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Soil surveys and related investigations in the Ord River area, East Kimberley, 1944

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By: G.H. Burvill

First campsite beside the Ord River, May 1944, near Ivanhoe Crossing, before the arrival of tents.

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Editor: D.A.W. Johnston

Preface

The results of this survey were first made available in typewritten form in June, 1945 when six copies were made. A further typing was done in 1974, but it has remained for this publication to put this important research into print.

Burvill's work was to become the basis for all subsequent soil survey work on the Ord. The original detailed maps are held by the Division of Resource Management, Western Australian Department of Agriculture. Apart from the abstract, all the data are presented in their original format.

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This survey was done when G.H. Burvill was the Assistant Plant Nutrition Officer, Department of Agriculture, Western Australia. He retired from the position of Assistant Director in 1971.

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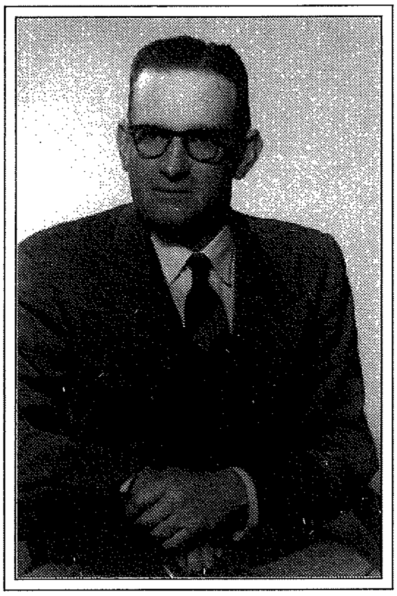
Foreword

The soil investigations reported in this Bulletin were undertaken in 1944 because, from 1941 to 1943, the Public Works Department, headed by R.J. Dumas, developed a strong interest in the damming of the Ord River.

A dam was needed to provide water for the irrigation of crops and pastures on the plains adjoining the river on Ivanhoe Station and the Mantinea Flats lower down the river.

K.M. Durack, a son of M.P. Durack who had established Ivanhoe Station in 1890, graduated from Muresk Agricultural College in 1936. Supported by the Public Works Department and the Department of Agriculture, he set up a small research station beside the Ord River near Carlton Reach in November, 1941. Durack pumped from the Reach the water held back by Bandicoot Bar. The Diversion Dam was built on the quartzite bar in 1963 and this produced what is now Lake Kununurra. The main supply channel for the irrigation of the Ivanhoe Plain takes off from Lake Kununurra close to the site of Durack's research plots. G. Barnett, Tropical Adviser at Carnarvon and A.R.C. Clifton of the Irrigation Branch in Perth, assisted Durack with the irrigation layout. They were nearly stranded when the river came down earlier than usual and Ivanhoe crossing became very hazardous. They missed the boat at Wyndham so left much of their gear and flew to Broome where they caught the boat south. The M.V. Koolama picked up the gear Barnett and Clifton had left at Wyndham, but did not call at Carnarvon when going south, nor on its next trip north when it was bombed by the Japanese off Cape Londonderry in January 1942 and again when the crew managed to get through to Wyndham. It remains sunk in Wyndham harbour, with Barnett's gear still on board.



Mr. George H. Burvill, Assistant Plant Nutrition Officer during the survey. Became Assistant Director of Agriculture.

The soil survey party left Perth in April 1944 and travelled by train to Meekatharra some 765 km north of Perth. Surveyor A.H. Richter was in charge of the party which included:

Surveyor, F.G. Medcalf (to do an erosion survey along the Ord River).

G.H. Burvill, Assistant Plant Nutrition Officer—to supervise the soil survey.

S.T. Smith, Agricultural Adviser—soil surveyor.

C.F.H. Jenkins, Government Entomologist.

C.A. Gardner, Government Botanist (flew to Broome to join the main party).

Lew Markey Darcy Ewing George Biggs	}	Drivers of the four trucks—two Fords, a Dodge and a Chevrolet—none was a 4-wheel drive vehicle and because of war time exigencies, all were fitted with recapped tyres.
Bill Leschen Ben Scrivener Bill Mutton	}	Survey hands
Peter Pedersen		Cook

The party was joined later by G.A. Stewart, Soil Surveyor, C.S.I.R. Division of Soils and W.H. Maze—a geographer from the University of Sydney.

Because of tyre troubles and several broken springs the 2,514 km trip from Meekatharra via Broome, Fitzroy Crossing and Halls Creek the survey group took about four weeks to reach the Ord River camp site between Carlton Reach and Ivanhoe Crossing.

Some of the stores and equipment had been shipped to Broome, but shipping to Wyndham was suspended because of Japanese air raids and a lugger was engaged to transport the survey party's needs from Broome to Wyndham. It arrived several weeks after the main party. When necessary, stores were obtained from the Army which was in control of Wyndham and its surrounds. Fresh meat from Ivanhoe Station supplemented the tinned and dehydrated supplies.

The field work continued from May to the end of September with visits from Dr L.J.H. Teakle. Plant Nutrition Officer, Department of Agriculture; Dr T.J. Marshall C.S.I.R. Division of Soils; H.L. Paine, Assistant Surveyor General and G.K. Baron Hay, Under Secretary for Agriculture. The Public Works Department had a party under F. Butson in camp beside the Ord in the same locality as the Lands—Agriculture party and did basic levelling work. R.J. Dumas visited Butson's group and also the party under D. Bryden which was doing preliminary surveys of the possible dam site up river (now Lake Argyle). Professor S.M. Wadham and C.R. Lambert of the Rural Reconstruction Commission also visited the area.

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Abstract

During the "dry" season of 1944, soil investigations were made in an area of 750,000 acres (303,514 ha) between Wyndham and the Western Australian border.

Most of the area was subjected to general reconnaissance only, but detailed soil surveys were made of two of the main areas of alluvial flats which had been suggested for irrigation from the proposed Ord River dam.

The soil surveys were made by G.H. Burvill, Assistant Plant Nutrition Officer, Department of Agriculture, in consultation with Dr L.J.H. Teakle, Plant Nutrition Officer, and assisted by S.T. Smith, Department of Agriculture, and G.A. Stewart, Division of Soils, C.S.I.R. These officers collaborated with officers of the Lands and Surveys Department, and were accommodated in the survey camp of Surveyor A.H. Richter.

Detailed soil surveys were made on:

(a) Carlton Reach Plain (55,864 acres) (22,607 ha) east of the Ord and about 45 miles (72 km) from Wyndham; and

(b) the Mantinea Flats—Goose Hill area (29,992 acres) (12,137 ha) closer to Wyndham on the south of the Ord (see locality plan. Figure 1, and soil survey maps).

These two areas, totalling 85,856 acres (34,745 ha), are estimated to include 56,071 acres (22,691 ha) of potential irrigable land; 41,930 acres (16,968 ha) on Carlton Reach Plain and 14,141 acres (5,723 ha) in the Mantinea—Goose Hill area.

From aerial photographs, and from general reconnaissance, chiefly along tracks between Wyndham and the Western Australian border, a number of other areas of alluvial flats which might be investigated for irrigation have been generally defined. These areas total 124,500 acres (50,383 ha) (see locality plan Figure 1.).

The general reconnaissance data and aerial photographs have enabled a general description to be made of an area of about 750,000 acres (303,514 ha) between Wyndham and the Western Australian border. The large extent of rough stony hills and deep sandy soils greatly restricts potential agricultural areas, especially as it seems likely that any permanent system of agriculture without irrigation would be hazardous, if not impossible.

The hydrology and drainage of this large area has been discussed as an important part of the background in which any proposed irrigation areas must be considered. Twelve main drainage areas have been outlined (see plan Figure 2).

It is pointed out that several of the areas of alluvial flats which might be potential irrigation areas receive the drainage waters from extensive hilly areas. The torrential character of the monsoon rainfall causes a big run-off from these areas and in such cases, local flooding of the flats is common in the "wet" season.

The Carlton Reach Plain is rather unique among the alluvial flats, in that, due to the geological formations on its east side, it receives very little drainage from areas beyond the plain. Further, it is not subject to flooding by overflow from the Ord River. By contrast, the Mantinea Flats—Goose Hill area receives the run-off from a large area to the south, via about ten large watercourses which do not drain directly into the Ord, but spill their waters into a broad flood channel area at the back of the alluvial flats. In some seasons also, overflow from the Ord accentuates the flooding.

In the soil survey of Carlton Reach Plain, four main soil types were identified, and named Ord sandy loam, Meruin sandy loam, Cununurra clay and Cockatoo sand. The first two are brown alluvial soils (known locally as "red" soils) near the Ord. They are attractive soils for agriculture and irrigation, but only 1,848 acres (747 ha) and 1,176 acres (475 ha), respectively, of these types have been mapped.

The Cununurra clay is a dark, grey-brown clay soil, known locally as "black" soil, extending almost unbroken over 38,906 acres (15,718 ha). It is formed, apparently, on lacustrine sediments, and its surface is very flat, showing a fall of 40 feet (12.2 m) in 15 miles (24 km) from south to north.

The Cockatoo sand is a deep sandy soil between the Cununurra clay and the sandstone hills east of the plain and 4,900 acres (1,980 ha) have been mapped within the survey. It is not likely to be suitable for irrigation. A complex belt of soils, covering 3,472 acres (1,403 ha), occurs at the junction of the clay plain and the sandy soils, and is mapped as Junction soil complex. Lateritic gravel and boulders occur in places in this area, and in similar situations in other parts of the district. These occurrences are of considerable scientific interest, and their significance is discussed.

Some erosion by wind and water has occurred on the Ord, Meruin and Cununurra types. Affected areas are mapped.

The suitability of the main soil types for irrigation has been discussed on the basis of tests made. Soil salinity should not be a problem on Carlton Reach Plain. Small-scale water infiltration tests were made on Ord sandy loam, Cununurra clay, and Cockatoo sand. The Ord sandy loam, which has also been tested under irrigation at Carlton Reach Experiment Station, is a satisfactory soil for irrigation. Cununurra clay takes in water very slowly after the surface is wetted, and the surface cracks closed by swelling. As this soil constitutes 92.8% of the potential irrigable land on Carlton Reach Plain, the testing of this type under practical irrigation conditions is imperative. Cockatoo sand absorbs water so rapidly that only spray irrigation methods would be suitable for it.

The Mantinea Flats—Goose Hill area has several soils generally similar to the Carlton Reach Plain. The brown alluvials adjoining the Ord include the Ord sandy loam, but because of their variability are mapped as Group A soils. Winbidji loam is a brown alluvial of heavier texture, merging with Mantinea clay, a dark grey-brown ("black") clay soil generally similar to Cununurra clay. At the back of the flats the deep sandy soils on alluvial fans are named Chunuma sand. They have similar potentialities to Cockatoo sand. Rainyerri sandy loam is a shallow soil, unsuitable for irrigation on the gently sloping shale foothills.

Of 29,992 acres (12,117 ha) in the Mantinea—Goose Hill survey, only 14,141 acres (5,713 ha) are potentially irrigable. Of this, 5,606 acres (2,265 ha) are made up of Mantinea clay, and a complex of Mantinea clay and Winbidji loam.

The light textured brown alluvials of Group A comprise 4,750 acres (1,919 ha).

Group A soils are expected to behave like the Ord sandy loam under irrigation, while Mantinea clay would be similar to Cununurra clay.

In the western part of the survey, between the Bend of the Ord and Goose Hill, soil salinity becomes a factor in the Mantinea clay and Winbidji loam.

Subsoils are strongly saline, due, it is believed, to these soils being formed from deltaic or tidal marsh deposits. Sea level is apparently lower now than when the alluvial deposits of Carlton Reach Plain and the Mantinea—Goose Hill area were laid down.

The Mantinea—Goose Hill area ranges between 30 and 70 feet (9 to 21 m) above low tide levels at Wyndham, where the tidal range is 23 feet (7 m). Because of soil salinity, and seasonal flooding due to the drainage from the south, the drainage of this area would require careful investigation in any irrigation proposals.

No laboratory analyses are yet available (1945, see note below) by which to judge the general fertility level of the potential irrigable soils. As they are alluvial soils of mixed parentage (due to a variety of rocks in the Ord watershed), it is expected that they will be generally fertile. Good results have been achieved at Carlton Reach without additions of artificial fertilizer.

The flats between the Nine-Mile, Parry's Creek, and Goose Hill have been examined for soil salinity. Subsoils are generally saline and this factor, coupled with the low elevations and seasonal flooding from Parry's Creek and the Ord River estuary, make these flats unsuitable for consideration at present in an irrigation scheme.

Aerial photographs, both verticals and obliques, produced by the trimetrogon system, proved of immense value in the soil and physiographic studies. No work of this character should be attempted without them.

Note: The metric equivalents of the original Imperial measurements are given in this abstract. Henceforth, only the original Imperial data are presented. The analytical data for the type soil samples were not available when this report was written in 1945. They became available in 1946 and are now included in Appendix 5. Analyses of pebble samples from the Kimberley Research Station collected by the author in 1950 are also recorded in Appendix 5.

Introduction

The Kimberley Division of Western Australia covers an area of about 80 million acres, and lies between 14° and 19.5° south latitude. It has been occupied for pastoral purposes since the 1880s and is mostly devoted to the extensive grazing of cattle and sheep, but under these conditions there is only a small white population. Statistics for 1939* show that the population of whites, Asiatics and half castes in the four Road Board districts of Broome, West Kimberley (Derby), Wyndham and Hall's Creek, totalled 2,006, of whom probably 1,200 to 1,300 were whites. Broome, with 973 persons in the total of 2,006, included those associated with the pearling industry.

At various times the possibilities for more intensive settlement and development, either for agriculture or pastoral pursuits, have been under consideration. In 1923/24, there was considerable interest in the possibilities of growing cotton, peanuts and other tropical crops in areas around Derby and Wyndham. Both Surveyor W.R. Easton and F.J.S. Wise, now Adviser in Tropical Agriculture, reported on the soils and possibilities of several areas up to 50 miles from Wyndham in various directions, as proposals had been made for a group settlement in the Wyndham district**. These schemes did not materialize, and over the next 10 to 15 years various proposals were made at different times by individuals and committees concerning the steps which might be taken to improve the conditions for the pastoral industry or enhance the development of the north.

From 1937 onwards more definite proposals for pasture research were considered and experimental areas proposed. Irrigated pastures to fatten cattle were mentioned, and the main emphasis appears to have been on improvement which would allow cattle to reach the Wyndham meat works in better condition.

The East Kimberley region has been frequently discussed in recent years with respect to Jewish settlement proposals. It was inspected in 1939 by Dr I. Steinberg, Secretary of the Freeland League for Jewish Territorial Colonization, who was seeking an area for Jewish refugees. Steinberg was accompanied by G.F. Melville, of the Institute of Agriculture, University of Western Australia and a joint report was prepared, entitled "Possibilities of settlement in Kimberley region, Western Australia" (1943). Subsequently, Steinberg made proposals to the Federal Government for a Jewish settlement, but in November 1944, it was reported that the Prime Minister (J. Curtin) had advised Steinberg that no departure from Australia's policy with respect to alien settlement could be agreed to.

The difficulties of the pastoral industry were reported on in 1940 by a Royal Commissioner, W.V. Fyfe (Surveyor General), who recommended the classification of the country along the Ord River for 100 miles from Wyndham, to ascertain the extent of land suitable for irrigation and pastoral development.

Early in 1941, K.M. Durack, son of M.P. Durack, one of the Kimberley pioneers, produced a brochure entitled "Developing the north, proposed research station for the Kimberleys". This contains, beside the proposals for experimentation, a useful discussion of the physical resources and environment of an area between the Ord River in Western Australia and the Victoria River in the Northern Territory. A useful map shows the distribution of various land types.

Later in 1941, R.J. Dumas, Director of Works, Public Works Department, investigated the possibilities of damming the Ord River about 70-80 miles—from its mouth where it runs through the rocky Carr Boyd Range, in what is known as "the gorge". The general nature of the country had suggested that there were suitable areas of land for irrigation downstream from the gorge.

In 1941 an experiment station was established near Carlton Reach on the Ord River about 60 miles, by road from Wyndham, and experiments with pastures under irrigation were commenced in 1942. Officers of the Public Works Department have continued the investigation of dam sites and have commenced contour surveys of the proposed irrigation areas.

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* Supplied by the Acting Government Statistician, R.J. Little

** The areas considered were:

1. South of the Ord River, about 25 miles, from Wyndham between Goose Hill and the Bend of the Ord. (This area is included in one of the 1944 surveys here reported.)
2. On the King River Water Reserve (Reserve 1127) south of Wyndham.
3. An area on the Durack River on Hay and Overheu's pastoral lease.
4. The Elephant Hill, Knob Peak, Wagon Creek area north-east of Wyndham near the False Mouth of the Ord.

Soil investigations 1944

General remarks

In 1944, surveyors of the Lands and Surveys Department, together with soil surveyors from the Department of Agriculture, spent several months (May 21—September 28), investigating the country between Wyndham and the Western Australian border, as well as the soil erosion on portions of the Ord River catchment, further south, especially on Argyle, Ord River and Turner stations.

This report is primarily concerned with the soil surveys of two areas in the lower Ord valley which, from general considerations, seemed likely to include large areas of land suitable for irrigation. These two areas total about 86,000 acres—and will be subsequently referred to as:

1. The Carlton Reach Plain; and
2. The Mantinea Flats—Goose Hill area.

In considering the possible agricultural development of this area, even with irrigation, other features of the physical environment besides the soils of the flats must be taken into account.

Therefore, to place the two surveyed areas in proper perspective a general description of a much more extensive area of about 750,000 acres—between Wyndham and the Western Australian border will be presented under the headings of climate, vegetation, physiography and geology, hydrology, laterite, and soils.

Objects of soil surveys

The objects of the soil surveys were:

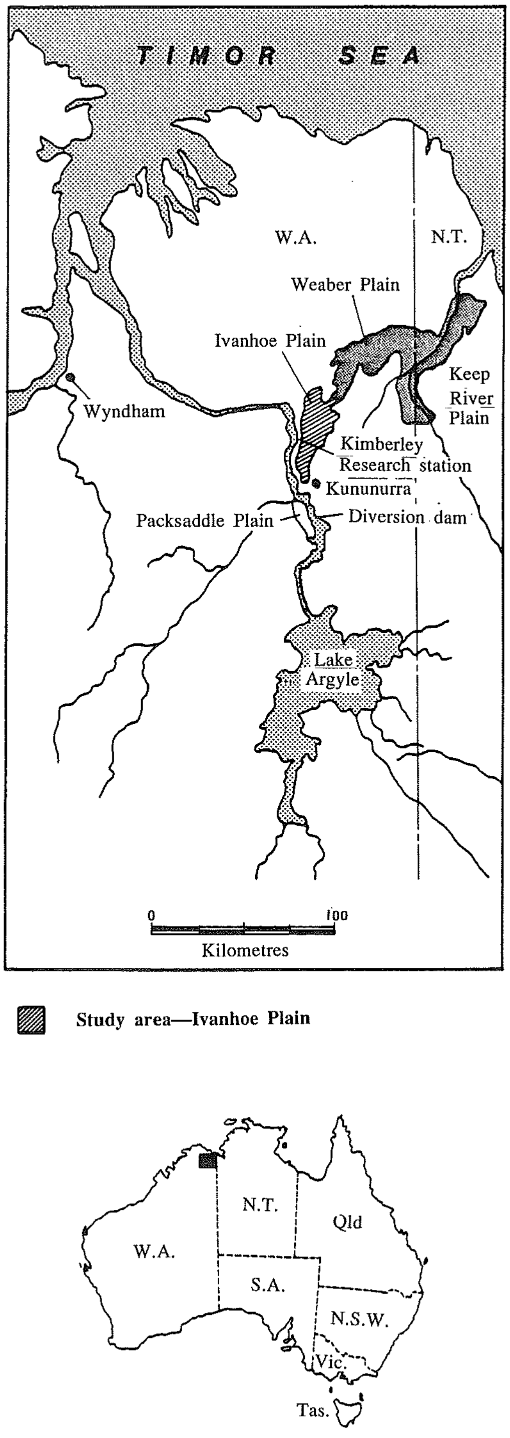
- To define and map the soil types.
- To assess the areas of potential irrigable land.
- To produce maps which would, if necessary, provide a basis for subdivision of the areas into farms.

Location of surveyed areas

Both the areas surveyed in some detail are on Ivanhoe station, the grazing leases of the Ivanhoe Grazing Co. Ltd. The Carlton Reach Plain lies on the east side of the Ord River, about 45 miles east of Wyndham (latitude 15° 30″S and longitude 128°E). It extends northwards from Carlton Reach for a distance of about 18 miles and from the river to the sandstone hills on its east side, a distance of 2-8 miles.

The Mantinea Flats—Goose Hill Area, lies south of the Ord River between Mantinea Creek and Goose Hill, which are respectively 32 and 18 miles from Wyndham.

The attached locality plans, Map 1 and Figure 1, shows the location of the two areas, together with other features of general interest.



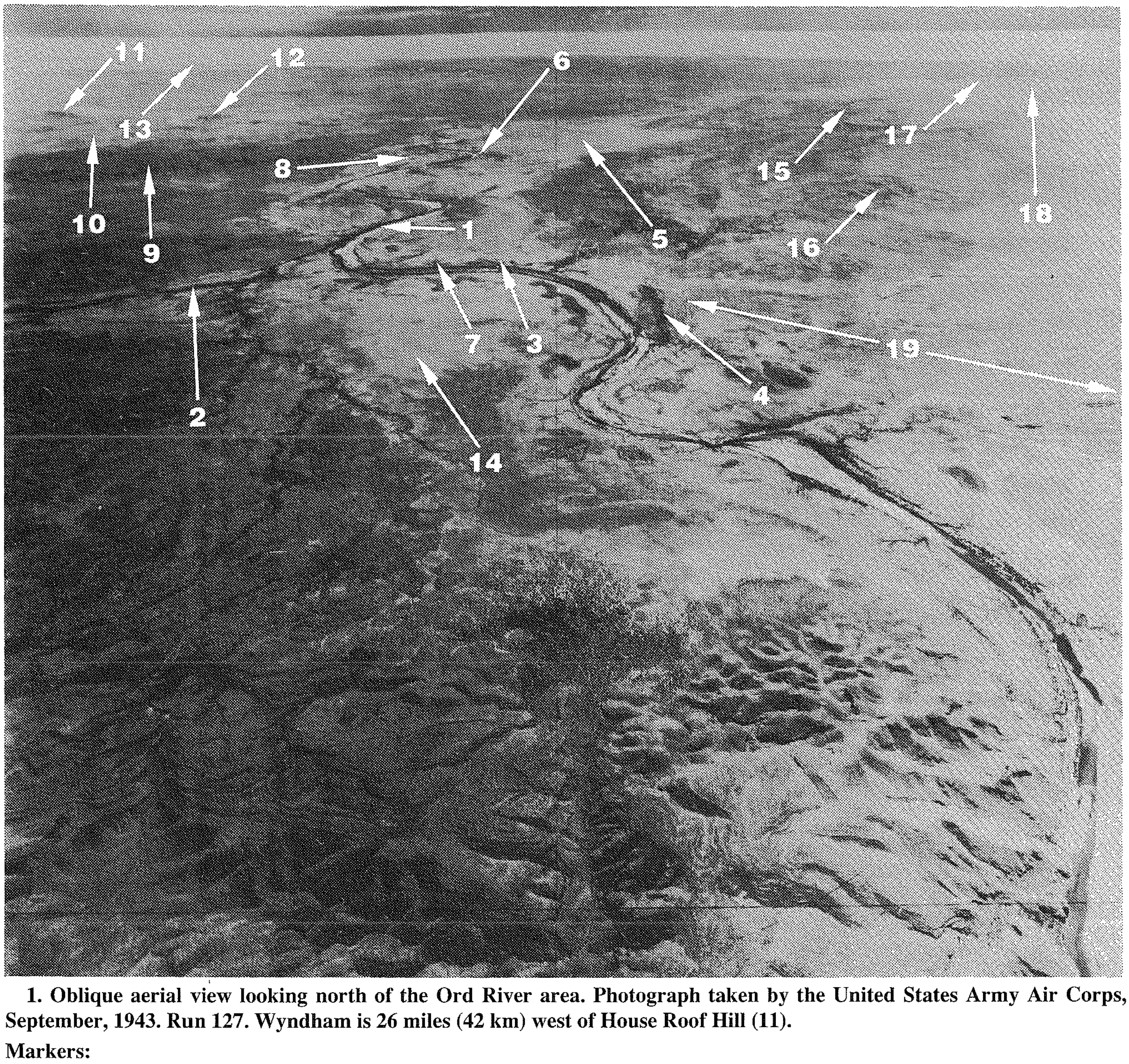
Location of the Ivanhoe Plain in the Ord River Irrigation Area, Western Australia.

Map 1. The location of the Ord River present and proposed irrigation areas in the Kimberley Province of Western Australia. The ultimate area of clay soil plains available for irrigation is about 76,000 ha. About one-third of this area is in the Northern Territory. The main dam was opened in 1972 which resulted in the formation of Lake Argyle. The Diversion Dam was built in 1963.

Use of aerial photographs

A set of aerial photographs covering the area between Wyndham and the Western Australian border was made available for these investigations through the Director of Works, R.J. Dumas. The photographs were taken in September 1943 by units of the United States forces and included vertical and oblique pictures produced by the trimetrogon system.

The aerial photographs proved of immense value and were constantly used during the soil survey. Further, by inspection of photographs covering a much wider area than was covered by soil survey or ground reconnaissance, it has been possible to gain a much wider knowledge of the physiography and hydrology of the country. These additional data are embodied in the ensuing descriptions under appropriate headings.



1. Oblique aerial view looking north of the Ord River area. Photograph taken by the United States Army Air Corps, September, 1943. Run 127. Wyndham is 26 miles (42 km) west of House Roof Hill (11).

Markers:

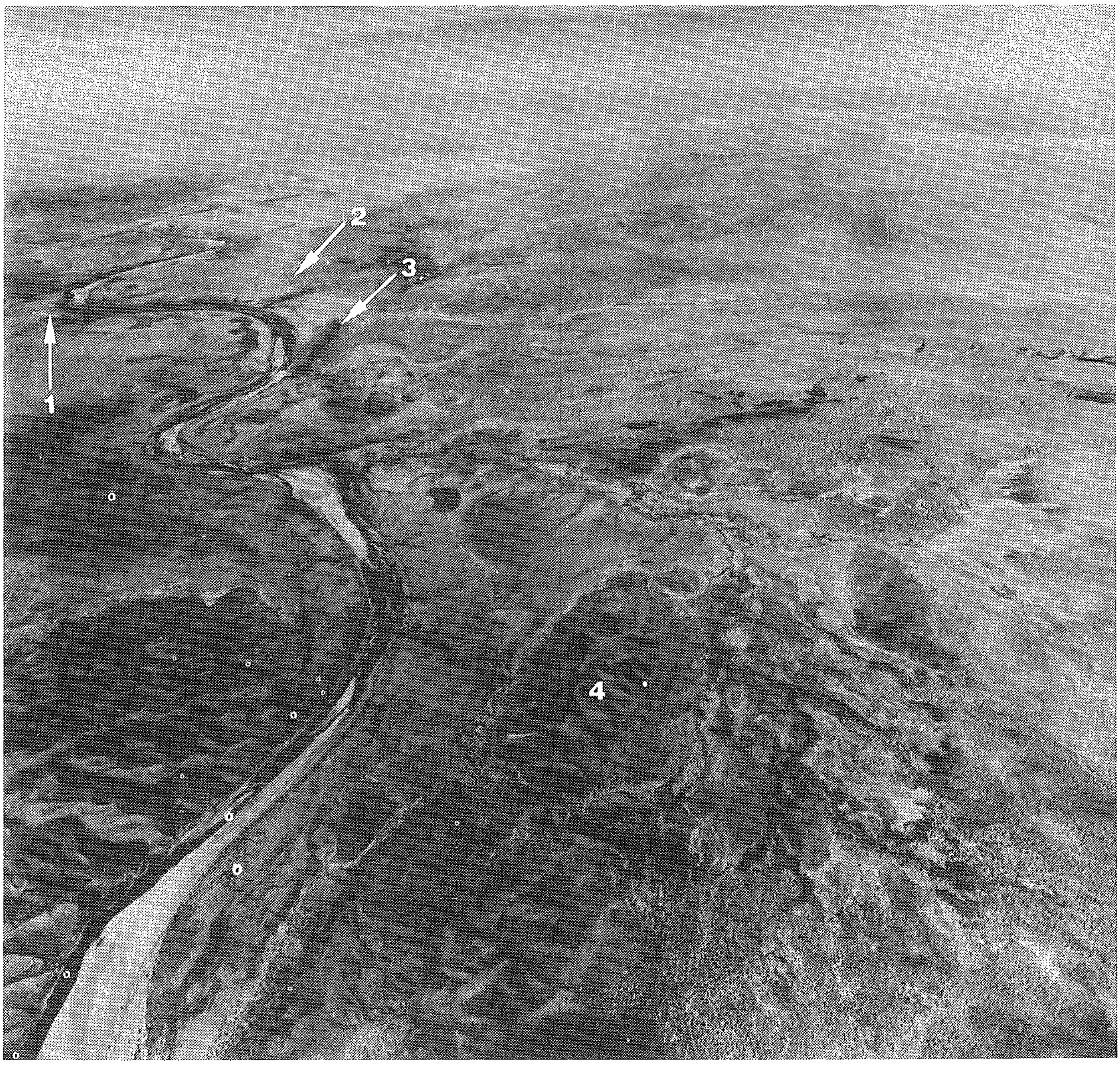
1. **Ord River**
2. **Denham River**
3. **Carlton Reach, Ord River**
4. **Carlton Reach Hills**
5. **Carlton Reach Plain (Ivanhoe Plain). About 40,000 acres (16,187 ha) proposed for irrigation**
6. **Kimberley Research Station (Frank Wise Institute for Tropical Agricultural Research)**
7. **Former Research Station at Carlton Reach (K. M. Durack)**
8. **Ivanhoe Station homestead**
9. **Deception Range**
10. **Mantinea Flats. About 14,000 acres (5,665 ha proposed for irrigation**
11. **House Roof-Hill**
12. **False House Roof-Hill**
13. **Mouth of Cambridge Gulf**
14. **Alluvial flats**
15. **Pincombe Range**
16. **Mt Cecil**
17. **Western Australia-Northern Territory border**
18. **Keep River**
19. **Sandstone hills and Cockatoo sands**

General description of country between Wyndham and Western Australian border

Climate

It is not intended to present any detailed discussion of the climate in this report, but several aspects must be considered in view of their relationships to the soils and their suitability for irrigation. The climate of tropical Australia has been discussed by Professor J.A. Prescott (1938). Also the Government Botanist, C.A. Gardner, has recently made a thorough investigation of the climatic records of the Kimberley areas.

The country east of Wyndham is a tropical area with a monsoonal rainfall, aggregating about 30 inches per annum, which is mostly received in the four month period December to March. Even so, the commencement and duration of the "wet" season is rather



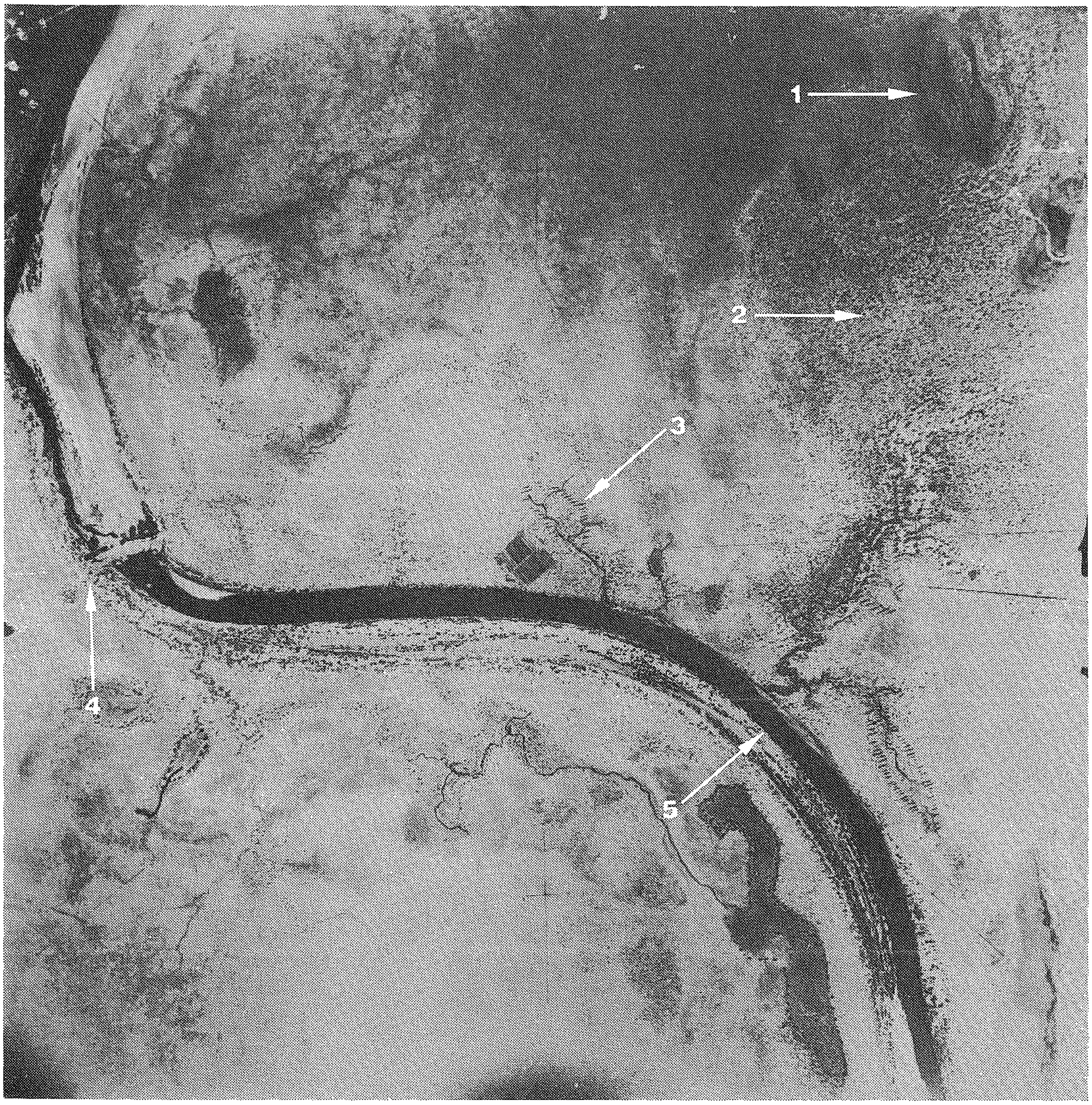
2. Oblique aerial view looking north of the Ord River area. Photograph taken by the United States Army Air Corps, September, 1943. Taken at 15,000 feet (4,572 m) with a 6 inch (152.4 mm) lens. Run 127. East side of the Ord River.

Markers:

1. Bandicoot Bar
2. Carlton Reach, Ord River
3. Razor Back Range
4. North end of the Carr Boyd Range

variable. The winter is, on the whole, extremely dry. High temperatures prevail throughout the greater part of the year. On account of the shortness of the useful rainfall season and the high temperatures it is unlikely that any permanent system of agriculture, based on the natural rainfall, would be possible.

The character of the individual rain storms will have an important bearing on the amount of run-off and therefore on the stream flow, floods and general hydrology of the whole area. It may be, too, an important factor, if irrigation is being practised during the wet season, for the effects of a heavy fall of rain, say 3-6 inches on a recently irrigated area,



3. Near vertical aerial view of the Ord River area above Carlton Reach. Photograph taken by the United States Army Air Corps, September, 1943.

Markers:

1. **Kelly's Knob**
2. **Site of present day Kununurra**
3. **Plots of experiments established by K. M. Durack, 1941-1945**
4. **Bandicoot Bar—site of the Diversion Dam built in 1963**
5. **Carlton Reach—now Lake Kununurra**

may be disastrous. This difficulty could be greatly minimized by an accurate weather forecasting service.

These aspects will be discussed in greater detail in dealing with the hydrology of the two surveyed areas.

Vegetation

The Government Botanist (Gardner 1941-42) has recently reported on the ecology of this area. It is part of Gardner's Northern Province, which is noted for the Indo-Melanesian elements of its flora. To persons accustomed to the vegetation of the south-western parts of the State, the mixture of eucalypts with deciduous trees such as *Gyrocarpus americanus*, and the quaint baobab (*Adansonia gregorii*), is at first strange. The deciduous habit is not confined to these trees. In August the *Bauhinia* (often called bohemia or butterfly tree) and rosewood (*Terminalia volucris*) of the Carlton Reach Plain were almost leafless. The former, after flowering, clothed itself with new foliage in September; the rosewood, still almost leafless, was just flowering in late September. The bloodwood (*Eucalyptus dichromophloia*) and cabbage gum (*E. clavigera*) of the savannah woodland adjoining the Ord River, also shed a large proportion of their leaves in September. The coolibah (*E. microtheca*) is reported to do the same, usually in October. The kurrajongs (*Sterculia* and *Brachychiton*) and the "cotton" tree (*Cochlospermum sp.*) are also deciduous.

The Cape lilac or white cedar (*Melia dubia*) found in places along the edge of the Ord, remains evergreen. In more temperate latitudes, as around Perth, it is deciduous in winter.

The relationship between soils and vegetation may be best discussed under the following headings:

* The savannah woodlands adjoining the Ord River.
* The savannahs of the clay plains, such as Carlton Reach Plain.
* The monsoon woodland of the sandy soils adjoining the sandstone hills.
* The vegetation of the stony hills.
* The vegetation of gullies, billabongs, watercourses and areas subject to seasonal flooding.

The savannah woodlands adjoining the Ord River

On alluvial soils of light and medium texture along the Ord, trees and grasses, mostly tussocky, form a savannah woodland. The trees, mostly 10 to 30 feet high, include bloodwood, cabbage gum, box (*E. spenceriana*), silver-leaved box (*E. pruinosa*) and carbeen (*E. spenceriana*). The latter is very common on the Mantinea Flats—Goose Hill area. Besides the eucalypts, other common trees are *Gyrocarpus americanus*, baobab, native apple (*Owenia reticulata*), mangaloo (*Careya australis*), kurrajong (*Brachychiton diversifolium*), sandpaper fig (*Ficus orbicularis*) and beefwood (*Hakea arborescens*).

Common grasses are kangaroo grass (*Themeda australis*), *Heteropogon contortus*, blue grass (*Dicanthium* spp.), and white grass (*Sehima pervosum*). These are perennials of tussocky habit. Low growing perennial grasses are water couch (locally called couch, *Brachyachne convergens*), *Sporobolus australasicus* and *Enneapogon planifolius*. The tall annual (?) *Panicum cymbiforme* was common on the river levee in 1944, but apparently varies in extent from season to season. The yellow flowered *Crotalaria Novae-Hollandiae* was also common in 1944. Though most of the grass species are, botanically, perennials, many appear quite dry during the winter and may be mistaken for annuals. A grass like water couch, when dry, easily shatters, and mostly blows away in August and September.

The savannahs of the clay plains

The clay plains, the so called "black soils" of the district, have tussocky and tall grasses as the main elements of their vegetation.

Trees are entirely absent on some of the plains of the Mantinea Flats—Goose Hill area, whereas on the Carlton Reach Plain and the plains east of Point Spring and the Pincombe Range, *Bauhinia cunninghamii* ("Bohemia") and rosewood from 3 to 20 feet high, generally occur. In many parts the *Bauhinia* is much smaller.

The grasses vary from place to place and it appears that the grazing of cattle has altered the proportions of them especially on areas nearer the river. Mitchell grass (*Astrebla,* three species), Flinders grass (*Iseilema fragile*), white grass, and *Aristida latifolia* are common on the Carlton Reach Plain; where also, in large patches, is found sugar grass (*Sorghum plumosum*) growing 8 to 14 feet high in a single season. Areas receiving somewhat more water often carry cane grass (*Coelorhachis rottboellioides*) and a pale green tussocky grass (? *Chloris* sp.).

Other plants of minor importance, but often noted on the Carlton Reach Plain, are the small grey leaved shrubs, *Flemingia pauciflora* and a trailing clover-like plant (*Rhyncosia minima*). These are both legumes. *Acacia bidwilli* (2-10 feet), the shrub konkerberry (*Carissa lanceolata*) and the low-growing *Neptunia* sp. are all prickly. Pea bush (*Sesbania aegyptica*) is practically the only vegetation on some eroded areas in and around Four Mile Creek. Whitewood (*Atalaya hemiglauca*) is common, but mostly less than four feet high.

On the clay plains of the Mantinea Flats—Goose Hill area, where the vegetation is almost exclusively grass, the principal ones are Mitchell grass (three species), blue grass, Flinders grass, *Aristida pruinosa* and *Chrysopogon fallax* ("golden beard grass").

The monsoon woodland of the sandy soils adjoining the sandstone hills

In these areas sugar grass and spear grass (both are varieties of *Sorghum plumosum*) and spinifex (*Triodia* and *Plectrachne*) are the only common grasses. They are of low grazing value. Trees are mostly 15-30 feet high and include the attractive orange-flowered woollybutt (*Eucalyptus miniata*), messmate (*E. tetrodonta*), box, long-fruited bloodwood (*E. terminalis*) and carbeen. Less common generally, but very common in places, are *E. setosa* (pale yellow-green leaves) and poplar gum (*E. platyphylla*). Other trees of these woodlands are baobab, *Gryocarpus, Owenia vernicosa, Terminalia circumalata*, ironwood (*Erythrophloeum chlorostachya*), cajuputs (varieties of *Melaleuca leucadendron*), *Gardenia pyriformis*, wattle (*Acacia tumida*) and the large furry-leaved, deciduous kurrajong (*Brachychiton tuberculatum*). *Grevillea agrifolia* is a common shrub growing to a height of about 10 feet. Pandanus palms or screw palms (*Pandanus odoratissimus*) are also common where there are indications of underground moisture seepage. Minor but common plants are the quinine tree (*Petalostigma sericea*) with its orange-coloured, bitter and astringent fruits, bird flower (*Crotalaria cunninghamii*), the small fern *Gleichenia microphylla* and the crimson-flowered statice (*Polycarpa longiflora*).

In the event of agricultural development, these monsoon woodlands would be the main sources of fuel and rough building timber. They might also be suitable areas for small townsites.

The stony hills

Stunted gums, *Terminalia* spp. "cotton" tree and spinifex are the main elements of the vegetation on the stony hills. *Calythrix microphylla*, or Star-of-Bethlehem, is an attractive shrub when in flower.

On the shallow stony soils developed from shale between Button's Gap and Mantinea Creek, a small paperbark (*Melaleuca minutifolia*) is common, along with *Terminalia platyptera*, beefwood (*Hakea arborescens*), coarse grass (*Sorghum plumosum*) and in places silver-leaved box.

On vertical faces of sandstone hills the interesting fig, *Ficus arborescens*), is found. Its roots penetrate and probably disrupt the sandstone strata.

Gullies, billabongs, watercourses, swamps and other areas subject to regular seasonal flooding

Under all these conditions coolibah, ranging from stunted forms up to 40 feet-high, is common. It is not common, however, adjacent to the Ord, where river gum (*E. camaldulensis*), from saplings to large trees, is found.

Gutta percha (*Excaecaria parviflora*), a small tree up to 25 feet, is also common, but is confined to heavy clay soils, mostly in what are locally called "swamps". These areas are flooded for varying periods during and after the wet season. Chestnut trees (*Terminalia platyphylla*) are common near watercourses. On the Ord banks, beside river gums, are the tall shady Leichardt tree (*Sarcoceplialus coadunatus*), with its soft wood of saffron colour, also cajuput and *Barringtonia acutangula*, sometimes called fresh-water mangrove. (This should not be confused with *Tristania suaveolens*, which also grows along stream courses and is sometimes wrongly called fresh-water mangrove.) Cape lilac or white cedar, and corkwood (*Sesbania grandiflora*) also occur, but are not common.

Minor, but interesting plants of the watercourses are the small loofah (*Luffa graveolens*) and *Passiflora foetida*, a relative of the cultivated passion fruit. Its small yellow fruits are edible. *Cymbidium canaliculatum* orchids are often seen on broken branches or forks of river gums.

In most of the clay swamps which are flooded for long periods, grasses are practically absent. In other parts various grasses, as on the clay plains, occur. Where the sandy outwash soils from the hills join the clay plains, depressions subject to wet season flooding usually carry a dense growth of the grass woolly top (*Eriachne* sp.).

Grewea polygala is a shrub well-known locally, where an infusion of its leaves is a standard remedy for dysentery. It is widespread on a variety of soils.

Physiography and geology

The Ord River and its tributaries drain an area approaching 20,000 square miles, extending from near Hall's Creek, about 200 miles south of Wyndham, north to Cambridge Gulf. The system dissects an area with a variety of rock types, many of them very ancient (Blatchford 1933). The Proterozoic age is strongly represented by sandstones and shales of the Nullagine series, while the highly metamorphosed quartzites and phyllites of the Mosquito Creek series are still older. Basalts of Cambrian age are extensive on the Antrim Plateau north-east of Hall's Creek, and in the middle reaches of the river around Argyle and Rosewood stations. Cambrian limestones and mudstones occur in the upper Ord valley, especially on Ord River and Turner stations. In the rugged country west of the Ord, granites are also extensive.

In consequence of the wide variety of rocks on the catchment area, the alluvial deposits in the lower reaches of the Ord have a very mixed parentage, but for this reason, like many other alluvial soils, they are likely to be relatively fertile.

About 60 miles from its mouth, the Ord leaves the grassy plains of Argyle station and flows for about 10 miles through "the gorge", a steep-sided valley cut through the Mosquito Creek quartzites and phyllites of the Carr Boyd Range. It is in this section that the Public Works Department has investigated proposed dam sites.

After leaving the gorge country, the Ord winds northward about 25 miles, past Carlton Reach and Ivanhoe station homestead, in a broad flat valley up to eight miles-wide, flanked by rocky hills. The Carlton Reach Plain lies on the east of the river in this vicinity.

Some miles north of Ivanhoe, the river, coming close to the hills, turns west round the north-east end of the Deception Range and again follows a winding course to its tidal estuary about 25 miles away in the east arm of Cambridge Gulf. For about seven miles there are practically no alluvial flats, but west of Mantinea Creek and False House Roof Hill (native name —Chicamidi), plains of varying width again occur.

On the south, the Mantinea Flats and other grass plains and flat alluvial areas extend for 14 miles from Mantinea Creek to Goose Hill and are up to five miles wide. Goose Hill, although only a few hundred feet high, is a prominent landmark. It is three miles from the present river course, but old river meanders, still flooded by very high tides and by the river in flood, lie at the foot of the hill. These meanders and the low stony hills running away south from Goose Hill form a natural division between the flats on the east and west.

West and north-west of Goose Hill are further extensive flats merging into tidal marshes around the Ord River estuary. The waters of Parry's Creek, draining from 25 miles south, spill on to these low flats. The hills round Mount Erskine, the Bastion Range and Wedge Hills separate these flats from the west arm of Cambridge Gulf on which Wyndham is situated.

North of the Ord in its westerly course there are no alluvial flats east of False House Roof Hill. Instead, sandstone hills and ranges with associated sandy soils make up most of the area. House Roof Hill (native name—Bulcamidi) and False House Roof Hill, named for their very similar profiles from certain aspects, are about 1,000 feet high and stand as residuals of erosion. House Roof Hill is surrounded by alluvial flats which end northwards at the sandstone hills near Carlton station homestead. They extend west and north-west, apparently to merge with the tidal marshes of the river estuary.

Between False House Roof and House Roof Hills, the Ord takes a large northward loop, bringing it close to the foot of House Roof. The next large bend south of House Roof Hill is known as "the Bend of the Ord". The river channels here are about three-quarters of a mile wide and up to 40 feet deep, yet in some seasons the Ord overflows its banks and floods large areas on the flats. The river is tidal as far as "the Bend of the Ord" and it probably requires the combination of a peak flow of the river and an incoming spring tide to cause an overflow. According to Kim Durack this occurs on the average about once in eight years. The last occasion was in 1942.

The maturity of the Ord River channel in the area under discussion, is shown by reference to levels taken by the Public Works Department and supplied by F. Butson. The river bed at Ivanhoe Crossing, over 50 miles from the mouth, is only 50 feet above high tide levels at Wyndham. The flats near Party's Creek and 12 mile lagoon are less than five feet, and the Goose Hill flats less than ten feet above high-tide levels. Aerial photographs show that the river has meandered extensively north of Goose Hill; in fact, all the flats to the west are probably deltaic and old tidal marsh formations. From the salinity of the subsoil (discussed later in more detail), it also seems probable that the areas now occupied by plains and old meanders between the Bend of the Ord and Goose Hill were once tidal marshes.

Most of the rocky hills bordering the Ord valley on the west, below the gorge, are composed of sandstones or shales of the Nullagine series. These have been folded and tilted and so the strata dip in various directions. Between the Gorge and Ivanhoe homestead in most hills the dip appears to be east or south-east, e.g. the Bandicoot Range between Valentine Creek and the Denham River, also east of Carlton Reach. In the Deception Range, west of Ivanhoe homestead, and in the westerly course of the river, the dip of the rocks seems to be north or north-westerly. Shales are much more common in this section and may underlie a large part of the Mantinea Flats-Goose Hill area.

Shale occurs in the river bed near Mantinea Creek, and at House Roof Hill Crossing, and seems to make up a large part of the lower portions of House Roof Hill and probably also of False House Roof Hill.

The sandstones occurring east of the Carlton Reach Plain show "current" or "false" bedding, and the colour in many cases is red-brown. The Government Geologist, F.G. Forman, considers that in this vicinity the sandstones may be much younger than the Nullagine series, and are possibly of Permian age. In some portions of the hills on the east side of this plain, limestones and calcareous

sandstones were also found. Conglomerate occurs beneath sandstone in a deep creek south of Carlton Reach hills.

The occurrence of basalt and other associated lavas is of considerable interest. Low basaltic hills are found between Wyndham and Parry's Creek, especially near the 'Nine Mile' and the '12 Mile' lagoon. At Ivanhoe crossing and a few miles upstream (near the 1944 survey camp) massive basalt occurs. On the river bank at the upstream end of Carlton Reach, basalt and lava with numerous amygdules of quartz crystals, outcrop along the western base of Carlton Reach Hills. A few miles north on the west slope of Kelly's Knob, similar basalt or lava is found. A low hill of basaltic lava lies about the centre of the Carlton Reach Plain. The rocky hill near Ivanhoe homestead is an agglomerate associated with the contact of the sandstone and basalt flow. A very small hill about half a mile south-west of Kelly's Knob seems to be a similar agglomerate. The rocky bar holding back the waters of Carlton Reach appears to be quartzite or case-hardened sandstone.

Fossiliferous limestone occurs in the river bed east of Button's Gap where the Martin's Gap base line reaches the river. Limestone was also seen on the Legune track between Carlton and Point Spring and on the east side of the northern part of the Pincombe Range. Cave Spring Range and the Weaber Range are sandstone and form steep cliffs a few hundred feet high. The cliffs face north-west in the Cave Spring Range where the rocks dip south-east. The Weaber Range cliffs face south.

The plains and flats are largely alluvial deposits. A study of the nature and distribution of the deposits (apart from a consideration of them as soils) leads to some interesting possibilities in the geological history of the area.

The Carlton Reach Plain has a very uniform clay surface for many miles. The plain widens in the north and reaches its maximum width between Button's Gap and Martin's Gap, where it is about seven miles wide. It ends in Martin's Swamp and the Green Swamp, two large areas subjected to seasonal flooding. However, the clay soil of the Carlton Reach Plain continues up the narrow valley at the foot of the Cave Spring Range and widens out into similar clay plains south of Point Spring. These continue in an easterly direction between the Weaber Range and the north end of the Pincombe Range to the Western Australian border. Similar clay plains also extend southward for about 15 miles on the west side of the Keep River.

The great uniformity of the upper 4 or 5 feet of the profile over such a large area suggests that the soils are formed from deposits in a very deeply indented, narrow bay which opened on to the northern coastline. Levels taken by the Public Works Department have indicated a gentle fall in a northerly direction on the Carlton Reach Plain, but whether there is a further fall via the Cave Spring valley to the Western Australian border is not yet determined.

Between Carlton Reach and the 16 mile peg on the Carlton Reach base line, the total fall is about 40 feet. At right-angles to the base line the plain is almost level.

The Carlton Reach Plain is at slightly higher elevation than the present natural levee of the Ord River and there is no evidence that it is now subject to flooding by the Ord. It seems probable that it never has been an ordinary river flood plain, but is a lacustrine deposit.

As previously mentioned, there are no extensive plains joining the Ord River after it turns west until the Mantinea Flats are reached. Both north and south of the river between this westerly bend and False House Roof Hill, there are stony hills and associated tracts of sandy soil. The clay plains between Mantinea Creek and Goose Hill are at lower levels than the river levee and are more typical river flood plains, though some of the more westerly may have been tidal marshes.

It seems possible that there has been a fall in sea level in this vicinity, so that an area such as the Carlton Reach Plain is now no longer subject to seasonal or continuous submergence. It is suggested that a stream reaching the sea near the present Ord mouth

may, by headward erosion, have cut back through the hills between False House Roof and the Carlton Reach Plain and connected up via the present Carlton Reach Plain area with a stream flowing out from the present gorge area. This stream, capturing the waters from a very large area extending southward, has become the present Ord River.

In the deepening of the Ord channel to reach its present mature condition, there has been normal erosion of portions of the lacustrine deposits of the present Carlton Reach Plain, so that a number of small gully systems now drain the western edges of that plain. The eastern and northern parts drain northward into Martin's Swamp and the Green Swamp. There is some drainage of the eastern side via a creek which crosses the plain to reach the river opposite Ivanhoe homestead near the site proposed for the new research station. It will be noted from the plans that this is the only well-defined watercourse which crosses the Carlton Reach Plain. These drainage phenomena will be discussed more fully in dealing with the hydrology of the area.

Hydrology

In a region such as that under discussion, any account of the soils and potentialities for agriculture would be incomplete without reference to the hydrology, i.e. the general drainage system and what happens to the rainfall after it reaches the ground.

The area between Wyndham and the Western Australian border has an annual rainfall of about 30 inches. Most of this comes from monsoonal storms in a four-months season from December to March. The heavy rainfall in short periods causes a high proportion of run-off especially on rocky hills. In fact, the rocky character of the hills has resulted from thousands of years of such intense rainfall. The weathered rock material, instead of remaining partly *in situ* to form soil, has been carried away to form alluvial deposits at lower levels or has been finally carried out to sea. The rocky hills and alluvial flats so characteristic of this region are, then, closely related to past and present hydrologic conditions. The soils of the alluvial areas are the only ones likely to be suitable for agriculture, but in some cases they are still subject to seasonal flooding, and this aspect must be assessed in deciding the suitability of any area for closer settlement.

From the general reconnaissance, from a study of the aerial photographs, and from watercourses already mapped on Lands Department lithograph 142/390, it has been possible to delineate 12 main drainage areas which are shown on the map of Figure 2. Within each area arrows show the general direction of drainages or of defined watercourses.

Examination of the map of Figure 2 reveals that although the Ord River runs through the area, only the drainage areas 4, 5, 6, 7, 9 (partly) and 12 drain directly into the Ord. Areas 1, 2 and 3 drain entirely or largely to the flats and marshes around the Ord estuary; 8 and 11 drain east and north-east respectively into the Keep River system; while 10 is believed to drain into Cave Spring valley with no outlet normally to river or ocean. Green Swamp and Martin's Swamp, included in area 9, are two other important areas of inland drainage.

Some details with respect to each of the drainage areas shown in Figure 2 are:

Area 1

This is drained by Parry's Creek, which flows out on to the extensive flats between Goose Hill and the Bastion Range. These flats are only a few feet above high tide levels and are apparently flooded each wet season. The soils have been examined at a number of places from the Nine mile to Goose Hill and are generally saline. Further details are given in a later section.

Area 2

This includes practically the whole of the detailed soil survey of the Mantinea Flats—Goose Hill area. All the area south of the survey is composed of rocky hills from which numerous watercourses must carry a considerable run-off. Drainage within the area of the soil survey is away from the Ord and via a broad flood channel into Salt Water

Creek and Goose Hill Creek, which deliver their waters into old river meanders and thence to the Ord estuary. The large volume of water draining from the south must be considered in any projected irrigation project for the Mantinea—Goose Hill flats. There is ample evidence of extensive seasonal flooding which is sometimes accentuated by overflow from the Ord, especially at the Bend of the Ord.

Area 3

The alluvial areas around House Roof Hill and between False House Roof Hill and Carlton homestead, also drain away from the Ord. The hilly areas north and east of Carlton and north-east of False House Roof drain on to the alluvial flats between Carlton and House Roof and thence westward to the flats and marshes of the Ord estuary. C. Pretlove, manager at Carlton, states that extensive flooding is common in the wet season.

Areas 4, 5 and 6

These are all hilly areas with practically no alluvial flats and all their creeks drain into the Ord. Mantinea Creek, shown in area 5, also connects to the flood channel of area 2, and may in times of high flood act as an anabranch of the Ord, feeding water into the flood channel at the back of Mantinea Flats.

Area 7

This is drained by the Denham River and Valentine Creek, also smaller creeks, into the Ord. Alluvial flats of limited extent occur in various parts, but have not been investigated in detail.

Area 8

This is a large area apparently draining ultimately via Border Creek, at the foot of the Weaber Range, into the Keep River. Clay flats generally similar to Carlton Reach Plain are extensive in the eastern part, i.e. south-west and south of Point Spring and eastward past the northern tip of the Pincombe Range to the Western Australian border (see map of Figure 1.).

Many large watercourses from the sandstone hills north of the Carlton-Legune track spread their waters on these clay flats. Waters also come from the northern part of Pincombe Range and other large sandstone hills north of Cave Spring. Coolibah and gutta percha grow on large areas and bear evidence of extensive flooding. A careful survey of the drainage of this area should precede any consideration of it as a potential irrigation area. The contrast with area 9 should be noted.

Area 9

This includes the soil survey of Carlton Reach Plain. By contrast with areas 2, 3 and 8, it has only a small proportion of its area other than alluvial flats. Stony hills are at a minimum, so that except in the north and north-east, very little water reaches the flats other than the rain which falls on them. Green Swamp and Martin's Swamp, which are the low points of this area, receive drainage from the hills about them and this evaporates in the dry season.

The western edge of Carlton Reach Plain drains into the Ord via a number of gully systems. The main body of the plain is not subject to flooding by the Ord.

The contrast in natural drainage conditions between areas 2 and 9 is discussed in more detail in describing the detailed soil surveys.

Area 10

The exact drainage of this locality is uncertain, but from traverses through it and from aerial photographs, it is believed that there is some drainage from the north into Cave Spring valley. The clay soils of Carlton Reach Plain are continuous through Cave Spring valley to the clay plains south of Point Spring. The drainage relationships of Martin's Swamp, Cave Spring valley and Point Spring plains can only be determined by levelling.

Area 11

Although this area comes within two miles of Carlton Reach, it drains away north-east to the Keep River. Sandstone hills and deep

sandy soils (Cockatoo sand) are extensive between Carlton Reach and the Burt Range and so a large proportion of the rainfall is probably absorbed. Further north, limestone areas occur, while between the Pincombe Range and the Keep River is the extensive Weaber Plain with clay soil generally similar to Carlton Reach Plain. Local opinion considers the Weaber Plain to be subject to considerable flooding from the Keep River and Knox Creek.

Area 12

South of Carlton Reach Hills are some relatively small alluvial areas which drain into the Ord.

Laterite

Laterite, both in the form of ironstone lumps and as ironstone gravel, was found in a number of places during the soil survey and reconnaissance. The occurrences have a special theoretical interest in connection with the formation of the soils and the present and past hydrology of the area. In most cases the laterite and ironstone gravel are now exposed on the soil surface or are very close to the surface.

Most of the occurrences are in a strip of almost flat ground at the junction of the clay plains with the sandy out-washes from the sandstone hills*. It appears that many of these areas are still subject to a seasonal waterlogging, although in most cases the main laterite occurrences may be what is called "dead" or "fossil" laterite, because the laterite is now exposed on the surface. No laterite was seen on any of the higher slopes or hill-tops of the sandstone hills in the area.

On the east side of the Carlton Reach Plain, lateritic gravel is fairly common in the belt of soils which has been mapped as the Junction complex. The most extensive occurrences of the laterite have been specifically marked on the soil map. Similar occurrences were noted to the west of the Green Swamp area where a relatively flat sandy stretch separates the clay soils of the swamp and plain from sandstone hills. In similar situations, laterite was found at the foot of the west and east sides of the north-east end of the Pincombe Range, also about five miles west-south-west from Point Spring. Another occurrence is at the foot of the hills west of the road from Ivanhoe, about half a mile before it enters Button's Gap. Large lateritic boulders about three feet across are to be seen in the bed of Waterfall Creek, close to the road, about three miles north of Ivanhoe homestead.

South-east of the Carlton Reach Hills is a very interesting occurrence, for in this section the normal erosion by a creek system has dissected the area and small rises between the creek branches are strewn with lateritic gravel and small lateritic boulders. This is obviously "dead" or "fossil" laterite. Limestone is exposed in some of the creek beds. At the south-west end of Carlton Reach Hills, where the Ord course goes right to the foothills, there are exposures of basalt and sandstone, with ironstone gravels weakly cemented to them at levels not many feet above the present peak levels of the river.

In the Mantinea Flats—Goose Hill area, laterite was seldom found. One occurrence was at the foot of a low sandstone hill south of the Mantinea Flats. There is also lateritic gravel around the base of Goose Hill. On the road between Carlton station homestead and Point Spring, laterite is seen in several places beside the creek beds in the area north-east of False House Roof Hill. In this vicinity, the lateritic gravel does not appear to be all at the same level.

It is believed that most of these lateritic occurrences fit in with the idea advanced previously that there has been a fall in sea-level in this vicinity. If the Carlton Reach

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*Pendleton, R.L. (Thai Science Bulletin Vol. III, Nos. 3-4, December 1941) has described similar occurrences of laterite as very common in sandy areas bordering the well-watered, fertile rice plains of Thailand. Massive laterite is there called "Sila Laeng", while the smaller gravel is "Luk rang".

Plain, for instance, is a lacustrine deposit, then the laterite occurrence would be in the area near the shoreline of the lake in which the muds of the present clay plains were deposited. It is suggested that the seasonal alterations in the water-level in this lake, alternate conditions of waterlogging and aeration would have occurred in the flat sandy soils adjoining the lake and laterites were here formed. Such occurrences are sometimes called lake laterite. The subsequent fall in sea-level has produced somewhat drier conditions, on the whole, and erosion of the surface soil has exposed the lateritic lumps and gravels which were previously in the subsoil.

The present rainfall conditions in the area must still lead to some waterlogging of the sandy soils between the plains and the hills in many places, and the dry conditions during the rainless season favour aeration, so that some of the conditions for the formation of laterite under the present climatic conditions are likely to be favourable. Dense layers of laterite are not to be expected, however, in very sandy soils formed principally from sandstones.

At various depths, usually between 3 and 6 feet, irregular lumps of brown to black ironstone gravel do occur in small quantities in many parts of the Cockatoo sand. Nevertheless, from the fact that the most important and massive occurrences of laterite are now exposed at the surface, it is believed that they represent "dead" or "fossil" laterite, rather than what may be termed "live" laterite.

Most of the laterites appear rather more sandy than those usually found in the south-western parts of Western Australia and may therefore be softer. Still, they may be valuable in the future for road-making purposes on the clay plains.

Soils

The nature and distribution of the soils of tropical Australia has not so far received much detailed attention from soil scientists and trained soil surveyors. J.A. Prescott (1941 and 1944) has produced maps based on a personal visit to some sections, with much supplementary information from the records of land surveyors, explorers and geologists. In the texts accompanying these maps he has pointed out the vast extent of rough stony tablelands and ranges where there is little soil, and among which potential arable areas are mostly relatively small alluvial pockets. The sharp contrast between the stony ranges and the soil-covered flats is one of the first impressions gained in travelling over the North-West and Kimberley Divisions of Western Australia. As Prescott has pointed out, the potential land use of any section cannot be assessed, particularly for agriculture, until the ranges and true soils are mapped in some degree of detail and accuracy.

In the Kimberley Division the valleys of the Ord and the Fitzroy are well known for their relatively large extents of soil-covered plains, but no detailed soil survey work has previously been done.

Soil investigations during the 1944 season were in an area between Wyndham and the Western Australian border—roughly a triangular area with the marshes nine miles south-east of Wyndham as its apex, and its base about 32 miles long on the border between the Weaber Range and the Burt Range. This area is about 750,000 acres and includes large areas of stony hills. Even omitting the hills, systematic examination of the soils of the whole area was not possible. However, a number of traverses along tracks, supplementing the detailed soil surveys and coupled with a careful interpretation of the aerial photographs, allows a general assessment of the whole area to be made.

The soils of the lower Ord valley and surrounding country are closely related to the physiography and geology of the area. Soil borings provide interesting information about the sequence of events, spread over thousands of years, which has resulted in the present land form.

Three major groups of soils occur. They have been mentioned in discussing the vegetation.

1. Brown alluvial soils of light and medium texture adjoining the Ord River.

2. Clay soils of the plains in the valleys of the Ord and Keep Rivers. These are formed on alluvial deposits and are called "black soils" locally. The dry soils are, however, dark grey-brown or grey. Such plains merge into tidal marshes in the Ord estuary, e.g. north-west of Parry's Creek.
3. Deep sandy soils adjoining the sandstone hills or on large alluvial sand fans where streams drain from the hills on to the alluvial flats.

In all three groups, the parent material is dominant in determining the characters of the soil profile. At the same time, it is considered that groups (2) and (3) are mature soils whose "parent materials are in equilibrium with the leaching factor" (Prescott: 1944). Group (2) comes in Prescott's "grey and brown soils of heavy texture", and group (3) in the "brown soils of light texture". The latter group includes the well-known "pindan" country of the Broome, Derby and Fitzroy areas. The brown alluvials of group (1) are frequently calcareous at various depths, but this is due to calcareous sediments rather than to accumulation in the development of the soil-profile.

The soils of groups (1) and (2) are the potential irrigation soils of the area. The deep sandy soils are not attractive agriculturally.

There are, in addition to the above groups, soils formed from shale and from limestone weathered *in situ*. The shale soil is extensive between Button's Gap and Mantinea Creek, where slopes are moderate, and is described for the Mantinea Flats—Goose Hill area under the name Rainyerri sandy loam.

Of the limestone soils little is known in detail. The track from Carlton homestead to Point Spring crosses a small area which possibly widens out southward in the direction of the Green Swamp. One profile was sampled on a small flat between two low limestone outcrops about four miles east of Redbank Creek, and the following details recorded:

0- 9″	Dark-grey cloddy clay
9-12″	Transitional
12-18″	Mustard-yellow clay
18-20″	Much limestone and mustard-yellow clay.

Moist below 8″ (sampled July 15)

This soil must be related to the well known rendzina soils. Further extensive limestone areas were recorded by Surveyor Richter between Martin's Gap and the Western Australian border, but no samples were taken.

At the junction of the clay plains and the sandy outwash soils a complex of transitional soils occurs. Their characters depend on their mixed parent material and on the degree of seasonal flooding or waterlogging. It is in these areas that laterite and lateritic gravel are most commonly found.

Soil survey of Carlton Reach Plain

Method of survey

A soil survey in considerable detail was carried out on the Carlton Reach Plain and a map produced.

It was apparent from soil borings in early reconnaissance work that the main body of the plain was made up of one soil type, now named Cununurra clay. The uniformity of this soil over large areas reduced the number of traverses and soil borings necessary for its delineation, but more detailed work along the Ord River, and also between the clay plain and the sandstone hills, was necessary. Throughout the survey, aerial photographs enabled ground traverses to be placed to best advantage. Without the photographs the survey would have taken much longer and involved much unnecessary work.

Before 1944, no permanent survey marks existed on the Carlton Reach Plain. It was therefore arranged for Surveyor Richter to establish the Carlton Reach base line (see map). Later the Martin's Gap base line was run. These two surveyed lines, together with a compass traverse of the Ivanhoe Bullock Paddock Fence, provided sufficient fixed points for the soil survey traverses, which were run with prismatic compass and roughly measured with a five chain band.

General description of the Carlton Reach Plain

Carlton Reach is a large pool in the Ord River, about 60 miles by road from Wyndham. A rocky bar holds back the waters in the dry season for a distance of about four miles. The Carlton Reach Plain covers about 54,000 acres east of the Ord, extending north from Carlton Reach about 18 miles. The width is from 2 to 8 miles, including a strip of sandy woodland up to one mile wide on the east side. Except for isolated hills the area is between 100 and 150 feet above sea level. It is mostly a large clay plain carrying grasses and scattered low trees and a large part of it is included in the Ivanhoe Bullock Paddock. In the north the plain ends in the Green Swamp, a large area subject to flooding during the wet season, and in the north-east part is another large swamp known as Martin's Swamp. Adjoining both these swamps are sandstone hills of variable height, of which the most prominent are the Cave Spring Range and the hills forming the western side of Cave Spring valley. North-east of Martin's Swamp is the extensive hilly area known as the Pincombe Range. On the east side of the central part of the plain there are only low sandstone hills, but in the southern portions the sandstone hills form a steep scarp, 300-400 feet high in places. In the extreme south-east, at the east end of Carlton Reach, are the Carlton Reach Hills.

The Carlton Reach Plain is connected by Cave Spring valley to similar plains west and north of the Pincombe Range, extending to the Western Australian border. Levels taken by the Public Works Department show that the southern end of the Carlton Reach Plain is 153 feet above sea level. for the most part, there is a gentle fall of 2 or 3 feet per mile in a northerly direction. The main portion of the plain is slightly higher than the river levee in the same vicinity, and there is no evidence that the plain is now subject to flooding by the Ord River.

The drainage of the plain is interesting. In the south-east corner, Avenue Creek drains from the sandstone hills into Carlton Reach, but only one other watercourse crosses the clay plain. This is the creek which reaches the Ord River opposite Ivanhoe homestead. The watershed in the sandstone hills on the east side of the plain is close to the western scarp of those hills, and as a result, only a relatively small area of hills drains to the west into the sandy soils which form the eastern edge of the plain. These creeks do not continue across the clay plain to the river. They either lose themselves in the sandy soils or, further north, appear to drain along the junction of the clay plain and the sandy soils into Martin's Swamp which also receives the drainage from the south-east side of the Cave Spring Range and from the south-western parts of the Pincombe Range.

The Green Swamp receives the drainage from the hilly and sandy areas which adjoin it on the north-west, north and north-east. It may also receive water from a gently northward movement over the northern part of the clay plain, where there are no well-defined channels.

The Green Swamp and Martin's Swamp are both apparently land-locked, and if any overflow does occur in a very wet season, it seems possible that Martin's Swamp would overflow into the Green Swamp and the Green Swamp would lose water from its south-west corner into creeks draining to the Ord River.

The western side of the plain adjoining the river is drained by a number of small creeks. These creeks enter the Ord River through the alluvial levee by steep-sided miniature canyons about 40 to 50 feet deep. When the river is in flood, its waters back up these gullies as is indicated by lines of drift wood. From an agricultural point of view, these gully systems badly dissect areas of otherwise attractive soils.

Borings to depths of 5-20 feet have been made in many places on the clay plain. They show great uniformity of profile to depths of about five feet. Dark grey-brown tough clay extends to this depth. Below five feet is usually a brown clay, and at 5-10 feet a brown friable sandy clay loam with much mica is very commonly found. In some places, layers of sand and rounded grit and gravel have also been found. It is apparent that the clay plain is an alluvial deposit.

The uniformity and tough consistency of its upper layers suggest that it is formed from lake muds deposited from ponded flood waters, or that the alluvial deposits have been laid down in an almost land-locked bay at a time when sea level was much higher than at present. This bay, if it existed, would be an indentation from the north coast in the vicinity of the mouth of the present Keep River.

The coarser and somewhat variable layers below 7 or 8 feet suggest variable alluvial materials deposited earlier in the erosion cycle under more active drainage conditions. There may have been several alterations in sea level since the valley first developed.

There is a general similarity at the surface between the Carlton Reach Plain and the clay plains associated with basalt on Argyle, Rosewood and Nicholson stations, south of the Ord gorge country. Although basalt occurs at several places in the Ord River, adjacent to the Carlton Reach Plain, and there is a low basaltic hill in the centre of the plain about 12 miles north of Carlton Reach, it is certain that the main area of the Carlton Reach Plain is not formed from the weathering of basalts *in situ*. It is possible that material eroded from the Cambrian basalt of Argyle, Rosewood and Nicholson stations, and brought down by the Nicholson, Negri, Behn and smaller tributaries, forms much of the parent material of the plain. The Mosquito Creek series of rocks of the gorge area may have provided the micaceous underlay.

Dr Dorothy Carroll, Soil Mineralogist of the Government Chemical Laboratory, has shown from examination of samples from the Carlton Reach Plain that the upper dark grey-brown clay stratum has a different mineral assemblage from the lower brown micaceous sandy clay loam.

The sandy belt along the east side of the clay plain has developed from the disintegration of the sandstone hills. There has been some outwash from the hills and at the junction of the sand and clay a complex belt occurs.

The present Ord River course may have cut through and partly removed the lacustrine deposits which make up the bulk of the Carlton Reach Plain. Brown alluvial soils of more recent origin have been deposited along the river and, with trees and grasses, form a savannah woodland.

Description of soil types

Four principal soil types have been defined and named for this area. They are:

1. Ord sandy loam
2. Meruin sandy loam
3. Cununurra clay
4. Cockatoo sand

Wind erosion has occurred on the first two, so that some areas are mapped as a wind eroded phase. (Water eroded areas of Meruin sandy loam do occur, but they are all mapped within the gully systems.)

Water erosion has occurred on the margins of the Cununurra clay and a water eroded phase is mapped. Also, some areas of this type are subject to regular seasonal flooding. These are defined as Cununurra clay-flooded phase.

Between the Cununurra clay and the Cockatoo sand a very complex band of soils occurs. This is mapped as the Junction soil complex.

Gully systems, including billabongs, subject to flooding, and unsuitable for agriculture, are separately mapped, as are also hills and smaller rock outcrops.

Ord sandy loam (Osl on map)

This is one of the soil types of the savannah woodland adjoining the Ord. It is the soil of the Ord levee and is typical of the so-called "red" soils of the district. The Carlton Reach experiment plots, established in 1942, are on this soil. Only 1,848 acres have been mapped in this survey.

Profile

0- 8″ — Grey-brown or dull brown fine sandy loam.
8-72″ — Brown fine sandy loam passing to fine sandy clay loam, and often becoming more sandy again with depth. Compact when dry; mellow when moist.

Below 72″, variable alluvial deposits have been found. Near the survey camp a boring to 24 feet passed through various layers, some of sand and some heavier than sandy loam, though some were weakly cemented. A small amount of lime occurred in some strata. Other profiles have shown dark brown or brown clay below six feet, sometimes with lime nodules. Away from the river and approaching the Cununurra clay this clay horizon was found in places within three feet of the surface. Such an area occurs on the site of the proposed new research station opposite Ivanhoe.

Examination of the high river banks and also the deep gullies passing through the levee, show the various strata which may occur below six feet under the Ord sandy loam. There are layers of water-worn gravels and layers of highly calcareous sediments weakly cemented into soft limestone, as well as layers of sand and clay.

Very detailed soil survey work would define and map light and heavy phases within the areas mapped as Ord sandy loam. The above profile is typical of the greater part of the area.

The natural vegetation of this soil has already been described in dealing with the savannah woodlands along the Ord.

In many places a large proportion of the trees are now dead, and up to perhaps six inches of the surface soil has been removed by wind. Areas so affected are mapped as Ord sandy loam-wind eroded phase.

The primary cause of this erosion is thought to be the concentration of cattle on to the soils adjoining the river during the "wet" season, when the Cununurra clay of the plain becomes very boggy. Also, during the dry season, cattle watering at the river often spend a large part of the day on these areas. The grasses and surface soil become pulverized and easily blown away.

The Ord sandy loam is an attractive soil for agriculture and irrigation. It is, however, of limited extent and immediately adjoins the river channel. Should closer settlement occur, the reservation of a strip adjoining the river would be essential and so the area for agriculture would be further restricted.

Meruin sandy loam (Msl on map)

Meruin sandy loam is a soil type mostly occurring between Ord sandy loam and Cununurra clay. It forms part of the savannah woodland adjoining the river and in any

general soil grouping is included in the "red" soils of the area. It is formed on alluvial deposits older than those which have provided the characteristic upper horizons of Ord sandy loam and Cununurra clay, and on the Carlton Reach Plain generally occurs between these two types. Small islands of the Meruin type occur in the Cununurra clay, and a very eroded phase is common on the slopes of the gully systems mapped G. Reconnaissance has shown that on the small plains east of the Ord and south of Carlton Reach Hills Meruin sandy loam occurs. Also, west of the Ord and south of the 1944 survey camp, the flats are composed largely of the Meruin type, with Cununurra clay—or at least a soil with a similar clay surface—forming islands in shallow depressions.

Some 1,176 acres of Meruin sandy loam have been mapped in this survey: this includes 420 acres of the eroded phase.

Profile

0- 3″	Brown sandy loam—(relatively coarse sand).
3-30″	Red-brown or dark red brown sandy clay or sandy clay loam.
30-84″+	Variable layers, principally of brown sandy clay or sandy clay loam. Calcareous nodules sometimes occur. Water-rounded gravel and grit are common. Strata of rounded gravel and grit with little finer material have been seen in eroded gullies. Thin strata of sand have sometimes been found in borings to six feet.

The Meruin type is notable for the coarse sand in its profile by contrast with other soils of the area.

The vegetation of Meruin sandy loam is similar to that of Ord sandy loam. The vegetation is as described previously.

For agriculture, Meruin sandy loam is likely to have potentialities similar to those of Ord sandy loam.

Meruin sandy loam—eroded phase

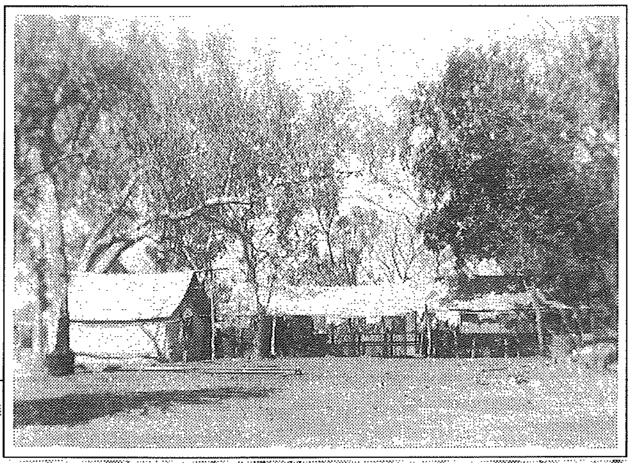
Most of the Meruin sandy loam mapped in this survey has suffered some erosion, principally by wind. Affected areas are mapped as an eroded phase. As with Ord sandy loam the erosion is thought to be a consequence of the concentration of cattle near the river for a large part of the year.

The removal of the sandy loam surface by erosion is often complete except for a thin film of sand or sandy loam. The red-brown clay beneath this film has, in the dry season, a crumbly structure to depths of 6 or 9 inches; this proved a useful characteristic to identify wind eroded Meruin sandy loam from wind eroded Ord sandy loam.

Areas of Meruin sandy loam, or more strictly speaking, the alluvial deposits on which this type normally forms, have been dissected and eroded in forming the gully systems which are separately mapped (G) in this survey. Such areas, on the slopes of the gully systems, usually show the characteristic crumbly red-brown sandy clay and are often strewn with residual rounded water worn gravel. The erosion which has produced these gullies is part of the normal erosion cycle, due probably to alterations in sea level. Some accelerated erosion, associated with the cattle industry, is occurring in places.

Cununurra clay ($C^{u}c$ on map)

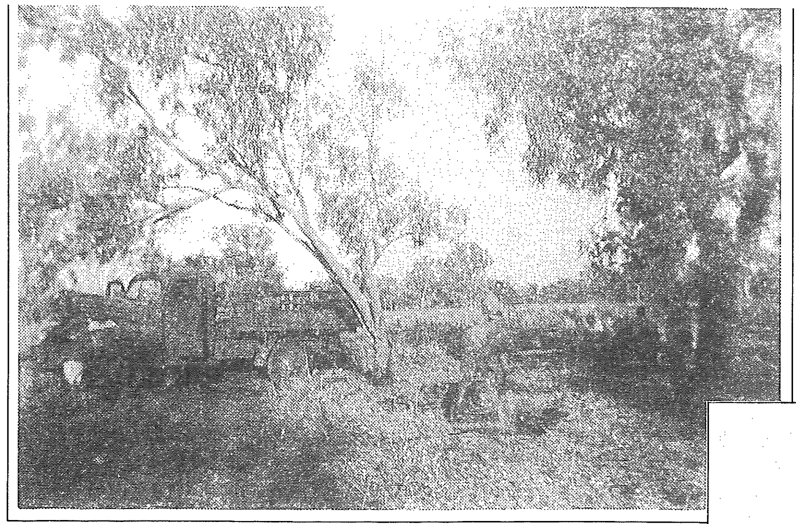
Cununurra clay makes up the bulk of the Carlton Reach Plain and 38,906 acres have been mapped. It is a tough clay soil which cracks into large irregular blocks during the dry season. The cracks are up to an inch wide and penetrate 2 to 3 feet. A shallow layer of 1 to 4 inches on the surface breaks into crumbs and small clods in the dry season, but below this the large blocks are hard and massive. The result is seen in the rough surface of long-established tracks. Motor vehicles, especially trucks, must travel slowly on tracks, while, on virgin areas, the rough clay and the tussocky grasses make it almost impossible to exceed 3 miles per hour. In the wet season the surface swells and the cracks close, but the wet clay has great adhesive powers.



Cook house and mess facilities for some 10 men

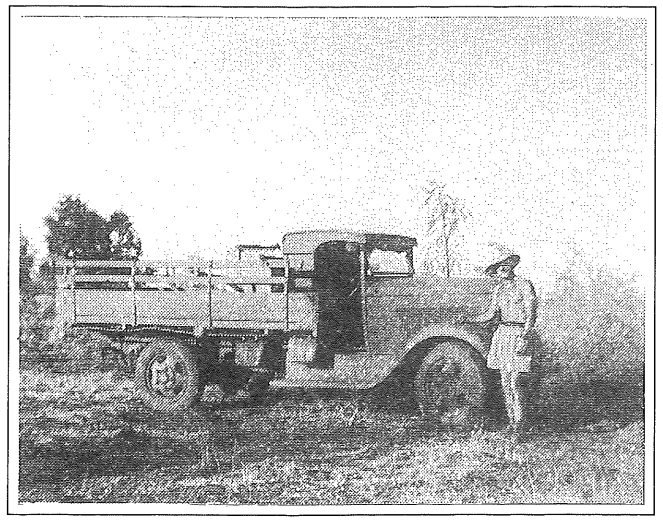
First campsite beside the Ord River, May 1944, near Ivanhoe Crossing, before the arrival of the tents. The initial party included, C.A. Gardner (Government botanist); C.F.H. Jenkins (Government Entomologist); G.H. Burvill (Assistant Plant Nutrition Officer); S.T. Smith (Agricultural Adviser).

Fuel dump and truck drivers' tents. (Trucks were: two Fords, one Dodge and one Chevrolet.)



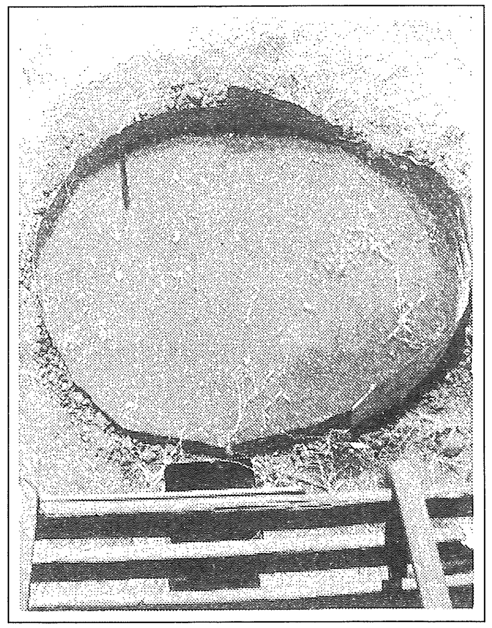
Flying (temporary) camp near point of Cave Spring Range, September 1944. Standing: Ben Scrivener at camp fire.

The Western Australian/Northern Territory border. George Burvill and Darcy Ewing.

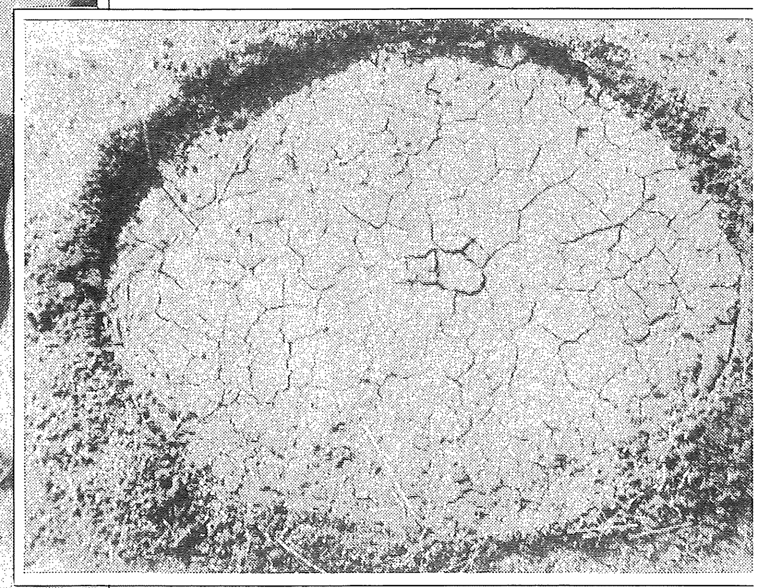


Truck driver George Biggs beside the Dodge truck.

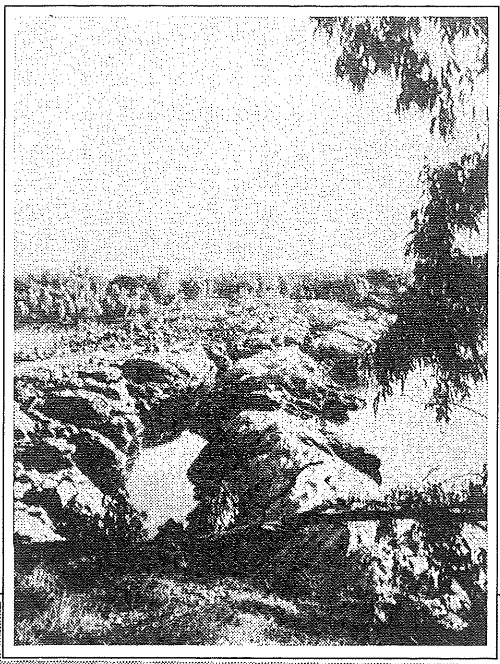
Infiltration test on Ord sandy loam. Dr. L.J.H. Teakle (standing) and George Biggs holding the perforated petrol bin bucket with which to add water. Dr. T.J. Marshall (C.S.I.R.) with notebook.



Water infiltration test. Any available scrap iron was used as an infiltration ring.

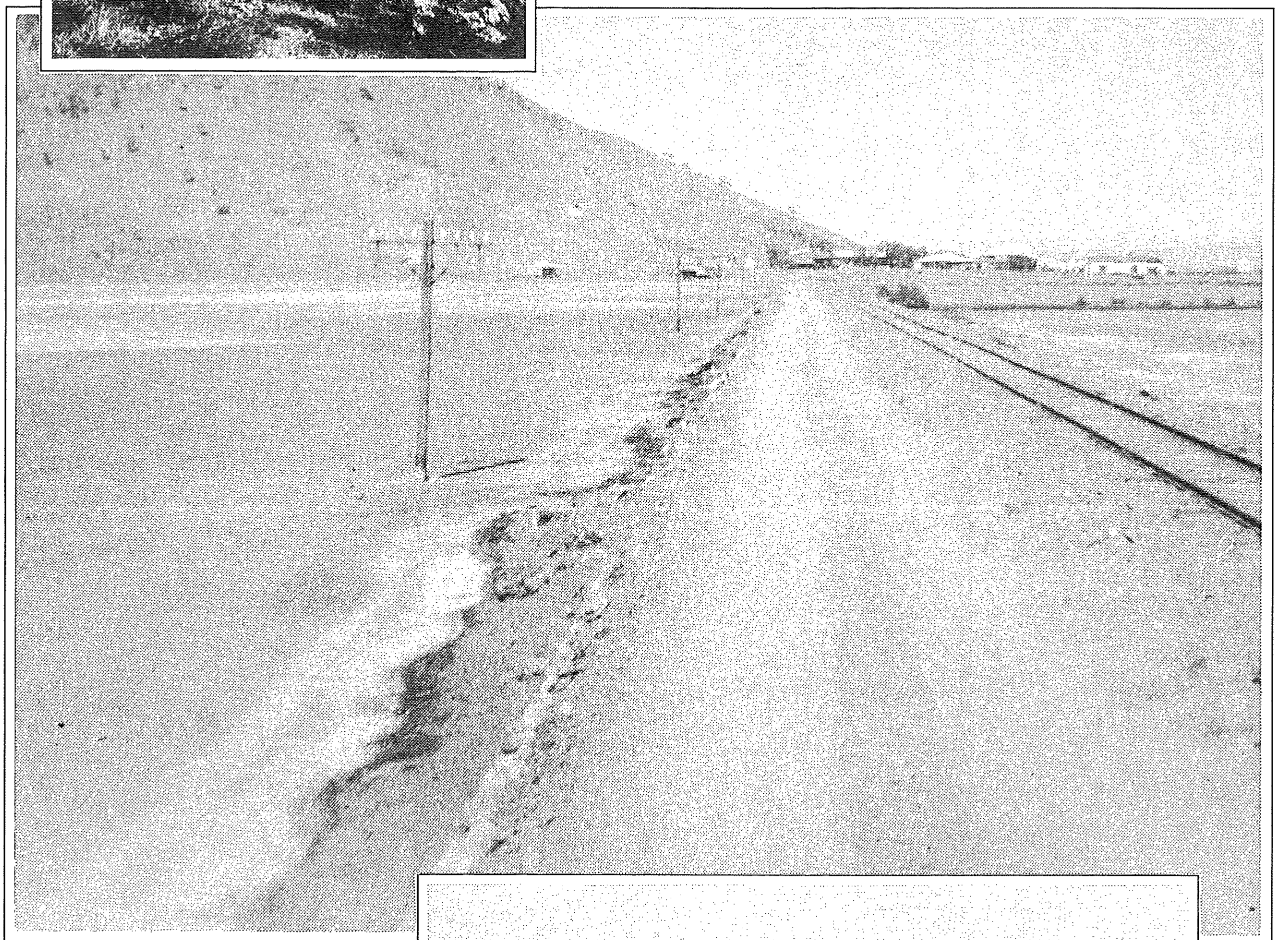


Infiltration test on Cununurra clay (black soil) showing drying and cracking.

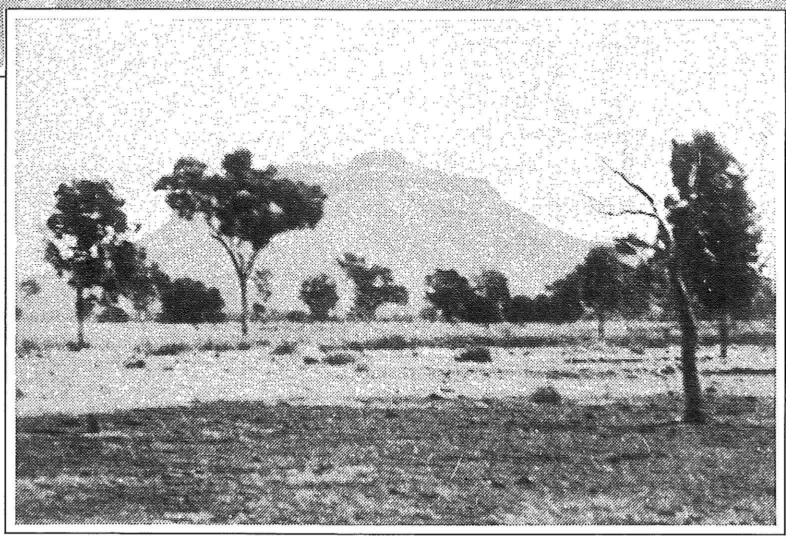


Bandicoot Bar. It was here that the Division Dam was built in 1963

Wyndham at the base of the Bastion as seen from the meatworks causeway, 1944.



House Roof Hill, as seen from the Mantinea Flats, 1944.



Profile—normal phase—dry season description

0- 4″	Dark grey-brown crumbly and cloddy clay.
4-48″	Dark grey-brown tough clay, usually slightly more moist and less tough below 24″. Small lime nodules about 1/8″ in size are common, also small soft black concretions*.
48-72″	Transitional layer. Dark grey-brown tough clay passing to brown clay of more mellow consistency. Lime nodules may increase in size. This layer may be as little as 6″ in thickness.
54″+	As shallow as 54″, but more commonly at depths between 6 and 8 feet, brown friable micaceous fine sandy clay loam with lime nodules is found. Deeper borings—in one instance to 20.5 feet—have shown various clays and sandy clays, mostly brown and often micaceous and calcareous. Sandy layers, and even coarse grits, have been found within 10 feet of the surface. Steely grey tubes about 1/16″ diameter frequently ramify the deeper clays.

The toughest and most compact and dense part of the Cununurra clay profile is invariably between one and four feet from the surface.

Even after four to five months of drought this soil was moist below two feet, but at all times the profiles were more friable and seemed drier below about five feet. This suggests that the normal wet season rainfall does not penetrate below five feet. The low infiltration rate of this type as found in watering tests is in keeping with this observation.

The transition from dark grey-brown to brown below about four feet is of some pedological interest. In soils formed on stratified alluvial deposits it is difficult in the field to determine the true C horizon, or parent material, of the true soil profile. It may be that this transitional zone marks the beginning of the C horizon. On a heavy clay deposit made up of material which may previously have been soil, evidence of soil profile development is not easily found in the field. The small lime nodules and the black shotty concretions seem to be the result of the operation of pedogenic factors since the Carlton Reach Plain changed from a lake or quiet bay and became dry land. The depth of organic matter penetration in such grassland soils might be a useful laboratory check. The normal phase of the Cununurra clay has a vegetation of tussocky grasses such as Mitchell, Flinders, white grass and *Aristida* spp. with scattered shrubs and small trees of *Bauhinia* and rosewood.

Cununurra clay—eroded phase

The western margins of the main area of Cununurra clay have been dissected by normal erosion into gully systems draining into the Ord. Accelerated gully erosion and sheet erosion is now occurring in some places and where this erosion is extensive an eroded phase of Cununurra clay has been mapped.

Some areas (as with Meruin sandy loam—eroded phase), are not separately mapped, but are included in the gully systems mapped G. Active headward erosion in these gullies is indicated by the letter E where it has been actually observed.

It is apparent from these areas of gully erosion that the Cununurra clay has a structure which is unstable in water. Water flowing in the gullies readily undercuts the clay and large blocks slough into the water and disintegrate. Lumps of dry clay dropped into water rapidly slake into a granular form, suggesting a weak macro-structure, but more stable micro-structure. Such physical aspects require careful investigation in connection with the movement of water in channels and drains.

*A sample of these black shotty concretions was examined by H.P. Rowledge, Mineral Section, Government Chemical Laboratory, and he reported as follows: "The concretions consist of partially altered microcline (potash felspar) with a cementing material consisting of oxides of iron and manganese containing a little cobalt".

Cununurra clay—flooded phase

On the eastern side of the main area of Cununurra clay, and also in the areas known as Martin's Swamp and Green Swamp, there is ample evidence from flood marks on trees that large areas of the clay soil are flooded for varying periods during and following the wet season. Coolibah and gutta percha trees grow on these areas; some grasses seldom seen on the main plain are also common. The longer the period of flooding, the less, apparently, the amount of grass, so that the lowest parts of these areas have practically no grass.

The soils are generally similar to the normal phase of Cununurra clay and are therefore mapped as a flooded phase of that type. The surface is usually grey or dark grey, instead of dark grey-brown, and is rougher and tougher and has bigger cracks when dry.

The use of these areas for agriculture would depend on satisfactory surface drainage. At present the main areas, Martin's Swamp and Green Swamp, are collecting basins for internal drainage. Their waters evaporate during the dry season. Depending on levels, it might be possible to drain Martin's Swamp into Green Swamp and thence south-westerly into the Ord.

Cockatoo sand

On the east side of Carlton Reach Plain is a belt of deep sandy soil adjoining the sandstone hills. The principal soil type has been named Cockatoo sand. Similar sandy soil is extensive between Carlton Reach Hills and the Western Australian border, and on the road from Ivanhoe to Argyle, the 17-miles section from Carlton Reach Hills to Cockatoo Spring is well-known as the "the Cockatoo sands". The name has been adopted for the soil type.

These areas of deep sand are apparently formed from the disintegration of the sandstones of the locality. The Government Geologist, F.G. Forman, considers that the sandstones of this locality may be of Permian age, much younger than the extensive Nullagine series. Residual hillocks of the sandstone occur scattered through the areas of Cockatoo sand. The vegetation, consists of characteristic eucalypts and other trees, also spinifex and coarse grass.

The main characteristics of Cockatoo sand are six feet or more of sand, red-brown, orange-brown, yellow, or light brown, with little or no evidence of clay accumulation. In more detailed survey work, various colour phases could be mapped. In places, too, where the adjacent sedimentary rocks contained thin bands of limestone and possibly strata of mudstone, a gradual increase of clay content with depth was found.

Profile

A surface film of red-brown, light brown or yellow sand gives the undisturbed soil a brighter appearance than when a surface layer of 6 to 9 inches is dug up.

0- 9″	Grey-brown sand.
9-72″	Red-brown, orange-brown, light brown or yellow sand, often containing small amounts of soft ferruginous gravel of irregular shape and brown or black. It is often black inside and brown or yellow outside. This gravel is usually below 36″.
72″+	Below 60″ to 72″ the sand may continue, but mottled brown, grey and yellow sandy clay loam or sandy clay, usually moist, and often gravelly, has been found in a number of places. Occasionally sandstone rock was found.

Areas of Cockatoo sand slope away gently from the hills towards the clay plain. The wet season run-off from the hill slopes facing the plain is via small water-courses, most of which spread out and lose their waters in the areas of Cockatoo sand. It seems that many parts of this belt of Cockatoo sand may be partly waterlogged during the wet season, but dry out by evaporation and transpiration in the dry months. These conditions would be favourable for laterite formation and the gravels frequently noted are thus explained.

It is possible, too, that the general colour of the sand in various parts may be related to the degree of wetness in the wet season. The

general impression gained was that red-brown phases were drier and gave way to light brown and yellow, passing to depressed areas or broad sub-surface water courses.

A number of borings in the Cockatoo sand during the 1944 dry season showed moist layers below 4 or 5 feet, especially where a layer of sandy clay loam or sandy clay was found at about six feet. Free water within nine feet of the surface was found in a few places.

About 4,900 acres of Cockatoo sand have been mapped in the detailed survey. Much larger areas lie between Carlton Reach Plain and the Burt Range on the Western Australian border. Agriculturally, this soil is not attractive and water infiltration tests indicate that it would be difficult to irrigate except by sprinkler methods. The monsoon woodland with its sandy soil has, however, a place in any future settlement plans, as townsite or homestead areas and for fuel and rough building timber.

Junction soil complex

The Cununurra clay does not abruptly join the Cockatoo sand; the two are separated by an area from a few chains to about half a mile wide, where the soils are very complex, because of drainage conditions and the proximity of such contrasting soils on opposite sides. Only by very detailed survey, not justified in this work, could the individual soil types of this area be mapped. Instead, the soils are grouped as Junction soil complex.

The whole strip appears to be low-lying and subject to waterlogging and local flooding, though the difference in level from the adjacent Cununurra clay is very small.

Adjoining the Cununurra clay, either normal or flooded phase, are many small depressions of grey clay, hard and rough when dry. Passing towards the Cockatoo sand, there is a sand or sandy loam surface and a sandy clay subsoil. The surface sand or sandy loam ranges from a film to depths of 2 to 3 feet, and sometimes contains ironstone gravel. Grey and grey-brown colours are most common, but in some areas, brown sandy loam occurs.

The sandy clay subsoil is hard and cemented in the dry season. It is usually mottled with shades of grey, yellow and brown, and may contain pieces of ironstone gravel.

Some areas included in the Junction complex have much ironstone gravel and laterite on and in the surface soil, and the presence of the laterite is indicated on the map. The main areas are on the east side of the plain approaching Martin's Swamp and on the north-west of the plain, south-west of Green Swamp.

Where the creeks draining from the Pincombe Range and Cave Spring Range enter Martin's Swamp, there is a complex area of sand deltas, levees and depressions. This has been included in the Junction complex. The sand brought in by the creeks has slightly modified the clay soils included in Cununurra clay—flooded phase, on the north side of this swamp.

The main area mapped as the Junction soil complex on the east side of the plain would probably become the locality for a main drain if the area is developed for irrigation. Some areas might then be suitable for agriculture, but on the whole, the soils of this complex are unattractive, partly because of their variable character, and partly because the mixing of relatively fine sands from the Cockatoo sand, with clay deposits at the edge of the Cununurra clay, produces soils which cement on drying.

Gully systems and billabongs (G on map)

The gully systems dissecting and draining the western side of the Carlton Reach Plain have already been mentioned. Although vegetated, many are juvenile in character, with steep banks. These gullies cannot be regarded as suited for agriculture because of:

1. the steep slopes;
2. flooding when the river level is high; and
3. the liability to erosion if the vegetation is removed.

In fact, there is accelerated erosion now taking place in these gully systems, especially where the water courses have their source in the Cununurra clay. Measures to check this erosion would be essential if closer settlement is undertaken.

A few billabongs lying between the Ord sandy loam levee and the Cununurra clay are included with the gully systems.

Accelerated erosion, where observed in the gully systems, has been indicated on the map by the letter E.

Soil salinity

To determine the salt status of the soils, samples were collected from various borings and analysed in the field laboratory for chloride and conductivity. On the whole, the soils were found to be low in water soluble salts to depths of six feet and more, so that soil salinity troubles under irrigation are not to be expected, unless much deeper saline layers occur and water tables develop after irrigation. In view of experiences in northern Victoria and the Murrumbidgee Irrigation Areas of New South Wales, these latter possibilities should not be overlooked.

In the Ord sandy loam, samples from ten sites all contained 0.02 per cent or less of sodium chloride (i.e. chloride expressed as sodium chloride). Six of these sites were sampled to six feet or deeper.

In nine sites on Meruin sandy loam, no sample exceeded 0.01 per cent sodium chloride.

Thirty sites were sampled in the Cununurra clay. Their salinity status is set out in the following distribution table. (Table 1)

Further details for the four sites showing figures greater than 0.1 per cent sodium chloride are as follows. (Table 2)

Gypsum, which often occurs in heavy clay soils along with calcium carbonate, was not seen in any profile of Cununurra clay. At one site (Serial nos. A 4017-4022) at 13 miles 60 chains on the Carlton Reach base line, the usual relation between chloride and conductivity did not apply for samples below four feet. A qualitative test confirmed the presence of unusual amounts of sulphate in the 1:5 water extract.

No sample collected from the Junction complex or Cockatoo sand contained more than 0.02 per cent sodium chloride; most had less than 0.005 per cent.

Table 1. Salinity of Cununurra clay

Chloride as sodium chloride per cent of air dry soil	Number of sites sampled 0 to 3 feet*	3 to 6 feet*	6 feet and deeper
0.01 and less	26	9	9
0.01—0.10	3	15	8
>0.10	0	3	4

* Composite samples representing the whole of each layer were not often taken, but rather small samples representing conditions at 24″ or at 48″ or 60″ etc.

Table 2. Salinity of Cununurra clay sites where salt (sodium chloride) exceeded 0.1 per cent

Serial no.	Locality	Depth inches	Sodium chloride per cent of air dry soil
A 4033	Two miles south of	0-9	Trace
34	Ivanhoe road	9-24	Trace
35	crossing	24-48	0.10
36		48-72	0.24
37		6-10 feet	0.22
38		10-13 feet	0.18
A 4284		13-16 feet	0.14
85		16-19 feet	0.14
86		19-20.5 feet	0.17
A 4208	At 16 miles peg on	0-6	Trace
09	Carlton Reach base	6-24	0.01
10	line. i.e. on south	24-60	0.06
11	side of the main Green Swamp area	60-114	0.28
A 4212	In the south-east part	0-6	Trace
13	of the Martin's	6-24	0.01
14	Swamp area	24-54	0.11
15		54-78	0.16
Field	About 50 chains	at 24	0.02
Book 4,	north of Martin's	at 48	0.17
site 75	Gap base line and 50 chains west of the foot of Cave Spring Range	at 72	0.13

In all four cases the relationship between conductivity and chloride indicated that chloride, expressed as sodium chloride, was the major constituent of the water soluble salts.

Suitability of the soils for irrigation

Assuming that any permanent agriculture in this area would not be possible without irrigation, and assuming also that irrigation water can be supplied for the Carlton Reach Plain, the next question which arises is: Which soil types are suitable for irrigation? Information on this question is available from the Carlton Reach Experiment Station and from water infiltration tests carried out in 1944 in collaboration with Dr T.J. Marshall, Senior Research Officer, Soil Physics, Soils Division, C.S.I.R. (Appendix 1). Marshall's report on wilting determinations is also included (Appendix 2).

Ord sandy loam

The Carlton Reach Experiment Station is entirely on this soil type. The results at the station since irrigation commenced in 1942 are very satisfactory from the soil point of view. The rate of infiltration of water is neither too slow nor too fast for standard irrigation practices, though there is some evidence that, as operated at present, the middle and the lower end of bays six chains long do not always receive adequate water. Experimentation seems necessary to determine the optimum length of run under suitable head ditch supply rates.

A variety of pastures has been tried in large and small scale plots. Fruits such as pawpaws and plantains are being grown, and vegetable crops, including especially tomatoes, peas, beans, cucumbers, watermelons and a cucurbit known as Goyder "bean", have been successful. In many cases little or no artificial fertilizer has been used.

Meruin sandy loam

This type is of restricted occurrence (1,176 acres), and some areas (420 acres) have already suffered from erosion of the surface soil. No infiltration tests have been made, but this type should behave similarly to the Ord sandy loam.

Cununurra clay

This type, extending over 38,906 acres including the flooded and eroded phases, makes up 92.8 per cent of the potential irrigable land. Its suitability for irrigation deserves special consideration and the establishment of a new experiment station opposite Ivanhoe to test this type is essential.

The 1944 small-scale infiltration tests have shown that the dry soil absorbs water rapidly at first, but later, with swelling of the clay and the sealing of all cracks, infiltration rates are very slow. As a result, water penetration to the deeper layers is hard to achieve. At one of the infiltration tests sites (site 1, Figure 2 Marshall's report), water was held on the soil surface for a total of 54 hours in two periods with a four days interval. Yet two days after finishing the second watering, i.e. eight days from the beginning of the first watering, none of the added water had penetrated beyond 42 inches.

The graphs of Figures 1 and 2 in Marshall's report show the low infiltration rates after the initial rapid uptake of water by the dry soil. Under practical conditions the soil could not be allowed to dry out too far between irrigations, so that infiltration rates as shown for graph Cuc (2a) in Figure 2 are to be expected. In this test, carried out 12 days after the first watering of this site, 2.5 surface inches of water took eight hours to enter the soil.

Under practical conditions, special techniques may be necessary for the Cununurra clay. Grading into level bays and fairly frequent waterings may be necessary. If water is not to be allowed to stand too long on the soil surface, small applications—say two or three surface inches—will be necessary.

In discussing Cununurra clay—eroded phase, it has been stated that this soil has an unstable structure in water and is readily eroded by moving water. Gully erosion was frequently observed. For channels and drains in Cununurra clay therefore, the question of erosion and slumping of the banks if flow rates become too high requires careful consideration.

The condition of the soil surface before stock are allowed access to irrigated pastures will require investigation. Also, during the wet season the co-ordination of irrigation with the seasonal rain storms will require an accurate weather forecasting service.

According to K. Durack, cattle usually leave the clay plains during the wet season and graze on the less sticky and less boggy soils adjacent to the river or the hills. If the large unbroken area of Cununurra clay is to be subdivided and developed under irrigation, its usefulness for grazing during the wet season must be assessed.

All aspects of the use of the Cununurra clay under irrigation and on restricted holdings should be investigated on the proposed new research station.

Cockatoo sand

This soil is not considered to be generally suitable for irrigation because of its very rapid infiltration of water. It might prove useful for special crops under spray irrigation methods.

Junction soil complex

Because of their situation and variable characters, the soils of this complex cannot, as a whole, be regarded as suitable for irrigation. Some small areas may be used.

General fertility of the soils

Neither laboratory data, nor results of field tests, are yet available (1945) by which to judge the inherent capacity of the soils to supply essential plant nutrients such as phosphorus, potassium, nitrogen and others.

On the Ord sandy loam at Carlton Reach, the use of artificial fertilizers has not been general, but good results have been achieved. There is some evidence of the need for nitrogenous fertilizers to sustain the productivity of grasses.

The Ord, Meruin and Cununurra types are all soils formed on alluvial deposits. From the variety of rocks in the Ord watershed which have contributed to the deposits, including especially large areas of basalt, limestone and mudstone, it is expected that the general fertility level will be good.

The present use of the area for the extensive grazing of cattle is not a very useful guide. Apparently, natural conditions are far from ideal for the production of high quality beef, but since so many factors are involved, such as seasonal conditions, feeding value of grasses in the dry season, animal diseases and insect pests, it is impossible to draw any reliable conclusions about inherent soil fertility. Practical tests will provide the only certain answer.

Areas of soil types and potential irrigable areas

The areas of the various soil types are set out in Table 3, which also indicates the areas probably suitable for irrigation. The dominance of Cununurra clay is outstanding.

It aggregates 38,906 acres or 69.7 per cent of this survey (including the whole of Green Swamp). Of the potential irrigable soils, it constitutes 92.8 per cent. The testing of this soil under practical irrigation conditions is of paramount importance.

Ord sandy loam, an attractive soil for irrigation, is only 1,848 acres in extent, and this area must certainly be greatly reduced by the reservation of a strip immediately adjoining the river channel.

Meruin sandy loam is also very restricted in this survey, but is probably more extensive on the flats south of the river opposite the 1944 survey camp site. South of Carlton Reach Hills limited areas of the Ord and Meruin types are also known to occur.

General comments

When the Wyndham meat works are operating, large numbers of cattle, probably upwards of 20,000, cross the Carlton Reach Plain from the Cockatoo sands to Button's Crossing. In developing the plain for irrigation, provision for a stock route would be necessary, unless a railway is provided running out from Wyndham at least to the Cockatoo sands. The construction of such a railway has often been discussed to avoid the concentration of cattle over the last 100 miles in this direction.

Table 3. Carlton Reach Plain soil survey, areas of soil types and potential irrigable areas

	Sheet 1 acres	Sheet 2 acres	Total area acres		Per cent of total area	Potential Irrigable areas* Acres	Per cent of irrig-able area
1. Brown alluvial soils near the Ord River.							
Ord sandy loam							
Normal phase	448	952	1400	1848	3.3	1848	4.4
Wind eroded phase	56	392	448				
Meruin sandy loam							
Normal phase	70	686	756	1176	2.1	1176	2.8
Eroded phase	168	252	420				
2. Dark grey-brown and grey (so-called "black") clay soils of the plains and swamps.							
Cununurra clay							
Normal phase	19180	9590	28770	38906	69.7	38906	92.8
Water eroded phase	140	462	602				
Flooded phase—within detailed survey area.	5320	714	6034				
—portion of Green Swamp north of detailed survey.	3500		3500				
3. Various soils at the junction of deep sandy areas and clay plain.							
Junction soil complex	2072	1400		3472	6.2	—	—
4. Deep sandy soils adjoining the sandstone hills.							
Cockatoo sand	322	4578		4900	8.8	—	—
5. Gully systems including billabongs unsuitable for agriculture.	1344	2128		3472	6.2	—	—
6. Stony hills.	1960	130		2090	3,7	—	—
Total	34580	21284		55864	100.0	41930	100.0

* No allowance has been made for reserves, levees, channels and drains.

04353-4

Soil survey of the Mantinea Flats—Goose Hill area

Introduction

A soil survey with considerable detail was made of the area south of the Ord River between Mantinea Creek and Goose Hill, using the same general methods and with the same objects as in the survey of Carlton Reach Plain.

In carrying out the survey, full use was made of aerial photographs, principally obliques. Traverses were run mostly in a north/south direction at half-mile intervals from fixed points on the Mantinea base line which had been established by F. Butson of the Public Works Department.

The area of this survey is 29,992 acres.

General description of the area

The Mantinea Flats and associated areas extend for about 14 miles on the south of the Ord River from near Mantinea Creek to Goose Hill (see locality plan, Figure 1). A brief inspection of these areas suggests a general similarity to the Carlton Reach Plain. There are brown alluvial soils in the savannah woodland adjoining the river. Further removed are the almost treeless grasslands with rough, cracked, "black" clay soils. Sandy soils slope out gently from the stony hills and form a monsoon woodland generally similar to that of the Cockatoo sand.

But there are, in fact, many important contrasts between this area and Carlton Reach Plain. The drainage and hydrology are quite different; seasonal flooding is sometimes extensive; the soil pattern is more complex; the subsoil of the clay plains becomes progressively more saline approaching Goose Hill. Also the alluvial deposits east and north of Goose Hill in old river meanders have an irregular surface which may be unsuitable for an irrigation layout.

East of Mantinea Creek the alluvial flats adjoining the Ord are very restricted and gently sloping stony areas, mostly weathered from shale, extend for about five miles towards Button's Gap. Likewise, south and south-west of Goose Hill are low hills. Between Mantinea Creek and Goose Hill the alluvial areas south of the Ord range from about half a mile wide near the Bend of the Ord to about seven miles just east of Goose Hill. They range in elevation from less than 30 feet to about 80 feet above sea level (low tide).

Many of the low hills south of the flats are of shale. Shale has also been noted in the river-bed at House Roof Hill Crossing and near House Roof Hill, also upstream towards Mantinea Creek and in the bed of Mantinea Creek. It seems, therefore, that these alluvial flats may be underlain, at depths of up to 40 feet, by shales whose strata dip gently in a general northerly direction.

The drainage and hydrology of this area are in marked contrast to those of Carlton Reach Plain. The bulk of the latter is above the level of the river levee in the same vicinity, and, except in the north, it receives little water other than the rain falling on it. On the Mantinea Flats—Goose Hill area, the river levee is the highest point on any section from the river till the foothills are reached*. Further, at least ten large watercourses, draining the stony hills for several miles south, spill their waters in the wet season on to the Mantinea Flats and the flats west of the Bend of the Ord. Large areas, delineated on the soil map as a complex flood channel area (F), are flooded by these waters which find their way into the old river meanders and swamps (D) via Salt Water Creek and Goose Hill Creek, and finally to the river estuary or the tidal flats. Also, the Ord in flood sometimes overflows at the Bend of the Ord and flows along the flood channel system. When this occurs the areas of Mantinea clay (see soil map) must be mostly flooded. At such times, too, Mantinea Creek probably

* Levels on north-south cross section lines taken in 1944 by F. Butson have been examined at the Public Works Department.

reverses its direction and functions as an anabranch of the river, feeding into the flood channel area.

All aspects of the hydrology will require careful assessment in determining the suitability of this area for settlement and agriculture.

Levels taken by the Public Works Department show that the clay plains east of Goose Hill are only about 30 feet above low tide levels at Wyndham and are therefore within ten feet of high tide levels. If, as suggested earlier, there has been a fall in sea level which changed the Carlton Reach Plain from a lake or bay to dry land, now out of reach of flooding, even by the Ord River, then it is reasonable to assume that the clay plains of the Mantinea—Goose Hill area are deltaic and tidal marsh formations. The brown light-textured alluvials which occur nearer the river are of more recent origin, like the Ord sandy loam of the Carlton Reach Plain.

If this explanation of events is correct, it is not surprising to find the subsoil of the clay plains becoming progressively more saline approaching Goose Hill. Between Goose Hill and Wyndham a reconnaissance sampling has shown considerable salinity on all the flats.

There is a general similarity of vegetation between the Carlton Reach Plain and the Mantinea Flats—Goose Hill area. Savannah woodland, with carbeen (*E. tessellaris*) as the principal tree, adjoins the river. The clay plains are almost treeless. The woodlands adjoining the hills seldom carry woollybutt or messmate as on the Cockatoo sand, but carbeen, cabbage gum, long-fruited bloodwood, boabab and *Gyrocarpus* are common. Spinifex is less common than on Cockatoo sand.

Description of soil types

The principal soils of this area have been named as follows:

1. Group A. These soils have shown more variations from place to place than it seemed desirable to allow in a single soil type, but sufficient data were not available on which to define and map a number of types. As a group, these soils are related to Ord sandy loam.
2. Winbidji loam
3. Mantinea clay c.f. Cununurra clay
4. Rainyerri sandy loam
5. Chunuma sand c.f. Cockatoo sand

For mapping purposes the following additional units have been recognized:

Group A soils, subject to seasonal flooding
Mantinea clay—flooded phase
Mantinea-Winbidji complex
A complex broad flood channel area
Swamps and billabongs
Rough stony hills

Group A (A and AF on map)

This is a group of brown soils, mostly of light texture, on the alluvial deposits adjoining the Ord and on the more or less crescentic banks within the old river meanders, north and east of Goose Hill. Even to depths of six feet the alluvial deposits are so variable that several soil types could be defined in more detailed soil survey work. The Ord sandy loam of the Carlton Reach Plain is much more uniform and it is one of the soil types which are included in Group A.

Profile

Group A soils have brown and grey-brown sandy loam, loam and silty loam surfaces, and brown, fine sandy clay loam, clay loam and silty clay subsoils. Below two feet, but sometimes as deep as five feet, the alluvial deposits become much more sandy. The texture is often fine sandy loam or loamy sand below two feet, but variable layers of clay loam and clay may be found in borings to 6 or 8 feet. East of the Bend of the Ord on Mantinea Flats, brown fine sandy clay loam from two feet to beyond six feet is common. This is the typical profile of Ord sandy loam. Tough clays seldom occur in Group A profiles. A friable and mellow consistency to at least six feet is characteristic.

On Mantinea Flats, Group A soils occur on fairly extensive and attractive areas. West of the Bend of the Ord, and within the old river

meanders, there are numerous long narrow depressions, also hollows between crescentic banks. These depressions are subject to seasonal flooding. Where they are extensive they are mapped as Group A, subject to flooding (AF on map). The uneven surface would complicate any irrigation layout.

The area of Group A soils mapped is 8,750 acres. This includes 938 acres subject to flooding (AF).

Winbidji loam (Wl)

This type occurs on old levee banks, and also extends as tongues on to the clay plains to form a complex pattern of Winbidji loam and Mantinea clay. It is not sharply defined from the heavier soils of Group A.

Profile

The surface soil is brown or grey-brown loam, silty clay loam or clay loam, and usually merges into brown or dark brown clay at 12 to 18 inches. The clay is often of tough consistency as on the clay plains. It continues for several feet, but layers of lighter texture below five feet have been noted.

Trees, especially coolibah and Bauhinia, occur on some areas of this type, but others carry only grass. Wind erosion has occurred in places, because of the concentration of cattle on them during both the wet season (to escape floods) and the dry season (to water at the adjacent billabongs). Also, the main motor track to Wyndham follows an old levee of Winbidj loam for some distance.

About 1,438 acres of this type have been mapped.

Mantinea clay (M^ac)

This is a soil very similar to the Cununurra clay, especially in the upper three feet of its profile. It seems to be developed, however, on river flood plain, deltaic and tidal marsh deposits, and in the western part of the survey has a saline subsoil. For these reasons it has been separately named, rather than include it with Cununurra clay. Locally. both are known as "black" soil.

Profile—normal phase—dry season description

0- 4″	Dark grey-brown crumbly and cloddy clay with large open cracks
4- 48″	Dark grey-brown tough clay, cracked to variable depth, often less dry and less tough below 24″. Small lime nodules and small black concretions as in Cununurra clay.
48-108″	Somewhat variable. Brown, red-brown, dark brown or grey-brown clay or fine sandy clay-loam, usually micaceous. Mellow consistency compared with upper four feet. Between Salt Water Creek and Goose Hill, grey, grey-brown and rusty mottled, moist, plastic clay has been found below 60″ and layers of sand or clayey sand sometimes occur below six feet.

A flooded phase of Mantinea clay has been mapped for areas of the type subject to regular flooding in the wet season. Black Pat Swamp and Blue Bush Swamp are the main areas shown, but other areas are included in the complex broad flood channel area mapped F.

As with Cununurra clay-flooded phase, the profile of Mantinea clay-flooded phase, is often dark grey in the upper four feet and is more tough and cloddy on the surface when dry.

About 3,318 acres of Mantinea clay have been separately mapped, including 742 acres of flooded phase.

Mantinea—Winbidji complex (M^a-W)

In passing from the Winbidji loam to the Mantinea clay, or in some areas from the Group A soils to the Mantinea clay, there are complex areas of soil. These include patches of typical Mantinea clay with strips or tongues of alluvial soil like the Winbidji loam. Some profiles have features of both types. These areas could not be mapped in detail in the present survey, and are shown as Mantinea—Winbidji complex. The area of this complex is 2,288 acres.

Rainyerri sandy loam (Rsl)

This soil occurs on the more gentle slopes where the hilly areas to the south meet the alluvial flats. The foothills, where seen, are mostly shales and fine-grained sandstones, and many are rough and stony. Where soil has developed, it is usually greyish-yellow and compact, and scattered surface stones of shale and sandstone are common. Fragments of stone may also occur in the profile.

0- 9″	Greyish-yellow, compact, fine, sandy loam
9-18″	Greyish-yellow, hard, sandy clay-loam and sandy clay
18″+	Shale has often been found at about 18″.

An extensive area of Rainyerri sandy loam occurs between Mantinea Creek and Buttons's Gap, and probably also east and north of False House Roof Hill. As the detailed soil survey extended only to the fringe of the foothills, the area of Rainyerri sandy loam mapped is only 1,260 acres.

Areas of this soil are locally regarded as of low pastoral value. Sugar grass and spinifex are the only important grasses and are rather sparsely distributed between the various small trees. This soil is not attractive for agriculture and cannot be considered for irrigation.

Chunuma sand (C^hs)

In being a deep sandy soil, this type has an important practical relationship to the Cockatoo sand. It is, however, the soil of large alluvial sand fans produced where streams flowing from the south have deposited relatively fine sands between the foothills. Some areas are fairly extensive—up to 1.5 miles wide—and go back beyond the limits of the detailed survey. Their limits were not pursued because, like the Cockatoo sand, the Chunuma sand cannot be regarded as suitable for irrigation.

Profile

0- 9″	Light grey or light grey-brown, fine sand
9-72″	Light brown or grey-brown fine sand, generally finer than Cockatoo sand. Grey and brown mottled sandy clay-loam or sandy clay sometimes occurs at 4 to 6 feet.

Old deserted watercourses occur in some areas. On the whole, areas of this type are apparently not now subject to flooding, but wet season waterlogging may occur because of their almost flat topography and the proximity of streams and hills.

The complex flood channel area which is mapped between the Chunuma sand on the south and the Mantinea clay on the north includes areas of both these types in its complex pattern. About 2,582 acres of Chunuma sand are separately mapped.

Complex flood channel area (F)

It has been necessary to map without detail the very complex flood channel area into which the streams from the south pour their waters in the wet season and along which river overflow sometimes passes. The surface is irregular, with billabongs, watercourses and various small local depressions. The soils are complex, ranging from flooded phase of Mantinea clay on the north to Chunuma sand on the south. All the variations produced by mingling sandy and clayey alluvial materials are found, such as sands of varying depths over clays and sandy clays, or fine sandy and silty clay surfaces. The influence of seasonal waterlogging is reflected in the grey and rusty mottling of surface layers in many parts.

To use parts of this area for irrigation, the construction of drains and levees would be necessary. Areas on the north side might be thus used, where the soils are mostly Mantinea clay or somewhat similar clay soil. It is doubtful if any areas on the south are suitable, since the flood channel area merges with Chunuma sand and Rainyerri sandy loam, neither of which is a suitable irrigation type.

Billabongs and "Swamps" (D)

Apart from the main complex flood channel area described above, a number of well-defined, lowlying areas, known locally as billabongs and swamps, have been distinguished on the soil map. The main areas are the old river meanders north and east of Goose Hill. The soils are mostly dark grey to black, tough clays, extensively cracked after the waters evaporate in the dry season. Coolibah and gutta percha comprise most of the vegetation, except in the area north-east of House Roof Hill Crossing, where freshwater mangrove (*Barringtonia* sp.) makes a dense thicket.

Because of their lowlying situation and inundation for long periods, the billabongs and swamps would be unsuitable for reclamation for agriculture. The area north and north-east of Goose Hill is within the range of the highest tides.

Soil erosion

Accelerated erosion is not extensive in the Mantinea Flats—Goose Hill area. Near the road crossing on Salt Water Creek, and also near Goose Hill Creek, gully erosion has eaten away small areas indicated on the plan by the letter 'E'. On the old low levee of Winbidji loam, north of Blue Bush Plain, wind erosion of the surface soil has occurred, because of the concentration of cattle drinking at the billabongs and to the use of this old levee as a motor route.

Soil salinity

West of the Bend of the Ord, and more especially between Salt Water Creek and Goose Hill, Mantinea clay was found to contain considerable amounts of salt in its deeper layers. Winbidji loam, west of Salt Water Creek, is also quite saline. If these types were used for irrigation, it would be necessary to use methods which would prevent surface concentration of salt. In irrigation areas the world over, salt is frequently a major problem, even on soils not originally saline. The presence of salt in considerable quantities in these soils is related to their origin as deltaic or tidal marsh deposits.

The salinity of Mantinea clay and Winbidji loam is summarized in Table 4.

The light-textured, more recent alluvial soils (Group A) were, like the Ord sandy loam, consistently very low in chloride. Only a few samples were taken for analysis from Rainyerri sandy loan, and Chunuma sand, and all were low in soluble salts. Several sites in the gutta percha swamps of the old river meanders showed high salt concentrations.

For data on soil salinity west of Goose Hill, see Table 7.

Table 4. Salinity of Mantinea clay and Winbidji loam

Chloride as sodium chloride per cent of air dry soil	Number of sites sampled			
	first foot*	1 to 3 feet*	3 to 6 feet*	6 feet and deeper
Mantinea clay				
(a) East of the Bend of the Ord (8 sites)				
0.02 and less	6	8	6	4
0.03—0.20	0	0	2	1
0.21—0.50	0	0	0	0
>0.50	0	0	0	0
(b) Bend of the Ord to Salt Water Creek Crossing (7 sites)				
0.02 and less	2	4	0	0
0.03—0.20	0	1	2	3
0.21—0.50	0	1	2	2
>0.50	0	0	1	1
(c) Salt Water Creek Crossing to Goose Hill (6 sites)				
0.02 and less	3	1	0	0
0.03—0.20	0	3	0	0
0.21—0.50	0	2	2	4
>0.50	0	0	4	1
Winbidji Loam				
(a) Mantinea Creek to Salt Water Creek Crossing (9 sites)				
0.02 and less	3	6	6	6
0.03—0.20	0	2	0	0
0.21—0.50	0	0	0	0
>0.50	0	0	0	0
(b) Salt Water Creek Crossing to Goose Hill (4 sites)				
0.02 and less	1	0	0	0
0.03-0.20	0	1	0	0
0.21-0.50	0	2	2	2
>0.50	0	0	0	1

* Composite samples representing the whole of each layer were not usually taken, but rather small samples representing conditions 0-6″, or at 24″, at 48″, at 72″ etc.

Suitability of the area for irrigation

For purposes of this report, it is assumed (as was also done in discussing Carlton Reach Plain), that (a) permanent agriculture would not be possible without irrigation, and (b) irrigation water can be supplied.

The complexity of the soil distribution and the natural drainage system of the area present more problems than on Carlton Reach Plain. Soil salinity is an additional factor.

None of the soil types of the Mantinea Flats—Goose Hill area was tested for its infiltration capacity, but by comparison with generally similar soils on Carlton Reach Plain, a reasonable assessment is possible.

Group A

These brown alluvial soils will have similar irrigation characters to the Ord sandy loam. They are attractive types, but the areas west of the Bend of the Ord, and especially within the old river meanders, have an uneven surface with many local depressions because of the character of the alluvial deposits. This would complicate an irrigation layout both for supply channels and on individual farms. No drainage difficulties are anticipated on these soils. As they are likely to be very permeable to water, the lining of supply channels to avoid seepage losses and to reduce the risk of waterlogging should be considered.

Mantinea clay

Under irrigation this soil should behave the same as Cununurra clay. After the initial wetting of dry soil it will have a low infiltration rate.

Where the deeper layers of this soil are saline, there is always the possibility of salt concentrating near the surface if water tables develop. Victorian experience at Kerang and Cohuna has shown that saline areas can be handled by careful grading and suitable watering technique. The provision of main drains penetrating to the more mellow and more permeable layers generally occurring below four feet would assist in controlling subsoil water, provided they can drain freely during the normal wet season.

Seepage from irrigation channels in Mantinea clay would be very small provided the channels do not dry out. In both channels and drains erosion may occur if flow rates are too great. This possibility is based on observed gully erosion in Cununurra clay.

Winbidji loam and Mantinea-Winbidji complex

These soils appear generally suitable for irrigation. The Winbidji loam is likely to have infiltration rates between those of Ord sandy loam and Cununurra clay. The complex areas would probably require an irrigation layout to water the Mantinea and Winbidji types separately as far as possible.

West of Salt Water Creek Crossing soil salinity must not be overlooked.

Chunuma sand and Rainyerri sandy loam

Neither of these types can at present be considered suitable for irrigation.

Complex flood channel area

The area mapped under this heading totals 6,734 acres, which is 22.4 per cent of this survey. Where it borders the Mantinea clay on the north side, the areas subject to flooding include areas of Mantinea clay, flooded phase, and, if protected by suitable flood levees, could be used for irrigation. Going south the area has numerous watercourses and becomes very complex with sand banks and small depressions. It then passes on to the deep sandy soil, Chunuma sand, which is not suitable for irrigation.

Because of its complexity and its associations, it is considered unlikely that more than one-fifth of the area mapped as flood channel area can be regarded as potential irrigable land.

Swamps and billabongs

These would be natural locations or end points for drains and are not suitable for irrigation.

General fertility of the soils

The remarks under this heading concerning the soils of the Carlton Reach Plain apply also to the Mantinea Flats-Goose Hill area.

Areas of soil types and potential irrigable areas

Table 5 sets out the areas of the various soil types.

The total area of the soil survey is 29,992 acres, of which 14,141 acres are shown as potentially irrigable. Group A soils, with 5,750 acres, or 40.6 per cent, are the major item. A further 4,000 acres of this group, in the north-west of the survey, have not been included on account of their distribution within and about old river meanders and their irregular surface.

Mantinea clay is shown as 3,318 acres, or 23.5 per cent, of the irrigable land. Further areas of this type are of course included in the Mantinea-Winbidji complex and in the complex flood channel area, so that the total area is between five and six thousand acres.

Table 5 gives the areas of the various soil types occurring east and west of the Bend of the Ord. These may be useful because the alluvial flats have a natural constriction in this vicinity, and also because soil salinity only becomes important west of the Bend.

Table 5. Mantinea Flats—Goose Hill soil survey. Areas of soil types and potential irrigable areas

	Sheet 1 west of Bend of Ord acres	Sheet 2 east of Bend of Ord acres	Total Area acres	Per cent of total area	Potential Irrigable Areas* Acres	Per cent of irrigable area
1. Brown alluvial soils near the Ord River, also in old meanders and on old levees						
Group A, generally of light texture	6188	2562	8750	29.2	5750	40.6
Normal phases	5250					
Subject to seasonal flooding	938					
Winbidji loam	938	500	1438	4.8	1438	10.2
2. Dark grey-brown and grey (so-called "black") clay soils of the plains and swamps.						
Mantinea clay	2492	826	3318	11.1	3318	23.5
Normal phase	2268	308				
Flooded phase	224	518				
Mantinea-Winbidji complex	1218	1070	2288	7.6	2288	16.2
3. Soil of the gently sloping shale and sandstone foothills						
Rainyerri sandy loam	560	700	1260	4.2	—	—
4. Deep sandy soil mostly on alluvial fans.						
Chunuma sand	2170	412	2582	8.6	—	—
5. Complex flood channel area.	5082	1652	6734	22.4	1347 (est. of total)	9.5
6. Swamps and billabongs, well-defined, lowlying, unsuitable for reclamation.	2660	56	2716	9.1	—	—
7. Stony hills.	840	66	906	3.0	—	—
Total	22148	7844	29992	100.0	14141†	100.0

* No allowance has been made for reserves, levees, channels, drains or roads.
† About 3000 acres of Group A soils in the north-west part of the survey is not included on account of its distribution within and about old river meanders and its irregular surface.

In assessing irrigable areas, no allowance has been made for reserves, levees, channels, drains or roads.

General comments

The Mantinea Flats—Goose Hill area lies on the route normally traversed by cattle coming from the east to the Wyndham meat works. If subdivided and developed for irrigation, cattle might pass in the dry season along the south part of the flood channel area and over the low foothills and areas of Chunuma sand and Rainyerri sandy loam, but would require a watering place, perhaps at the Bend of the Ord. The construction of a railway out from Wyndham for up to 100 miles for the transport of cattle would eliminate Carlton Reach Plain and Mantinea Flats from use as a stock route.

Other areas which may be suitable for irrigation

Besides the Carlton Reach Plain and the Mantinea Flats-Goose Hill area, there are several other areas of alluvial flats which may be suitable for irrigation. Some of these were examined in a brief reconnaissance during 1944, but others were not seen. On the locality plan of Figure 1, these various areas are indicated. Their limits have been determined by reconnaissance, by collaborative work with Surveyor Richter, and from aerial photographs. The areas involved are set out in Table 6.

The general features of each area, as far as they are known, are set out below.

House Roof Hill-Carlton homestead (21,000 acres)

This area almost completely surrounds House Roof Hill and apparently merges into the marshes of the Ord estuary. The run-off from much of House Roof Hill and from a large area east of Carlton, flows over these flats on its way to the Ord estuary (see drainage area 3, Figure 2).

There appear to be large areas of brown alluvial soils similar to the Ord sandy loam and the Group A soils of the Mantinea Flats, also smaller areas similar to Mantinea clay.

Table 6. Other areas of alluvial flats which may be suitable for irrigation

	Acres
(a) House Roof Hill—Carlton homestead	21,000
(b) Ivanhoe homestead	2,500
(c) Valentine Creek—Bandicoot Range	5,000
(d) Denham River—Carlton Reach	21,000
(e) South of Carlton Reach Hills	4,000
(f) Point Spring—Cave Spring—Border Creek	47,000
(g) Weaber Plain	24,000
	124,500

Ivanhoe homestead (2,500 acres)

Around Ivanhoe homestead is an area of soils like Ord sandy loam and Cununurra clay. It drains into the lagoon at Ivanhoe homestead, thence north into a watercourse leading into the Ord.

Valentine Creek—Bandicoot Range (5,000 acres)

A reconnaissance of this area to interpret the aerial photographs, showed that it is made up principally of brown soils carrying box timber and generally similar to Meruin sandy loam. Strips of dark grey-brown clay soil with a surface similar to Cununurra clay occur among the brown soil. Adjoining the river a belt of Ord sandy loam of variable width occurs. Sandy and stony soils adjoin the Bandicoot Range.

Denham River—Carlton Reach (21,000 acres)

No inspection of this area was possible in 1944, but from aerial photographs, large flat alluvial areas adjoining Carlton Reach and running back along the Denham valley can be outlined. These areas may be subject to flooding by river overflow during the wet season.

South of Carlton Reach Hills (4,000 acres)

On the right bank of the Ord between the gorge and Carlton Reach Hills are two small areas of alluvial flats. The smaller of these, between Crossing Falls and Carlton Reach

Hills was examined. The Ord sandy loam and Mervin sandy loam types both occur. Some of the drainage is into a central lagoon.

Point Spring-Cave Spring-Border Creek (47,000 acres)

This is a large area of heavy clay soil similar in general to the Cununurra clay of Carlton Reach Plain. Large areas are subject to seasonal flooding. The drainage has already been discussed under drainage area 8 (see Figure 2). It seems likely that irrigation water from the Ord could be gravitated to this area via Cave Spring valley, but only by levelling could this be confirmed.

Weaber Plain (24,000 acres)

The limits of this area associated with the Keep River were fixed by Surveyor Richter in the course of his surveys associated with the Martin's Gap base line. It is said to be an area of clay soil similar to Cununurra clay. Local station people report that flooding by the Keep River and Knox Creek is common. It is doubtful whether irrigation water from the Ord could reach this area by gravitation.

The flats between the "Nine-Mile", Parry's Creek and Goose Hill

After passing the 'Nine Mile', the track from Wyndham to Goose Hill crosses a low stony spur of basalt and sandstone and then passes on to extensive flats. These flats extend north to the tidal marshes of the Ord estuary, and are bounded on the south by the foothills between Mount Erskine and Goose Hill. Levels taken along the track on these flats by the Public Works Department range from 23 to 34 feet above low tide levels at Wyndham. As the tidal range is 23 feet*, much of these flats is very little above the levels of the highest tides. They are probably deltaic and tidal marsh deposits. Parry's Creek, draining a large area to the south (Figure 2), pours its waters on to the western part of these flats and has contributed much alluvium to them. Judging from the aerial photographs, much of the drainage from east of Goose Hill, which passes into the old river meander north of Goose Hill, probably also flows out on to these flats in times of flood.

The distance in a straight line from the 'Nine Mile' to Goose Hill is 11 miles. The soil was examined at a number of sites along the track, particularly to study the salt status. Grey clay surfaces are common, but strata of sand are often found below two feet. All profiles examined were saline, but the surface foot contained relatively small amounts of salt at some sites. Details are given in Table 7.

The flooding, drainage and salinity problems of this area are such that it cannot at present be considered worthy of any further detailed investigation for agriculture and irrigation.

* Information from Mr Gorham, North-West Branch, Public Works Department.

Table 7. Details of soils from the "Nine-Mile" to Goose Hill July 10-11, 1941. Field Book 2, Sites 23 to 31

Location and general remarks	Serial no.	Depth inches	Salt NaCl % air dry soil	Soil description
On tidal marsh 0.7 mile west of the 'Nine Mile' buildings	A 4293	0-1	5.83	Grey-brown clay. Surface mud cake.
	A 4294	1-12	2.17	Dark grey-brown tough clay.
	A 4295	12-24	4.33	Dark grey mottled yellow
	A 4296	24-36	5.17	and yellow-brown. Very plastic smooth clay. More wet and sticky 24-36″.

Location and general remarks	Serial no.	Depth inches	Salt NaCl % air dry soil	Soil description
At bench mark B12, 1.85 miles east of 'Nine Mile'. Reduced level of bench mark 26.5 feet. Mostly bare, some rice grass (*Zerochloa barbata*) and samphire (*Salicornia* sp.)	A 4297	0-2	0.42	Grey crumbly clay, laminated 0-1/4″.
	A 4298	2-12	0.92	Dark grey-brown crumbly clay. More tough 9-12″.
	A 4299	12-24	1.33	Dark grey-brown plastic clay.
	A 4300	24-60	2.08	Dark grey-brown, grey and brown mottled sticky clay.
	A 4301	60-72	2.25	Olive and brown and yellow-brown mottled sticky clay with gypsum crystals.
	A 4302	72-75	2.58	Dark grey sticky clay and gypsum and white decomposed rock. Solid 75″.
About 1 mile S.E. of Twelve Mile lagoon and 1/2 mile E. of B.15 (R.L. 27.12). Site in grassed area. Grasses include woolly top (*Eriachne*), but not rice grass. Basalt hills to south.	A 4303	0-2	0.02	Light grey silty loam.
	A 4304	2-12	0.08	Grey clay with rusty mottlings 2-4″, then dark grey-brown. Tough below 6″.
	A 4305	12-24	0.37	Dark grey-brown tough clay. Small lime nodules and small black nodules.
	A 4306	24-36	0.32	Grey mottled sandy clay and sand in layers, 36-39″ sand, discarded.
	A 4307	39-60	0.60	Grey-brown sticky clay, mottled olive-brown and yellow, cf A 4296 and 4301.
Near B.17 (R.L. 30.79) about 1 mile N.W. of road crossing on Parry's Creek. About 20 chains south of Parry's Creek. Grass flat, mostly *Eriachne*.	A 4316	0-2	0.01	Grey clay—rusty mottlings.
	A 4317	2-12	0.01)	Dark grey, tough clay,
	A 4318	12-24	0.08)	some rusty mottlings.
	A 4319	24-33	0.21	Light grey-brown sandy clay. Lime nodules up to 1″.
	A 4320	33-54	0.14	Mostly sand with/thin clay bands, grey and grey-brown.
	A 4321	54-63	0.26	Brownish-grey sticky line sandy clay. 63-72″ sand and clay.
	A 4322	72-90	0.55	Grey, olive and brown mottled, smooth sticky clay of A 4307.
1/2 mile east of road crossing on Parry's Creek. Grass flat mostly *Eriachne*, scattered chestnut and gutta percha trees.	A 4308	0-3	0.01	Light grey laminated clay rusty mottlings.
	A 4309	3-12	0.02	Dark grey tough clay.
	A 4310	12-24	0.21)	Dark grey-brown to dark
	A 4311	24-36	0.45)	olive tough clay.
	A 4312	36-48	0.44	Grey-brown clay some fine sand, lime nodules to 1″ and soft lime in pockets.
	A 4313	48-66	0.41	Layers of grey-brown mottled clay and sand.
	A 4314	66-78	0.21	Mostly grey-brown and pale brown sand.
	A 4315	78-90	0.37	Greenish-grey and rusty mottled sticky clay, then light grey line sandy clay-loam and grey clay.

Location and general remarks	Serial no.	Depth inches	Salt NaCl % air dry soil	Soil description
1.15 miles N.E. of the road crossing at Parry's Creek. In large gutta percha swamp Rough cracked surface. Receives drainage from low foothills between Parry's Creek and Goose Hill.	A 4323	0-6	0.01	Dark grey cloddy clay, very hard.
	A 4324	6-12	0.14)	Dark, grey, very tough clay.
	A 4325	12-27	0.32	Light grey-brown
	A 4326	27-36	0.21	micaceous sandy loam.
	A 4327	at 42	0.51	Light grey-brown micaceous line sandy clay, sharp lime pieces.
	A 4328	at 66	0.39	Light grey-brown sandy loam.
	A 4329	78-108	0.33	Grey-brown wet micaceous sandy loam and sandy clay loam. No free water.
		108-116		Grey-brown sand no sample.
2 miles W. of Goose Hill in coolibah country bordering old river meander. No grass but a ground cover of a dried up herb (? Halophytic).	A 4330	0-3	0.05	Grey-brown dry clay loam.
	A 4331	3-12	0.02	Grey-brown dry clay.
	A 4332	12-24	0.27	Dark grey-brown moist mellow clay.
	A 4333	24-36	0.44	Dark brown clay, passing to grey-brown fine sandy clay-loam with sharp lime pieces.
	A 4334	36-60	0.40	Light grey-brown micaceous line sandy loam.
	A 4335	60-75	0.24	One clay layer then light grey-brown clayey sand with big lime pieces.
1 mile W. of Goose Hill on open flats south of coolibahs which are along the old meander levee. Some sheet erosion nearby. Only vegetation a dry herb (? Halophytic)	A 4336	0-2	0.02	1/2″ laminated silty material on grey-brown clay.
	A 4337	2-12	0.17	Grey-brown friable to tough clay.
	A 4338	12-24	0.59	Dark brown-dark grey-brown moist clay.
	A 4339	24-54	0.63	Similar to 12-24″, but tougher. Contains lime nodules.
	A 4340	54-78	0.60	Dark Grey-brown tough clay.

Acknowledgements

Soil investigations in the east Kimberley during 1944 were aided by many people in various ways. The organization of the overland transport from Perth to Wyndham of personnel, stores and equipment was very capably organized by Surveyor A.H. Richter, of the Lands and Surveys Department, assisted by Surveyor G.F. Medcalf. Mr Richter was in charge of the administration and general survey work of the survey camp, in which soil survey officers of the Department of Agriculture, and the Division of Soils, C.S.I.R., were accommodated. The Lands and Surveys Department, through the staff of the Chief Draftsman, Mr P. Stanley, also supplied working plans, skilfully compiled from the aerial photographs, on which to plot the soil information. The colouring and copying of the soil survey plans and the plans of Figures 1 and 2 were also carried out by the Chief Draftsman's staff.

Dr L.J.H. Teakle, Plant Nutrition Officer, Department of Agriculture, gave very valuable advice and help during two visits to the area. Mr S.T. Smith, Department of Agriculture, and Mr G.A. Stewart, seconded from Soils Division, C.S.I.R., gave sterling service as soil surveyors throughout the routine soil survey work.

Mr K. Durack provided much valuable information about the district and the cattle industry, and his discussions of the irrigation project in the light of his experience at Carlton Reach were always stimulating. His sister, Mrs H.C. Miller (Mary Durack), provided many local aboriginal names from which several were selected to name the soil types (Appendix 4).

The aerial photographs which were so valuable in understanding the area, were loaned by the Director of Works, Mr R.J. Dumas. His officer, Mr F. Butson, provided data concerning the levels on Mantinea Flats and Carlton Reach Plain as they became available.

The Government Geologist, Mr F.G. Forman, and the Government Botanist, Mr C.A. Gardner, gave considerable help with the geology and botany, respectively, of the area.

The visit of Dr T.J. Marshall, Soils Division, C.S.I.R. to the area in September, when water infiltration tests were made, gave an opportunity to discuss on the spot, the irrigation potentialities and problems of the soils.

A visitor to the camp for about two months was Mr W.H. Maze, lecturer in geography, University of Sydney. Discussions with him of geography, physiography and river action were a valuable help in the interpretation of the area, while his good companionship will be a lasting memory.

All the personnel of the soil survey camp contributed to the success of the season's work under isolated, and often arduous conditions. Mr G. Biggs, as motor driver—survey hand, on most of the soil survey work, is specially mentioned.

On the long overland journey from Perth to the Ord River, the Government Entomologist, Mr C.F.H. Jenkins, was a mine of information concerning the fauna along the route. The Government Botanist Mr C.A. Gardner, also travelled overland with the party from Broome to the Ord River. The presence of Messrs Jenkins and Gardner added greatly to the interest of the trip.

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Appendix 1

Council for Scientific and Industrial Research
Division of Soils
Waite Institute
ADELAIDE
Divisional Report No. 15/44

Physical properties of Ord River soils
By T.J. Marshall

At the invitation of the Department of Agriculture, Western Australia, an investigation has been made of the physical properties of soils in the area proposed for irrigation on the Ord River. The object of this work was to assist soil investigators from the Department, who were engaged on a soil survey of the area, in the assessment of the following factors:

1. Suitability of the soils for irrigation.
2. Likelihood of development of water tables or of saline conditions in the area.
3. Natural and artificial drainage of the soils.
4. Effect of irrigation practices upon soil structure.

The field work has been planned and carried out in co-operation with Dr L.J.H. Teakle (Plant Nutrition Officer) and Mr G. Burvill of the Department. It consisted of the measurement of the rate of infiltration of water into the soil, the depth of penetration for a given irrigation, and the amount of water retained by the soil*. In the laboratory, further work will be done in connection with items 1 and 4.

Description of soils

Representative sites were chosen for investigation on the three major soil types of the area—Cununurra clay, Type A and Cockatoo sand. A description of the soil at each site is given below:

Cununurra clay

Two sites were selected,
1. on an area proposed for use as experimental plots and situated across the river from Ivanhoe homestead, and
2. on the Argyle-Ivanhoe road about 3/4 mile north from the Lands Department survey camp.

This type is characteristic of the extensive clay plains and is the most important. At the time of this investigation (September 1944) the soil was heavily cracked to a depth of 24 or 30 inches. The profile at site 1 is illustrated below.

	Depth (0)	
Dark grey brown	7"	clay (cracked; crumb to clod structure)
Dark grey brown	24"	clay with some lime nodules and black concretions (cracked; tough consistence)
Dark grey brown	45"	clay, as above, but not cracked
Transitional zone	52"	
Brown	75"	clay
Light brown	96"	micaceous fine sandy clay loam; slight lime streaks
Light brown	114"	loamy fine sand

* Mr G.A. Stewart (Division of Soils, C.S.I.R.) and Mr S.T. Smith (Department of Agriculture, Western Australia) undertook many of these measurements.

Type A (later named Ord sandy loam)

This is representative of the alluvium found in a narrow strip along the river banks. The test was carried out on non-irrigated land at the Carlton Reach experimental plots. Here the soil had the following profile:

	Depth	
	0	
Dull brown	6"	fine sandy loam
Brown	36"	fine sandy clay loam with mica (1 mm. tubes through soil)
Brown	60"	fine sandy clay to sandy clay loam
Brown	84"	sandy loam
Brown		loamy sand

Cockatoo sand

This is a sandy colluvial soil adjoining quartzite hills. It is not likely that serious consideration will be given to this type in the irrigation project.

	Depth	
	0	
Grey brown	9"	sand
Greyish yellow brown	30"	sand, somewhat compact
Light yellow brown	60"	Sand with occasional soft ferruginous gravel below 55"
Light yellow brown	86"	Sand with some ferruginous gravel; some increase in clay content
Light yellow	9'	sand (as above)
Mottled red-brown, grey and yellow	12'	sandy clay loam with some ferruginous gravel

Field methods

At each site the soil was broken up to a depth of six inches, and a ring of galvanized iron five feet in diameter was pressed about two inches into the soil. At the Cununurra clay sites, large cracks outside the ring were stopped to some extent by throwing soil into them. The initial water content of the soil was determined on samples taken from a hole bored nearby (Table A.1.1.) Water was run on to the enclosed surface through a siphon from 100 and 200 gallon tanks at intervals to bring the water on the surface of the soil to a predetermined level. The amount added at each time was gauged. Results are given in Figure A.1.1. and an illustration of the method employed is given in Figure A.1.4.

When the infiltration rate had become steady, the wetted surface was covered with galvanized iron and left for three or four days. Samples were then taken to determine the amount of water retained in the wet horizons (field capacity) and the depth of penetration was in addition determined from the appearance of the soil and the ease of boring. Excavations and borings at the edge of the wetted zone showed the lateral penetration of the water (Figure A.1.3.). In the case of the Cununurra clay, a second watering was given some time later at each site after blocking up any holes made by sampling. At site 1 this was given four days after the first application had ceased, the soil having been covered during the interval. At site 2, the surface was covered for four days and then left exposed for eight days before the second application was given, by which time cracks 3/8″ wide and 1 1/2″ apart had developed. Results from these second waterings are included in Figure A.1.1.

Rate of entry

It can be seen from Figure A.1.1. that water entered with great rapidity at first into the Cununurra clay soil—over five inches having entered in the first hour at both sites. This

Table A.1.1. Water content of soil before and after irrigation

Soil type	Depth (inches)	Water content, % by wt. Initial	Final ⊗ 1st irrig.	Final ⊗ 2nd irrig.	Water added (in 1st irrigation) % by wt	Water added (in 1st irrigation) % by vol.*
Cununurra clay	0-7	8.7	30.0	26.9	21.3	25.5
Site 1,	7-15	12.9	28.9	26.7	16.0	19.4
proposed	15-24	12.8	25.9	25.5	13.1	15.7
experimental	24-36	12.5	21.9	24.5	9.4	11.3
plots	36-42	14.4	21.8	18.5	7.4	8.9
	42-48	—	—	14.6+	—	—
Cununurra clay	0-12	9.0	34.4	30.8	25.4	30.5
Site 2, near	12-24	12.1	31.7	28.5	19.6	23.6
survey camp	24-36	16.8	19.4	21.0	2.6	3.1
	36-48		—	18.7+	—	—
Type A	0-6	2.9	19.8	—	16.9	22.0
Ord sandy loam	6-18	5.6	18.7	—	13.1	17.0
	18-36	6.8	20.7	—	13.9	18.1
	36-48	6.8	16.7	—	9.9	12.9
Cockatoo sand	0-9	0.5	6.4	—	5.9	8.9
	9-18	1.7	5.2	—	3.5	5.3
	18-30	1.7	6.5	—	4.8	7.2
	30-45	2.5	8.4	—	5.9	8.8
	45-60	2.5	9.9	—	7.4	11.1
	60-80	3.1	8.5	—	5.4	8.1

* Assuming that the apparent specific gravity of all horizons in Cununurra clay was 1.2; Type A, 1.3; Cockatoo sand, 1.5.
+ Unwetted appearance.
⊗ After the 2nd irrigation the surface was left uncovered for four days before sampling; hence lower values near surface due to evaporation.

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Table A.1.2. Infiltration summary

Soil type	Cununurra clay Site 1 1st irrig.	Site 1 2nd irrig.+	Site 2 1st irrig.	Site 2 2nd irrig.+	Type A (Ord sandy loam)	Cockatoo sand
Duration of irrigation hours	27	27	13	17	10	0.7
Total water added, *inches	17	5	12	8	20	8
Percentage of total water directly below wetted surface	36	—	46	—	40	95
Water directly below wetted surface, inches	6	2⊗	6	4⊗	8	8
Depth of wetting inches	33	42	27	36	48	78
Actual rate of entry (thousandths of an inch per min.)						
(a) After 30 mins.	40	17	30	12	40	50
(b) After 2 hours	25	5	20	8	35	—
(c) After 8 hours	7	2	7	6	28	—

* Including water which remained on surface when gaugings were completed.
⊗ Using percentage factor obtained for 1st irrigation.
\+ Second irrigations followed 4 days after the first at Site 1 and 12 days after the first at Site 2. The surface was covered for four days in each case.

was because of the heavy cracking which had occurred in the dry soil to a depth of two feet. The rate of entry then progressively decreased, and at the end of eight hours, water was soaking in at a rate of less than 1/2″ per hour at both sites.

At the Type A and Cockatoo sand sites a fairly even rate of infiltration was maintained throughout the period of trials.

A few comparative figures for rate of entry are given in Table A.1.2.

Irrigation profile

The volumes wetted by these irrigations are represented diagramatically in cross section in Figure A.1.3. In the Cununurra clay, penetration below the cracked zone was restricted. After soaking for 27 hours, water had not penetrated appreciably below 33″*. On the Cununurra clay a second irrigation was carried out at both of the original sites (Figure A.1.1.). At site 1 after a total irrigation period of 54 hours, water had penetrated effectively to a depth of only 42″. After 10 hours of irrigation, Type A soil was wetted to a depth of 48″, and after 45 minutes the Cockatoo sand was wetted to 78″.

Lateral penetration (beyond the limits of the irrigated surface) was considerable in the Cununurra clay and Type A profiles. It was not great in the Cockatoo sand because there are no horizons within seven feet to restrict the downward movement of water.

In Table A.1.1. the final water content (per cent, by weight) represents the field capacity of those horizons that were fully wetted—probably to a depth of two feet in the Cununurra clay, three feet in Type A and six feet in the Cockatoo sand. It can be seen that to a depth of two feet the amounts of water retained (by weight) in the three types are of the order 30%, 20% and 6% respectively. An estimate of the portion of this amount that is available to plants will be made experimentally later. (Wilting points later determined by Dr Marshall as 16.3, 6.2 and 1.6% respectively.)

* For a few inches above and below that depth there was an intermediate zone consisting partly of wet and partly of dry soil.

Movement downward and laterally

It can be seen from Figure A.1.3. that much of the water entering the soil penetrates laterally. Consequently, the measured infiltration rates are higher than would be the case in a confined cylinder of the same soil or in a larger area under irrigation. The amount of water actually added to a cylindrical column of soil, located immediately under the wetted surface, can be calculated from the water contents of the soil before and after irrigation and the apparent specific gravity of the soil. No actual measurements of the latter quantity were made, but—based on the texture—the figures quoted in Table A.1.1. were adopted and are probably within 0.1% of a unit of being correct. The increased amount of water found within the cylinder at the end of the irrigation was expressed as a percentage of the total amount added and as surface inches of water (Table A.2.2). It will be seen that, except in the Cockatoo sand, less than 50% of the added water is contained in the cylindrical column.

Further use was made of this estimate of the percentage of total water actually within the cylindrical column of soil at the conclusion of the irrigation. The infiltration curves given in Figure A.1.1. represent the full amount entering each soil and include that part of the water which spreads laterally beyond the cylindrical column. As a rough guide to the infiltration rates to be expected when a large area is wetted (when the boundary effect will be negligible), these percentages were applied to the infiltration data and the curves given in Figure A.1.2. were obtained. The last point on each of the curves for the first irrigations is reasonably accurate (subject only to errors in sampling and in the apparent specific gravity). However, all other points on the curves are to be treated with reserve, since it is unlikely that the percentage used in these adjustments is constant throughout the period of the irrigation. These percentage factors can be applied with similar reservations to the rate of entry data in Table A.1.2 and it will be seen that on this basis the vertical movement

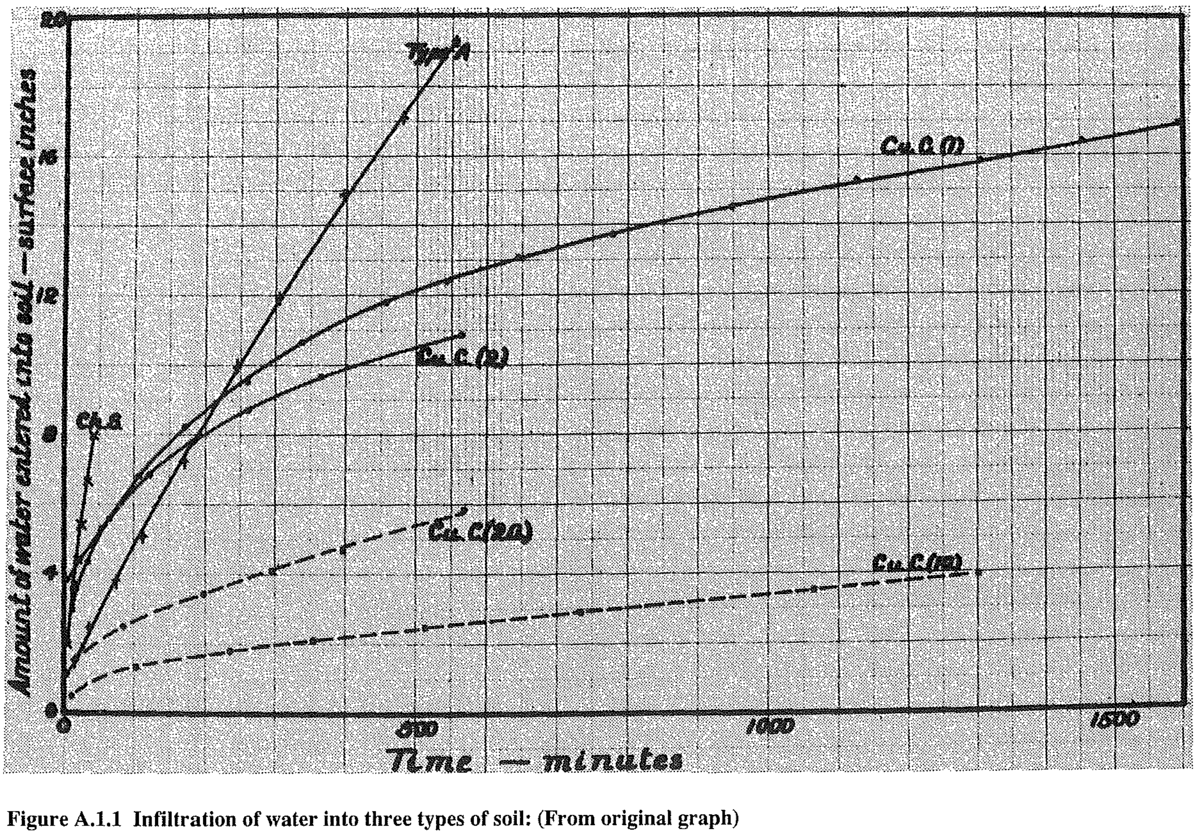

Figure A.1.1 Infiltration of water into three types of soil: (From original graph)

Cockatoo sand (Ck.s.), Type A and Cununurra clay (Cu.c.)
Cu.c. (1) and Cu.c. (2) represent sites 1 and 2 respectively on the Cununurra clay.
Second irrigations on these two sites are shown by the broken lines Cu.c. (1a) and Cu.c. (2a) respectively.

of water into Cununurra clay at both sites, after eight hours soaking into initially dry soil, is at the rate of 0.2″ per hour.

Summary of field observations

Cununurra clay

Water enters this soil readily when it is dry and cracked. After swelling has occurred and and the cracks are sealed over, the entry of water is restricted.

Penetration of water was not deeper than 42″ even when water was maintained on the surface for two periods aggregating 54 hours.

This soil would be particularly well adapted to the irrigation of rice, and should be satisfactory—subject to the finding of suitable varieties—for pasture and crop production. There may be some difficulty in irrigating deep-rooted plants such as lucerne satisfactorily.

The building up of underlying water tables should not constitute a problem. As a consequence, salt, except in those areas noted as dangerous in the soil survey, should not be generally troublesome.

Irrigation channels should hold water well and lining would not be called for.

Damage to pastures because of heavy summer rains which will soak in rather slowly if the soil happens to be already wet from irrigation, will have to be guarded against by provision for surface drainage.

Cockatoo sand

This soil is highly permeable and has a low field capacity. As a consequence, water penetrated to a depth of 78″ from an irrigation lasting only 40 minutes. This type would be extremely difficult to handle except by spray irrigation.

Type A (later named Ord sandy loam)

Type A has irrigation characteristics intermediate between Cununurra clay and Cockatoo sand and is suitable for horticulture or for crop and pasture production.

Water penetration (of four feet after a 10-hour irrigation) is satisfactory. This should enable the watering of deep-rooted crops without undue risk of developing water tables. However, since the rate of entry was still relatively high at the end of this irrigation, it follows that the chance of building up water tables cannot be ignored.

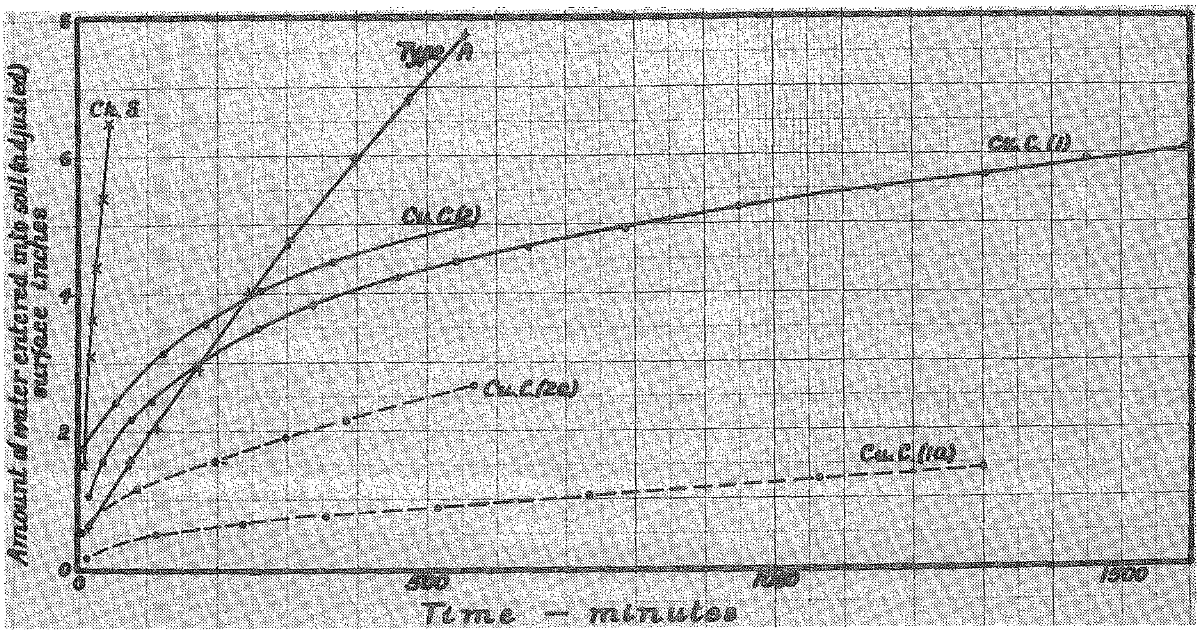

Figure A.1.2 Infiltration of water into a uniform column of soil (amounts adjusted to exclude lateral flow—see text)

Key as for Figure A.1.1 (From original graph)

Proximity to the river would facilitate artificial subsoil drainage should this ultimately prove necessary. Natural drainage through fairly sandy horizons below seven feet may obviate this.

Lining of irrigation channels would be advisable, particularly if horticultural plantings are proposed.

Salt will not constitute a serious hazard in this type, provided unwise irrigation practices are avoided.

Laboratory investigations

Further measurement of physical properties of these soils will be undertaken in the laboratory. This work will concern the stability of the soil structure and the availability of soil water to plants growing on these soil types.

T.J. Marshall
Senior Research Officer
Soil Physics
Waite Institute
Adelaide

October 23, 1944

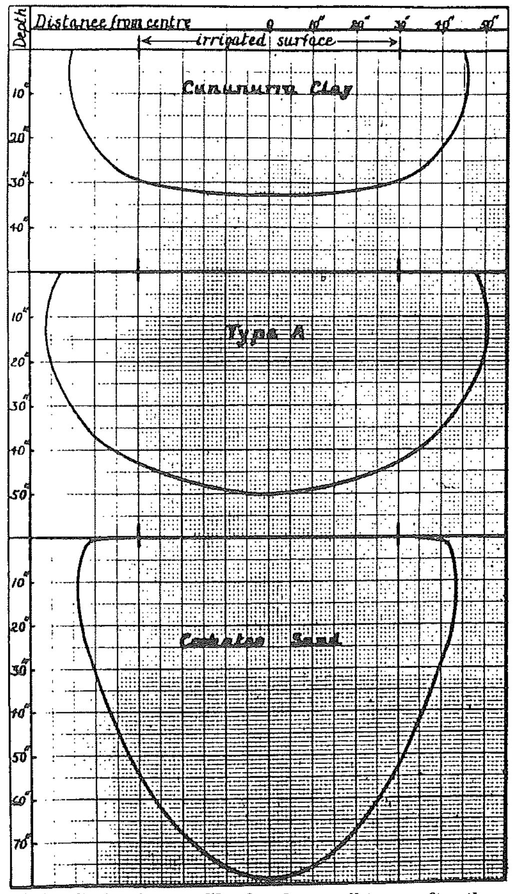

Figure A.1.3 **Irrigation profiles for three soil types after the first irrigation.**
Uneven lateral penetration due to cracks has been smoothed out in the diagram for the Cununurra clay. (From original graph)

Figure A.1.4 **Infiltration test, Cununurra clay, on the site proposed for experimental plots. Overnight readings were taken at this site.**

Vegetation here is *Bauhinia Gregorii* (deciduous at this time) and various dry grasses including *Aristida*, Flinders (*Iseilema*), *Sorghum* and *Sehima*. The timber in the background represents the position of a strip of Type A soil on the river bank.

Photo by T. J. Marshall *G. K. Stewart* *S. T. Smith* *G. H. Burvill*

Appendix 2

Council for Scientific and Industrial Research
Division of Soils
Waite Institute
Private Bag
ADELAIDE S.A. August 20, 1946

Mr G.H. Burvill
Department of Agriculture
St George's Terrace
PERTH W.A.

Dear Mr Burvill

The wilting determinations on Ord River soils were completed some time ago. Mr Gurr has now undertaken indirect measurements through the freezing point method and the results are included as a matter of interest. The figures for the direct method are of course more dependable where there is disagreement between the two.

Soil type	Permanent wilting percentage			
	depth inches	soil no.	direct method	indirect method
Ord sandy loam	0 - 6″	9218	6.2	6.2
Cununurra clay	0 - 7″	9224	16.3	17.7
Cockatoo sand	0 - 9″	9228	1.6	1.5

We are finding that the indirect method is giving us satisfactory results and propose to make use of it in the future.

With kind regards,

Yours sincerely,
(Sgd) T.J. MARSHALL
Senior Research Officer
Soil Physics and Mechanics

Appendix 3

Reduced levels of bench marks along road from Wyndham to Cockatoo Spring, also levels of Mantinea base line and Carlton Reach base line. Supplied by Public Works Department.

The datum (zero) for these levels is the bottom of the gauge board at Wyndham meat works Jetty. This would approximate extreme low tide. The tidal range is 23 feet.

Levels from Wyndham to Cockatoo Spring

Bench marks are approximately at mile intervals along the road.

Bench mark	Reduced level feet	Locality
B 1	37.84	P.W.D. building Wyndham
2	26.25	
3	29.34	
4	29.35	
5	29.35	Along all-weather road
6	30.86	from Wyndham to near
7	60.70	"9-Mile"
8	41.61	
9	27.83	
10	30.08	
11	39.53	
12	26.50	Rice grass and samphire flats.
13	26.06	
14	25.12	Near 12-mile lagoon
15	27.12	
16	29.87	
17	30.79	Approaching Parry's Creek
18	35.12	
19	33.87	On wet weather track
20	31.30	not through gutta
21	30.11	percha swamp.
22	46.25	
23	34.16	1/2 mile W. of Goose Hill
24	33.81	Just E. of Goose Hill Creek
25	35.29	
26	37.47	
27	38.16	
28	38.90	
29	38.76	Just E. of Salt Water Creek
30	38.39	
31	43.69	
32	47.03	
33	48.93	
34	51.77	
35	56.15	
36	57.83	
37	60.19	Following river levee
38	62.48	past Bend of Ord and
39	65.38	along track close to
40	66.50	river in large northward
41	72.19	loop between House Roof
42	74.25	and False House Roof Hills
43	75.74	
44	72.01	Near Mantinea Creek (63.47)
45	75.95	
46	88.86	

Bench mark	Reduced level feet	Locality
47	84.39	
48	107.83	
49	141.31	
50	158.49	
51	130.46	Button's Gap.
52	103.65	Highest point on road
53	90.84	in gap 201.12
54	113.52	
55	113.93	
56	106.97	
57	116.05	(Old Ivanhoe Homestead 125.10′)
58	117.73	S. end of Goat Hill, Ivanhoe
59	130.72	Ord River levee at Ivanhoe Crossing
	73.07	River bed at Crossing
	130.33	Levee on S. side of Crossing
60	129.65	
61	137.26	
62	138.86	
63	144.27	
64	127.08	In gully system Four-Mile Creek
65	147.31	
66	154.26	On plain N. of
67	156.20	Carlton Reach
68	156.15	
69	160.97	
70	180.08	
72	174.67	Cockatoo sands
75	257.99	
80	330.35	
84	402.49	Highest point
85	354.23	
88	408.13	About Cockatoo Spring

Levels along Mantinea base line, Mantinea Flats, Goose Hill Area

Base line mileage	Reduced level feet	Remarks
0 miles	79.43	In sloping shaly area of Rainyerri sandy loam
0 miles 40 ch	64.66	In Mantinea Creek system
1 miles	66.53	
2 miles	60.51	
3 miles	56.71	
4 miles	50.01	
5 miles	58.29	On river levee at "Bend of the Ord": 40 chains south the level is 49.37′.
6 miles	50.21	
7 miles	44.80	
8 miles	43.79	
9 miles	41.66	100 chains south the level is 34.47′
9 miles ch	35.06	In gutta percha swamp
10 miles	36.55	On bank among swamps
11 miles	30.02	In gutta percha swamp
11 miles ch	38.22	On levee south of
12 miles	39.05	swamps
13 miles	32.59	On plain east of Goose Hill Creek

Levels along Carlton Reach base line, Carlton Reach Plain

Base line mileage	Reduced level feet	Remarks
0 miles	147.86	N. corner of Carlton Reach plots (River levee 151′ approx.)
0 miles 60 ch	153.94	Highest point on base line
1 mile	153.60	Falls to 3 miles 70 ch
3 miles 70 ch	142.36	
4 miles 10 ch	145.44	
7 miles	132.02	
7 miles 30 ch	121.03	Creek just N. of Ivanhoe Bullock Paddock Fence
8 miles	132.51	
12 miles 40 ch	117.79	
16 miles	113.02	South part of Green Swamp area

Appendix 4

Aboriginal names used in naming soil types

Mrs H.C. Miller (Mary Durack) kindly supplied a comprehensive list of native names and words belonging to the Aboriginal tribes of the Ord River areas. Several were used as series names in naming the soil types of the Carlton Reach Plain and the Mantinea Flats-Goose Hill area. These are as follows:

Cununurra	Means Ord River, or possibly any big river.
Meruin, Winbidji	Two of the larger waterholes in the Ord River
Chunuma, Rainyerri	Names of local male aborigines

Appendix 5

Western Australia

Tel. No. B3114
Your No. 23/44

Government Chemical Laboratories
Adelaide Terrace, PERTH
February 4, 1946

The Under Secretary for Agriculture
PERTH W.A.

Certificate of analysis

Lab. No.: 5286—5374/44.
Material: Eight-nine samples of soil in connection with Kimberley Soil Survey
From whom received and when: The Under Secretary for Agriculture, on December 4, 1944.

Table A.5.1 Mechanical analyses of 55 soil samples, Ord River soil survey, 1944

	Mechanical analyses							
Lab no./1944	5311	5313	5315	5316	5317	5319	5321	5322
Serial No.:	4216	4218	4220	4221	4222	4224	4226	4227
Type:				Ord sandy Loam				
Depth—inches	0-6	18-36	60-84	84-108	0-6	18-36	54-68	72-96
% Stones	—	—	—	—	—	—	—	.8
Coarse sand	4.1	6.4	8.38	6.2	8.2	11.3	7.4	3.4
Fine sand	70.7	54.7	65.5	71.8	75.8	66.0	72.0	43.1
Silt	10.8	13.5	10.3	9.3	8.5	8.6	7.9	12.8
Clay	12.0	22.6	13.4	10.7	7.6	11.9	11.3	37.2
Loss on acid treatment	0.7	1.1	0.5	0.6	0.5	0.9	0.7	1.3
Moisture	2.0	3.2	3.1	2.4	1.5	2.0	2.4	4.4
Loss on ignition	2.9	3.4	2.4	2.4	2.6	2.7	2.0	3.9

	Mechanical analyses						
Lab no./1944	5349	5350	5352	5354	5324	5326	5329
Serial No.:	4254	4255	4257	4259	4229	4231	4234
Type:		Ord sandy loam				Meruin sandy loam eroded phase	
Depth	0-6	6-24	54-90	114-144	0-5	27-48	69-84
% Stones	—	—	—	1.6	1.2	1.5	3.1
Coarse sand	2.4	4.6	11.1	4.2	26.8	16.8	45.4
Fine sand	67.0	58.1	69.6	47.6	41.3	38.0	29.4
Silt	12.2	11.1	6.0	13.7	11.5	12.1	6.4
Clay	14.5	22.1	9.8	30.9	19.2	31.8	16.2
Loss on acid treatment	1.5	1.5	1.5	2.7	0.4	0.9	2.2
Moisture	1.8	2.5	1.6	3.2	1.7	2.8	1.9
Loss on ignition	3.5	3.2	2.1	4.1	3.1	4.3	3.3

	Mechanical analyses									
Lab no./1944	5286	5287	5289	5290	5292	5295	5296	5301	5303	5306
Serial No.:	4001	4002	4005	4201	4203	4206	4207	4017	4019	4022
Type:	Cununurra clay									
	One mile N of Carlton Reach			Kimberley Res. Station				14 miles N of Carlton Reach		
Depth—inches	0-12	12-36	102-156	0-6	24-45	75-96	96-114	0-5	24-48	92-138
% Stones	0.2	0.5	0.7	—	0.9	—	1.0	—	—	3.4
Coarse sand	3.1	2.6	0.7	3.6	3.4	0.8	1.3	1.0	1.1	1.0
Fine sand	35.0	29.3	43.0	33.7	30.8	71.0	84.2	17.8	17.2	15.3
Silt	11.0	12.8	22.9	13.5	15.1	11.8	4.9	14.6	15.4	30.1
Clay	44.8	46.7	29.3	42.9	46.1	15.8	8.5	58.0	60.5	47.2
Loss on acid treatment	1.6	1.8	1.4	1.5	1.4	1.8	0.4	1.9	2.2	2.1
Moisture	5.5	6.7	4.6	5.0	5.6	2.6	2.1	8.1	7.3	6.3
Loss on ignition	5.8	4.4	4.6	5.5	5.0	3.0	2.2	5.8	5.6	5.8

	Mechanical analyses								
Lab no./1944	5297	5298	5300	5307	5309	5310	5330	5332	5335
Serial No.:	4208	4209	4211	4212	4214	4215	4235	4237	4240
Type:	Cununurra clay flooded phase						Cockatoo sand		
	Green Swamp			Martin's Swamp					
Depth—inches	0-6	6-24	60-114	0-6	24-54	54-78	0-9	30-60	108-144
% Stones	—	—	13.1	—	2.2	4.8	—	—	0.4
Coarse sand	1.0	1.2	1.1	7.0	7.5	4.9	26.6	22.8	16.4
Fine sand	16.0	15.7	9.6	20.5	20.8	18.2	65.2	63.7	55.4
Silt	13.0	13.0	18.6	10.9	11.2	11.9	2.8	2.7	4.3
Clay	64.4	63.9	65.9	56.4	56.2	61.1	5.2	11.1	23.9
Loss on acid treatment	2.3	2.7	2.8	1.3	1.5	1.9	.4	.5	.7
Moisture	8.0	7.7	6.6	6.5	6.1	6.0	.1	.3	1.4
Loss on ignition	6.1	6.3	6.4	5.0	4.4	5.0	1.2	1.5	2.9

	Mechanical analyses						
Lab no./1944	5336	5337	5338	5339	5341	5343	5344
Serial No.:	4241	4242	4243	4244	4246	4248	4249
Type:	Junction complex						
Depth—inches	0-12	15-24	24-27	0-9	24-30	0-12	12-30
% Stones	20.3	12.5	1.2	1.0	3.5	35.7	7.8
Coarse sand	17.8	15.3	16.0	37.5	27.4	44.8	21.1
Fine sand	53.8	43.4	48.1	45.6	30.8	45.2	25.9
Silt	8.1	7.4	6.1	6.6	6.6	4.5	1.6
Clay	19.6	32.3	27.8	9.8	33.1	5.9	48.6
Loss on acid treatment	0.9	1.1	0.8	0.6	0.8	0.5	1.3
Moisture	0.8	1.8	1.9	0.4	1.8	0.1	3.1
Loss on ignition	2.6	3.9	2.7	1.4	3.8	1.0	4.6

Lab no./1944	5360	5362	5364	5365	5367	5370	5355	5356	5359
				Mechanical analyses					
Serial No.:	4265	4267	4269	4270	4272	4275	4260	4261	4262
Type:			Mantinea clay				Mantinea flats A		
Depth—inches	0-6	14-48	84-102	0-3	12-36	78-108	0-8	8-40	40-60
% Stones	—	—	—	—	—	1.0	—	—	—
Coarse sand	0.1	0.2	0.1	0.4	0.4	0.2	0.8	0.2	0.9
Fine sand	11.1	12.1	17.1	16.0	16.5	36.5	39.0	37.0	66.8
Silt	31.0	26.2	24.8	24.4	24.8	27.4	33.2	26.1	13.9
Clay	53.9	53.3	53.8	53.8	52.7	34.5	25.1	33.0	16.1
Loss on acid treatment	3.1	4.1	2.2	3.0	2.0	1.4	1.9	2.2	1.9
Moisture	5.7	6.0	4.8	5.6	6.4	4.8	2.6	4.0	2.4
Loss on ignition	5.9	4.8	5.3	6.0	6.2	4.8	5.6	4.7	3.1

Lab no./1944	5347	5348	5372	5374	5371
			Mechanical analyses		
Serial No.:	4252	4253	4277	4279	4276
Type:		A/C		Chunuma sand	Swamp
Depth—inches	0-6	24-27	0-9	36-72	9-12
% Stones	—	—	—	—	1.7
Coarse sand	1.7	2.6	10.6	11.4	0.6
Fine sand	58.0	42.6	72.7	79.9	14.0
Silt	11.1	13.1	9.4	4.5	24.1
Clay	24.3	35.7	6.5	4.8	52.9
Loss on acid treatment	1.8	2.2	Tr.	Tr.	5.8
Moisture	2.9	4.0	0.5	0.3	4.4
Loss on ignition	3.7	4.3	1.6	0.5	7.4

Table A.5.2. Reactions, (pH 1-5 glass electrode) of soil samples, Ord River soil survey 1944

Lab. no. 1944	Serial no.	Depth (inches)	pH
Ord sandy loam			
5311	4216	0-6	7.1
5312	4217	6-18	7.2
5313	4218	18-36	7.4
5314	4219	36-60	7.6
5315	4220	60-84	7.9
5316	4221	84-108	8.1
5317	4222	0-6	6.9
5318	4223	6-18	6.8
5319	4224	18-36	6.9
5320	4225	36-54	7.2
5321	4226	54-68	6.9
5322	4227	72-96	8.5
5323	4228	96-114	8.6
5349	4254	0-6	6.9
5350	4255	6-24	7.1
5351	4256	24-54	7.2
5352	4257	54-90	7.6
5353	4258	90-114	8.6
5354	4259	114-144	8.7
Meruin sandy loam			
5324	4229	0-5	5.8
5325	4230	5-27	6.4
5326	4231	27-48	6.9
5327	4232	48-60	7.5
5328	4233	60-69	8.4
5329	4234	69-84	8.5
Cununurra clay			
5286	4001	0-12	7.7
2977	4002	12-36	8.6
5287	4003	36-60	8.9
5288	4004	60-102	9.0
5289	4005	102-156	8.8
5290	4201	0-6	7.6
5291	4202	6-24	8.6
5292	4203	24-45	9.2
5293	4204	45-52	9.3
5294	4205	52-75	9.4
5295	4206	75-96	9.4
5296	4207	96-114	9.2
5301	4017	0-5	7.8
5302	4018	5-24	8.4
5303	4019	24-48	8.6
5304	4020	48-60	8.6
5305	4021	60-87	8.7
5306	4022	92-138	8.8
Cununurra clay-flooded phase			
5297	4208	0-6	8.0
5298	4209	6-24	8.7
5299	4210	24-60	8.9
5300	4211	60-114	8.5
5307	4212	0-6	7.4
5308	4213	6-24	8.2
5309	4214	24-54	8.8
5310	4215	54-78	8.8

Lab. no. 1944	Serial no.	Depth (inches)	pH
Cockatoo sand			
5330	4235	0-9	6.7
5331	4236	9-30	6.3
5332	4237	30-60	6.4
5333	4238	60-87	6.5
5334	4239	87-108	6.5
5335	4240	108-144	6.2
Junction complex			
5336	4241	0-12	6.0
5337	4242	15-24	7.4
5338	4243	24-27	8.0
5339	4244	0-9	5.9
5340	4245	12-24	5.6
5341	4246	24-30	5.8
5342	4247	30-39	8.1
5343	4248	0-12	5.8
5344	4249	12-30	6.8
5345	4250	30-39	6.9
5346	4251	39-42	7.1
Mantinea clay			
5360	4265	0-6	8.1
5361	4266	6-24	8.6
5362	4267	24-48	8.1
5363	4268	48-84	7.9
5364	4269	84-102	7.7
5365	4270	0-3	7.8
5366	4271	3-12	8.2
5367	4272	12-36	9.0
5368	4273	46-60	8.7
5369	4274	69-78	7.8
5370	4275	78-108	7.2
Mantinea flats A			
5355	4260	0-8	6.9
5356	4261	8-40	7.2
5357	4262	40-60	7.9
5358	4263	60-78	8.8
5359	4264	78-108	9.6
A/C			
5348	4252	0-6	6.9
5349	4253	24-27	7.6
Chunuma sand			
5372	4277	0-9	6.5
5373	4278	9-36	6.7
5374	4279	36-72	6.8
Swamp			
5371	4276	9-12	9.9

Director
Government Chemical Laboratories
Adelaide Terrace
PERTH W.A.

When visiting the Kimberley Research Station in July, 1950, Mr G.H. Burvill of this Department collected a number of dark brown, to almost black, fine pebbles from an erosion gully at the Research Station. These particles occur in the soil profile of the Cununurra clay—so-called black soil of the locality. The soil also contains small calcareous concretions of similar size—about one-inch diameter.

A sample of the dark concretions has been submitted to your laboratories and I should be pleased if you could arrange for mineralogical examination of them to be made, also a determination of the major chemical constituents. It is wondered if these particles may be rather high in manganese.

A.L. McKenzie Clark
ACTING DIRECTOR OF
AGRICULTURE

Government Chemical Laboratories
Adelaide Terrace, Perth

April 3, 1951
863/51 HK

Your ref: 23/44

Report on One Sample for:
Acting Director of Agriculture, Perth

Lab. No.: 1794/51

Description: Dark brown shotty pebbles from Cununurra clay.

Locality: One sample from Kimberley Research Station.
Lateritic pebbles containing appreciable manganese

Partial analysis:

Manganese, Mn	9.13 per cent
Iron, Fe	16.39 per cent
Insoluble	35.71 percent

Appreciable alumina is also present

(Sgd) C.R. LeMesurier
Deputy Government Mineralogist

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1. Cultivation and traffic hardpans in Swan Valley vineyards, by S.T. Smith, T.C. Stoneman and C.V. Malcolm.
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16. Grit for broilers, by P. Smetana and B.R. Vale.

17. Varietal variation in resistance to clover scorch (*Kabatiella caulivora* (Kirchn.) Karak) in *Trifolium subterraneum* L., by D.L. Chatel, C.M. Francis and A.C. Devitt.

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57. Perennial pasture grasses in south-western Australia. 3. Productivity under grazing, by P.T. Arkell, R.N. Glencross, D.A. Nicholas, J.G. Paterson, G.W. Anderson, E.F. Biddiscombe and A.L. Rogers.

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62. An inventory and condition survey of rangelands in the Ashburton River catchment, Western Australia, by A.L. Payne, A.A. Mitchell and W.F. Holman.

63. Toxic ferns of Western Australia, by T.E.H. Aplin, P. Steele and M.C. Nottle.

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68. Virus, viroid, mycoplasma and rickettsial diseases of plants in Western Australia, by G.D. McLean and L.K. Price.

69. Survey of parasite control practices in sheep and cattle, by J.R. Edwards, R.V.R. Gwynn, R.A. Love, R.T. Norris. G. Dalton-Morgan and R.B. Besier.

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72. Studies on times of lambing in ewes grazing subterranean clover based pastures in relation to stocking rates in south-western Australia, by H. Lloyd Davies.

73. An inventory and condition survey of rangelands in the Carnarvon basin, Western Australia, by A.L. Payne, P.J. Curry and G.F. Spencer.

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77. The soils of the Salmon Gums district—Western Australia, by G.H. Burvill.

78. Seed production and hard-seededness of *Trifolium subterraneum* subsp. *brachycalcinum*, by M.D.A. Bolland.

79. Evaluation of pulses and other seed legumes for crop rotations in Western Australia, by G.W. Walton and T.R. Trent.

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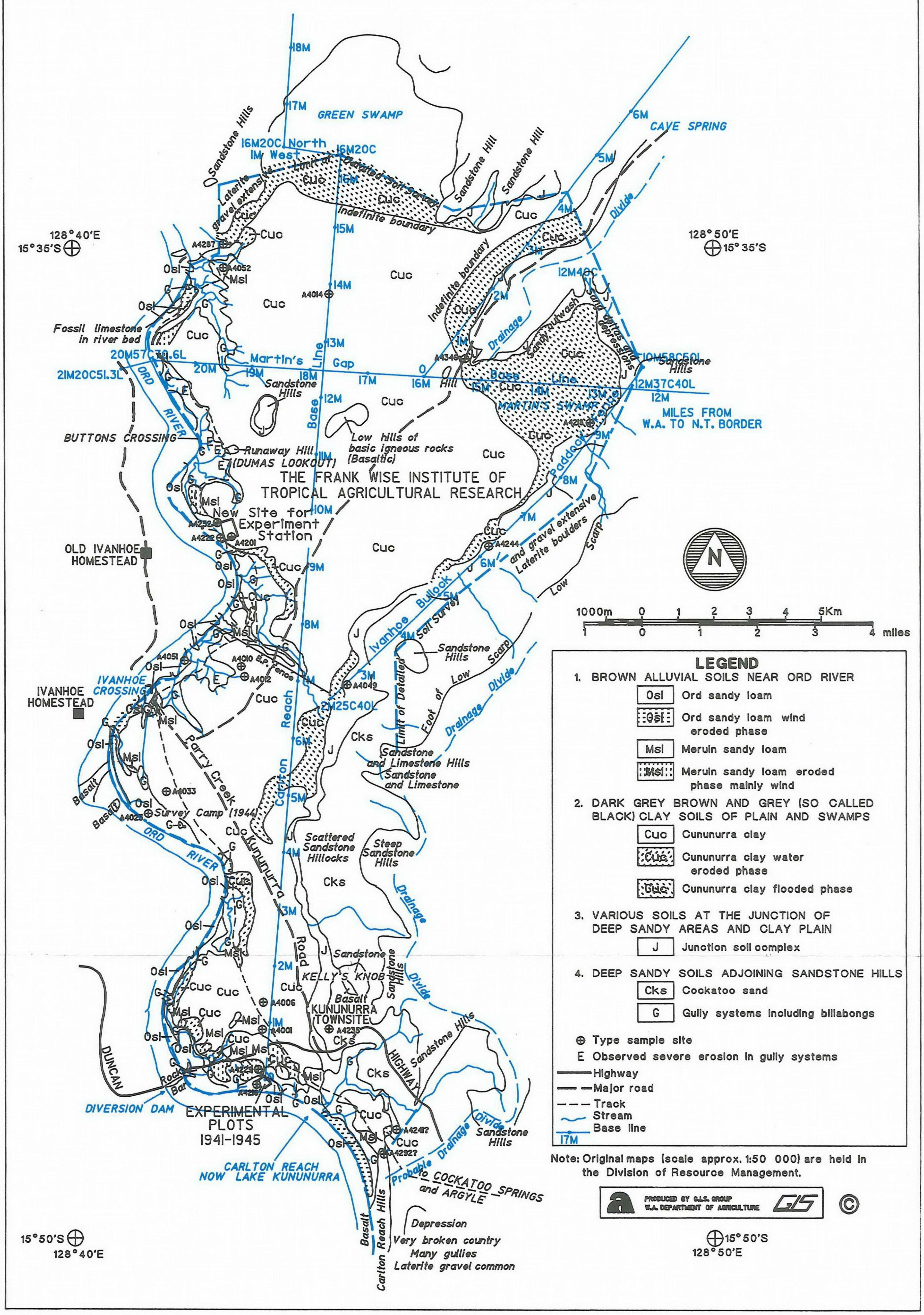
SOIL SURVEY CARLTON REACH PLAIN



SOIL SURVEY MANTINEA FLATS AND GOOSE HILL AREA

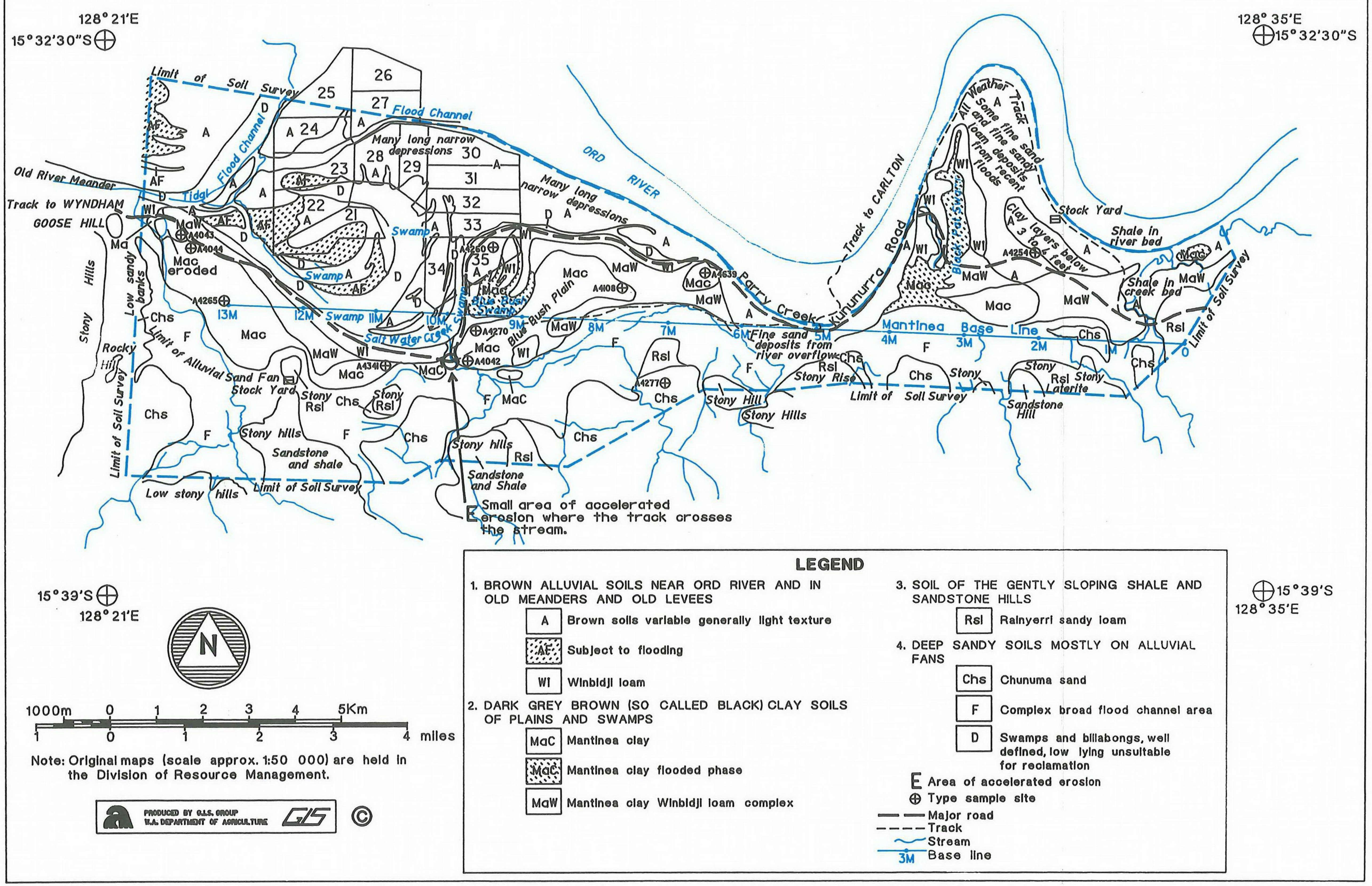


FIGURE 1: LOCALITY PLAN showing the two areas surveyed and three further areas which may be suitable for irrigation

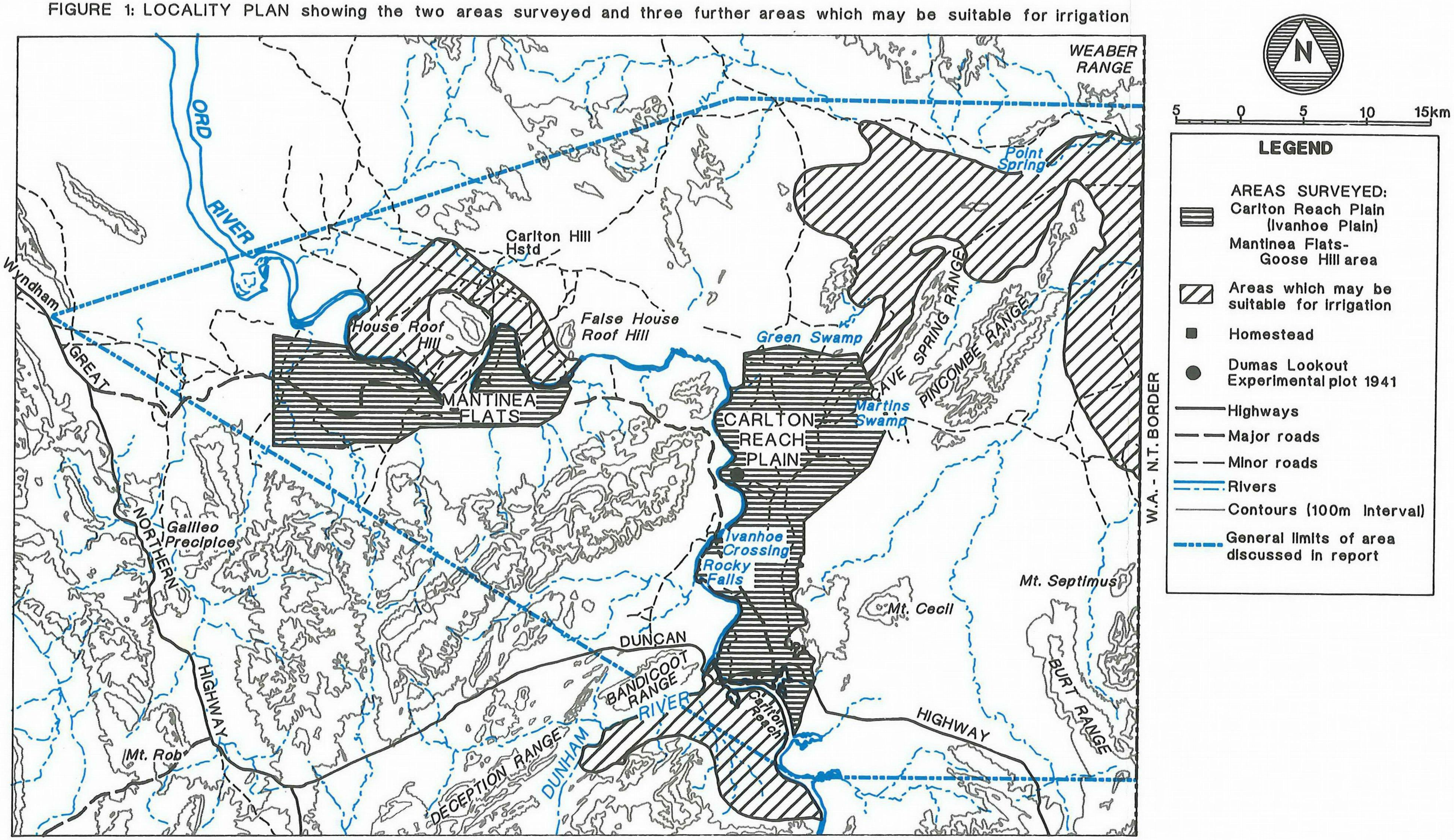
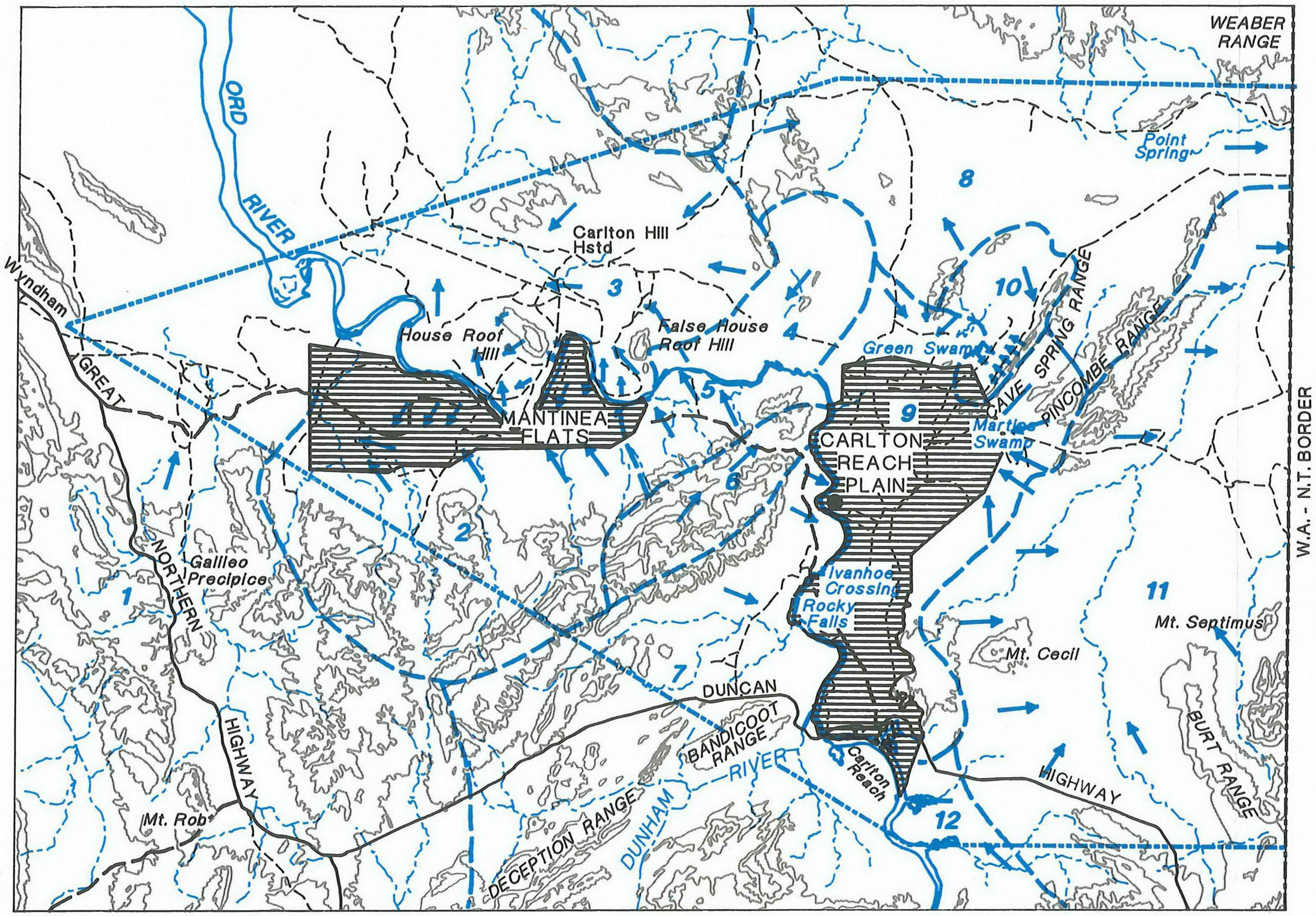
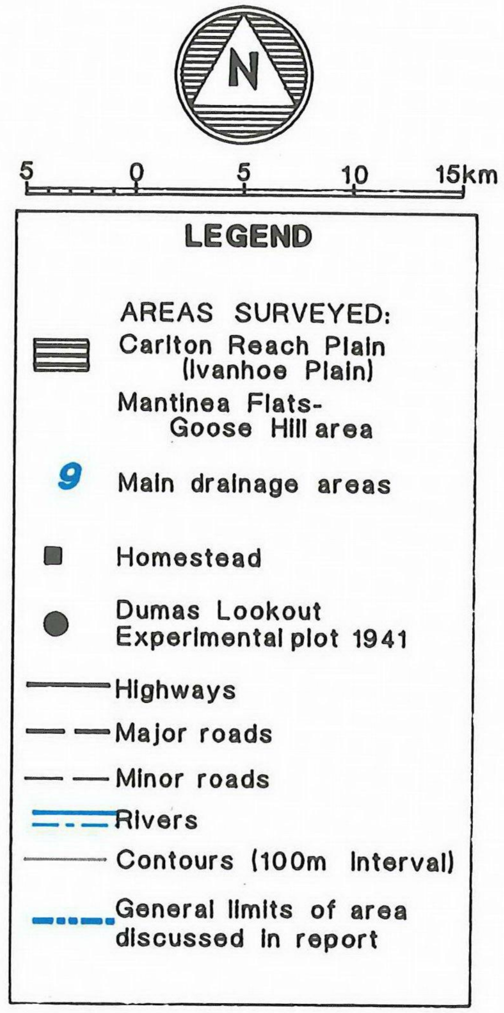


FIGURE 2: MAIN DRAINAGE AREAS





The 12 main drainage areas in the surveyed area are shown. Areas 4, 5, 6, 7, 8 (partly) and 12 drain directly into the Ord River. Areas 1, 2 and 3 drain entirely or largely into the flats and marshes around the Ord River estuary. 8 and 11 drain east and north-east respectively into the Keep River system; while 10 is believed to drain into Cave Spring Valley. Area 9 includes Green Swamp and Martin's Swamp.