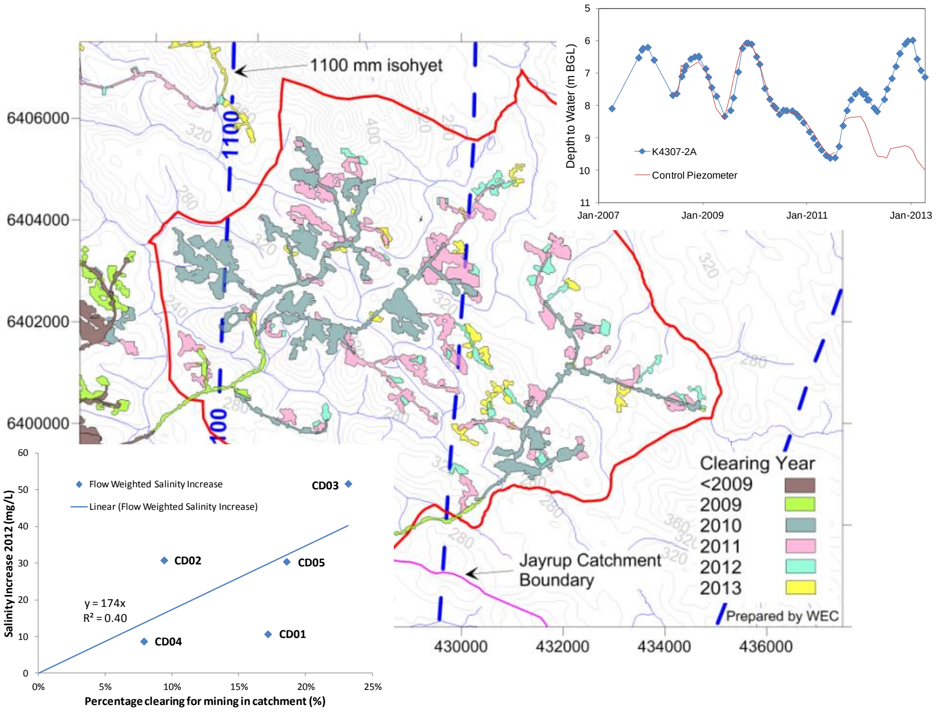
REPORT
TO
BAUXITE HYDROLOGY COMMITTEE

HYDROLOGICAL RESPONSE OF THE O'NEIL TO McCOY MINING AREA



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EXECUTIVE SUMMARY

A study was undertaken to assess the hydrological responses associated with mining the O'Neil-to-McCoy mine area in the Intermediate Rainfall Zone (900 to 1,100 mm/annum, IRZ). The O'Neil to McCoy area was a logical extension of the present operations within the McCoy mining area. Initial salinity-risk assessments for O'Neil to McCoy have already been produced, and tabled at Bauxite Hydrology Committee (BHC) meetings (Croton & Dalton 2008, Croton, *et al*. 2008, Croton & Dalton 2010 and Croton & Dalton 2011). The BHC recommended to the MMPLG that O'Neil-to-McCoy mining should proceed, providing additional items of research and monitoring that were described in Croton & Dalton (2008) be undertaken by Alcoa.

First mining of O'Neil-to-McCoy commenced in 2010 with first clearing in 2009. The historically low rainfall of 2010 caused a decline in groundwater levels and a strong dampening of hydrological behaviour in the O'Neil to McCoy area. In 2011 the BHC decided that a full review of the hydrological responses be held over until after the hydrological system had recovered. With above average rainfall in 2011 and close to average in 2012, this recovery is now at least partly complete. The present report is the requested detailed review and includes a full assessment of the groundwater and stream salinity responses to the mining in the O'Neil-to-McCoy area, as well as recommendations for future monitoring.

Starting with groundwater, Figure I shows the nine responsive piezometers in the O'Neil-to-McCoy mine area. All nine of these piezometers have responded by essentially returning to pre-treatment levels while the control piezometers have languished at deeper levels.

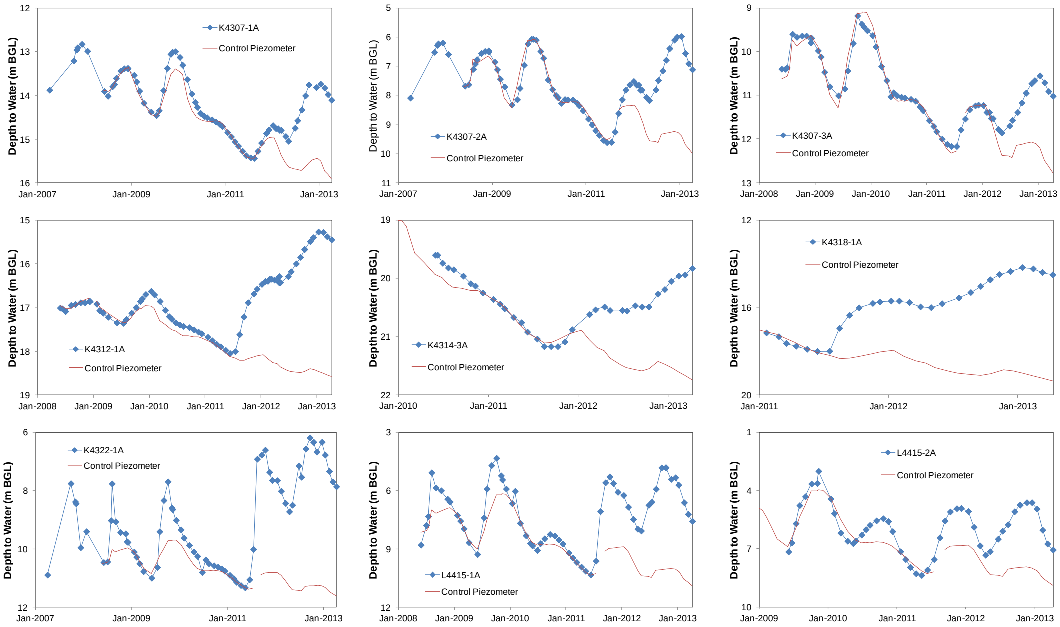

Figure I: Piezometer hydrographs for the nine responsive piezometers in the O'Neil-to-McCoy mine area.

As there are a number of sections of the valley-floor in the O'Neil-to-McCoy mine area where the groundwater is at or near to the soil surface, groundwater contributes to streamflow. The rises shown in Figure I have therefore provided groundwater to streamflow over and above that expected under full forest conditions; resulting in what appears to be a mining-related stream-salinity signature. Using the manually-collected stream-salinity sample data, Figure II shows the salinity responses for the six treated stream-sites compared to the untreated control site. Figure III is a plot of the estimated flow-weighted stream-salinity increase for 2012, obtained by plotting the data for the five continuous-logger sites against the percentage area of clearing for mining in their catchment.

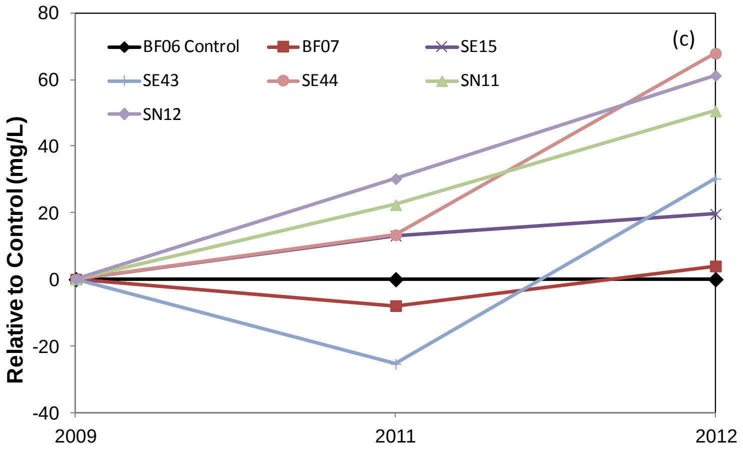

Figure II: October 2009, 2011 and 2012 stream salinity values for those manual stream-salinity sampling points of the O'Neil-to-McCoy mine area that have October data for all three years.

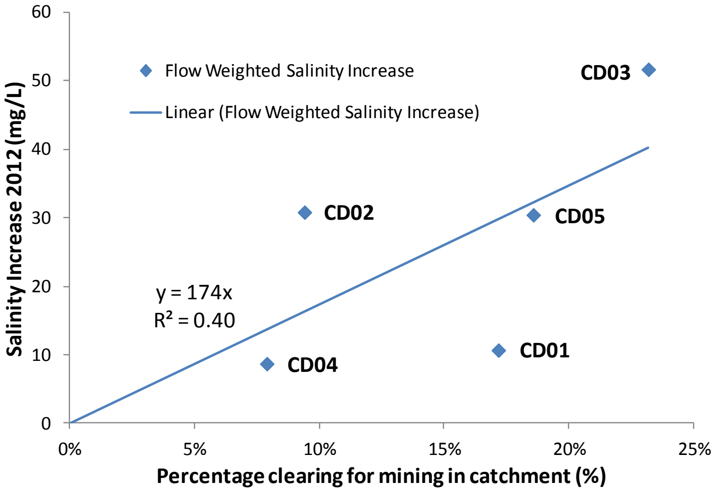

Figure III: Estimated flow-weighted stream-salinity increase for 2012 for the continuous-logger sites, plotted against the percentage area of clearing for mining up to the beginning of 2012.

The data for the O'Neil-to-McCoy mine area was combined with the estimated stream-inflow and water-storage volume for 2012 for the Serpentine Reservoir, to create estimates of the effect of mining of the O'Neil-to-McCoy area on the salinities of the reservoir; these are shown in Table I. The stream-inflow salinity was estimated to increase by 3.0 mg/L due to mining effects, and the pond salinity was estimated to increase by 0.44 mg/L. Neither of these responses were unexpected and are on the low side of what was predicted by Croton & Dalton (2010), and accepted by the BHC when making their recommendation to the MMPLG that O'Neil-to-McCoy mining should proceed. As well, due to the continued below-average rainfalls during the mining period of the O'Neil-to-McCoy area, the saltloads that have actually occurred are an order of magnitude less than those predicted by Croton & Dalton (2010). The estimated mining-related saltload increase in 2012 due to actual O'Neil-to-McCoy mining was 15.3 tonnes, compared to 361 and 419 tonnes for the two scenario-predictions by Croton & Dalton (2010). Given that the salinity of the overall water-supply system is driven by the saltload calculations, that is total salt vs. total water in the system, then what matters to the overall water-supply system is the saltload of the stream-inflow to Serpentine Reservoir rather than the salinity of the stream-inflow.

Table I: Mining related stream-inflow and reservoir-lake saltload calculations for 2012 for the Serpentine Reservoir and mining of the O'Neil-to-McCoy area.

Item	**Flow and Volume** (ML)	**Saltload** (kg)	**Salinity** (mg/L)
Total reservoir inflow	5,047		
Change in reservoir inflow		15,268	3.0
Reservoir pond volume Dec 2012	34,366		
Change in reservoir pond salinity		15,268	0.44

Recommendations were also made as to what monitoring should be continued for the O'Neil-to-McCoy mine area. These recommendations are strongly affected by the present climate, and its likelihood of continuing. It is proposed that if the present below-average rainfalls continue then the hydrological monitoring of the O'Neil-to-McCoy mine area can be maintained at a much lower level than if rainfall patterns change.

A climate change that would trigger consideration of a change in monitoring was defined as at least 1,300 mm/yr rainfall for the Big Brook rain-gauge. Such a rainfall would provide a large water-excess and would significantly replenish soil-water storages and boost streamflow. If rains continue at or below average levels, then they are expected at best to maintain the hydrological status quo.

It is proposed that the monitoring programme outlined in Table II be maintained at least until the end of 2015, unless a rainfall year of 1,300 mm/yr or more occurs, in which case a follow-up review should be undertaken.

Table II Proposed monitoring programme for the O'Neil-to-McCoy mine area.

Item	**No. of sites**	**Monitoring frequency**
Continuous stream salinity loggers	5	15 minute logging interval plus manual check-sampling during winter.
DoW gauging stations	2	Big Brook as treated and Gordon as control. Gordon may have too little flow from 2013 to be useful.
Manual stream salinity monitoring	6 primary sites and 30 secondary	Once per year in October.
Groundwater levels	23	Six weekly manual water-level readings, which is nine times year.
Groundwater water-quality	none	Considered that sufficient data has already been collected.

1. INTRODUCTION

Alcoa of Australia (Alcoa) operates the Huntly and Willowdale mines in the northern jarrah forest on the Darling Plateau. Due to the known issues associated with salinity and agricultural clearing in the south-west of W.A., as part of the revised 1978 Environmental Review and Management Program (ERMP) for the Wagerup Alumina Project, Alcoa made the commitment that "*mining will not take place in the eastern, lower rainfall portion of Alcoa's lease until research shows that operations can be conducted without significantly increasing the salinity of water resources*".

As part of the latest Wagerup approval, this commitment has been changed to now read: *"Bauxite mining will not take place in the eastern, lower rainfall portion of Alcoa's lease, until research shows that mining can be conducted without significantly increasing the salinity of the water resources with exception of the Trial Mining Project in the intermediate rainfall zone which commenced in 2005 to test modelling predictions and mining and rehabilitation methods developed from the 25 years of research to date. This trial was approved by the Mining and Management Programme Liaison Group. Results from the trial mining and continuing hydrology research and modelling will form the basis for future approval by the Mining and Management Programme Liaison Group of Alcoa's plans for mining in the intermediate rainfall zone. These plans will be presented in Alcoa's annual Mining and Management Programme submission at an appropriate date."*

In line with these changes, Alcoa no longer considers an application for general access to the Intermediate Rainfall Zone (900 to 1,100 mm/annum, IRZ) appropriate. Alcoa prefers now to apply for access in a staged approach by including strategically determined sections of the IRZ as part of the annual five-year mine-plans, using the existing approval process with the Mining and Management Programme Liaison Group (MMPLG). The first area of interest is a section of the IRZ within the Serpentine Reservoir catchment, known by the mining area name "O'Neil to McCoy" (Figure 1).

It can be seen from Figure 1 that O'Neil to McCoy is a logical extension of the present operations within the McCoy mining area; this present mining includes the IRZ mining in the Cameron Experimental Mining Exercise (CEME) in the Jayrup and associated catchments (Croton, *et al.* 2011). Initial salinity-risk assessments for O'Neil to McCoy have already been produced, and tabled at Bauxite Hydrology Committee (BHC) meetings (Croton & Dalton 2008, Croton, *et al.* 2008, Croton & Dalton 2010 and Croton & Dalton 2011). The BHC recommended to the MMPLG that O'Neil-to-McCoy mining should proceed, providing additional items of research and monitoring that were described in Croton & Dalton (2008) be undertaken by Alcoa. First mining of O'Neil-to-McCoy commenced in 2010 with first clearing in 2009.

The historically low rainfall of 2010 caused a decline in groundwater levels and a strong dampening of hydrological behaviour in the O'Neil to McCoy area. In 2011 the BHC agreed with the proposal by Croton & Dalton (2011) that a full review of the hydrological responses be held over until after the hydrological system had recovered. With above average rainfall in 2011 and close to average in 2012, this recovery is now at least partly complete. The present report is the requested detailed review and includes a full assessment of the groundwater, streamflow and stream salinity responses to the mining in the O'Neil-to-McCoy area, as well as recommendations for future monitoring.

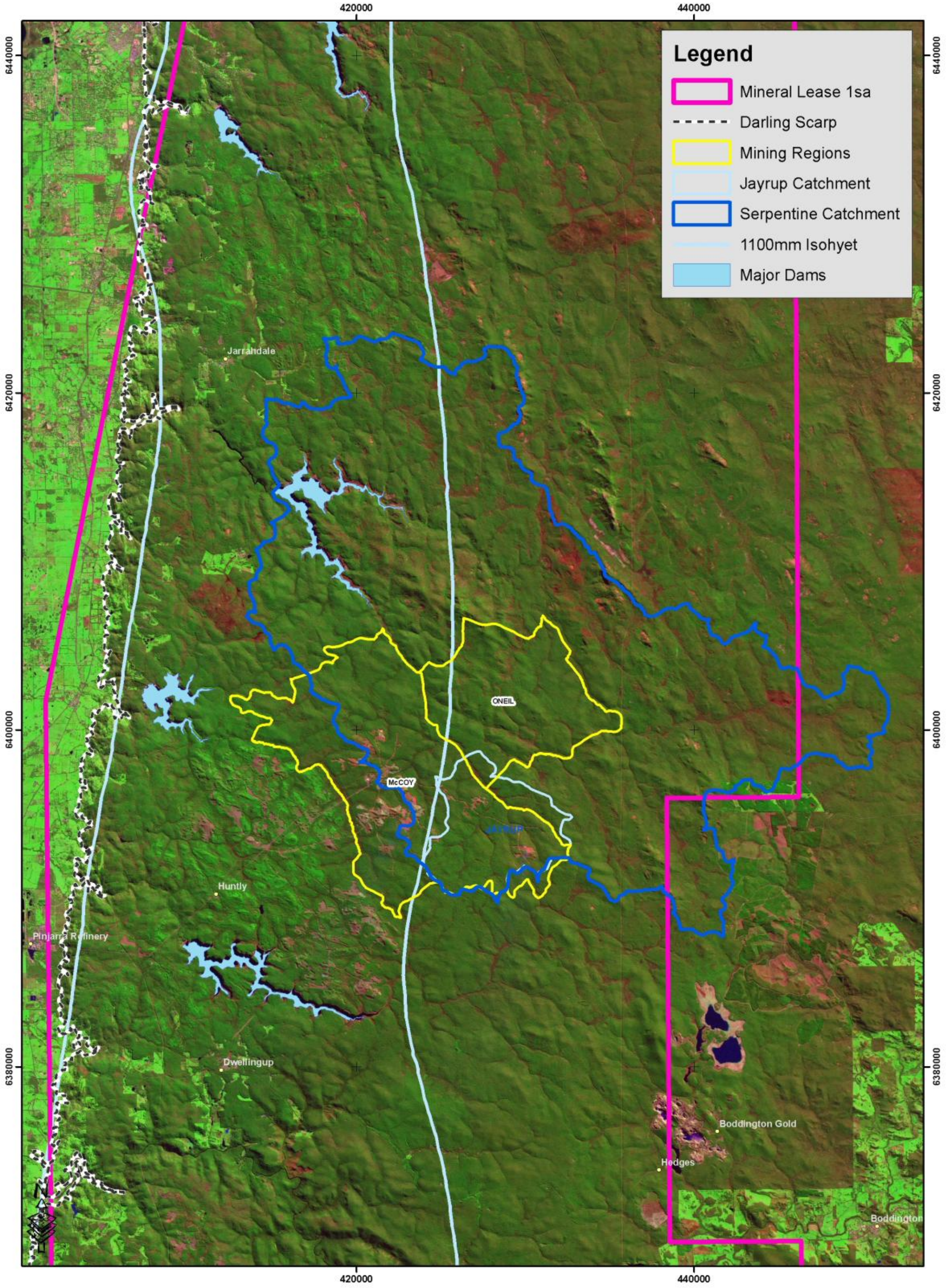

Figure 1: Location of the O'Neil-to-McCoy mine area plotted over the major features of the Darling Plateau. See author's note 1 regarding 1,100 mm isohyet.

Author's note 1: The pre-1978 rainfall isohyets by Hayes & Garnaut (1981) are used throughout this report to estimate rainfalls, as they are the most widely accepted and were used in previous studies.

2. O’NEIL TO McCOY BACKGROUND

2.1 Hydrological Setting

Using data previously collected by Alcoa, Croton & Dalton (2010) provided a detailed review of the soil salt-storages, groundwater salinities and stream salinities of the Darling Plateau and compared them with data collected in the O’Neil-to-McCoy mine area. They concluded that for its rainfall regime, the soil salt-storages, groundwater salinities and stream salinities of the O’Neil-to-McCoy mine area can all be considered typical (Figure 2).

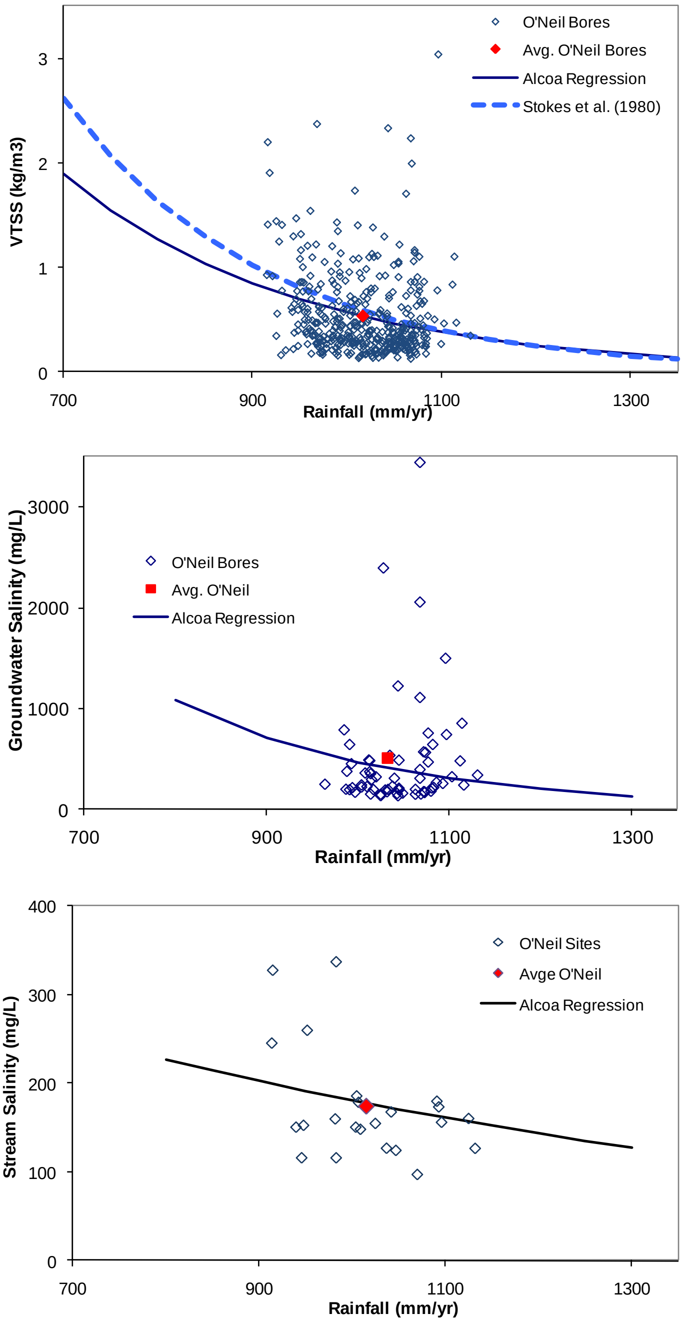

Figure 2: **:** Soil salt-storage (VTSS), groundwater salinity and stream salinity for the O’Neil-to-McCoy mine area. Also plotted are regression curves for the Alcoa data, and for soil salt-storage the regression by Stokes *et al.* (1980) is included as well.

Croton & Dalton (2010) also noted that for stream salinities there has been a definite decline with time, probably associated with the present below-average rainfall period (Figure 3).

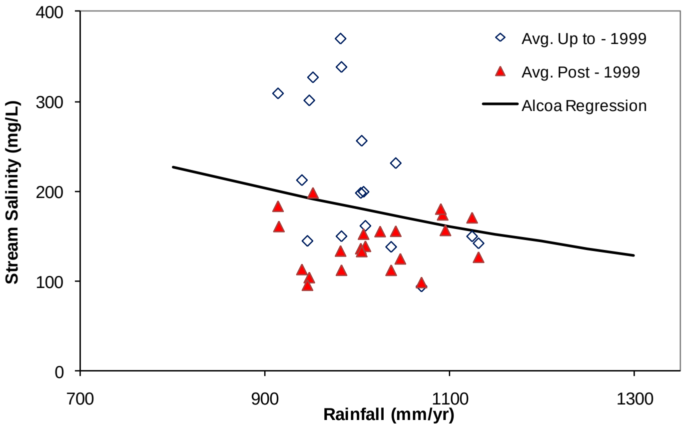

Figure 3: Average stream-salinity for the monitoring points in the O'Neil-to-McCoy mine area, divided into the two periods of upto-1999 and post-1999. The regression curve from Figure 2 has also been plotted.

The depth to groundwater is a significant factor in the O'Neil-to-McCoy mine area hydrology, particularly in stream areas downslope of mine areas. Croton & Dalton (2010) used the available minimum depth-to-water data for 2009 to produce an estimated depth-to-water map for that year (Figure 4).

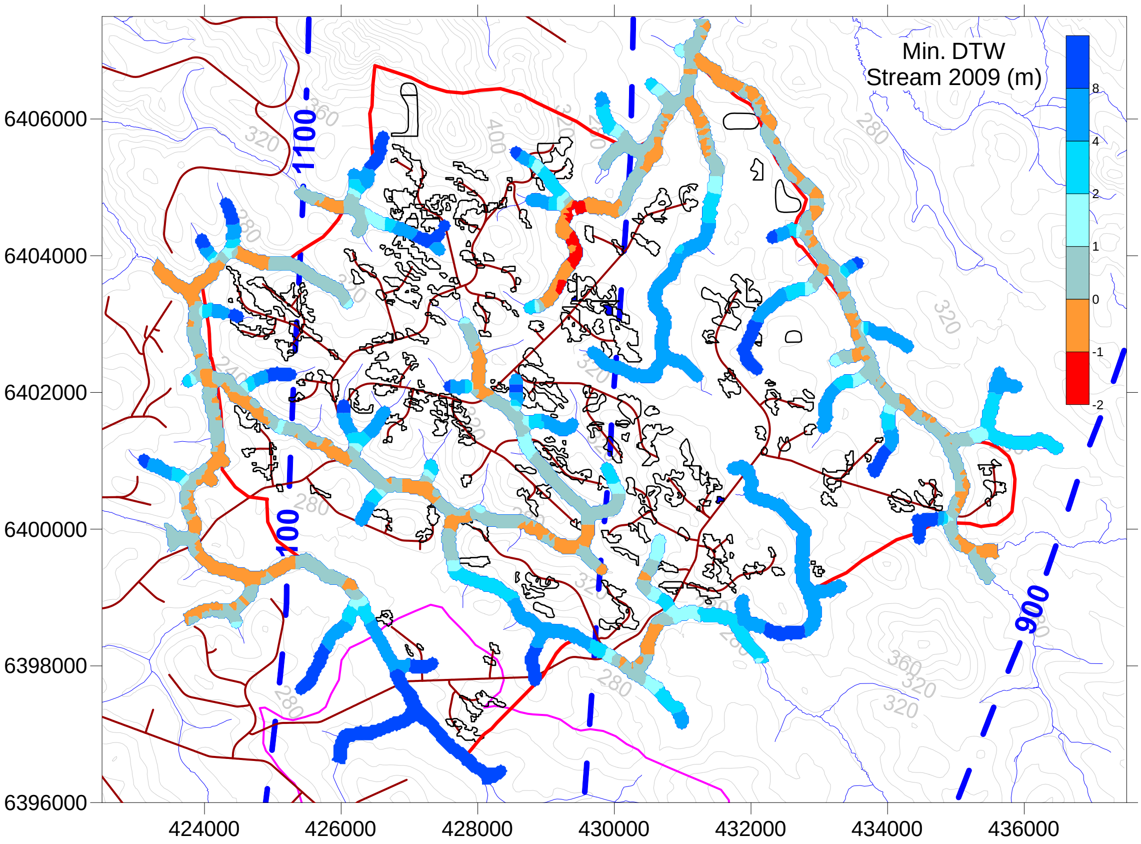

Figure 4: Estimated minimum DTW in 2009 for streamlines in the O'Neil-to-McCoy mine area.

A key conclusion from Figure 4 is that for a considerable fraction of the stream system in the O'Neil-to-McCoy mine area the peak groundwater level in 2009 was at or near the soil surface. Given the present below-average rainfall conditions, it can be assumed that historical groundwater-levels would have been higher and the historical contact between groundwater and the soil surface in the streamzone would have been more extensive. This proximity of the groundwater to the soil surface implies groundwater contributions to streamflow across significant sections of the O'Neil-to-McCoy mine area stream-system; borne out by the stream salinities in Figures 2 and 3 being 100 mg/L and above. When the groundwater system is fully disconnected from streamflow generation, e.g. the Gordon catchment in the Cameron catchment group, stream salinities remain below 100 mg/L (Croton, *et al.* 2011).

The removal of the vegetation cover to allow mining to proceed in the O'Neil-to-McCoy area will cause an increase in groundwater discharge compared to the unmined situation, resulting in some increase in stream salinity compared to unmined levels. The estimates of likely mining effects made by Croton & Dalton 2008, Croton, *et al*. 2008 and Croton & Dalton 2010 were all based on this premise and placed emphasis on putting these effects into hydrological perspective. Past recommendations by the BHC that mining in the O'Neil-to-McCoy area should proceed were based on the committee's consideration that these effects are likely to be acceptable.

In defining the hydrological setting for the O'Neil-to-McCoy mine area, an important component is understanding the differences between this area and the Cameron experimental catchments directly to the south of the O'Neil-to-McCoy mine area (Figure 1). Croton, *et al.* (2011) found that there was almost complete absence of any observable response to mining in the streamflow and stream-salinity records for the Cameron experimental catchments. This lack of stream response in the Cameron experimental catchments was considered by Croton, *et al.* to be directly due to groundwater being at depth in the streamzones of all the catchments prior to the study commencement, and at no time during the study did mining cause it to rise near to the surface. This situation is very different to that for the O'Neil-to-McCoy mine area.

2.2 O'Neil to McCoy Mineplan

Figure 5 shows by clearing year the O'Neil-to-McCoy area and the mine areas that are within and adjacent to it. First clearing within the O'Neil-to-McCoy mine area was in 2009, with all complete by mid-2013. In Figure 6 the mine areas have been divided into two: those cleared, mined and rehabilitated; and those cleared but still within the mining process and not yet rehabilitated.

Figure 7 is a false-colour Landsat 8 image for 31st May 2013 using the bands near-infrared, green and blue. The presently cleared or recently rehabilitated areas with little vegetation cover show as light brown, forest as a dark green, and mine rehabilitation two or more years old as bright green. The O'Neil-to-McCoy mine area is presently at a minima in terms of vegetation cover on mine areas; no areas yet have the bright green of new foliage as seen in the bottom left-hand corner of Figure 7.

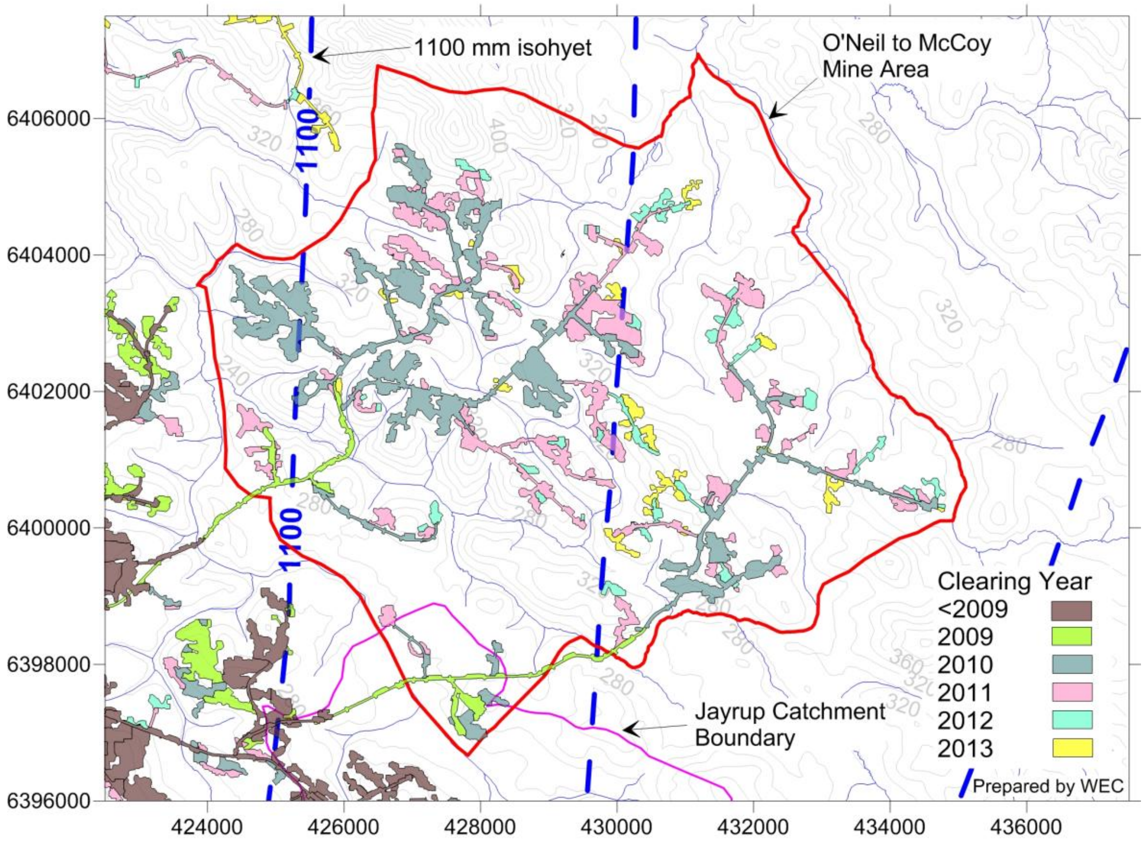

Figure 5: Clearing by year for the O'Neil-to-McCoy mine area.

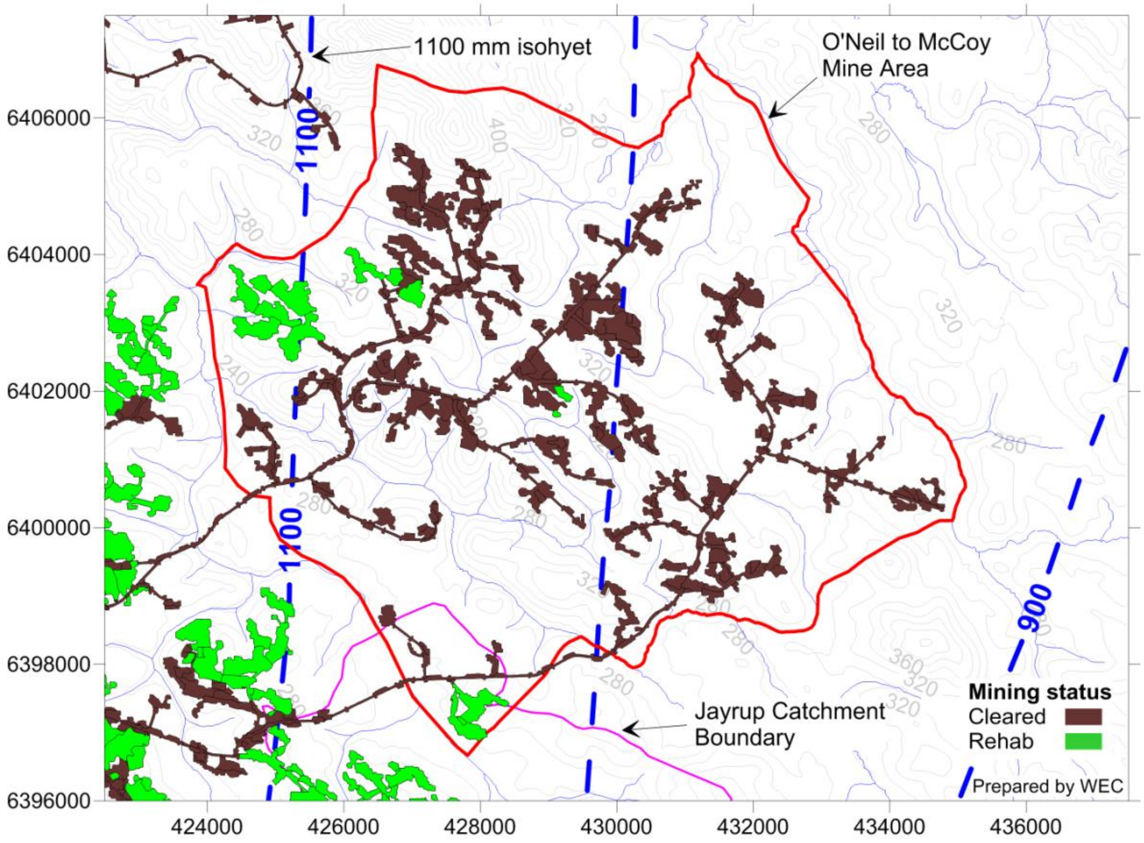

Figure 6: Clearing and post-mining rehabilitation areas for the O'Neil-to-McCoy mine area.

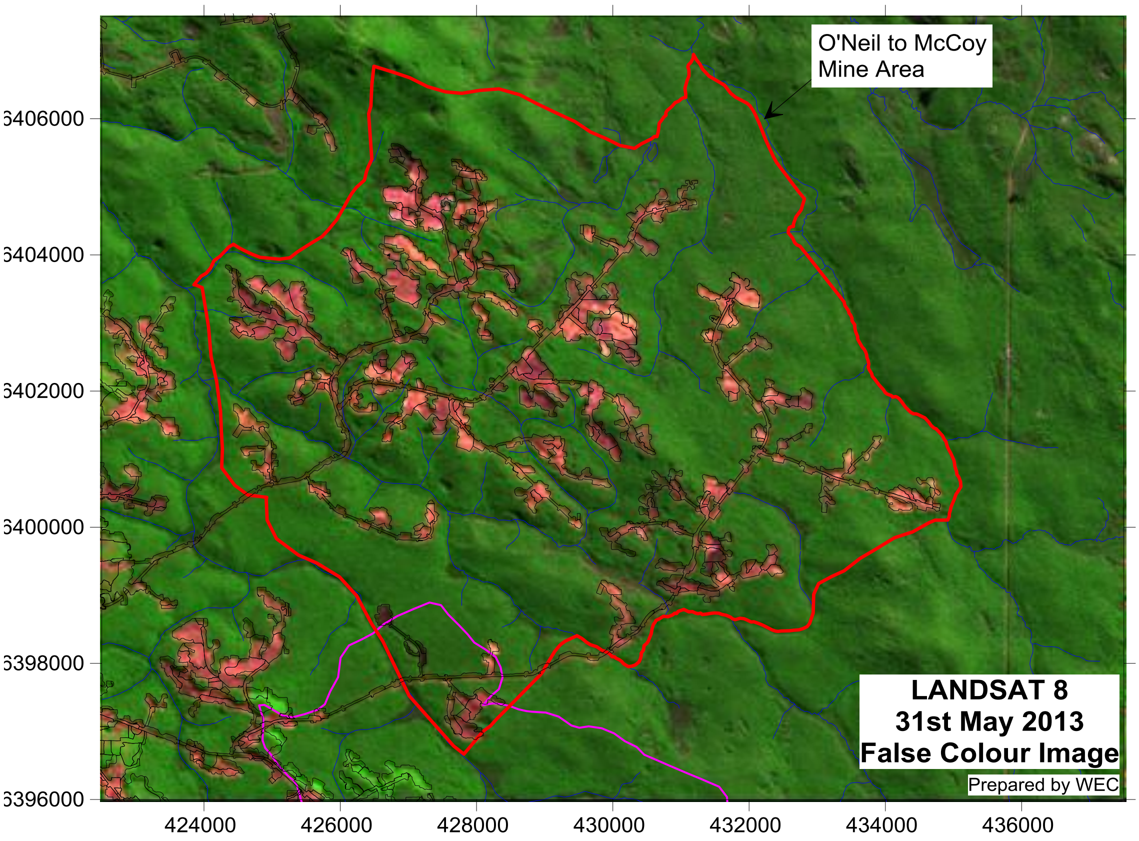

Figure 7: Clearing outlines for the O'Neil-to-McCoy mine area plotted over a false colour Landsat 8 image for 31st May 2013.

2.3 Climatic Setting

Before embarking on a review of the monitoring results per se, it is best to first review the historical rainfalls and to understand the trends they contain, particularly those associated with the recent below-average rainfall period. Figure 8 shows the annual-rainfalls (see author's note 2) for the Big Brook pluviometer for the period 1889 to present. These are synthetic annual rainfalls obtained from the SILO Data Drill system (http://www.longpaddock.qld.gov.au/silo/, see author's note 3).

It can be seen there have been four distinct periods of rainfall behaviour for the Big Brook site. Firstly, there was a period of below-average rainfall which persisted up to the dry year of 1914. This was followed by a period of average and above average rainfall from 1915 till 1974. The year 1975 marks the beginning of a below-average period where, while the mean for this period is below the record average, there are still frequent moderate-rainfall years which rise above the mean. The fourth, and last, period is from 2001 to date where only one year (2003) rose above the long-term mean, with the rest below it. There are only eight years with a rainfall below 800 mm/yr in the complete 124 years of record; three of these occur from 2001 on, including the historically-low year of 2010.

Author's note 2: This report uses the standard calendar year, 1st January to 31st December, for annual reporting of data. A water year of 1st May to 30th April is often used in south-west W.A., but this is not considered advisable here as it fails to consider the effects of summer rainfall on the antecedent conditions of a catchment and its effect on streamflow in the coming winter.

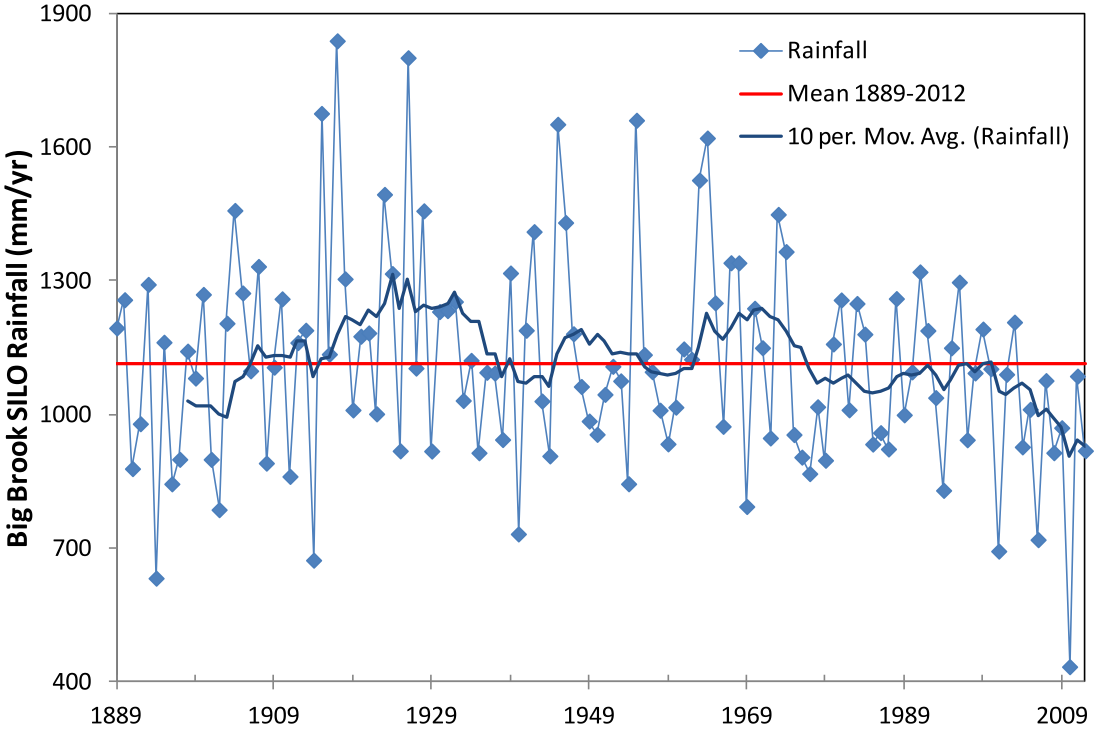

Figure 8: Synthetic annual rainfalls from 1889 for the Big Brook pluviometer obtained using the SILO Data Drill system, see author's note 3.

A close inspection of Figure 8 reveals two components to the rainfall behaviour of the recent period compared to the balance of the dataset. Firstly, as already said, there is the over-representation of low rainfall years, there are three years with a rainfall below 800 mm/yr in the 12 years since 2001. Secondly, there is the general absence of high-rainfall years with this trend extending back to 1975; there has been only one year with a rainfall above 1,300 mm/yr since 1975 (1,321 mm in 1991, or once in 37 years), while there are some 20 years above 1,300 mm/yr in the balance of the record (once every 4.5 years). Given the non-linearity of hydrological processes on the Darling Plateau due to its dominance by evapo-transpiration, with the high-rainfall years producing proportionally much more groundwater recharge and streamflow, it is likely that the general lack of high-rainfall years since 1975 is a greater driver of the presently observed hydrological decline than is the increase in the number of below-average rainfall years.

In the following review of the hydrological responses in the O'Neil-to-McCoy area to mining, it appears that the recent below-average rainfall period is acting as a dampener on the observed responses, and the hydrological behaviour is much more subdued than would be expected if we were studying a treatment during a wetter period.

Author's note 3: There a number of significant differences between the annual rainfalls for Big Brook from the SILO Data Drill system (http://www.longpaddock.qld.gov.au/silo/) and those previously developed for long time-series by using observed data, e.g. those for the Cameron West catchment by Croton *et al*. (2011). However, for the purposes of Figure 6, the SILO Data Drill data has been deemed sufficient.

3. O'NEIL TO McCOY GROUNDWATER DATA

3.1 Groundwater Level Data

Figure 9 shows the location of the 96 deep piezometers that have been established in the O'Neil-to-McCoy mine area. Appendix A provides hydrograph plots for all available water-level data for these piezometers.

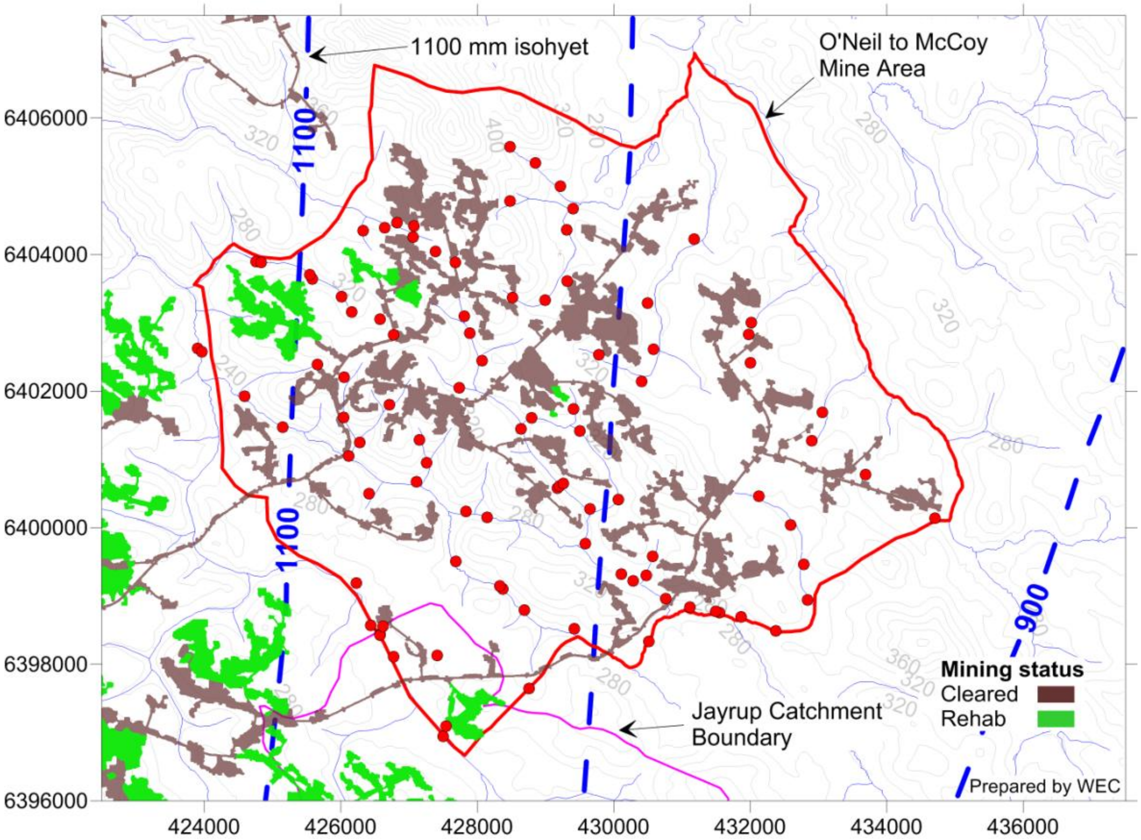

Figure 9: Location of the 96 deep groundwater piezometers in the O'Neil-to-McCoy mine area.

To make the groundwater-level data easier to interpret, we have divided the data into annual minimum depth-to-water classes of <1.0 m, 1 to 2 m, 2 to 4 m and >4 m. The map for 2009 is shown in Figure 10. Like the estimated depth-to-water map shown in Figure 4, it can be seen that a number of valley-floor piezometers had a groundwater depth of <1.0 m in 2009. However, the historically-low rainfall of 2010 had a marked effect, with groundwater declines (increasing depth-to-water) for every piezometer in the O'Neil-to-McCoy mine area regardless of its position or association with activities such as clearing for mining. Figure 11 shows the minimum depth-to-water for 2010 plotted in the same manner as in Figure 10. There are only seven piezometers in 2010 with groundwater within a metre of the surface, whereas there were 24 in 2009. There was some recovery in 2011 (Figure 12), when there were 11 piezometers with groundwater within a metre of the surface, and nine in 2012 (Figure 13).

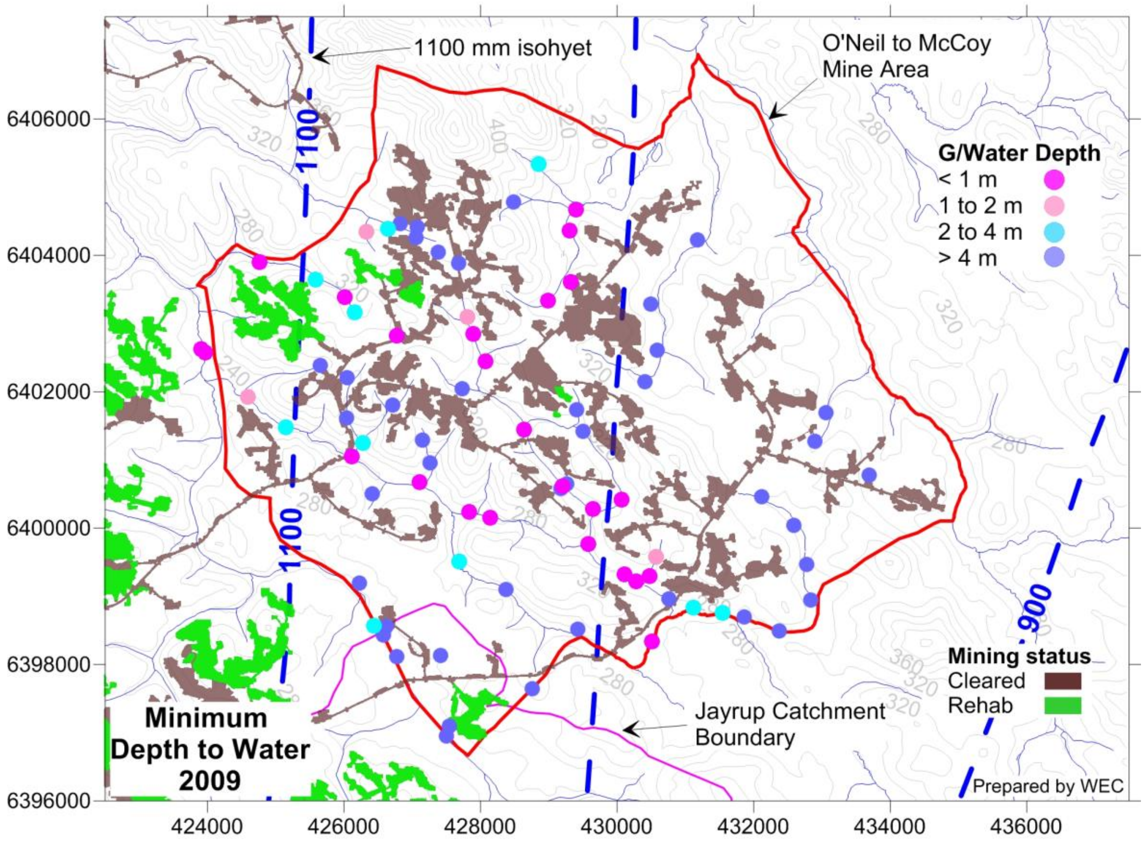

Figure 10: Minimum depth-to-water for 2009 for the groundwater piezometers in the O'Neil-to-McCoy mine area.

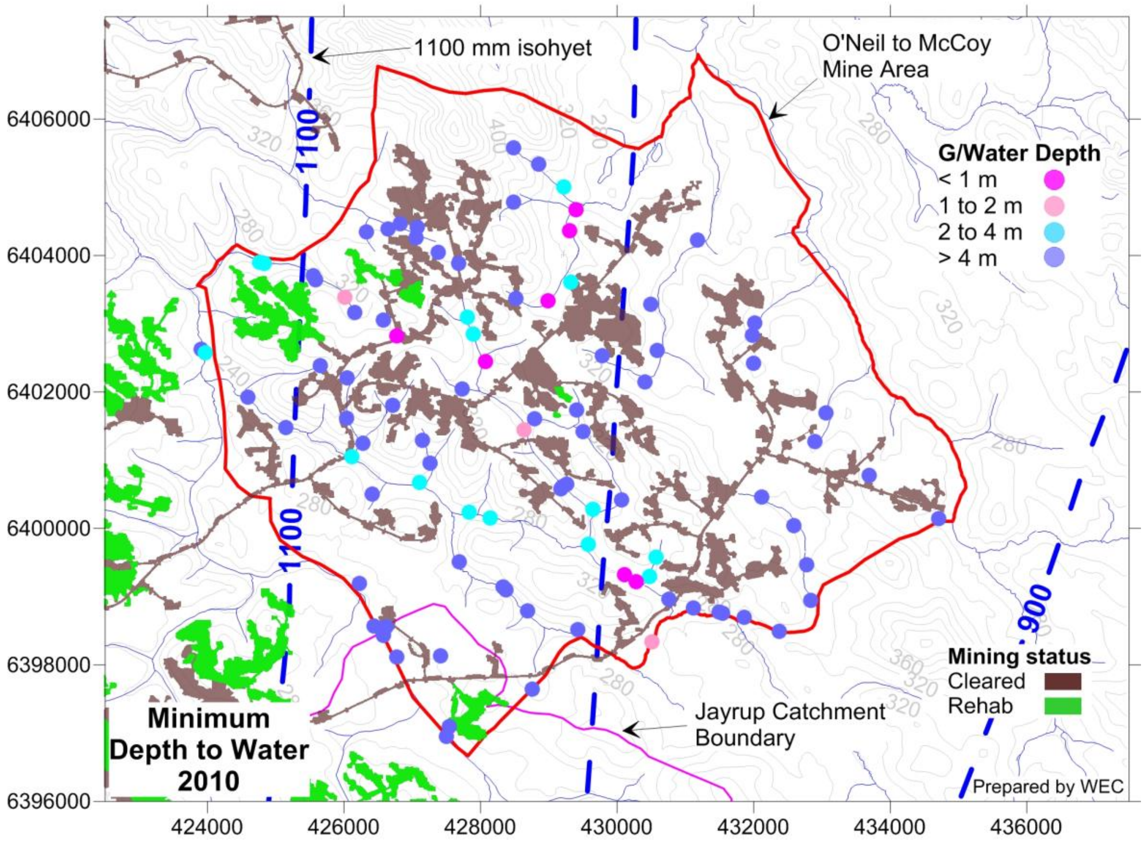

Figure 11: Minimum depth-to-water for 2010 for the groundwater piezometers in the O'Neil-to-McCoy mine area.

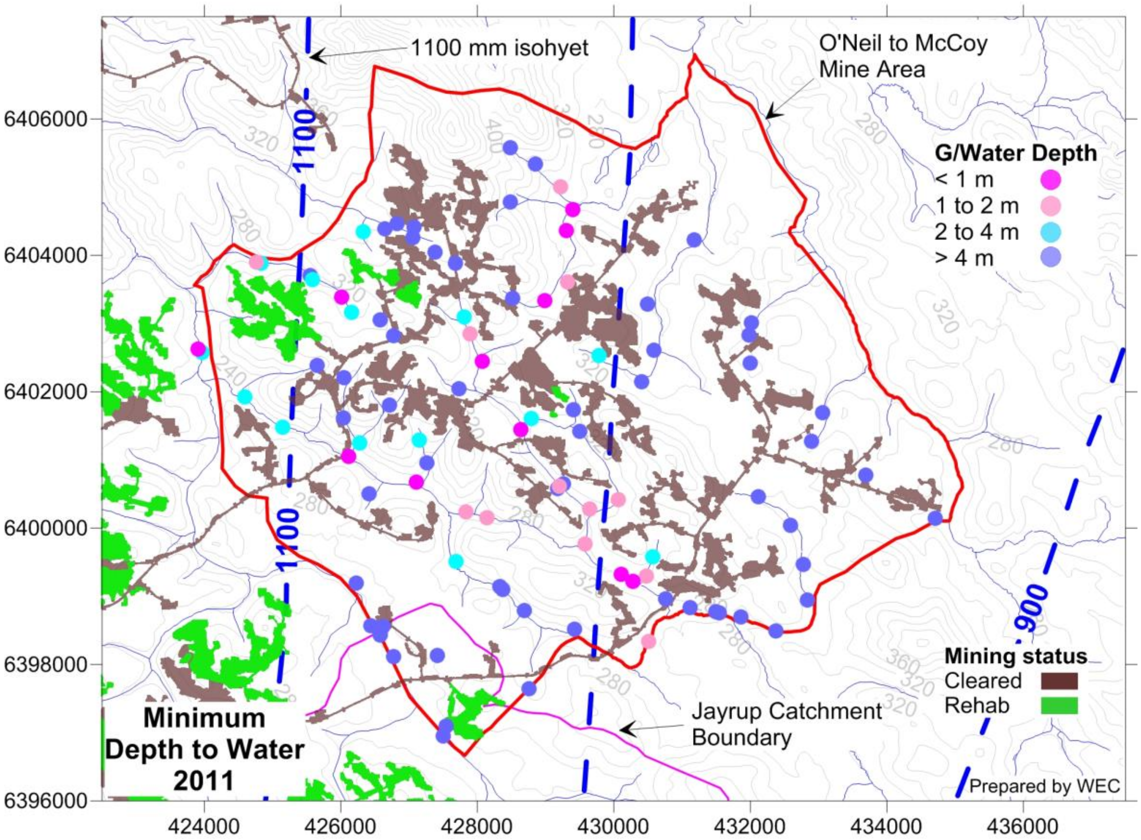

Figure 12: Minimum depth-to-water for 2011 for the groundwater piezometers in the O'Neil-to-McCoy mine area.

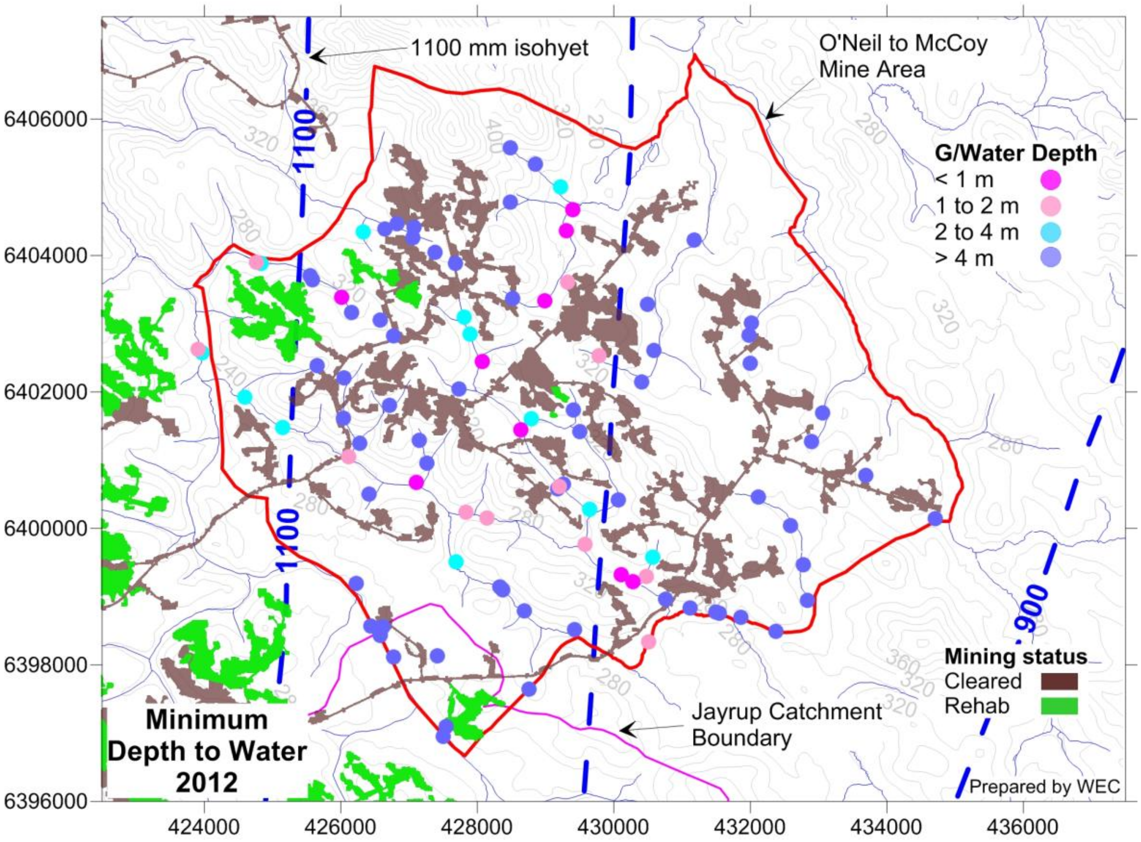

Figure 13: Minimum depth-to-water for 2012 for the groundwater piezometers in the O'Neil-to-McCoy mine area.

The most useful plots when interpreting the responses to mining are those where the difference in level is compared between years. It was seen in Figure 5 that only a small area within the O’Neil-to-McCoy mine area was cleared in 2009 and so 2009 can for all practical purposes be taken as the last pre-treatment year.

Figure 14 is a plot of the change in minimum depth-to-water from 2009 to 2011 for the groundwater piezometers in the O’Neil-to-McCoy mine area. As mentioned already, the historically-low rainfall of 2010 caused every piezometer in the O’Neil-to-McCoy mine area to decline in 2010, so this year isn’t being used in the comparisons. It can be seen that between 2009 and 2011 only two piezometers have risen in level, K4312-1A and K4322-1A, with all others essentially equivalent between years in level or declining.

Figure 15 is a plot of the change in minimum depth-to-water from 2009 to 2012 for the groundwater piezometers in the O’Neil-to-McCoy mine area. While there are differences between Figures 14 and 15, these are not large and there are only three piezometers with significant rises between 2009 and 2012: K4312-1A and K4322-1A as per Figure 14, plus K4419-3A in the south of the O’Neil-to-McCoy mine area. However, K4419-3A has a doubtful hydrograph shape and has been dropped from the following analysis.

Figure 16 shows a difference plot between 2011 and 2012. While the majority of the piezometer water-levels are still essentially equivalent or declining, nine piezometers in this plot have risen in 2012 to be 0.25 m or more above the 2011 level; all these rising piezometers are closely associated with mining. The groundwater hydrographs for these nine piezometers are shown in Figure 17, and their rises compared to control piezometers are tabulated in Table 1.

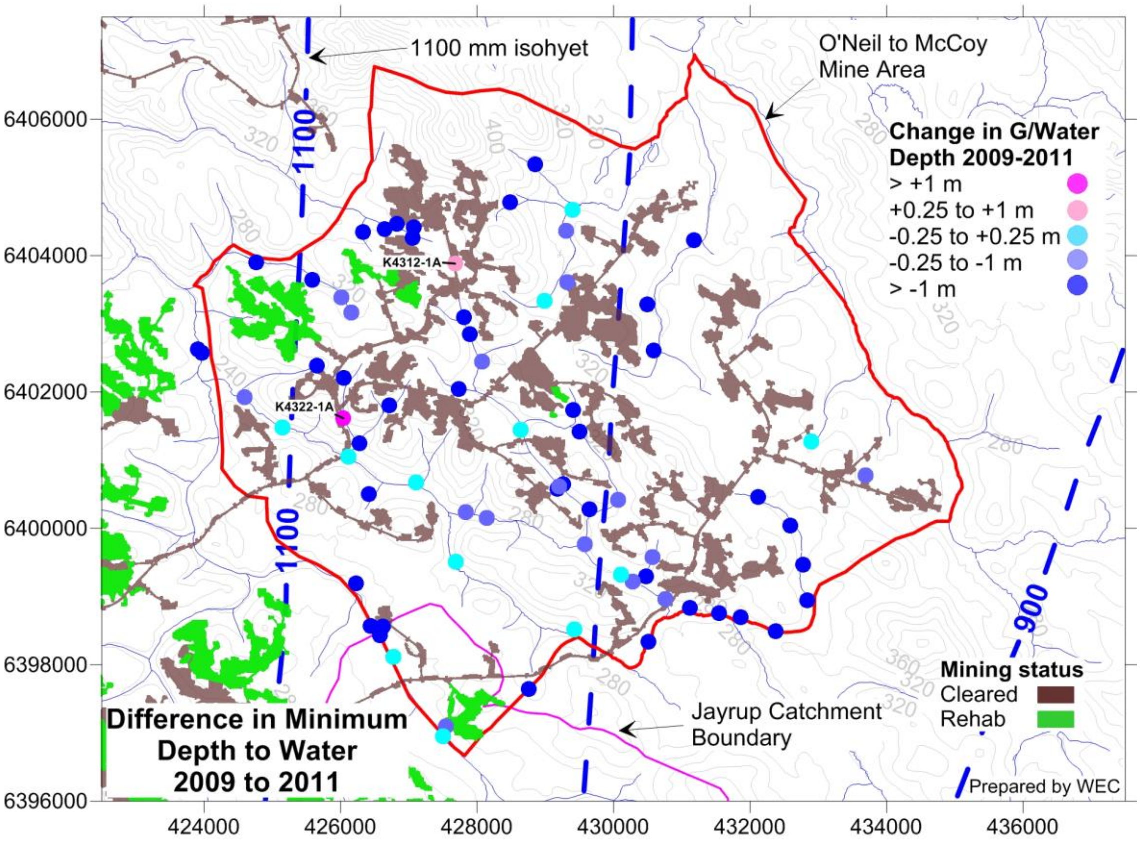

Figure 14: Change in minimum depth-to-water from 2009 to 2011 for the groundwater piezometers in the O’Neil-to-McCoy mine area.

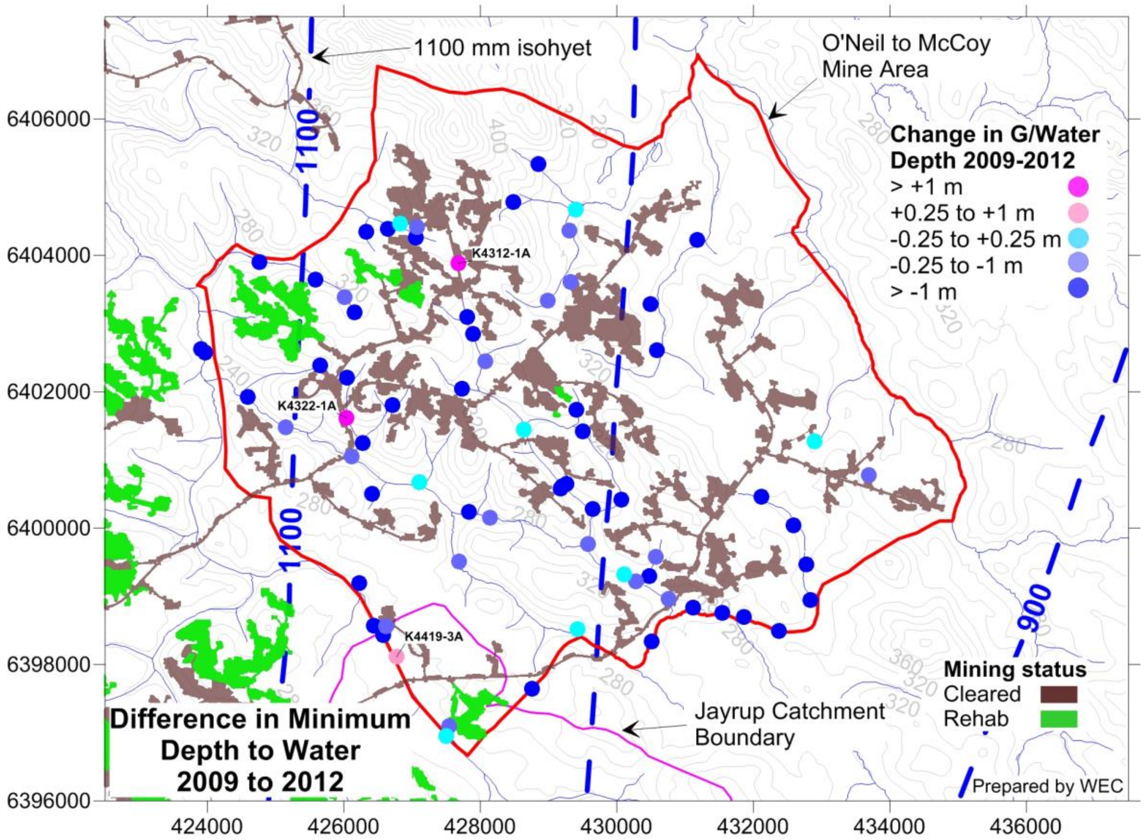

Figure 15: Change in minimum depth-to-water from 2009 to 2012 for the groundwater piezometers in the O'Neil-to-McCoy mine area.

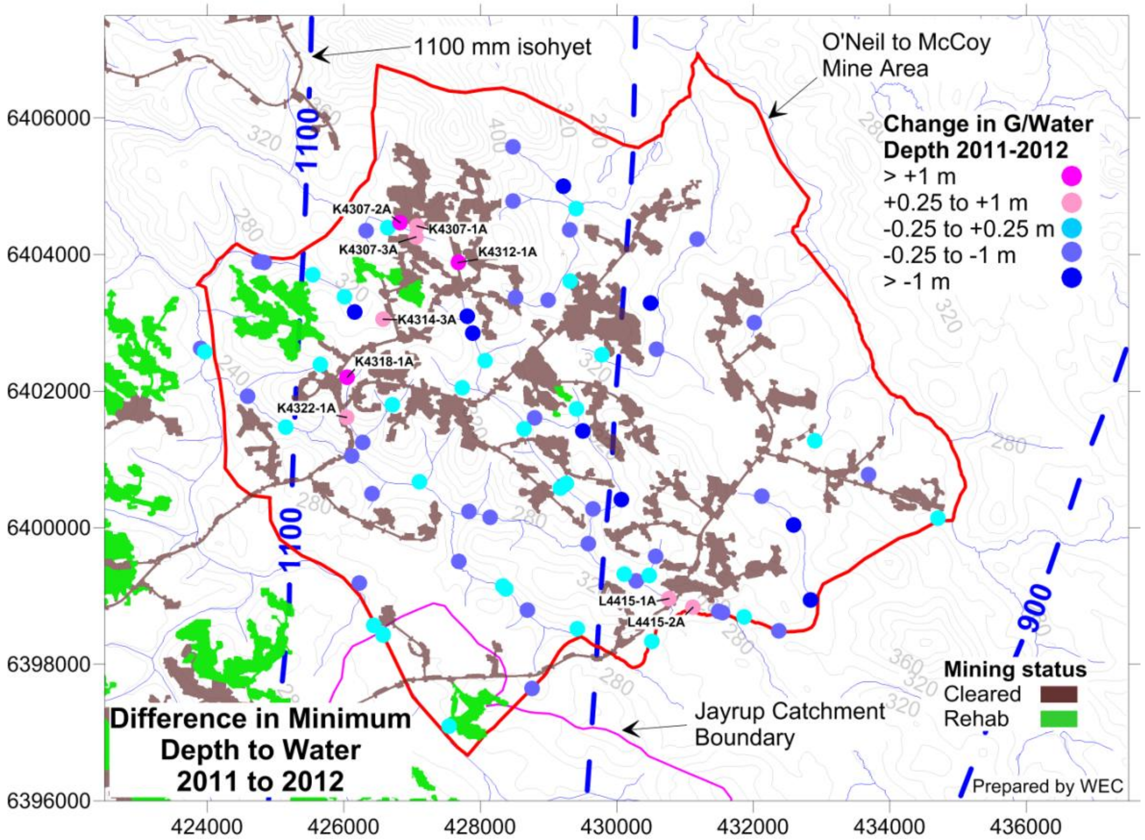

Figure 16: Change in minimum depth-to-water from 2011 to 2012 for the groundwater piezometers in the O'Neil-to-McCoy mine area.

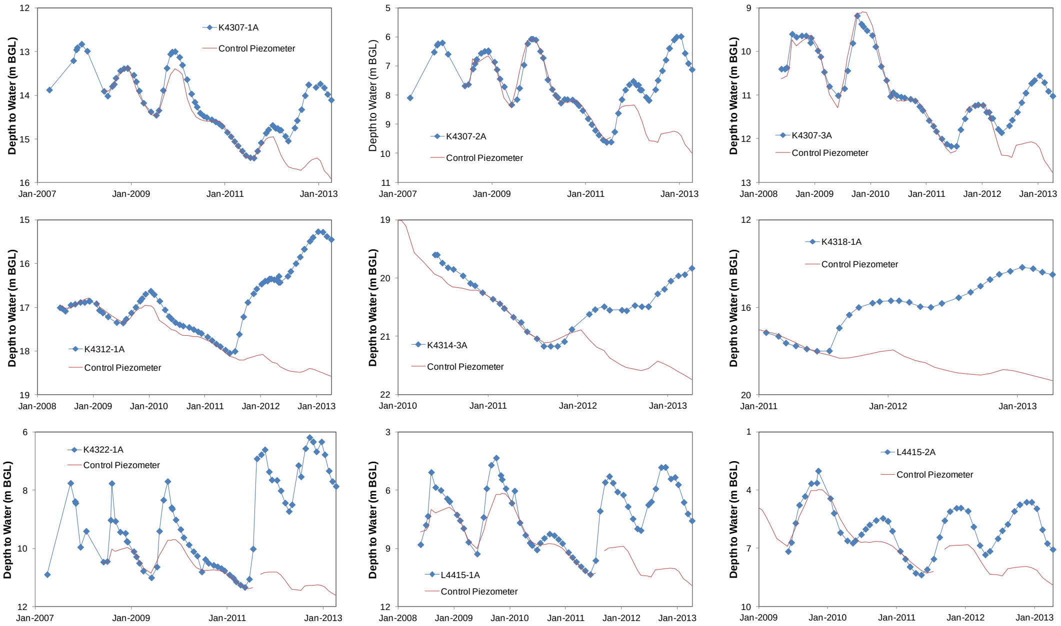

Figure 17: Piezometer hydrographs for the nine responsive piezometers labelled in Figure 16.

Table 1: Groundwater rises for the nine responsive piezometers labelled in Figure 16 compared to control piezometers.

Piezometer	**Easting** (m GDA94)	**Northing** (m GDA94)	**Rise Relative to Control** (m)
K4307-1A	427071	6404417	1.8
K4307-2A	426823	6404469	3.4
K4307-3A	427058	6404259	1.5
K4312-1A	427676	6403882	3.2
K4314-3A	426576	6403052	1.6
K4318-1A	426050	6402205	4.8
K4322-1A	426040	6401615	4.0
L4415-1A	430763	6398962	5.4
L4415-2A	431115	6398834	3.2

It can be seen from Figure 17 and Table 1 that significant rises have occurred relative to the control piezometers. The largest rise was 5.4 m for L4415-2A which is directly downslope of a crescent-shaped area of mining. It can be seen from Figure 17 that the historically-low rainfall of 2010 caused there to be little or no hydrograph peak in 2010, and this in turn makes the rises due to mining essentially a restoration of the levels in 2009 rather than a rising to higher levels.

3.2 Groundwater Salinity Data

It was shown in the previous section via Figures 10 to 13 that the yearly peak groundwater-level in the valley-floors of the O’Neil-to-McCoy mine area was at or near the surface for a number of streams over this period. This implies that groundwater would have interacted with streamflow generation during this period and would also be having an effect on stream salinity. Such a process was expected, and was discussed at length by Croton & Dalton (2010). A key component of the modelling by Croton & Dalton (2010) was an assumed salinity for the discharging groundwater that was contributing to streamflow. They produced a map of groundwater salinity for the O’Neil-to-McCoy mine area from the groundwater salinity data collected in November 2009 (Figure 18). To assess whether the groundwater salinity has been varying due to the mining process, follow-up groundwater salinity collection programmes have been undertaken each year; Figure 19 shows the latest for November 2012, and Figure 20 shows the difference between 2009 and 2012. It can be seen that there is consistency between the two datasets, with only one piezometer, K4408-2A, having a significant increase in salinity (223 mg/L in 2009 to 638 mg/L in 2012). Interestingly, this piezometer is distant from any mining, so the variation almost certainly relates to some factor other than mining.

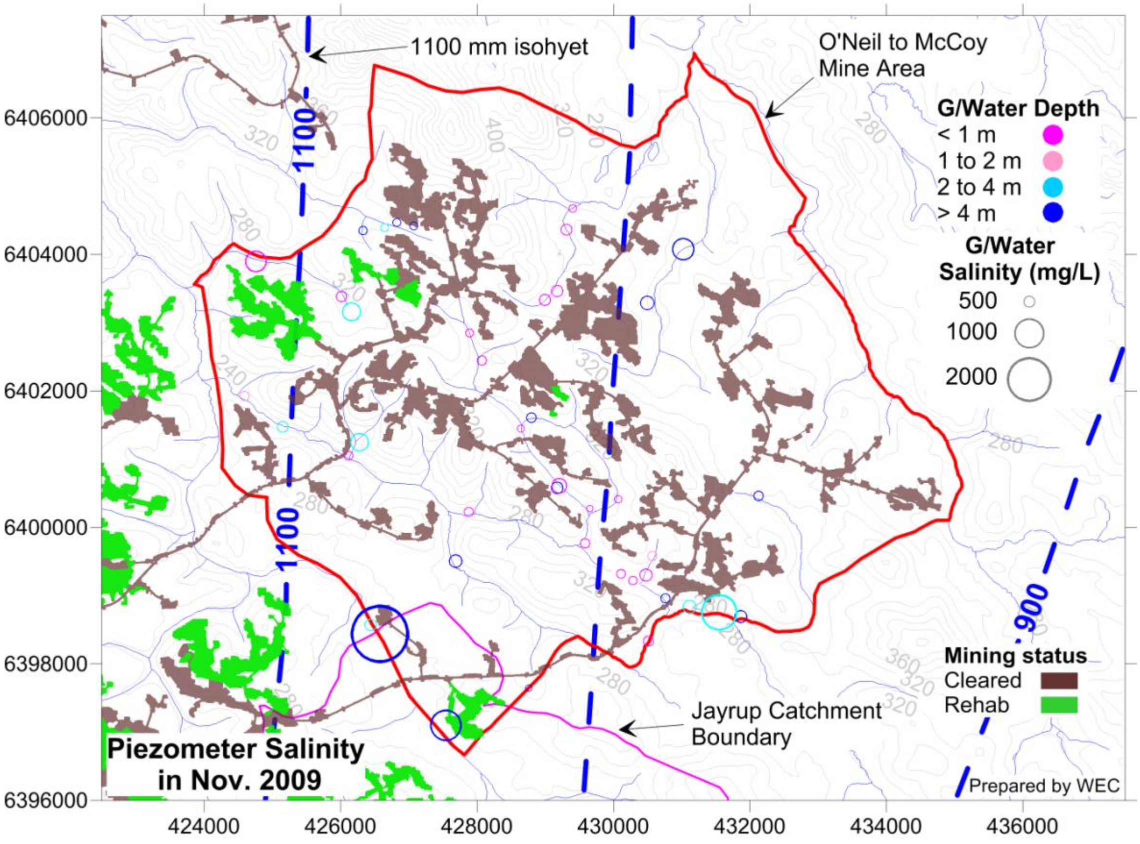

Figure 18: Piezometer groundwater salinities from the pump-sampling programme in November 2009.

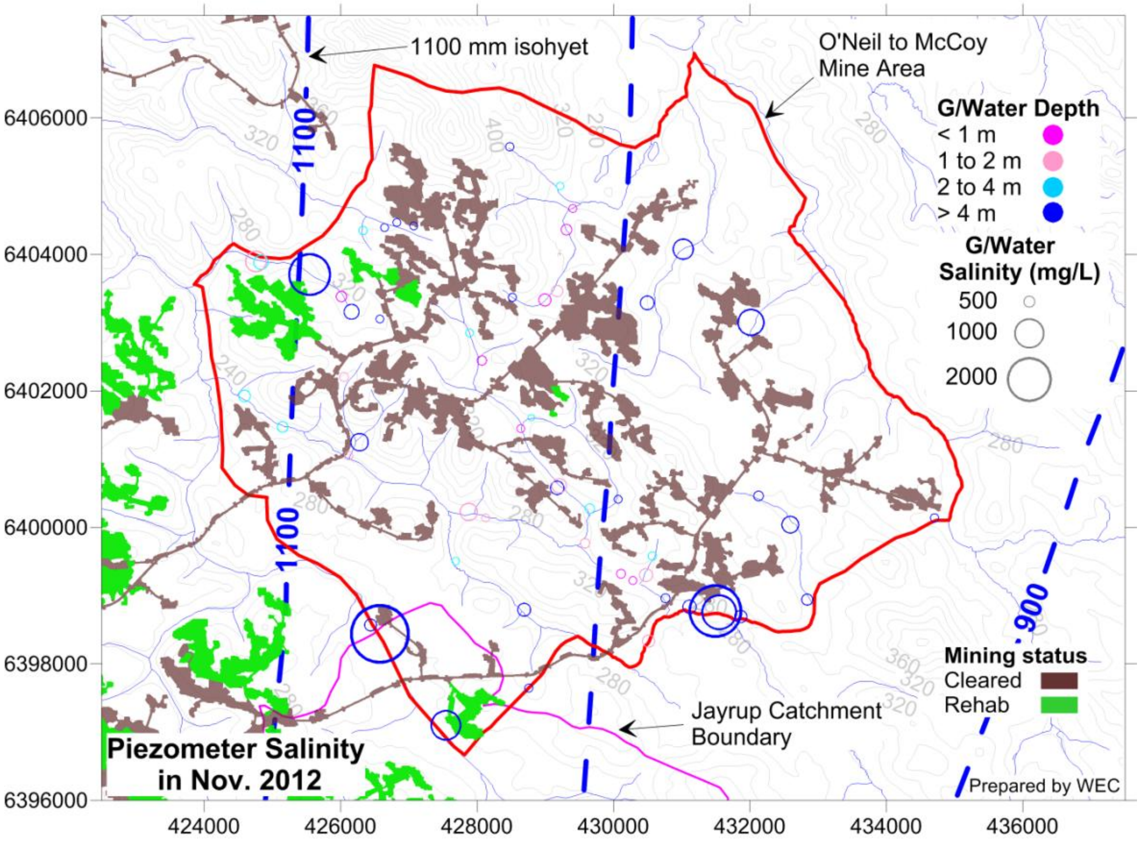

Figure 19: Piezometer groundwater salinities from the pump-sampling programme in November 2012.

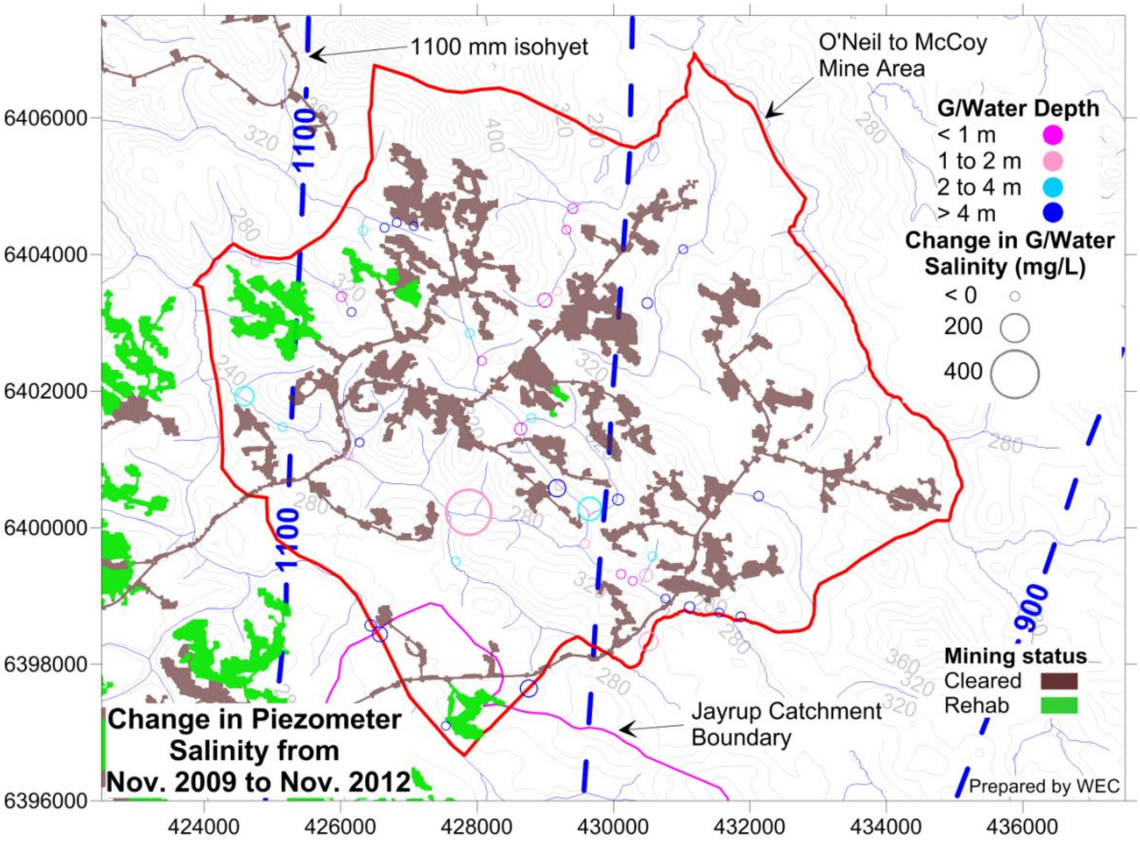

Figure 20: Change in piezometer groundwater salinities from November 2009 to November 2012.

4. O'NEIL TO McCOY STREAM DATA

The stream salinity monitoring for O'Neil-to-McCoy mine area can be divided into three parts. Firstly, there is a manual sampling network that covers the area and is intended to track any local changes (Figure 21). Secondly, there is a continuous-logger network consisting of five sites, CD01 to CD05, at which stream-salinity loggers have been deployed by Alcoa. Most of the mining in the O'Neil-to-McCoy area is contained within the catchments of these loggers. Croton & Dalton (2008) developed these manual-sampling and logger networks, and the BHC recommended to the MMPLG that O'Neil-to-McCoy mining should proceed providing this monitoring was undertaken by Alcoa.

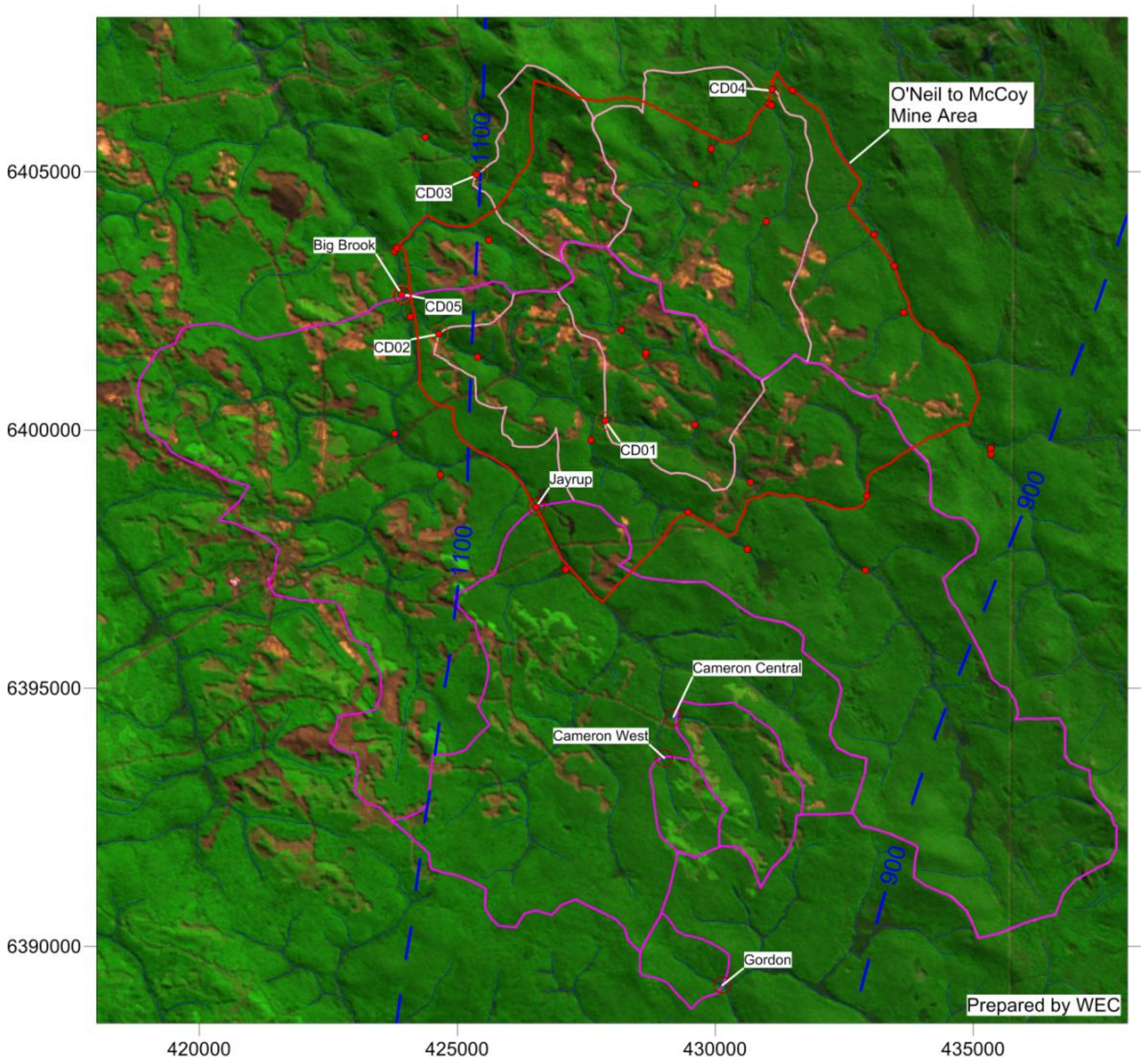

Figure 21: Manual stream-salinity sampling points, and continuous-logger stream-salinity monitoring points and their catchments, for the O'Neil-to-McCoy mine area. Also shown are the DoW monitoring sites and catchments associated with the Cameron Experimental Mining Exercise (CEME).

The third component to the monitoring system is the gauging stations operated by the Department of Water (DoW); this is both the long-term station of Big Brook and the catchments which are part of the Cameron Experimental Mining Exercise (CEME) (Croton, *et al.* 2011). The CEME stations are the treated catchments of Cameron West, Cameron Central and Jayrup and the control catchment of Gordon (Figure 21). It should be noted that continuous-logger site CD05 is located at the Big Brook gauging-station to allow direct comparison between the Alcoa and DoW monitoring. Big Brook is also important in that it contains not just the CEME, but also the majority of the O'Neil-to-McCoy mine area and a significant proportion of the mining directly to the west.

In the following sections the manual sampling will be analysed first, followed by the continuous-logger, and then the DoW gauging stations. Comparisons will then be made between all the data types. Key dates in the analysis are: first significant clearing for mining in the Big Brook catchment was 2003; first clearing for mining in Jayrup was 2004; first clearing for mining in the O'Neil-to-McCoy area was 2009, with significant clearing from 2010.

4.1 Manual Stream-Salinity Data

There are 36 stream monitoring sites in and around the O'Neil-to-McCoy mine area and all the available data for them has been tabulated in Appendix B. To show the relativity between the sample values for 2009, 2011 and 2012, Figure 22 is a proportional plot of the October values for each of these years. October has been used as it tends to be the month in which flow is still expected to occur, but is after the winter streamflow peaks and is therefore indicative of the salinity of the interflow/baseflow component of streamflow. It can be seen that stream salinity has increased year by year for all sites which have at least two readings, this is for both sites that have and don't have mining in their catchments. There is also a degree of complication in Figure 22 in that some sites weren't visited in 2009, hence they lack a value for this year even though there was probably flow at them for that year. As well, the lower rainfall in 2012 compared to the other two years, and the resultant reduction in flows, has meant that a number of sites lack a salinity value for that year. This lack also has a geographical component in that the first and second-order catchments on the eastern side of the O'Neil-to-McCoy mine area are generally lacking a 2012 value while the first and second-order catchments on the western side generally have one. This is probably associated with two factors, the east-west trend of rainfall with higher rainfall on the western side, and the level of topographic incision with the eastern section being much flatter than the west.

There are seven sites in Figure 22 which are directly associated with the O'Neil-to-McCoy mine area and have October data for all three years; these have been labelled in Figure 22 and are plotted as a time-series in Figure 23(a). Of these points, BF06 was established as a control; and Figure 23(b) is a plot with the October salinity values for each year for the other sites plotted as a percentage of the BF06 October value for that year. The 2011 value for SE43 has plotted below BF06, all other values in Figure 23(b) have plotted above BF06. The averages for the non-control values are 107% in 2011 and 124% in 2012. Figure 23(c) is a plot, with the salinity values as differences for a year compared to the control value for that year; these are an estimate of salinity change due to mining. The averages for the non-control values are 8 mg/L in 2011 and 39 mg/L in 2012. All the plots in Figure 23 show a geographical component, with the values for the westerly sampling points being higher than those for the easterly ones.

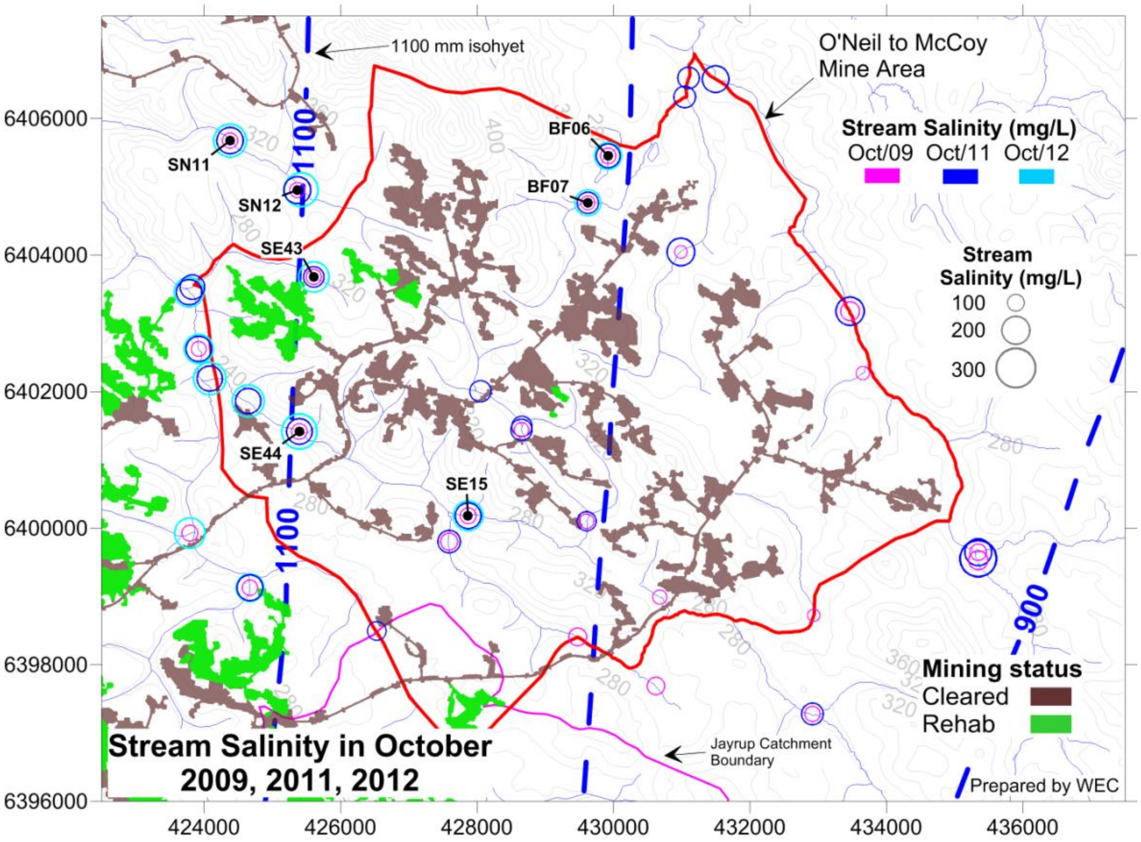

Figure 22: October 2009, 2011 and 2012 stream-salinity values for the manual stream-salinity sampling-points for the O’Neil-to-McCoy mine area.

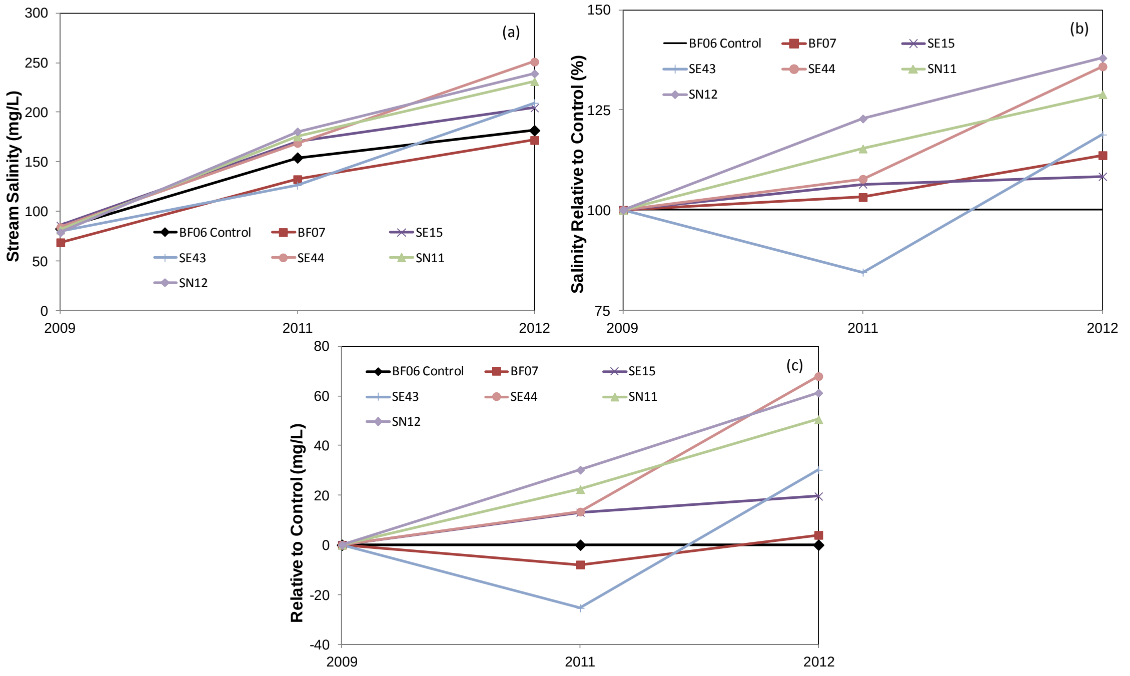

Figure 23: October 2009, 2011 and 2012 stream-salinity values for the manual stream-salinity sampling-points for the O’Neil-to-McCoy mine area that have October data for all three years.

4.2 Continuous-Logger Stream-Salinity Data

Five continuous-logger stream-salinity sites were established by Alcoa in 2009, their locations are shown on Figure 21. The sites were run-of-stream, where the logger was placed on the stream-bed on an anchor block and was open to the passing flow. There was full data-recovery for these loggers in 2009 and 2011; for 2010, any flows that did occur at the sites were generally insufficient to inundate the loggers and no real data was available for this year. For 2012 there was complete failure of all five loggers and no useful logger-data was collected at any of the sites. There was however manual check-samples still being collected at the sites in 2012, and these are plotted in Figure 24 along with the continuous data for 2009 and 2011. Various options were considered for creating a synthetic record for 2012, including using the Big Brook salinity trace and morphing it to fit the manual check-samples. However, while this of course can be done for CD05 as it is located at the Big Brook gauging-station, realistic traces could not be developed for the other four sites and the only useful 2012 data for these remains the manual check-samples.

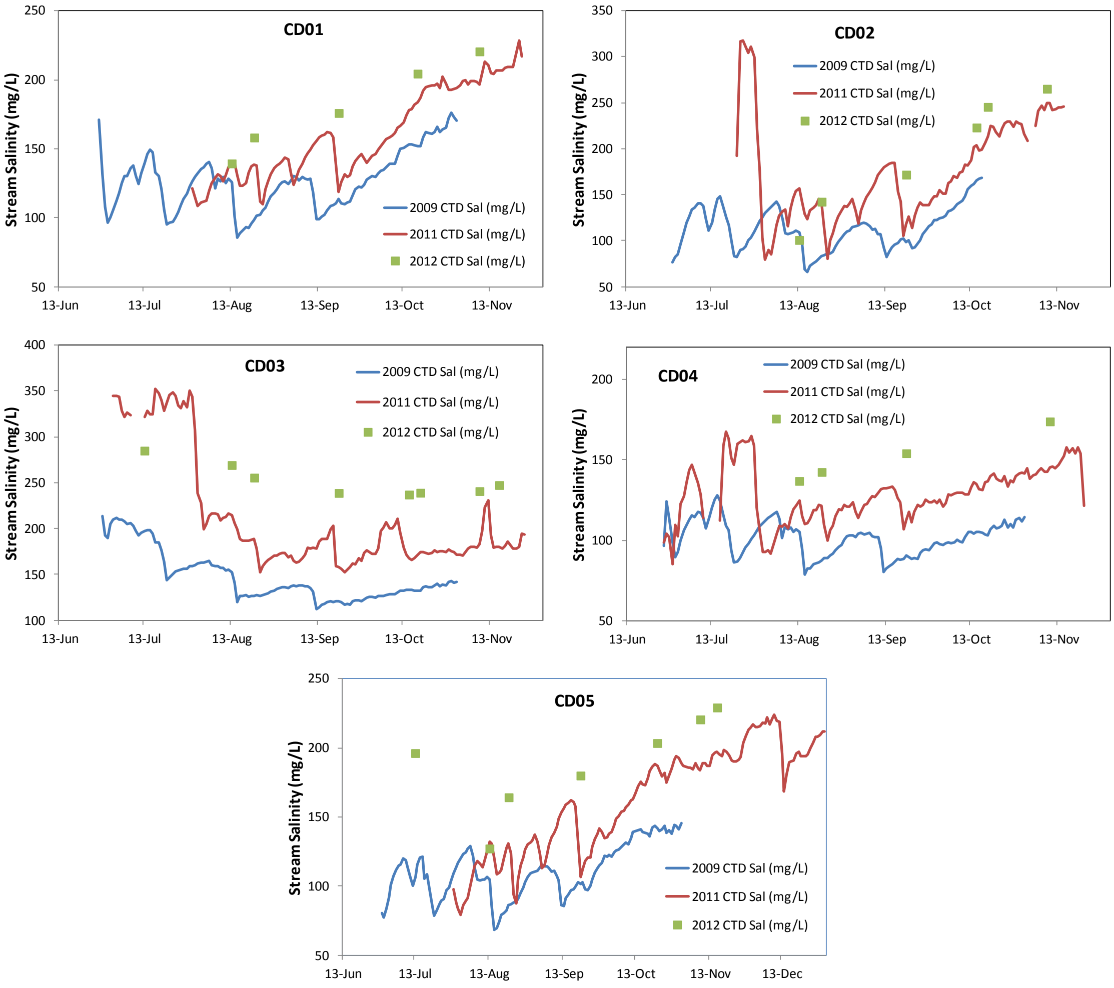

Figure 24: Stream salinity traces for the stream-salinity logger sites in the O'Neil-to-McCoy mine area.

As was seen for the manual stream-salinity sampling points discussed in the previous section, there has been a steady rise in stream salinities for successive years for the stream-salinity logger sites. Again the question is, how much of this is related to mining responses, and how much relates to climatic factors, particularly the historically-low rainfall of 2010. Figure 25 is a plot of the differences in average salinity between the two years 2012 and 2009 for the five stream-salinity logger sites plotted against the percentage area of clearing for mining up to the beginning of 2012. The catchment areas for CD02 and CD05 have been adjusted by the deletion of that 27.3 km^2 of the catchments that is flowing from the forest tributary to the east This lower rainfall area (isohyet average of 900 mm/annum) has markedly lower streamflow than the O'Neil-to-McCoy mine area; it was not possible to obtain a salinity sample from this catchment stream in 2012, implying it had little to no flow in that year.

As streamflows are not being measured at any site other than CD05, where the Big Brook gauging station is located, it isn't possible to calculate flow-weighted salinities and those in Figure 25 are simple averages. Despite this limitation and that associated with the lack of continuous data for 2012, it appears likely from Figure 25 that there is some relationship between the area cleared for mining and the salinity difference. The intercept of 39 mg/L is an estimate of the natural increase independent of clearing for mining.

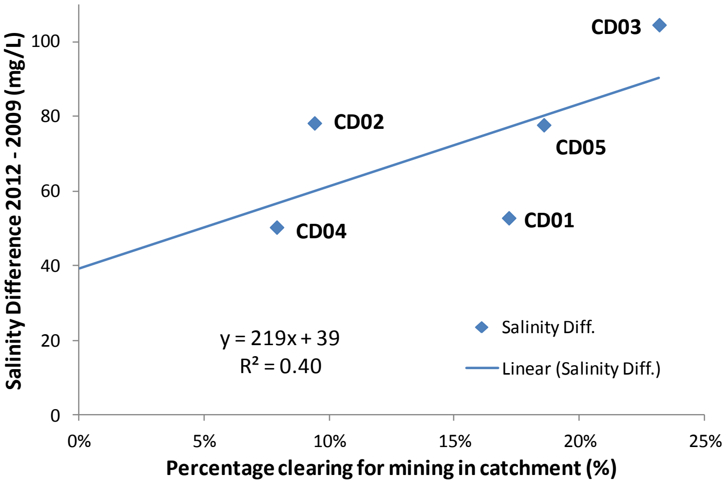

Figure 25: Salinity difference between 2012 and 2009 for continuous-logger sites plotted against the percentage area of clearing for mining up to the beginning of 2012.

4.3 DoW Data

4.3.1 Gordon

Gordon is the control catchment that was established as part of the CEME. It is a small catchment of only 2.1 km^2, but was established at the time as no larger alternatives presented themselves. Figure 26(a) is a plot of the annual rainfall vs. streamflow relation for Gordon with the data divided into two groups, that up to and including 2002 and that from 2003 on. This division is chosen because it matches with the first significant clearing in the Big Brook catchment (Figure 21). Two things are readily apparent from Figure 26(a). Firstly, the relationship between rainfall and streamflow isn't strong with low R^2 values and a wide scatter in the points. Secondly, 2011 and 2012 have both plotted well below all the other years; it appears that the historically-low rainfall of 2010 has "dried" the catchment to such a level that streamflow hasn't recovered during either of these years. Figure 26(b) is a plot of rainfall vs. stream salinity for Gordon catchment. While 2011 has plotted slightly above mid-level in this graph, 2012 has plotted at the top. Figure 27(a) is a plot of annual streamflow vs.

stream salinity for Gordon; again 2011 has plotted fairly consistently with the other years while 2012 has plotted at the top.

Figure 27(b) is a plot of streamflow vs. flowdays for Gordon, flowdays are defined as days with an average flow of 0.2 L/sec or more (17 m^3/day). For 2011 there is a respectable number of flowdays at 59 days, but for 2012 there are only six flowdays. The total flow for 2012 was only 0.17 mm/yr or 357 m^3/yr (0.357 ML/yr), as well the saltload for 2012 totalled only 35 kg/yr. Such small flow volumes and saltloads for 2012 make it a year for which Gordon can’t be confidently used as a control for the other catchments. There was 793 ML/yr of flow for Big Brook (5.3 mm/yr) and the saltload was 110 tonnes/yr; these are 2,200 and 3,100 times as much as Gordon.

Interestingly however, if Gordon is accepted for the moment as a salinity control and is processed as an unweighted or simple average in the same way as for the continuous-logger sites in Figure 25, the increase in average salinity between 2009 and 2012 is 19 mg/L (108 – 89). While this is half the Figure 25 intercept of 39 mg/L (zero area of clearing for mining), it would still be considered confirmation of the regression in Figure 25, though it does imply that the natural increase may be overestimated in Figure 25. However, as already discussed, Gordon 2012 data is questionable and alone isn’t sufficient grounds to revise the preceding analysis.

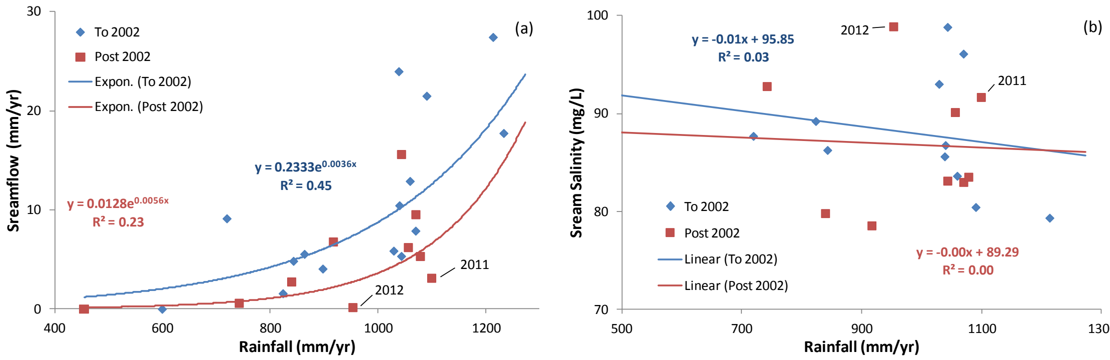

Figure 26: Gordon annual rainfall vs. streamflow and rainfall vs. stream-salinity divided into two periods, up to 2002 and post 2002.

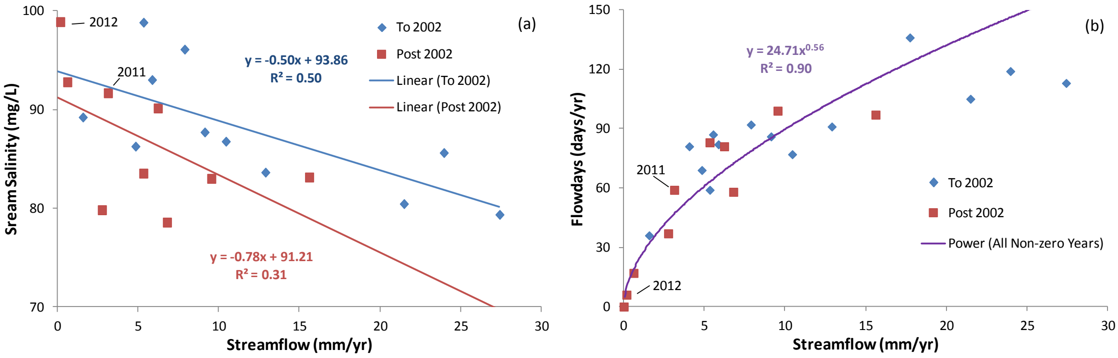

Figure 27: Gordon annual streamflow vs. stream-salinity and streamflow vs. flow-days divided into two periods, up to 2002 and post 2002.

Figure 28 is a plot of the daily salinities for Gordon for the years 2009, 2011 and 2012. With the exception of the shorter flow durations, this graph is similar in form to those given in Figure 24 for the stream-salinity logger sites in the O’Neil-to-McCoy mine area.

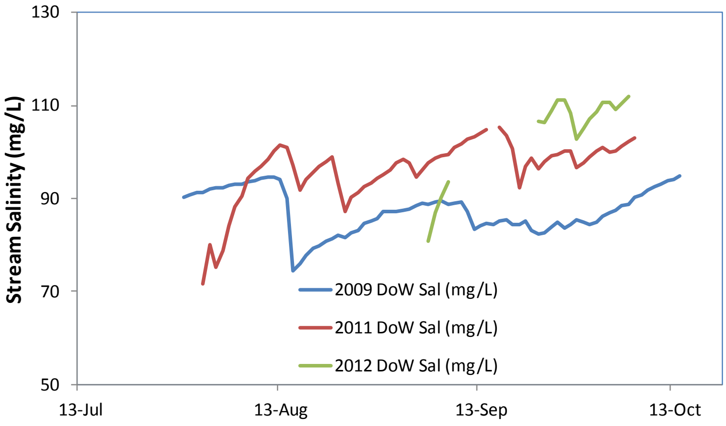

Figure 28: Gordon daily stream salinities for 2009, 2011 and 2012.

4.3.2 Jayrup

Jayrup is the medium-scale treated catchment within the CEME and has an area of 45.5 km^2, the first-order treated catchments of Cameron West and Central are sub-catchments of it (Figure 21). Figure 29(a) is a plot of the annual rainfall vs. streamflow relation for Jayrup with the data divided into two groups, that up to and including 2002 and that from 2003 on. This division is chosen as it matches with the first significant clearing in the Big Brook catchment (Figure 21). Two things are readily apparent from Figure 29(a). Firstly, unlike Gordon, the relationship between rainfall and streamflow is strong with high R^2 values, 0.94 and 0.85. Secondly, like Gordon, 2011 and 2012 have both plotted well below all the other years, but unlike Gordon, there is still significant flow in 2012. Figure 29(b) is a plot of rainfall vs. stream salinity for Jayrup catchment; unlike Gordon, both 2011 and 2012 have plotted mid-level in this graph. Figure 30(a) is a plot of annual streamflow vs. stream salinity for Jayrup; again 2011 and 2012 have plotted fairly consistently with the other years. However, before reading too much into these differences in salinity behaviour between Jayrup and Gordon, the freshness and small range of the salinity readings needs to be noted; the range of annual average-salinities for Jayrup is 71 mg/L to 83 mg/L (12 mg/L) and for Gordon is 79 mg/L to 99 mg/L (20 mg/L). Neither range is large, and small errors in measurement, including sensor drift, could be driving some of the observed variation between catchments. Figure 30(b) is a plot of streamflow vs. flowdays for Jayrup, flowdays are defined as days with an average flow of 0.5 L/sec or more (43 m^3/day). For 2011 there are 93 flowdays and for 2012 there are 63 flowdays. The 2012 flowdays' value for Jayrup is markedly different to the six days for Gordon.

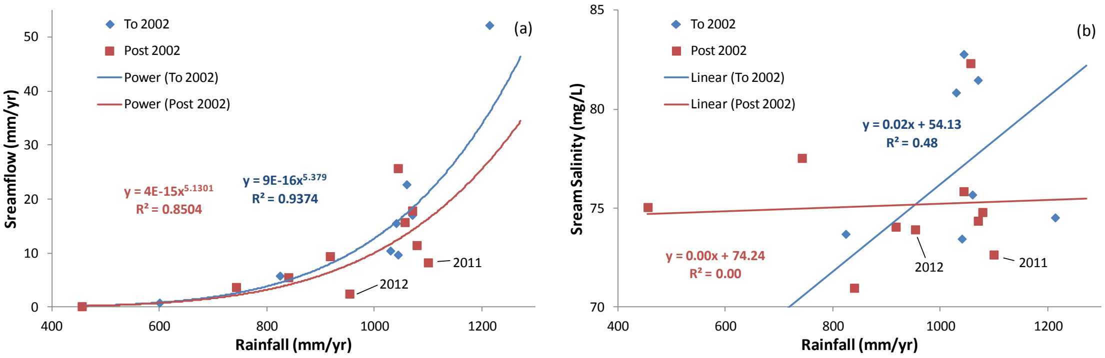

Figure 29: Jayrup annual rainfall vs. streamflow and rainfall vs. stream-salinity divided into two periods, up to 2002 and post 2002.

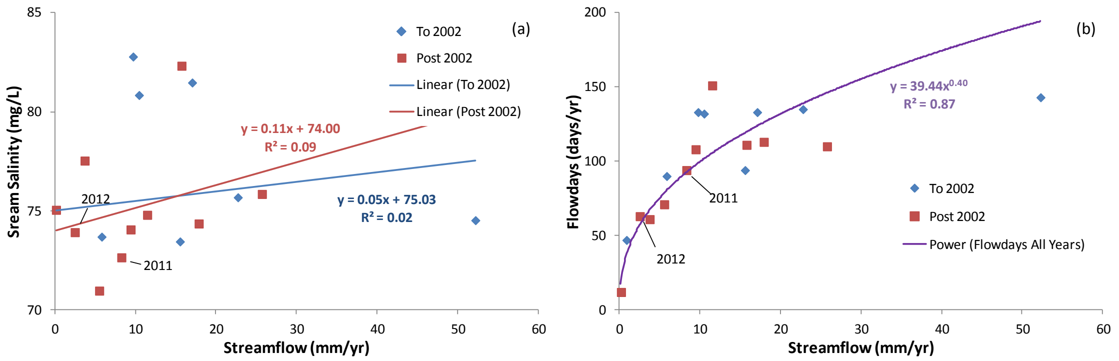

Figure 30: Jayrup annual streamflow vs. stream-salinity and streamflow vs. flow-days divided into two periods, up to 2002 and post 2002.

Figure 31 is a plot of the daily salinities for Jayrup for the years 2009, 2011 and 2012. This graph has a much higher activity level than that for Gordon in Figure 28; this is consistent with the larger flows and apparently greater hydrological activity level of Jayrup compared to Gordon.

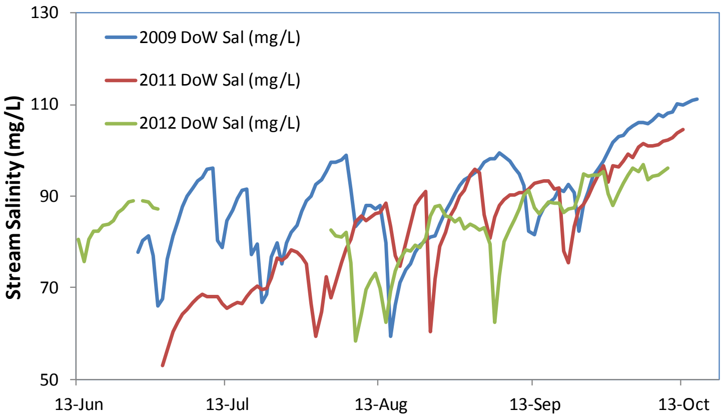

Figure 31: Jayrup daily stream salinities for 2009, 2011 and 2012.

4.3.3 Big Brook

The Big Brook catchment includes the CEME, the majority of the O'Neil-to-McCoy mine area, and a significant proportion of the mining directly to the west of these areas (Figure 21); its catchment area is 149 km^2. Figure 32(a) is a plot of the annual rainfall vs. streamflow relation for Big Brook with the data divided into two groups, that up to and including 2002 and that from 2003 on. This division is chosen as it matches with the first significant clearing in the Big Brook catchment (Figure 21). In terms of the strength of the annual rainfall vs. streamflow relation, Big Brook with R^2 values of 0.69 and 0.50 falls midway between Gordon and Jayrup. However, 2011 for Big Brook, while still plotting below the regression, is clustered with the other years rather than in an isolated pairing with 2012. 2012 has plotted below all the other years, but there is still significant flow in 2012.

Figure 32(b) is a plot of rainfall vs. stream salinity for the Big Brook catchment, this graph is introducing a new behaviour that wasn't observed for either Gordon or Jayrup. 2011 has plotted in the general grouping while 2012 has plotted well above. Also, while it is plotting in-line with two of the upto-2002 years (1998 and 2001), it is well above all the post-2002 values.

Figure 33(a) is a plot of annual streamflow vs. stream salinity for Big Brook; 2011 has plotted with the other post-2002 years while 2012 has plotted at the top of the graph and like Figure 32(b) has associated itself with the upto-2002 years of 1998 and 2001. Given the range of annual salinity values for Big Brook, 93 mg/L to 138 mg/L (45 mg/L), these variations appears to be a genuine catchment response. Figure 33(b) is a plot of streamflow vs. flowdays for Big Brook, flowdays are defined as days with an average flow of 0.5 L/sec or more (43 m^3/day). For 2011 there are 121 flowdays and for 2012 there are 129 flowdays; this exceeding of flowdays for 2011 by those in 2012 is the first such occurrence, both Gordon and Jayrup had markedly less flowdays in 2012 than 2011.

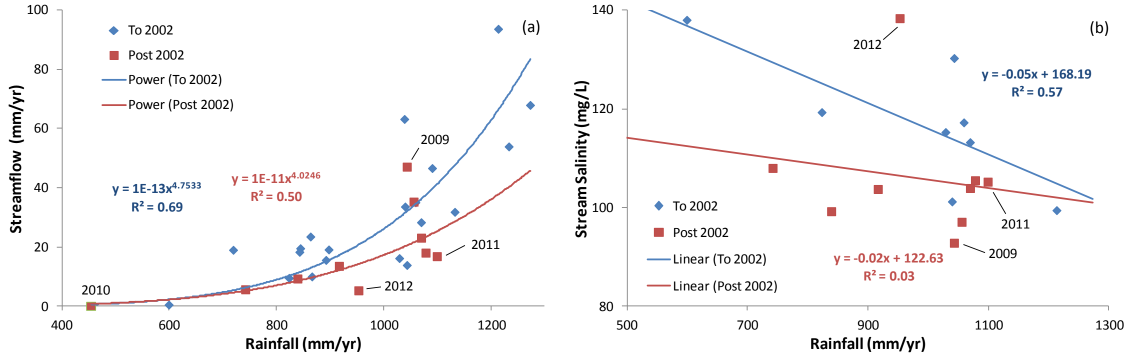

Figure 32: Big Brook annual rainfall vs. streamflow and rainfall vs. stream-salinity divided into two periods, up to 2002 and post 2002.

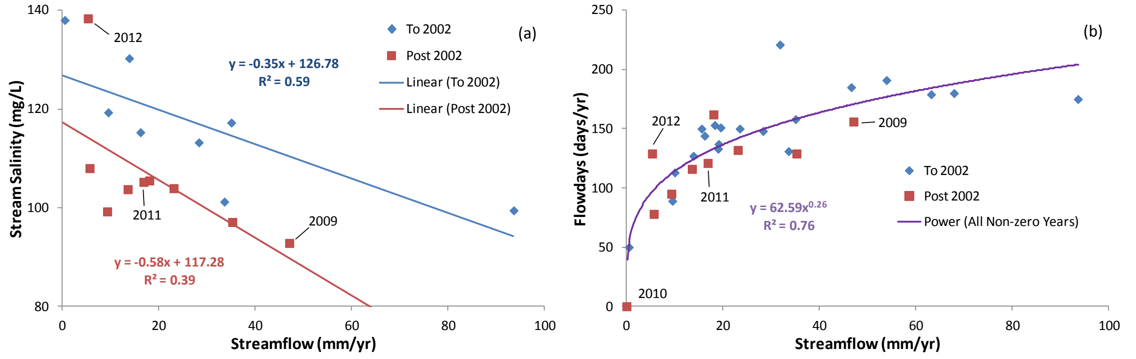

Figure 33: Big Brook annual streamflow vs. stream-salinity and streamflow vs. flow-days divided into two periods, up to 2002 and post 2002.

Figure 34 is a plot of the daily salinities for Big Brook for the years 2009, 2011 and 2012. This graph is interesting in that it displays a much higher range of variation in salinity in the early period of 2012 than it does for 2009 and 2011. Peak to trough ranges are around 40 to 80 mg/L in 2012 while they were 40 mg/L or less in 2009 and 2011. Jayrup has similar ranges for all years of about 20 mg/L; and Gordon has so little flow in 2012 that a range can’t really be defined for that year, with ranges of 10 to 20 mg/L in the other years. This increased range of salinities for Big Brook in 2012 probably indicates a mining-related response with the higher salinities being associated with increased groundwater discharge.

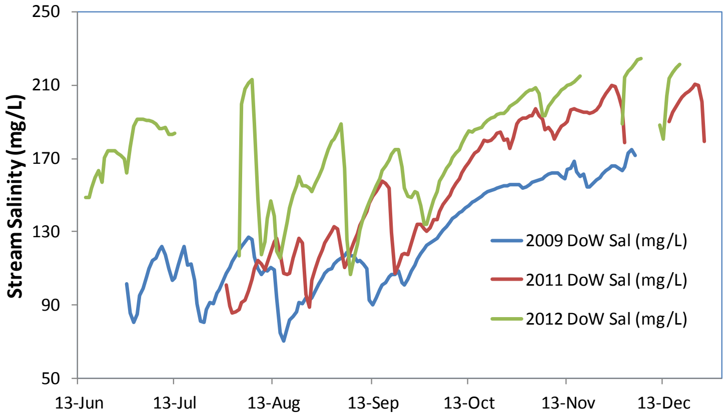

Figure 34: Big Brook daily stream-salinities for 2009, 2011 and 2012.

5. ESTIMATION OF MINING RELATED RESPONSES

5.1 Stream Response for the O'Neil-to-McCoy Mine Area

Figure 25 in Section 4.2 was the salinity difference between 2012 and 2009 for continuous-logger sites plotted against the percentage area of clearing for mining up to the beginning of 2012. A linear relationship was passed through the five data points on this graph and the intercept, or zero-mining salinity-increase, was obtained. If Figure 25 is plotted with the intercept set to zero, then we have an estimate of the increase in stream salinity in 2012 for these five sites due to mining. However, such a plot would be based on a simple average rather than a flow-weighted average for the stream salinity. The only continuous-logger site at which flow was measured was CD05 (Big Brook). For the DoW data for Big Brook for 2012, the simple-average stream-salinity is 174 mg/L while the flow-weighted average is 138 mg/L, which gives a factor of 79% as the adjustment between simple average and flow-weighted average for 2012 stream salinities. Applying this same factor to the continuous-logger sites produces Figure 35 as the flow-weighted increases in stream salinity in 2012 due to mining.

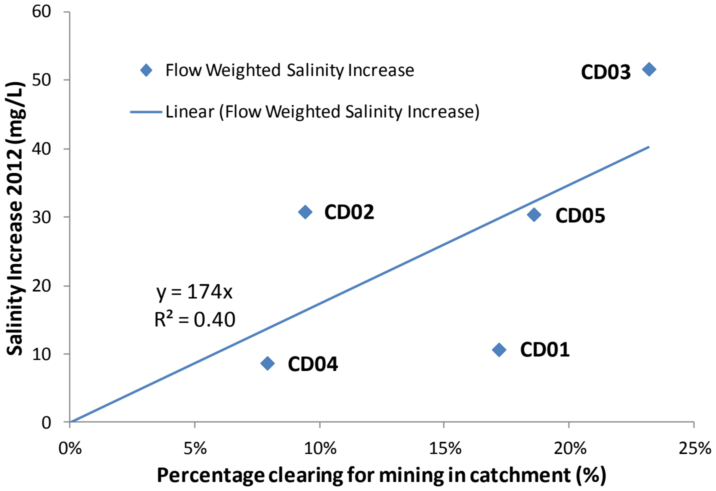

Figure 35: Estimated flow-weighted stream-salinity increase for 2012 for the continuous-logger sites plotted against the percentage area of clearing for mining up to the beginning of 2012.

Further, if the streamflow per unit area for Big Brook (mm/yr) is assumed to be the streamflow per unit area for the other continuous-logger sites (mm/yr), an estimate of stream saltload increase can be developed using the catchment areas for the logger sites in combination with the estimated flow-weighted stream-salinity increase for 2012 from Figure 35. These equate to the estimates given in Table 1. It needs to be noted that as CD05 is at the Big Brook gauging station, then the saltload increase for this site includes more than just that emanating from the O'Neil-to-McCoy mine area; Big Brook will be considered further in the next sub-section.

Table 1: Estimated mining-related stream-saltload increases for 2012 for the continuous-logger sites. Note that for CD02 an adjusted catchment area without the forest tributary to the east is being used (34.3 km^2).

Logger Site	**Stream Salinity Increase 2012** (mg/L)	**Catchment Area** (km^2)	**Stream Saltload Increase 2012** (tonnes)
CD01	11	9.7	0.85
CD02	31	61.6 (34.3)	8.67
CD03	52	6.8	2.86
CD04	9	17.8	1.27
CD05	30	149.4	30.4

5.2 Stream Response for Big Brook to Mining

In the previous sub-section an estimate was made for the stream-salinity and saltload increases due to mining for the continuous-logger site CD05, this site is also the Big Brook gauging station. Now using DoW data only, an estimate will be made of the change in stream salinity due to mining for Big Brook. If simple differences in flow-weighted stream salinity between 2009 and 2012 are calculated for the three DoW catchments we get: a 16 mg/L increase for Gordon, a 2 mg/L reduction for Jayrup, and a 45 mg/L increase for Big Brook. Further, if Gordon is accepted as control, despite its limitations in terms of lack of flow in 2012, then the increase for Big Brook due to mining in 2012 would be the overall increase for Big Brook (45 mg/L) minus the increase for Gordon (16 mg/L) which is 29 mg/L, or essentially the same as the increase of 30 mg/L that was obtained in the previous section using the five continuous-logger sites to develop a relation between percentage clearing for mining and increase in stream salinity.

Obtaining the same increase in stream salinity in 2012 due to mining for Big Brook using two independent methods implies that this estimate is probably realistic. Qualitative support for this also comes from Figures 32(b) and 33(a); in both of these figures the year 2012 is plotting separate to all other post-2002 years and it appears to be about 30 mg/L higher than would be expected if climate was the only variable.

5.3 Response of Inflows to the Serpentine Reservior

The Water Corporation produces a monthly estimate of stream inflows into the Serpentine Reservoir and these were used with the data above to create an estimate of the effect of mining the O'Neil-to-McCoy area on stream-inflow salinities to Serpentine Reservoir. The first step in this process is to determine the saltloads for the areas of mining at O'Neil to McCoy; most of the mine areas are contained within continuous-logger sites CD02, CD03 and CD04, though there are some areas on the eastern and western sides which aren't. Table 2 lists the estimated saltload increases for 2012 due to mining, including the calculated increase for Big Brook in total and that part of Big Brook which is outside of the O'Neil-to-McCoy mine area. These have been combined in Table 3 with the stream-inflow flow-rate estimate for 2012 and the estimated reservoir-pond volume on 31st Dec 2012, to calculate the changes in inflow salinity and reservoir-pond salinity due to both mining of O'Neil-to-McCoy area and mining of the balance of the Big Brook catchment.

Table 2: Estimated mining-related stream-saltload increases for 2012 for the continuous-logger site catchments and the other misc. areas of the O'Neil-to-McCoy area. Also included are the mining-related saltloads for Big Brook.

Catchment	**Stream Saltload Increase for 2012** (tonnes)
CD02	8.67
CD03	2.86
CD04	1.27
Western side extra mine areas	1.52
Eastern side extra mine areas	0.95
Total for O'Neil-to-McCoy	**15.3**
Total for Big Brook	30.4
Big Brook Outside of O'Neil-to-McCoy	**21.6**

Table 3: Mining-related stream-inflow and reservoir-pond saltload calculations for 2012 for the Serpentine Reservoir.

Item	**Flow and Volume** (ML)	**Saltload** (kg)	**Salinity** (mg/L)
Total reservoir inflow	5,047		
Change in reservoir inflow due to O'Neil-to-McCoy mining		15,268	3.0
Change in reservoir inflow due to Big Brook mining outside of O'Neil-to-McCoy		21,557	4.3
Reservoir-pond volume Dec 2012	34,366		
Change in reservoir-pond salinity due to O'Neil-to-McCoy mining		15,268	0.44
Change in reservoir-pond salinity due to Big Brook mining outside of O'Neil-to-McCoy		21,557	0.63

5.4 Comparison with Croton & Dalton (2010) Predictions

Croton & Dalton (2010) estimated the likely effects of mining the O'Neil-to-McCoy area on the salinity of the Serpentine Reservoir, and the BHC recommended to the MMPLG that O'Neil-to-McCoy mining should proceed based on these estimates. Their worst-case scenario estimated the change in stream-inflow salinity for the Serpentine

Reservoir for 2012 was 4.9 mg/L for mining of the O'Neil-to-McCoy area; this was based on assuming that the historical rainfall for 1997 to 2007 inclusive fell for the period 2009 to 2019 and that 2012 was represented by the historical year 2000. They also produced a best-case scenario based on the historical rainfalls for 1970 to 1980 and obtained a 2.6mg/L increase in 2012 based on the rainfall for 1973 being used to simulate that year. The present estimated value of 3.0 mg/L (Table 3) falls between these two estimates and is at the lower end of their range.

What differs markedly between the calculations of Croton & Dalton (2010) and what has actually occurred in the period 2009 to 2012 is the very low actual stream-inflow rates to Serpentine Reservoir (see author's note 4). Table 4 lists the actual inflows and the predictive scenarios used by Croton & Dalton (2010). While the actual and the scenario flows for 2009 fall within a similar range, the historically-low rainfall of 2010 caused the actual inflows in that year to be an order of magnitude less than the two scenarios. As well, the drawing down of catchment soil-water storages by the low rainfall of 2010 has caused a knock-on effect so that the inflow in 2011 is less than the inflow in 2009 (18.7 GL/yr compared to 30.9 GL/yr), even though the rainfall in 2011 was greater than in 2009. There is a similar occurrence for 2012: the actual 2012 inflow was 5.0 GL/yr while the rainfall of 2012 was greater than in 2008 when the inflow was 15.2 GL/yr, a threefold difference.

Table 4: Actual stream-inflows for Serpentine Reservoir and those assumed by Croton & Dalton (2010).

Year	**Actual Stream-inflows** (GL/yr)	**Worst Case Stream-inflows** (GL/yr)	**Best Case Stream-inflows** (GL/yr)
2009	30.9	22.7	88.5
2010	3.0	24.7	59.3
2011	18.7	25.5	45.8
2012	5.0	41.1	101.3
Total	**57.6**	**114.0**	**294.9**

The net result of all of the above is that while the predictions of stream-inflow salinity changes made by Croton & Dalton (2010) are similar to what has occurred in reality, the large reductions in actual stream-inflow rates has meant that the saltload increases predicted by them are significantly greater than what actually occurred. Given that the salinity of the overall water-supply system is driven by the saltload calculations, that is total salt vs. total water in the system, then it is the saltload of the stream-inflow to Serpentine Reservoir rather than the salinity of the stream-inflow which matters to the overall water-supply. For saltloads, the estimated mining-related saltload increase in 2012 due to actual O'Neil-to-McCoy mining was 15.3 tonnes compared to 361 and 419 tonnes for the two scenario predictions by Croton & Dalton (2010).

Author's note 4: The actual inflows are those estimated by the Water Corporation using a water-balance model of the Serpentine Reservoir. These have been provided to the study by Charles Jeevaraj of the Water Corporation.

6. FUTURE MONITORING RECOMMENDATIONS

The following is a listing of our recommendations as to what monitoring should be continued for the O'Neil-to-McCoy mine area. The monitoring recommendations have been strongly affected by the present climate, and the realisation that the recent past is probably the most likely scenario for the near future. Even this *modus operandi* can lead to overestimates of the true position: Croton & Dalton (2010) assumed that the period 1997 to 2007 was a reasonable worst-case scenario for what would happen from 2009 on; history has disproved this. As discussed in Section 2.3, the present rainfall period is both an increase in the number of low-rainfall years and essentially an absence of high-rainfall years. There have been three years of rainfall below 800 mm/yr in the 12 years since 2001 and only one year of rainfall above 1,300 mm/yr since 1975. If these trends continue then hydrological monitoring of the O'Neil-to-McCoy mine area can be maintained at a much lower level than if rainfall patterns change to a higher state.

Perhaps unexpectedly, the definition of a change that would trigger an increase in monitoring isn't associated with the relative mix of below-average and average rainfall years. With the present level of soil-water storages, an average-rainfall year seems to do little more than maintain the below-average status quo. This was well demonstrated by the recent stream-inflows to Serpentine Reservoir where the above-average year of 2011 followed by the slightly below-average year of 2012 still resulted in well below average stream-inflows to the reservoir.

Instead, the trigger for a possible upward revision of the monitoring would be the occurrence of a rainfall year that was well above average. A suggested threshold for this is at least 1,300 mm/yr for the Big Brook rain-gauge. As discussed in Section 2.3, there has been only one year with a rainfall above 1,300 mm/yr since 1975 (1,321 mm in 1991, or once in 37 years), while there are some 20 years above 1,300 mm/yr in the balance of the record (once every 4.5 years). From a simple water-balance calculation using all the available rainfall and streamflow record for Big Brook, it appears that evapo-transpiration and other misc. losses account for something like 950 mm/yr. Therefore a rainfall of 1,300 mm/yr provides an excess of about 350 mm/yr to be available for soil-water replenishment and streamflow, while a rainfall of 1,000 mm/yr provides only 50 mm/yr, or one seventh, and 950 mm/yr just maintains the soil-water status quo with nothing available for streamflow.

It is proposed that the monitoring programme suggested below be maintained at least until the end of 2015, unless a rainfall year of 1,300 mm/yr or more occurs. The proposed programme has been divided into five segments.

6.1 Continuous-Logger Sites

The present five continuous-logger sites CD01 to 05 were not logged in 2012 due to failure of all five loggers; they were operated successfully from 2009 to 2011. As sites CD01 to 04 cover the majority of the stream outflows from the O'Neil-to-McCoy mine area, it is proposed that these loggers be reinstated (Figure 21). CD05 was placed at the Big Brook gauging-station to allow comparison of the logger data with the DoW station record. Given all the issues with the continuous-loggers, this comparison site should be maintained.

6.2 DoW Stream-Gauges

The two DoW stream gauges of direct interest are Big Brook and Gordon. It is recommended that both still be considered part of the O'Neil-to-McCoy mine area monitoring-programme, though it is likely that Gordon will have so little flow from 2013 on that it can no longer be considered a useful streamflow control.

6.3 Manual Stream-Salinity Sites

There are 36 stream monitoring sites in and around the O'Neil-to-McCoy mine area, many of which have at least some data going back to the early 1990s. In the past there has been an intention to collect regular samples during winter at these sites, though without flow information it is somewhat difficult to place a useful interpretation on this data. One targeted use has been to take the results for the later part of winter, e.g. the October sample, and compare the values between years (e.g. Figure 22). October has been used as it tends to be the month in which flow is still expected to occur, but is after the winter streamflow peaks and is therefore indicative of the salinity of the interflow/baseflow component of streamflow.

It is considered justifiable to continue the October manual-sampling of stream salinity to identify year-to-year changes, but without a definite use for manual sampling in the other parts of the year, sampling outside of October can't really be justified. Also with the October sampling, it is recommended that emphasis be placed on six of the seven sites where values for 2009, 2011 and 2012 have already been obtained, with the other 30 sites being of secondary priority. The seventh site, SN11, was dropped from the primary list as the upstream SN12 site makes it redundant. BF06 has the highest priority of the six primary sites as it is acting as the untreated control. The details for the six primary sites are given in Table 5.

Table 5: Manual stream-salinity sampling-points that are in the primary list.

Site	Easting	Northing
BF06	429920	6405452
BF07	429624	6404763
SE15	427865	6400181
SE43	425606	6403679
SE44	425394	6401416
SN12	425365	6404953

6.4 Groundwater Level Monitoring

There are 96 piezometers on the present monitoring list (see Appendix A). These were strategically placed to be either controls or downslope of mining areas. However, with the present dampened hydrological responses, many of these have little to no response; while others do have a response but that local response is also seen in another, more suitable, piezometer. It was decided that the list could be rationalised to 23 piezometers of which four are controls and 19 are associated with mining. This listing is given in Table 6 and is plotted in Figure 36. Regarding monitoring frequency, presently piezometers have their water-levels manually read on a monthly basis. Due to the dampened responses, it is considered reasonable to reduce the frequency to six weekly, nine times per year.

Table 6: The 23 pieozmeters recommended for continued water-level monitoring.

Site	Easting	Northing	Control
K4228-1A	428482	6405580	Yes
K4307-1A	427071	6404417	
K4307-2A	426823	6404469	
K4307-3A	427058	6404259	
K4312-1A	427676	6403882	
K4314-1A	426010	6403385	
K4314-3A	426576	6403052	
K4318-1A	426050	6402205	
K4320-1A	428070	6402448	
K4322-1A	426040	6401615	
K4410-1A	426225	6399189	Yes
L4301-1A	429403	6404669	
L4309-2A	428993	6403333	
L4309-3A	429318	6403611	
L4318-1A	429782	6402532	
L4325-1A	428641	6401447	
L4410-2A	430111	6399320	
L4415-1A	430763	6398962	
L4415-2A	431115	6398834	
L4419-1A	430515	6398336	
M4407-1A	434707	6400139	
M4413-1A	432836	6398942	Yes
M4417-1A	432375	6398492	Yes

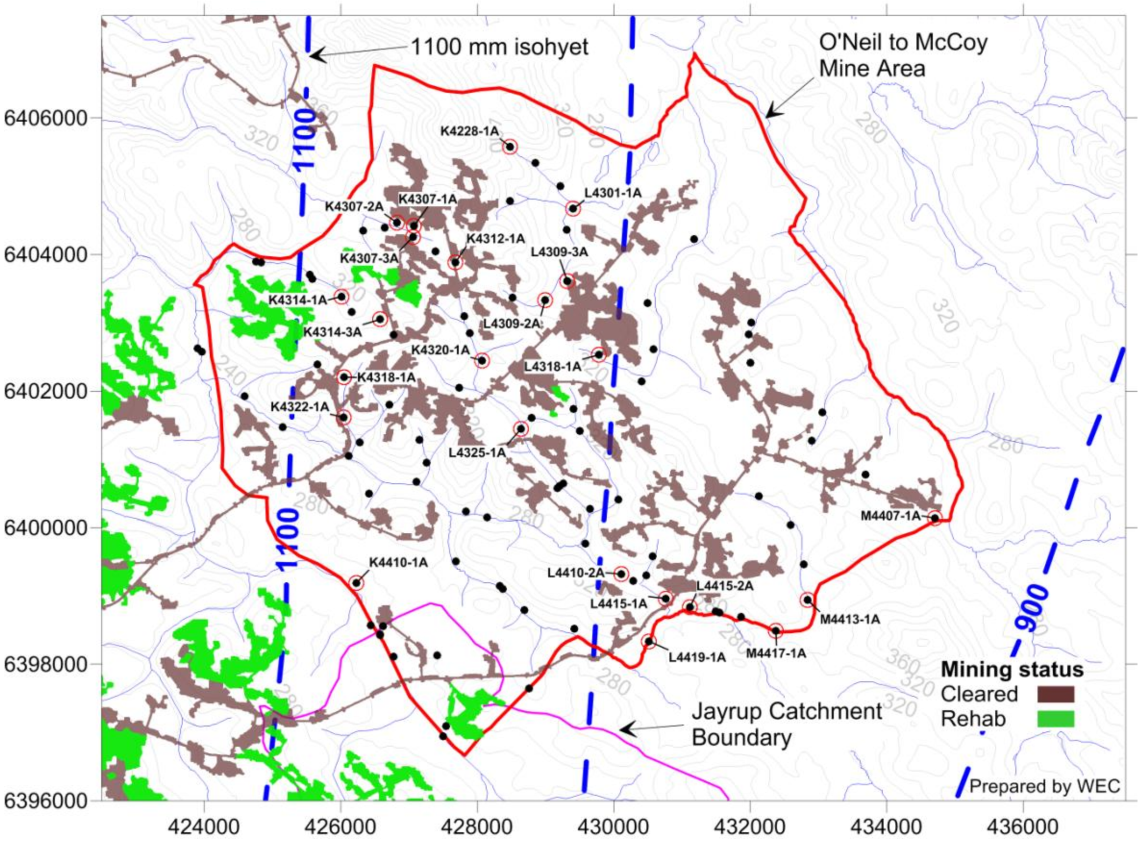

Figure 36: The 23 pieozmeters recommended for continued water-level monitoring

6.5 Groundwater Water-Quality Sampling

Groundwater water-quality sampling has been undertaken in previous years to establish a base dataset and to also allow assessment of changes with time. The reality is that while there are some within-year and year-to-year variations in groundwater salinity, these aren't of a significant level. Further, it needs to be asked for what the groundwater water-quality data is to be used. In a baseline study it can be used to make pre-operational estimates of possible treatment effects, such as in Croton & Dalton 2008, Croton, *et al*. 2008 and Croton & Dalton 2010. However, the O'Neil-to-McCoy mining exercise is mature and reaching the end of its operational phase, so baseline studies are no longer required. Instead the emphasis for monitoring is on tracking treatment-responses and ensuring they do not exceed previously predicted levels; and in the case of O'Neil-to-McCoy this is primarily by monitoring groundwater levels, streamflows and stream salinities. It is therefore recommended that sampling groundwater-salinities be discontinued for the O'Neil-to-McCoy mine area.

7. CONCLUSION

The study successfully defined the hydrological responses associated with mining the O'Neil-to-McCoy area. There were significant groundwater level rises in parts of the area, with the nine most responsive piezometers having rises between 1.5 and 5.4 m compared to equivalent controls. As the groundwater in a significant proportion of the valley-floors of the O'Neil-to-McCoy mine area was at or close to the soil surface, such rises also seemed to influence streamflows and stream salinities. A relation between percentage-area of mining and stream-salinity was developed and estimates were made of the additional stream-inflow salinity for the Serpentine Reservoir due to mining of the O'Neil-to-McCoy area. The stream-inflow salinity was estimated to increase by 3.0 mg/L due to mining effects and the pond salinity was estimated to increase by 0.44 mg/L. Neither of these responses were unexpected and are on the lower side of what was predicted by Croton & Dalton (2010), and accepted by the BHC when making their recommendation to the MMPLG that O'Neil-to-McCoy mining should proceed.

Due to the continued below-average rainfalls during the mining period for the O'Neil-to-McCoy area, the saltloads that have actually occurred are an order of magnitude less than those predicted by Croton & Dalton (2010). The estimated mining-related saltload increase in 2012 due to actual O'Neil-to-McCoy mining was 15.3 tonnes compared to 361 and 419 tonnes for the two scenario predictions by Croton & Dalton (2010). Given that the salinity of the overall water-supply system is driven by the saltload calculations, that is total salt vs. total water in the system, then it is the saltload of the stream-inflow to Serpentine Reservoir rather than the salinity of the stream-inflow which matters to the overall water-supply system.

Recommendations were also made as to what monitoring should be continued for the O'Neil-to-McCoy mine area. These recommendations were strongly affected by the present climate, and its likelihood of continuing. If the present below-average rainfalls continue, then it is proposed hydrological monitoring of the O'Neil-to-McCoy mine area can be maintained at a much lower level than if a change in the rainfall patterns were to occur. The definition of a climate change that would trigger consideration of an increase in monitoring was suggested to be at least 1,300 mm/yr rainfall for the Big Brook rain-gauge. This is because such a rainfall would provide a large water-excess and would significantly replenish soil-water storages and boost streamflow. If rainfalls continue at average levels or below, then they are expected to do little more than maintain the hydrological status quo.

8. REFERENCES

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APPENDIX A – Observed Groundwater Data for the O’Neil-to-McCoy Mine Area

Figure A1 shows the locations of the 96 deep piezometers in the O’Neil-to-McCoy mine area. Figure A2 shows the piezometer hydrographs for all available data. Table A1 is a listing of the piezometers including a flag as to whether they have been water-quality sampled by pumping. Table A2 is a listing of water quality data since 2007 for the O’Neil-to-McCoy mine-area piezometers.

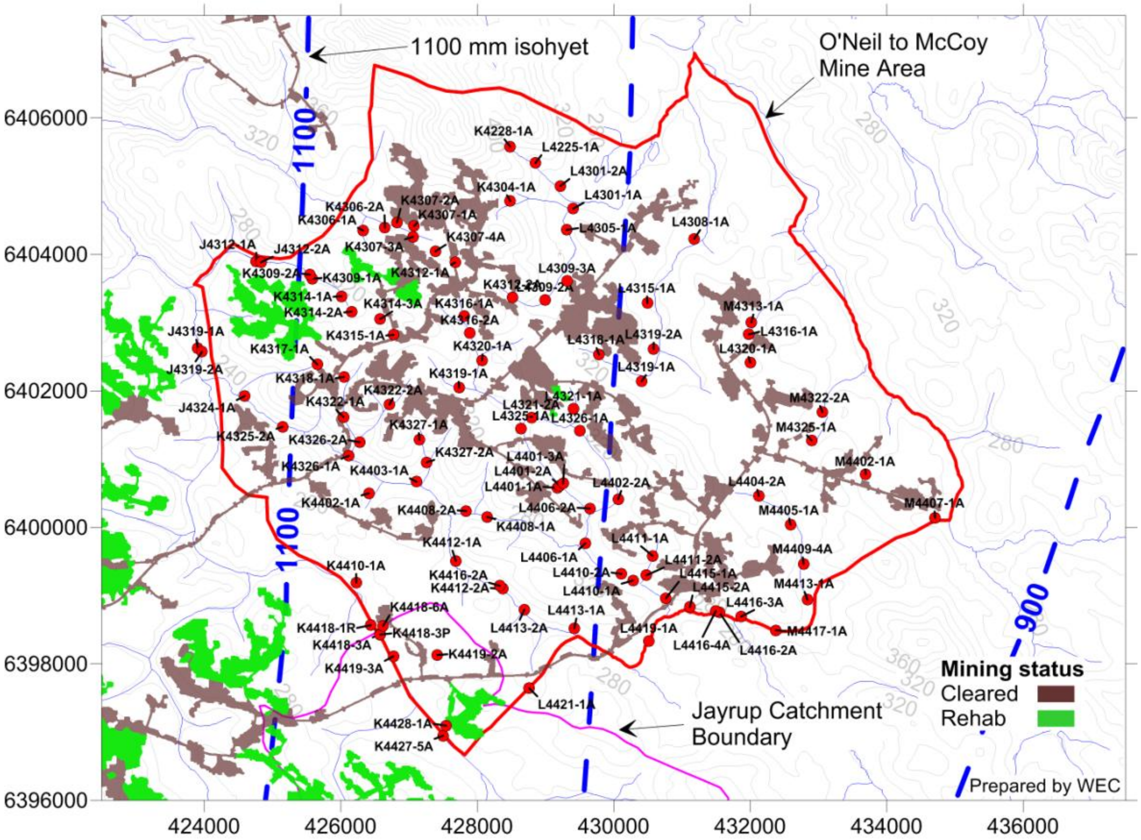

Figure A1: Location of the 96 deep groundwater piezometers in the O’Neil-to-McCoy mine area.

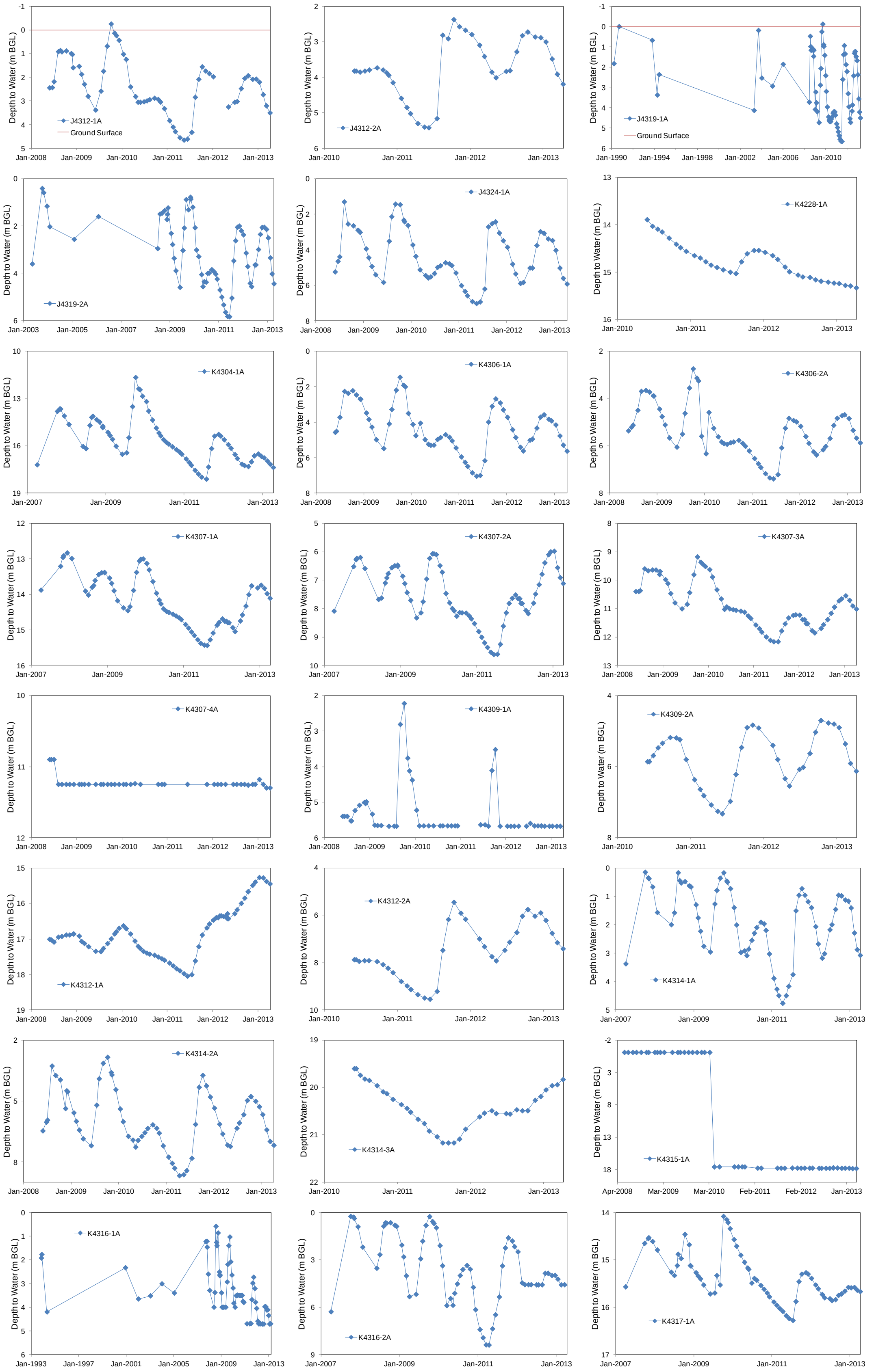

Figure A2 continued

Figure A2 continued

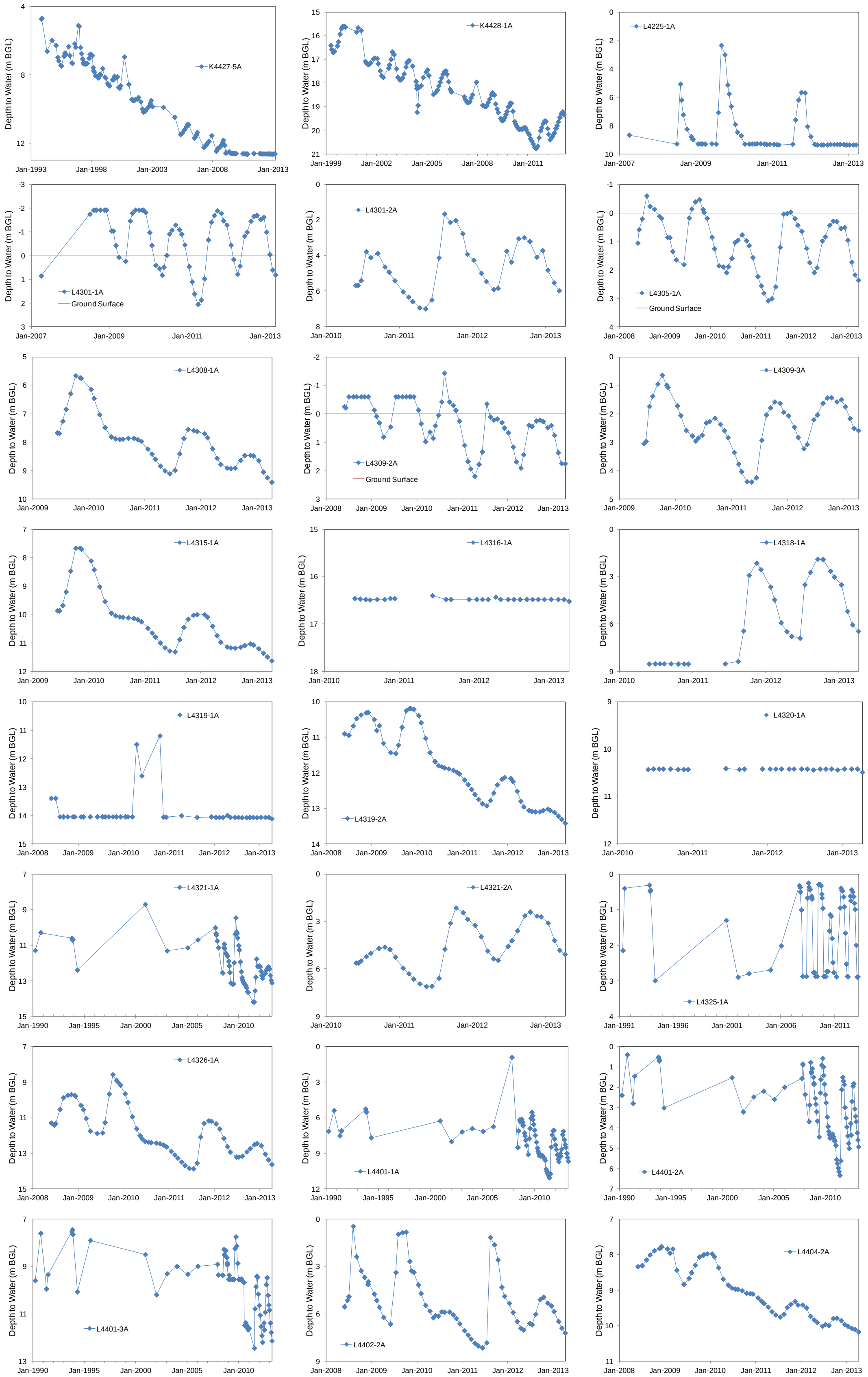

Figure A2 continued

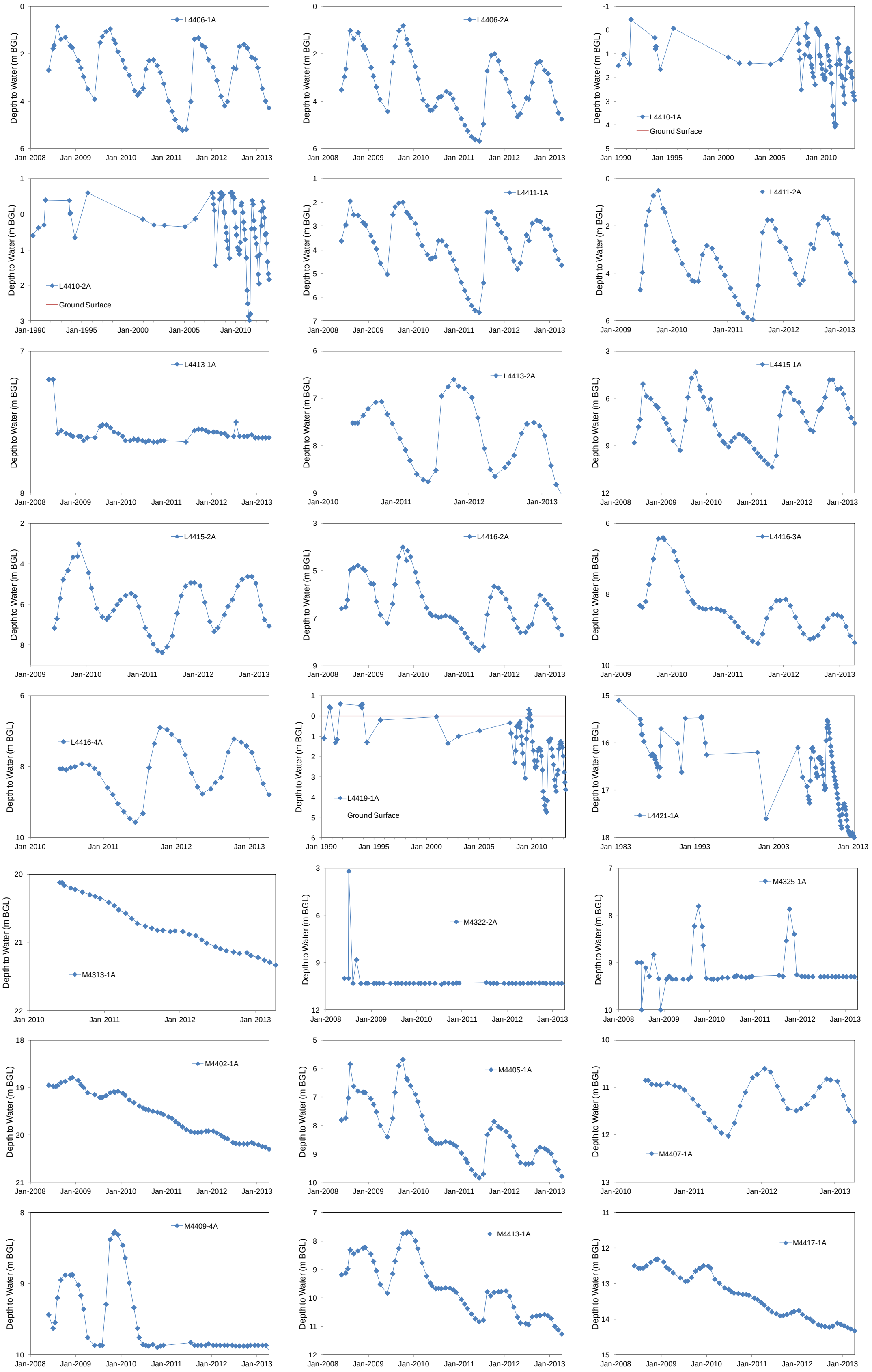

Figure A2: Hydrographs of the 96 deep groundwater piezometers in the O'Neil-to-McCoy mine area.

Table A1: A listing of the O’Neil-to-McCoy mine area piezometers including a flag as to whether they have been water-quality sampled by pumping.

Site	Easting	Northing	Sampled
J4312-1A	424759	6403896	Yes
J4312-2A	424830	6403885	Yes
J4319-1A	423905	6402623	Yes
J4319-2A	423966	6402573	
J4324-1A	424593	6401926	Yes
K4228-1A	428482	6405580	Yes
K4304-1A	428482	6404784	Yes
K4306-1A	426329	6404349	Yes
K4306-2A	426645	6404391	Yes
K4307-1A	427071	6404417	Yes
K4307-2A	426823	6404469	Yes
K4307-3A	427058	6404259	Yes
K4307-4A	427385	6404046	
K4309-1A	425584	6403645	Yes
K4309-2A	425546	6403702	Yes
K4312-1A	427676	6403882	Yes
K4312-2A	428519	6403372	Yes
K4314-1A	426010	6403385	Yes
K4314-2A	426159	6403162	Yes
K4314-3A	426576	6403052	Yes
K4315-1A	426774	6402823	
K4316-1A	427811	6403095	Yes
K4316-2A	427891	6402851	Yes
K4317-1A	425655	6402388	Yes
K4318-1A	426050	6402205	
K4319-1A	427733	6402046	Yes
K4320-1A	428070	6402448	Yes
K4322-1A	426040	6401615	Yes
K4322-2A	426712	6401800	Yes
K4325-2A	425150	6401474	Yes
K4326-1A	426118	6401051	Yes
K4326-2A	426279	6401247	Yes
K4327-1A	427151	6401286	Yes
K4327-2A	427257	6400954	
K4402-1A	426412	6400500	Yes
K4403-1A	427107	6400670	
K4408-1A	428145	6400152	Yes
K4408-2A	427836	6400240	Yes
K4410-1A	426225	6399189	Yes
K4412-1A	427686	6399508	Yes
K4412-2A	428371	6399100	Yes
K4416-2A	428331	6399145	
K4418-1R	426442	6398569	Yes
K4418-3A	426578	6398440	Yes
K4418-3P	426578	6398430	Yes
K4418-6A	426620	6398559	Yes
K4419-2A	427411	6398132	
K4419-3A	426771	6398112	
K4427-5A	427499	6396947	Yes
K4428-1A	427543	6397097	Yes
L4225-1A	428851	6405339	Yes
L4301-1A	429403	6404669	Yes
L4301-2A	429217	6405003	Yes
L4305-1A	429308	6404360	Yes
L4308-1A	431177	6404227	Yes
L4309-2A	428993	6403333	Yes
L4309-3A	429318	6403611	Yes
L4315-1A	430493	6403287	Yes
L4316-1A	431979	6402828	
L4318-1A	429782	6402532	
L4319-1A	430407	6402141	
L4319-2A	430584	6402611	Yes
L4320-1A	432000	6402417	
L4321-1A	429410	6401738	Yes
L4321-2A	428794	6401610	
L4325-1A	428641	6401447	Yes
L4326-1A	429503	6401416	Yes
L4401-1A	429176	6400577	Yes
L4401-2A	429205	6400613	Yes
L4401-3A	429258	6400646	Yes
L4402-2A	430065	6400414	Yes
L4404-2A	432123	6400463	Yes
L4406-1A	429580	6399765	Yes
L4406-2A	429651	6400278	Yes
L4410-1A	430283	6399223	Yes
L4410-2A	430111	6399320	Yes
L4411-1A	430570	6399582	Yes
L4411-2A	430476	6399299	Yes
L4413-1A	429422	6398521	
L4413-2A	428687	6398794	Yes
L4415-1A	430763	6398962	Yes
L4415-2A	431115	6398834	Yes
L4416-2A	431549	6398753	Yes
L4416-3A	431863	6398693	Yes
L4416-4A	431493	6398774	Yes
L4419-1A	430515	6398336	Yes
L4421-1A	428761	6397643	Yes
M4313-1A	432016	6403007	Yes
M4322-2A	433057	6401690	
M4325-1A	432898	6401274	
M4402-1A	433690	6400780	Yes
M4405-1A	432590	6400040	Yes
M4407-1A	434707	6400139	
M4409-4A	432781	6399466	Yes
M4413-1A	432836	6398942	Yes
M4417-1A	432375	6398492	Yes

Table A2: A listing of the water-quality data for the O'Neil-to-McCoy mine area piezometers for 2007 to 2012.

Site	Date	Salinity (mg/L)
J4312-1A	22-Aug-08	922
J4312-1A	27-Nov-08	848
J4312-1A	17-Nov-09	805
J4312-1A	11-May-10	843
J4312-1A	8-Nov-10	852
J4312-1A	8-Mar-11	817
J4312-1A	21-Nov-12	811
J4312-2A	8-Jun-10	481
J4312-2A	8-Nov-10	462
J4312-2A	8-Mar-11	510
J4312-2A	9-Jun-11	464
J4312-2A	8-Sep-11	449
J4312-2A	8-Nov-11	527
J4312-2A	21-Nov-12	489
J4319-2A	22-Aug-08	326
J4319-2A	27-Nov-08	317
J4319-2A	10-Nov-09	326
J4319-2A	11-May-10	393
J4319-2A	8-Nov-10	340
J4319-2A	8-Nov-11	330
J4319-2A	16-Nov-12	333
J4324-1A	18-Jun-08	248
J4324-1A	27-Nov-08	243
J4324-1A	10-Nov-09	230
J4324-1A	11-May-10	242
J4324-1A	8-Nov-10	253
J4324-1A	8-Mar-11	252
J4324-1A	8-Nov-11	261
J4324-1A	16-Nov-12	348
K4228-1A	9-Jun-10	198
K4228-1A	11-Nov-10	174
K4228-1A	15-Nov-11	173
K4228-1A	20-Nov-12	172
K4304-1A	3-Apr-07	153
K4304-1A	7-Nov-07	168
K4304-1A	22-Aug-08	264
K4304-1A	4-Dec-08	139
K4304-1A	16-Nov-09	141
K4304-1A	11-May-10	151
K4304-1A	9-Mar-11	156
K4306-1A	5-Jun-08	177
K4306-1A	4-Dec-08	196
K4306-1A	16-Nov-09	178
K4306-1A	12-May-10	168
K4306-1A	10-Nov-10	170
K4306-1A	9-Mar-11	163
K4306-1A	15-Nov-11	202
K4306-1A	21-Nov-12	181
K4306-2A	19-Jun-08	179
K4306-2A	4-Dec-08	160
K4306-2A	16-Nov-09	146
K4306-2A	12-May-10	178
K4306-2A	10-Nov-10	152
K4306-2A	9-Mar-11	190
K4306-2A	15-Nov-11	147
K4306-2A	21-Nov-12	150
K4307-1A	3-Apr-07	167
K4307-1A	7-Nov-07	179
K4307-1A	21-Aug-08	135
K4307-1A	4-Dec-08	154
K4307-1A	16-Nov-09	154
K4307-1A	12-May-10	155
K4307-1A	21-Nov-12	152
K4307-2A	3-Apr-07	186
K4307-2A	7-Nov-07	190
K4307-2A	21-Aug-08	154
K4307-2A	4-Dec-08	150
K4307-2A	16-Nov-09	154
K4307-2A	12-May-10	148
K4307-2A	10-Nov-10	184
K4307-2A	15-Nov-11	159
K4307-2A	21-Nov-12	147
K4307-3A	19-Jun-08	195
K4307-3A	4-Dec-08	182
K4307-3A	16-Nov-09	185
K4307-3A	12-May-10	233
K4307-3A	9-Mar-11	198
K4309-1A	27-Nov-08	1,500
K4309-2A	8-Jun-10	743
K4309-2A	8-Nov-10	4,767
K4309-2A	8-Mar-11	2,918
K4309-2A	9-Jun-11	2,175
K4309-2A	8-Nov-11	6,275
K4309-2A	11-Dec-12	1,848
K4312-1A	10-Jun-08	185
K4312-1A	4-Dec-08	150
K4312-1A	16-Nov-09	152
K4312-1A	12-May-10	155
K4312-2A	8-Jun-10	192
K4312-2A	15-Nov-10	176
K4312-2A	9-Mar-11	174
K4312-2A	9-Mar-11	171
K4312-2A	15-Nov-11	192
K4312-2A	20-Nov-12	166
K4314-1A	3-Apr-07	242
K4314-1A	6-Nov-07	312
K4314-1A	21-Aug-08	235
K4314-1A	27-Nov-08	291
K4314-1A	10-Nov-09	272
K4314-1A	12-May-10	274
K4314-1A	8-Nov-10	344
K4314-1A	8-Mar-11	286
K4314-1A	9-Jun-11	314
K4314-1A	8-Sep-11	253
K4314-1A	8-Nov-11	225
K4314-1A	21-Nov-12	283
K4314-2A	24-Jun-08	563
K4314-2A	27-Nov-08	613
K4314-2A	10-Nov-09	671
K4314-2A	12-May-10	729
K4314-2A	9-Nov-10	605
K4314-2A	8-Mar-11	533
K4314-2A	9-Jun-11	507

K4314-2A	8-Sep-11	681
K4314-2A	8-Nov-11	539
K4314-2A	21-Nov-12	517
K4314-3A	8-Jun-10	174
K4314-3A	9-Nov-10	197
K4314-3A	8-Mar-11	174
K4314-3A	9-Jun-11	194
K4314-3A	8-Sep-11	194
K4314-3A	8-Nov-11	185
K4314-3A	21-Nov-12	151
K4316-1A	4-Oct-07	79
K4316-1A	6-Nov-07	118
K4316-1A	2-Dec-08	210
K4316-2A	4-Apr-07	150
K4316-2A	6-Nov-07	176
K4316-2A	22-Aug-08	159
K4316-2A	2-Dec-08	155
K4316-2A	17-Nov-09	161
K4316-2A	13-May-10	155
K4316-2A	17-Nov-11	118
K4316-2A	20-Nov-12	160
K4317-1A	2-Apr-07	277
K4317-1A	5-Nov-07	298
K4317-1A	29-Jul-08	266
K4317-1A	28-Nov-08	263
K4317-1A	17-Nov-09	196
K4317-1A	21-May-10	303
K4319-1A	4-Apr-07	174
K4319-1A	6-Nov-07	215
K4319-1A	22-Aug-08	182
K4319-1A	2-Dec-08	191
K4319-1A	10-Nov-09	172
K4319-1A	21-May-10	229
K4319-1A	9-Mar-11	191
K4320-1A	26-Jun-08	230
K4320-1A	2-Dec-08	229
K4320-1A	17-Nov-09	229
K4320-1A	13-May-10	232
K4320-1A	9-Mar-11	228
K4320-1A	17-Nov-11	237
K4320-1A	20-Nov-12	233
K4322-1A	2-Apr-07	209
K4322-1A	5-Nov-07	248
K4322-1A	29-Jul-08	216
K4322-1A	28-Nov-08	236
K4322-1A	10-Nov-09	201
K4322-1A	12-Mar-11	186
K4322-2A	2-Apr-07	404
K4322-2A	6-Nov-07	414
K4322-2A	29-Jul-08	299
K4322-2A	27-Nov-08	394
K4322-2A	10-Nov-09	403
K4322-2A	21-May-10	486
K4322-2A	12-Mar-11	348
K4325-2A	17-Jun-08	317
K4325-2A	28-Nov-08	375
K4325-2A	10-Nov-09	304
K4325-2A	11-May-10	298
K4325-2A	17-Nov-10	354
K4325-2A	8-Mar-11	302

K4325-2A	8-Nov-11	294
K4325-2A	16-Nov-12	291
K4326-1A	24-Jun-08	192
K4326-1A	27-Nov-08	220
K4326-1A	10-Nov-09	202
K4326-1A	21-May-10	233
K4326-1A	9-Nov-10	213
K4326-1A	12-Mar-11	219
K4326-1A	11-Nov-11	213
K4326-1A	26-Nov-12	176
K4326-2A	24-Jun-08	889
K4326-2A	27-Nov-08	738
K4326-2A	10-Nov-09	646
K4326-2A	21-May-10	755
K4326-2A	9-Nov-10	692
K4326-2A	12-Mar-11	771
K4326-2A	11-Nov-11	637
K4326-2A	26-Nov-12	643
K4327-1A	28-Sep-07	112
K4402-1A	17-Jun-08	547
K4402-1A	28-Nov-08	516
K4402-1A	10-Nov-09	537
K4402-1A	21-May-10	660
K4408-1A	28-Nov-08	536
K4408-1A	11-Nov-11	1,004
K4408-1A	26-Nov-12	154
K4408-2A	7-Nov-07	223
K4408-2A	20-Aug-08	210
K4408-2A	28-Nov-08	213
K4408-2A	10-Nov-09	223
K4408-2A	14-May-10	590
K4408-2A	9-Nov-10	683
K4408-2A	12-Mar-11	629
K4408-2A	11-Nov-11	434
K4408-2A	26-Nov-12	639
K4410-1A	9-Jul-08	469
K4410-1A	28-Nov-08	424
K4410-1A	10-Nov-09	399
K4410-1A	21-May-10	586
K4412-1A	9-Jul-08	120
K4412-1A	28-Nov-08	143
K4412-1A	10-Nov-09	129
K4412-1A	14-May-10	147
K4412-1A	17-Nov-10	148
K4412-1A	8-Mar-11	144
K4412-1A	12-Mar-11	144
K4412-1A	10-Jun-11	200
K4412-1A	8-Sep-11	113
K4412-1A	11-Nov-11	147
K4412-1A	26-Nov-12	127
K4412-2A	28-Nov-08	2,700
K4412-2A	10-Nov-09	2,093
K4418-1R	21-Jul-08	350
K4418-1R	23-Nov-09	333
K4418-1R	21-May-10	1,029
K4418-1R	9-Nov-10	988
K4418-1R	10-Nov-11	416
K4418-1R	27-Nov-12	362
K4418-3A	17-Jul-08	1,311
K4418-3A	23-Nov-09	2,606

K4418-3A	21-May-10	2,256
K4418-3A	9-Nov-10	2,529
K4418-3A	12-Mar-11	2,901
K4418-3A	10-Jun-11	2,830
K4418-3A	10-Nov-11	1,233
K4418-3A	27-Nov-12	2,677
K4418-3P	17-Jul-08	3,319
K4418-3P	20-Nov-09	3,113
K4418-3P	21-May-10	3,902
K4418-3P	9-Nov-10	3,219
K4418-3P	12-Mar-11	3,148
K4418-3P	10-Jun-11	3,260
K4418-3P	10-Nov-11	2,965
K4418-6A	23-Nov-09	1,110
K4427-5A	21-Jul-08	488
K4428-1A	23-Jul-08	1,069
K4428-1A	2-Dec-09	1,290
K4428-1A	21-May-10	1,315
K4428-1A	17-Nov-10	1,229
K4428-1A	15-Mar-11	1,300
K4428-1A	18-Mar-11	1,300
K4428-1A	10-Jun-11	1,217
K4428-1A	10-Nov-11	1,293
K4428-1A	26-Nov-12	1,247
L4225-1A	18-Aug-08	140
L4225-1A	4-Dec-08	188
L4225-1A	16-Nov-09	121
L4225-1A	15-Nov-11	156
L4301-1A	18-Aug-08	151
L4301-1A	4-Dec-08	147
L4301-1A	16-Nov-09	140
L4301-1A	12-May-10	166
L4301-1A	11-Nov-10	211
L4301-1A	11-Mar-11	158
L4301-1A	15-Nov-11	197
L4301-1A	19-Nov-12	155
L4301-2A	9-Jun-10	197
L4301-2A	11-Nov-10	151
L4301-2A	9-Mar-11	160
L4301-2A	15-Nov-11	122
L4301-2A	20-Nov-12	127
L4305-1A	6-Jun-08	296
L4305-1A	4-Dec-08	290
L4305-1A	12-Nov-09	306
L4305-1A	12-May-10	297
L4305-1A	11-Nov-10	304
L4305-1A	9-Mar-11	308
L4305-1A	15-Nov-11	291
L4305-1A	20-Nov-12	296
L4308-1A	22-Jun-09	796
L4308-1A	12-Nov-09	839
L4308-1A	26-May-10	731
L4308-1A	16-Nov-10	833
L4308-1A	11-Mar-11	776
L4308-1A	16-Nov-11	790
L4308-1A	22-Nov-12	782
L4309-2A	6-Jun-08	298
L4309-2A	4-Dec-08	279
L4309-2A	12-Nov-09	314
L4309-2A	12-May-10	398
L4309-2A	11-Nov-10	347
L4309-2A	11-Mar-11	349
L4309-2A	15-Nov-11	350
L4309-2A	20-Nov-12	372
L4309-3A	22-Jun-09	345
L4309-3A	12-Nov-09	329
L4309-3A	13-May-10	388
L4309-3A	16-Nov-10	344
L4309-3A	9-Mar-11	343
L4309-3A	15-Nov-11	321
L4309-3A	20-Nov-12	330
L4315-1A	22-Jun-09	476
L4315-1A	12-Nov-09	439
L4315-1A	26-May-10	443
L4315-1A	16-Nov-10	452
L4315-1A	11-Mar-11	515
L4315-1A	16-Nov-11	458
L4315-1A	22-Nov-12	459
L4319-2A	30-Jun-08	546
L4319-2A	4-Dec-08	669
L4319-2A	12-Nov-09	665
L4319-2A	26-May-10	695
L4321-1A	7-Nov-07	184
L4321-1A	18-Aug-08	144
L4321-1A	2-Dec-08	237
L4321-1A	12-Nov-09	239
L4321-1A	13-May-10	285
L4321-1A	17-Nov-11	744
L4325-1A	4-Oct-07	90
L4325-1A	6-Nov-07	135
L4325-1A	25-Aug-08	172
L4325-1A	2-Dec-08	126
L4325-1A	12-Nov-09	108
L4325-1A	15-Nov-10	178
L4325-1A	17-Nov-11	123
L4325-1A	20-Nov-12	147
L4326-1A	20-Jun-08	266
L4326-1A	2-Dec-08	397
L4326-1A	16-Nov-09	377
L4326-1A	13-May-10	403
L4326-1A	14-Mar-11	428
L4401-1A	7-Nov-07	556
L4401-1A	25-Aug-08	431
L4401-1A	2-Dec-08	372
L4401-1A	12-Nov-09	347
L4401-1A	13-May-10	345
L4401-1A	15-Nov-10	356
L4401-1A	17-Nov-11	436
L4401-1A	27-Nov-12	444
L4401-2A	25-Aug-08	489
L4401-2A	2-Dec-08	491
L4401-2A	12-Nov-09	500
L4401-2A	13-May-10	454
L4401-2A	15-Nov-10	473
L4401-2A	14-Mar-11	422
L4401-2A	17-Nov-11	381
L4401-2A	27-Nov-12	480
L4401-3A	25-Aug-08	490
L4402-2A	20-Jun-08	168
L4402-2A	2-Dec-08	166

L4402-2A	18-Nov-09	134
L4402-2A	13-May-10	207
L4402-2A	15-Nov-10	178
L4402-2A	11-Mar-11	245
L4402-2A	14-Mar-11	408
L4402-2A	17-Nov-11	200
L4402-2A	21-Nov-12	159
L4404-2A	30-Jun-08	239
L4404-2A	3-Dec-08	278
L4404-2A	11-Nov-09	235
L4404-2A	26-May-10	245
L4404-2A	16-Nov-10	249
L4404-2A	11-Mar-11	245
L4404-2A	16-Nov-11	246
L4404-2A	23-Nov-12	245
L4406-1A	9-Jul-08	261
L4406-1A	3-Dec-08	235
L4406-1A	17-Nov-09	229
L4406-1A	14-May-10	246
L4406-1A	15-Nov-10	247
L4406-1A	14-Mar-11	236
L4406-1A	11-Nov-11	208
L4406-1A	27-Nov-12	230
L4406-2A	20-Jun-08	204
L4406-2A	2-Dec-08	200
L4406-2A	17-Nov-09	77
L4406-2A	13-May-10	385
L4406-2A	15-Nov-10	232
L4406-2A	14-Mar-11	521
L4406-2A	17-Nov-11	581
L4406-2A	27-Nov-12	241
L4410-1A	8-Nov-07	224
L4410-1A	20-Aug-08	211
L4410-1A	3-Dec-08	173
L4410-1A	11-Nov-09	179
L4410-1A	14-May-10	216
L4410-1A	15-Nov-10	203
L4410-1A	14-Mar-11	198
L4410-1A	11-Nov-11	167
L4410-1A	26-Nov-12	157
L4410-2A	25-Sep-07	206
L4410-2A	8-Nov-07	227
L4410-2A	20-Aug-08	209
L4410-2A	3-Dec-08	199
L4410-2A	11-Nov-09	200
L4410-2A	14-May-10	251
L4410-2A	15-Nov-10	201
L4410-2A	14-Mar-11	208
L4410-2A	26-Nov-12	206
L4411-1A	30-Jun-08	185
L4411-1A	2-Dec-08	189
L4411-1A	18-Nov-09	222
L4411-1A	14-May-10	203
L4411-1A	16-Nov-10	199
L4411-1A	15-Mar-11	202
L4411-1A	11-Nov-11	169
L4411-1A	27-Nov-12	179
L4411-2A	22-Jun-09	411
L4411-2A	18-Nov-09	371
L4411-2A	14-May-10	348

L4411-2A	16-Nov-10	359
L4411-2A	15-Mar-11	422
L4411-2A	11-Nov-11	365
L4411-2A	27-Nov-12	418
L4413-2A	9-Jun-10	459
L4413-2A	17-Nov-10	382
L4413-2A	12-Mar-11	411
L4413-2A	10-Jun-11	387
L4413-2A	8-Sep-11	447
L4413-2A	11-Nov-11	376
L4413-2A	26-Nov-12	414
L4415-1A	14-Jul-08	221
L4415-1A	3-Dec-08	221
L4415-1A	12-Nov-09	223
L4415-1A	14-May-10	214
L4415-1A	17-Nov-10	208
L4415-1A	14-Mar-11	229
L4415-1A	10-Nov-11	204
L4415-1A	27-Nov-12	209
L4415-2A	22-Jun-09	417
L4415-2A	12-Nov-09	421
L4415-2A	14-May-10	387
L4415-2A	17-Nov-10	431
L4415-2A	14-Mar-11	403
L4415-2A	16-Nov-11	416
L4415-2A	23-Nov-12	442
L4416-2A	14-Jul-08	1,288
L4416-2A	3-Dec-08	1,827
L4416-2A	12-Nov-09	1,532
L4416-2A	14-May-10	1,498
L4416-2A	17-Nov-10	1,547
L4416-2A	11-Mar-11	1,499
L4416-2A	10-Jun-11	1,461
L4416-2A	16-Nov-11	1,520
L4416-2A	23-Nov-12	1,492
L4416-3A	22-Jun-09	451
L4416-3A	12-Nov-09	366
L4416-3A	14-May-10	389
L4416-3A	17-Nov-10	396
L4416-3A	11-Mar-11	414
L4416-3A	11-Mar-11	448
L4416-3A	16-Nov-11	404
L4416-3A	23-Nov-12	378
L4416-4A	9-Jun-10	2,160
L4416-4A	17-Nov-10	2,254
L4416-4A	14-Mar-11	2,406
L4416-4A	10-Jun-11	2,405
L4416-4A	16-Nov-11	2,335
L4416-4A	23-Nov-12	2,376
L4419-1A	22-Jul-08	889
L4419-1A	3-Dec-08	876
L4419-1A	11-Nov-09	259
L4419-1A	21-May-10	438
L4419-1A	17-Nov-10	831
L4419-1A	14-Mar-11	783
L4419-1A	10-Nov-11	416
L4419-1A	26-Nov-12	374
L4421-1A	8-Nov-07	111
L4421-1A	20-Nov-09	72
L4421-1A	17-Nov-10	156

L4421-1A	10-Nov-11	139
L4421-1A	26-Nov-12	164
M4313-1A	9-Jun-10	1,094
M4313-1A	16-Nov-10	1,035
M4313-1A	11-Mar-11	1,001
M4313-1A	9-Jun-11	991
M4313-1A	16-Nov-11	1,047
M4313-1A	22-Nov-12	1,074
M4402-1A	21-Jul-08	693
M4402-1A	3-Dec-08	673
M4402-1A	12-Nov-09	705
M4402-1A	14-May-10	676
M4405-1A	21-Jul-08	610
M4405-1A	3-Dec-08	616
M4405-1A	11-Nov-09	536
M4405-1A	14-May-10	570
M4405-1A	16-Nov-10	589
M4405-1A	11-Mar-11	596
M4405-1A	16-Nov-11	558

M4405-1A	23-Nov-12	607
M4409-4A	17-Jul-08	243
M4409-4A	3-Dec-08	203
M4409-4A	11-Nov-09	188
M4409-4A	14-May-10	189
M4413-1A	17-Jul-08	332
M4413-1A	3-Dec-08	324
M4413-1A	11-Nov-09	336
M4413-1A	14-May-10	415
M4413-1A	16-Nov-10	374
M4413-1A	11-Mar-11	324
M4413-1A	11-Mar-11	344
M4413-1A	16-Nov-11	339
M4413-1A	23-Nov-12	320
M4417-1A	14-Jul-08	535
M4417-1A	3-Dec-08	680
M4417-1A	12-Nov-09	600

APPENDIX B – Stream-Salinity Data for the O'Neil-to-McCoy Mine Area

Figure B1 shows the locations of the 36 manual-sampling, stream-salinity monitoring sites in the O'Neil-to-McCoy mine area and Table B1 lists their locations (m GDA94). The sample data is plotted in Figure B2.

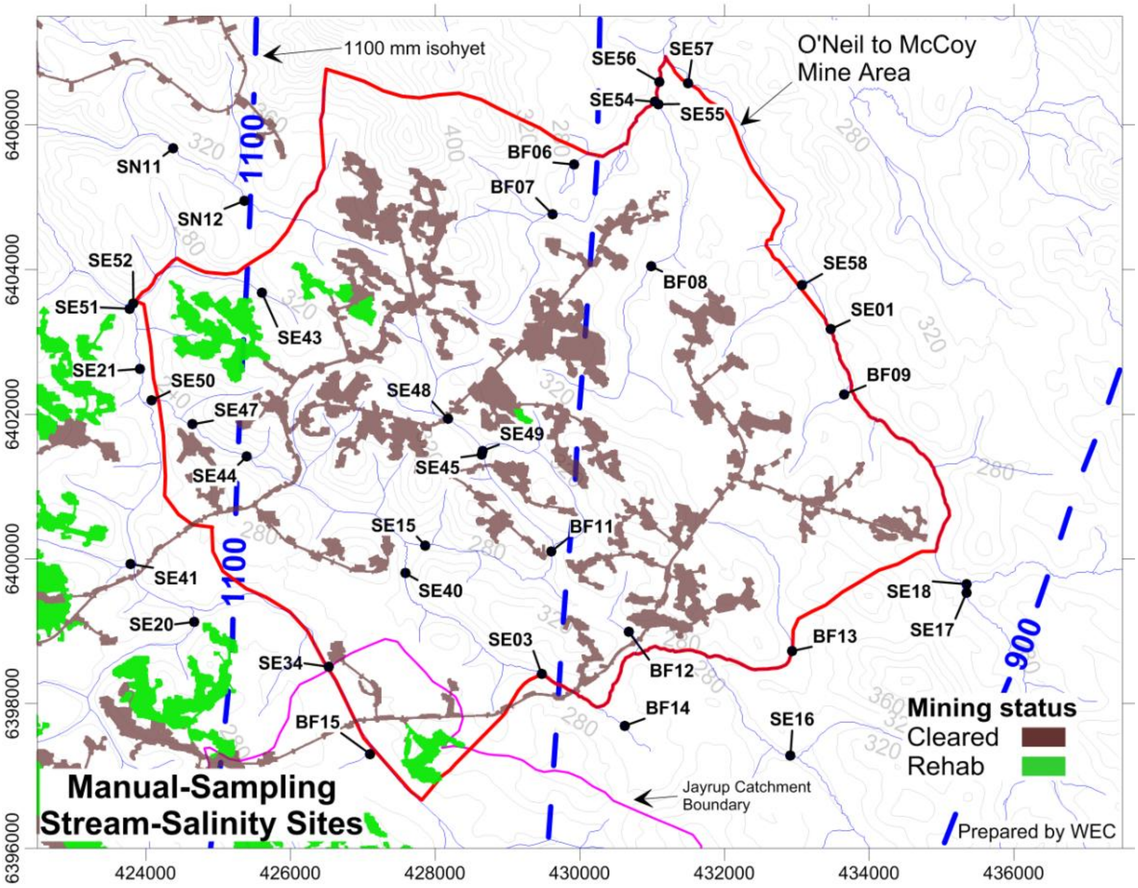

Figure B1: Location of the 36 manual-sampling, stream-salinity monitoring sites in the O'Neil-to-McCoy mine area.

Table B1: Listing of the 36 manual-sampling, stream-salinity monitoring sites in the O’Neil-to-McCoy mine area along with their locations (m GDA94).

Site	Easting	Northing	Site	Easting	Northing
BF06	429920	6405452	SE40	427590	6399802
BF07	429624	6404763	SE41	423789	6399929
BF08	430984	6404045	SE43	425606	6403679
BF09	433651	6402274	SE44	425394	6401416
BF11	429605	6400104	SE45	428646	6401445
BF12	430676	6398990	SE47	424643	6401861
BF13	432931	6398726	SE48	428177	6401938
BF14	430620	6397693	SE49	428654	6401494
BF15	427099	6397303	SE50	424082	6402193
SE01	433467	6403177	SE51	423778	6403458
SE03	429471	6398407	SE52	423828	6403529
SE15	427865	6400181	SE54	431039	6406319
SE16	432911	6397281	SE55	431087	6406286
SE17	435343	6399531	SE56	431100	6406594
SE18	435343	6399651	SE57	431497	6406579
SE20	424667	6399130	SE58	433073	6403783
SE21	423919	6402628	SN11	424377	6405677
SE34	426527	6398509	SN12	425365	6404953

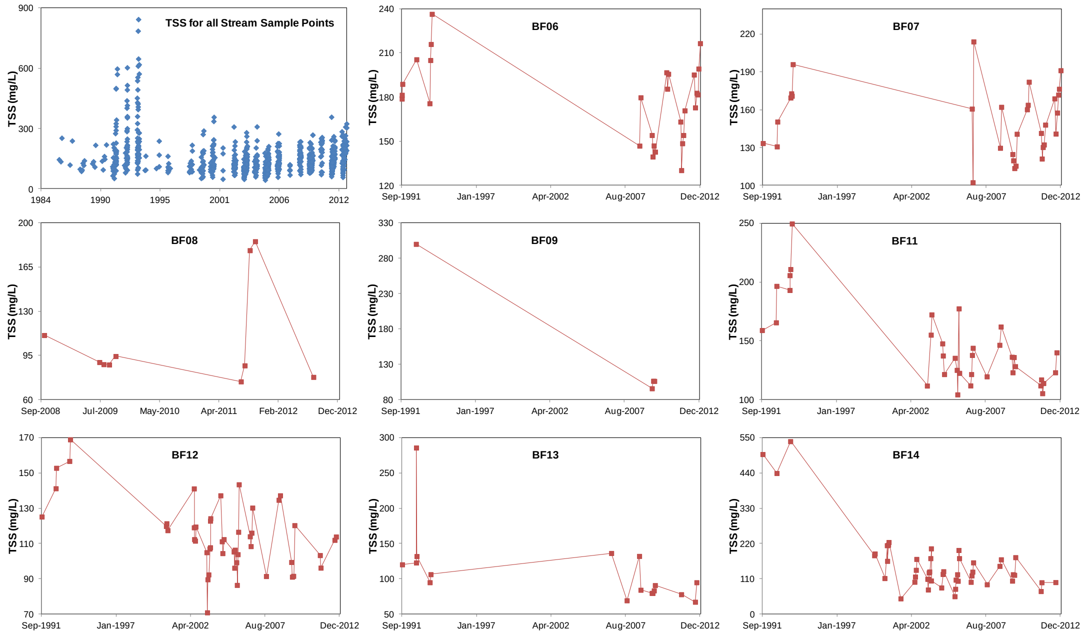

Figure B2 continued.

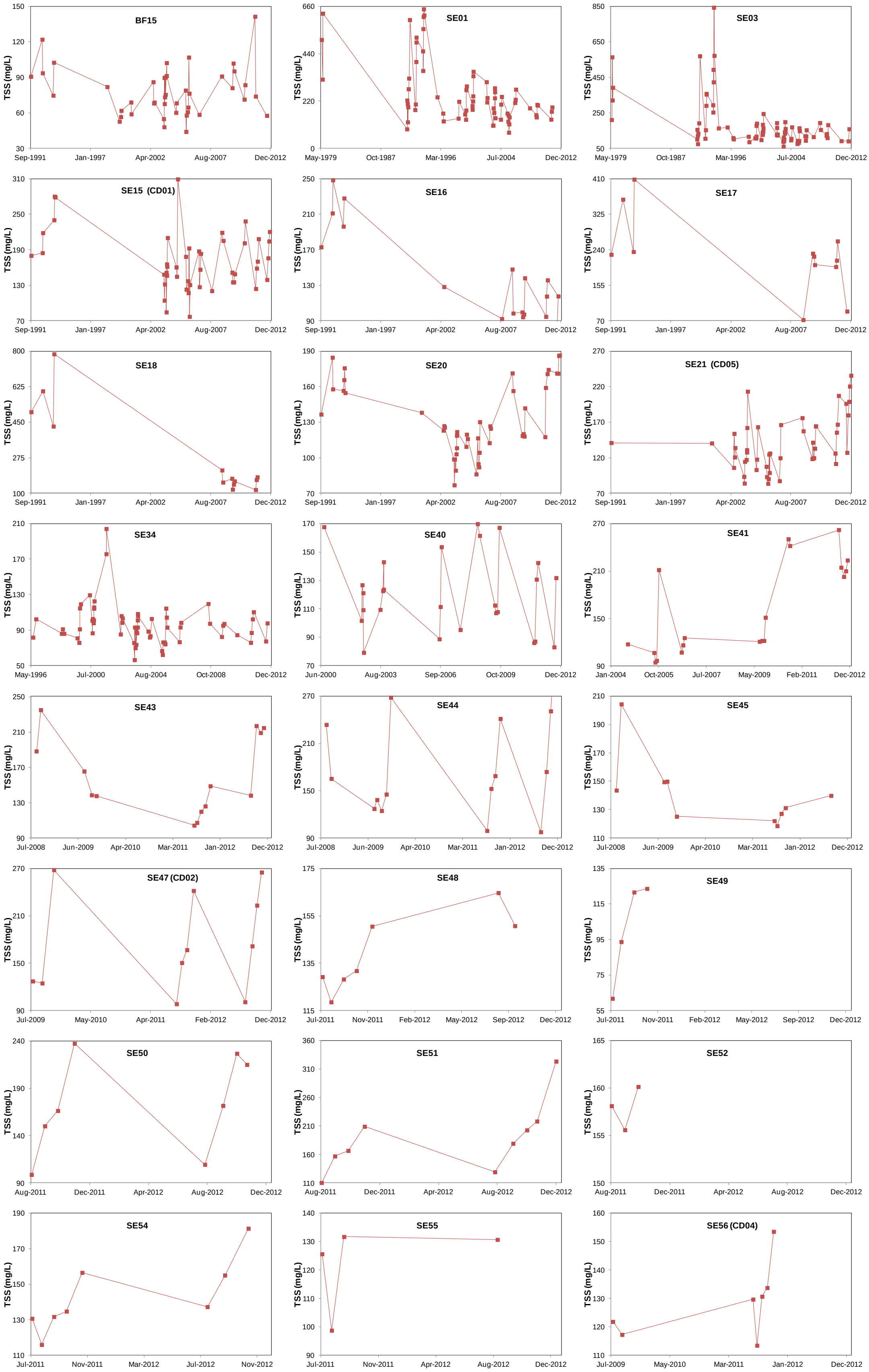

Figure B2 continued.

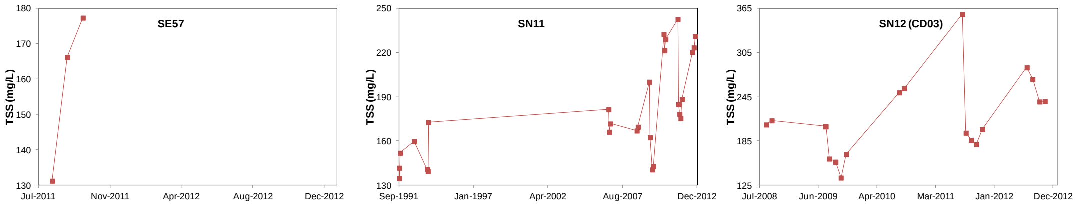

Figure B2: Plots of stream-salinity for 35 manual-sampling, stream-salinity monitoring sites in the O'Neil-to-McCoy mine area. Note that SE58 isn't plotted as no sample has yet been collected there.