



Setting Aspirational, Resource and Management Action Targets Across the Glenelg Hopkins CMA.

3rd Milestone Report – Models and tools used.

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Table of Contents

INTRODUCTION	2
BACKGROUND	2
METHODS	2
1. STATISTICAL ANALYSIS	2
2. CONCEPTUAL HYDROGEOLOGICAL MODELS.....	5
3. GROUNDWATER MODELLING	5
EXAMPLE OF RESULTS.....	7
1. STATISTICAL ANALYSIS.....	7
2. CONCEPTUAL HYDROGEOLOGICAL MODELS.....	8
3. GROUNDWATER MODELLING.....	10
RESULTS	12
REFERENCES	12



GLENELG-HOPKINS CMA

MILESTONE REPORT 3: APRIL 2004

INTRODUCTION

This is the third milestone report on Setting Aspirational, Resource and Management Action Targets across the Glenelg-Hopkins Catchment Management Authority (GHCMA). The general objective of this project is to assess, spatially re-define and prioritise the aspirational, resource and management action targets that have been set for the GHCMA region within their Regional Catchment Strategy.

The specific activity addressed by this milestone report is to briefly summarise the models and tools used to set the targets (this information will be provided in more detail in the Final Milestone Report in June 2004).

BACKGROUND

Milestone Report 1 contained background information to the project. Groundwater modelling and catchment response for four base level sub-catchments areas in the GHCMA were in Milestone Report 2. The Final Milestone Report (4) is due by June 30th 2004 and will present no change conditions and change conditions under appropriate management for eight base level sub-catchments, which have been chosen as high risk from 132 across the GHCMA. These base level sub-catchments will be used as a basis for assessing the effectiveness of salinity management across other sub-catchments with similar hydrogeological attributes.

METHODS

The methods and tools used to set aspirational, resource and management action targets across the GHCMA included:

1. Statistics (GAM analysis) to determine and predict stream EC trends (i.e. are they rising or falling),
2. Development of conceptual hydrogeological models for cross sections across the base level sub-catchments where assets are at risk of salinity and estimation of hydrogeological parameters needed for the groundwater modelling, and
3. Groundwater modelling using FLOWTUBE to determine whether land management changes will protect the assets at risk of salinisation.

1. Statistical analysis

Attempts were made to analyse stream salinity trends at each stream gauging stations within the GHCMA, however, long term stream salinity monitoring has been infrequent and irregular across most of the CMA, making the establishment of salinity trends difficult in many cases.



The aim of this type of data analysis is to obtain stream salinity trends that are independent of fluctuations in flow and season, and hence are indicative of the impacts of saline groundwater inflows caused by catchment salinisation. A standard approach used in water agencies throughout the world is the non-parametric Seasonal Kendall's τ and LOESS smoother techniques (Hirsch *et al.*, 1982; Cleveland, 1994). As highlighted in Jolly *et al.* (2001), problems arise from the application of the Seasonal Kendall's τ technique when the stream salinity data are autocorrelated, as was shown to be the case for many of the stations in the Murray Darling Basin. To overcome this problem a new semi-parametric statistical methodology was employed (Morton, 1997) which uses the Generalised Additive Model (GAM) approach (Hastie and Tibshirani, 1990). While corrections for flow and seasonal effects are implicit in the technique, it is important to note that the analysis does not account for long-term climatic variations *per se*.

In this technique, additive regression terms were fitted to $\log EC$ ($\log \mu\text{S/cm}$), the explanatory variables being time (months), $\log flow$ ($\log \text{ML/day}$) and sinusoidal seasonal terms. This non-linear GAM model represented the response of $\log EC$ to time and $\log flow$ by arbitrary smooth curves using cubic splines with knots at each data point. The mathematical form of the regression was:

$$\log EC = \alpha + S(\text{time}; df_t) + S(\log flow; df_f) + \beta \sin(2\pi \text{month}/12) + \gamma \cos(2\pi \text{month}/12) + \varepsilon \quad (1)$$

where $\log EC$ was the natural logarithm of EC, $\log flow$ was the natural logarithm of flow + 1, $time$ was in years, $month$ had values of 1 to 12, $S(t; df_t)$ was a smoothing spline of $\log EC$ versus time with df_t degrees of freedom, $S(\log flow; df_f)$ was a smoothing spline of $\log EC$ versus $\log flow$ with df_f degrees of freedom; α, β, γ were linear regression coefficients and ε was the residual error. The terms df_t and df_f are smoothing parameters that determine the shape of the splines fitted to the data.

We followed Morton's (1997) recommendation that values of 4 for df_t and 2 for df_f were adequate for data sets of the length used in this project. The term $S(x; m)$ is the sum of the linear (which is of the form $a+b*x$) and the non-linear (which has mean zero and no linear trend) components of the trend. By separating the linear and non-linear components of the spline function, Equation (1) was rewritten as:

$$\log EC = \alpha + \eta \text{time} + C_{\text{time}} + \chi \log flow + C_{\log flow} + \beta \sin(2\pi \text{month}/12) + \gamma \cos(2\pi \text{month}/12) + \varepsilon \quad (2)$$

where η and χ were linear coefficients of $time$ and $\log flow$ respectively, and C_{time} and $C_{\log flow}$ were the non-linear components of $S(\text{time}; df_t)$ and $S(\log flow; df_f)$ respectively. The linear coefficient of $time$, η , was used to calculate the percentage change in EC per annum using the formula:

$$\{100 * (e^\eta - 1)\} \quad (3)$$



Figure 1 shows the two components of the trend. The significance of the non-linear component cannot be determined and as such is qualitative. The significance of the linear component of the trend can be determined quantitatively.

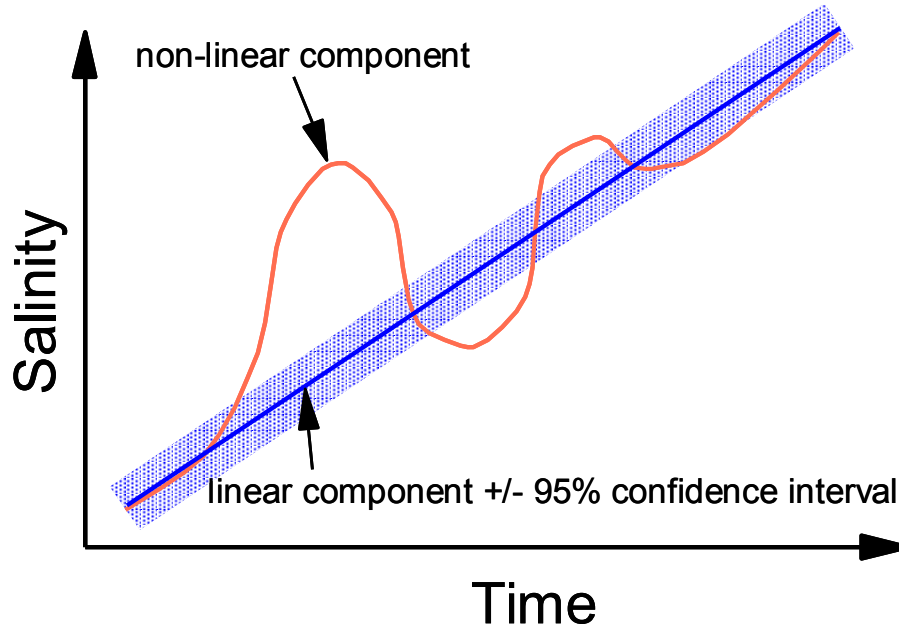


Figure 1. Conceptual graph showing the linear and non-linear components in a flow and seasonally corrected stream salinity trend.

The model fits were carried out using Ordinary Least Squares (referred to as the OLS approach) regression. If autocorrelation of the residuals of the OLS fits were found to be high (>0.2), then fits were carried out with first order autoregressive parameters (referred to as the TSM approach).

The significance of the linear components of the trends at the 5% probability level was estimated as ± 2 standard errors. Standard errors for stations with sufficient data to use the TSM approach were taken directly from the statistical output. However, if the number of missing months was too large ($>20\%$), then the TSM approach failed and it was necessary to use the OLS approach with a multiplier applied to the standard errors. This multiplier was derived from likelihood theory and was adjusted both for the magnitude of the autocorrelation and for the amount of missing data:

$$\{1 + 2pAR / (1 - AR1)\}^{1/2} \tag{4}$$

where p was the proportion of available data and $AR1$ was the first order autocorrelation coefficient. It should be noted that this multiplier is an approximation, which assumes that the missing values occur independently and at random.

For each station, all available EC data were used to determine the trends. Obvious outliers, caused by erroneous flow or EC values, were identified by high residual values and were removed from the



data set and the trends recalculated. There were never more than six points per station where this was necessary.

2. Conceptual hydrogeological models

A workshop was initially held prior to this project to develop the groundwater flow systems (GFSs) across the GHCMA (Dahlhaus *et al.* 2002). A small group met during the course of this project to then develop appropriate conceptual models of groundwater flow and hydrological parameters needed for the FLOWTUBE modelling for the base level sub-catchments chosen. In some instances there was little information to substantiate some of the conceptual models. In these cases, it was acknowledged that the information was best guess based on the workshop participants knowledge of the area.

3. Groundwater modelling

Catchment scale groundwater modelling is used to examine the effect of different recharge rates on the extent of salinity. Groundwater heads along transects across high risk assets¹ in base level sub-catchments in the GHCMA will be simulated using FLOWTUBE (Dawes *et al.* 1997, Dawes *et al.* 2000, Dawes *et al.* 2001). This is a simple numerical one-dimensional groundwater flow model. It is a mass-balance model that solves for a change in hydraulic head induced by recharge and discharge fluxes, and lateral transfers in the direction of flow. The results of FLOWTUBE are considered to be a hydraulic head transect along an aquifer.

The model considers a one or two-layer system. In the case of a single layer, the aquifer is assumed to be unconfined and having variable transmissivity dependent on the saturated thickness of aquifer. In the case of a two-layer system, the lower layer is assumed to contain any lateral transmission of water while the upper layer contributes storage capacity only. In this case the lower layer is usually confined or semi-confined, and how this is conceptualised controls the simulated mechanism for groundwater discharge.

Water sources considered by FLOWTUBE are (i) point sources of runoff at the upstream end of the aquifer, often manifested as recharge beds collecting surface water from a steeper part of the catchment, and (ii) diffuse recharge or discharge spread in an arbitrary spatial and temporal pattern across the aquifer being modelled. The latter source is the recharge component most altered by the replacement of native species with annual cropping and grazing systems in Australia.

FLOWTUBE allows a variety of boundary conditions for the aquifer. At the downstream end there are two options: (i) the flux is controlled by a specified groundwater head at a nominated distance, useful where a permanent water source occurs nearby that controls head build up such as a river or irrigation area, or (ii) the flux is controlled by local aquifer properties and the groundwater surface and

¹ An earlier version of the Geospatial Salinity Hazard and Asset Risk Prediction (GSHARP) process was used to identify the assets at risk in each sub-catchment (Heislors and Brewin, 2003).



drains freely, which can be useful when the groundwater catchment is poorly defined or only the upper part of a catchment is considered.



For diffuse recharge input there are three options: (i) a user-specified pattern of fixed recharge amounts with an evaporation component controlled by an extinction depth, which is the traditional implementation within groundwater models, (ii) recharge calculated by FLOWTUBE internally as the difference between the current head and a reference elevation multiplied by an impedance factor, applicable where definite connection and transfers exists between a surface storage and transmitting aquifer with little outside influence, and (iii) a continuous function of recharge/discharge based on GIS analysis of depth to water from a DEM, most useful when there are near surface water levels causing discharge controlled by topographic features.



It should be noted that with the current version of FLOWTUBE, the continuous recharge/discharge functions are mutually exclusive with the head-induced and fixed recharge pattern, as are the two-aquifer flux conditions. This means it is not possible to switch between recharge/discharge functions and a sudden flood or drought through a fixed recharge distribution within the one simulation. Spikes of recharge however may be superimposed on head-induced recharge situation.



The aim of the modelling exercise is to improve our understanding of the groundwater processes and catchment characteristics along with examining land use change with groundwater behaviour (water balances). The sub-catchments where sufficient data exists will be identified and will be chosen in such a way that it will represent each GFS within the GHCMA. Each sub-catchment chosen will have a fairly close series of networked bores with sufficient data to accurately describe the responsive nature if the GFS to certain land use changes.



Several hypothesis will be tested by the FLOWTUBE modelling:

1. to elucidate the hydrogeological processes operating within the sub-catchments and thereby understand the causes of the salting in affected areas of the GHCMA;
2. to quantify the relationship between these hydrogeological processes by simulating them using a groundwater model of the base level sub-catchments;
3. to use this model to test the efficacy of different salinity management strategies.



Sensitivity analysis will also be carried out to demonstrate depth of weathering (aquifer thickness); width of valley/drainage line and aquifer properties (calibrate using rear heads).



FLOWTUBE was attempted in all (8) base level sub-catchments selected but it was acknowledged where the model could not be calibrated and where the model would probably not apply because the hydrogeology is too complex.





EXAMPLE OF RESULTS

1. Statistical Analysis

The mean EC and saltload for seasonally corrected linear EC trends for one of the major stream gauging stations is shown in Figure 2 as an example of the GAM analysis predictions. Within the last 10 years it is evident that the EC trend is rising however this is not a significant rise over the entire recorded period. A summary of stream EC trends across the GHCMA is shown in Figure 3.

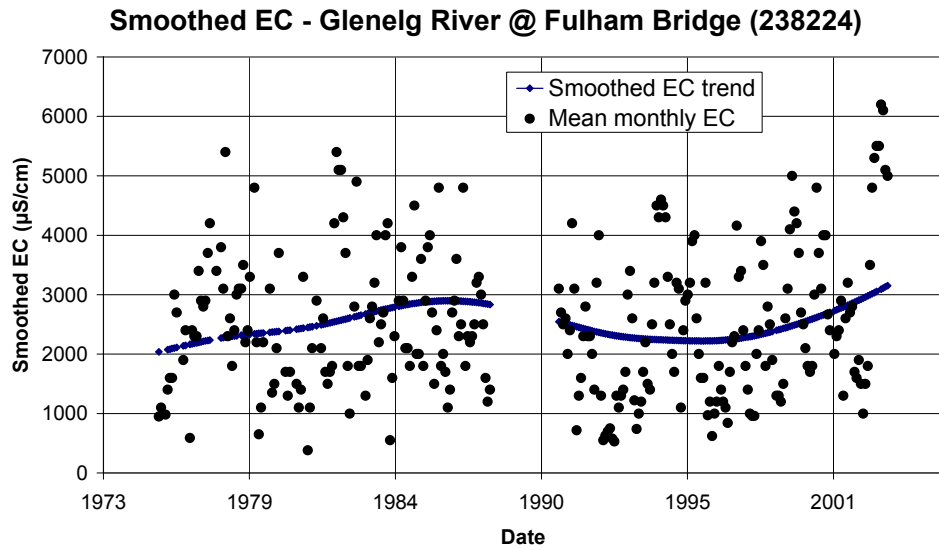


Figure 2. Statistical analysis of smoothed EC at Hopkins River at Wickliffe.

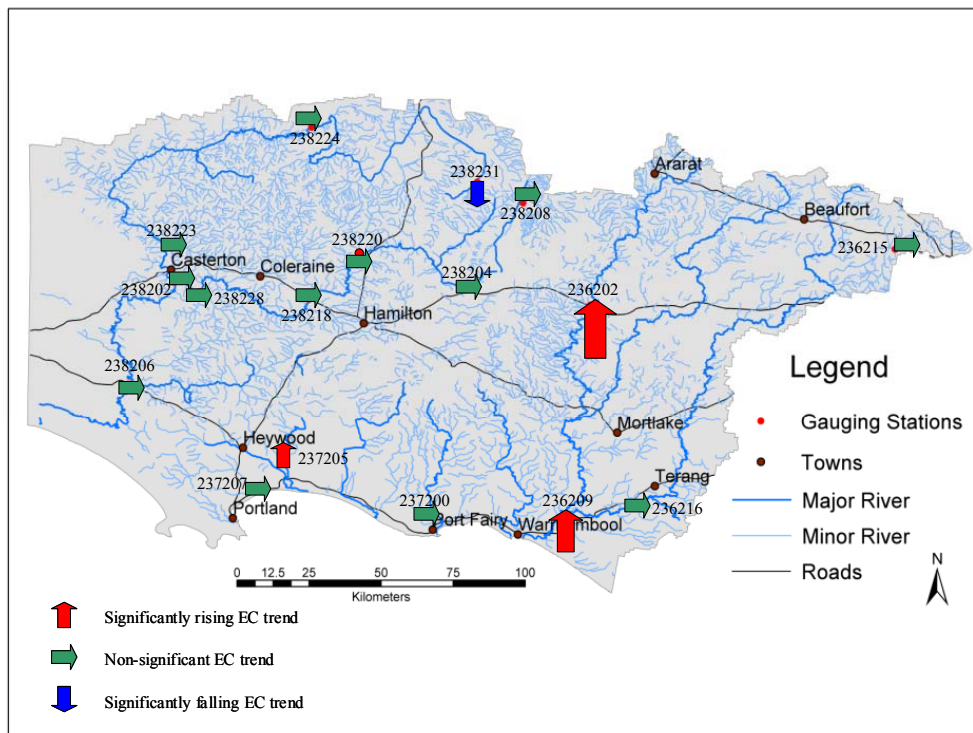


Figure 3. Summary of the statistical analysis of smoothed EC at the major gauging stations within the GHCMA.

2. Conceptual hydrogeological models

Eight sub level sub-catchments were chosen which have a high risk asset rating (Figure 4). Conceptual hydrogeological models are then developed for each base level sub-catchment (an example for Sub-Catchment 7.3 is shown in Figure 5) and a transect (or several transects) see A – A' in Figure 5. Conceptual model of salinity process within sub-catchment H7.3., which cut across the high risk assets (Heislars and Brewin 2003) chosen for FLOWTUBE modelling. Thus the modelling will determine if changed land management can result in lower groundwater levels and thus protect the assets as risk of salinisation.

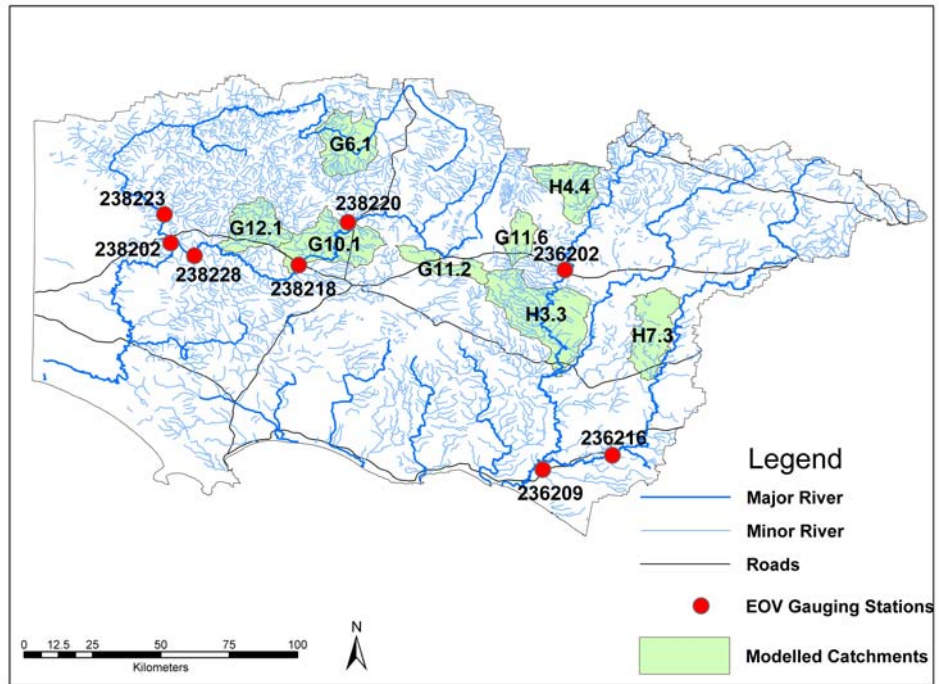


Figure 4. Selected base level sub-catchments chosen to assess management strategies to reduce salinity

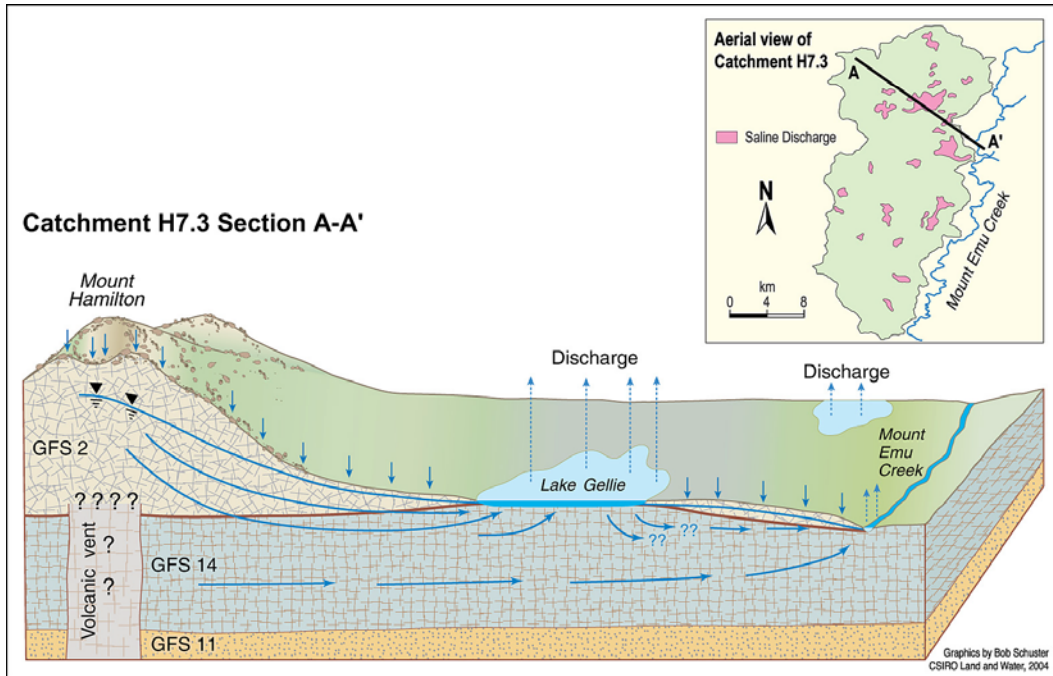


Figure 5. Conceptual model of salinity process within sub-catchment H7.3.

3. Groundwater Modelling

Figure 6 is an example of how FLOWTUBE is used in this study to model the affects of land use change on groundwater response in base level sub-catchment H3.2 (Hopkins River/Mustons Creek area).

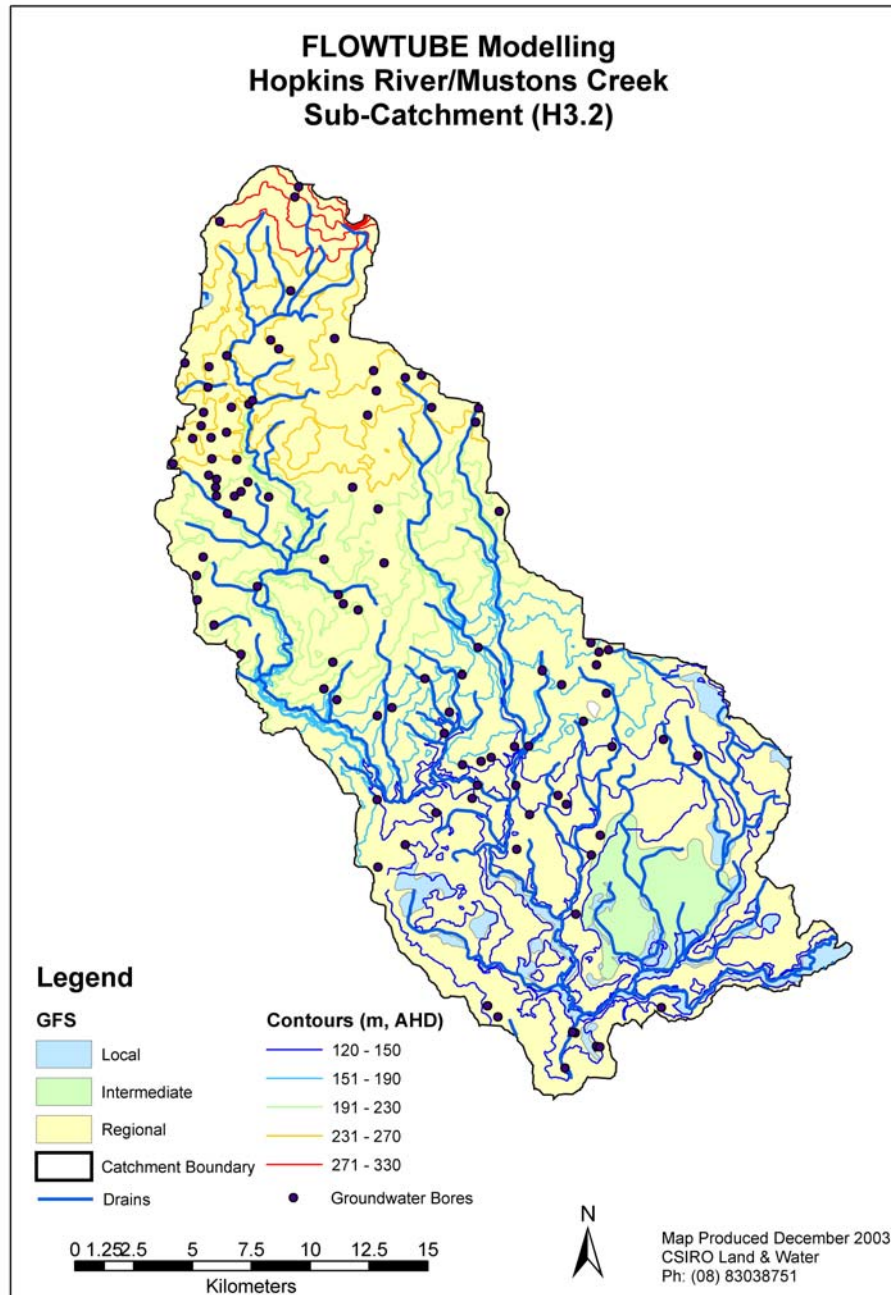


Figure 6. Characteristics and bore locality of Sub-catchment H3.2 within the GHCMA.

One "FLOWTUBE" as illustrated in Figure 7 will be utilised to model the area, as the topography and GFS are not all that complex here. A point source of recharge (or flux) will be specified in the upper part of the "tube" along with any regional through-flow.

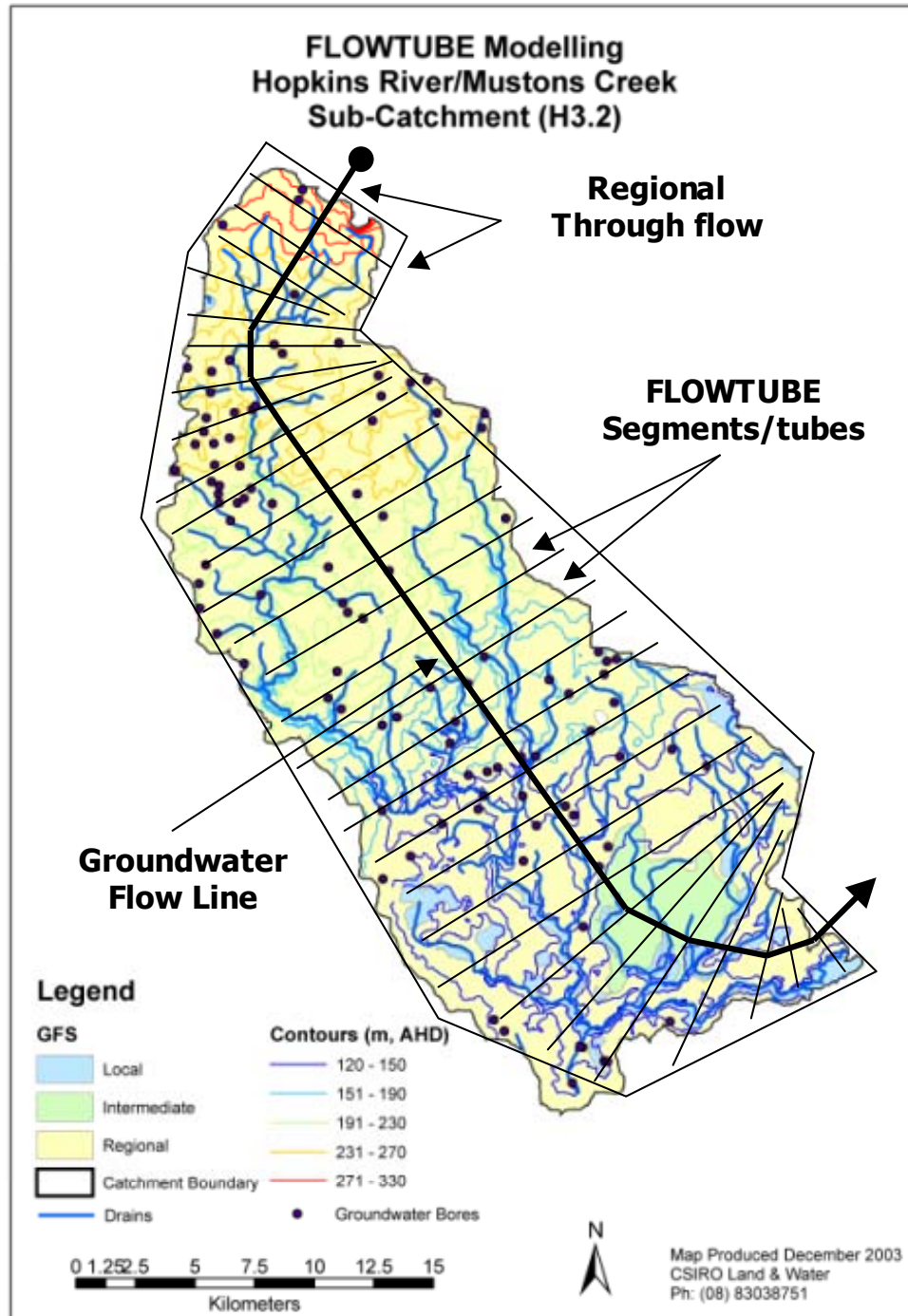


Figure 7. Discretisation of Sub-catchment H3.2 within the GHCMA for FLOWTUBE modelling.



RESULTS

Preliminary results were reported in Milestone 2. All results will be presented in the Final Milestone Report (Milestone 4, June 2004).

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