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Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

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1. Background

Many farmers have constructed deep, open drains on their properties. These drains are generally excavated by a back hoe or a bulldozer. Whilst the farmers are prepared to pay for and construct these drains, land-holders further downstream are usually unhappy about receiving the extra saline water that flows in the drains. They are also concerned about sediments carried in the water. The result of this conflict has been bitterness between some land-holders. To reduce these conflicts and the degradation of land downstream, drainage regulations were introduced in 1992. Under these regulations “farmers must notify the Commissioner of Soil and Land Conservation of their intention to drain or pump water for the control of salinity” so that anyone likely to be affected is informed.

In April 1995, Agriculture WA undertook a stock-quality drilling program in the North Stirling area. Three of the selected sites were on Mr. Ken Pech’s farms (Figure 1) which form the headwaters of the Six Mile Creek. Ken showed us the deep drains he had constructed more than ten years earlier. His photos showed that there was an apparent reduction in salinity in an area between 100 and 200 m away from the drains. The improvements were unusual because similarly constructed drains in other landforms have had little or no effect on the salinity status of their surrounding areas (Speed and Simons, 1992). We decided to evaluate these drains and present the results for the benefit of other land-holders that may want to construct deep drains. This report is the result of that study.

2. Previous Work

Silberstein (1989) studied Ken's drains which are in the headwaters of the Six Mile Creek. He concluded that:

- the watertable had been lowered in the vicinity of the drains;
- the main effect of the drains was to alleviate waterlogging in near by areas. This could have been achieved by other types of drains;
- there had been considerable erosion on either side of the drain;
- the drain and spoils from it had caused difficulties in gaining access to some areas;
- the overall effect of the drainage system could not be measured and its long-term effect could not be predicted, despite some visible improvements in the vicinity of the drains.

Lewis (1992) studied hydrology and salinity in the North Stirling Basin, which is south-west of the study area. She suggested that some groundwater may flow out of the North Stirling Basin and discharge into the headwaters of the Six Mile Creek. She estimated the maximum flow rate to be 40 m^3/day.

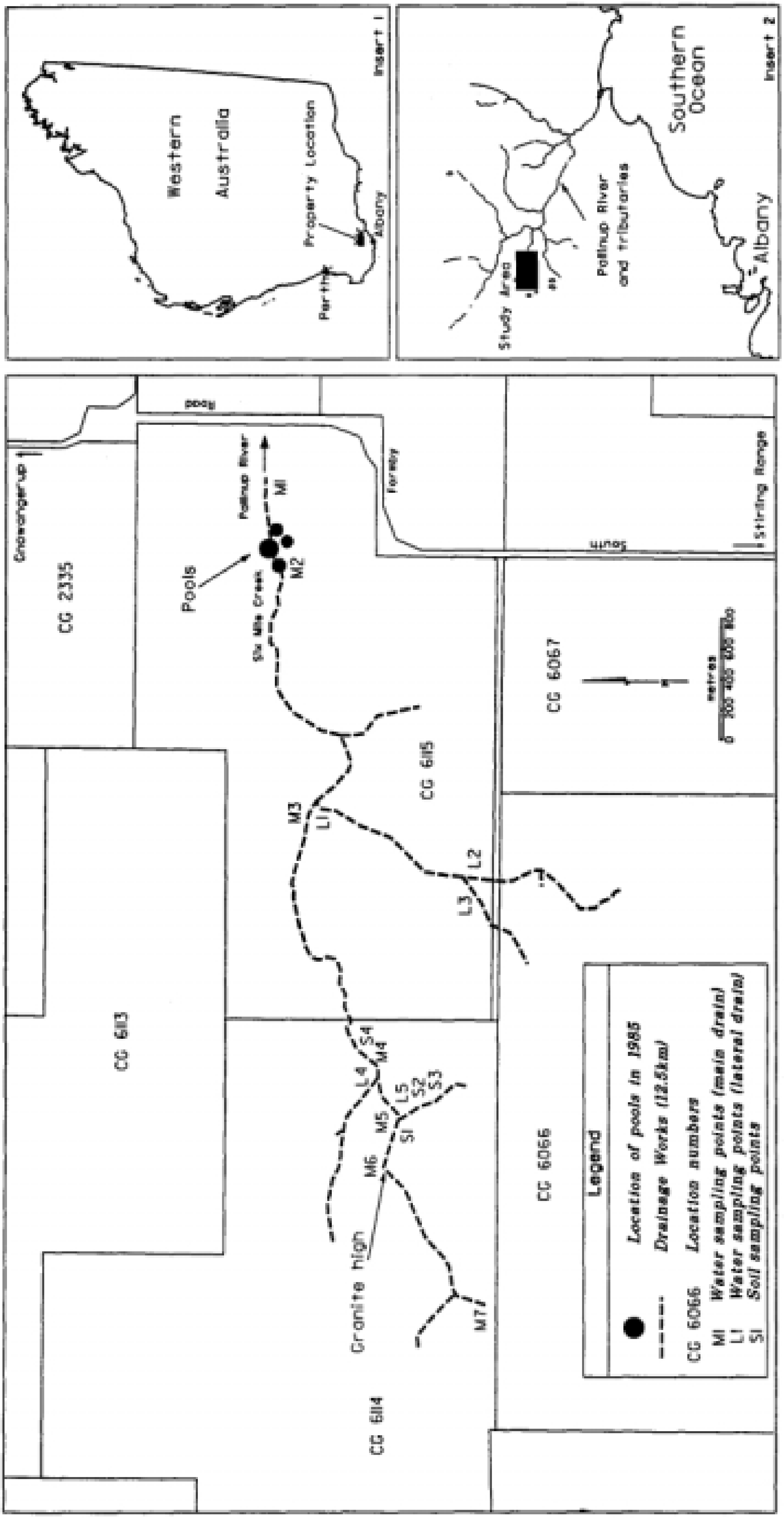

Figure 1. Location boundaries, numbers and sampling points in relation to drainage works on Ken Pech's property, Gnowangerup

3. Methods

Geological description of the area were based on:

- soil profile information from three bores which were drilled. Appendix 1 shows the drilling logs for two of these bores, which are typical of the profiles in the area.
- the rocks found in the area were Pallinup Siltstone (Photograph 1) and spongolite, both of which are of Tertiary origin, and a few Precambrian basement rocks (found in the upper section of the drain).
- descriptions of soil profiles along the drain (Table 1 and Figure 1).

We recorded the position of major seepage zones (Figure 1 and Photograph 2) which were along the mid section of the drain.

Aerial photographs from 1985 and 1993 were interpreted to find the extent of salt-affected land before, and eight years after, construction of the drains.

The length of the drain was measured from the 1993 aerial photographs.

We contacted a local contractor to obtain current construction costs. These quotes are related to the size of drains (Table 2). We asked Ken how much he had paid in 1985 for the construction of the drain.

In December 1996, we walked along the drains and:

- noted which areas were strongly salt-affected (had become bare grounds);
- used a Geonic EM38 instrument to define the salinity status of the suspected areas (using the relation given in Ferdowsian and Greenham, 1992);
- described four typical soil profiles (Table 1);
- estimated the flow rate at several sites (Figure 1; Table 2);
- sampled the baseflow to measure its salinity.

4. Results

4.1 Geology and Soil Material

The area is covered by Pallinup Siltstone which is a Tertiary Formation. The Pallinup sediments in this area, are mainly composed of fine silt, clay (Photograph 1) and occasionally fine to medium sand (Table 1). The siltstone, in some areas, contains pink and white spongolite (a siltstone full of sponge spicules). The Pallinup Siltstone overlays the basement rock which is of Precambrian origin and part of the Yilgarn Craton. There are basement (granite and gneiss) highs in the area that are covered by sediments. Weathered granite can be seen along the bed of the main drain (Figure 1).

Table 1: Descriptions of soil colour and soil texture for profiles that are either near or away from discharge sites.

Depth (m)		Soil profiles near discharge sites		Soil profiles away from discharge sites	
from	to	Site 1	Site 2@	Site 3	Site 4#
00	0.20	light yellowish brown fine sand	light grey fine sand	light yellowish brown fine sand	light yellowish brown fine sand
0.20	0.40	olive colour silty clay	pale yellow silty clay	olive colour silty clay	olive grey silty clay
0.40	0.60	olive grey silty clay*	pale yellow silty clay	olive grey silty clay*	olive grey silty clay*
0.60	0.80	olive yellow silty clay*	pale yellow silty clay*	pale yellow silty clay*	olive yellow silty clay*
0.80	1.00	grey fine sand	pale yellow silty clay	light grey silty clay	light grey heavy clay
1.00	1.50	grey medium to fine sand	light grey fine sand	light grey heavy clay	light grey heavy clay
1.50	2.00	not sampled	light grey clayey fine sand	not sampled	not sampled

Notes:

1. Sub-soils, along the drain, are mostly silty clay and occasionally (at discharge sites) fine to medium sand.
2. * = There were some mottles in that depth interval.
3. @ = Photograph 2 shows photo of this site.
4. .# = Photograph 3 shows photo of this site.

4.2 Drain Specification

The drainage system is composed of one main drain (6.5 km) and 7 km of lateral ones. The main drain and a few of the laterals (8 km altogether) were constructed in 1984. Another 4.5 km of lateral drains were constructed in 1985 and 1986. Only one lateral drain (about 1 km) was constructed after 1993 and so this cannot be seen on the 1993 aerial photographs.

All drains have a trapezoidal cross-section. The bed of the main drain is 3 m wide and its sideslopes 1:1 (vertical : horizontal). The beds of lateral drains are 1.2 m wide and their sideslopes 2:1. With the exception of approximately 100 m (Figure 1; the granite high near M6), the drains are entirely in the Pallinup Formation.

Photo 1: Sedimentary layers of the Pallinup silty clay in the study area.

Photo 2: One of the few major seepage zones. Note: the collapse of material at the seepage zone which is in the centre of the photograph.

Photo 3: With the exception of a few sites, the soil profile along the main drain is very tight silty clay. Note: The bed of the drain is filled with silt.

Parts of the drain had fences on both sides while other parts were fenced on one side only. Sheep were found walking on the slopes and bed of the unfenced sections.

4.3. Condition of the drain

With the exception of a few places, the sideslopes of the lateral drains are stable (have not collapsed). The large piles of spoils are bare and exposed to erosion. Coarse grains of sand could be seen along the banks of the lateral drains which indicate that the spoils from the lateral drains have been eroded and entered the drains.

Some sections of the main drain were badly eroded. Gullies, 1 m apart and up to 0.5 m deep, had formed along the sideslopes in some sections of the main drain (Photograph 4). Part of the eroded material had filled the base of the main drain (Photograph 3) and part was transported out of the area. There were also indications of sedimentation further downstream. A typical site where this silting may be seen is 500 m before the creek crosses the South Formby Road (Figure 1). On the 1985 aerial photographs there are four pools in this area. These pools are absent on the 1993 aerial photographs. It is likely that these pools have been filled with silt between 1985 and 1993. Silting of the creek bed can also be seen further downstream, east of the South Formby Road.

4.4. Flow rates, baseflow salinity, evaporation along the drainage system and salt export

The bed of the drain was wet throughout its entire length but only a few seepage areas which had sandy profiles (Table 1) contributed to the baseflow. Seepage zones included sections of the drain which had been cut into the floor of salt lakes.

The flow rate along the main drain (December 1996) varied between 0.2 L/sec (site M7; Figure 1) and 2 L/sec (M1; at the outlet of the property). A few of the lateral drains had no or little flow (Table 2 and Figure 1).

The flowing water was baseflow which was groundwater seeping into the drain. Baseflow salinity varied between 5600 and 8400 mS/m (Table 2). The lowest salinity reading (5600 mS/m) was at site L5 which is close to a seepage zone (S2; Figure 1). This salinity is probably similar to the salinity of the groundwater. The salinity of the baseflow at the outlet of the property was 8300mS/m (M1; Table 2). The increase in salinity is probably due to evaporation.

The ratio of baseflow salinity at the outlet of the property (8300 mS/m) and the lowest salinity (5600 mS/m) shows salt concentration due to evaporation along the drainage system. Thus without evaporation, the flow rate at the outlet of the property (Q) would be :

$$Q = 2 \text{ L/sec} \times 8300/5600 \quad \text{or} \quad Q = 3 \text{ L/sec}$$

Table 2: Flow rate (L/sec) and baseflow salinity (mS/m) in different parts of the drain.

Sites (Figure 1)	Flow Rate	Salinity of water
M1	2.0	8310
M2	2.0	8060
M3	1.2	7900
M4	1.0	7410
M5	0.5	8830
M6	0.4	11,070
M7	0.2	10,070
L1	1.0	6480
L2	0.8	5680
L3	0.1	10,800
L4	0.1	8450
L5	0.4	5600

Thus evaporation losses along the drainage system reduce the flow by about 1L/sec.

The baseflow was carrying approximately 7.9 tonnes of salt out of the property each day in December 1996. We expect that the salt export will probably be much higher during winter months. Silberstein (1989) found that the average salt export, at the outlet of the drainage system, was approximately 240 tonnes per day, between 10th May and 30th July 1988. The annual salt export figure was 120 tonnes per day during 1988. He attributed the large salt export to the excessive runoff which was the result of an exceptionally wet season. The total rain falling during May, June, and July 1988 was 287 mm, compared to the 10 year average of 144 mm for the same period.

Lewis (1992) studied the North Stirling Basin, which is west of the study area. Average salt storages in the 13 bores which she studied were 1830 t/ha (average depth 13.50 m). Salt stored in the drain's catchment (9600 ha) would probably be the same as reported by Lewis. Assuming that the drain would continue to remove 7.9 tonnes of salt each day, it will take more than 6000 years for the drain to remove all of the salt from the soil profile. Even with the highest salt export rates (120 tonnes per day; in 1988), it would take about 200 years to flush half of the stored salt from the catchment of the study area.

4.5. Water balance and potential salinity

We expect that between 10 mm (in a year with average rainfall) and 50 mm (in a decile 8 year; two wettest years out of ten) of the annual rainfall would recharge the aquifer each year. If we assume that the catchment boundaries are the same as the aquifer boundaries, then the total area that contributes to the baseflow in the drain will be 9600 ha. The annual baseflow out of the property and evaporation along the drainage system is 94,600 m^3 (3 L/sec) which is <1 mm per year over the total catchment area. This figure does not and should not include the surface runoff. The rate of baseflow discharge is very little compared with the recharge under pastures and crops. Thus, the deep drain alone will not stop soil salinity and many more areas may eventually become salt-affected. As an example, area 1 (Figure 3), has become saline since 1993.

4.6. Effect of the deep drain on the extent of the salt-affected area

In this report, salt-affected areas are defined as lands that have become bare and appear as highly reflective areas on the aerial photographs. These areas do not include moderately or slightly salt-affected areas (barley grass areas or salt-affected cropping land).

About 251 ha of land was strongly salt-affected on the 1985 aerial photographs. These areas looked continuous and spread out (Figure 2). Most of the affected areas were in the natural drainage beds.

The total salt-affected area based on 1993 aerial photographs was about 224 ha (Figure 3). By comparing the 1985 and 1993 aerial photographs, we could see that:

- salt-affected areas close to the deep drains had been reduced, and in some places had become isolated (Figures 2, 3 and 4);
- during the same period, salinity had encroached into other areas that were further away from the drain (Figures 2 and 3).

We found that the salt-affected land in the study area had reduced by 27 ha between 1985 and 1993. Out of the 27 ha which showed signs of improvement, about 8 ha was cropped in 1996 and the balance (19 ha) was within the natural creek beds and flood plains.

Improvement of creek beds and flood plains (eg. Area 2; Figure 3) could be partly attributed to them being fenced off and revegetated with salt-tolerant species. These areas had been mounded and planted with salt-tolerant species. *Melaleuca thyoides, Acacia saligna* and *Atriplex spp.* were among the surviving plants. *Melaleuca thyoides* was very impressive (Photograph 5) with a large canopy (5m in diameters) and healthy growth.

The improved area, furthest from the drain which was cropped in 1996 was a 3 ha patch of land (Area 3; Figure 3) up to 200 m away from the main drain. Improvement of this land is entirely due to the effects of the drain since there is no treatment other than the drain. The area was bare in 1985 (Photograph 6a). At the time of our second visit (December 1996), this area had been cropped but not harvested because the crop (barley) looked patchy. The Geonic EM38 readings on this area were between 80 and 120mS/m. These reading showed that the area was still moderately salt-affected. Photograph 6b shows lupins grown in the area in 1995. This land is probably on a sandy lens that crosses the deep drain (Site S1; Figure 1). By having a high hydraulic conductivity, this sandy lens has extended the effect of the drain far beyond the expected distance. We observed one section (Site S1; Figure 1) of the deep drain that had higher seepage rates than other areas and found that the sandy lens crossed the drain here.

Photo 4: The slopes of the main drain are badly eroded.

Photo 5: Melaleuca thyoides *(foreground) had more impressive growth than* Atriplex spp*. (saltbush).*

Photo 6a : This area was extremely salt-affected and bare in April 1985.

Photo 6b: The same area in September 1995 growing a crop of lupins.

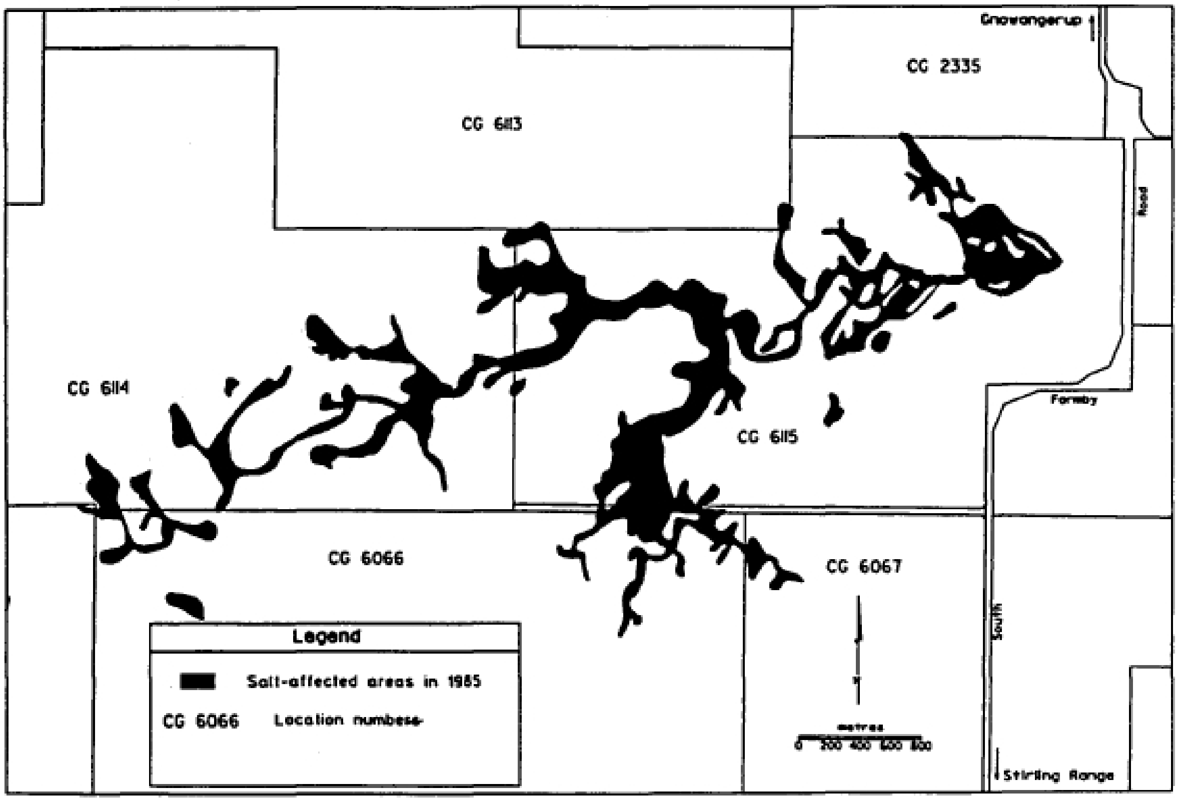

Figure 2: Extent of strongly salt-affected areas in 1985 (251 ha).

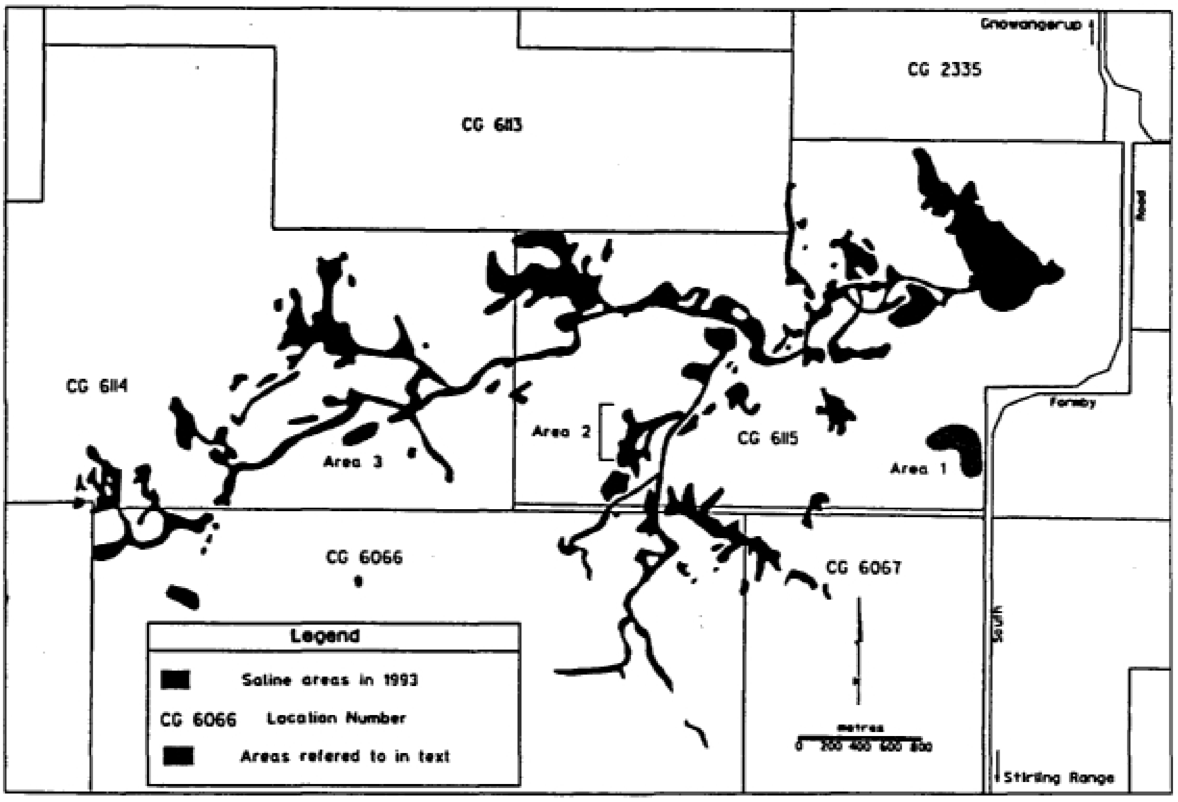

Figure 3: Extent of strongly salt-affected areas in 1993 (224 ha).

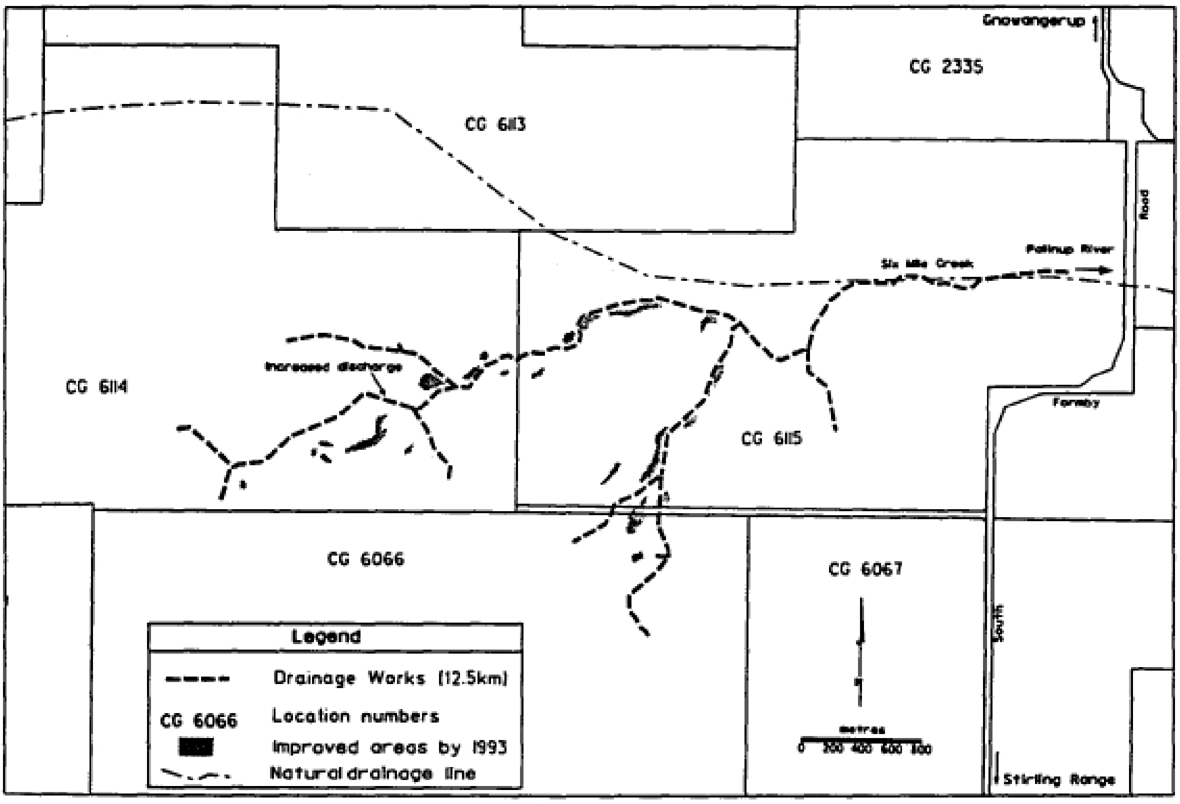

Figure 4: Areas where salinity improved (27 ha) between 1985 and 1993 and a major discharge site.

4.7. Costs and improvements due to the deep drain

The 1996 costs of constructing deep drains with U-shaped excavations and vertical sides are shown in Table 3.

Table 3: Present cost of constructing deep drains in relation to size of drains (estimates from Ray Collard, a local contractor).

Drain size (m; depth X width)	2.7 X 1.5	2.4 X 1.5	2.1 X1.5	1.8 X 1.2	1.5 X 1.2
Costs ($/km)	5800	5150	4500	3000	2570

- The drain in the study area is moderately deep (1.8 m) and would have costed less than the very deep (>3 m) drains that some land-holders have constructed. Ken paid >$30,000 for the construction of his drain, in 1985.
- We estimate that the present cost of constructing the main drain is about $8,000/km and for the laterals about $4000/km. Thus it would cost $80,000 to construct 13.5 km of drain. The gains, in the form of land reclamation, have been less than 8 ha of cropping land plus additional areas which may have become saline in the absence of the drain.

5. Feasibility of the deep drain

The Net Present Value (NPV) is a measure used in economic analysis to determine a project's net benefits. It is the discounted value of expected benefits, less the discounted value of expected costs. The Net Present Value of the drain has been calculated based on the following assumptions:

- Drain construction cost $30,000 (1985);
- No maintenance until year 2000;
- Benefits from construction of drains commence in 1989;
- Barley grown on reclaimed area;
- Barley gross margin $130/ha.

The analysis indicated that at a discount rate of 8% the investment cost would be recovered if 40 ha of land was reclaimed. The actual reclaimed area (8 ha) will not recover costs over the life of the project. The area required to break even varies with the level of discount rate (Figure 5).

The analysis does not account for off-site effects of the drain such as export of salt and silt to the other properties. It also does not account for intangible gains or losses such as the scenic values of reclaiming land, look of the drain with its spoil mounds and access to paddocks.

6. Discussion and recommendation

The valleys in this area have sandy lenses in their Tertiary sediments. The existence of sand has made this area one of the most suitable areas for constructing deep drains in the district. The drain has therefore reduced the extent of salt-affected land in some nearby areas but it has not been a cost-effective exercise. The area required to break even, with the lowest level of discount rate (6%), is four times the reclaimed land.

These limited gains are unlikely to happen in other areas, particularly if the soil profiles are less permeable. Most areas that are already, or are becoming, salt-affected have tight clays that restrict the movement of groundwater. Thus the effect of deep drains in those areas would be localised and confined to the immediate vicinity of the drains (eg. within 10 m; Speed and Simons, 1992).

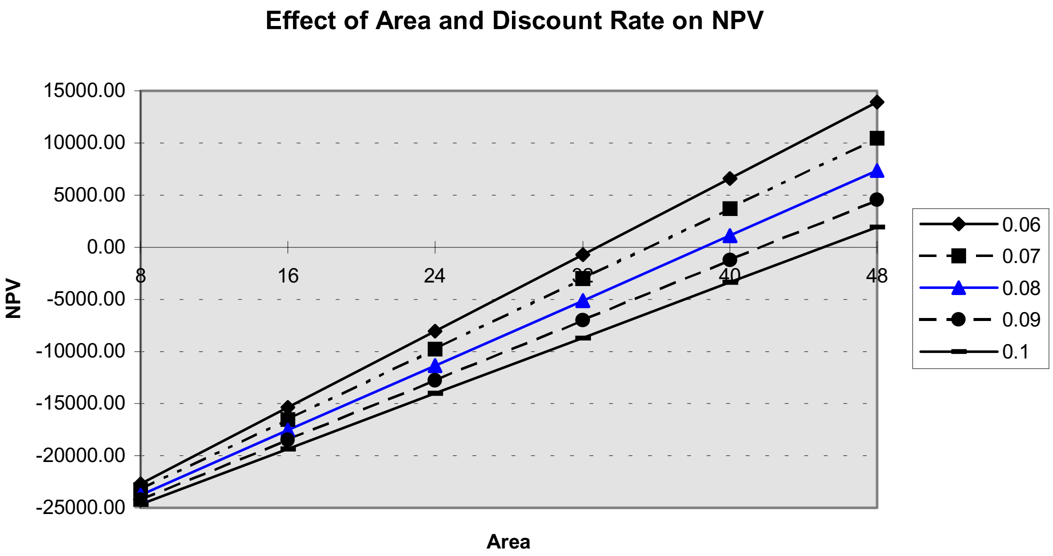

Figure 5: Effect of discount rates and reclaimed area (ha) on the Net Present Value (NPV) of Pech's drain.

Note: The area required to break even, with the lowest level of discount rate (6%), is 32 ha (four times the reclaimed land).

Deep drains are costly (2500 to 8000 $/km) to construct and to maintain. Therefore a feasibility study should be done before they are constructed. In most cases, the money is better spent on other conservation work, such as shallow surface drains ($500 to $1000/km). These are more cost-effective than deep drains. In addition, shallow surface drains should always be tried first, before embarking on ambitious deep drains. Fencing off the potentially saline areas and planting salt tolerant species such as *Melaleuca thyoides* which has an impressive, large canopy (5 m in diameter) and seems to be more salt tolerant than *Acacia saligna* and saltbush, is also recommended.

The environmental consequences of the deep drains must also be considered before any deep drain is constructed. Some of these consequences include:

- disposal of saline water into properties and creek lines further down stream. This saline water may kill the riparian vegetation and increase soil and creek salinity. A good example of these off-site effects is a deep drain at the Esperance Downs Research Station (EDRS). In 1981, a deep drain was constructed at the EDRS that went through a remnant vegetation before discharging into the Dalyup River. By 1988, a 10 ha patch of remnant vegetation at the end of the drain had been affected by salinity (Rod Short, Max Crowhurst and Grant Lubcke, Agriculture WA; personal communication). Salinity of this 10 ha was mostly the result of the saline water from deep drains in EDRS.
- gully erosion due to storm water dropping into the drain channel;
- siltation and movement of sediments due to the collapse of banks and gully erosion;
- siltation of inlets and also pools along the rivers; As an example, many pools along the Pallinup River have been filled by sediments.
- eutrophication of closed pools and inlets due to nutrient in the runoff; and
- saline water collected by deep drains, may recharge the aquifer further downstream.

These problems may be seen in almost all deep drains that have been constructed in the district. Almost all of the deep drains that we have observed were designed poorly and constructed poorly. Proper design of deep drains needs technical knowledge. Issues such as: side slope, longitudinal slope, erodability of the material, erosive velocity, free board, drop structures, culverts, headwater protection, excluding storm water and disposal of saline water should be addressed.

7. Acknowledgments

We are indebted to Mr Ken Pech, Dr. Richard George, Dr. Bob Nulsen, Russell Speed and Dr. Jo McFarlane who reviewed this report.

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Appendix 1

The following pages show the drill logs of 2 bores that were drilled in the study area in April 1995. The drill logs contain the following information:

- Co-ordinates of sites;
- Salt storage profile(kg/m^3), which ranges from 1 to 30;
- Groundwater salinity (mS/m);
- Water level (m);
- Which landform pattern it is drilled in;
- Interpreted geology;
- Full lithology of the profiles.

Drilling Log Ken Pech 1995

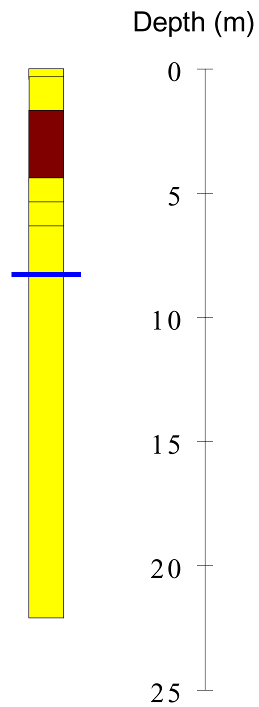
KP1/95

Easting: 592550 **Northing:** 6222928
Groundwater salinity (mS/m): 1075 **Water level below ground (m):** -8.7
Landform Pattern: Lunette Fields
Interpreted Lithology: Tertiary Pallinup Formation

Drilling log

0-0.2 m loamy sand (medium) 10YR 7/2 (light gray)
0.2-1.2 m loamy sand (30% gravel) 10YR 7/2 (light gray)

1.2- 4.5 m sandy clay loam 10YR 8/2 (white)
4.5-5 m loamy sand 10YR 8/2 (white)
5-6 m loamy sand 10YR 8/1 (white)
6-23 m fine sand 10YR 8/1 (white)



Legend

heavy sandy clay, sandy clay
coarse sandy clay

heavy silty clay
reddish or pinkish silt, silty clay

fine sand, loamy sand, loamy clay sand

hardpan
in-situ weathered material
water-table
bedrock
coarse sand

lignite

Drilling Log Ken Pech 1995

KP4/95

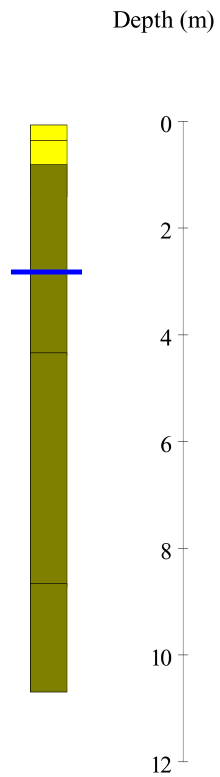
Easting: 589720 **Northing:** 622114
Groundwater salinity (mS/m): 5870 **Water level below ground (m):** -2.8
Landform Pattern: Stagnant Flats
Interpreted Lithology: Tertiary Pallinup Formation

Drilling log

0-0.2m loamy sand (medium) 10YR 7/2 (light gray)
0.2-1.2m sandy loam 10YR 8/2 (white)
1.2- 5m clay loam 10YR 8/2 (white)

5-9m clay loam 10YR 6/6 (brownish yellow)

9-11m clay loam 10YR 8/1 (white)



Legend

heavy sandy clay, sandy clay	hardpan
coarse sandy clay	in-situ weathered material
	water-table
heavy silty clay	bedrock
reddish or pinkish silt, silty clay	coarse sand
fine sand, loamy sand, loamy clay sand	lignite