segmentation* process was run to assign each stream segment with a unique value.



Example of the Segmentation grid

Step 6 – sub-basin delineation

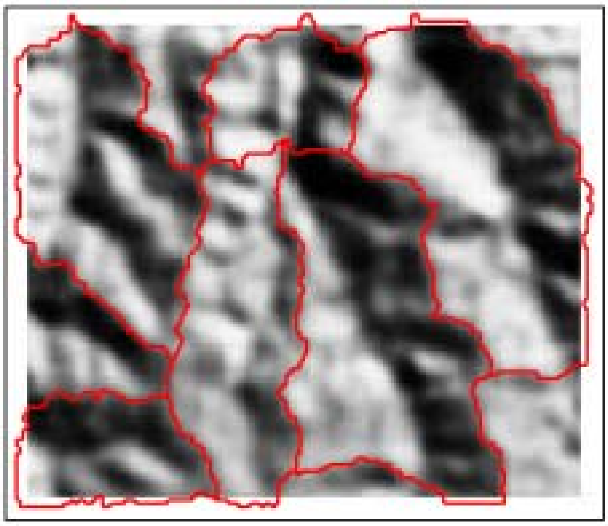
To create the final sub-basins, the *Sub-Basin Delineation* process combines the Segmentation grid and the Downhill Path grid created previously to generate a Sub-Basin grid which defines a watershed for each stream segment.



Example of the Sub-Basin Delineation grid

Step 7 – vectorising the sub-basins

In order to analyse the relationship between the sub-basins and other themes such as the run-off values form the soils database, the sub-basins were converted to vectors using the *Vectorise to Feature Class* process. Due to the size of the dataset, the process of delineating sub-catchments was done in six tiles. Some errors along the tile boundaries were edited using sun-shaded DEM and aerial photography (1:25,000).



Example of vectorised Sub-basin Delineation grid with shaded relief DEM as an underlay

Step 8 – finding sub-basins with more than 75 megalitres run-off

Once the sub-basins were in vector format, a spatial intersection was performed between the sub-basins and the map unit run-off theme. The product was designed to further attribute the map unit run-off rates to each sub-basin polygon. An expression query was run on this intersection in order to multiply the run-off rates by map unit areas, which in turn, was summed according to the sub-basin unique ID. While the result of this process provided the total run-off for each sub-basin, further analysis was required because the grouping function had placed the calculated total value onto a single map unit polygon in each sub-basin. Therefore a spatial query was used to find those sub-basins that contained a single map unit polygon with a calculated run-off equal to or greater than 75 megalitres.

A summary of the analysis required for step 8 is:

(a) Cut the run-off per unit area to the edges of the mini-catchments.

Spatial intersection of mini-catchments and run-off values (mm) dataset

(b) Determine areas of polygons generated in step 8a.

Analyse geometry of spatial intersection mini-catchments and run-off values dataset (to determine Area)

(c) Determine the volume of annual run-off from polygons generated in step 8a.

Expression query of Area (8b) x run-off values dataset x 10 (mm to kilolitres)

(d) Determine the total volume run-off generated in each catchment by adding 9c and grouping them based on catchments.

Expression query: Sum8c, grouped by unique mini-catchment ID (ID1)

(e) Determine which sub-catchments generate at least 75, 100, 200 and 400 ML.

Attribute query: total volume ≥ (a) 75,000 kL, (b) 100,000 kL, (c) 200,000 kL, (d) 400,000 kL

(f) Display the various run-off catchments by undertaking a spatial query to define sub-catchments that contain a, b, c, d in step 8e above.