Chapter 4 Discussion: Effects of flooding and turbidity on water plant germination and establishment from pond trials with wetland seed banks

4.1 Introduction

The first aim, to map the underwater light climate to determine if the lack of light was the main factor controlling poor germination and establishment of water plants in turbid water of farm dams is discussed in Chapter 4.2. The suitability of relating secchi depth transparency in turbid water in ponds to determine the depth of plant colonisation in farm dams from the calculated euphotic depth is discussed in Chapter 4.2.1. In Chapter 4.2.2 the amount of light available at shallow depths in turbid water is related to the species that tolerated turbidity and some known compensation points.

The hypotheses to establish if the species richness of submerged plants which germinated and established from the two seed banks changed under turbid and clear conditions and if density (biomass) was increased are discussed in Chapter 4.3. The effects of turbidity on the seed banks and the germination and biomass results from the two wetlands are discussed separately in Chapters 4.3.1 and 4.3.2.

The second aim, to assess the suitability of the source of seed bank and species present in two wetlands, one temporary and one permanent, for the revegetation of turbid farm dams is discussed in Chapter 4.3.3.

Morphogenic changes with depth and turbidity are discussed in Chapter 4.3.4.

The experiment is summarized in Chapter 4.4.

4.2 The underwater environment in ponds

In the set up of the ponds the increase in SRP with increased turbidity was due to the of the phosphorus would have been in an insoluble form. All levels were in the higher range at the start of the experiment and in hindsight it was unfortunate that samples were not taken at the conclusion of the experiment as well. This increase in SRP and TP in the higher turbidity ponds may have had some effect on biomass, but there was little algal growth in the higher turbidities when plants were still in the ponds. Algal scums established in the turbid ponds a few days after the pots and plants were removed for harvesting which indicates the nutrient resources were quickly utilised by algae after the plants were removed. Previous research found no significant relationship between phosphorus loading or concentration and the biomass of aquatic plants (Balls *et al.* 1989) but the possibility that available SRP may have affected biomass is not discounted.

The increase in water pH after 8 weeks was slightly higher in the clear water and low turbidity ponds than in the medium and high turbidity ponds which indicates higher plant and algal use of carbon from the dissolved carbon dioxide. It may indicate that high turbidity does restrict algal growth as light would be minimal except in the top few cm.

The maximum and minimum air temperatures (Appendix III) reflected the high variability between day and night air temperatures in Armidale. Water temperatures in the turbid ponds became slightly colder with depth but temperatures were found in the range suitable for seed germination (Haag 1983, Hartleb *et al.* 1993, Hill 1996).

Air and underwater light irradiance varied with the extent of cloud cover (Appendix II). With reference to Figure 3.1, downwelling Ed (PAR) in turbid water at shallow depths from 0 to 10 cm showed a high level of variation but there was less difference between Ed at each depth at low air irradiances than at high ones. At 20 cm in the turbid ponds, downwelling light, (Ed), was more diffused and stable with fewer peaks and troughs. This may dull the high intensity light wavelengths in Spring that trigger germination. The graph of light climate at shallow depths in turbid water indicates that the Ed (PAR) was greater than was expected and light irradiance was above the minimum compensation point of 5 μmol $m^{-2}s^{-1}$ given for older leaves of *Vallisneria americana* (Blanch 1997). Therefore light was not likely to be limiting for all water plant species and was not a factor preventing plant colonisation.

4.2.1 The suitability of using secchi depth as a measure of Z_{eu}

Measures of turbidity and secchi depth transparency, Z_{SD}, are negatively and highly correlated in many studies (Arruda *et al.*1983, Gippel 1989, Kirk 1994) often with some variation in their regression relationship dependent on the type of turbidity under study, whether of algae, suspended clay or glacial flour. However most research reports are on studies of submerged plants or algae in deep oligiotrophic lakes, often to depths greater than 20 metres where secchi disc transparency is also high (Tanner *et al.* 1993, Schwarz and Hawes 1997, Schwarz *et al.* 1999). Other reports are European studies on shallow, winter-frozen, summer-eutrophic lakes (van Dijk and van Vierssen 1991, Blindow 1992a, 1992b, Van den Berg *et al.* 1998). At the start of this experiment, there was no relevant or published research on submerged water plants or light studies of the same in shallow turbid lakes, rivers or dams in Australia. A few light compensation point studies had been done on Australian species but they were unpublished at the time (Blanch, 1997).

Blanch (1997) produced similar turbidities and secchi disc transparencies to those in this experiment using bentonite (a commercially available clay) and highly ionic tap water to simulate light regimes similar to those in the Murray River below its confluence with the Darling River. Blanch appears to have successfully reproduced the turbid conditions found in the Murray River under experimental conditions in his larger ponds. This was done by continuously running an electric mixer to keep the clay particles in suspension and adding extra clay when required to replace that which had flocculated and settled out of the water column (Blanch 1997). As the experiment discussed in this thesis used locally mined fine clays (that are similar to those found in the New England Tablelands) suspended in rain water, flocculation of suspended clay particles was less of a problem and an electric mixer was not needeed. Monitoring indicated constant turbidity conditions, and while the light being measured was purely incident underwater radiation, no attempt was made to measure the specific wavelengths of light that were being transmitted through the turbid medium which were being utilised by the water plants.

To make valid deductions on the effect of turbidity on water plants, the recording of turbidity and other variables in the ponds was an important part of understanding the conditions under which the water plants germinated and established. Reducing the amount of variability in the environment by keeping water and turbidity maintained at a constant level was an important aspect of this experiment. Light readings indicate the amount of available PAR in μ moles m^{-2} sec^{-1}; secchi disc depth gives an ease of reading and practicality in community Landcare, and turbidity is a standard measure commonly used by both scientist and layman. Measurement of the three variables - PAR, secchi disc depth and turbidity - meant strong associations could be made between these measurements and these associations would then be valid for establishing the depth of colonisation (Zc) for water plants in farm dams in the Tablelands and elsewhere. Plant responses in the ponds are the result of the turbidity treatments imposed at known depth, water temperatures and quantities of light

The secchi disc transparency, Z_{SD}, is used to calculate the euphotic depth, Z_{eu} (using the equation $Z_{eu} = x \text{ X } Z_{SD}$ where x = 2 or 3) (Moss *et al.* 1996, Boulton and Brock 1999) and gives the maximum range of plant colonization, in a turbidity of 135 NTU and $Z_{SD} = 0.13$m, as between 26 and 39 cm. Extrapolation from the graph of underwater light (Figure 3.2) gives a maximum Z_{eu} for plant colonization at 25 cm in the high turbidity where light falls to zero. The maximum depth at which the pots containing seed bank were placed in the highly turbid ponds was 20 cm, or 4 cm less than the extrapolated depth and 6 cm less than the minimum calculated depth (using the equation above). Light measurement gives a more accurate estimation of Z_{eu} than secchi disc transparency but the rough 'rule of thumb' equation of 2 X Z_{SD} still gives a close estimation of Z_{eu} and is sufficient for field-work with Landcare communities. In the low and medium turbidity ponds, plants would have sufficient light at a Z_{eu} of 0.38 and 0.6 m although there could be differences in the quality of the wavelength and the long-term effects of sedimentation.

In the pond experiment Z_{SD}, turbidity and light measurements were good predictors of each other and any one could be used to determine the depth at which water plants could colonize sediments. The results of secchi disc depth indicate that turbidity was maintained at appropriate levels in all ponds and that secchi disc readings are a good estimate of Z_{eu} (Figure 3.3). When working with Landcare communities who may not have access to expensive turbidity equipment, Z_{SD} has the advantage of being a quick and simple measure and a secchi disc can be made with readily obtained materials, and no calibration of equipment is necessary.

4.2.2 Light irradiance in turbid ponds and the survival of water plants

The high biomass of water plants which was generated in pots in all ponds suggests light is not the main factor preventing water plants from colonising farm dams. Several species of angiosperms and charophytes are adapted to low light irradiances (Blindow 1992a, Blanch 1997) and their different growth forms may affect their ability to compete under low light conditions. Angiosperms such as *Potamogeton* sp. are able to grow deeper than charophytes in the most turbid lakes by canopy formation. There are also indications that high phosphorus concentrations may not be the culprit in the decline of all water plants. Smaller, low growing species of charophytes are able to form dense mats in eutrophic lakes with high phosphorus concentrations in which large charophyte species are unable to grow (Blindow 1992a). This was contradicted by the larger and more brittle *Chara muelleri* and *C. fibrosa* in the turbid ponds that were successful at growth and survival. Perhaps this was due to their protection from wave action rather than the high phosphorus concentrations. This observation is supported by the work in the field of Weisner *et al.* (1997) and Blindow (1992a). Because charophytes appeared to increase their germination with increased turbidity, this thesis will intensify its focus on this group because of their known effect in Europe on water quality, particularly on water clarity (Blindow *et al.* 1993, Van den Berg *et al.* 1998).

The minimum Ed (PAR) for photosynthesis measured at 20 cm in the highly turbid ponds was 26 μmol m^{-2} s^{-1}. This was higher than the known mean compensation points for *Chara*, *Hydrilla* and *Vallisneria* species but less than that for *Myriophyllum* or *Potamogeton* species (8, 15, 20 and 35 and 52 μmol $m^{-2}s^{-1}$ respectively) (Kirk 1994, Blanch 1997). The additional light energy of upwelling Eu (PAR) places the total incident radiant flux well into the agreeable zone for many submerged water plants especially those with canopy forms. The quantity of light at the sediments at 20 and even 24cm depth is sufficient for photosynthesis in *Chara* and *Vallisneria*. It is possible that the quality of the wavelengths is unsuitable for other water plants as the blue and green wavebands are highly absorbed in turbid waters (Kirk 1994). *Vallisneria gigantea* and the charophytes showed morphogenic adaptions to depth and/or lack of light (Chapter 4.3.4) and also showed ontogenic adaption through a change in chlorophyll content as observed by the change in leaf colour in *Vallisneria* to green-purple, and in *Chara* to yellow-green. The significance of these signs of ontogenic adaption is that it shows these species may be able to establish in a wider range of habitats (Kirk 1994, Hill 1996).

4.3 Effects of turbidity on species richness, biomass and germination of water plants

Dumaresq Dam and Racecourse Lagoon had many species in common but distinctive submerged plant communities established from the seed banks. The influence of the different hydrological regime of each wetland on the germination, establishment and reproduction of water plants, can be better understood by referring to the functional groupings of the species, which germinated from the seed banks. The pot community compositions appeared visually different with Racecourse Lagoon pots appearing 'fluffy' with a higher biomass of charophytes and *Myriophyllum variifolium* (Plate 1b, Figure 3.5 c, d). Dumaresq Dam pots contained half the biomass of the Racecourse Lagoon pots but contained *Vallisneria gigantea*, *Myriophyllum variifolium* and *Elatine gratioloides,* except in the highest turbidity when charophytes increased their biomass (Figure 3.5 a, b).

There was no reduction in species richness or biomass with depth to 20 cm or turbidity to 135 NTU therefore the hypothesis that species richness and biomass would decline was not supported (Figures 3.4 and 3.5). Charophytes responded in a variety of ways to turbidity, but were not inhibited by high turbidity, contrary to expectations. There was a significant difference in germination of plants in turbid and clear water from both seed banks.

Elatine gratioloides and *Glossostigma diandrum*, both low growing, sediment covering amphibious responder species (ARp) was able to survive in clear water at all depths or in shallow, turbid water. *Limnosella australis,* another ARp, tolerated higher turbidities and greater depth. These species never emerged or produced seed, as water levels were kept constant. This is consistent with Crosslé (1998) who found that the few species other than the submerged species that germinated in flooded regimes were amphibious responders. These species may have suffered light deprivation from shading by the charophytes and angiosperms and from turbidity. These three species are known to survive a few weeks of flooding after germination, but in this experiment they germinated under water and survived eight weeks of flooding and turbidity.

Crosslé (1998) suggested that any germination of the amphibious fluctuation tolerator emergent, ATe, *Eleocharis pusilla*, from flooded conditions should be treated with suspicion as it can be confused with *Limosella australis*. All *Eleocharis* sp. (ATe) were absent or rare in Racecourse Lagoon seed bank but more common in Dumaresq Dam seed bank. Two other ATe, *Typha australis* and *Gratiola latifolia*, were abundant in Dumaresq Dam pots. This will be discussed in Chapter 4.3.2.

4.3.1 Racecourse Lagoon seed bank

The clustering of pots by multivariate analysis into two main groups delimited by clear and turbid water indicates that submerged water plant species are either tolerant of turbidity or they are not. The low numbers of charophyte germinations and the lower biomass in the clear water ponds compared to the significantly higher numbers and biomass in the turbid water ponds is interesting.

The germination of large numbers of species is not an uncommon phenomenon in the field or in the glasshouse, but turbidity appeared to have a stimulating effect on the germination and biomass of charophytes. This is supported by previous findings that charophyte germination is stimulated by reduced and diffused light but at the same time contradicts European findings that a decline in charophytes occurs with increased turbidity. Charophytes were significant predictors of of total dry weight and increased their bulk with increased turbidity at least to 135 NTU in the shallower depths. As depth increases in the higher turbidity ponds, the biomass of charophytes shows a tendency to fall suggesting that charophytes growth was light limited but can survive very well under low light if at shallower depths.

In Racecourse Lagoon this high germination and establishment may be the result of:- a) adaption to turbid inflows after heavy rain, especially after drought or to b) growing in shade under angiosperms. (In years when the lagoon has remained full through winter other plants may shade the sediments in the spring when the water is warm enough for the oospores to germinate). This seed bank has species that are well adapted to turbidity and this may be the consequence of Racecourse Lagoon being situated on a granitic soil type, which has a B-horizon of fine clay that leaves fine particles in suspension. Turbidity is a ‘natural’ occurrence after rain in Australia and this could be beneficial to charophyte survival in that oospores are ‘triggered’ to germinate, establish and reproduce before other species such as angiosperms that can compete with them for resources. *C. fibrosa* and *C. muelleri* germination was stimulated by turbidity and depth and both species showed reduced germination and establishment at 5cm which may be the result of photoinhibition caused by increased light irradiance. *C. muelleri* produced fertilised oospores but *C. fibrosa* did not. As suggested by Blindow (1992a) the larger charophytes are adapted to deeper water that supports their tissues and are probably less able to tolerate wave disturbance in shallow waters. Many *Chara* and *Nitella* plants elongated into the maximum light flux but stayed just below the water surface, which prevented their desiccation. *C. muelleri* germination is enhanced in spring and its high growth rate is correlated with high light and a pH greater than 7.0 (Casanova 1993). In all ponds the pH was greater than 7.0.

The long-term effect of turbidity on *C. fibrosa* is unknown and as high turbidity reduces its average stem length this may be having a negative effect on this species' ability to capture PAR, and consequently the energy available for reproduction and survival. It has been suggested that *C. fibrosa* colonises new dams and may settle floating clay particles through calcium secretion (Romanowski 1995). Calcium carbonate deposition in plants was not confirmed by studies of the species in the New England Tablelands (Casanova 1993). It could be that *C. fibrosa* is able to tolerate periods of low light until turbidity is reduced by one factor or a combination of factors discussed in Chapter 1.6.

There were few germinations of emergent amphibious tolerators, ATe, from this seed bank in contrast to Dumaresq Dam seed bank (see Chapter 4.3.2). Few species, other than the four species of charophytes and *M. variifolium* produced a high biomass and the angiosperms could have been shaded by and had to compete with the faster growing charophytes. *Vallisneria gigantea* and *Potamogeton ochreatus*, two other species belonging to the submerged functional group, rarely germinated from the seed bank with a total of only 8 and 2 plants respectively from all ponds. Because these species need a period of time in which to reproduce and set seed the environmental conditions offered by the shallow and temporary Racecourse Lagoon were likely to be unsuitable for increasing the number of seeds of these two species in the seed bank.

4.3.2 Dumaresq Dam seed bank

The multivariate cluster analysis of the pots from the clear and turbid water established that both turbidity and small changes in depth affect species germination and establishment from this seed bank. The groups are dominated by pots at depth and high turbidity and there were more emergent ATe and ARp which suggests that deeper, more permanent waters encourage dominant submerged species such as *V. gigantea* and abundant edge vegetation. Of the species to germinate from this seed bank, the larger *Chara* species preferred depth and turbidity, the smaller *Nitella* species tolerated shallower depths and preferred turbid conditions for germination. *Vallisneria gigantea* biomass was positively correlated with depth but this was not significant. ANOVA's however showed that the difference in germination and biomass of charophyte species with turbidity was significant. The ponds mimicked the permanently flooded water regime of Dumaresq Dam. The dominance of the dioecious perennial *Vallisneria gigantea* (94 plants from 48 pots) reflects the man-made water regime of Dumaresq Dam. *Vallisneria*'s prolific biomass and reproductive habits in irrigation channels (Sainty and Jacobs 1981) indicates that this plant could easily become a nuisance 'weed' in small and medium sized farm dams).

Eight emergent amphibious tolerator species, ATe, and six plastic amphibious responder species, ARp, also germinated and established. These species are useful for habitat and bank protection to break wave action and prevent sediment resuspension. Some ATe's can survive under submerged conditions and some have an upright growth form eg *Typha orientalis* and *Gratiola latifolia* which results in their photosynthetic parts being above water at all times (Sainty and Jacobs 1981, Brock and Casanova 1997). The presence of *Typha orientalis* and *Gratiola latifoila* in the pots indicates that they have developed a tolerance for depth and/or turbidity but these species were not present in Racecourse Lagoon seed bank. *Typha orientalis* although not dominant in pots, has several plants present in most pots, indicating the possibility of increased biomass and more widespread establishment as they can colonise to 2m and one flower spike can produce 200,000 seeds (Sainty and Jacobs 1981). This is another species that should not be used in small farm dams.

Of the other emergent amphibious tolerators, ATe, *Eleocharis pusilla* was rare and *E. acuta* germinated at 5 cm in all turbidities and at 10 and 20 cm in clear, not turbid water. It perhaps gained enough light energy in the clearer water to emerge and increase its biomass and it did not tolerate increasing turbidity. Another ATe, *E. dietrichiana*, also germinated and extended its range into the higher turbidities but never obtained much biomass. Germination was not common under either flooded/ clear or flooded/ turbid conditions, but the hardiness of these variants may reflect the adaption and survival of these species to regular disturbance and edge turbidity in the shallower waters at the edge of the dam. *M. variifolium*, a less abundant amphibious responder species, ARp, in Dumaresq Dam seed bank than Racecourse Lagoon seed bank survived well under the imposed turbidity and depth. *Elatine gratioloides*, another ARp, as indicated by the high germination of seeds from the seed bank, has established well from Dumaresq Dam seed bank.

Potomogeton ochreatus, a submerged functional species, S, and *Ottelia ovalifolia*, a floating amphibious responder, ARf, behaved most similarly, with little germination. *O. ovalifolia*, germinated in both clear (at various depths) and highly turbid water (from 20 cm) Both *O. ovalifolia* and *Potomogeton ochreatus* appear tolerant of turbidity and have been found growing in highly turbid waters in irrigation channels at Griffith, N.S.W. and in farm dams (pers. obs.). They are best avoided in smaller dams as both species have a high biomass and are capable of dominating small water bodies. An increased biodiversity and high biomass of water plants in farm dams may be seen as a desirable outcome to an ecologist, but from the perspective of a landowner these same characteristics may be seen as problems caused by nuisance water weeds.

4.3.3 Use of seed banks in the rehabilitation of dams

The second aim (b) to assess the suitability of the source of seed bank and species present in two wetlands, one temporary and one permanent for revegetation of farm dams is discussed here.

When the sediment seed bank of a farm dam is known to be of poor quality or non-existent, introduced seed bank can be useful in rehabilitation. An understanding of the size and depth of the dam to be rehabilitated and some understanding of the species that establish from the introduced seed bank is important. Either of these two seed banks would be suitable for the rehabilitation of farm dams. The use of Racecourse Lagoon seed bank is preferable because of the higher proportion of charophytes and lower proportion of water plants that would float and cover the dam surface or become 'potential weeds'. If this seed bank could be replicated commercially it has advantages in that:-

1) charophyte species can germinate in turbid water and are completely submerged.

2) the larger charophyte species can survive at depth which is an useful characteristic for the colonisation of deep dams.

3) *Myriophyllum variifolium*, an amphibious fluctuation responder, ARp, could tolerate fluctuations in depth and would be suitable for sediment stabilization in shallow water or at wetland edges.

4) charophytes can leave numerous propagules (oospores) in the sediments after dams or wetlands dry out during drought and re-establish themselves again after reflooding and

5) seed banks can be manipulated so that they contain few *Vallisneria* or *Potamogeton* seeds. Smaller, shallower dams or wetlands would soon be completely dominated by species such as *V. gigantea, Potomogeton ochreatus, Ottelia ovalifolia* and *Typha australis*. A mixture of charophytes with their ability to grow under different turbidities, their low growth and dense rhizoid mat that effectively binds the sediment would be more acceptable to the average landowner.

Large, deep permanent dams could be rehabilitated using seed banks from permanent wetlands containing the more aggressive submergents, *Vallisneria gigantea* and

Potamogeton ochreatus as well as a variety of charophytes. Large dams are more likely to attract larger numbers of waterfowl or larger waterbirds that uproot water plants (Moss *et al.* 1996) so the more aggressive water plant species have an advantage. Two amphibious fluctuation responders, the floating *Ottelia ovafolia* and *Marsilea* sp. may be used to provide extra edge water habitat and water plant diversity. Smaller, low-growing ARp species such as *Eleocharis pusilla* and *Limosella australis* may be used as edge protectors both under and above water where the degree of slope is small.

4.3.4 Effect of depth and turbidity on length

The hypothesis that the depth of flooding in combination with high turbidity would cause a change in plant morphology was supported by the significant changes in length in four charophyte species. Obviously if a submerged plant species can increase its stem length to put its leaves in a position to obtain maximum light for biomass production, it will have an advantage in turbid water over the less plastic species.

Chara muelleri showed the greatest plastic response and *N. sonderi* and *N. subtilissima* showed some plasticity to increasing turbidity. Casanova (1993) records that *Chara muelleri* plants in the New England Tablelands grow to 15 cm high, that this species has the highest growth rate recorded in the field of 6.8mm day $^{-1}$ and that a positive growth rate was recorded in response to depth changes. At 20 cm depth in the highly turbid ponds *C. muelleri* reached an average of 16.4 cm in height with a maximum height of 29.6 cm. Monoecious species are capable of self-fertilization, which may reduce their offspring's tolerance to environmental change, but this is often buffered by higher plasticity (Casanova 1993). This appears to be the case with *C. muelleri.*

Chara fibrosa, an attractive Chara species, is found in farm dams and known to be turbidity tolerant (Romanowski 1995). It grew to its greatest length in the clear water, reduced its length as turbidity increased and was less competitive in the higher turbidity ponds. Even though *C. fibrosa* survived well in the higher turbidities, its significantly shorter length in highly turbid water suggests that turbidity is having a more detrimental effect on this species than on the others.

Blindow (1992a) found small shoot-diameter charophytes were more numerous and found as low mats in lakes with a secchi depth of < 1m and they were limited to shallow water. Large shoot-diameter species were more numerous in lakes with secchi depth of >1m and inhabited deeper waters. She suggested that the reason the larger forms did not grow in shallow water be connected to structural damage from wind and waves. As the effect of structural damage can be discounted in the ponds it is possible that in the field *C. muelleri* would only grow in clearer water at depth and the smaller charophytes would colonize the shallows. Since

Nitella sonderi and *N. subtilissima* are both dioecious with smaller shoot diameter, they should display less plasticity. The increase in length with increasing turbidity was significant for both species, but the increase was much smaller than in the larger *Chara muelleri*. It would be expected that these species would first colonize shallow turbid wetland edges and move down as the turbidity was reduced. *C. muelleri*, being tolerant of turbidity, could colonize at greater depths and move downwards as water turbidity was reduced with a corresponding stabilization of the sediment. Having a larger stem diameter (for strength) and the ability to elongate gives plants a competitive edge. It allows a plant to buffer itself against water currents to reach the light and also compete against other plants to prevent them from shading it.

M. variifolium's survival advantage lies in it's ability to emerge at the surface and quickly produce a large and robust biomass with a maximum number of vegetative propagules as well as reproductive shoots. High turbidity will inhibit the advantage in growth and reproduction of *M. variifolium* if seed germinate at a depth where light is limited, as plants will take longer to manufacture the energy required to reach the surface. At 20 cm in highly turbid water this species was at a disadvantage as it took longer to reach the surface. *M. variifolium* would have a better chance of survival at the edges of turbid farm dams until the water column cleared sufficiently for these plants to establish in deeper water.

The dominance of *V. gigantea* and *C. muelleri* in the deeper pots of Dumaresq Dam seed bank may have reduced the biomass of the smaller charophytes and rivalled the less turbidity tolerant *M. variifolium* for both light and nutrients. In these species, both depth and turbidity tolerance is an advantage and they would do well in larger and deeper farm dams.

4.4 Summary

Turbidity influenced the species that germinated and established from seed banks as shown by the different groupings of the pots in the PATN analysis. This confirmed that there was a demarcation zone in both seed banks between the plant groupings in the pots in the clear water ponds and those in the turbid ponds. This demarcation indicates that some species have higher turbidity tolerance (or tolerance for low light conditions) and some species will only survive in clear water. Many species prefer damp, but not flooded conditions, as many seedlings did not survive prolonged inundation long enough to be identified. Fewer submerged and floating species germinated under turbid water regimes from these seed banks compared to the number found by Casanova (1993), but this may have been an effect of season (Tables 2.1 and 3.3.). The diffuse, stable light environment found in the highly turbid water at 10 to 20 cm may reduce the impact of light fluctuations in triggering germination in dormant seeds of angiosperms but not in the oospores of *Chara* species (Figure 3.1, bottom).

The numbers of germinations and the total dry biomass of charophytes increased with increased turbidity in both seed banks, but particularly in the seed bank from Racecourse Lagoon. The high germination of charophytes in the ponds was possibly a result of a combination of the ideal conditions of warmth, low disturbance, seasonal influence and diffuse light. The higher biomass of the submerged angiosperm species, *V. gigantea* and the larger *C. muelleri* from Dumaresq Dam seed bank indicates the dominant presence of these species in the seed bank is a consequence of permanent inundation and low light conditions.

In the USA, charophytes are known as first colonizers in farm ponds (Crawford 1977) so sediment condition is obviously an important parameter and the sandy substrate onto which the seed bank was spread may have been of some significance. The lower compensation point of charophytes which enables them to do well under low light conditions is due to special adaptions to poor light availability (e.g. chromatic changes, shoot elongation, rapid growth during spring, canopy formation) (Kirk 1994, Blindow 1992a, Van den Berg 1999). These morphological adaptions to increased turbidity were significant as seen in the rapid growth and increased length of *C. muelleri, N. sonderi* and *N. subtilissma.*

It was difficult to separate the effects of permanent inundation from those of turbidity and in hindsight, placing pots at greater depths would have helped separate the changes in species germination and establishment. Extra replicates of pots would have been useful to balance any artifacts that were the result of unequal mixing of seed bank. With the benefit of recent published work of functional groups (Brock and Casanova 1997) and the effect of different water regimes on functional groups (Crossle' 1998) a better understanding of plant responses in this pond experiment was obtained. This turbidity-flooding experiment showed similar responses to flooding with clear water over long periods obtained by both Brock and Casanova (1997) and Crossle' (1998). Constant flooding saw the dominance of certain submerged species but it was not determined if they would have persisted over a longer period under these conditions of low light.

The difference between the two wetland seed banks in terms of germination numbers and biomass of charophyte genera reflects the numbers of oospores in the seed banks. More temporary wetting and drying episodes in Racecourse Lagoon would trigger sexual reproduction in short lived annual charophytes and give the advantage to water plants able to grow and reproduce quickly and scatter their propagules into the seed bank. In the more permanent waters of Dumaresq Dam fewer opportunities for charophytes with short reproductive cycles would occur so *Vallisneria* sp. and larger, deeper growing charophytes would take their place. Even though the species that germinated from these two wetland seed banks indicate the presence of several turbidity tolerant species in both, the seed bank composition is not the direct result of turbidity *per se*, as under present conditions both wetlands contain clear water most of the time. Their tolerance of turbidity may be the result of adaption to depth and shading by other plants, both situations that reduce underwater light. However, any long-term increase in turbidity in these wetlands has the potential to change the plant community in terms of species' dominance and structure, and ultimately, the composition of the seed bank.

Changes in underwater light climate in shallow lakes have been shown to evoke changes in dominant macrophyte vegetation (Coops and Doef 1996, Schwarz and Hawes 1997, Van den Berg 1999) and proffer the idea that submerged species respond differently to light availability or light quality. In Europe, shifts towards *Chara* have been observed when clarity was increased or a decline noted with increased turbidity but the results from these experimental ponds contradict this research. It could be feasible to hypothesise that antipodean charophytes have evolved a tolerance for turbidity as a result of ancient soil conditions where turbid waters occurred with floods, or in response to the higher irradiance experienced in summer or at lower latitude.

It is possible that plants that are found in clear water in the field may have initially tolerated turbid water and established enough biomass to stabilize the sediments and increase the clarity of the water body. In turn, these species may have been replaced with species that were less tolerant of turbidity. This could explain the 'switching' of dams and lakes from turbid to clear. Depths greater than 30 cm and in turbidities greater than 150 NTU would be anathema to all water plants and yet these are the conditions found in many rivers, wetlands and farm dams in Australia. Australia does not have a history of recording turbidity except sporadically over the last 20 years, consequently the writer hesitates to use the term 'natural' turbidity as water turbidity has increased worldwide under pressure from increasing population (Klein *et. al.* 1972) and Australia is no exception. The abundance and the percentage cover of submerged water plants is usually determined visually (Casanova *et al.* 1997) and limnologists often neglect to investigate the sediments below the secchi disc depth. It is possible that aquatic macrophytes have disappeared from many Australian inland waters that are becoming increasingly turbid and this is also the view of several other limnologists and palaeolimnlogists (Odgen 1995, 2000, Roberts and Sainty 1996, Blanch 1997). Remnants of water plants may endure in turbid dams, inland rivers and wetlands but are not observed and hence are not recorded.

If turbidity had been more easily sustained in ponds, the experiment could have investigated the long-term impact of turbidity on water plants. At low turbidities flocculation caused by bacteria, algae or plants on the suspended clays and the greater difficulty in stabilising the turbidity in these ponds (Figure 3.3.) indicates that natural water ecosystems are inclined towards clarity. At higher turbidities, which indicate higher erosion rates, algae may not receive enough light in the water column, and zooplankton, which ingest clay particles, may suffocate (Kirk 1991). This may explain why highly turbid dams appear to remain turbid over a long period of time. Dams with limited nitrogen (little zooplankton excreta, low organic matter) and high, under-utilized phosphorus loads appear to be highly suitable conditions for the growth of blue-green algae.

The results of the pond trials raise the question that the absence of water plants in turbid dams and other wetlands may be due to:

1) Suffocation of germinating seedlings by sedimentation.

2) Continuous edge and shallow water disturbance by stock trampling, grazing or wave action during germination and establishment especially of ARp and Ate functional species.

3) Reduction of energy inputs for submerged species to grow to and reproduce at the surface. Under low PAR conditions there will be a reduction in growth and biomass available for vegetative propagules and seed production will be impeded. There is a smaller window of opportunity for plants to reproduce.

4) The lack of a rich and viable seed bank through wetland species being unable to complete their reproductive lives through (2) and (3) above.

5) Sediment conditions may not be suitable for germination. Sediments are rarely dried out from one year to another (the seed banks used in this experiment were previously dried). Low water and soil temperatures may retard germination as light energy does not reach to great depths in a turbid water column, and benthic bacteria may cause anoxia and low pH.

Part 2

Farm Dam Rehabilitation

Chapter 5: Introduction and Methods

Chapter 6: Results

Chapter 7: Discussion

Chapter 5 Farm dam rehabilitation

5.1 Introduction

Turbidity is a common condition in Australia farm dams (Geddes 1986, Douglas-Hill 1995, Lloyd 1996, Casanova *et al.* 1997). Like many larger water storages in Australia, farm dams in the Northern Tablelands are often plagued with blue-green algal blooms in the late summer and autumn months (February-April) although some of these blooms can persist all year round (Vernhoeven *et al.* 1992). In a previous study of 65 farm dams, Casanova *et al.* (1997) (see Chapter 1.10), identified five groups of dams which could be related to the four phases of nutrient loading found in water bodies and described by Moss *et al.* (1996a) (Figure 5.1). The fifth group was made up of amenity dams that had been modified to 'improve' their appearance or function with floating plants such as *Marsilea* or *Nymphaea* (Casanova *et al.* 1997). Casanova *et al.* (1997) identified one group characterised by high water clarity, abundant water plant and low phytoplankton numbers as related to Phase I. This group strongly contrasted with a group of dams characterised by high turbidity, high nutrient levels, no water plants and dominated by phytoplankton (usually blue-green algae) which related to Phase IV. The dams in Phase I and IV were described as being in 'alternative stable states' according to Moss *et al.* (1996a). Phases II and III are transition phases between Phase I and IV. Douglas-Hill (1995) also found evidence that phytoplankton dominant and macrophyte dominant phases (or states) could be found as alternative conditions in farm dams and many farm dams could be found in a transition phase between the two phases. In this study, the water plant cover described was the percentage of the sediments covered by submerged water plants.

The clear water plant-rich phase (Phase 1) is the most desirable in terms of better water quality and is the condition we should aim for in farm dam and wetland rehabilitation. To switch between Phase I to IV through Phases II and III involves a 'forward switch' such as high turbidity (lack of light) that obliterates or removes the water plants or an increased input of nutrients. To overcome this decline in water plants, a switch between Phase IV to 1 through III and II involves a 'reverse switch'. This may involve a reduction in turbidity or a reduction in nutrient input (and algae) that restores the light to the water plants (Moss 1990, Moss *et al.* 1996, Perrow *et al.* 1997a). Research to date (Van den Berg *et al.*. 1998) suggests that it is possible to manipulate shallow lakes from one state to another through changes to nutrient levels and biota and restoring water plant cover although states are very stable and may revert to the previous state or equilibrium. Many of these methods assume water plant propagules are present in the first place, even in low density (Moss *et al.* 1996, Perrow *et al.* 1997a). While the restoration of lakes is a different challenge from the restoration of farm dams, those containing water plants obviously have better quality water (Casanova *et al.* 1997). Introducing water plants to farm dams will not restore the original habitat or biodiversity as many dams never had a plant-rich state and were always turbid and plant-free. The best we can aim for is rehabilitation and for this reason, the term 'rehabilitation' is used in this thesis instead of 'restoration'. In Chapter 5.1.1, factors that influence water plant cover or the 'switching' between a phytoplankton-dominant and a water plant-dominant state in farm dams are discussed.

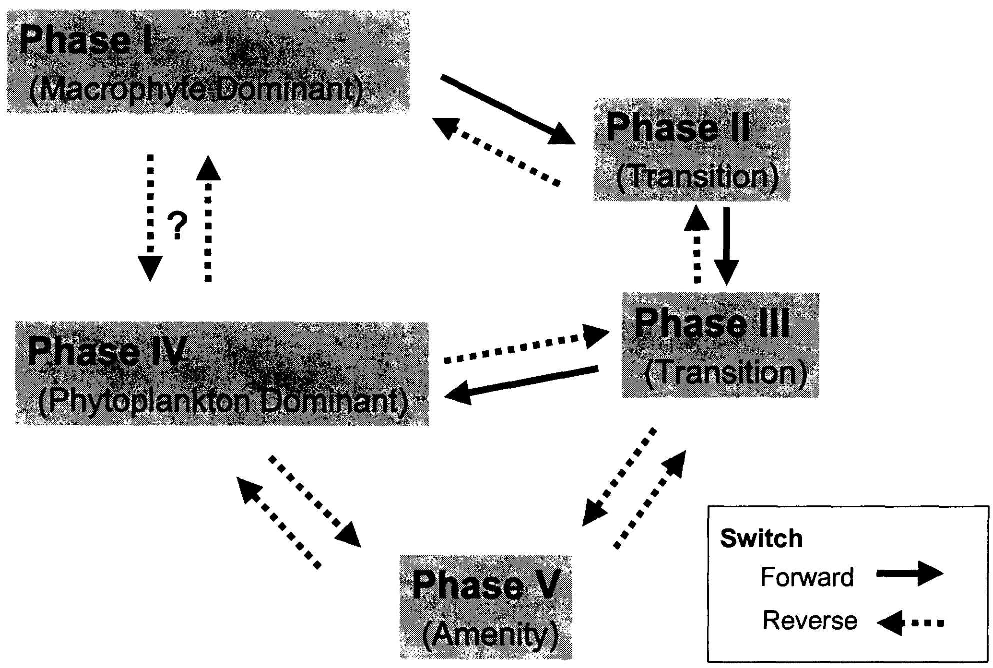

Figure 5-1 Diagram showing the five groups of dams identified in Casanova *et al.* (1997) as they relate to the 4 phases identified by Moss *et al.* 1996. Phase I - aquatic plant dominant state: with abundant submerged water plants, high water clarity, low nutrient concentrations, low phytoplankton nos. Phase II – low to medium cover of submerged water plants, low to medium nutrient concentrations, low phytoplankton numbers. Phase III- no submerged water plants, medium to high nutrient concentrations, moderate phytoplankton numbers. Phase IV- phytoplankton dominant state: with high phytoplankton nos. (usually blue-green algae), an absence of submerged water plants, high nutrient concentrations, high turbidity. Phase V- amenity dam with introduced, floating water plants. Phases I & IV are described as being in 'alternative stable states', Phases II and III are described as 'transition phases'. Bold arrows represent 'forward switches', dotted arrows represent 'reverse switches'.

5.1.1 Reasons for low submerged plant establishment in farm dams

Light

Literature reviewed in Chapter 1 indicates that low PAR may reduce submerged plant establishment at depth but the pond experiment (Part 1, Chapters 1-4) indicates that restricted light is not the limiting factor for the germination and establishment of all species and not in shallow water. The amount of light reaching the sediments will partly determine the species that can germinate and establish and the final community composition. Water depth and turbidity are seen as of major importance in submerged plant establishment (Scheffer *et al.* 1992).

Nutrients

One could hypothesise from nutrient studies on phytoplankton that low nitrate-nitrogen levels in sediments could also inhibit water plant germination and establishment. Nutrient levels in water and sediments may be either too high or too low. In the 65 farm dams surveyed, the nitrate-nitrogen levels in the water were too low (average 0.026 mg L^{-1}) to support green algal blooms (Casanova *et al.* 1997) but combined with high phosphate levels and unbalanced N-P ratios could encourage nitrogen-fixing blue-green algal blooms. This was also hypothesised and supported in laboratory studies a year later (Brookes 1998). Lake fertilization experiments in Canada have found similar increases in blue-green algae with phosphorus addition but not with nitrogen addition (Schindler *et al.* 1973). Sediment nitrogen studies will not be done on these dams due to previous findings and lack of resources but it is worth hypothesising that low nitrogen in the sediments may play a factor in low water plant germination. However, it did not appear to be a limiting factor in the pond studies where seed bank was placed on washed river sand in pots and initial NO_3-N levels measured in the water were very low.

High water phosphorus levels were correlated with low submerged water plant cover (Douglas-Hill 1995, Casanova *et al.* 1997) and high biotic and abiotic turbidity. SRP levels in farm dams have been found as high as 1.7 $mg.L^{-1}$ (1700 $\mu g.L^{-1}$) with a mean 0.174 $mg.L^{-1}$ and a range of 0.004 to 1.7 ± 0.359 $mg.L^{-1}$ (Douglas-Hill 1995). The low water plant cover was assumed to be due to the high concentration of phosphate leading to the growth of algae and subsequent shading during the establishment period of water plants, rather than to excessive or toxic concentrations of phosphates. TP levels for assessment of water quality are given in Chapter 1.3 (EPA 2000).

Salinity, which is the result of dissolved salts of sodium chloride in a water body, can cause suspended solids to flocculate and will also affect the species of water plants that germinate and establish. Electrical conductivity measurements, which indicate the ability of water to conduct an electrical current, is an appropriate indicator of salinity as it is proportional to the concentration of total dissolved salts and is easily measured. Conductivity levels for assessment of water quality used in this thesis are: good <500 µS cm $^{-1}$, Fair 500-1500 µS cm $^{-1}$ and Poor >1500 µS cm $^{-1}$ (EPA 2000).

Water regime

Water regime exerts a primary influence on plant performance in wetlands and rivers, so it follows that in farm dams with a high variation in water levels, water regime must also play a strong role in water plant establishment. Water regime is a complex variable consisting of water depth, fluctuations and variations in the timing of drying and wetting events (Walker *et al.* 1994, Casanova 1994, Rea and Ganf 1994b, Brock and Britton 1995). Weirs, dam-modified rivers and farm dams usually have a more stable, permanently flooded water regime with deeper water, steeper banks and little shallow edge habitat to attract edge and emergent water plants (Walker *et al.* 1994, Froend and Mc Comb 1994, Brock et al 1999). . Water regime studies by other researchers were being drafted for Newholme Wetlands, located on one of the University of New England rural properties, but had not been initiated when this farm dam rehabilitation experiment started and so did not influence the design of the experiment. Several important structural designs that would be appropriate in the reconstruction of old farm dams as wetlands were suggested by these experiments. One design outcome was that gentler fluctuations of water level create a variety of habitats and allow plants time to germinate establish and reproduce. On the other hand, stable water levels, either more permanently flooded or dry, can decrease habitats for biota as can bank slopes that are too steep (Sansom 1997, Crossle' 1998, Brock 2000).

Bank slope

Banks of farm dams are constructed with embankment ratios of 2:1 and 3.5:1 (Nelson 1996), which creates a slope that is steeper than that found in natural wetlands (Romanowski 1998). Slope will affect the stability and depth of edge sediments. Sediments that wash in will drift into the deeper parts of the dam, and with it, seed ('seed rain') and organic matter. Sansom (1997) conducted a glasshouse experiment into the effect of slope on seed bank germination that was held simultaneously with the previous pond experiment. He found that germination and the final distribution of wetland plants on slopes was dependent on the species. He also found that a steep slope caused high density and low species diversity in emergent and amphibious water plants, and a low slope decreased the density but gave a greater species diversity (Sansom 1997).

Depth and physiological limits of water plants in turbid conditions

From the light and germination experiments in Part 1, light was found not limiting up to 20cm in highly turbid water. At depths greater than 20cm light was severely restricted but could still support some species, particularly charophytes. The 65 dams in the farm dam survey (Chapter 5.1) had an average turbidity of 54 NTU (maximum 408, minimum 2) (Casanova *et al.* 1997) which was much less than the ponds in the previous experiment. Theoretically these dams could have submerged plants colonising their sediments to the depth at which light was completely attenuated, but few did so. Charophytes and some angiosperms can colonise deep water lakes in Europe and New Zealand to 25 metres if water is clear, but most studies of charophytes have been undertaken in shallow lakes up to 3m deep (Scheffer *et al.* 1992, 1994, Perrow 1997a).

Age and Disturbance in farm dams

In Australia, edge disturbance and increasing turbidity caused by introduced hoofed stock is one reason water plants have difficulty in establishment along rivers and around waterholes (Blanch 1991, Robertson 1997). Time since excavation of the dam and the fact that during excavation, the topsoil is usually removed and buried under deeper, more clayey soil horizons (Yeomans 1993) determine propagule establishment. The age of the dam was positively correlated with the the percentage cover of water plants (Casanova *et al.* 1997). Grazing by waterbirds is often cited as an important factor in suppressing water plant development in shallow lakes undergoing restoration in Europe (Perrow *et al.* 1997b).

Seed bank in farm dam sediments

Seed bank germination studies on farm dam sediments did not record a deficiency of seed or oospores (Casanova 1999b). Newly excavated farm dams are unlikely to have propagules and many dams would contain few viable seed or propagules if water plants had not established in them after many years. Seed may drift into the deeper areas of farm dams (Sansom 1997) and be buried or not obtain enough light for germination. A preliminary germination study to demonstrate the presence of wetland plants is necessary to determine the potential for restoration of a wetland (Brock 1997) and likewise, seed bank studies of farm dam sediments can indicate the propagules present and the potential to rehabilitate the dam.

5.1.2 Rehabilitation techniques or 'impacts'

Seed bank addition to farm dams

At the time of this experiment, studies of seed bank assessment of natural wetlands had been done (Brock *et al.* 1994b, Brock 1997) but the use of seed bank as a rehabilitation tool is not well documented (M. Casanova pers. comm). Whole plants have been successfully transferred from one place to another either by man or through water-flow (Moss *et al.* 1996, Romanowski 1998) or by seeds attached to or ingested by birds or animals (Bungin *et al.*. 1997, Perrow *et al.*. 1997). Successful establishment has been documented for some local and introduced water plants which have unfortunately become nuisance species in the high nutrient water irrigation channels in Australia's inland cropping areas (Mitchell 1978, Bowmer 1979). Three of the indigenous species that became a nuisance weed in these irrigation areas were *Vallisneria gigantea*, *Potamogeton crispus* and *Typha* species. The addition of seed banks containing these species could cause a similar situation in some nutrient–rich farm dams. For the rehabilitation of farm dams using water plants to be acceptable to both ecologists and landowners and to encourage on-farm biodiversity, a compromise situation is required. Australian landowners often have similar perceptions of economic success and a dam holding a large quantity of water in a dry continent is seen as an asset and improvement to the value of a property. A farm dam which holds less water, even if of better quality, or if overgrown with emergent water plants, is not necessarily perceived as an improvement on a farm dam with no edge vegetation and algal blooms. Emergent growth around farm dams may be seen either as a resource or a nuisance that must be utilised as stock feed or cleared away. Landowners' perceptions are changing and a natural wetland is more often seen as a valuable asset to a property rather than a liability (Brouwer 1995, Brock and Jarman 2000). Preliminary talks with landowners often revealed a desire for improved water quality, a vague understanding of the connection between water plants and improved water quality, and confusion and concern about introducing water plants to farm dams that could ultimately become nuisance weeds. This is a legimate concern which is a legacy of our post World War II agriculture (1950-1980) when introduced or dominant water plant species invaded nutrient enriched waterways and the European Carp (*Cyprinus carpio)* was introduced, and herbicides were used for water weed management in irrigation channels (Sainty and Jacobs 1981).

The success of charophyte establishment in the turbid pond experiment suggests that these species could be used as a rehabilitation tool in farm dams. Charophytes were first seen to colonise farm ponds (Crawford 1979) and are known as a coloniser species (Casanova and Brock 1996). Charophytes are small growing, completely submerged and have higher biomass per unit area than angiosperms (Blindow 1992b), are adapted to low light and store large amounts of phosphorus and nitrogen (Blindow 1992a), and reproduce quickly to produce high numbers of oospores (Casanova 1993). For all the reasons listed they appear to be ideal components in a seed bank which is used in farm dam rehabilitation.

Flocculation of clay and algae suspensions

British research has suggested that clarifying water of algae is necessary before attempting to establish water plants (Moss *et al.* 1996) and this is achieved through the management of nutrient loads and sediment loads. The use of calcium salts as calcium carbonate (calcite), $CaCO_3$, calcium hydroxide (slaked lime), $Ca\,(OH)_2$ and calcium sulphate (gypsum), $Ca\,SO_4$

to remove or inactivate phosphate in ponds (rather than in deep lakes) has had some success. Calcium and iron salts may also be used, respectively to remove the conditions for denitrification and to increase the phosphorus binding capacity of the sediment (Cooke *et al.* 1993, Moss *et al.* 1996). Gypsum has been shown to reduce clay turbidity, algae and SRP (Wu and Boyd 1990), calcite reduced algae but was less successful over the longer term, and slaked lime, when added to hardwater ponds, reduced phosphates and algae (Murphy *et al.* 1990. There are numerous methods where lime is used for the treatment of eutrophication and hypereutrophication (Murphy *et al.* 1988, Babin *et al.* 1989, 1994, Mandaville 1996, Cooke *et al.* 1993), in shallow hard water phosphate rich lakes of glacial origin (Prepas *et al.* 1990); as a lake rehabilitation technique in an eutrophic hardwater lake to remove turbidity and hardness; and to change macrophyte species in acidified lakes (Hagley *et al.* 1996). Lime is used to precipitate phosphates as apatite (Avnimelech 1982, Murphy *et al.* 1988, Cooke *et al.* 1993) (see chemical equation below) and to fix phosphates in the sediments. Lime treatment can improve water clarity by reducing chlorophyll-$_a$, and shift the dominant algal taxa from blue-green to green flagellated forms and diatoms (Prepas *et al.* 1990) and change the structure of zooplankton communities (Wright *et al.* 1996). Lime can cause competitive changes in aquatic plant communities in mildly acidified lakes, increasing or decreasing species such as *Nitella* and *Potamogeton* species by changing the bicarbonate ion concentration of the water (Hagley *et al.* 1996).

Cooke *et al.* (1978) and Young *et al.* (1988) noted macrophyte proliferation in the years following the use of a phosphorus inactivation treatment, which produced an increase in secchi disc depth. Presumably the water plants were stimulated by the increased light rather than the alum and ferric sulphate treatments. Other chemical methods which have been used to reduce phosphates in water have been the use of aluminium sulphate (alum), $Al_2 (SO_4)_3$, which forms a colloidal floc of aluminium hydroxide, $Al(OH)_3$ with high coagulation and phosphate adsorption. Alum has been used to precipitate clay turbidity from fish ponds (Boyd 1979), in the restoration of lakes and reservoirs (Welch *et al.* 1990, Cooke *et al.* 1993, EPA U.S.A.1994), to inactivate phosphorus and oxidate sediments (Cooke *et al.* 1993, Foy and Fitzsimons 1987, Martin and Connor 1989, Mc Comas 1989). It can form a barrier between the water and the sediment (Douglas 1998) and is used to remove blue-green algae from farm dams (Department of Land and Water Conservation, NSW, 1995). The reduction in soluble phosphate through the treatment of sediments with aluminium sulphate was correlated with long-term increased macrophyte cover in a lake (Welch *et al.* 1990).

As the alum floc settles through the water column it forms large visible particles and as they settle, water transparency increases. However at pH < 6.0 the soluble form of aluminium reforms which is toxic and at pH > 8.0 solubility again increases and phosphates may be released so the pH needs to be maintained between pH 6.0 and 8.0 for large amounts of Al

$(OH)_3$. As a consequence of the difficulties in managing the pH of large waterbodies, the toxicity of alum has been reported in alga, aquatic plant roots, invertebrates, fish and other animals. (Lamb and Bailey 1981, Hall and Hall 1989, Narf 1990, George *et al.* 1995, Moss *et al.* 1996, Rosseland *et al.* 1997, USA EPA 1999). Changes in phytoplankton populations (Foy and Fitzsimons 1987) have been recorded as well as the release of toxins from blue-green algae after treatment of drinking water after the use of alum (Drikas 1994). Alum (ferric or sulphate) is often used (Department of Agriculture, W.A. 1994). Sometimes gypsum ($CaSO_4$) is required to be used in combination with alum to reduce acidic changes in pH, and the gypsum also acts as a flocculant and phosphorus remover. Nitrate salts have been used as an oxidising agent to oxidise the sediment surface to favour the formation of ferric phosphates in which the phosphate is rendered unavailable for algal growth (Moss *et al.* 1996). Other chemical treatments such as the use of the algicides, copper sulphate and calcium hypochlorite, were once widely used in Australia until mid-1990 to increasing turbidity. Copper sulphate is still used in Northern Tablelands reservoirs and other water supply impoundments (Raman 1991) but in the U.S.A. its use is largely discontinued (Prepas *et al.* 1990).

5.1.3 The use of lime in turbidity reduction

Lime has fewer known toxicity problems than aluminium or copper sulphate, and is a more effective phosphate binder than calcium carbonate (calcite) as it has more binding sites for phosphorus removal and retention (Babin 1989). Calcite tends to dissolve in the sediments and shows a reduced effectiveness over time (Cooke *et al.* 1993). If too much lime is used it can cause a rise of water column pH to 10 at which it is toxic to invertebrates and other biota (Murphy *et al.* 1988, Cooke *et al.* 1993). A water body can reach a pH of 10 'naturally' during a blue-green algal bloom (Verhoeven *et al.* 1992, Casanova *et al.* 1997) become depauperate (Douglas-Hill 1995) and yet appear to recover (pers.obs.). Although lime was not the favoured treatment because of the possibility of creating the high pH favoured by blue-green algae, a 'one-off' use of lime was expected to flocculate the clay suspension for long enough in the spring growing season to offer 'a window of opportunity' for seed germination. Dose guidelines were not given for treatment of ponds in Cooke *et al.* 1993, so flocculation tests were done in the laboratory to test the efficiency or otherwise of both alum and lime treatments on suspended clays and algae (See Chapter 5.3.3). On an equal weight for volume ratio the cheapest treatment was calculated to be the lime treatment at $7.00 for 25 kg at the rate of 25 kg per megalitre (ML).

The reaction that occurs with the addition of lime is that of the dissociated calcium hydroxide forming calcium carbonate (calcite) and water with the carbon ion coming from the carbon dioxide ion in solution. Organic carbon is reduced in this way but increases to pre-treatment values within 5 weeks (Prepas *et al.* 1990)

$$Ca\,(OH)_2 + CO_2 \Rightarrow CaCO_3 + H_2O$$

Calcium hydroxide (dissociated) + carbon dioxide => Calcium carbonate (calcite) and water

Phosphate adsorption occurs to the calcite to form apatite especially when pH > 9.0.

$$\underline{3CO_3 - 2\ (s)} + 2PO_4 - 3\ (L) \Leftrightarrow 3CO^3 - 2\ (L) + \underline{2PO^4 - 3\ (s)}$$

$$\underline{\text{calcite}} + \text{phosphate} \Leftrightarrow \text{carbon dioxide} + \underline{\text{apatite}}$$

Where L = aqueous phase, s = solid phase. The apatite is insoluble as hydroxyapatite, $Ca_{10}\,(PO_4)_6\,(OH)_2\,(s)$.

5.2 Aims

The intention of the experiment discussed here was to establish water plants in farm dams as had been achieved in the artificial ponds under protected conditions. Three kinds of 'reverse switches' were applied to achieve a physical and chemical change in the farm dams that could transform them into Phase I - the water plant dominant phase. Reverse switches or treatments applied by man can be likened to environmental impacts and the changes can be monitored and analysed using Before After Control Impact (BACI) methods (Stewart-Oaten et al 1986).

The first treatment aimed to reduce turbidity by chemical flocculation and increased sedimentation so that the amount of PAR reaching the sediments was improved. At the same time phosphates attached to the suspended clays were expected to be flocculated from the water column and deposited in the sediments with the addition of lime up to a point before the pH reached pH 9.0. The objective was to encourage water plant seeds and charophyte oospores present in the sediments to germinate and establish before algae became dominant and restricted the underwater light through shading. The second treatment aimed to establish plants in turbid water by seeding farm dams with seed bank known to contain turbidity tolerant water plants (Chapters 2 to 4). This was to determine if water plants could reduce turbidity through the feed back mechanisms discussed in Chapter 1. The third treatment was a combination of the previous two, lime flocculation and seed bank addition, to observe if submerged plant establishment was enhanced by giving them a 'window of opportunity' during germination.

The aims of this field experiment were to:

1) Examine the germination from the sediments collected from farm dams without submersed vegetation in a glasshouse to determine the seed bank quantity and content (species richness) and from the cover that established, determine the 'potential' percentage cover of submerged, amphibious and floating plants.

2) Apply a reverse 'switch' or impact via one of the three treatments described above: 1) by increasing flocculation with lime or 2) introducing seed bank containing oospores and seeds of known turbidity tolerant water plants or 3) a combination of these two treatments to turbid farm dams without water plants.

3) Record the main changes in the physical, chemical and biological variables and the establishment of submerged plants before and after treatment.

4) Repeat the collection of farm dam sediments and examine the germination from the sediments of farm dams after treatment in the glasshouse to determine if the seed bank content and percentage cover had changed.

5) Examine whether increased clarity through lime addition is important for enhanced submerged water plant establishment or if increased clarity can be achieved biologically by the addition of seed bank alone.

5.3 Methods

5.3.1 Study sites and experimental design

Research that is done in the field is more complex due to the increasing reality of environmental factors such as rainfall and a decreasing control of adverse impacts, a dependence on the cooperation of landowners; extra time and travel, often with difficulty of access to sites. Access to refrigeration is important to keep samples from deteriorating. To reduce the adverse impacts in field experimentation, some environmental variables can be imposed and other variables monitored but not all variables that impact on the research can be foreseen or avoided.

With river and wetland studies there is rarely an opportunity for an identical site for a Before-After-Control–Impact-Pairs (BACIP) study (Stewart-Oaten et al 1986). This kind of BACI study has one impact site to a control site - or 'paired' study. The BACI sampling design is used to assess the effects of an environmental change or impact made at a known point of time (Green 1993, Underwood 1991, 1993, Manly 2001). In this BACI study the 3 treatment (impact) groups each consisting of three sites (replicates) - were 'paired' with the same group of three control sites (replicates). In the statistical analysis, each group treatment was compared with the control group – identical to a paired study. The advantage of this design to a BACIP study is that the averages of the group variables are being compared and not the individual variables. As farm dams are ubiquitous in the landscape, dams with similar sediment type, size, volume and depth can be chosen more or less at random on which to impose certain conditions and hence reduce the variability of the experimental group. As previous studies have shown conditions are never exactly the same in any two dams (Casanova *et al.* 1997) but experimental and analytical techniques inherent in BACI sampling can be used to compensate for this variability.

In this field experiment, farm dams were chosen carefully after a one page newsletter was distributed through the Department of Land and Water Conservation, Harnham Landcare and the May 1996 Armidale Wool Expo. This requested access by landowners to fenced and turbid farm dams as research sites. A previous and intensive survey had been carried out on 65 farm dams (Douglas-Hill 1995, Casanova *et al.* 1997), and as a result, the choice of sites was limited by the specific characteristics that had been found to pre-dispose farm dams to blue-green algae and/or high chlorophyll-$_a$ concentrations. These dams were usually on granitic or metasediment soil type rather than on basalt for the reason that these less fertile soils have a greater tendency to support algal blooms. These dams have high phosphate concentrations and are turbid due to suspended clay (Casanova et al 1997, Douglas-Hill 1995) (Plate 2a).

Dams were chosen with these characteristics:- (a) moderate to high turbidity >10 NTU, (b) an absence of submerged water plants, (c) shallow and up to 5m deep, (d) located on a granitic or metasediment soil (e) subject to algal blooms.

To reduce the amount of environmental variability (rainfall, climate, light irradiation) and increase the homogeneity of the dam sites, dams were chosen with the following limitations:- (a) access of stock was removed or restricted to a 1-2 metre access (b) were not located below or near to cropping areas or stockyards, (c) landowners agreed to keep stock out for the duration of the experiment (1-year) (d) removal of water was restricted to emergencies, (e) water catchments and stream banks were well covered with grasses or had been replanted with tree or grass seedlings, (c) alien fish species were absent including mosquito fish, *Gambusia holbrooki* (f) site was within 70 km of Armidale.

5.3.2 Treatments or impacts

There were enough expressions of interest to obtain a group of 35 dams to choose from within a 50 km range, not too large (< 10 ML) and not too small (> 0.1 ML) and most of them lying within the Macleay River catchment (Figure 5.2). Sixteen suitable fenced dams were offered but only twelve, shallow (< 3m deep), turbid farm dams were eventually used. Dams close together were chosen at random and given one of the four treatments to minimise the impacts of local environmental differences such as rainfall on the BACI. The reduction in the number of replicates from 4 to 3 dams was due to a problem with logistics and difficulties with access. Treatment sites were sampled 4 times before and 4 times after the treatment or 'impact', and control sites (which are not treated) were sampled along with the treatment sites. The modified BACI design (Underwood 1991) was chosen to allow for sampling at different times in each location as up to four dams could only be sampled each day over three days. This 'nested' sampling design had advantages over fixed schedule sampling in that it ensured that no cyclic differences would influence the magnitude of the difference before and after the treatment or impact. This is of more importance in accurate quantitative estimates of zooplankton and phytoplankton populations rather than measuring changes in water variables, but it ensured that the phytoplankton sampling gave a more accurate picture of the genera and species present after the impact or treatment.

The 'impact' on the sites was one of the following three treatments:

1) the clearing of turbidity using lime

2) the addition of charophyte rich-seed bank

3) a combination of clearing with lime and addition of charophyte rich-seed bank.

Dams were treated in early spring 1997 when the first algal blooms became visible. An amount of lime was mixed and applied at the rate of 25 kg per megalitre (kg/ ML) of water volume to the water surface (see Chapter 5.3.3). Impact and control sites were selected in the same geographical area to allow for local variations in rainfall, sunshine and temperature and were within a 50km radius of the University of New England (Figure 5.2). Information was also collected on variables that described the characteristics of the individual sites such as wetland slope and upstream or catchment condition. Sampling times were carried out between July 1997 and April 1998 and a final (A9 or 9^{th}) sampling of the dams was done in May 1999.

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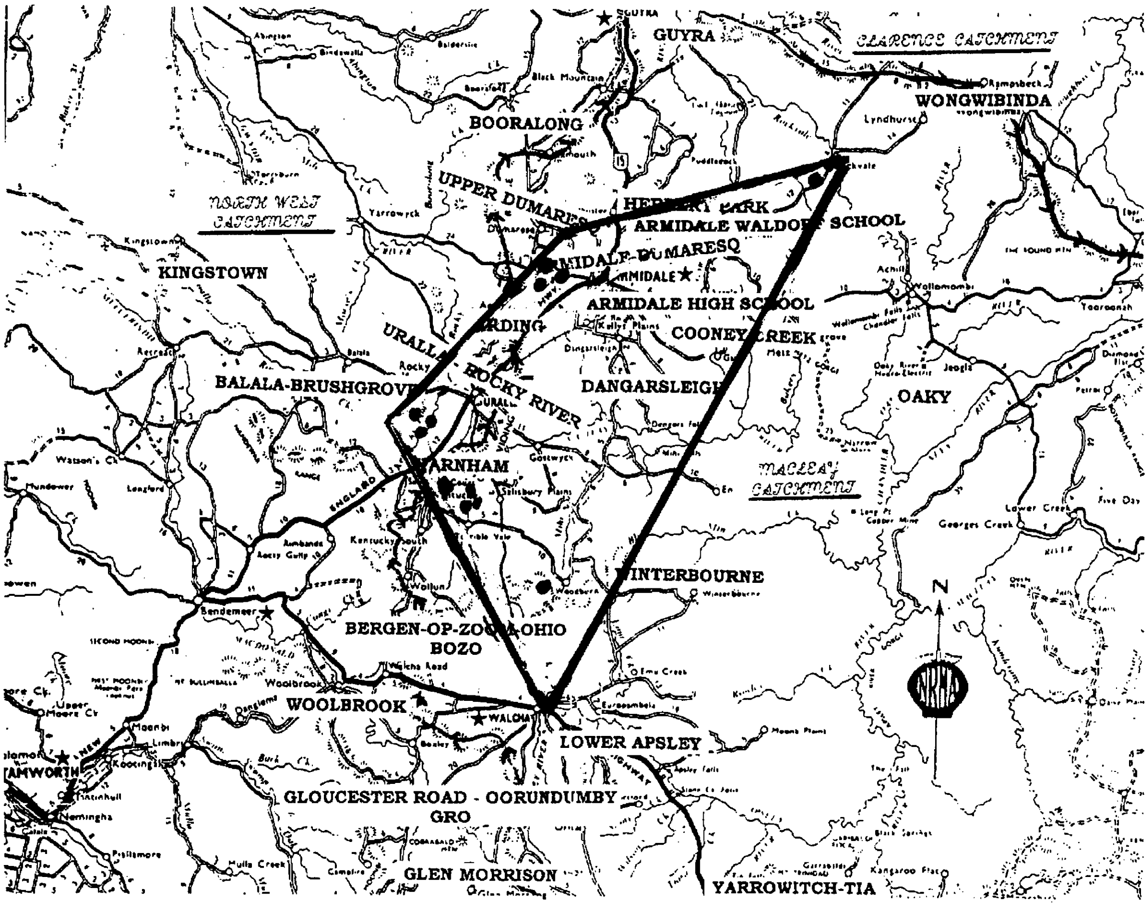

● Dams ▬ Boundary

Figure 5-2 Boundaries of the area for the farm dam rehabilitation experiment in the Macleay River catchment of the New England Tablelands and location of Landcare groups. Dams are shown as black dots. Scale 2 cm = 20 km. Northwestern boundary of marked area is approximately the western edge of the Great Dividing Range.

Table 5 1 Turbid farm dams and their responses to two chemical flocculation treatments. Treatments of dams were chosen at random and then 4 X 500ml water was tested for its response to both aluminium sulphate (alum) and calcium hydroxide (lime) stock solutions. (Stock 1 $mgml^{-1}$). *Dam 2 flocculated in the field with lime. **Dam 5 had a blue green algal bloom at the time, which only flocculated with alum.

Dam No.	**1**	**2***	**3**	**4**	**5****	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Treatment	SB	SB/L	C	SB	L	C	SB/L	L	SB/L	L	SB	C
Best flocc'n	alum	alum	both	lime	alum	both	both	both	both	both	alum	both

Table 5 2 Treatment impact on dams and quantities of lime and seed bank used. Each treatment (Impact) was randomly allocated to each of the four dams in the same neighbourhood (group). Seed bank amounts are calculated from buckets of seed bank spread by hand. 1-bucket seed bank covers 5 m^2 to 1-cm depth. *Note- Dam 5 with blue-green algae; algae was not flocculated by lime although treatment was still given. Impact (treatment) C = control, SB = seed bank, L = lime, SB/L = seed bank and lime.

Treatment	Dam No.	Dam Vol. ML	Lime calc'd kg.	Lime actual kg	Seed bank m^2
SB	1	2.0	Nil	Nil	40
SB/L	2	1.0	25	25	25
C	3	6.0	Nil	Nil	Nil
SB	4	8.84	Nil	Nil	60
L	*5	5.0	125	125	Nil
C	6	6.0	Nil	Nil	Nil
SB/L	7	6.0	150	150	35
L	8	6.0	150	125	Nil
SB/L	9	5.5	137.5	137.5	25
L	10	2.8	70	100	Nil
SB	11	5.5	Nil	Nil	20
C	12	1.0	Nil	Nil	Nil

5.3.3 Pre-treatment flocculation experiment

Water samples in bulk quantities of up to 5 litres were taken from each dam and kept cold in an esky on ice in the field until return to the laboratory where they were refrigerated until used. From quantities used to treat ponds in previous studies laboratory stock solutions (1 mg ml^{-1}) of calcium hydroxide and agricultural grade aluminiun sulphate were made up with distilled water. 1ml of the lime stock solution was added to 2 replicates of a 500 ml water sample in a cylinder and the millilitres of flocculation that occurred over an hour was recorded. After 15 hours this was recorded again and this indicated whether the treatment could clear the water body and at what rate. This test was repeated in 2 replicates of 500ml water with 1ml of aluminium sulphate stock solution. The number of ml. of alum and lime was converted kg ML^{-1}. An average of 25kg ML^{-1} was calculated from measuring the amount of lime or alum (mg ml^{-1} converted to kg ML^{-1}) required to cause complete flocculation in the same dam water collected and tested in the laboratory. This amount was the same or similar to previous doses calculated by other researchers (Murphy *et al.* 1988, Cooke *et al.* 1993, Babin *et al.* 1994).

5.3.4 Discussion of treatment

Treatment with Lime

In the laboratory tests with lime and alum (Chapter 5.3.3) it was found that the majority of dams experienced flocculation of their water in response to lime. Two dams that were randomly chosen for treatment with lime did not, but one of these did later, and to maintain consistency of treatment, lime was used on all dams. In the spring, an algal bloom had formed in one of these two dams (Dam 2), which in a separate test flocculated with lime. When the dam was treated in the field with lime the suspended clays and algae flocculated out together very quickly. Dam 5 had a blue green algal bloom (*Anabaena circinalis*) which was only flocculated by alum but was treated with lime, as this was expected to reduce the SRP in the water column.

A rough idea of the dams' bathymetry was formed by wading in to each dam and measuring the maximum depth using a plumb line tied to a string held out over the deeper parts of the dam with the use of a long stick held parallel to the water surface. Dam volumes were calculated and the number of 25kg bags of lime required to treat each dam was calculated against the volume of the dam. Bags of lime were mixed individually in a 1m wide x 0.6m deep transportable pond with water, forming slurry (Plate2 b). This slurry was sprayed evenly on the water surface using a fire fighting pump and hose to which was attached a fine spray nozzle. As the suspended clay clumped and flocculated out of the water column it was visually obvious where the lime had been sprayed and in this way it was possible to treat all areas of the dam. The pH was monitored in different areas of the dam using a portable pH meter. Before the pH reached 9.0, lime treatment was stopped and the pH checked until the pH was stable at approximately 9.0. This point was usually reached when all allocated bags had been used plus or minus half a bag.

Treatment with Seed bank

Racecourse Lagoon (30°, 39′ S; 151°, 30′ E) was used as a sole source of wetland plant seeds for the field experiments. Seed bank from the wetland was collected in one day in the winter of 1997. (Plate 2 (c, d, e). This was labour intensive and entailed the removal of sediments in up to 0.5m depth of water, and after discarding any water plants, sediments were dried on tarpaulins, broken up and sieved through a rough sieve and mixed thoroughly with a shovel. Buckets of seed bank was introduced to dams by dispersing by hand to a depth of 1.5m and wearing waders. One 10 litre bucket of seed bank soil mixture covers 5 m^2 to one cm depth. The number of metres covered by hand was given in metres (Table 5.2)

The design of the dam was the main consideration in the method of spreading. For dams with the typical triangular shape (shallow at one end and deep towards the dam wall) the following procedure was followed. Starting 1 metre in the water from the dam edge, for each two steps taken one handful of seed bank was spread to the right. When the length of the dam is completed the original path is retraced in the opposite direction with seed bank again spread to the right. Wading depth was kept to the top of the thigh (approximately 1m) and deep areas > 3m were not seeded. This ensured areas of 2 to 3m width and up to 2m depth were fairly evenly and lightly covered with seed bank. For dams more or less circular with the greatest depth in the centre, the circumference was seeded to the same wading depth and then the path retraced in the opposite direction, while seeding to the right. This procedure ensured the safety of the person spreading the seed as turbid dams can have unseen and dangerous submerged impediments such as hidden logs, hollows or wire. Retracing the original path reduced the opportunities for slipping or injury.

Combination treatment

This was the same as for lime and seed bank treatments. Lime was sprayed first then seed bank was spread soon afterwards, being careful not to stir up the sediments unneccessarily.

Quantities of lime and seed bank that were used per dam are given in Table 5.2.

5.4 Data collection

Four measures were made before-impact and four after-impact and these measures will be discussed as measures Before 1 to 4 (B1-B4) and After 5 to 8 (A5-A8) or the 4-before and 4-after samplings. A 'one-off' measure was made 20 months after treatment in June 1999 and this will be discussed as the A9 or 9^{th} sampling but it is not included in the BACI data for analysis. Data on dam variables were collected monthly using the methods and techniques reported in Chapter 2, Table 3.3. The following parameters were scored in all dams every 4 weeks on 8 occasions over a time frame of 2 to 3 days per month between winter and late summer:- pH, turbidity, secchi disc transparency, temperature, conductivity, soluble reactive phosphate (SRP), total phosphate (TP). A problem with the hand filter pump meant chlorophyll-$_a$ was only sampled on two occasions before treatment (Sept. and Oct. 1997) but was done on four occasions after treatment (Nov.and Dec. 1997, Feb. and Mar.1998) and not at the A9 sampling. Two 250ml phosphate free bottles of filtered water were collected and frozen for SRP analyses and two unfiltered for TP. SRP and TP analyses were analysed in the laboratory every two months and chlorophyll-$_a$ analyses were completed each month soon after sampling. Methods for SRP and TP analysis are given in Wetzel and Likens (1991) and American Public Health Association Standard Methods (1989). Conductivity was measured with a Beta 81 conductivity meter (CHK Engineering) in micro Siemens per cm (μScm^{-1}). Depth variation was measured in cm, starting after the treatment in late Spring, by marking the water level with a marked stake and measuring the rise or drop in water level against the stake.

Nitrate-nitrogen was not measured as previous surveys of 43 farm dams in the area had found low concentrations (mean 0.026 mg L^{-1}) (Casanova *et al.* 1997, Douglas-Hill 1995) suggesting widespread N-limitation. Chlorophyll-$_a$ concentration was determined through the Trichromatic method for the extraction and determination of chlorophyll-$_{a,b,c}$ using 90% acetone and extracts were read at 664, 665, 647 and 630 nm on a 'Varian' spectrophotometer (American Public Health Association, 1989) and given as $\mu g\ L^{-1}$. The filtration of a measured quantity of water (which was either filtered in the field or put on ice and then filtered in the laboratory) using a suction pump and Whatman GF/C glass-fibre filters with pore size 0.2 µm. Chlorophyll-$_a$ samples were filtered in triplicate, the filters were folded, algae innermost, wrapped in foil inside sealed plastic bags, put under crushed ice until return to the laboratory where they were frozen to –20°C for later analysis.

Qualitative zooplankton and phytoplankton scoops were made using a 20 µm mesh plankton net across the dam in 10 random sweeps to 1m, straining half each amount of water before another scoop was made. Both zooplankton and phytoplankton samples were kept on ice in the field and refrigerated on return to the laboratory. Algae were identified within a few hours using the following: Prescott (1978), Belcher and Swale (1976), Bold and Wynne (1978), Canter-Lund and Lund (1995) and Entwistle, Sonneman and Lewis (1997). For zooplankton, 70% alcohol was used as a preservative and to prevent loss of species through predation. Identification was to genus level utilising Williams (1980). A Leitz Laborlux high magnification was used for the algae and a Wild Heerbrugg top light microscope was used for the zooplankton.

The percentage underwater cover of the functional groups of submerged, S, water plants, the submerged edge cover of plastic amphibious fluctuation responders, ARp, and the water surface cover of floating amphibious responders, ARf, was assessed visually or by sight before and at the end of the BACI study. The whole area of the dam was observed visually and a 1m long wide glass-bottomed cylinder was used to scan the sediments of the dams in a random manner to detect any germinating water plants. These were tagged with a marker stake when the depth was not too great. There were some complications with using this method in deeper turbid water as the cylinder was only 1 metre long and for good visibility underwater it was essential that it reach to a few centimetres from the sediments. Wading out to this depth was also difficult due to both the stickiness of the mud and on the grounds that some resuspension of the sediments would occur. ARp's included the genera *Myriophyllum, Potamogeton, Elatine, Glossostigma and Limnosella*; ARf's included the genera *Marsilea* and *Ottelia*. A presence-absence and abundance score of S, ARp and ARf species was carried out before and after the impact and any changes were recorded each month. ATe and Tda species were recorded but not measured or sampled.

5.5 Glasshouse trials to detect the presence of water plant seeds in farm dam sediments

To measure the potential submerged percentage plant cover of sediments from farm dams, 6 trays of sediment were collected from the edge of each dam to 0.5m with 8 cores per tray, both before (September 97) and 4 months after treatment (March 1998). These 72 trays were air dried for up to two weeks. They were then placed randomly in two large clear water tanks in a glasshouse on up-ended pots, with three trays at two depths, 5 and 20 cm (the depth defined as the length between the sediment and the air-water interface) and left submerged for three months (Plate 3). Three control trays of washed sand were placed at each of these two depths in both tanks to allow for any possibility of transfer of seed between trays. It was expected there would be similar patterns in germinations between spring and autumn in the glasshouse but that more species would grow in the glasshouse (Britton and Brock 1994). The timing of the glasshouse trials was chosen to correspond with this known seasonal pattern. Turbidity and the maximum and minimum water and air temperatures were measured twice weekly and the water in the tanks was gently flooded when necessary to remove any alga scum. Turbidity was kept at a minimum of 1 to 2 NTU. The presence of germinating plants in the submerged trays was recorded at both depths.

5.6 Data analysis

5.6.1 Sediment seed bank potential percentage cover and species richness.

The potential germination numbers and cover from the seed bank of each dam was determined both before and after the BACI experiment was done, to determine if the farm dam seed bank had changed in response to the experimental treatments (Plate 3).

Calculating the cover of water plants per square metre can be done knowing the area of the corer, the number of cores per container and the number of germinated plants per container (Brock 1997). From the average germination of plants from the 3 trays germinated at each depth the average potential cover at the two depths is calculated. Seed bank species germination and percentage cover records were entered in Excel and Access and number of species and average percentage cover to 20 cm for the before and after treatments were graphed with standard deviations. They were analysed with one-way ANOVA to determine if the difference in percentage cover was significant in the trays before and after treatment.

5.6.2 Changes in measured water variables

Data from the 8 samplings (4-before and 4-after) of the 8 dam variables were entered in Excel, analysed and graphed in Excel and the Minitab (version 9.0) was used to undertake t-tests and ANOVAS for the BACI analyses. The results of the A9 sampling (June 1999) was added to the database but not used in the BACI analysis.

1) Descriptive statistics for the 4-before and 4-after measures for the treatment groups were done and the increases or decreases in the variables for each treatment group were examined for large differences. If differences were large that indicated either a seasonal or treatment effect. The differences (positive or negative) between the averages for the control dams and the averages for the treatment dams before and after treatment were calculated and presented as a table.

2) The averages of each variable from the treatment and control groups were plotted over time to observe the changes in trends before and after treatment. Seasonal changes between Before-impact (measured in winter to early spring) and After-impact (measured in spring to late autumn) will show their influence on the water variables, but the control dams will also be expected to show the same variation with season. By comparing the difference between the averages of the control and impact groups before and after treatment, the influence of season on the variation in the measured variables is negated.

3) The 12 dams were also examined for individual variation to observe any large changes and determine their cause.

4) Levene's test to check for the homogeneity of the group variances was undertaken. If $p > 0.05$ variances were homogenous, if $p < 0.05$ variances were heterogenous. To ensure homogeneity of variances the values were log base 10 transformed. ANOVAS were done on variables showing large differences with seed versus control, lime versus control and seed bank-lime versus control (Underwood 1991).

5) Paired t -tests and confidence intervals were done on the averages of each measured variable in the 3 treatment groups and the control group before and after treatment to determine if there was a significant difference in the 4 groups before and after treatment. This analysis was repeated comparing the treatment groups with the control group both before and after treatment.