Task Report GAH99_2: Application of HARSD landscape classification and groundwater surface mapping techniques to study catchment at Ucarro.

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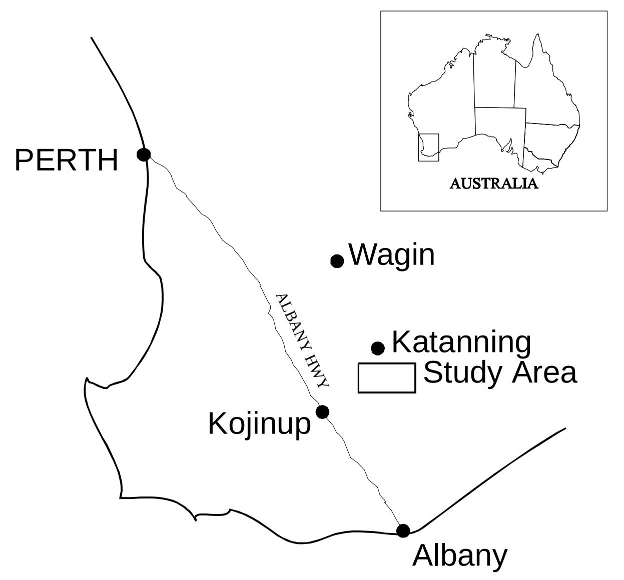
Abstract:

Ucarro is a small farm catchment that has been intensively monitored for around three years. The site has a number of electronically monitored bores (piezometers), detailed soil descriptions and a high resolution DEM. The principles of Hydrogeomorphic Analysis of Regional Spatial Data (HARSD) were applied to examine the effect of morphology on regional groundwater levels. The underlying hypothesis is that the groundwater or Hydraulic Head Surface is a smoothed version of the Surface Topography or DEM (Salama, *et.al.*, 1996) and that linear relationships between measured groundwater levels (bore readings) and surface elevation can be used to construct reasonably accurate groundwater surfaces. Hydraulic Head Surfaces were constructed from the 2m Land Monitor DEM. The following is intended as a demonstration of the method.

Site Description:

Ucarro is located 280 km south-east of Perth and approximately 14.5 km south-west of Katanning (Figure 1). The average annual rainfall is approximately 485mm and the climate is Mediterranean characterised by hot, dry summers and relatively wet, cool winters. Ward *et.al.*(1997) describes the soil profile as "*a duplex with an A horizon of loamy medium sand or clayey coarse sand to between 35 and 50 cm underlain by a B horizon of medium to light clay with 10 to 20% smooth faced lateritic gravel at depth*". The site has an array of piezometers, a weather station, hydraulic conductivity measurements, a V-notch weir (installed winter 1998) and various other monitoring equipment. Two aquifer systems have been identified within the Ucarro sub-catchment. The regional (deep) system, which is relatively stable with only weak seasonal trends, and the "perched" (shallow) system, which shows strong seasonal variation. Piezometers have been installed to monitor both systems; however, this report relates to data from the deep piezometers network only (Figure 2.4).

Figure 1: The location of the Ucarro sub catchment in the south-west of Western Australia.



Method:

The principles of HARSD were applied to the sub-catchment "Ucarro" to derive a Hydraulic Head Surface (HHS). The technique involves three main components (Salama, *et.al.*1996):

1. Hydrogeomorphic Classification
2. GIS and Hydrogeological methods for constructing Hydraulic Head Surfaces
3. Flow Net Analysis

This report relates to an initial investigation of the first two steps in this process, applied to the sub-catchment Ucarro.

Results and Discussion:

1. **Hydrogeopmorphic classification:** This technique attempts to classify the landscape into units with similar hydrological properties (Salama, *et.al.*, 1996). A DEM is used to derive variables such as elevation, slope, curvature, break of slope, etc., which are then grouped according to their statistical distributions. This classification may be arbitrary initially, then adjusted to reflect existing classifications such as landform maps, soil maps, etc.

   There were two high-resolution DEMs available for the Ucarro sub-catchment. The Land Monitor DEM (approx. 2m resolution) generated via an automated technique and a manually generated DEM (approximately 1m resolution). Both have been

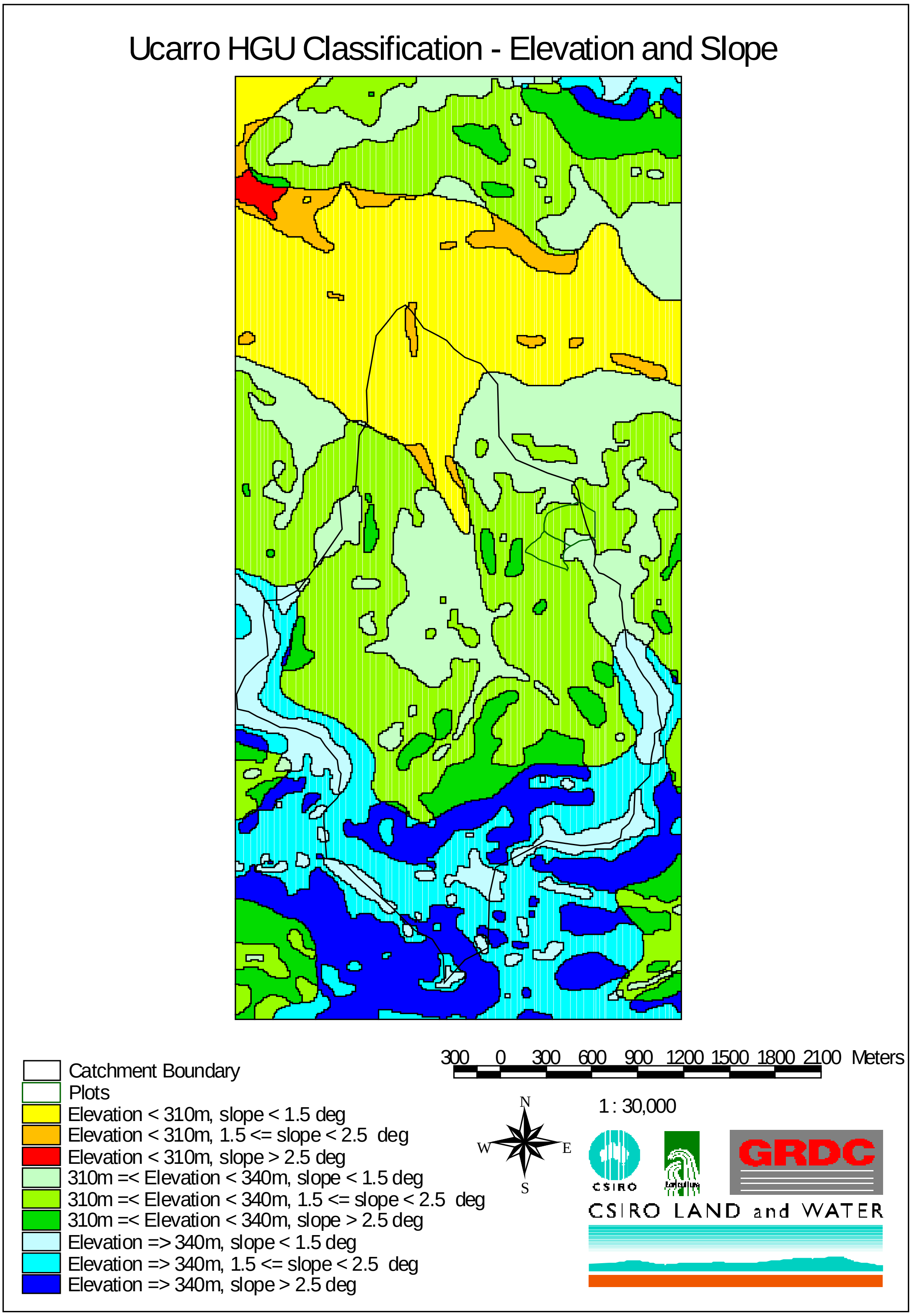


Figure 1.1. **Initial hydrogeomorphic classification of Ucarro sub-catchment**

found to contain artefacts which affect the output from the hydrogeomorphic mapping. The Land Monitor DEM has a quilting artefact in the northern half resulting from the DEM generation procedures of the contractor that produced this section. This problem was only recently identified and DOLA is currently considering options to rectify this. The 1 meter DEM is a raster version of a contour map made from aerial photo interpretation. The grid has artefacts resulting from this process. This can be corrected by obtaining the original contour map and re-griding via different methods. For the purpose of demonstration, these problems have been ignored and the Land Monitor DEM has been used in the following classifications.

Figure 1.1 shows an initial hydrogeomorphic classification using slope and elevation as the two variables. Classes were chosen based on examination of the statistical analysis performed as part of the HARSD procedure, the aim being to "slice" the range of values for slope and elevation into three classes, of slope (upslope, midslope and lowerslope). The grade of slope is also divided into three classes resulting in nine distinct classes. This type of classification works well in a regional context; however, as we are dealing with a relatively small sub-catchment, a simpler classification might be more appropriate. Figure 1.2 represents a hydrogeomorphc classification done via aerial photo interpretation. This method has identified three units: U1 - lower slopes, U2 - mid U3 - upper slopes (Bartle, *pers. comm.*, 1999).

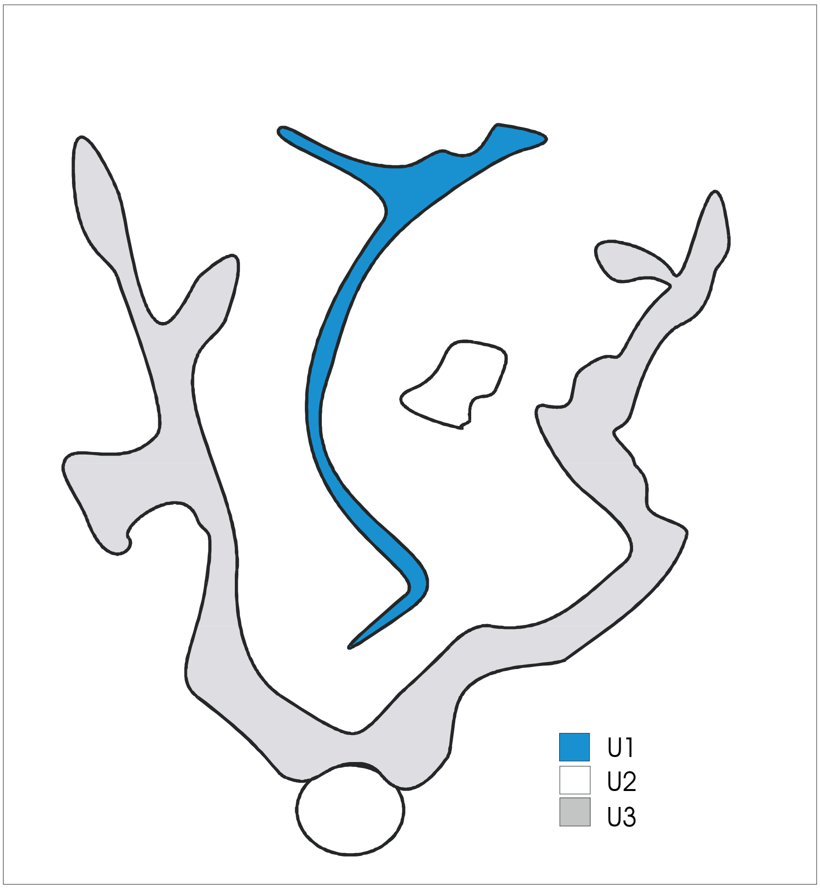


Figure 1.2. Hydrogeomorphic units for the Ucarro sub-catchment interpreted from aerial photography

Note that the interpreter considers the knoll in the southern section to be a unique entity. In fact, this rocky outcrop is likely to be a remnant of a layer that has been eroded away in the rest of the catchment. Further classifications were examined. However, when measured groundwater levels were considered, the correlation between groundwater levels and surface elevation suggested that no classification was necessary (see below).

2. **Bore Data:** Groundwater levels were obtained from all 29 deep piezometers for the month of May 1998. During May, 1998, some loggers were moved from existing holes within an experimental plot to new holes spread throughout the catchment. For this reason, a monthly average for May 1998 was used, to include as many bores as possible. While the recorded water levels during this period are changing, and in some cases trending, the magnitude of change was found to be insignificant. The average trend (absolute value) in the 29 bores was 0.04m. One bore (P35D) had a range of 0.65m and an overall trend (fall) of -0.5m; however, this may be considered an anomaly as a nearby bore (within 20m) showed a trend (fall) of only -0.05m.

   Linear regression was performed for monthly average water levels and surface elevation (Figure 2.1) measured in meters AHD (Australian Height Datum). Groundwater Elevation and Surface Elevation were found to be highly correlated with an r^2 of 0.9245. Given that elevation is inherent to both variables, a reasonable correlation is not surprising. There is a good argument for using a measure of depth to groundwater rather than groundwater elevation for the regression (see Figure 2.3). However, this initial investigation gives similar results to those found by Salama, et.el. (1996) from bore data in the Loddon and Campaspe catchments. The HARSD technique uses the regression equation to estimate the groundwater surface in a GIS environment. Future work will focus on identifying the best variables.

   Figure 2.2 shows that the removal of two spurious points improves the fit slightly. These bores are located in an area where the surface elevation and the groundwater elevation are both relatively high. Drilling records show that these points have very shallow bedrock. There are two likely explanations that can be made for these anomalies:

   1) groundwater is effectively confined (vertically) at these points; or

   2) the watertable that has been sampled is a perched system and the regional aquifer resides somewhere beneath a layer of rock.

   Regardless of which explanation is correct, it is unlikely that any classification system based on DEM derived variables will be able to distinguish these types of anomalies without additional information (i.e. geology, depth to basement, soils etc.). For a small sub-catchment such as Ucarro, such information may be necessary to accurately predict groundwater levels using the HARSD techniques. However, for regional catchment systems with sparse bore data, localised anomalies are unlikely to affect the predictions such that gross errors in prediction of water levels will result.

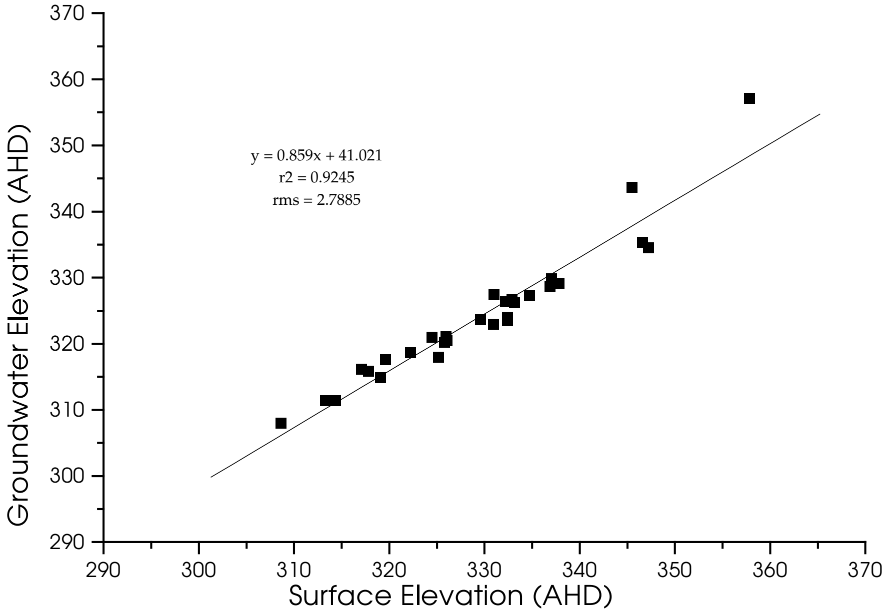


Figure 2.1. Average Groundwater Elevation (May, 1998) versus Surface Elevation for Ucarro Deep Bores

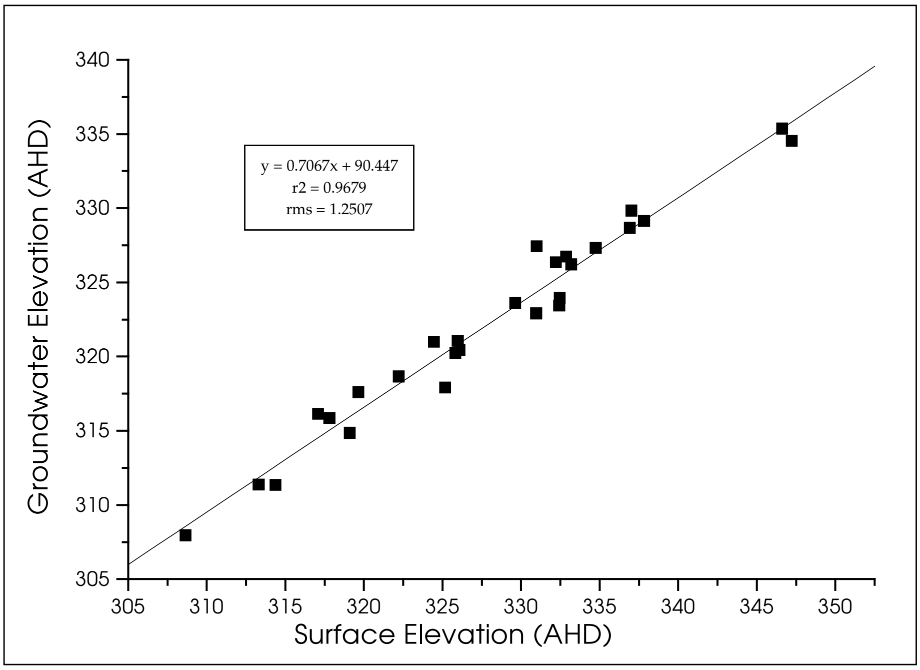


Figure 2.2. Average Groundwater Elevation (May, 1998) versus Surface Elevation for Ucarro Deep Bores - anomalies removed

The simplest answer is to delete such anomalies from the dataset where they are easily identified. This process will be vital to any regional application of the technique.

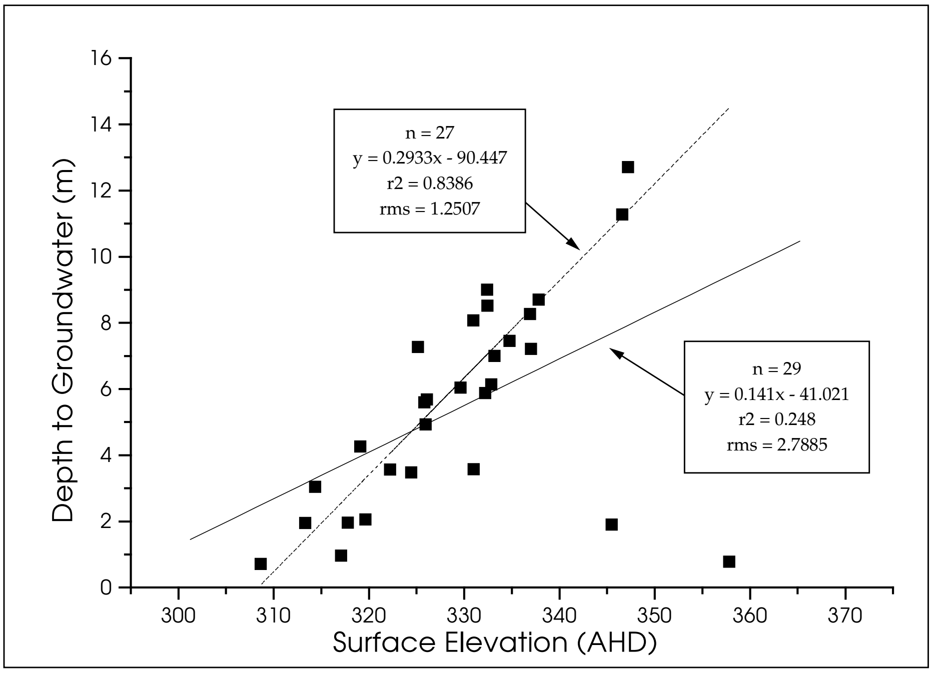


Figure 2.3. Average Depth to Groundwater (May, 1998) versus Surface Elevation for Ucarro Deep Bores

These data can also be represented as depth to groundwater versus surface elevation (Figure 2.3) which clearly shows a poorer correlation between the two. The two anomalous points within the dataset drag the r^2 down significantly. The exclusion of these points changes the r^2 from 0.248 to 0.8386 (n=27, dotted line). This representation more clearly shows the general dependence of groundwater depth on topography.

Salinity Data: In addition to bore data salinity maps were used to define areas of discharge (groundwater close to surface) to provide more control on the HHS. Salinity maps for much of the Great Southern have been produced as part of the Land Monitor project. Mapping involves stratification and separation of groundcover types from selected dates of Landsat-TM images combined with DEM derivatives (position in slope) to calculate probability of areas being salt-affected (Evans, 1998). It is a reasonable assumption that where there is saline discharge then the groundwater is effectively in contact with the surface. A salinity map for the Ucarro catchment was obtained (Figure 2.4) and 16 points were selected within well defined areas of salinity were chosen to supplement bore data (Figure 2.5). As expected, the r^2 is higher with the addition of these discharge points, which, in this case, groundwater elevation equals surface elevation. In reality, discharge can occur when groundwater levels are within 2 meters of the surface. This is because evaporation and capillary rise can facilitate discharge in such situations (given certain soil and climatic conditions). Furthermore, these processes will tend to limit further groundwater rise once discharge has begun. Thus, the assumption that mapped discharge represents zones in which groundwater is in contact with surface may introduce error into the model.

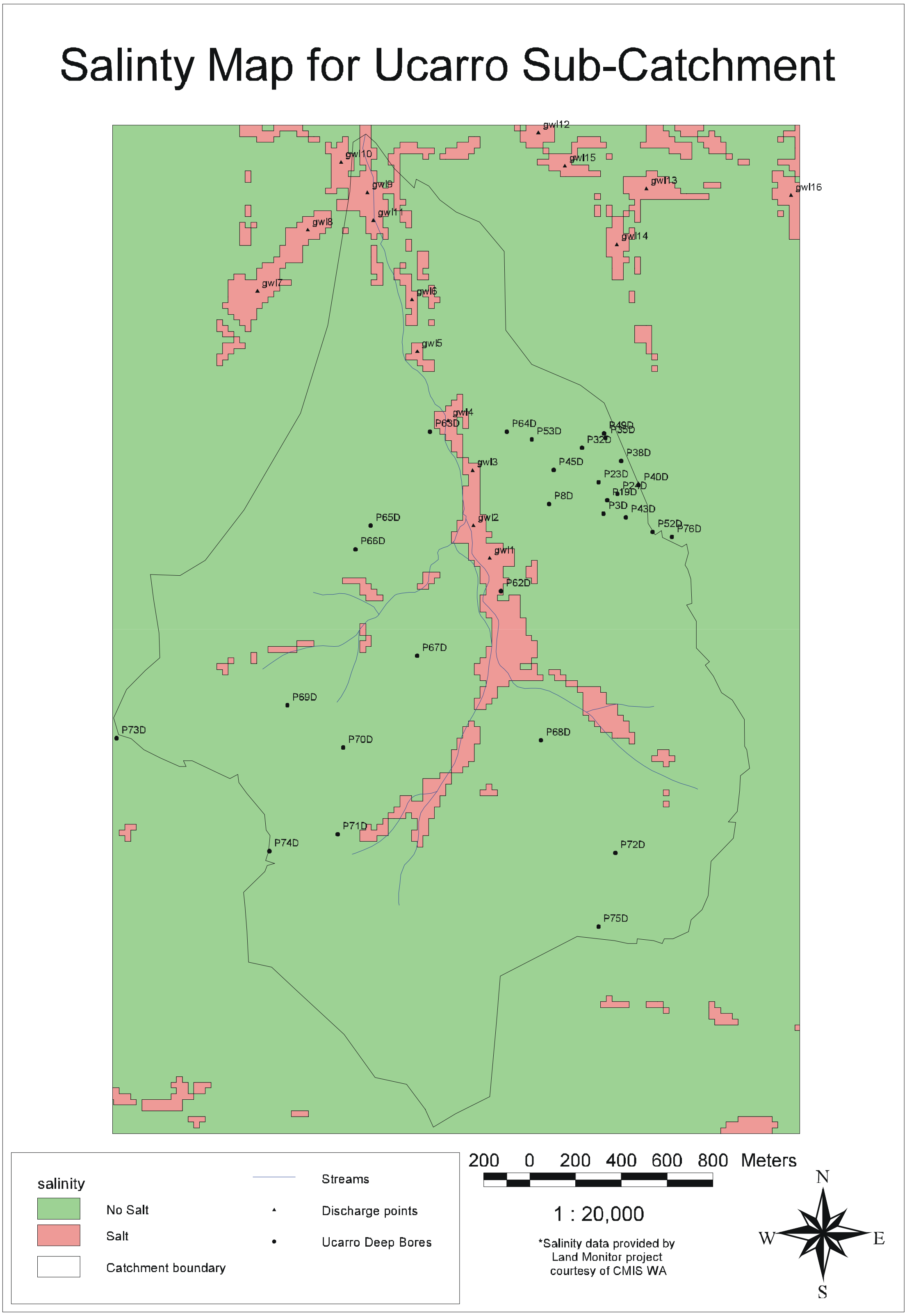


Figure 2.4. Salinity map for Ucarro sub-catchment showing locations of piezometers and discharge points.

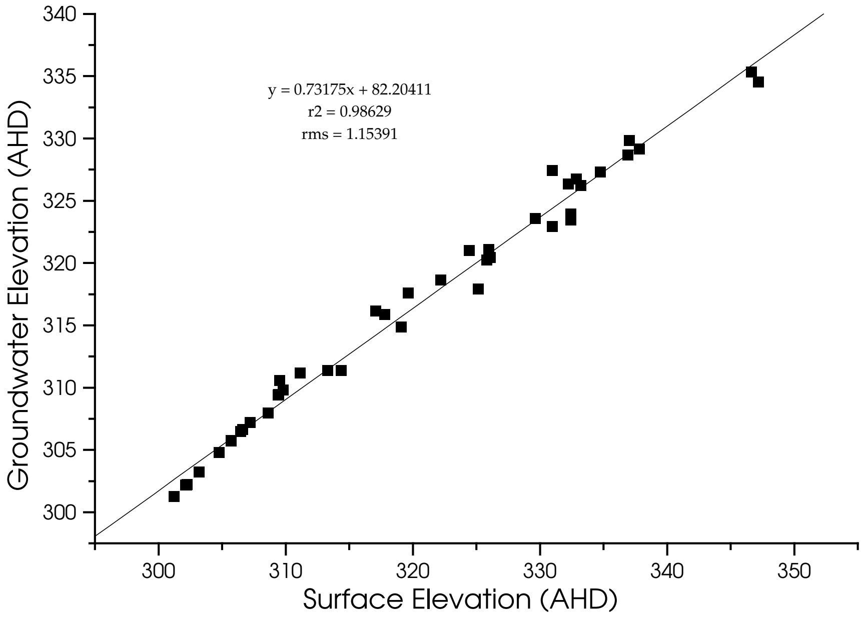


Figure 2.5. Average Groundwater Elevation (May, 1998) versus Surface Elevation for Ucarro Deep Bores with Discharge Points

For this reason, it was decided to assume that the groundwater levels for all the discharge points could be represented as:

$$\mathbf{E_w = E - 1}$$

Where E = Surface Elevation at a Discharge Point
E_w = Groundwater Elevation at a Discharge Point

The resulting regression (Figure 2.6) gives us a better fit yet again but probably not significantly so. This assumption may be reasonable for the Ucarro sub-catchment; however, other methods need to be explored with respect to a regional application, such as using the edges of discharge zones for input points and applying the above formula or using the centres of zones and adding 1 meter.

When this relationship is expressed in terms of groundwater depth for each point, (Figure 2.7) it is again weaker but to a much lesser degree than before anomalies were excluded and salinity data were included (Figure 2.3). It is acknowledged that the strength of this relationship is largely dependent on the number of discharge points included in the regression. A high percentage of discharge points will bias the slope of the line towards the slope of the discharge points with respect to the land surface (i.e. slope = 1). There will always be a trade-off between a good spatial representation of points and a realistic use of the salinity data.

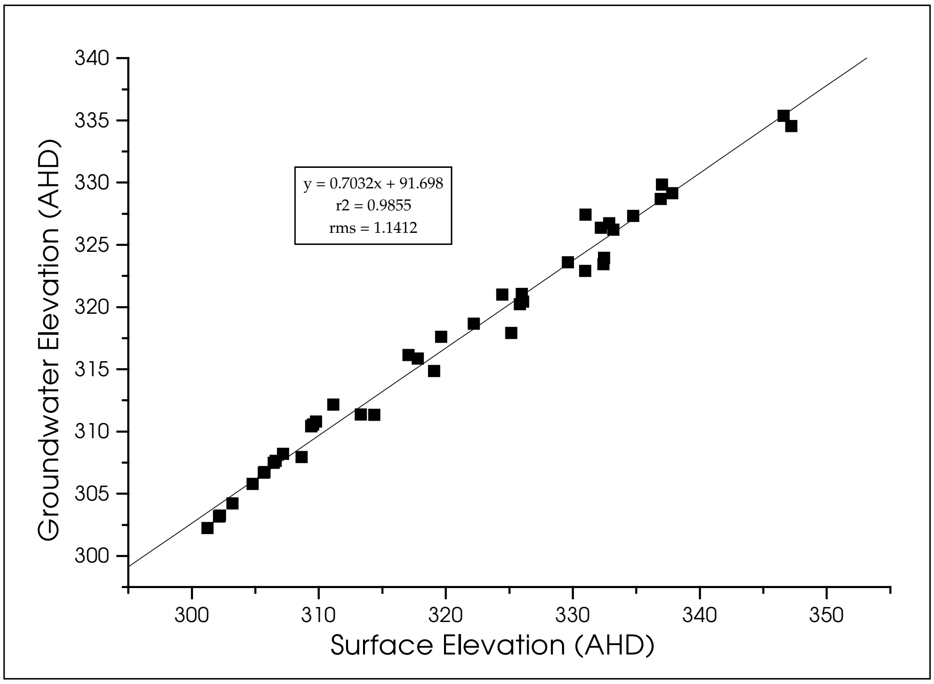


Figure 2.6. Average Groundwater Elevation (May, 1998) versus Surface Elevation for Ucarro Deep Bores with Discharge Points (E-1).

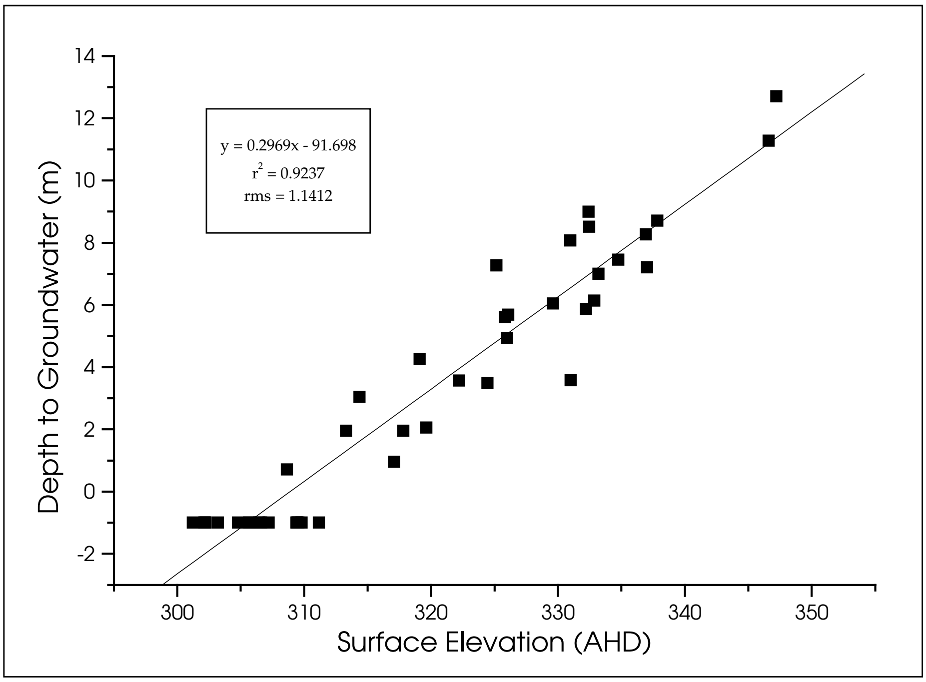


Figure 2.7. Average Depth to Groundwater (May, 1998) versus Surface Elevation for Ucarro Deep Bores with Discharge Points (E-1).

3. **Hydraulic Head Surface (HHS) generation:** Initially a HHS was produced for the Ucarro using the linear regression for average water level in May, 1998 (Figure 2.1) for all bores across the whole domain. Using the HARSD technique the HHS is constructed using the following equation:

$$\mathbf{P_w = 0.859(Z) + 41.021}$$

where

P_w is the local hydraulic head elevation and Z is the local surface elevation. This relationship has been used to produce the surface shown in Figure 3.1.1. The residuals from this regression (Figure3.1.2) show a reasonable prediction of water levels versus measured levels. The two points discussed earlier (P72D & P75D) represent the area where bedrock has been found at very shallow depths. If the two anomalous points are removed from the regression (Figure 2.4) this new relationship can be expressed as:

$$\mathbf{P_w = 0.7067(Z) + 90.447}$$

Figure 3.2.1. shows the groundwater elevation to be generally lower than in the previous model, especially in the upper regions of the catchment. This is probably a better representation of the regional groundwater levels with the residuals plot (Figure 3.2.2.) showing less variation. The addition of the known discharge points where the groundwater is considered to intersect the surface produces the following:

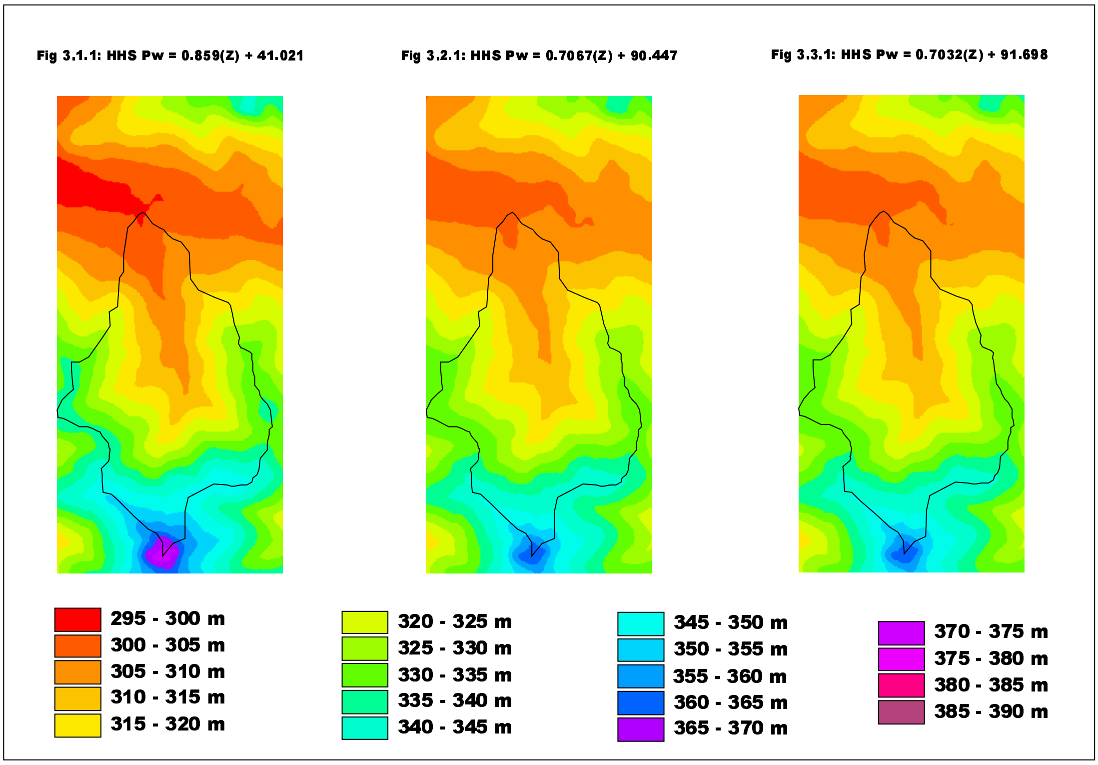
$$\mathbf{P_w = 0.7032(Z) + 91.698}$$

When this is used to construct the HHS the differences are more subtle but the prediction is better (Figure 3.3.1.). As this model does not force the HHS to pass through the known points (bore levels). The plot of residuals demonstrates the accuracy of prediction to be within three meters (Figure 3.3.2.)

Once a HHS has been constructed it can be used to map the discharge area for the region of interest. Figure 3.4 shows the mapped discharge zones for Ucarro for May 1998 and the change in discharge area given a universal rise of 1m in groundwater. In terms of the catchment area, discharge zones can be quantified by the following:

Groundwater Depth (m)	May 1998 (Ha)	May 1998 + 1m (Ha)
0	40.80	80.40
0-2	83.26	94.15
2-25	498.80	448.31

The most significant point to note is that the discharge area almost doubles with only a 1 meter rise in groundwater. If we accept that groundwater at shallow depths (0-2m) is also discharging, then the discharge area constitutes 20.24% of the catchment as of May 1998 and 28.02% after 1 meter rise. The rise of groundwater may not be



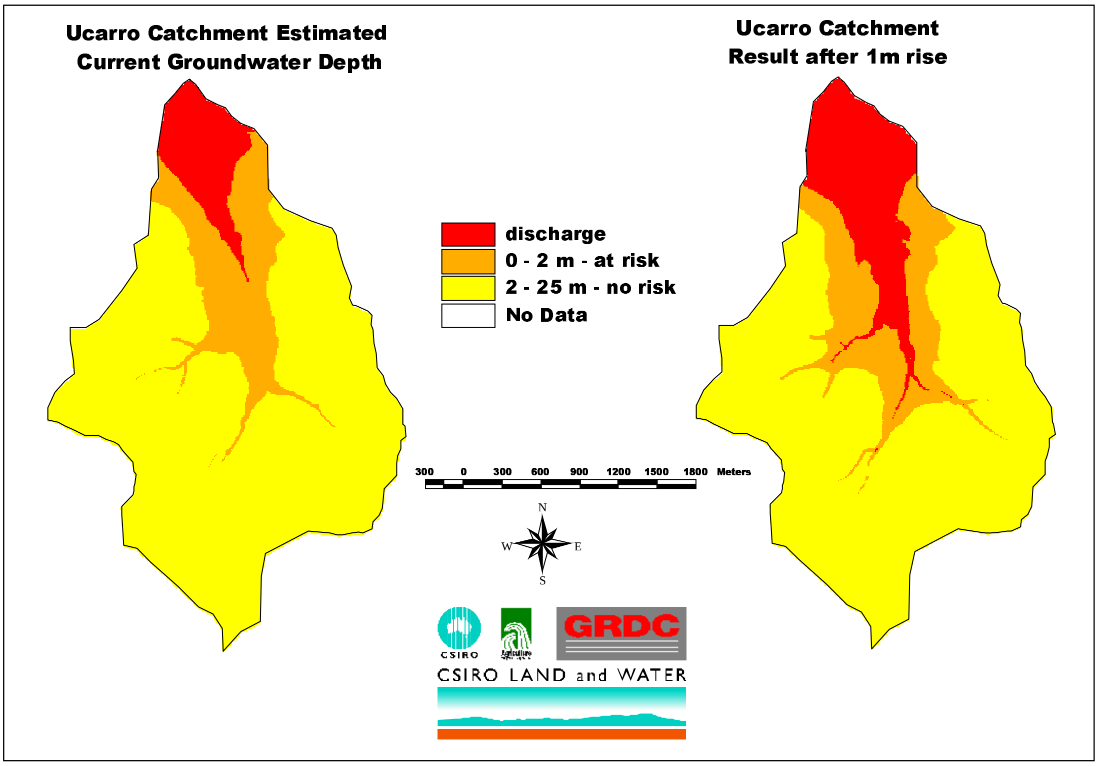


Fig 3.4 Inferred discharge zones for current groundwater levels and after 1m rise.

uniform across catchments, so future models need to account for factors such as remnant vegetation, position in landscape, re-forestation zones, soil type, etc.

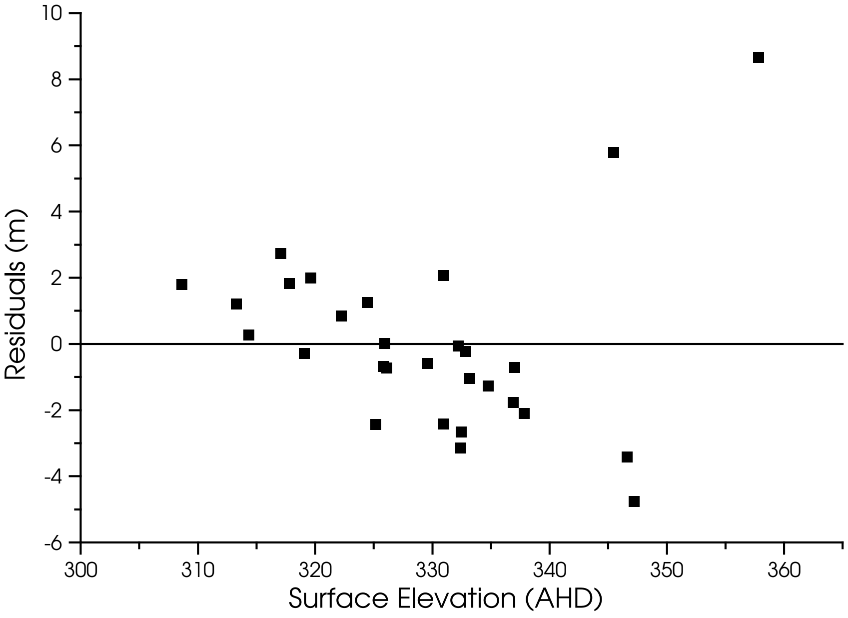


Figure 3.1.2. Residuals for $P_w = 0.859(Z) + 41.021$

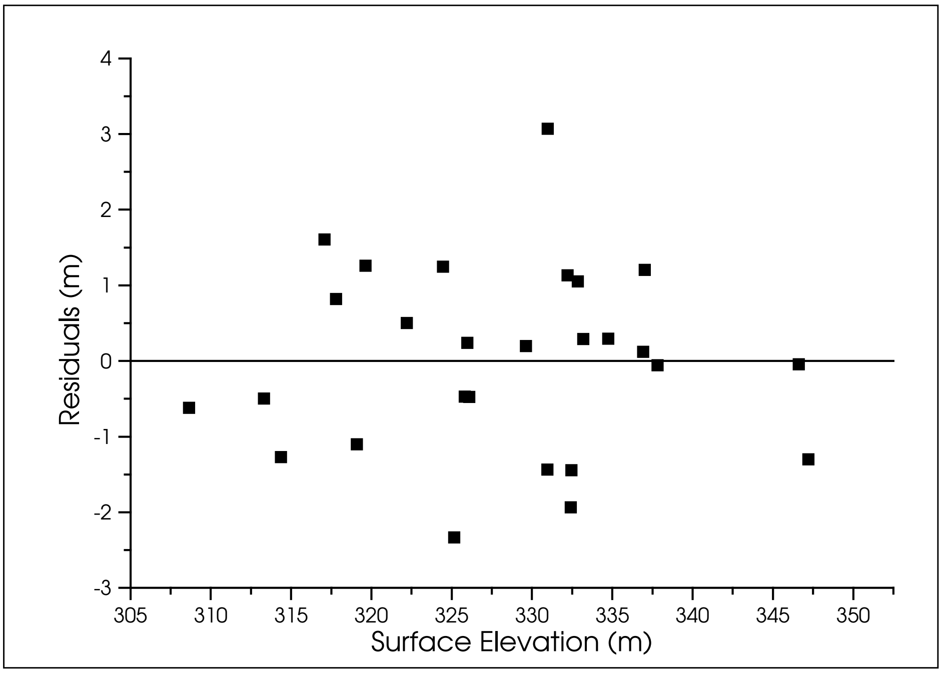


Figure 3.2.2. Residuals for $P_w = 0.7067(Z) + 90.447$

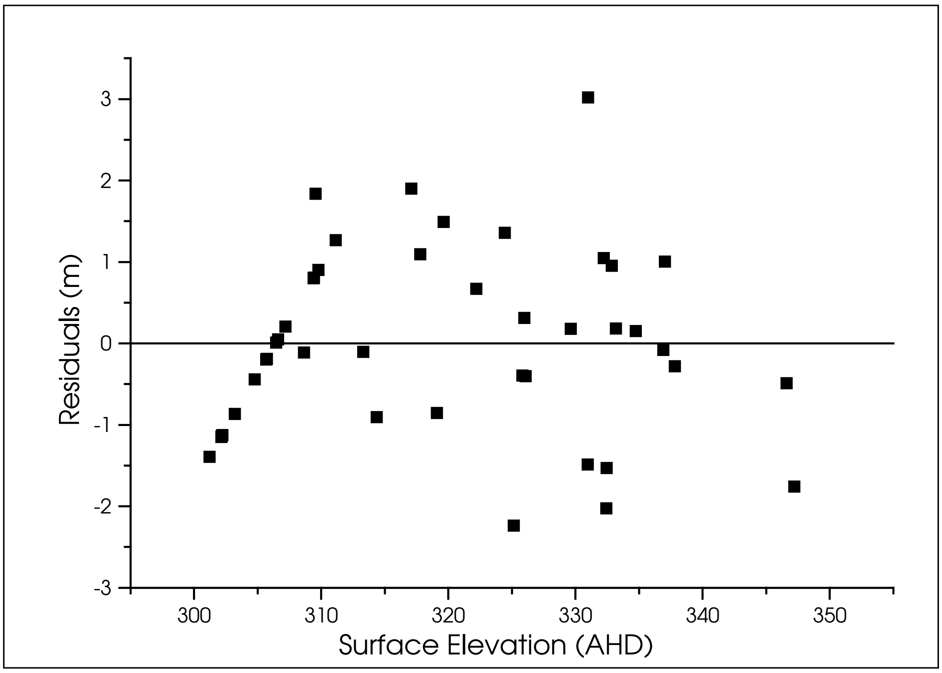


Figure 3.3.2. Residuals for $P_w = 0.7032(Z) + 91.698$

Future Directions:

Clearly this is a rather simplistic approach to prediction of groundwater levels from bore data. For a single sub-catchment like Ucarro this method provides reasonable results, however, at large scales, where multiple catchments and diverse landscapes are involved (i.e. SS2020 study area), pure elevation driven predictions are unlikely to be this accurate. Future work will involve the investigation of using DEM derived variables in the classification of landform units. The concept of "relative elevation" will be examined to address the problem of large-scale variation and the reliance on pure elevation within the regression. If similar relationships between relative elevation and groundwater depth can be identified then this should prove a more robust and statistically acceptable method.

There is also a need for validation and testing of predictions which could be achieved through "leave out" techniques. This has not been attempted in the Ucarro dataset due to the small sample size. Typically one third of the input points are reserved and are used to validate the prediction. There will also be a significant number of bores within the SS2020 study area which do not have sufficient trend data to be included in the prediction of trends but may be used to test predictions for particular dates. It is anticipated that if the trends in groundwater levels can be accurately identified, then a prediction of a water level for a bore can be made for any given date. Thus predictions into the future can be made with a reasonable estimate of error.

Conclusions:

- The principles of HARSD can be applied at the sub-catchment scale to accurately predict groundwater levels.
- Hydrogeomorphic classification may not be necessary to predict water levels at this scale.
- Hydrogeomorphic classification doesn't necessarily account for localised anomalies
- The vetting of anomalous data is critical for accurate prediction
- The addition of known discharge areas improves the fit of the surface

References

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