

## **Economic returns from environmental problems - Potential for breeding to make lower rainfall areas a reality**

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### **Abstract**

Initial results from across-site analysis of a sub-set of 21 medium to low rainfall trials from Saltgrow's nationwide network of *E. camaldulensis* x *E. grandis* and *E. camaldulensis* x *E. globulus* hybrid trials are presented. The results indicate that rainfall and site quality are the two principle factors affecting productivity. Rainfall explains 36 to 44% of the growth variation across all trials in the study, and 72 to 95% of growth variation for average and high quality sites when trials are classified according to site quality. The results indicate that the hybrids are broadly adapted, possibly through the combination of the adaptive range of the two pure species parents to each hybrid.

Deployment of a fixed set of selected clones across all sites to buffer out minor site x genotype interaction can achieve commercially viable growth rates down to 500mm/yr rainfall on high quality sites, and 700mm/yr on average sites. Matching of the best clone to specific site conditions can lower these rainfall limits to 400mm/yr and 600mm/yr respectively. However, deployment of a selected clone mixture relative to individual clones provides less risk, particularly where site conditions have not been previously trialed, or are not well characterised.

The opportunity for commercial plantations integrated with agriculture in medium to low rainfall areas to address a range of natural resource management issues including salinity, water quality, biodiversity and carbon sequestration, and to provide agricultural production benefits are discussed.

### **Introduction**

Forest plantation development in medium to low rainfall areas offers significant opportunities to combine natural resource management with commercial timber production, enhanced agricultural production and improved sustainability. In parallel, declining availability of higher rainfall land is increasing pressure on the plantation industry to consider lower rainfall options. Yet adoption of forestry in medium to low rainfall areas has been limited to date by below commercial productivity.

An expansion at the margin from 600mm/yr rainfall, currently considered as the lower limit for *E. globulus* plantations on good sites, to 500 or even 400mm/yr, would represent a significant potential expansion of the land available to forestry. At the same time it would allow expansion of commercial forestry into a large proportion of Australia's cropping and grazing zones where targeted integration of forestry into agriculture would create a more diverse landscape of trees and agriculture, one of three key pillars of on-ground action recommended to limit the spread of salinity and loss of native biodiversity in Australia's land and river systems (Stirzaker *et al.*, 2000). In addition, integration of trees into agricultural production systems offers to provide direct benefits to agricultural production from shade and shelter for crops and pastures (Cleugh and Prinsley, 2003), reduced waterlogging of seasonally wet areas (RIRDC, 1997), and increased populations of natural insect predators.

In 1996, the XylonovA R&D Project commenced a collaborative breeding program to combine the stress tolerance of *E. camaldulensis* with the growth rate, stem form and wood properties of the commercial species *E. grandis* and *E. globulus*. This project, managed since 2000 by Saltgrow Pty Ltd, has established over 100 trials around Australia. Initial across site results from these trials are discussed in terms of major environmental factors affecting productivity, the lower rainfall limits to productivity, and the opportunities and risks from alternative clonal deployment strategies.

## Materials and Methods

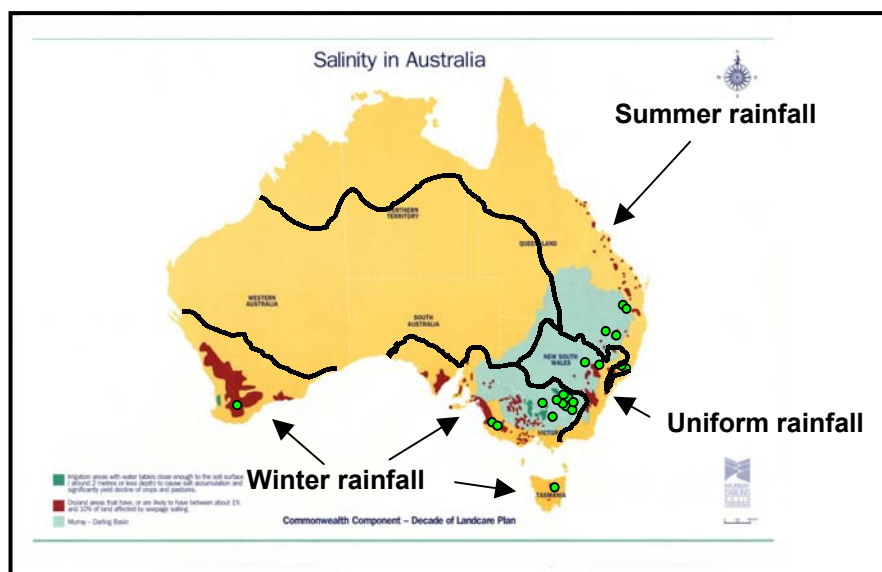
### *Hybrid pedigrees*

Eleven full-sib F<sub>1</sub> hybrid families were constructed, comprising combinations of three *E. camaldulensis*, three *E. globulus* and two *E. grandis* parents. The *E. camaldulensis* parents were selected on the basis of above average growth and stem form in replicated clonal trials under saline conditions in Victoria and Western Australia. The *E. grandis* parents were selected on the basis of early growth and form in an irrigated provenance trial at Shepparton in northern Victoria, and *E. globulus* parents were chosen on the basis of growth, form and wood quality for pulp production. Over 1300 clonally propagated hybrid lines from these crosses were established in trials across Australia.

### *Trial descriptions and locations*

This study considers 21 non-saline to mildly saline trials distributed around Australia. The trials span the range of low (400 to 600mm/yr) to medium (600 to 800mm/yr) rainfall, and winter maximum, summer maximum and uniform rainfall seasonality. A summary of trial details and site conditions is presented in Table 3. Locations of trials is depicted in Figure 1.

These trials comprise a subset of a larger trial program undertaken by Saltgrow Pty Ltd of the hybrid material described above. Each of the trials included in this study was established as a “clonal selection” trial, and is comprised of a random selection of clones from among a pool of over 1300 clones under evaluation.



**Figure 1:** Location of Saltgrow trials included in the study and detailed in Table 3, illustrating geographic distribution and rainfall seasonality.

### ***Site Categories***

Trials summarised in Table 3 were qualitatively divided into three broad categories based on site conditions affecting potential productivity. Broadly, these categories were defined as:

Site Class 1: Deep, fertile soils with no impediments to favourable tree growth and good capacity for soil water storage.

Site Class 2: Sites generally with at least one impediment to tree growth including poor to average fertility, some limitations to soil water storage or upper slope position.

Site Class 3: Sites generally with more severe or multiple impediments to tree growth including ridge sites, shallow soils, highly sodic sites, poor fertility or sites prone to severe frost.

### ***Standardisation for comparison between trials of differing age***

Comparison of productivity between trials was achieved by standardising measured trial growth to projected MAI at age 10 years. For this purpose, the measured growth in each trial was compared to growth derived from a reference growth curve for pure *E. grandis* at the same age, then projected by simple proportion to growth at age 10. Growth projections are based on measure data in unthinned stands ranging between two and seven years of age.

While there is potential for error in projecting young age measure data, the projected age 10 MAI from the oldest trial (Gundagai, age 7) was unchanged from the projections of age 3 data for this trial.

### ***Rainfall***

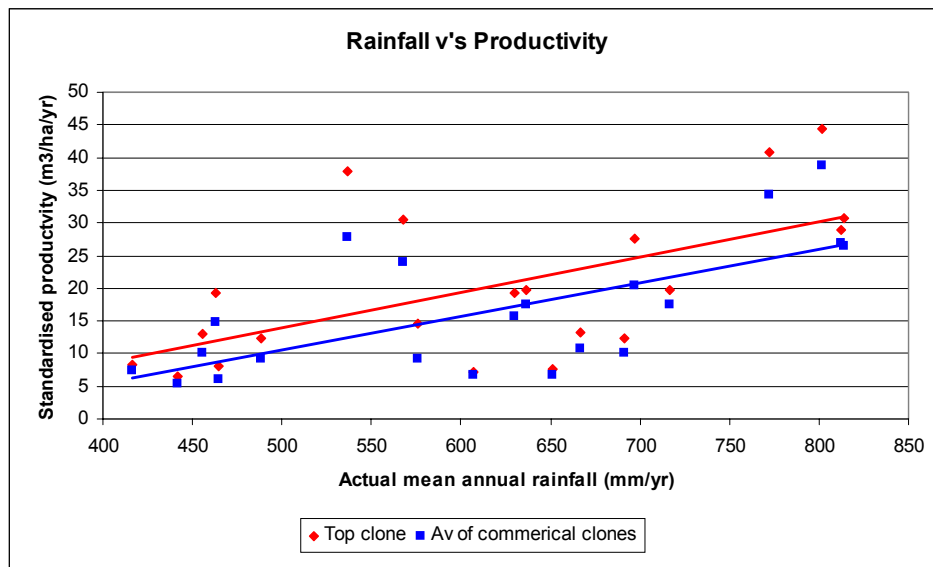
Actual annual rainfall at the nearest meteorological station to each trial site over the period of measurement were obtained from Rainman Streamflow V4.3+ (Clewett *et al.*, 2003). Where trials were distant from meteorological stations, data from surrounding stations was interpolated to estimate rainfall at the trial site.

## **Results**

### ***Trial growth with rainfall only***

Figure 2 illustrates the regression of mean actual annual rainfall with standardised productivity for all 21 trials listed in Table 3 for: (a) the top performing clone at each site; and (b), the mean performance of the commercial clone selections at each site.

The correlation co-efficient between rainfall and growth for the top clone was 0.36, and for the mean performance of the commercial clones was 0.44, indicating that rainfall alone explained 36 to 44% of the observed variation in growth productivity between the trials.



**Figure 2:** Standardised trial productivity (m<sup>3</sup>/ha/yr) at age 10 relative to actual average annual rainfall over the period of trial measurement, for various sub-sets of trial clones. Correlation co-efficients (r<sup>2</sup>) are: (a) top clone at each site - 0.36; (b) mean of commercial clone selections - 0.44.

### ***Trial growth with site category and rainfall***

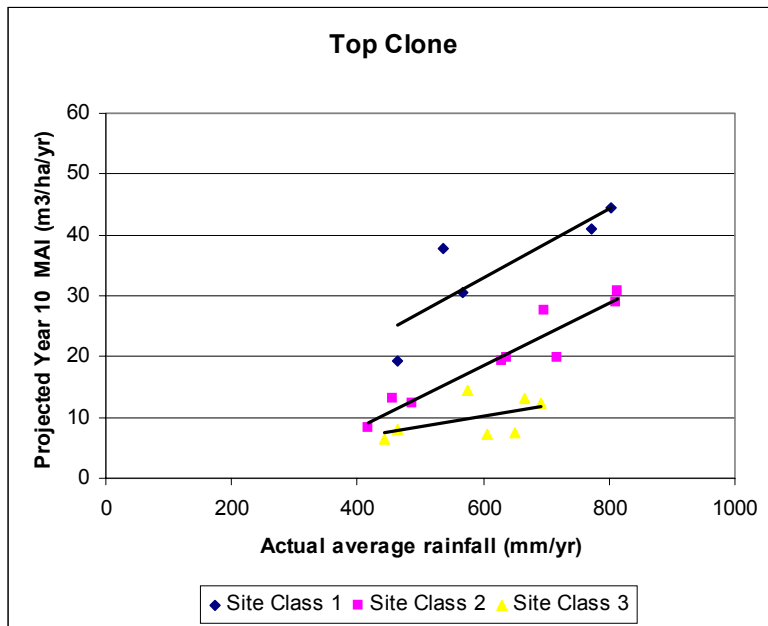
Figure 3 illustrates the regression of standardised year 10 MAI against rainfall for the top performing clone at each trial site, by Site Class 1, 2 and 3, and Figure 4 illustrates the same regression for the mean productivity of the commercial clone set.

The correlation co-efficients for the six regressions illustrated in Figure 3 and Figure 4 are summarised in Table 1. Within Site Class 1 and 2, variation in growth performance of the top clone at each site and the mean of the commercial clones ranged between 72% and 95%, while for Site Class 3, rainfall explained only 25 to 57% of the variation.

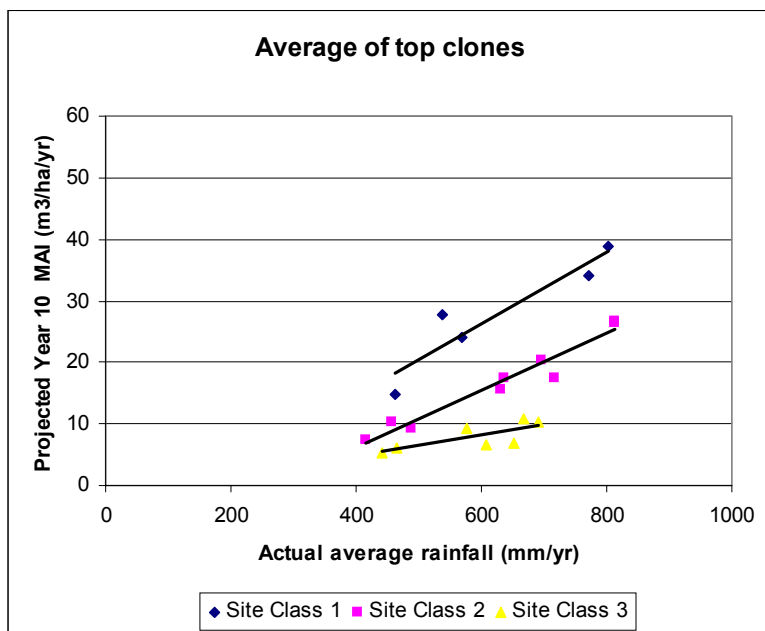
**Table 1:** Correlation co-efficients (r<sup>2</sup>) for the regression between rainfall and growth within site class for the top clone at each trial site, and the mean performance of the commercial clones at each site.

Site Class / Clone Group	Top Clone	Mean of commercial clones
Site Class 1	0.72	0.87
Site Class 2	0.91	0.95
Site Class 3	0.25	0.57

It can be seen from Figure 3 that deployment of the top clone at each site is projected to achieve greater than 20 MAI at rainfalls as low as 400mm on Site Class 1 soils, and at rainfalls down to 600mm on Site Class 2 soils. Site Class 3 soils remain non-commercial regardless of rainfall. Similarly, it can be seen from Figure 4 that deployment of a mixture of commercial Saltgrow clones is projected to achieve greater than 20 MAI at rainfalls as low as 500mm on Site Class 1 soils, and at rainfalls down to 700mm on Site Class 2 soils. Again, Site Class 3 soils remain non-commercial regardless of rainfall. These results are summarised in Table 2.



**Figure 3:** Projected productivity at age 10 relative to actual average annual rainfall for three site qualities, where the best performing Saltgrow clone at each site is deployed.



**Figure 4:** Projected productivity at age 10 relative to actual average annual rainfall for three site qualities, where Saltgrow clones are deployed as a mixture of selected clones.

**Table 2:** Projected year 10 MAI (m<sup>3</sup>/ha/yr total stand volume) by rainfall and site category for the alternative deployment options of: (a) matching the top clone to each site; and (b) deploying a fixed set of selected clones across all sites. Projected productivities exceeding or close to 20 MAI are shown highlighted yellow, indicating the combination of conditions where there is potential to establish commercially viable plantations.

Rainfall (mm)	Site Class 1			Site Class 2			Site Class 3		
	Top Clone	Mixture	Top clone gain	Top Clone	Mixture	Top clone gain	Top Clone	Mixture	Top clone gain
300	16.0	8.9	80%	3.2	1.4	129%	5.1	3.0	70.0%
400	21.6	14.7	47%	8.3	6.1	36%	6.8	4.7	44.7%
500	27.3	20.5	33%	13.4	10.7	25%	8.4	6.4	31.3%
600	33.0	26.3	25%	18.5	15.4	20%	10.1	8.1	24.7%
700	38.6	32.1	20%	23.5	20.0	18%	11.8	9.8	20.4%
800	44.3	37.8	17%	28.6	24.7	16%	13.5	11.5	17.4%
900	49.9	43.6	14%	33.7	29.3	15%	15.2	13.2	15.2%
1000	55.6	49.4	13%	38.7	34.0	14%	16.8	14.9	12.8%

## Discussion

### *Environmental factors affecting hybrid productivity*

This study provides strong evidence that rainfall and soil conditions explain a significant proportion of the variation in productivity of the hybrids between sites. The regression of rainfall across all sites simultaneously, irrespective of site class, explained 36 to 44% of the variation in productivity for either the top clone at each site, or a selected commercial clone set. This is despite this set of trials spanning winter maximum, though uniform to summer maximum rainfall seasonality; a geographic range from south-west Western Australia to south-east Queensland; and a wide range of site conditions from shallow soils, highly sodic sites, poor fertility soils or sites prone to severe frost, to deep, fertile soils with no impediments to favourable tree growth and good capacity for soil water storage.

This strong relationship between rainfall and productivity indicates that the hybrids are broadly adapted. This is an important trait in order to enable reliable clonal deployment in commercial plantations, particularly in areas where trials have not been previously established.

When trial sites were stratified according to a simple site class system based largely on soil impediments to tree growth, then rainfall was able to explain between 72 and 95% of the variation in growth for average (Site Class 2) and high (Site Class 1) quality sites. This result indicates that rainfall seasonality and geographic/latitudinal/elevational variation have only a minor influence (within the range of such conditions encountered in the trials) on productivity of the hybrids after the influence of rainfall and site quality. These results support work with tropical eucalypts in Brazil where the majority of variation in productivity between sites is explained by rainfall and vapour pressure deficit (Stape *et al.*, 2004).

The lower correlation between rainfall and productivity for Site Class 3 indicates that the trials within this site class may capture a broader range of factors limiting growth of the hybrids or, conversely, the effects of limiting soil conditions encountered in the trials, including sodicity, soil depth, fertility and frost severity, are not equal in their effect, and that

there may be opportunity to further sub-divide this site class. Improved stratification of Site Class 3 may identify site conditions where commercially viable levels of productivity may still be achieved.

### ***Limits to productivity, and hybrid deployment strategies***

The regressions presented in Figure 3 and Figure 4 and summarised in Table 2 indicate that commercially viable productivity (total stand MAI greater than 20m<sup>3</sup>/ha/yr) could be achieved down to a rainfall of 700 mm/yr on Site Class 2, and 500 mm/yr on Site Class 1. With more targeted site-clone matching, involving the deployment of the best clone for a given site, then the limits to commercial productivity could be lowered by approximately 100mm/yr rainfall for each site class, being 600mm for Site Class 2 and 400mm for Site Class 1. Alternatively, deployment of the best clone at each site relative to a set of selected clones could deliver gains in productivity of 33 and 25% under Site Class 1 and 2 conditions respectively at 500mm, or 17 and 16% under Site Class 1 and 2 conditions respectively at 800mm.

The potential for deployment of the best clone at each site, compared to a set group of selected clones across all sites, to:

- achieve gains in productivity at a given rainfall; and
- reduce the rainfall limit to commercial productivity,

identifies an important issue in deployment strategies for these clonal eucalypt hybrids.

Although rainfall and site explain a significant proportion of the observed variation in trial productivity, there remains an element of clone x site interaction, such that the top performing clone may vary between sites. Where clone x site interaction effect is strong, then the best clone at one site can perform relatively poorly at another site, although it will usually still rank in the top 10% of clones. In contrast, deployment of a fixed set of clones across all sites buffers out the effect of clone x site interaction for any individual clone included in the set. Deployment of a set of clones thus provides a more predictable deployment strategy without the need for detailed clone-site matching, albeit at the cost of some loss in potential productivity and/or higher rainfall limit, but with lower risk of below expected growth on any particular site. This is graphically illustrated in a series of six species-clonal trials spanning central-western NSW where the best of seven pure species trialed varied between sites, but a fixed set of select clones consistently outperformed the best pure species at each site, and outperformed the best pure species across all six sites by an average of 67% for mean stem volume at age four (data not shown).

### ***Opportunities for multiple benefits from medium/low rainfall forestry.***

The limit to commercial productivity achieved by the hybrids in this study identifies a significant opportunity for breeding and clonal selection to both push the lower viable limits to commercial forestry, and improve productivity at currently marginal rainfall. An expansion in the margin from 600mm rainfall, currently considered as the lower limit for *E. globulus* plantations on good sites, to 500mm for a mixed set of hybrid clones, or 400mm where individual clones can be matched to site conditions, represents a significant potential expansion of the land available to forestry. Importantly, it would allow expansion of commercial forestry into a large proportion of Australia's cropping and grazing zones where targeted integration of forestry into agriculture can help address a range of natural resource management issues including salinity, water quality, biodiversity and carbon sequestration (Stirzaker *et al.*, 2000), in addition to providing direct benefits to agricultural production from shade and shelter for crops and pastures (Cleugh and Prinsley, 2003), reduced waterlogging of

seasonally wet areas (RIRDC, 1997), and possibly increased populations of natural insect predators allowing reduced use of insecticides.

## Conclusions

This study has identified rainfall, modified by site quality, as the principle factors affecting productivity of *E. camaldulensis* x *E. grandis* and *E. camaldulensis* x *E. globulus* hybrids across temperate and sub-tropical regions of Australia. Rainfall seasonality and geographic/latitudinal/elevational variation appear to have only a minor influence within the broad range of such conditions encountered in the trials. This indicates that the hybrids are broadly adapted. This broad adaptation may result from the combination of the adaptive range of the two pure species parents to each hybrid, one of which, *E. camaldulensis*, is naturally a broadly adapted species. This result should allow repeatable and predictable plantation growth to be achieved using these hybrids in medium-low rainfall areas provided sites can be adequately characterised.

The study further indicates that commercially viable productivity using these hybrids can be achieved for Site Class 1 down to 400mm mean annual rainfall where individual clones are matched to sites, but a more conservative deployment strategy of using a fixed set of around five selected clones across all sites still allows commercial production down to 500mm annual rainfall for Site Class 1. The relative benefits in terms of productivity at a given rainfall from deployment of specific clones matched to sites increases with decreasing rainfall, particularly below 800mm. This deployment strategy is most appropriate where good information is available to match the most appropriate clone to the site.

## Acknowledgements

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**Table 3:** Details of trials included in analysis of productivity in relation to rainfall.

Site Class	Property	Location	State	Planted	Average annual rainfall (mm)	Actual annual rainfall (mm)	Rainfall Seasonality	Site Description
Site Class 1	Barton's	Gundagai	NSW	Oct-99	713	802	Winter	Alluials
Site Class 1	Graham's	Coleambally	NSW	Nov-00	772	772	Irrigated	Medium-heavy clay
Site Class 1	Martins	Borambola	NSW	Sep-00	648	568	Winter	Mildly saline, seasonally waterlogged
Site Class 1	Coolabunya Saline	Coolabunya	QLD	Apr-01	780	537	Summer	Mildly saline Kraznozem
Site Class 1	Burrendong	Kojonup	WA	Aug-01	533	463	Winter	Gritty duplex over weathered rock
Site Class 2	Kemiss	Ladysmith	NSW	Aug-01	584	416	Winter	Moderately saline
Site Class 2	Smith's	Kalangadoo	SA	Sep-99	797	814	Winter	Seasonally waterlogged
Site Class 2	Hunt	Kalangadoo	SA	Jul-00	710	812	Winter	Seasonally waterlogged heavy clay
Site Class 2	Coutts	Wangaratta	VIC	Aug-00	636	630	Winter	Riveine flats, grey loam over heavy clays
Site Class 2	Coolabunya Red Soil	Coolabunya	QLD	Apr-01	780	637	Summer	Rapidly drying Kraznozem
Site Class 2	Champaign	Bethungra	NSW	Sep-00	626	488	Winter	Silty loam over light-medium clay
Site Class 2	Nash	Wagga	NSW	Sep-00	584	456	Winter	Red earth, upper slope position
Site Class 2	Bloomfield	Maitland	NSW	Oct-01	894	717	Summer	Mine rehabilitation
Site Class 2	Silsoe	Willow Tree	NSW	Sep-00	685	697	Summer	Recharge site
Site Class 3	MacGen	Liddell	NSW	Nov-00	638	667	Summer	Loam over clay
Site Class 3	Lui Station	Lui	NSW	Aug-00	675	691	Uniform	Recharge site
Site Class 3	Williams	Cumnock	NSW	Aug-00	707	651	Uniform	Dryland
Site Class 3	Formosa	Cressy	TAS	Nov-00	636	607	Winter	Saline, seasonally waterlogged
Site Class 3	Emerald Plains	Emerald Hills	NSW	Sep-00	619	576	Summer	Recharge site
Site Class 3	Tufnell Park	Junee	NSW	Aug-00	531	465	Winter	Recharge site
Site Class 3	Mona Vale	Ladysmith	NSW	Aug-00	584	442	Winter	Recharge site