ORD RIVER DAM

SUBMISSION TO
THE
INSTITUTION OF ENGINEERS, AUSTRALIA
NATIONAL COMMITTEE FOR
ENGINEERING HERITAGE

FOR AN
HISTORIC ENGINEERING MARKER
COMMEMORATIVE PLAQUE

PREPARED BY A MOULDS, H E HUNT AND R G HARTLEY

NOVEMBER 2000

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NOMINATION FOR AN HISTORIC ENGINEERING MARKER COMMEMORATIVE PLAQUE

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NOMINATION FOR HISTORIC ENGINEERING MARKER COMMEMORATIVE PLAQUE

1 NAME, OWNERSHIP, LOCATION

Current Name	ORD RIVER DAM impounding LAKE ARGYLE
Current Owner	WATER CORPORATION OF WESTERN AUSTRALIA (formerly the Water Authority of Western Australia, 1985–1995) Address – 629 Newcastle Street, Leederville WA 6007
Aboriginal Traditional Owners	Miriuwung people (surrounding communities with regular interaction are the Gajerrang, Gidja, Ngarinyin, Yiji, Ngarinman, Jaminjung and Murrinh-patha language groups)
Location	The dam is located on the Ord River approximately forty kilometres south of the town of Kununurra. The dam and reservoir is shown on 1: 100 000 National Topographical Map Series, Maps 4664 (Lissadell) and 4665 (Argyle Downs).
Boundary	The boundaries of the area of dam and reservoir which is nominated for National Estate listing are: upstream, that area in the arm of Lake Argyle to the north-east of the dam encompassed by the full supply level of the reservoir; the area of the dam itself, outlet valves and hydro-electric power house and the lookout to the north of the dam; the quarry 800 m south-west of the dam; the spillway 8 km to the north-east of the dam; down-stream, an area 800m along the Ord River to include the look-out and picnic areas to the east and west of the river.
Local Government Area	The dam and reservoir are in the Shire of Wyndham – East Kimberley. During the record high water levels following Cyclone 'Steve' in early 2000 the reservoir extended into the Shire of Timber Creek, NT.

2 DESCRIPTION

2.1 THE PLACE

The Ord River Dam is located towards the southern end of Carlton Gorge, (at a location known as Coolibah Pocket) where the Ord River cuts through the Carr-Boyd Ranges and flows northwards to discharge into Cambridge Gulf. The dam is 40 km south of Kununurra and the Ord River Diversion Dam (completed in 1963 as part of the first stage of Ord River Irrigation Scheme). At full supply level, Lake Argyle has a surface area of 725 km^2 and stretches 56 km to the south and 32 km to the east. At design flood level this area would more than treble in size.

The dam is a rockfill dam of hard durable quartzite rock compacted in layers with a heavy vibrating roller. The dam has a narrow impervious core of silty sand with zones of filter material on either side of it. Construction of the dam took place over three dry seasons, commencing in 1969, and was substantially complete by December 1971. The1970-71 wet season river flows were allowed to pass over the partially completed dam which, because of the protective measures provided, was undamaged by these substantial flows. The height of the dam was extended to above the maximum design flood level and after completion wet season floods were designed to pass over a comparatively low capacity spillway at full supply level which was sited at a saddle eight kilometres north-west of the dam.

Rock for the rockfill material was obtained from a quarry 800 metres south-west of the dam. Almost all the rock required was obtained from two very large "coyote" blasts. The silty clay required for the impervious core was obtained from the river flats approximately 400 metres upstream of the dam while the filter material came from the river bed deposits further upstream.

Two tunnels through the northern abutment from a freestanding intake structure provide discharges for irrigation and for the hydroelectric station. One of the tunnels also served to divert the small dry season flows during construction. The privately owned 30-megawatt hydroelectric power station located downstream of the north abutment was opened in 1996. Additional storage to guarantee supply for the hydro power generation was provided by building a mass concrete 'plug' in the main spillway, raising the full supply level of the reservoir by six metres and increasing storage capacity to 10,760 million cubic metres.

The main 35 kilometre-long access road to the site runs in a north-easterly direction, to join the Victoria Highway from Kununurra to Katherine 35 km south east of Kununurra. Apart from the addition of the hydroelectric station and the spillway plug, the dam remains substantially as constructed. Buildings used to house PWD staff during construction, 800 m north of the dam, have been converted for use as tourist accommodation.

2.2 HISTORICAL SUMMARY

The first official proposals for the development of irrigated pasture in the Ord valley were made by Geoffrey Drake-Brockman during his period as State Commissioner for the North-West (1921-26) in association with his adviser on tropical agriculture, Frank Wise (later State Labor Premier). However, when a change in government took place in 1926, the Department of the North-West was abolished and the proposals shelved.

One of the first public discussions in Western Australia about irrigated agriculture in the Ord valley took place in 1939 following a proposal by Dr Isaac Steinberg of the London-based Freeland League for Jewish Territorial Colonisation to establish a group settlement of Jewish refugees from Europe on pastoral leases held by the Durack family and their partners in the East Kimberley, including the Ivanhoe and Argyle Downs stations. Initially the League planned to send about five hundred settlers to found the colony, intended to have a population of 50 000. Because of the Commonwealth's policy of assimilation of non-British migrants, the settlement scheme was never likely to have been approved, but it undoubtedly led to the State Government examining further the possibility of irrigated agriculture in the Ord valley.

The first experiments in irrigation from the Ord were also being made at about that time by Kimberley Durack, a graduate of Muresk Agricultural College, who had returned to the East Kimberley to work on his family's cattle stations. He planned to fatten up open-range cattle on irrigated pasture and experimented with the growing of lucerne at Argyle and Ivanhoe stations.

In 1941 the Hawke Labor State Government instructed its Director of Building and Works, Russell Dumas to examine the possibilities for closer settlement in the north-west. Because pastoralism was the only activity in the region, apart from gold mining at Marble Bar and banana growing at Carnarvon, it was considered that further long term development would have to be in association with the pastoralism and that irrigated grazing should be considered. The East Kimberley was favoured because of the large river system, large areas of fertile plains, the only port in the north-west accessible at all tides (Wyndham), and an existing meatworks at Wyndham.

Dumas visited the Ord valley in 1941 and, accompanied by Kimberley Durack, located three possible dam sites on the Ord in the Carr Boyd Range (called sites 4,5 and 6). The following year the PWD Resident Engineer in the North-West, F.H. Bottrell, again accompanied by Durack, penetrated further south into the Ord gorge and located three further sites (1,2 and 3). Preliminary survey work was carried out in 1943 and the southernmost site (no.1), located at the narrowest part of the gorge, was considered the most suitable. A suitable site for a diversion dam near the proposed areas for irrigation was also located.

In 1942, soon after Dumas' first visit, the State Government set up an agricultural research station at Carlton Reach on the southern Ord. Durack was appointed manager and for the next three years he carried out successful trial planting irrigated sorghum and millet. In 1945, a new research centre, the Kimberley Research Station, was established on a site 16 km downstream from Carlton Reach, as a Federal-State joint venture. Its main aim was to determine whether irrigated agriculture could be successfully established on the area proposed.

In the four years to 1947 further investigations were made into site no.1 for the main dam but, as the magnitude of the wet season discharges of the river became apparent, provision of adequate spillway capacity in the narrow gorge became a problem. Depth to foundation rock was also greater than expected. For these reasons, from 1954, investigations moved to site no 2, one kilometre further north. A submission to the Commonwealth for funding in 1956 for the whole scheme was unsuccessful but a five million pounds grant for northern development was offered by Canberra. In the same year Kimberley Research Station reported favourably about the establishment of irrigated agriculture and the Hawke State Government decided to develop stage one of the scheme (the diversion dam, preparation of the irrigation area and the building of Kununurra) under the grant. It was completed in 1963.

At No. 2 site a rockfill dam with a thin impervious core was found to be more economical than the type of mass concrete dam that had been proposed for the site No. 1. It was initially planned to provide for a huge volume of the design flood level by means of a concrete-lined spillway cut through a saddle just downstream of the right abutment of the dam. An innovative alternative was found to be more economical. The spillway was relocated by cutting through rock at a lower saddle 8 km North-East of the dam. The dam was raised so that it would be able to store major floodwaters and release them gradually over the spillway during the dry season.

The Commonwealth decided to provide a grant for the construction of the main dam in 1967 and the contractor for the works. Dravo Pty Ltd commenced work in April 1969. As work could not be carried out on the dam during the wet season the work was programmed to be carried out during three dry seasons (from April to November). Work was completed in 1971. As wet season flows had to be routed over the incomplete dam in 1970-71, special protective measures were successfully taken which prevented any damage to the dam.

Commercial success of tropical agriculture and horticulture has been hard won on the Ord. In 1974 growing of the main crop, cotton, had to be suspended due to the increased resistance of the *heliothis* moth to insecticides, and during the 1980s the growing of low-priced field crops, such as sorghum, ceased to be viable. In the 1990s a highly diversified pattern of horticulture and agriculture proved to be more resilient and profitable, especially those targeting niche markets during the southern winters.

Construction of the Ord River Dam

The following passage giving details of those who contributed to the construction project were taken from the pamphlet 'Ord River Dam – Official Opening by the Prime Minister of Australia, The Rt. Hon. William McMahon, CH, MP'.

'The Constructing Authority for the Ord River Dam was the Public Works Department of Western Australia. Since approval for the dam was given in 1967, the position of Director of Engineering has been held by Mr J. E. Parker (until September 1969), Mr D. C. Munro (from September 1969 to November 1971) and Mr R. M. Hillman (since January 1972). The detailed work was principally coordinated by Mr D. C. Munro who was Chief Engineer until September 1969.

The investigations and design of the dam were carried out by the Planning Design and Investigation Branch of the Public Works Department headed by Mr K C. Webster. The work was under the supervision of Mr W. J. Wilkin with Mr R. J. Wark responsible for the detailed design.

The geological investigations were carried out under the direction of the Government Geologist, Mr J. Lord. The field investigations were supervised by Mr F. Gordon.

The construction of the dam was undertaken by the Construction Branch of the Public Works Department headed initially by Mr K. J. Kelsall and subsequently by Mr W. S. Shelton. Mr Kelsall was responsible for the administration of the Contract. Resident Engineer was Mr B. E. Gale and Messrs. P. J. Shaw, R. J. Perkins, and A. Bacon were his senior site engineer and Mr P. J. Burgess was the site geologist. Landscape work at the dam was planned by Mr J. B. Oldham.

The Mechanical and Plant Engineer's Branch of the Public Works Department headed by Mr J. McBurney, carried out the electrical design and assisted with the inspection of the mechanical and electrical equipment. This work was under the general supervision of Mr. D. Rickman.

During the design and construction phases of the work specialised technical services and general supervisory assistance were received from the Snowy Mountains Hydro-Electric Authority (now the Snowy Mountains Engineering Corporation).

The activities of the main contractor were under the general direction of Mr G. M. Shupe, Vice President of the Dravo Corporation of the United States of America. Mr G. V. Reid was Project Manager for the Contractor while Messrs. J. L. Jordan and A. N. Ahles were his senior engineers.

The provision of access roads for the project was directed by the Commissioner of Main Roads, Mr D. H. Aitken. The fieldwork was carried out by the Kimberley Divisional Engineer of the Main Roads Department and supervised by Mr J. D. Butorac.'

Ord Irrigation Area Stage 2

In July 1997 the WA Cabinet authorised the Water Corporation to acquire the land required for the M2 Supply Area infrastructure and then build and own such infrastructure.

In April 1998 the WA Government approved Westfarmers Limited and Marubeni Corporation to undertake a feasibility study for a raw sugar industry in the M2 Supply Area and that they should work closely with the Water Corporation.

In September 2000 the first stage of environmental approvals was gained.

A possible early start date for construction, should all approvals be gained and site conditions be adequate, is April 2002. At time of writing (November 2000) the construction works are expected to take three years.

2.3 HISTORICAL BIOGRAPHIES

The planning and construction of the Ord River Dam was closely associated with a number of prominent engineers in the public service, as well as Charles Court (later, Sir Charles), then Minister for the North-West and Minister for Industrial Development. Sir Russell Dumas was an advocate of a dam from 1941.

Sir Russell John Dumas (1887-1975) was born in South Australia and was educated at the University of Adelaide. He graduated in 1909 and joined the South Australian Engineer-in-Chief's Department. After war service in France he returned to the department in 1919 and worked on the construction of the River Murray locks and weirs. In 1925 he joined the Metropolitan Water Supply Sewerage & Drainage Dept in Western Australia, and worked on the construction of the Churchman Brook Dam. He transferred to the Public Works Department, and worked on the design of the Drakesbrook and Wellington Dams, and the raising of Harvey Weir, under B.S. Crimp, the PWD Hydraulic Engineer. He was responsible for the design of the Canning Dam and for supervising some of the early work on its site. He was appointed Engineer for Metropolitan Water Supply and Sewerage and directed the remainder of the construction of the Canning Dam for that department.

In 1941 he became Director of Buildings and Works and also Chief Hydraulic Engineer. After an investigation of the potential of the north - west for closer settlement in 1941-2, he recommended irrigation based on two potential dam sites on the Ord River. He was appointed Chairman of the North-West Development Committee and was a strong advocate for the development of the Ord River Irrigation Scheme.

During the war he served as liaison officer between the Allied Works Council and the state government departments. He also served as Regional Controller of Electricity and in 1946, became first Chairman of the State Electricity Commission. After the war he directed the completion of the Stirling Dam (for the Harvey Irrigation Scheme) and also the raising of Mundaring Weir and Wellington Dam, the two headworks for the Comprehensive Agricultural Areas Water Supply Scheme, for which he was largely responsible for obtaining federal funding.

In 1951–52 Dumas was largely responsible for negotiating the establishment of the Anglo-Iranian Oil Company's BP oil refinery and other key industries at Kwinana, south of Fremantle. Because of his crucial part in establishing these industries, he was given the additional title of Coordinator of Works and Industrial Development. He retired in December 1953, but remained influential as an adviser to the Brand – Court government. He was knighted for services to the state.

Dumas has the unusual distinction of having been closely connected with four of the twenty-five Australian dams nominated for heritage recognition. The four are the Murray River Weirs, Canning Dam, Mundaring Weir and the Ord River Dam.

Sir Charles Walter Michael Court (b.1911) qualified as a chartered accountant in 1933 and became a foundation partner of Hendry, Rae and Court, accountants in 1938. He served in the army from 1940 to 1946 and entered Parliament in 1953 as Liberal MLA for Nedlands, a seat that he held until he retired in 1982.

When the Liberals were returned in 1959 under David Brand, Court became Minister for the North-West and also Minister for Industrial Development. He had an important influence on mineral development in the Pilbara region and on other rural and mineral industries. He coordinated and was actively involved in the first stages of farm development and the establishment of the town of Kununurra, following the provision during 1963 of the diversion dam and the first irrigation facilities with Commonwealth and State funding.

Submissions from the Brand Government for further federal funding to proceed with the building of the main Ord Dam were unsuccessful as the Commonwealth Government, headed by Sir Robert Menzies, wished to see farming on the Ord proven on a sustainable basis before providing further funding, although the Kimberley Research Station (a joint state/federal organisation) had been reporting favourably on the prospects of irrigated agriculture since 1958. It was Court's enthusiasm for the project and his energy in marshalling the technical and economic arguments in favour of the dam's construction, and also his ability to exploit political opportunities, that were the key factors in finally securing federal finance for the dam in 1967.

During the Tonkin Labor Government (1971-4) he became Leader of the Opposition and then served as Liberal Premier from 1974 to 1982. During this time agriculture on the Ord went through a difficult period. However, Court lived to see the increasing success of diversified horticulture and agriculture there in the mid-1990s. He was knighted in 1972 for services to state and national development.

Sir John E Parker, a Graduate of the University of Melbourne (1925), joined the Main Roads Department WA in 1930, subsequently transferring to the MWSS&DD in 1935. After army service overseas he became MWSS&DD Construction Engineer in 1946. He moved to the PWD as the deputy to the then Director of Works and Buildings (J W Young) in 1953. In this position he coordinated, inter alia, the detailed work of the Comprehensive Water Supply Scheme, eventually succeeding Young in 1962.

Through the period of the development of the Pilbara iron-ore industries, North-West and Kimberley towns, North-West ports, the Ord irrigation project, and the bauxite and nickel industries he played a role of coordination in the public service departments, mirroring and supporting that of Sir Charles Court, Minister for Industrial Development and Minister for the North-West.

He was a member of the State Electricity Commission, 1962 – 69, and Chairman of the North-West Planning and Coordinating Authority 1962 – 71. He retired from the PWD in October 1969

Donald Campbell Munro was born in Fremantle in 1909 and was educated at Fremantle Boys' School, Perth Modern School and the University of Western Australia. He was an engineering cadet with the Public Works Department, and during university vacations, worked on a survey for the Lake Grace to Hyden railway, the raising of Harvey Dam and the building of Drakesbrook Dam. He graduated in 1932 and joined the Hydraulic Engineers Department of the PWD, working under Victor Cranston Munt on the construction of the Wellington Dam, and later the Canning Dam, when he was engineer of concreting operations until its completion in 1940. He worked under Munt on the Samson Brook Dam and Stirling Dam, being Resident Engineer on the latter in 1941.

After military service from 1942 to 1945, Munro returned to the Public Works Department as Principal Assistant Hydraulic Engineer working under Munt, inter alia on the raising of Mundaring Weir which commenced in 1946. He was Hydraulic Engineer, 1955- 61, and was the deputy to the Director of Engineering, 1962- 69, in which position he coordinated the detailed work of the Diversion Dam (1961- 63) and the Ord Dam at site No 2.

He was appointed Director of Engineering in 1969 and became head of a new Department of Development and Decentralisation in 1972. One of its important roles was to negotiate agreements with large scale mineral developers. Munro was also a member of the Metropolitan Regional Planning Authority, the Metropolitan Water Board and the State Electricity Commission (1969-1979, Chairman 1974-75).

2.4 TECHNICAL DESCRIPTION

Dam Type	Rockfill with impervious core
Height	99 m above lowest foundation level.
Length	335 m at crest level
Volume of Rockfill	1.55×10^6 m^3
Volume of Impervious Core	243×10^3 m^3
Volume of Filters	109×10^3 m^3
Spillway Type	Unlined channel excavated in granite.
Spillway Capacity	3 500 m^3 per sec (at top water level)
Reservoir Volume	10 760 000 ML (megalitres) (at full supply level)
Reservoir Area	72 500 ha (at full supply level)

Comparison with other dams in Australia

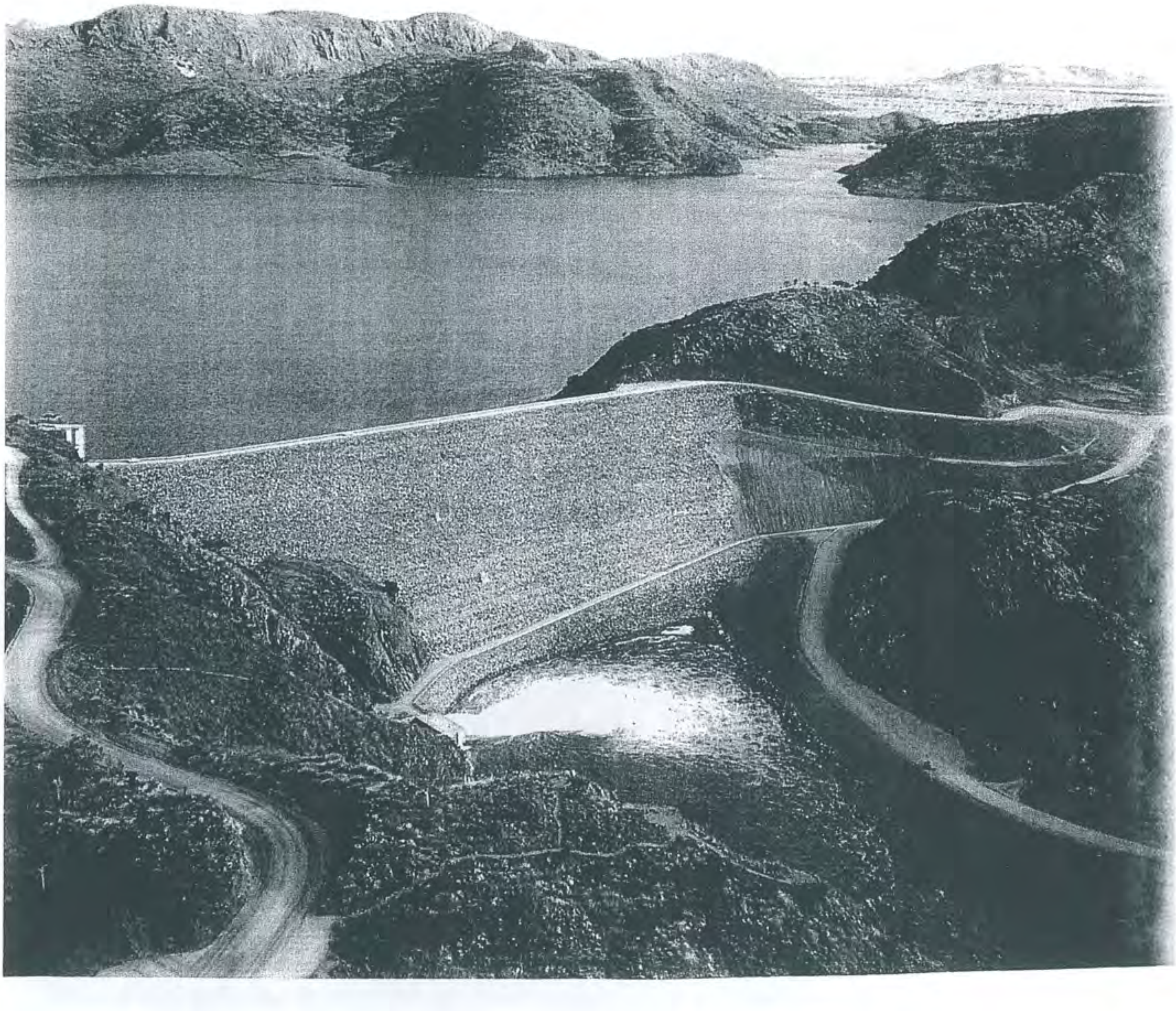
When completed in 1971 the Ord River Dam had the largest active storage at full supply level of any dam in Australia and impounded the largest capacity man-made lake in Australia. Subsequently this was exceeded by the Gordon Dam (completed 1974) which has a storage of 12.5 million ML at full supply level.

Whereas most dams are designed to pass major floods directly through their reservoirs by discharging the floodwaters over spillways, because of the huge volume of the Ord River floodwaters, the dam has been designed to store them and release them gradually over the main spillway (and three auxiliary ones in major floods). The reservoir, therefore, has a very large flood storage capacity (28 million ML) above its full supply level (the spillway level). In this regard the Ord dam has by far the largest flood storage capacity of any dam in Australia.

The Ord River Dam is the sixth highest earth or rockfill dam in Australia. Of the other five, the oldest, Eucumbene Dam in the Snowy Mountain Scheme (116 m, completed 1958) is an earth dam with a clay core. Two other Snowy Mountain dams, Talbingo (162 m, 1970) and Blowering (112 m, 1968), and the Copeton Dam on the Gwydr River in New South Wales (109 m, 1973) are rockfill dams with impervious cores, while the Cethana Dam in Tasmania (110 m, 1970) is a rockfill dam with an upstream facing of reinforced concrete.

2.5 ILLUSTRATIONS

Photographs

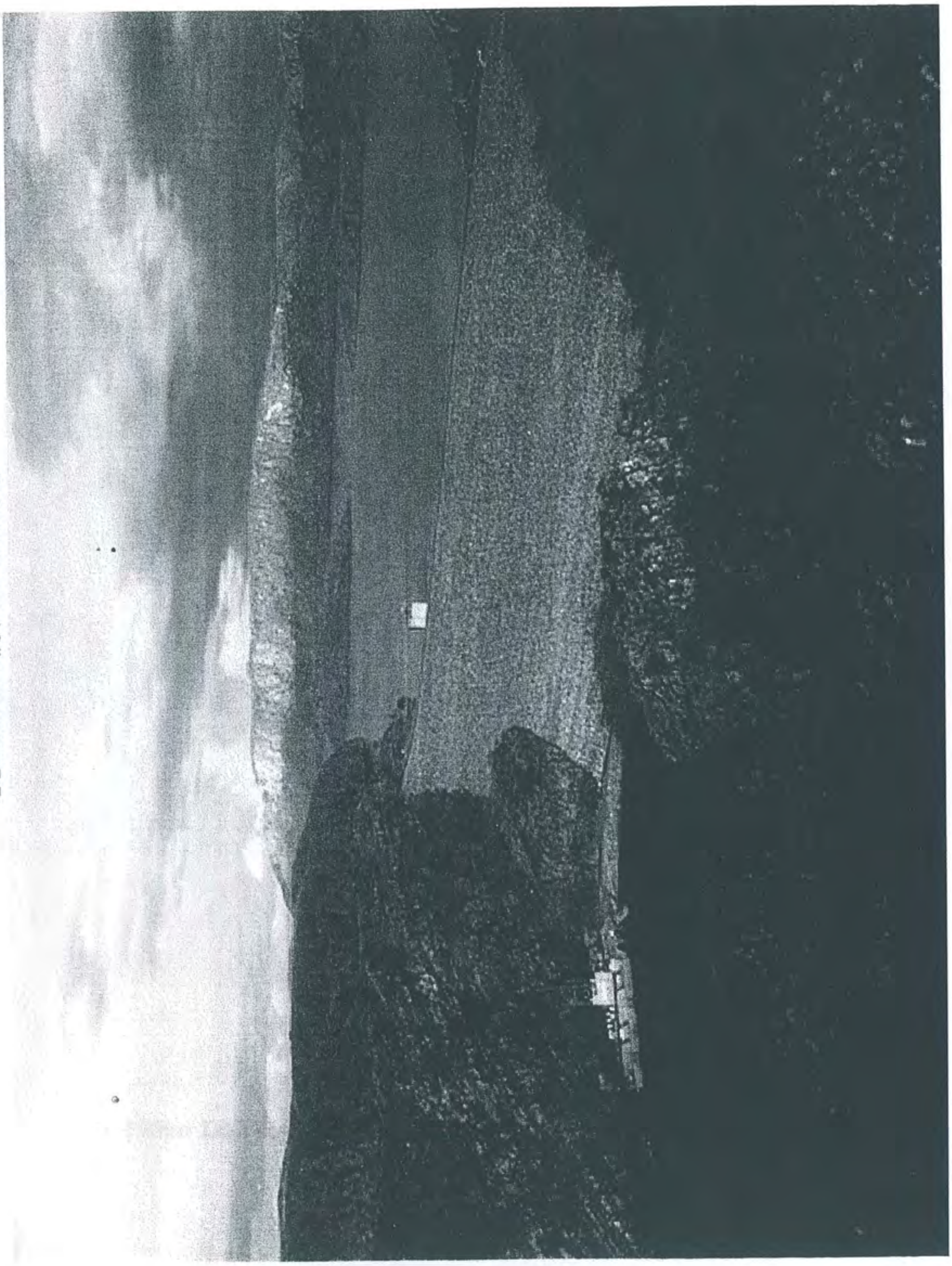


Ord River Dam and Lake Argyle in the initial stages of filling in the early 1970s

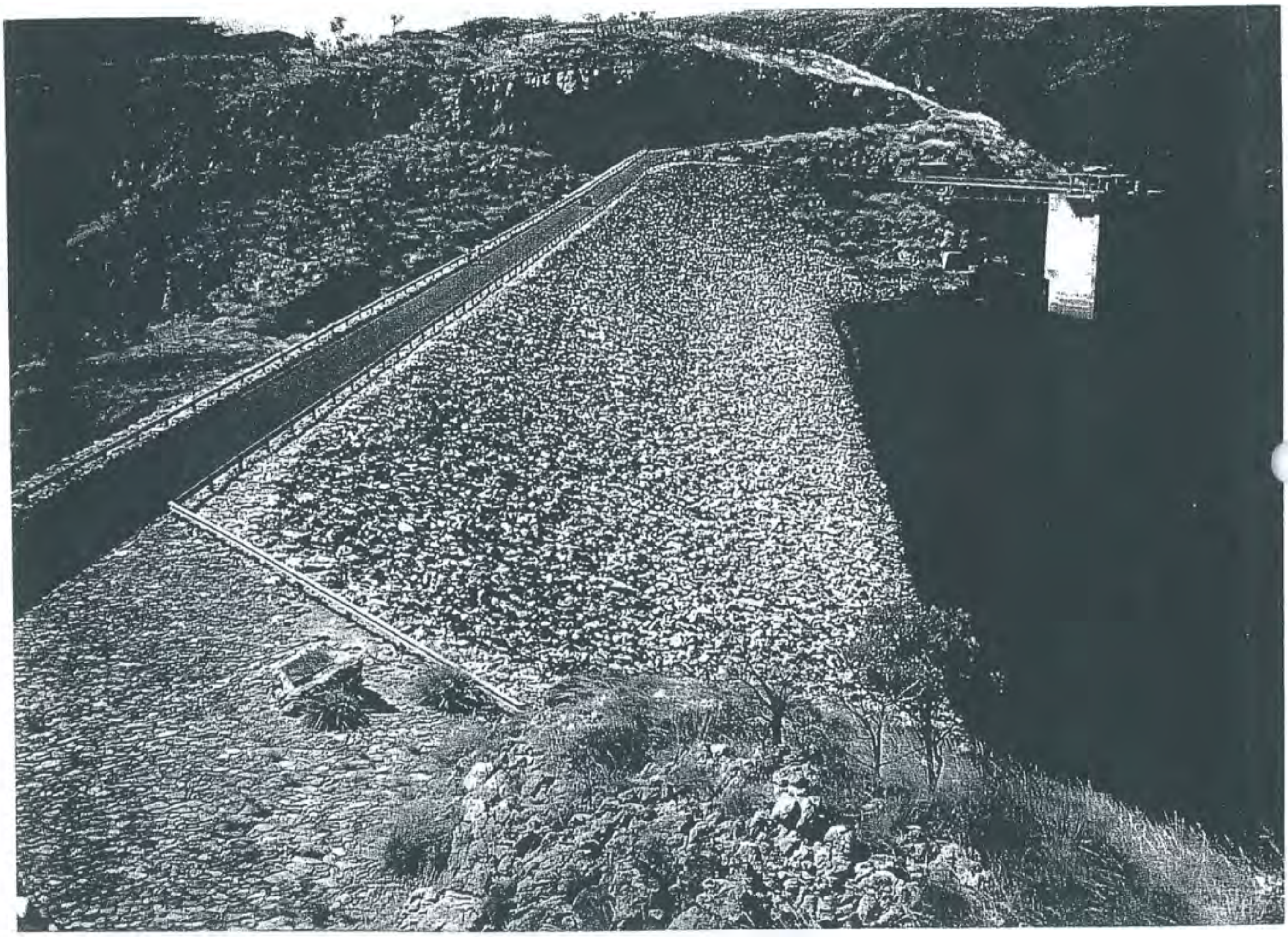
Inundation of the upper Ord River valley and formation of Lake Argyle in the early 1970s, looking north-east towards the new dam in the Carr Boyd Ranges.

5_3_2000OrdDamA.jpg (1024x768x16M jpeg)

5_3_2000OrdDamA.jpg (1024x768x16M jpeg)



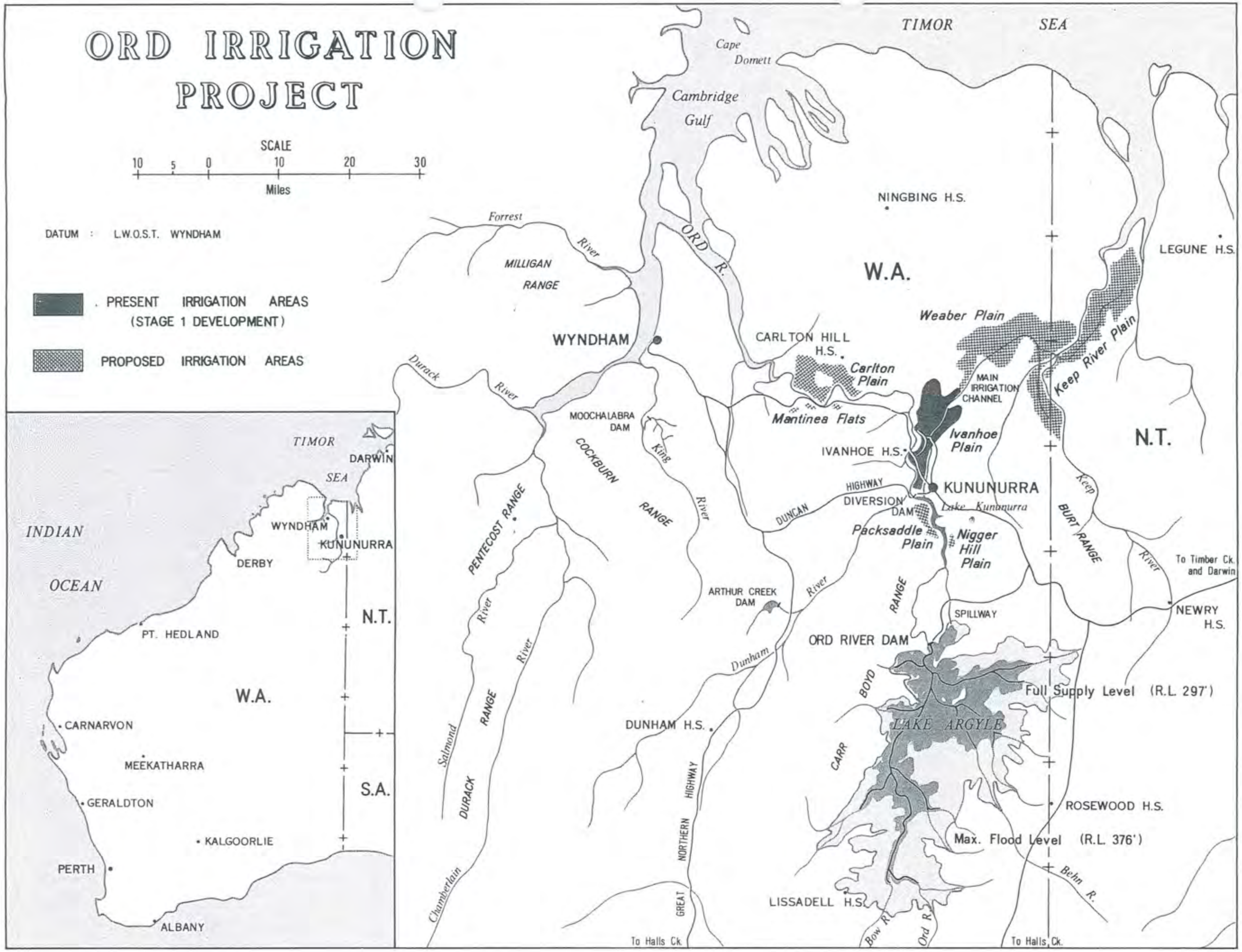
Ord River Dam downstream face, 1998



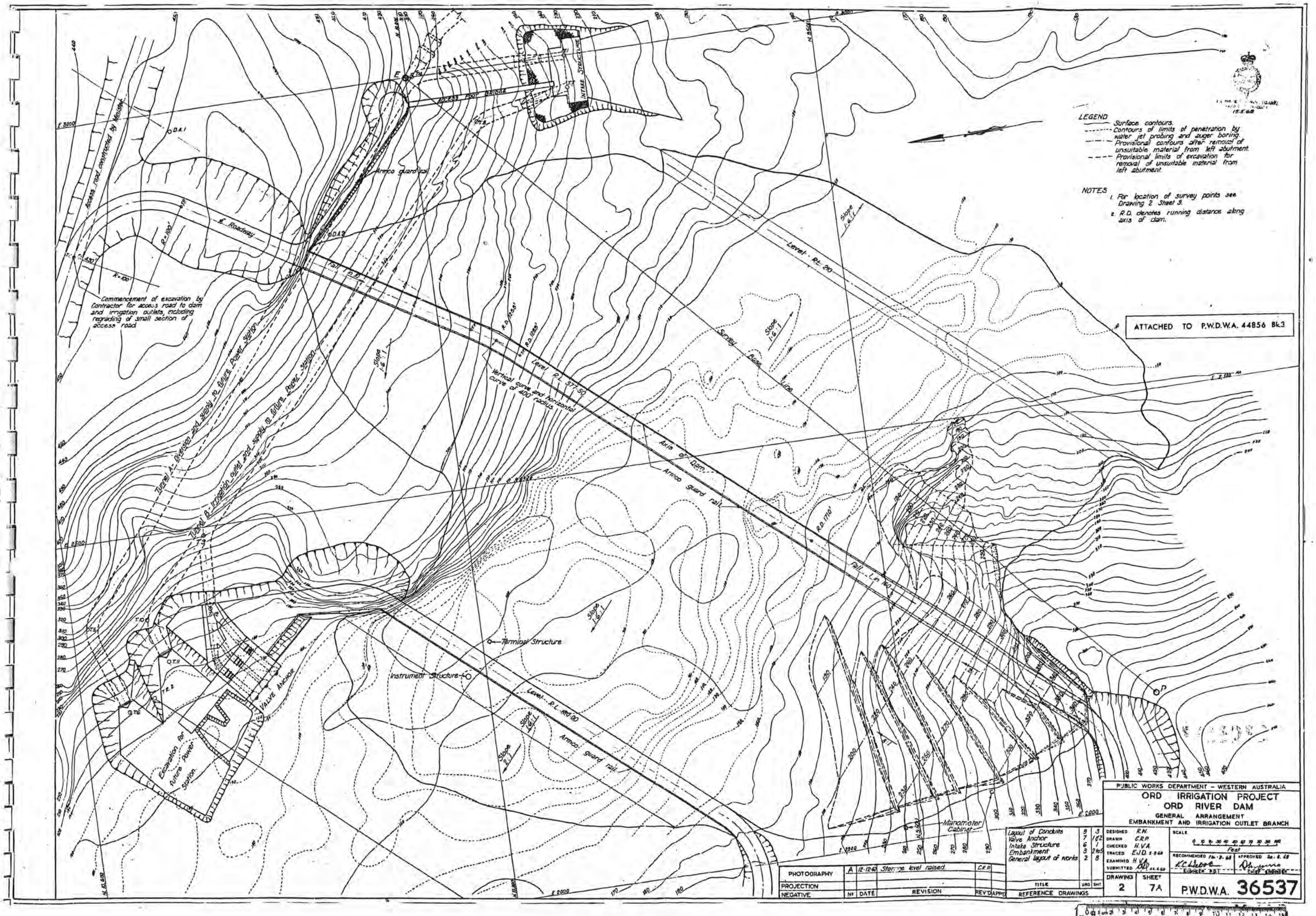
Ord River Dam upstream face, roadway and intake tower, 1998.

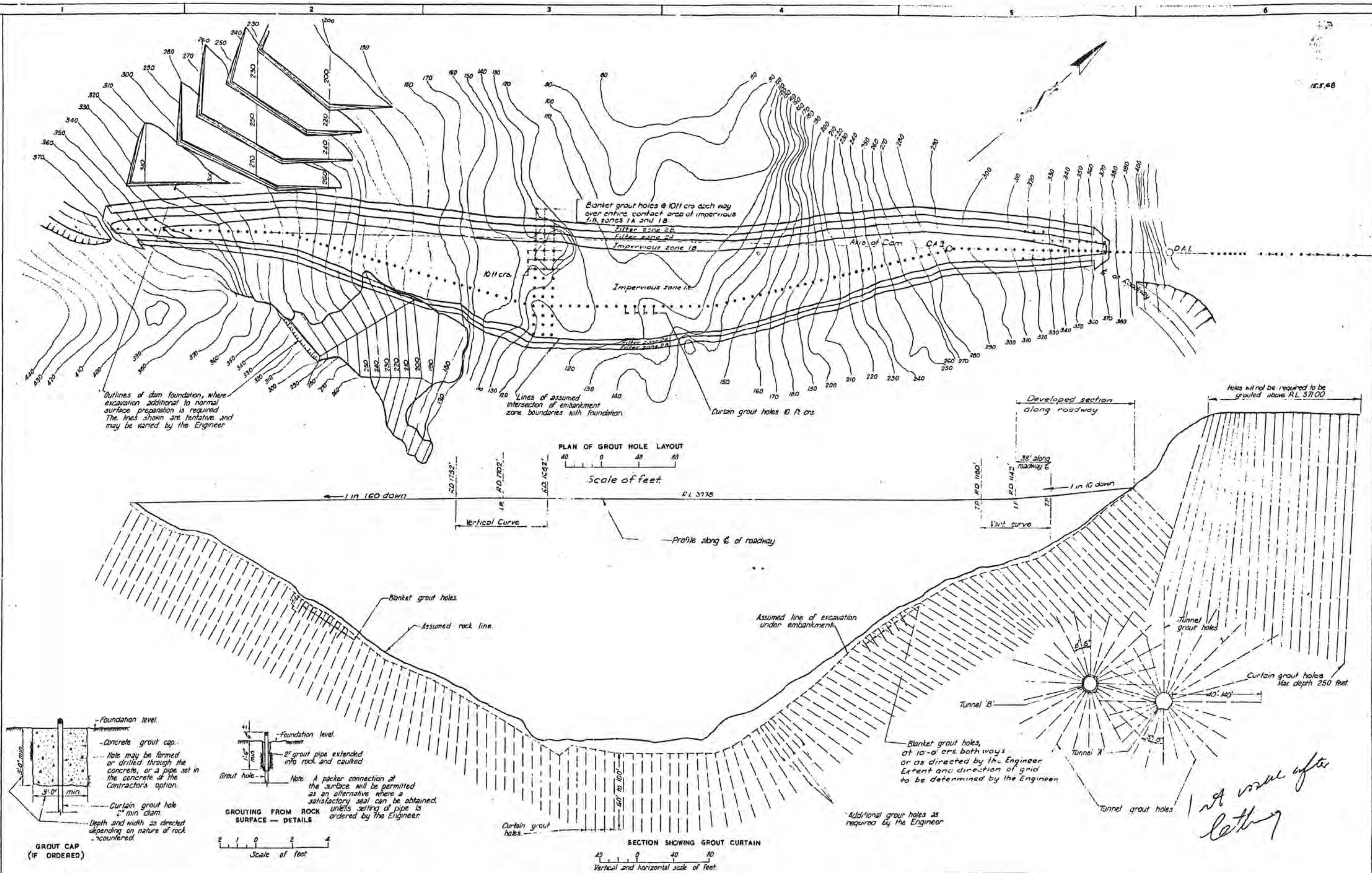
Figures

- Locality plan
- General Arrangement
- Embankment Profile and Details of Grouting
- Embankment – Typical Cross Sections
- Embankment – Steel Mesh Protection of Downstream Slope of Stage 1.



ORD IRRIGATION PROJECT
SCALE
10 5 0 10 20 30
Miles
DATUM : L.W.O.S.T. WYNDHAM
PRESENT IRRIGATION AREAS (STAGE 1 DEVELOPMENT)
PROPOSED IRRIGATION AREAS
TIMOR SEA
Cape Domett
Cambridge Gulf
ORD R.
NINGBING H.S.
LEGUNE H.S.
W.A.
N.T.
Weaber Plain
Keep River Plain
Forrest River
MILLIGAN RANGE
WYNDHAM
CARLTON HILL H.S.
Carlton Plain
Mantinea Flats
MAIN IRRIGATION CHANNEL
Ivanhoe Plain
IVANHOE H.S.
KUNUNURRA
Lake Kununurra
HIGHWAY
DIVERSION DAM
DUNCAN
Packsaddle Plain
Nigger Hill Plain
Durack River
MOOCHALABRA DAM
King River
COCKBURN RANGE
PENTECOST RANGE
BURT RANGE
Keep River
To Timber Ck. and Darwin
NEWRY H.S.
ARTHUR CREEK DAM
River
RANGE
SPILLWAY
ORD RIVER DAM
Dunham
BOYD
Full Supply Level (R.L. 297')
LAKE ARGYLE
DUNHAM H.S.
CARR
ROSEWOOD H.S.
Max. Flood Level (R.L. 376')
Salmond
DURACK RANGE
River
Chamberlain
GREAT NORTHERN HIGHWAY
Behn R.
LISSADELL H.S.
Bow R.
Ord R.
To Halls Ck.
To Halls Ck.
TIMOR SEA
DARWIN
INDIAN OCEAN
WYNDHAM
KUNUNURRA
DERBY
N.T.
PT. HEDLAND
W.A.
CARNARVON
MEEKATHARRA
S.A.
GERALDTON
KALGOORLIE
PERTH
ALBANY


LEGEND
Surface contours.
Contours of limits of penetration by water jet probing and auger boring.
Provisional contours after removal of unsuitable material from left abutment.
Provisional limits of excavation for removal of unsuitable material from left abutment.
NOTES
1. For location of survey points see Drawing 2 Sheet 9.
2. R.D. denotes running distance along axis of dam.
ATTACHED TO P.W.D.W.A. 44856 Bk.3
Access road constructed by Ministry
Roadway
Access Foot Bridge
Intake Structure
Armco guard rail
Commencement of excavation by Contractor for access road to dam and irrigation outlets, including regrading of small section of access road
Tunnel A - Diversion and supply to future Power Station
Tunnel B - Irrigation outlet and supply to future Power Station
Level R.L. 377.50
Vertical curve and horizontal curve of 400' radius
Axis of Dam
Survey Base Line
Level R.L. 180.00
Terminal Structure
Instrument Structure
Valve Anchor
Excavation for future Power Station
Manometer Cabinet
PUBLIC WORKS DEPARTMENT - WESTERN AUSTRALIA
ORD IRRIGATION PROJECT
ORD RIVER DAM
GENERAL ARRANGEMENT
EMBANKMENT AND IRRIGATION OUTLET BRANCH
REFERENCE DRAWINGS: Layout of Conduits 9 3; Valve Anchor 7 1&2; Intake Structure 6 1; Embankment 3 2to5; General layout of works 2 8
DESIGNED R.W.
DRAWN C.R.P.
CHECKED H.V.A.
TRACED E.J.D.
EXAMINED H.V.A.
SCALE Feet
RECOMMENDED K.C. Webb ENGINEER P.D.I.
APPROVED CHIEF ENGINEER
DRAWING 2
SHEET 7A
P.W.D.W.A. 36537
PHOTOGRAPHY
PROJECTION
NEGATIVE
A 12-12-68 Starting level raised C.R.P.
No DATE REVISION REV'D APP'D



GENERAL NOTES

1. All pipes and fittings to be furnished and installed by Contractor
2. Grout cap concrete requirements:- Min compressive strength after 28 days 2000 p.s.i. Finish U-1 or F-1.
3. The grout curtain as shown is located on the approx ℄ of the zone 1A material
4. The final position, direction, length and spacing of curtain grout holes may be varied by the Engineer.

REFERENCE DRAWINGS TITLE	DRG	SHT
Embankment Cross Sections	3	4
General Arrangement Embankment / Outlet System	2	7

PHOTOGRAPHY: NEGATIVE / PROJECTION

DATUM: Low water ordinary spring tide – Wyndham.

ZONE	DATE	REVISION
E		Tunnels re-located
D		Modification of grout holes
C		Survey ref. mark D.A. re-located
B		Dam axis relocation
A	Dec. 67	Storage level raised

SCALES: As shown

ATTENTION: SCALES STATED MAY HAVE BEEN VARIED BY PHOTOGRAPHY. THE BAR SCALE WILL INDICATE THE EXTENT

DESIGN CALC. — CHECKED — DRAWN — CHECKED — TRACED — CHECKED — SUBMITTED — SECTION LEADER — RECOMMENDED — ENGINEER — APPROVED — CHIEF ENGINEER

PUBLIC WORKS DEPARTMENT— WESTERN AUSTRALIA

ORD IRRIGATION PROJECT

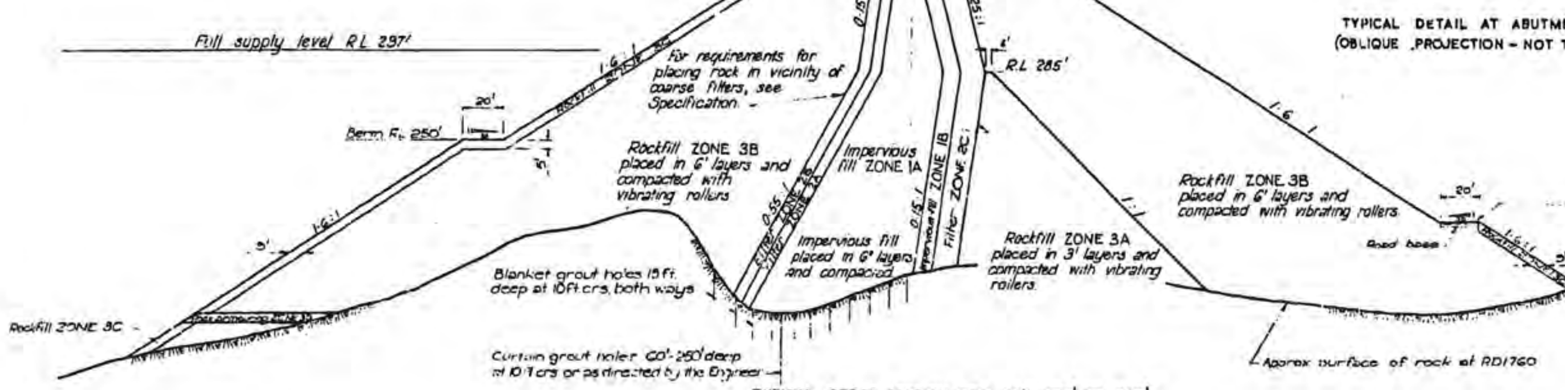
ORD RIVER DAM

EMBANKMENT PROFILE AND DETAILS OF GROUTING

P.W.D., W.A. 36537-3-2E

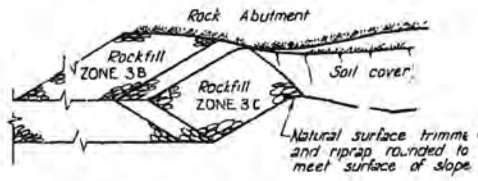
FOR BINDING ONLY

As issued after letting



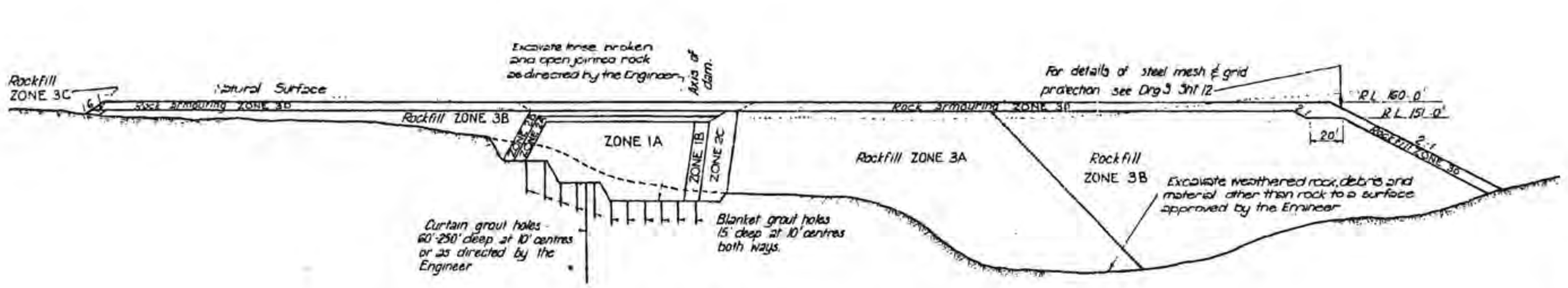
TYPICAL CROSS SECTION FOR RD'S 1755' TO 1940'

Scale of feet



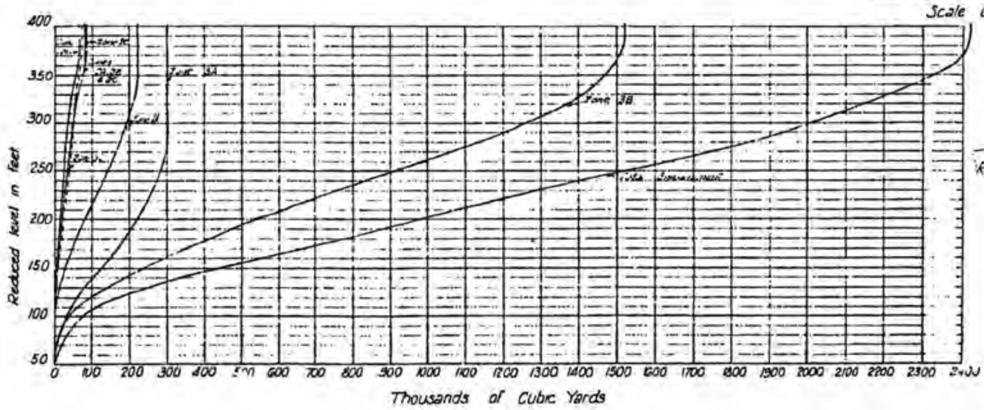
TYPICAL DETAIL AT ABUTMENT
(OBLIQUE PROJECTION - NOT TO SCALE)

Note:
1 For embankment cross section for RDs from 1162 to 1585' see PWD.WA 36537-3-20
2 For details of the top of embankment see PWD.WA 36537-3-7
3 For details at the left abutment see PWD.WA 36537-3-42
4 For details at the right abutment see PWD.WA 36537-3-13 & 7
5 For cross sections between RDs 1585 and 1755 see the transition shown in Section 'X'-'X' on PWD.WA 36537-3-20

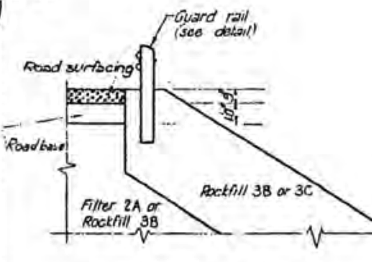


TYPICAL SECTION OF OVERTOPPED SECTION

Scale of feet

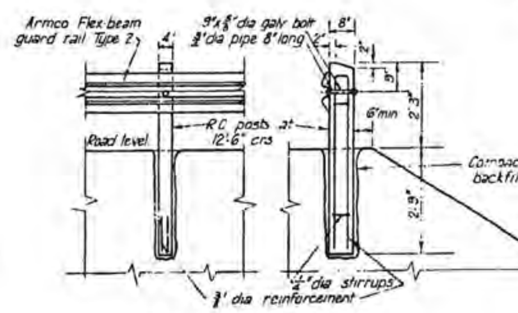


EMBANKMENT QUANTITIES



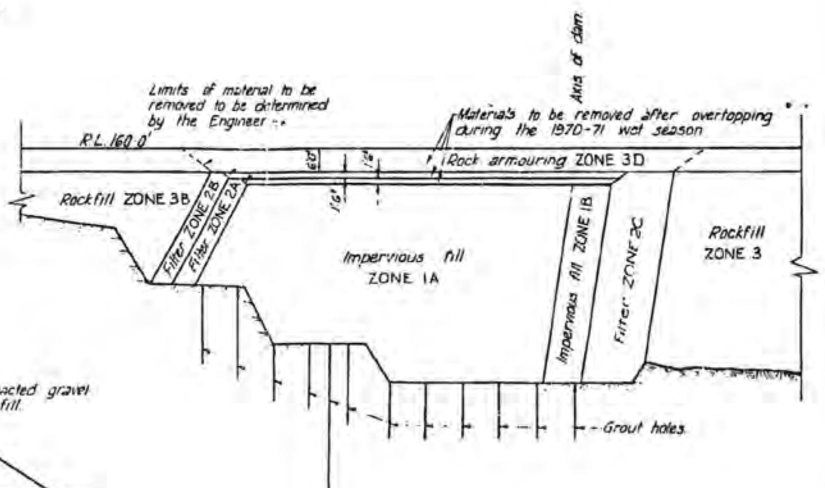
DETAIL OF ROADWAYS

Scale of feet



DETAIL OF GUARD RAIL

Scale of feet



DETAILS OF SPECIAL PROTECTION OVER CORE MATERIALS

Scale of feet

GENERAL NOTES
1. Zone 2 materials are to be placed and compacted in 18" layers
Zones 2A, 2B & 2C are processed filter material
2. Borrow area F to be used for Zone 1B material
Borrow area A to be used for Zone 1A material

REFERENCE DRAWINGS TITLE	DRG	SHT
Embankment	2	7
Steel Mesh Protection	3	12

PHOTOGRAPHY: NEGATIVE / PROJECTION / DATUM: Low water ordinary spring tide Wyndham. This level is 12.50 ft below mean sea level

	ZONE	DATE	REVISION	DRN	APPD
F			Crest raised	DKS	
E					
D				HVA	DCM
C				HVA	DCM
B			Storage level raised	DKS	DCM
A			Revised filter layout	DKS	DCM

FILE No | SURVEY BOOKS

SCALES: As shown

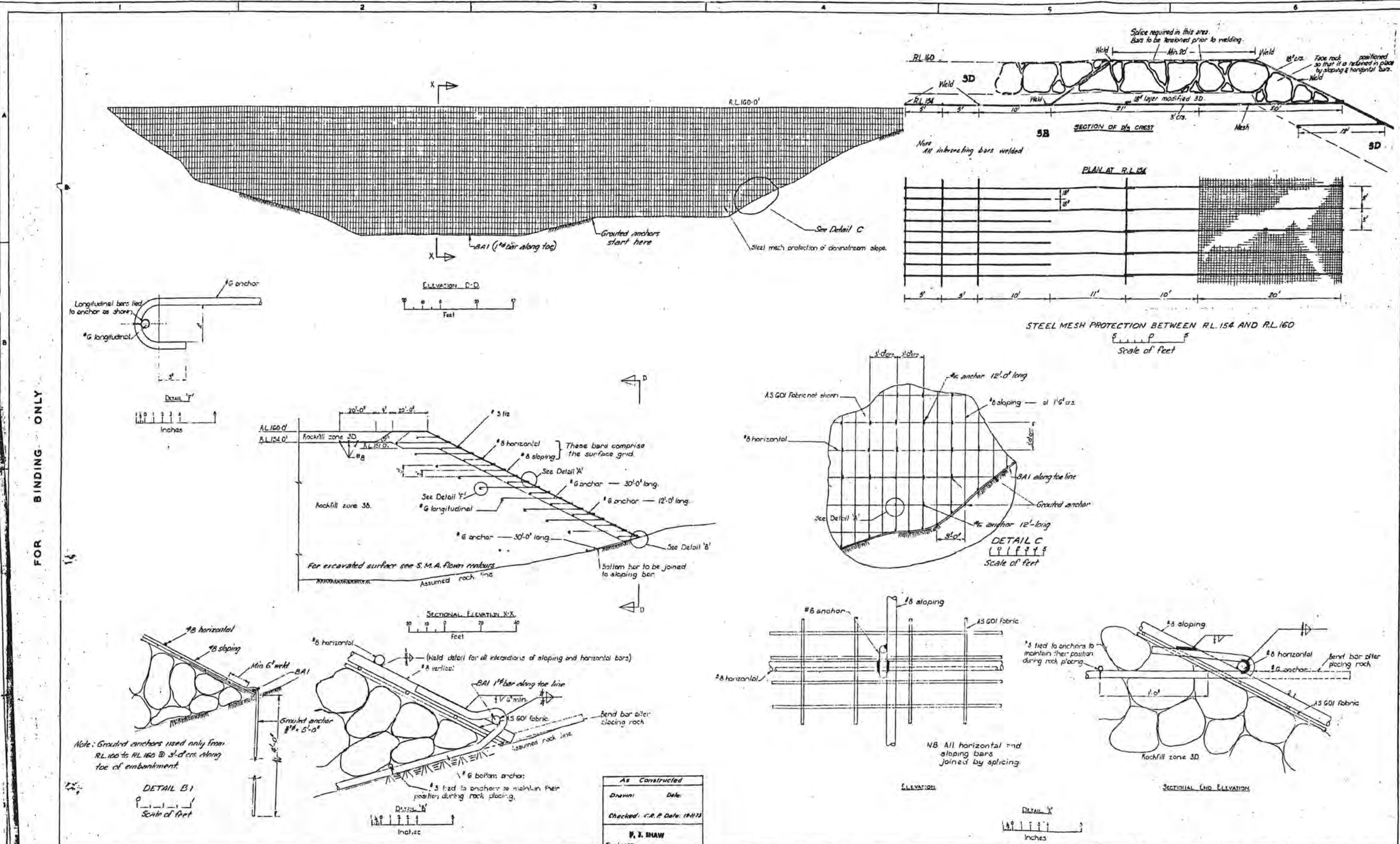
ATTENTION: SCALES STATED MAY HAVE BEEN VARIED BY PHOTOGRAPHY THE BAR SCALE WILL INDICATE THE EXTENT

DESIGN CALC. BFH — BOOK
CHECKED FSP RJK — BOOK
DRAWN DKS — CHECKED
TRACED EJD — CHECKED HVA
SUBMITTED — SECTION LEADER
RECOMMENDED — DATE — ENGINEER
APPROVED — DATE — CHIEF ENGINEER

PUBLIC WORKS DEPARTMENT — WESTERN AUSTRALIA
ORD IRRIGATION PROJECT
ORD RIVER DAM
EMBANKMENT - TYPICAL CROSS SECTIONS

P.W.D., W.A. 36537-3-4 F

FOR BINDING ONLY



As Constructed

Drawn: Date:

Checked: C.R.P. Date: 19.11.73

V. J. SHAW
Engineer

GENERAL NOTES

1. Zone 3D placed under the steel mesh shall have the maximum size modified to allow placing and compacting in 18" layers.
2. Surface of the fill to be compacted and trimmed to an even surface to allow the mesh to be placed flush.
3. The connection between the anchors and the surface grid is to be made in accordance with the specification.
4. Splices in bars shall be lap splices welded both sides for a minimum length of 6", with a ¼" fillet for #6, and a ⅛" fillet for #3.

REFERENCE DRAWINGS TITLE	P.W.D.	SHT.
Embankment - Stage I.	5	4

PHOTOGRAPHY — NEGATIVE — PROJECTION

DATUM: Low water ordinary spring tide Wyndham 12.50 feet below M.S.L.

ZONE	DATE	REVISION	DRN.	APP'D
A	12.8.68	Alter Vertical bars to Sloping bars.	J.M.C.	

FILE Nº — SURVEY BOOKS

SCALES: As shown

ATTENTION: SCALES STATED MAY HAVE BEEN VARIED BY PHOTOGRAPHY. THE BAR SCALE WILL INDICATE THE EXTENT

DESIGN CALC. W.J.W. BOOK
CHECKED R.J.W. BOOK
DRAWN J.L.M. CHECKED
TRACED CHECKED
SUBMITTED
DATE 11.7.68 SECTION LEADER
RECOMMENDED DATE 17.7.68 ENGINEER P.D.I.I.
APPROVED 7.7.68 DATE CHIEF ENGINEER

PUBLIC WORKS DEPARTMENT — WESTERN AUSTRALIA

ORD IRRIGATION PROJECT

ORD RIVER DAM

EMBANKMENT — STEEL MESH PROTECTION OF DOWNSTREAM SLOPE OF STAGE I.

P.W.D., W.A. 36537-3-12

3 ASSESSMENT OF SIGNIFICANCE

Ord River Dam – National Engineering Significance

The Ord River Dam structure introduced two innovative measures to Australia. These are enlarged on in the Attachments by a technical paper due to Webster, delivered to the Commission Internationale Des Grands Barrages in Madrid 1973. A brief summary arising from this paper follows: -

Flood Discharge

In keeping with the Kimberleys region in the North of the state of Western Australia, the Ord River is of grand scale. The dam catchment extends over an area of 46,000 square kilometres. The land is used solely for the rangeland grazing of beef cattle and is divided into some 18 properties. Some 40 km downstream of the dam is the town of Kununurra, which is the administrative centre for the irrigation area.

The maximum probable flood at the dam site is estimated at 71,000 m^3/sec. Such a massive flood appeared to necessitate a concrete structure capable of overtopping, with substantial erosion protection downstream of the dam. Concrete is an expensive building material in such a remote locality.

In the event, a rockfill dam was commenced in 1968 and completed by December 1971. It is 99 m in height above the lowest foundation and contains 1,800,000 cubic metres of material. The reservoir formed by the dam had an active storage of 5,278 million cubic metres below full supply level (this has since been increased by raising the spillway crest level in 1995) and 34,154 million cubic metres of flood surcharge.

The main spillway is an unlined cut through a granite saddle approximately eight km from the dam embankment. There are a further three auxiliary spillways at appropriate higher levels through saddles in the north-east rim of the reservoir, which it is estimated would operate no more frequently than once in 400 to 600 years.

This spillway concept made use of: -
(1) the extremely large flood surcharge which could be obtained for small increase in the height of the dam;
(2) the fact that no land of significant commercial value would be submerged by a higher dam;
(3) the predictable flow-pattern of the Ord River into distinctive dry and wet seasons.

Diversion of River During Construction.

Construction of the embankment required two dry seasons, which necessitated diversion of one wet season's river flow. Conventional diversion works were clearly impractical and so the embankment had to be designed to pass one wet season's flow over the partly completed structure. A 4.43 m diameter diversion tunnel was constructed in the right abutment to deal with most of the dry season flows.

Hydraulic model studies were conducted to show that stable slopes, the degree and type of protection, and the height to which the first season's rockfill could be constructed and remain stable when overtopped. These model studies showed that the partly completed embankment would be stable if built approximately to the original pre-stripped stream bed level with "special protection" to the top and downstream face of the structure.

Almost 400,000 cubic metres of sand and silt were excavated before placing of the fill could commence, the lowest foundation level being 30 m below the original stream bed.

The "special protection" comprised a 1.8 m layer of rock armouring. Over the core area, the rock armouring was underlain by a 1 m thick layer of filter material as a blinding zone. As an added safety measure the downstream slope was protected with a steel bar grid securely anchored and with a mesh behind the grid.

The maximum depth of flow recorded in the wet season of 1970- 71 was 10.5 m over the embankment, with a peak recorded velocity in the order of 4.5 m/s. The steel mesh remained undamaged apart from the build up of silt on the surface during the recession of the flow.

In addition to the above innovations it is interesting to note that prior to the dam construction the problem of overgrazing in the catchment area was addressed. From sampling done prior to construction it was estimated that the annual sediment load would approach 600 m3 per km2 per year. Controls were put in place, including resuming the pastoral leases in some cases, and a program of fencing and the planting of native grasses in denuded areas have led to substantial improvements.

The Significance of the Dam for State and National Heritage

The significance of the Ord River Dam is further assessed in accordance with the requirements established in *Criteria for the Register of the National Estate: Application Guidelines* (Australian Heritage Commission, April 1990).

CRITERION A3 *(landscape)*	*Importance in exhibiting unusual richness or diversity of flora, fauna, landscape or cultural features*
CRITERION E1 *(aesthetic)*	*Importance for a community for aesthetic characteristics held in high esteem or otherwise valued by the community.*

The construction of the Ord River Dam and irrigation areas brought about dramatic changes to the Ord valley, both environmentally and scenically. The extensive body of water created by Lake Argyle, with its numerous islands and secluded inlets provides a form of landscape completely new to the region. The vivid blue of the water contrasts with the yellow and reds of the rounded hilltop islands and the rugged grandeur of the Carr Boyd Range to the west. From the lake and the air the dam merges with the ranges either side of it as a continuation of the shoreline.

Downstream from the dam, control of the floodwaters has allowed all year access by boat to the grandeur of the Ord River gorge with its steep cliffs patterned in varied colours. The dam provides a dramatic visual closure to the gorge, which is in scale with its surroundings and of congruent texture and colour.

From the air the rich greens and browns and formal shapes of the irrigated areas contrast with the natural browns and greens of the surrounding rangeland river flats and with the steep hills in the background and provide one of the most dramatic and contrasting landscapes in northern Australia.

The thousands of people who visit the East Kimberley every year are drawn by the scenic grandeur of Lake Argyle and by the interest in the development of the Ord scheme and its impact on the region. Kununurra and the Ord valley have also increasingly become an important gateway to the other natural attractions of the Kimberley region.

Lake Argyle is now a wetland of international significance and has been gazetted under the Ramsar Convention as being especially important for birds migrating from Asia and Siberia.

CRITERION A4 *(historic)* — *Importance for association with events, developments of stages in Australian history or in the history of a state, region or community.*

The Ord River Dam and the associated irrigation scheme has been the means of providing the remote, sparsely populated, East Kimberley region, where the only economic activity for over a hundred years has been open range pastoralism, with a new economic structure based on an expanding tropical agricultural and horticultural industry, a thriving tourism industry and urban centre, Kununurra, containing many modern urban amenities which were previously not available in the region.

Kununurra was the first modern town to be built in the north of Western Australia and experience gained in its construction and development proved invaluable for the subsequent planning and establishment of the new mining towns at Tom Price, Newman, Karratha, Paraburdoo and Wickham.

The development of the Ord irrigation area has been part of two important Australian historical themes, 'peopling the north' and 'testing the land'. A common preoccupation of Australian governments, whether state or federal, Labor or non-Labor, has been 'the successful settlement of the northern portion of the continent of Australia' (as Russell Dumas put it). This has been partly for strategic reasons and also because of a remnant of European colonial thinking retained by Australians actually lived there and worked the land.

'Testing the land' has traditionally been the harsh philosophy that Australian governments have resorted to when popular demand for agricultural land which they had stimulated exceeded the amount of available land in proven agricultural areas and settlers have been allowed to 'test the land' in marginal areas (like the wheat growers in South Australia in the 1870s and in the Yilgarn in the 1920s). There were differences on the Ord of course. It was the taxpayer, not the farmers, who paid for the testing there but the farmers experienced the same heartaches and despair as the earlier wheatbelt 'testers'. Commercial success on the Ord has been hard won over twenty years of hopes and disappointments but is at last a tangible reality.

CRITERION B2 *(rarity)* — *Importance in demonstrating a distinct way of life, land-use, function or design no longer practised, in danger of being lost, or of exceptional interest.*

The East Kimberley region was one of the last parts of Australia to be opened for pastoralism and the cattle industry there has a rich and comparatively recent history, much of which is associated with the Durack family, one of the first groups to overland cattle from the eastern colonies in 1883-85. The Durack's two main stations, Argyle Downs and Ivanhoe were the properties most directly affected by the Ord Dam and the Irrigation Area. Ivanhoe Plain on the lower Ord was the first area to be developed for irrigation, while the site of Argyle Downs Station homestead and the station's most fertile river-front land were submerged by Lake Argyle. It was at this homestead that Mary Durack wrote her early books and her sister Elizabeth commenced her career as a painter, and it was on the Argyle river flats that their brother Kim commenced his irrigation experiments.

Before Argyle Downs homestead was flooded it was dismantled stone by stone and re-erected near the dam. It now functions as a museum, which seeks to interpret the working operation of a pastoral station in the pre-motorised era, and also the lives of the Europeans and Aboriginal people working there. With the coming of motorised cattle transport, helicopter mustering, greatly improved communications and the provision of urban amenities at Kununurra, there have been dramatic changes to the cattle industry in the last fifty years. Yet there are still people alive today who remember the early pioneering days of the Kimberley industry. The development of the Ord Dam and Irrigation Area and of Kununurra has greatly stimulated general interest in the pioneering period of the pastoral industry and the roles not only of Europeans but also of the Aboriginal people in the industry.

CRITERION C2 *(scientific)* — *Importance for information contributing to a wider understanding of the history of human occupation of Australia.*

Since Kim Durack's early work during the war on irrigated sorghum and millet crops, the Ord River valley has been an important research centre for the development of tropical agriculture. During the last ten years the Frank Wise Institute (formerly the Kimberley Research Station) has been involved in the trialing of a wide variety of horticultural produce and in encouraging the cultivation of a diverse number of high value commodities cultivated for niche markets. Growing this type of product is currently the most profitable type of farming on the Ord.

Parts of the Ord River Dam's catchment that had been eroded by overgrazing were destocked in the early 1960s and resumed to form the Ord River Regeneration Reserve. A major revegetation program was commenced in the Reserve, which has reduced siltation in the dam and has provided valuable information which has been used to improve land management practices in other parts of the catchment and elsewhere in the Kimberley.

CRITERION D2 *(representativeness)* — *Importance in demonstrating the principal characteristics of classes of human activities in the Australian environment (including way of life, custom, process, land-use, function, design or technique).*

The Ord River Dam is a fine example of a rock-fill dam, a design that was used increasingly during the 1960s and 1970s in locations where one could be built more economically than an earthfill dam or a concrete gravity dam. A rock-fill dam was particularly suited to the Ord River site because high strength rock was available locally, whereas there was a shortage of suitable soils for an earthfill dam and the high cost of transporting large quantities of cement to such a remote site weighed against the use of a concrete dam

CRITERION F1 *(creativity)* — *Importance for its technical, creative, design or artistic excellence, innovation or achievement.*

Several innovative features were incorporated into the design and construction of the Ord River Dam. Construction of the dam required three dry seasons, which meant that one wet season's flow, had to be diverted or passed over the partially completed dam. A diversion tunnel was provided to take dry season flows but it was impossible to provide full diversion of such large flows as those of the Ord during the wet season, especially in the narrow gorge where the dam was sited. The solution adopted was to complete the dam to just above original river bed level during the second dry season and to protect the partially completed embankment against wet season flows with a 2 metre layer of rock armouring over the dam's top surface and downstream face, held in place on the sloping face and downstream toe by a grid of steel reinforcement tied back into the embankment. These measures successfully accommodated wet season flows far more severe than any known to have been experienced before in Australia during dam construction operations.

Another innovative design feature was the method of accommodating the estimated peak flood flow of the river. Normally this is provided for by means of a spillway with sufficient capacity to take the full flood. The long-term peak flood flow of the Ord is so huge that the construction of a spillway of that capacity would have been prohibitively expensive. The solution adopted was to extend the height of the dam to above the maximum flood level and to provide a much smaller capacity spillway (of 3 500 cubic metres per second compared with the flood flow of 71 000 cubic metres per second) which would gradually release wet season floodwaters during the dry season.

Rock for the dam was obtained from a quarry 800 metres upstream from the dam on the western bank using what is known as 'coyote blasting' on an exceptionally large scale. Two tunnels were driven into the side of the mountain and the rock shattered into the two million tonnes required by detonating about 500 tonnes of explosives in each tunnel in what were reported to have been the largest blasts ever detonated in Australia.

The original design of the dam provided for a hydro-electric power station to be built at the dam when local demand justified its construction. It was not until the Argyle diamond mine was established near the southern end of Lake Argyle in the 1980s and there was increased demand on Western Power's Kununurra diesel power station, that a small hydro-electric station at the dam became viable. In October 1994 a private company, Ord Hydro Consortium, signed an agreement with the state government to build a privately owned 30 megawatt hydro-electric station at the dam. This came into operation in 1996 supplying power to Western Power for use mainly by Argyle Diamond, and at Kununurra and Wyndham. The station is only the second hydro-electric power station in the state and is the first to be privately constructed for the purpose of providing power to a public authority.

CRITERION G1 *(social)* — *Importance as a place highly valued by a community for reasons of symbolic, cultural, educational, or social associations.*

The Ord River Dam and its associated irrigation scheme was of major social significance as it changed the social structure of the region by planting a new town, Kununurra, of 4 000 people with modern facilities, in the midst of a community made up of widely separated, sparsely populated cattle stations and a small port town (Wyndham). Housing for the new irrigation farmers and their families was also provided in an unusual manner for a farming community. Instead of farmers having to build housing on their blocks this was provided for them in Kununurra itself which helped to build up the community. The region also benefited from the infrastructure provided for the town and the dam construction, such as telecommunications, roads and airport facilities, and irrigation structures.

The Diversion Dam provided a crossing of the lower Ord River and this provision assured road access in the "wet season" between Kununurra and the port of Wyndham

The Ord River Scheme has been a landmark in the development of Western Australia's north and has put the East Kimberley region 'on the map' for many Australians. Over 100 000 visitors, from other parts of Australia and overseas, pass through Kununurra every year, whereas only thirty years ago the region was visited by only a handful of people on government or pastoral business. The huge body of water impounded by the dam in a region which, has little rain for much of the year, attracts thousands of interested tourists, and cruises on the lake are featured by most tours.

The two dams also provide an important recreational base for local residents with swimming, yachting, rowing and water skiing being available. Fishing in the river below the dams, is also a popular recreation for residents and visitors.

CRITERION H1 *(historic)*	*Importance for close associations with individuals whose activities have been significant within the history of the nation, State or region.*

The planning of the Ord River Irrigation Scheme is most closely associated with Sir Russell Dumas and the building of the main dam with Sir Charles Court.

- *Sir Russell Dumas,* after inspecting the East Kimberley in 1942, recommended damming the Ord in the Carr Boyd Ranges, to service irrigated agriculture on Ivanhoe Plains and was Director of Works during the initial planning stages of the work.

- *Sir Charles Court* was largely responsible for obtaining federal funding for construction of the main Ord Dam within four years of completion of the Diversion Dam.

  Sir John Parker was Director of Engineering PWDWA during the period the Diversion Dam, irrigation facilities, the town of Kununurra and infrastructure were provided and construction of the Ord Dam was commenced.

- *Donald Munro* succeeded Sir John Parker and had previously coordinated the detailed engineering of the Diversion Dam and the Ord Dam.

4 STATEMENT OF SIGINIFICANCE

The Ord River Dam is of national significance because:

the dam and its associated irrigation scheme changed the economic and social structure of the region by establishing a new agricultural industry and a new town with modern facilities in the midst of a community of sparsely populated cattle stations and a small port town.

the Ord River Scheme has been a landmark in the development of Western Australia's north and, in putting the East Kimberley "on the map" for most Australians, has inaugurated a flourishing tourist industry in the region.

the dam is a fine example of rock-fill dam technology and its design incorporated several innovative features, which included

- the staging of the works to permit one wet season's river flows to pass over the partially completed works and the provision of special measures to protect the works from these flows; and
- accommodation of the very large estimated peak flood flow by extending the height of the dam to above maximum flood level and providing a small capacity spillway which would gradually release wet season floodwaters during the dry season.

the Ord Scheme has been an important research centre for the development of tropical agriculture and the Ord River Regeneration Reserve has provided valuable information on the regeneration of overgrazed pastoral country.

the establishment of the Ord irrigation scheme followed in the continuum of two important Australian historical themes, "peopling the north" and "testing the land" and, like earlier examples, commercial success on the Ord has been hard won over more than twenty five years.

the development of Kununurra as the Ord scheme's service centre served as an important model for the establishment of subsequent modern mining towns in the state's north-west.

its historic associations with prominent persons associated with its development, in particular:

Sir Russell Dumas
Sir Charles Court
Sir John Parker
Donald Munro

The Ord River Dam is also significant because:

its creation on a grand scale of distinctive land and water scapes was completely new to the region, with the brilliant colours of Lake Argyle and the irrigated farmlands contrasting dramatically with those of the Carr Boyd Range and the river flats.

as a consequence of the Durack family's close association with the areas inundated by the dam, it provides an opportunity to develop interpretative material about the cattle industry in the pre-motorised era and the work undertaken by both European and Aboriginal people in it.

the 30 megawatt hydro-electric power station built at the dam in 1996 was the first in the state to be privately constructed to provide power to the state power authority.

the dam and the diversion dam provide important resources for water sports and passive recreation for both residents and visitors. Lake Argyle, impounded by the dam, is Australia's largest man made lake.

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The Investigation and Design of the Ord River Dam

BY K. C. WEBSTER, M.I.E.AUST. and W. J. WILKIN, B.C.E., M.I.E.AUST.*

Summary.—The Ord River Dam, which is a 320-ft-high rockfill dam with thin sloping clay core, was constructed between 1969 and 1971. The construction of a dam across the Ord River, which has a probable maximum flood of 2 500 000 cusecs, posed some unusual design problems.

The paper describes the investigation and design of the dam, the techniques adopted to allow flood waters to pass over the partially completed embankment and the development of an economic spillway arrangement.

INTRODUCTION

The Ord River Dam is the major engineering feature in the development of the Ord Irrigation Project. The dam forms a storage reservoir of 4 600 000 acre-ft capacity to spillway crest level. Water released from this storage will flow 30 miles down the Ord River to the Diversion Dam where it will be diverted into earth channels to supply some 180 000 acres of irrigable black-soil plains.

In 1941, Mr R. J. Dumas, Director of Works, and Mr F. Foreman, the Government Geologist, made the first engineering reconnaissance survey for a major dam on the Ord River. Six sites were identified in gorges where the Ord River cuts through the Carr Boyd Ranges. The site first favoured was surveyed and some preliminary drilling was carried out between 1942 and 1947. However, as the full magnitude of wet season discharges of the Ord River became apparent, the provision of adequate spillway capacity became a major problem and this, coupled with the depth to foundation rock at the first site, led to investigations being commenced in 1960 at a second site some three-quarters of a mile further downstream. Investigation and design proceeded at this site as resources permitted and, in November 1967, the Commonwealth made a grant of 20.9 million dollars to the State of Western Australia for the construction of the Ord River Dam. Construction of the dam commenced in 1969 and was substantially completed by December 1971.

DESCRIPTION OF WORKS

The works, shown in Fig. 2, comprise:

(*a*) A rockfill dam, some 1100 ft long at crest level and 320 ft high above the lowest foundation.

(*b*) An unlined spillway cut through a granite saddle approximately five miles from the dam embankment—the maximum depth of cut is 90 ft, the bottom width 40 ft and the length 7000 ft.

(*c*) Three auxiliary spillways through saddles in the north-east rim of the reservoir.

(*d*) An intake structure with two fixed-wheel gates, stop logs, trash racks and access bridge.

(*e*) Two conduits, mainly in tunnel, in the right abutment, each with an effective diameter of 14.5 ft and an approximate length of 1200 ft. The downstream ends of the tunnels are steel-lined and the irrigation outlet branch terminates in three steel pipes.

(*f*) Three irrigation outlets, each with a 78″-dia outlet valve and a 96″-dia guard valve to control the flow of irrigation water.

Provision is made for connection of the tunnels to a hydro-electric station to be constructed later.

The reservoir contains 4 200 000 acre-ft of active storage below full supply level and 27 700 000 acre-ft of flood storage. At full supply level the reservoir area is 280 square miles and at design flood level, 850 square miles.

The storage capacity was determined by the most economic combination of spillway and embankment and will produce a yield of 1 500 000 acre-ft per annum, well in excess of the irrigation demand.

GEOLOGY

The geological setting is a sequence of Upper Proterozoic sedimentary rocks showing only minor metamorphic effects. Rock types are principally quartzites, sandstones, siltstones and mudstones. Within the river bed there are extensive recent deposits of silts, sands and gravels, which are subject to periodic removal by high river flows. Auger drilling and jetting showed that these alluvial deposits were up to 100 ft deep.

Faulting in the area is common and intense local deformation has been caused by the major faults, of which there are three within the vicinity of the dam site (Fig. 3).

Jointing systems are well-developed and the rocks vary from thin-bedded and closely-jointed to massive. Soil covers parts of the site but intermittent scree and talus slopes are common. Generally, surface weathering is shallow except in fault zones and in the stronger joint planes.

The foundations of the dam are on both quartzite and siltstone. The left abutment is a quartzite ridge on the limits of an anticlinal fold. Erosion of this anticline has exposed siltstone on the downstream side of the ridge but a massive, extensively-jointed quartzite rampart remains as a capping on the upstream side. The rock of the right abutment rises steeply from the river to form a cliff of massive quartzites and sandstones. Above the cliff is a series of terraces, scree slopes and rocky outcrops.

SITE INVESTIGATION

Site investigation commenced in 1960 and continued intermittently until 1968. Subsurface exploration consisted of diamond drilling, water jetting and probing, trenching and the driving of two adits. A total of 52 diamond drill holes was put down, ranging in length from 13 to 301 ft, with a total length of approximately 7040 ft. Most of the early holes were cored at AXT or AX, whereas the later holes were generally NMLC or BMLC size.

Due to the hardness and the abrasiveness of the quartzite rock, the bit life in 1960-61 was 5.3 ft per bit. This was improved to 7.0 ft per bit in 1964 by the use of step bits and drilling oil. Core recoveries averaged 97% for holes drilled mainly in the massive quartzite. Poorer recoveries were experienced in the thinly-bedded silty quartzite, the figure being 84%. The two adits were driven in 1961 into the left abutment to test the thickness of the quartzite capping over the siltstone and to investigate the nature of the contact zone.

During the early years of the investigation, the climatic conditions, remoteness and ruggedness of the area posed considerable difficulties of access, communication and the provision of supplies.

HYDROLOGIC CONDITIONS

Catchment and Climate:

The Ord River Dam catchment is within the 18″ to 25″ rainfall belt and has an annual evaporation of 102″. It extends over an area of 17 800 square miles of mostly rough, hilly country with thin soils, rocky outcrops and with sparse cover of spinifex and small trees. There are two distinct seasons, a wet season and a dry season. The wet season extends from about December to April and the rains of this season occur somewhat irregularly from monsoons and the occasional tropical cyclone.

Rainfall and Streamflow:

Gauging of the river commenced in 1945 and has enabled estimation of runoff to be made from rainfall records back to the 1904-5 season. Flood peaks of around one million cusecs have occurred three times in the past 15 years. During such floods the river transports large volumes of sediment. Base flows are very small in relation to these flood flows and become insignificant or cease altogether for several months during the dry season.

There is wide variation in flows from year to year, as shown by the following figures which are based on synthesised flows over a 62-year period:

Lower decile of annual flows	600 000 acre-ft
Median annual flow	2 800 000 acre-ft
Mean annual flow	3 500 000 acre-ft
Upper decile of annual flows	8 700 000 acre-ft
Flow exceeded once in 100 years	18 000 000 acre-ft
Flow exceeded once in 1000 years	32 000 000 acre-ft

DEVELOPMENT OF THE DESIGN CONCEPT

Type of Dam:

During the investigation stage of the project, three main dam types were considered. These were gravity, hollow gravity and rockfill with a clay core. Alternative studies were made and the conclusion reached in 1964 was that a rockfill dam with a sloping clay core and a spillway cut through a low saddle was the most economic and sound engineering solution.

Outlet Works:

The geology and topography of the site dictated that the outlet conduits should be tunnels located in the right abutment. The locations

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Fig. 1.—View of Completed Dam.

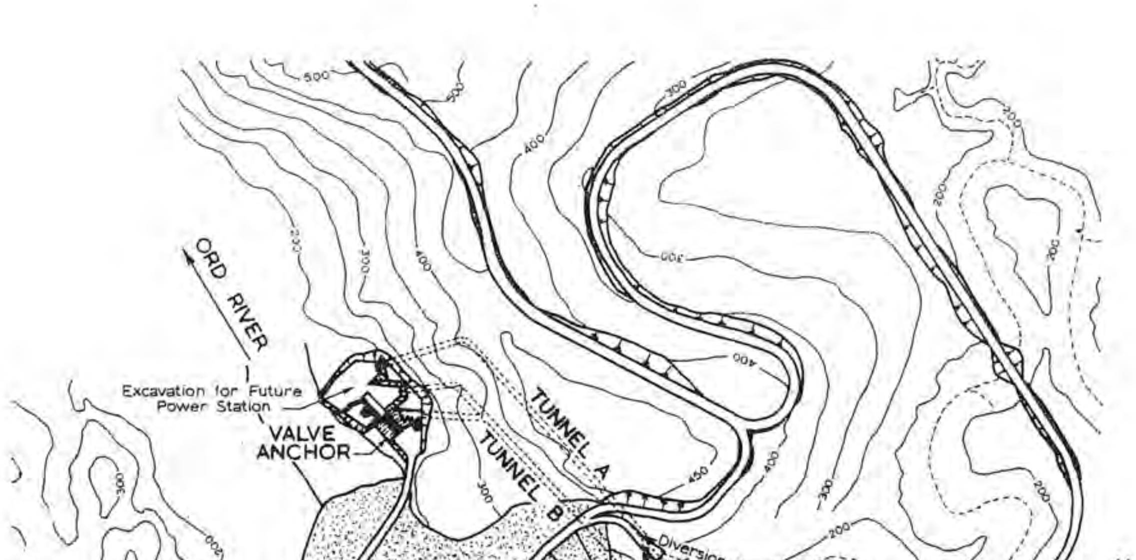

Fig. 2.—Ord River Dam—General Arrangement.

of the intake structure and the outlet valves were also fixed within close limits by the topography.

The system had to provide for irrigation and power requirements and for the diversion of dry season river flows during construction.

Embankment:

Site geology and topography, along with the limitation on the location of the outlet works, were critical in determining the configuration of the embankment. On the right abutment the axis of the embankment was fixed within the limits of these constraints.

On the left abutment the axis of the dam was located so that the core was immediately downstream of the highly jointed quartzite cap and the quartzite-siltstone contact area.

Spillway:

Because of the extremely large flood flows of the Ord River, the spillway played a major part in the investigation and design of the dam.

The concept adopted makes use of the extremely large flood storage volume available. Individual flood events are of reduced importance and the total runoff for a complete season is the governing factor in determining peak spillway discharge. The flood storage will be used to store the runoff from an entire wet season and the flood volume will be discharged at a relatively low rate during that wet season and the subsequent year. With this arrangement, the spillway can be made very small compared with the requirement for the more conventional concept of discharging individual floods. Its cost is thereby very greatly reduced. Against this, the dam embankment has to be constructed somewhat higher in order to provide flood storage, but the spillway costs dominate the economics.

The spillway, which is a narrow channel cut through a saddle in the rim of the reservoir, is some five miles from the dam on a long bay of the reservoir which extends downstream of the dam site. This spillway has a capacity of 125 000 cusecs but in the event of extremely high reservoir levels, three natural saddles will operate as auxiliary spillways, giving a total spillway discharge capacity of approximately 800 000 cusecs at RL 376.

MODEL STUDIES

Embankment:

Placement of the 2 400 000 cu yd of material in the embankment required two dry seasons, necessitating the passage of one wet season's flow over the top of the partially completed dam. Model studies, both two-dimensional and three-dimensional, were carried out to determine stable slopes, type of protection and the height to which the first season's rockfill could be constructed and remain stable when overtopped. These studies showed that the Stage 1 section would be stable if built to RL 160 with 2:1 downstream slope and protected with a 6-ft layer of 3-ft rock.

Spillway:

A model was constructed of the main spillway to test its behaviour. These tests confirmed that the hydraulic calculations were conservative and showed that the assumed normal depth within the channel was not actually achieved as there was accelerating flow throughout the channel length. The studies showed that channel approach banks were required at the entrance to the spillway to improve entry conditions. The shape of these banks and the size of facing rock were determined from the model.

EMBANKMENT MATERIALS

Impervious Core:

Material for the impervious core was a silty-clay of CL classification located approximately a quarter of a mile upstream of the dam on a flat terrace on the right-hand side of the river, as shown in Fig. 4. The properties of this material are: liquid limit 33%, plasticity index 10, optimum moisture content 16.25%. The grading curve for the material is shown in Fig. 5. An area some 3 to 4 miles from the dam site consists of soils derived from the adjacent granite hills, overlying flat ground of weathered in-situ granite. This material, which has a grading as shown in Fig. 5, is a silty-sand of SM classification and was used in the downstream 10 ft of the core zone.

Filter Material:

Filter material was obtained from the river bed deposits upstream from the dam. These sand, gravel and shingle deposits are transported by the river flows and it was realised that the quality and quantity of these deposits could vary considerably from one season to another. It was therefore specified that filter zones should be constructed from material processed so as to fall within the limits shown in Fig. 5.

Rockfill:

Suitable quartzite rock for rockfill was obtained from a quarry located approximately half a mile upstream from the dam on the left side of the river. This quarry site was developed by two coyote blasts, each designed to produce over one million cubic yards of rock. A further source of rockfill was the 600 000 cu yd of granite available from the

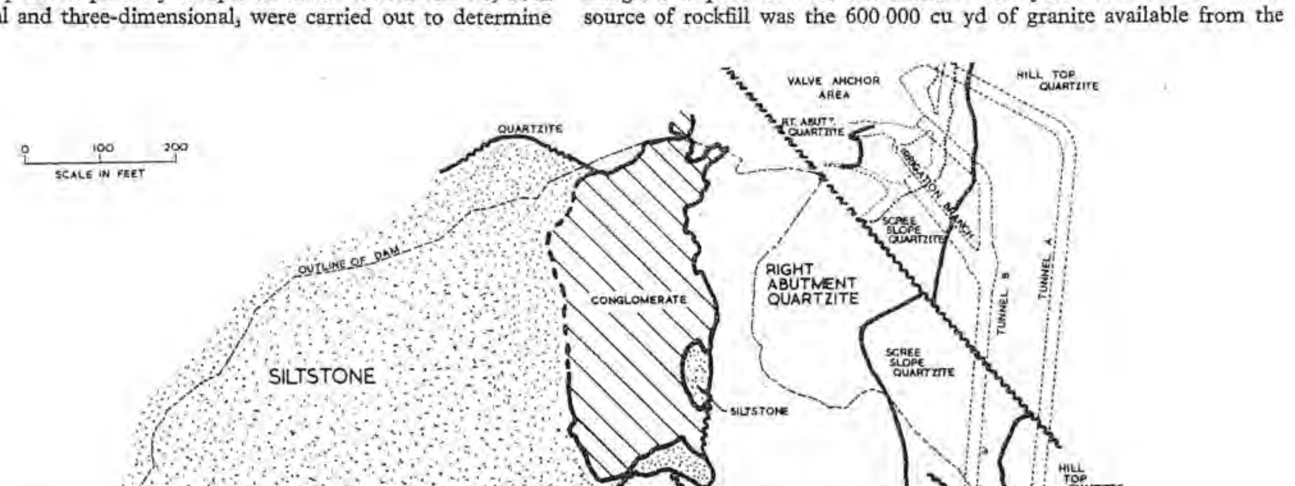

Fig. 3.—Ord River Dam Site—Geological Plan.

excavation for the spillway cut. The use of rockfill from the spillway was left at the option of the contractor, apart from the large-sized rock armouring which was required to be stockpiled as a precaution to ensure that adequate quantities of such material were available for use as protection of the partially completed embankment during overtopping.

EMBANKMENT

Configuration:

Effective use of the available material indicated the adoption of a narrow impervious core. Further, the open-jointed nature of the quartzite on the upstream half of the left abutment restricted considerably the area suitable as a foundation for the core. The minimum thickness of the core was fixed at 0.4 times the maximum head of water, though the infrequency with which higher levels will be reached means that the effective ratio of core width to head will be in excess of 0.5 for nearly all of the time. The 1A Zone of the core is composed of the fine-grained material from the river terrace but on its downstream side there is a 10-ft-wide 1B Zone of the coarser-grained, weathered granite material. The contract provided for two processed filter zones both upstream and downstream of the core. A triangular Zone 3A of rockfill downstream of the core which carries the major thrusts from the water load was required to be placed in 3-ft layers while the remainder of the rockfill, Zone 3B, was placed in 6-ft layers; both zones were compacted by a 10-ton vibrating roller. The whole of the upstream slope and the downstream face below maximum tailwater level have a selected rock rip-rap layer, Zone 3C.

The construction programme necessitated three dry seasons. the first season the abutments were stripped and the diversion tunnel constructed. In the second season the foundation preparation and the placing of the initial fill were carried out and in the third season, the main body of the embankment was placed.

To protect the initial embankment fill against water flowing over it, the surface between RL 154 and RL 160 was protected by a layer of 3-ft rock. The downstream slope was also protected with a steel grid of 1"-dia reinforcing bars on a 4 ft by 1½ ft spacing anchored into the fill (Fig. 6).

The site conditions resulted in two significant changes being made in the cross-section during construction:

> The inclination of the core was altered by 0.1 to 0.65:1 in an upstream direction in order to avoid the core being draped over a steep cliff face in the river bed which had formed at the quartzite-siltstone contact.
>
> Early testing of the 1B material established that it did not break down during working as allowed for in the filter design. A single downstream filter was therefore substituted between core and rockfill for the original two filters (see Fig. 7).

Embankment Stability:

The stability of the embankment was analysed by the conventional slip circle method, taking account of interslice forces, and modified by the use of tangents at the lower end of the failure surfaces. Check analyses were made at a later stage using a wedge type analysis.

In the complete analyses of failure surfaces carried out using a computer, the factor of safety was defined as the factor by which all the strengths of all the materials in the dam would need to be reduced to bring the dam to the point of failure. This is a more rational definition than the usual one in which it is imagined that all the potential strengths of the materials are developed, an impossible situation.

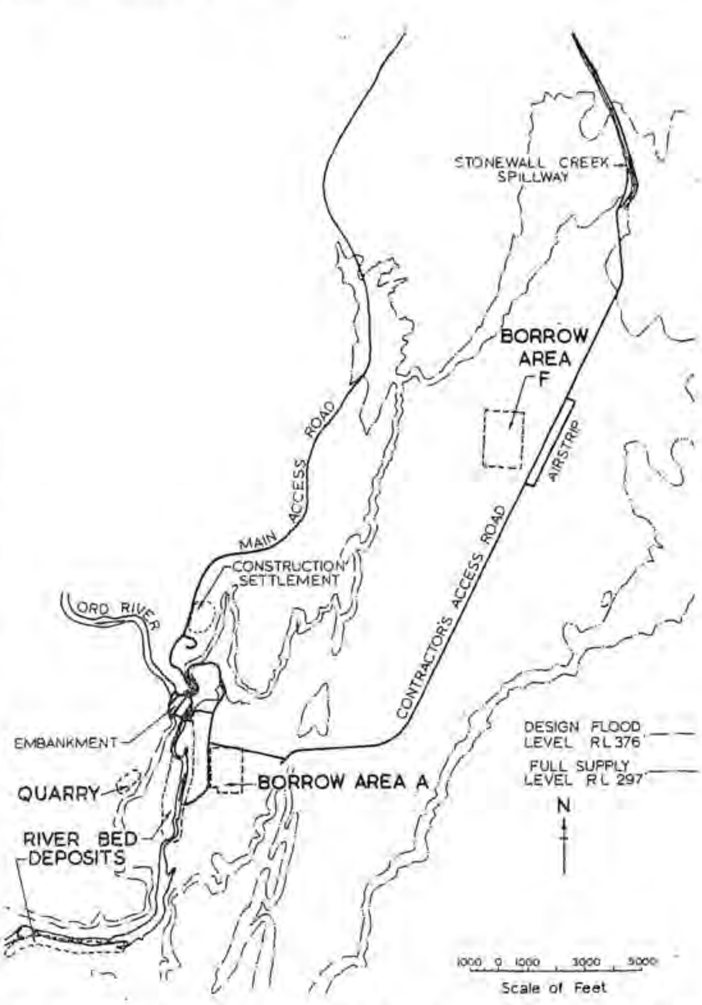

Fig. 4.—Ord Irrigation Project and Ord River Dam—General Plan.

TABLE I

Properties of Embankment Materials Assumed in Design

Property	Zones 1A and 1B	Zones 2A, 2B, 3A, 3B, 3C, 3D
Density	130 lb/cu ft	105 lb/cu ft dry 138 lb/cu ft submerged, total
Friction Angle	11.5°	42°
Cohesion	420 lb/sq ft	0

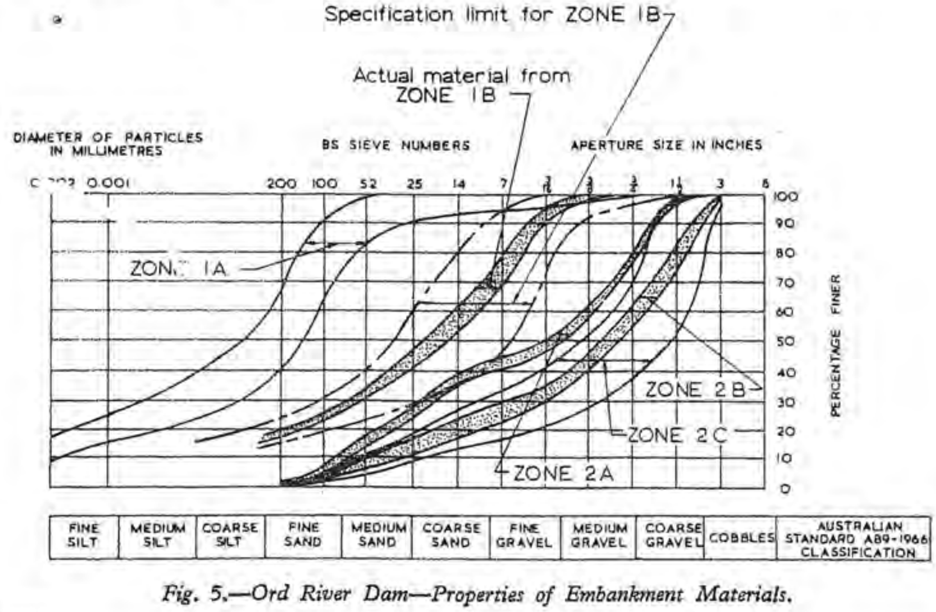

Fig. 5.—Ord River Dam—Properties of Embankment Materials.

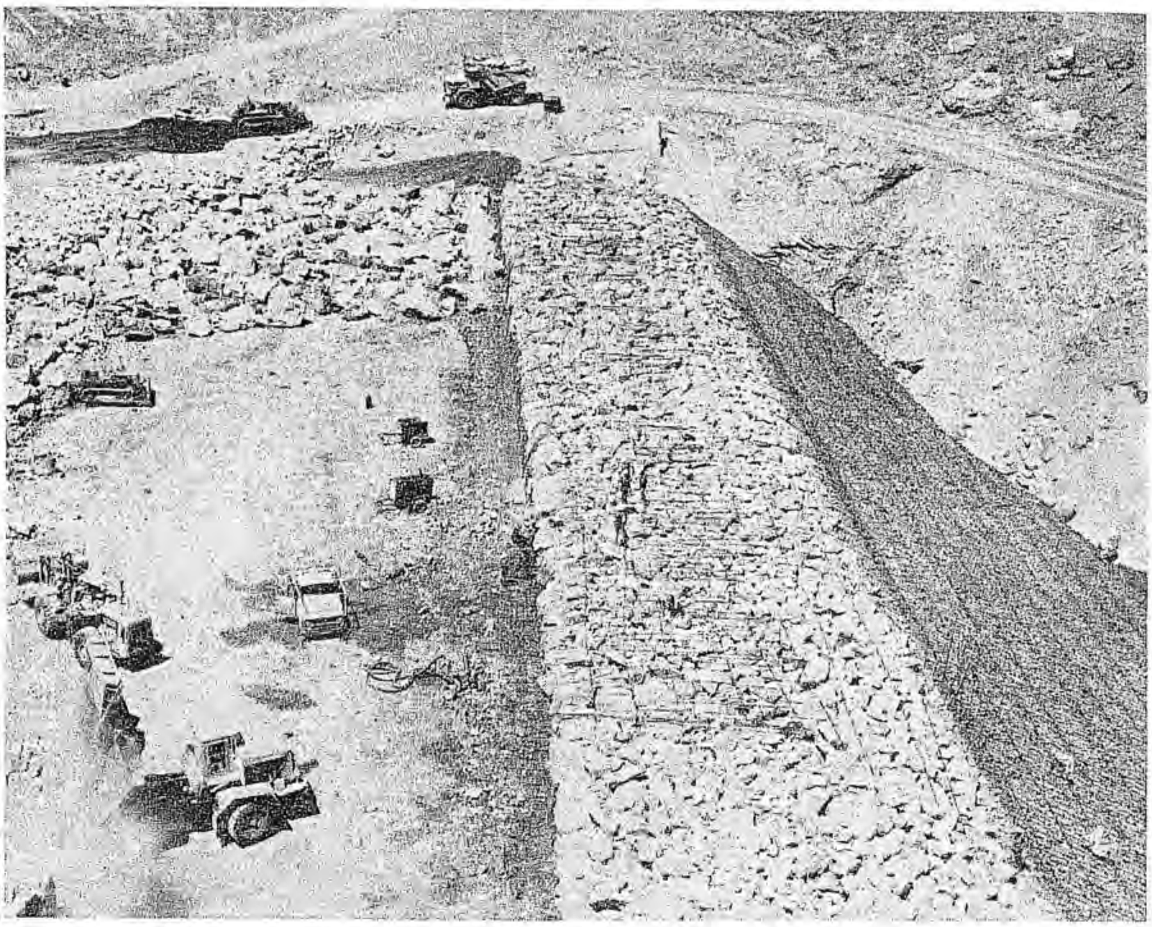

Fig. 6.—First Stage of Embankment, showing Protection against Overtopping being placed.

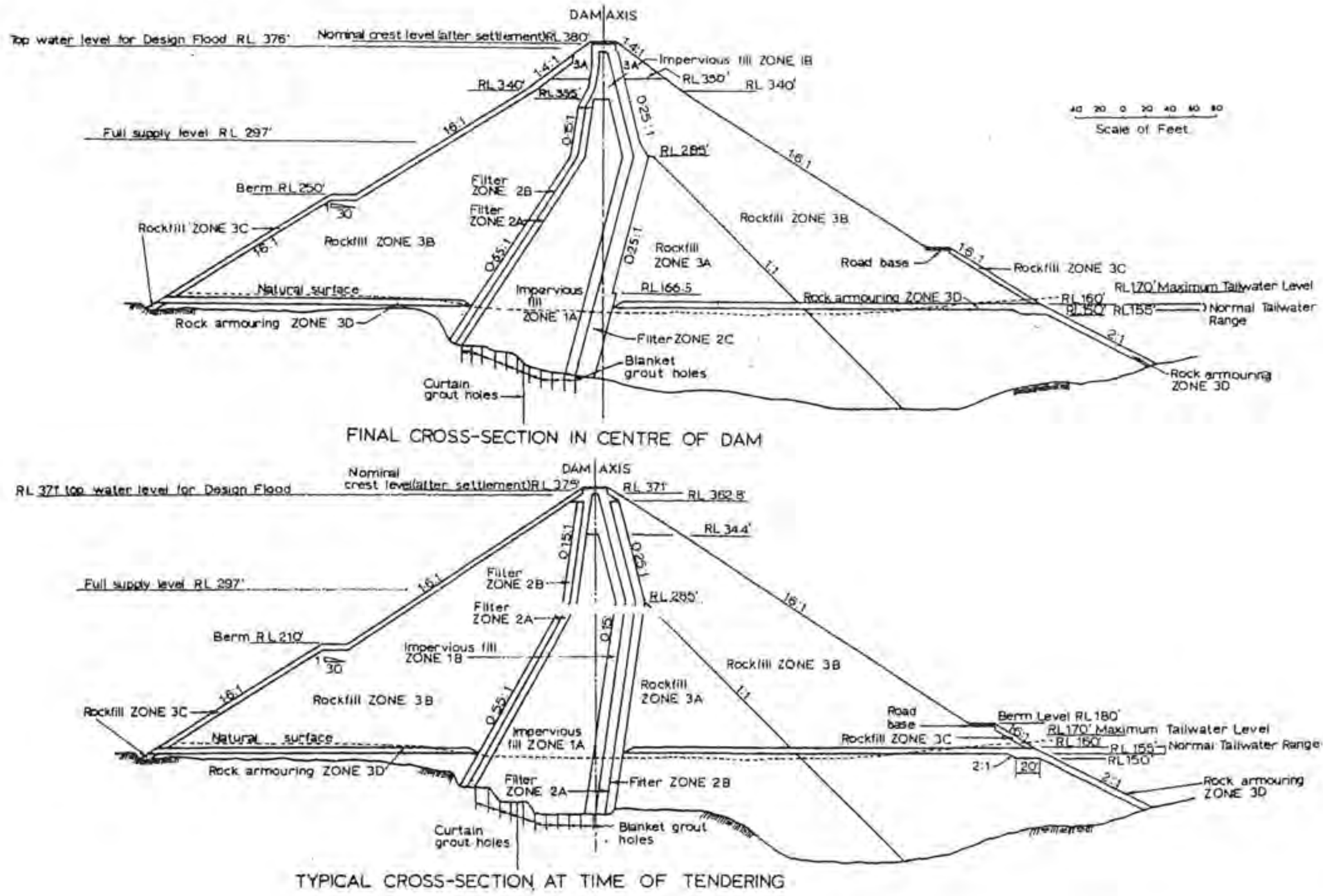

Fig. 7.—Ord River Dam—Embankment Cross-Sections.

The low capacity of the spillway and outlets relative to the very large reservoir capacity makes rapid drawdown an unrealistic design condition. A limited drawdown condition was therefore adopted.

Based on the results of consolidometer tests, design pore pressures, up to 0.55 × height at the deepest part of the critical surface, were used in the analysis, although with the narrow core it was not expected that these pore pressures would be fully developed.

Because of the seismic activity which has been recorded in the Ord area, an earthquake loading, represented by a horizontal acceleration of 0.1*g*, was also included in the analysis.

The design factor of safety against design flood level, for failure through the core, was 1.5. The required factor of safety for upstream failure under critical pool or drawdown conditions, was 1.3, and the same value was required for earthquake conditions.

The properties of the materials used in design are shown in Table I.

Foundation Treatment:

In all, 370 000 cu yd of loose material, almost entirely fine sand, were removed from the river bed to obtain a foundation on in-situ rock.

The principal foundation defect was the quartzite-siltstone contact, which crossed under the core at the foot of the left abutment. This zone was excavated, two concrete cut-offs 40 ft apart were constructed to intersect it, and the whole excavation covered with a concrete cap.

As a general protection against seepage through joints close to the surface, which could result in admitting high water pressures to the underside of the core, the core area was treated by blanket grouting, generally with 15-ft-deep holes at 10-ft centres. In a few places, hole spacing was reduced to 5 ft. The actual grout takes were low, with an average take of only 0.18 cu ft per ft of hole. The only area of significantly greater takes was in the weaker quartzite high on the right abutment, where the average take was 0.65 cu ft per ft of hole. A grout curtain, consisting of a single row of holes at 10-ft spacing, up to 100 ft deep with a few holes up to 35 ft deeper, was located approximately under the centre of the core throughout the length of the dam. In twelve places, where grout takes were relatively high, additional holes were drilled which reduce the spacing to 5 ft. This provided a general cut-off against leakage through the foundation. Again, grout takes were low, averaging only 0.20 cu ft per ft of hole.

Instrumentation:

The embankment has been instrumented with a horizontal movement gauge, a vertical settlement gauge, 20 hydrostatic settlement gauges, 36 settlement points and 5 electric piezometers. There are also 3 settlement gauges in the foundation. In the narrow ridge of the right abutment, holes have been drilled for observation of the water table, in case this should affect the stability of the hillside.

To detect possible shocks caused by reservoir filling, an accelerograph is being installed on the top of the embankment and another on the foundation rock. There is a three-motion seismograph at Kununurra.

Silt deposition in the reservoir is to be monitored along 13 contoured strips, by a combination of echo sounding and photogrammetry.

SPILLWAY

The main spillway is cut through a granite saddle and the rock in the centre of the saddle is of good quality, so that no lining is required. Some of the channel at both ends is of less stable material and may suffer some erosion but this will not affect the spillway performance. Control of spillway discharge is determined by the hydraulics of the spillway channel. Rock-faced banks have been provided to improve entry conditions.

Flow from the main and the three auxiliary spillways will be into existing natural creeks which do not have the capacity to discharge spillway flows. It is anticipated that the water will develop these creeks and some substantial movement of material is likely.

Hydrologic Design:

The unusual concept of flood design made it inappropriate to use the conventional " maximum probable flood " method and a probability study of seasonal inflows provided the most satisfactory approach to the design, although some deterministic assessments involving the " maximum probable storm" were also made. For a major structure such as the Ord River Dam, where a failure would be catastrophic, it was considered that the design basis should be for a recurrence interval of not less than 10 000 years plus freeboard.

Using a Monte Carlo process, 50 000 years of monthly rainfalls were generated from 62 years of monthly rainfall data and, using a rainfall/runoff relationship derived from 11 years for which adequate river gauging records were available, monthly runoffs were obtained. The flows of extreme seasons were routed through the reservoir from starting levels determined by first routing the season preceding them in the random sequence. In this way, the recurrence intervals of extreme annual peak water levels were calculated. Because it was found that the distribution of flows within the month had effects on peak levels, random selection from six alternative daily flow patterns were applied to the monthly flows before routing.

The estimated frequencies with which water rises to various levels are shown in Table II.

TABLE II

Frequency of Peak Annual Reservoir Levels

RL	Level exceeded	RL	Level exceeded
297*	9 years in 10	348	1 year in 100
310	1 year in 2	363	1 year in 1 000
326	1 year in 10	372.5	1 year in 10 000 to 15 000

*Spillway Crest.

In most years, the spillway will flow continuously, the median reservoir level at the beginning of the wet season being RL 304 (7 ft above spillway crest). The flood storage at RL 304 is 1 200 000 acre-ft, which is 4% of the total. Following a flood year there will be a greater than median water level when the next wet season arrives. However, it was found that the level to which the reservoir falls by the beginning of the following wet is relatively insensitive to the magnitude of the preceding season's flow. For example, after a 1-in-10-year seasonal flood has occurred, the next season will commence with some 90% of the flood storage still available. This available flood storage reduces to 80% of the total after a 1-in-100-year flood and approximately 72%, or some 20 million acre-ft of the total flood storage, at the start of a season following the 1-in-10 000-year season.

Thus, although the probability analysis took account of this storage " carried over ", it had only a secondary effect on the flood levels at high recurrence intervals. In these circumstances a serious compound effect could only result from the successive occurrence of two seasons so rare that their probability of combined occurrence would be extremely remote and less than once in a million years.

As a further aid to determining the crest level of the embankment, a deterministic assessment was made of the maximum design flood level based on consideration of the maximum probable storm.

The " maximum probable storm " was estimated to have a peak inflow rate of 2 500 000 cusecs and a volume of 15 800 000 acre-ft, i.e. 4½ times the average annual flow or half the volume of the 1-in-10 000-year season discharge. The absolute maximum reservoir level becomes asymptotic at RL 382.5 for a chain of maximum probable floods spaced 15 days apart and for a chain of floods of 80% of the maximum probable, the asymptotic level is RL 380.

At the time of tendering, analysis of all aspects of the spillway hydrology had not been completed, but tendering could not be delayed and the design was issued on the basis of the data then available, the top of the embankment being at RL 375. This was close to the limiting size which could be fitted in the site.

After considering the consequences of dam failure, the possible sources of error in the probability analysis and the small cost of obtaining greater security, a level of RL 380 was adopted for the top of the embankment. This is equivalent to a maximum design level of RL 376 which is estimated to have a recurrence interval of between 30 000 and 50 000 years.

The embankment was modified by steepening the slopes of the upper 35 ft to achieve the extra height. Opportunity was taken to modify the cross-section to simplify placing of the narrow zones near the crest.

Optimisation of Spillway Design:

Two constraints prevented the full optimisation of spillway design, the objective of which was to minimise the total cost of spillway plus embankment. These were the restricted dam site, which limited embankment height, and the desirability of limiting the frequency of operation of the auxiliary spillways.

It was found that the flood storage available was so large that the discharge capacity of the spillway for small and medium surcharges above full supply level had only a minor effect on reservoir operation behaviour and on the maximum flood level reached. Lowest cost was therefore obtained with minimum spillway invert width, and 40 ft was chosen as being a suitable width for the operation of large earthmoving plant. Side slopes of ½:1 were selected for excavation in rock, with a 15-ft-wide berm 50 ft above the invert.

A spillway invert level of RL 297 was adopted so that the auxiliary spillways would not operate more frequently than approximately once in 400 to 600 years, although a higher invert level would have given slightly lower total cost.

OUTLET WORKS

The outlet works were designed to provide for irrigation discharges, for supply to the proposed future hydro-electric station and also to convey diversion flows during the construction period. The arrangement adopted consisted of two tunnels through the right abutment. One tunnel was located at a low level to provide for diversion of small flows during the dry season and will later be used to supply two 7.5-megawatt sets in the hydro-electric station. The low-level diversion portal was blocked off during the last stages of the construction and permanent flow through this tunnel is by inclined shaft from the intake structure. The second tunnel is also connected to the intake structure by inclined shaft. This tunnel bifurcates at the downstream end to supply both the irrigation outlets and the other two sets of the future hydro-electric power station.

Tunnels:

Each of the tunnels has a finished diameter of 14.5 ft. The criteria used for the design of the tunnels allowed for a partial support of internal pressure by the surrounding rock. The remainder of the support is provided either by reinforcing or by steel lining. The downstream end of the irrigation tunnel and the power station branch of the same tunnel are steel lined for 139 ft and 224 ft respectively. The steel lining, which is fabricated from ⅝"-plate, commences immediately downstream of the bifurcation, which is constructed in reinforced concrete. The lining is coated with coal tar epoxy applied to a sand-blasted surface.

The upstream portals of the diversion tunnel and both intake tunnels were relocated some 150 ft and 40 ft respectively after the surface scree had been removed from the hillside, to obtain better portalling conditions.

Intake Structure:

A 185-ft-high reinforced concrete intake structure houses two 18 ft by 9 ft fixed-wheel gates to provide for emergency closure and for dewatering the tunnels for inspection and maintenance. The gates are operated by hydraulic hoists connected to the gates by rigid rods. The hoists are located above normal reservoir level, although they will be subject to inundation during extreme floods. Steel trash racks are located upstream of the gates and provision has been made for stop logs. Controls for the gates are located in a machine room at the top of the intake structure and access to the structure is by means of a steel truss bridge from the right abutment to the top deck of the structure. The intake trash racks are protected by zinc metallising and the gates are blast cleaned and coated with a coal tar epoxy.

Outlet Valves:

At the downstream end of the irrigation tunnel, a 14.5-ft-dia steel conduit conveys water to three outlet pipes. These outlets are controlled by Howell-Bunger type regulating valves with discharge hoods to prevent wide cone dispersion, and each regulator is backed up by a butterfly-type guard valve. The guard valves are 96"-dia and the regulating valves 78"-dia. Each outlet has a nominal capacity of 1500 cusecs under minimum head conditions of 77 ft.

Power Supply:

Power supply for gate and valve operation is by separate interchangeable diesel-driven generators housed in buildings adjacent to the intake and valve anchor. The guard valves and fixed-wheel gates can both be closed by gravity without the use of any power.

RIVER DIVERSION

It was impossible to provide full diversion of a river of the magnitude of the Ord in a site as narrow as that in which the Ord River Dam has been constructed. Design of the diversion was based on providing for the exclusion from the dam site of all but extremely infrequent flows during the period from May to October. The capacity of the diversion tunnel was of the order of 3000 cusecs with the upstream and downstream coffer dams at RL 180 and RL 172 respectively.

The final plugging of the diversion tunnel required a rather complex method, made necessary by the diversity of situations which it had to cover.

The design provided for initially dropping a gate at the intake to the diversion tunnel. The rock near the portal is not particularly sound and some leakage into the tunnel even after the gate had closed was to be expected. The tunnel plug is at a distance of 300 ft downstream of the portal, where the rock is much sounder. The closure of the tunnel plug was done in two stages. The bulk of the concrete in the tunnel plug was placed in August, leaving a 4 ft by 4 ft opening through the centre, to allow small flows to pass downstream. Following closure of the portal gate, the final seal was effected by a steel flap gate, which could be closed by remote control, at the upstream end of the opening through the plug. The opening was then plugged with concrete and the joint was pressure grouted.

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Rainfall-Runoff Models Using Digital Computers

BY A. PATTISON, PH.D., M.I.E.AUST. and T. A. MCMAHON, B.E., PH.D., M.I.E.AUST.

(concluded from page 4)

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SPILLWAY DESIGN AND RIVER DIVERSION FOR THE ORD RIVER DAM (*)

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DESCRIPTION OF WORKS

The Ord River Dam is the major engineering feature in the development of the Ord Irrigation Project in the north of the State of Western Australia. Construction of the dam and appurtenant works commenced in 1968 and were completed by December 1971. The rockfill dam with thin sloping clay core is 99 m high above the lowest foundation, 335 m long at the top of embankment and countains 1,800,000 cubic metres of material. Irrigation water is released downstream through a 4.43 m dia concrete-lined tunnel in the right abutment. The discharge is regulated by three Howell-Bunger valves set in a concrete valve anchor adjacent to the downstream toe of the embankment.

The main spillway is an unlined cut through a granite saddle approximately five miles from the dam embankment. There are a further three auxiliary spillways through saddles in the northeast rim of the reservoir.

The reservoir formed by the dam has an active storage of $5{,}278 \times 10^6$ m^3 below full supply level and $34{,}154 \times 10^6$ m^3 of flood surcharge. At full supply level, the reservoir area is 725 sq km and at design flood level 2,221 sq km.

(*) *Plan du déversoir et du détournement du fleuve pour la construction du barrage de l'Ord.*

HYDROLOGIC CONDITIONS

Catchment and Climate.

The Ord River Dam catchment is within the 457 mm to 635 mm rainfall belt and has an annual evaporation of 2,590 mm. It extends over an area of 46,000 sq km of mostly rough, hilly country with thin soils, rocky outcrops and with sparse cover of spinifex grass and small trees. Although extremely rugged and inaccessible, the maximum elevation of the catchment is only 800 metres above sea level. The highest area is to the south near the town of Halls Creek, which is the only town on the catchment and has a population of 650 people. The elevation of the catchment in the vicinity of the dam site is 80 m (Fig. 1).

The land over the entire 46,000 sq km is used solely for the rangeland grazing of beef cattle and is divided into some 18 properties. Some 40 km downstream from the dam is the town of Kununurra, with a population of 1,700 people, which is the administrative centre for the irrigation area presently under construction on 7,300 ha of black soil plains.

There are two distinct seasons; a wet season and a dry season. The wet season extends from about December to April and the rains of this season occur somewhat irregularly from monsoons and the occasional tropical cyclone.

Streamflow.

Since the commencement of river gauging in 1945, three flood peaks of around 28,000 m^3/s have occurred. The base flows are very small in relation to these flood flows and become insignificant or cease altogether for several months during the dry season. The seasonal variations of river flows are illustrated by the flow-duration curve in Figure 2. There are also wide variations in flow from year to year, as shown by the following figures which are based on flows synthetised from 62 years of rainfall records :

Lower decile of annual flows	740×10^6 m^3
Median annual flow	$3{,}450 \times 10^6$ m^3
Mean annual flow	$4{,}320 \times 10^6$ m^3
Upper decile of annual flows	$10{,}700 \times 10^6$ m^3
Flow exceeded once in 100 years	$22{,}300 \times 10^6$ m^3
Flow exceeded once in 1,000 years	$39{,}500 \times 10^6$ m^3

HYDROLOGIC DESIGN

Hydrologic studies calculated the design flood to have a total volume of $18{,}800 \times 10^6$ m^3 and a peak inflow to the reservoir of 71,000 m^3/s. The cost of the spillway therefore became a very significant factor in arriving at a suitable and economic design. The spillway concept which was developed made use of;

i) the extremely large flood surcharge which could be obtained for small increases in the height of the dam;

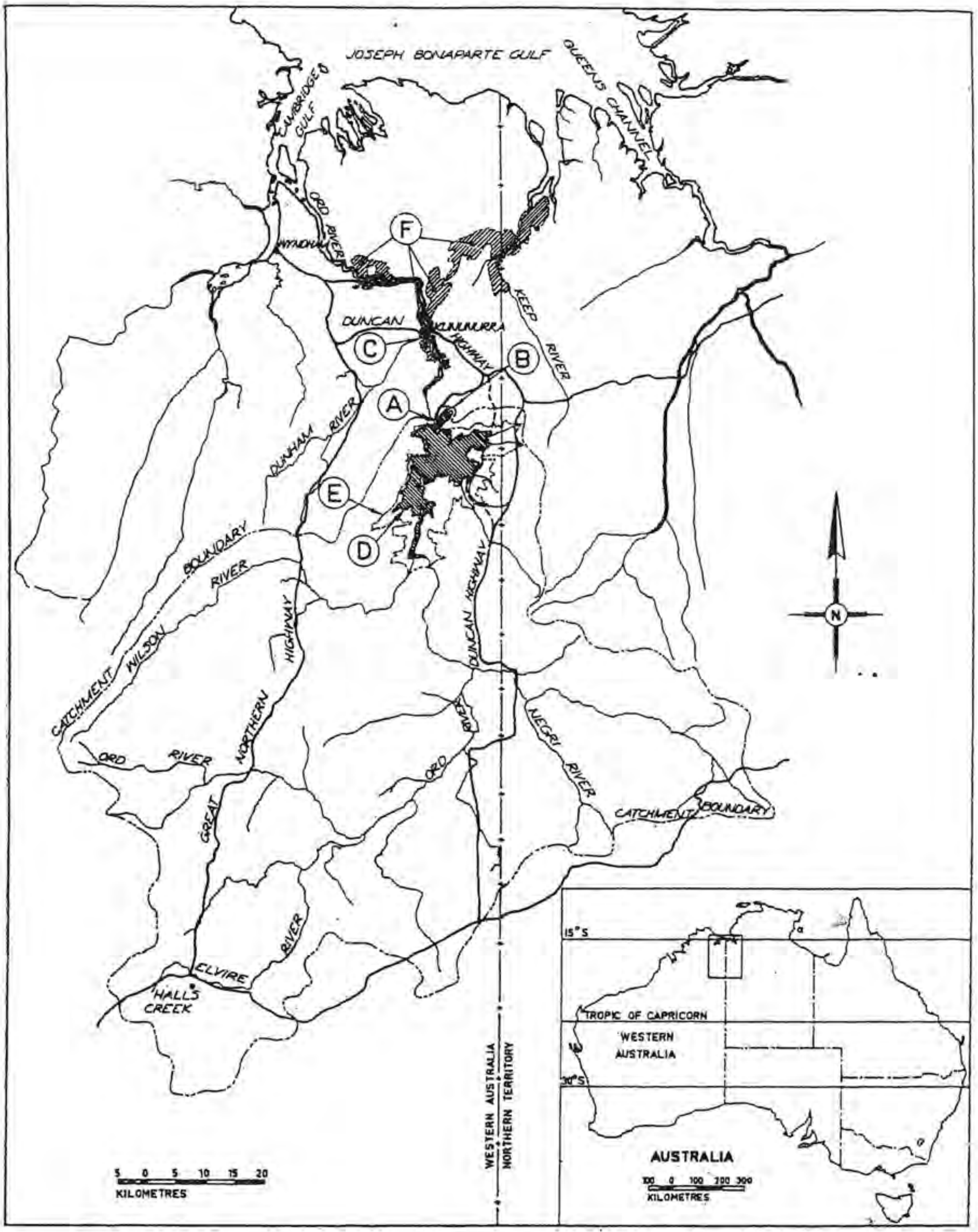

Fig. 1

Ord irrigation project : Locality Map.

(A) Ord River Dam.
(B) Spillway.
(C) Kununurra Diversion Dam.
(D) Full Supply Level.
(E) Maximum Flood Level.
(F) Irrigation areas.

Les irrigations du fleuve Ord.

(A) Barrage de l'Ord.
(B) Déversoir.
(C) Barrage de dérivation.
(D) Niveau normal de la retenue.
(E) Niveau maximum de la retenue.
(F) Zones des irrigations.

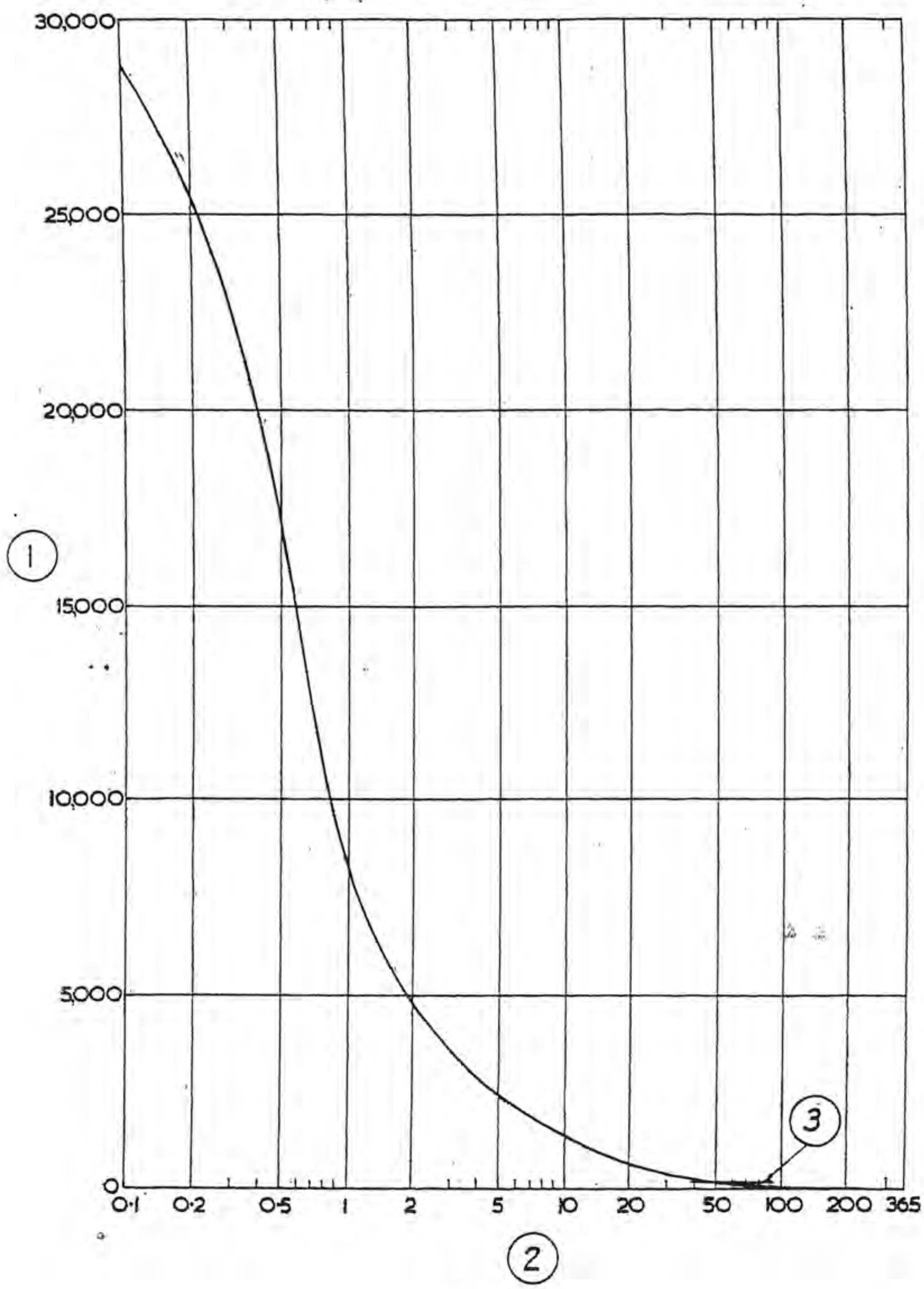

Fig. 2

Flow duration curve : Ord River 1955-1956 to 1967-1968.

(1) Flow : m³/s.
(2) Average time in days per year for which flow is equalled or exceeded.
(3) Average flow for period : 174 m³/s.

Courbe des débits classés : fleuve Ord 1955-1956 à 1967-1968.

(1) Débit : m³/s.
(2) Nombre de jours pendant l'an que le débit est égal ou dépassé.
(3) Débit moyen pendant la période : 174 m³/s.

ii) the fact that no land of significant value would be submerged by a higher dam, and.

iii) the predictable flow pattern of the Ord River into distinctive dry and wet seasons.

Because of the very large flood surcharge volume, individual flood events were of reduced importance and the total run-off for a complete season was the governing factor in determining peak spillway discharge. The flood surcharge will be used to store the run-off from an entire wet season and the flood volume will be discharged at a relatively low rate during that wet season and the subsequent years. With this arrangement, the spillway was made very small compared with the requirement for the more conventional concept of discharging individual floods. Its cost was thereby very greatly reduced. Against this, the dam embankment had to be constructed somewhat higher in order to store the flood surcharge, but the spillway costs dominated the economics.

The unusual concept of flood design made it inappropriate to use the conventional maximum probable flood method and a probability study of seasonal inflows provided the most satisfactory approach to the design, although some deterministic assessments involving the maximum probable storm were also made. For a major structure such as the Ord River Dam where a failure would be catastrophic it was considered that the design basis should be for a recurrence interval of not less than 10,000 years plus freeboard.

Using a Monte Carlo process, 50,000 years of monthly rainfalls were generated from 62 years of monthly rainfall data and, using a rainfall/run-off relationship, derived from 11 years for which adequate river gauging records were available, monthly run-offs were obtained. The flows of extreme seasons were routed through the reservoir from starting levels determined by first routing the season preceding them in the random sequence. In this way, the recurrence intervals of extreme annual peak levels were calculated. Because it was found that the distribution of flows within the month had effects on peak levels, random selection from six alternative daily flow patterns were applied to the monthly flows before routing.

TABLE 1

Frequency of peak annual reservoir levels.

R.L. metres	Level exceeded	R.L. metres	Level exceeded
90.6 (*)	9 years in 10	106	1 year in 100
95	1 year in 2	110	1 year in 1,000
100	1 year in 10	114	1 year in 10,000 to 15,000

R. L. is the level above the Low Water of Spring Tides at the port of Wyndham.
(*) Spillway Crest.

The estimated frequencies with which water rises to various levels are shown in the following table :

In most years, the spillway will flow continuously, the median reservoir level at the beginning of the wet season being R.L. 93 m, more than two metres above spillway crest. The flood surcharge at R.L. 93 m is $1{,}400 \times 10^6$ m^3, which is 4 % of the total flood surcharge available. Following a year of high flows, there will be a greater than median water level when the next wet season arrives. However, it was found that the level to which the reservoir falls by the beginning of the following wet is relatively insensitive to the magnitude of the preceding season's flow. For example, after a 1 in 10 years seasonal flow has occurred the next season will commence with some 90 % of the flood surcharge still available. This available flood surcharge reduces to 80 % of the total after a 1 in 100 years flood and approximately 72 %, or some $24{,}670 \times 10^6$ m^3 of the total flood surcharge, at the start of a season following the 1 in 10,000 years season.

Thus, although the probability analysis took account of this storage which is carried over, it had only a secondary effect on the flood levels at high recurrence intervals. In these circumstances a serious compound effect could only result from the successive occurrence of two seasons so rare that their probability of combined occurrence would be extremely remote and less than once in a million years.

As a further aid to determining the level of the top of the embankment, a deterministic assessment was made of the maximum design level based on consideration of the maximum probable storm.

The maximum probable flood with a peak inflow rate of 71,000 m^3/s and a volume of $18{,}800 \times 10^6$ m^3 is 4 1/2 times the average annual flow or half the volume of the 1 in 10,000 years season discharge. The absolute maximum reservoir level becomes asymptotic at R.L. 117 m for a chain of maximum probable floods spaced 15 days apart and for a chain of floods of 80 % of the maximum probable, the asymptotic level is R.L. 116 m.

After considering the consequences of dam failure, the possible source of error in the probability analysis and the small cost of obtaining greater security, a crest level of R.L. 116 m was adopted. Allowing for freeboard, this is equivalent to a maximum design water level of R.L. 114.7 m which is estimated to have a recurrence interval of between 30,000 and 50,000 years.

SPILLWAY DESIGN

Two constraints prevented the full optimisation of spillway design, the objective of which was to minimise the total cost of spillway plus embankment. These were the restricted dam site, which limited embankment height, and the desirability of limiting the frequency of operation of the auxiliary spillways.

The main spillway channel is 2,130 m long with a maximum depth of 27 m and a bottom width of 12 m. The channel was cut through a granite saddle of good quality rock and no concrete lining was required. The side slopes of the excavation were 1/2 : 1 with a 4.5 m wide berm, 15 m above theinvert.

There are three auxiliary spillways in the form of natural saddles which come into operation when the reservoir level rises 19 m above spillway crest level, equivalent to a flood surcharge of 22,800 × 10^6 m^3. Two of these auxiliary spillways have substantial quartz bars and are unlikely to erode to any extent. The third and largest is a flat earth channel and on rare occasions when overflow takes place it is likely that some erosion will take place. The erosion of the saddle will not endanger the effective storage but should it become a problem, it can be remedied by constructing a fuse plug type bank in the eroded area.

It was found that the flood surcharge available was so large that the discharge capacity of the spillway for small and medium surcharges had only a minor effect on reservoir operation behaviour and on the maximum flood level reached. Lowest cost was therefore obtained with minimum spillway invert width, and 12 m was chosen as being a suitable width for the operation of large carthmoving plant. A spillway invert level of R.L. 90.6 m was selected so that the auxiliary spillways would not operate more frequently than approximately once in 400 to 600 years, although a higher invert level would have given slightly lower total cost.

Studies on reservoir behaviour showed that for only one year in ten will water fail to pass over the main spillway and that within the last 62 years there would have been a 25 year sequence of continuous overflow. The spillway discharges for various reservoir levels are shown in Table 2.

TABLE 2

Spillway Discharges.

R.L. metres	Storage 10^6 m^3	Spillway Discharge m^3/s			Remarks
		Main	Auxiliary	Total	
116	41,000	3,930	24,200	29,600	Top of embankment
114.7	39,800	3,500	19,000	22,500	Maximum design level
110	28,500	1,960	0	1,960	Crest of auxiliary spillway
90.6	5,700	0	0	0	Crest of main spillway

Flow over the main and auxiliary spillways will be into existing creeks, the natural channels of which do not have the capacity to discharge the spillway flows. It is anticipated that the water will develop these creeks and substantial movement of material is likely. Apart from the access road to the dam, there are no man-made or natural features along the route which will suffer any damage of economic value.

DIVERSION OF RIVER DURING CONSTRUCTION

Construction of the embankment required two dry seasons, which necessitated the diversion of one wet season's river flow. Conventional diversion works were clearly impractical and so the embankment had to be designed to pass one wet season's flow over the partly completed structure. A 4.43 m dia diversion tunnel was constructed in the right abutment to deal with most of the dry season flows. The capacity of the diversion tunnel with an upstream water level 6 m above normal stream bed level, was 70 m^3/s.

Hydraulic model studies, both two dimensional and three dimensional, were carried out to determine stable slopes, degree and type of protection, and the height to which the first season's rockfill could be constructed and remain stable when overtopped.

These model studies showed that the partly completed embankment would be stable if built approximately to the original stream-bed level with the top and downstream face of the structure protected by a 1.8 m thick layer of 1 m rock. The model was run at various tailwater levels to ensure that the downstream face would be stable under the most severe conditions. At low flows, the stability of the rockfill on the downstream face was critical due to turbulence, whereas at high flows the structure was completely drowned and the critical feature was the high velocities across the top surface of the embankment.

In the first construction season, 1969, the abutments were stripped and the diversion tunnel for the small dry season flows was constructed. In the 1970 season, the foundation preparation and the placing of the initial fill was carried out. Almost 400,000 cubic metres of sand and silt were exavated before placing of the fill material could commence, the lowest foundation level being 30 m below the original stream bed. When the structure had been built to stream bed level, the 1.8 m layer of rock armouring was placed over the complete top surface and downstream slope of the embankment. Over the core area, the armouring was underlain by a 1 m thick layer of filter material as a blinding zone. Large rocks were individually placed by bulldozer, in contact one with the other, and spaces remaining were filled with smaller stones.

As an added safety measure, the downstream slope was protected with a steel grid of 25.4 mm diameter bars on a 1.3 m × 0.45 m spacing, securely anchored in the fill and the foundation, with a 152 mm × 152 mm mesh behind the grid.

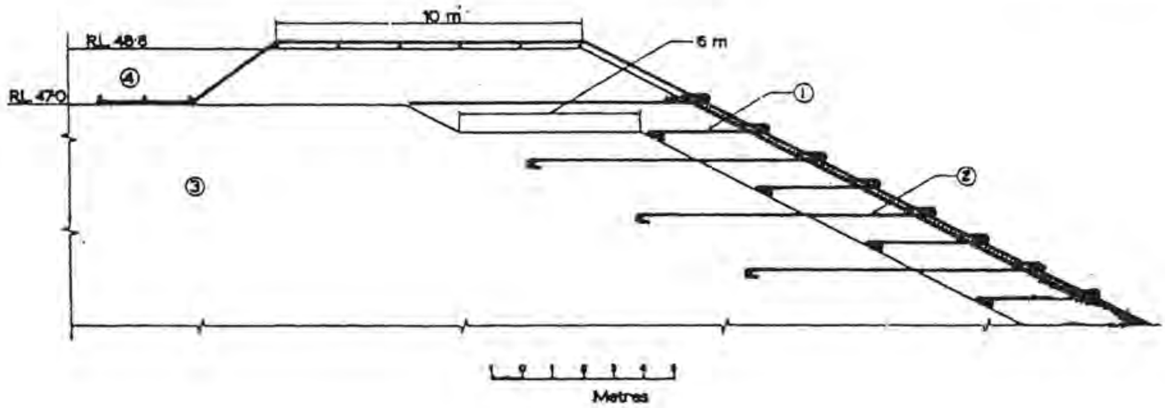

Fig. 3

Downstream Protection of Partially Completed Embankment.

(1) Anchor 4.2 m long.
(2) Anchor 10 m long.
(3) Rockfill.
(4) Rock Armouring.

Protection aval : ouvrage partiellement achevé.

(1) Ancrage 4.2 m de long.
(2) Ancrage 10 m de long.
(3) Enrochements.
(4) Enrochements armés.

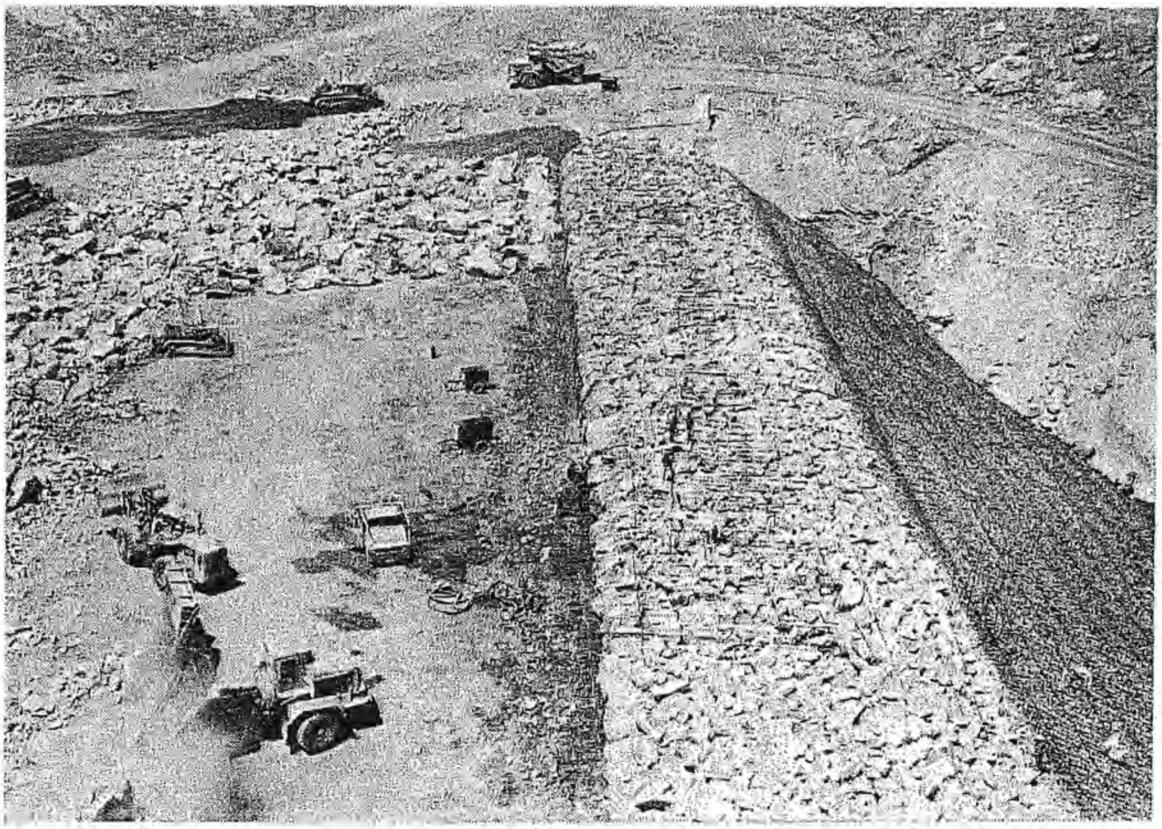

Fig. 4

Rock Armouring and Steel Grid.
Enrochements armés et grillage en acier.

Special care was taken at the downstream crest, where selected large rock was placed for 10 m along the surface of the embankment. The grid of 25.4 mm bars was continued over these large rocks but, because of the large size of material, no steel mesh was used (Fig. 3, 4 and 5).

In order to obtain some correlation with the model study, flows were measured both at a point 1.2 km upstream from the site and on three lines across the top of the embankment. The maximum depth of flow recorded was 10.5 m over the embankment on March 21, 1971. This corresponded to a flow of some 5,600 m^3/s and agreed, within 10 %, with the flow predicted from the model. This was equivalent to a flow of 46 m^3 per metre width.

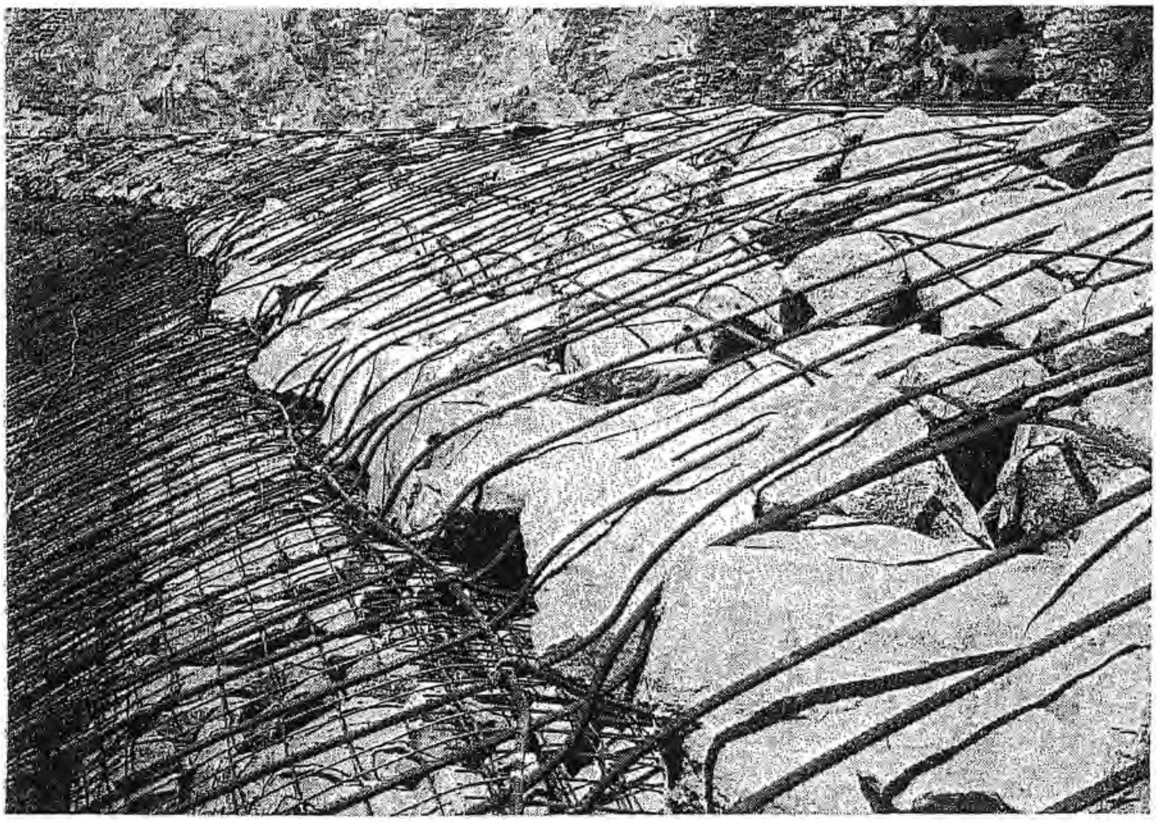

Fig. 5

Protection at Downstream Crest.

Protection a la pente aval.

The peak recorded mean velocity over the embankment was in the order of 4.5 m/s with a velocity of some 3.0 m/s, 15 mm to 30 mm above the rock surface. Measurement of velocities across the embankment was very difficult because of the large amount of debris being carried by the river. The prototype velocities determined from the model for a flow of 5,600 m^3/s were 5.5 m/s at the water surface and 4.0 m/s over the rock.

The steel mesh suffered no damage and the only noticeable change to the embankment, apart from the build up of silt on the surface during the recession of the flow, was a slight settling of the rockfill under the mesh, estimated to be about 30 mm in some places. Some of the smaller rocks on the surface, which were not interlocked into the rockfill mass, were displaced downstream, but the rockfill mass retained its integrity.

The rock armouring was left as rockfill with only the portion above the filters and core being removed prior to the commencement of the following construction year.

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SUMMARY

The Ord River in the north of the State fo Western Australia, drains a catchment area of 46,000 sq km and has a maximum probable flood of 71,000 m^3/s. The river has a distinctive wet and dry season flow pattern with periods of up to 6-7 months with no discharge at all. The rains during the wet season occur somewhat irregularly from monsoons and occasional tropical cyclones.

Harnessing the water from this river posed some unusual design problems. Construction of a dam with a conventional spillway would have been costly; a very high proportion of the total cost being directly attributable to the spillway. A design was therefore developed which provided for $34{,}154 \times 10^6$ m^3 of flood surcharge and enabled a very economical arrangement of dam and spillway to be developed. This arrangement was made feasible by a good dam site which enabled a 99 m high rockfill dam to be constructed; a large reservoir basin; suitable natural saddles for spillways on the rim of the reservoir basin and the distinctive wet and dry season flow of the Ord River.

The main spillway is an unlined cut through a granite saddle approximately five miles from the dam embankment. The spillway cut is 2,130 m in length, 12 m wide at the bottom, with a maximum depth of 27 m. The capacity of this spillway is 3,500 m³/s, with a further 19,000 m³/s discharging over three natural saddles at the maximum design reservoir level.

Construction of the embankment was over three years, requiring the river to be passed over the top of the partly-completed structure during one wet season. The top of the embankment was protected with a 1.8 m layer of 1 m rock and the downstream face had the added protection of steel mesh on 1.3 m by 0.45 m grid. A flow of some 5,600 m³/s was passed successfully over the structure during construction.

RÉSUMÉ

Le fleuve Ord, situé au nord de l'État de Western Australia, draine un bassin de réception de 46 000 km² et son débit maximum est probablement de 71 000 m³/s. Ce fleuve est tantôt sec, tantôt plein; parfois il est à sec pendant six à sept mois. Les précipitations sont irrégulières pendant la saison des pluies et sont dues aux moussons et éventuellement, aux cyclones tropicaux.

Aménager les eaux de ce fleuve posait des problèmes insolites du point de vue de la conception. Construire un barrage à déversoir conventionnel aurait été très coûteux puisqu'il aurait fallu dépenser beaucoup d'argent sur le déversoir lui-même. On a donc conçu un projet qui permettait d'avoir un surplus de débit de 34 154 × 10⁶ m³ et d'arranger de façon économique le barrage et le déversoir. Cet agencement a été rendu possible grâce à l'emplacement excellent du barrage qui permettait la construction d'un barrage en enrochements de 99 m de haut; au grand réservoir; à la présence de cols naturels appropriés pour servir de déversoirs sur le bord du réservoir et enfin grâce au débit saisonnier, alternativement haut et bas, du fleuve Ord.

Le déversoir principal est une entaille sans revêtement dans un col granitique situé à environ 5 miles du remblai du barrage. Le déversoir a 2 130 m de long, 12 m de large au fond et 27 m de profondeur. La capacité de ce déversoir est de 3 500 m³/s avec 19 000 m³/s qui s'écoulent par-dessus trois cols naturels lorsque le niveau maximum du réservoir est atteint.

La construction du remblai a duré plus de trois ans, car il fallait que le fleuve déverse ses eaux par-dessus la structure inachevée lors d'une saison très humide. Le sommet du remblai était protégé par une couche de 1,8 m d'épaisseur (1 m de roches) et le parement aval était protégé par un grillage d'acier de 1,3 m sur 0,45 m. On a réussi à faire passer un débit de quelque 5 600 m³/s sur la structure sans causer aucun dégât.

ORD RIVER DAM

OFFICIAL OPENING BY

THE PRIME MINISTER OF AUSTRALIA

The Rt Hon. William McMahon, C.H., M.P.

30TH JUNE, 1972

THE HON. JOHN T. TONKIN, M.L.A.
Premier of Western Australia

THE HON. H. E. GRAHAM, M.L.A.
Deputy Premier and Minister for Development and Decentralisation, Town Planning and the North West

THE HON. C. J. JAMIESON, M.L.A.
Minister for Works and Water Supplies

ORDER OF PROCEEDINGS AT THE CEREMONY TO OFFICIALLY OPEN THE ORD RIVER DAM

Chairman

THE HON. C. J. JAMIESON, M.L.A.
Minister for Works and Water Supplies

Welcome to the Prime Minister of Australia

THE HON. JOHN T. TONKIN, M.L.A.
Premier of Western Australia

Unveiling of Commemorative Plaque

THE RT HON. WILLIAM McMAHON, C.H., M.P.
Prime Minister of Australia

Vote of Thanks to the Prime Minister of Australia

THE HON. H. E. GRAHAM, M.L.A.
Deputy Premier and Minister for Development and Decentralisation, Town Planning and the North West

THE RT HON. WILLIAM McMAHON, C.H., M.P.
Prime Minister of Australia

ORD IRRIGATION PROJECT

Kununurra Diversion Dam

A Dethridge wheel metering water at farmer's supply point

The Ord Irrigation Project comprises the following principal features:

(a) A major storage reservoir in the Carr-Boyd Ranges some 100 miles south-east of Wyndham.

(b) A diversion dam, to raise and divert the water released from the major storage reservoir.

(c) An irrigation area of up to 180,000 acres, one third being within the Northern Territory.

(d) The generation of hydro-electric power by water released from the storage reservoir, and the reticulation of power.

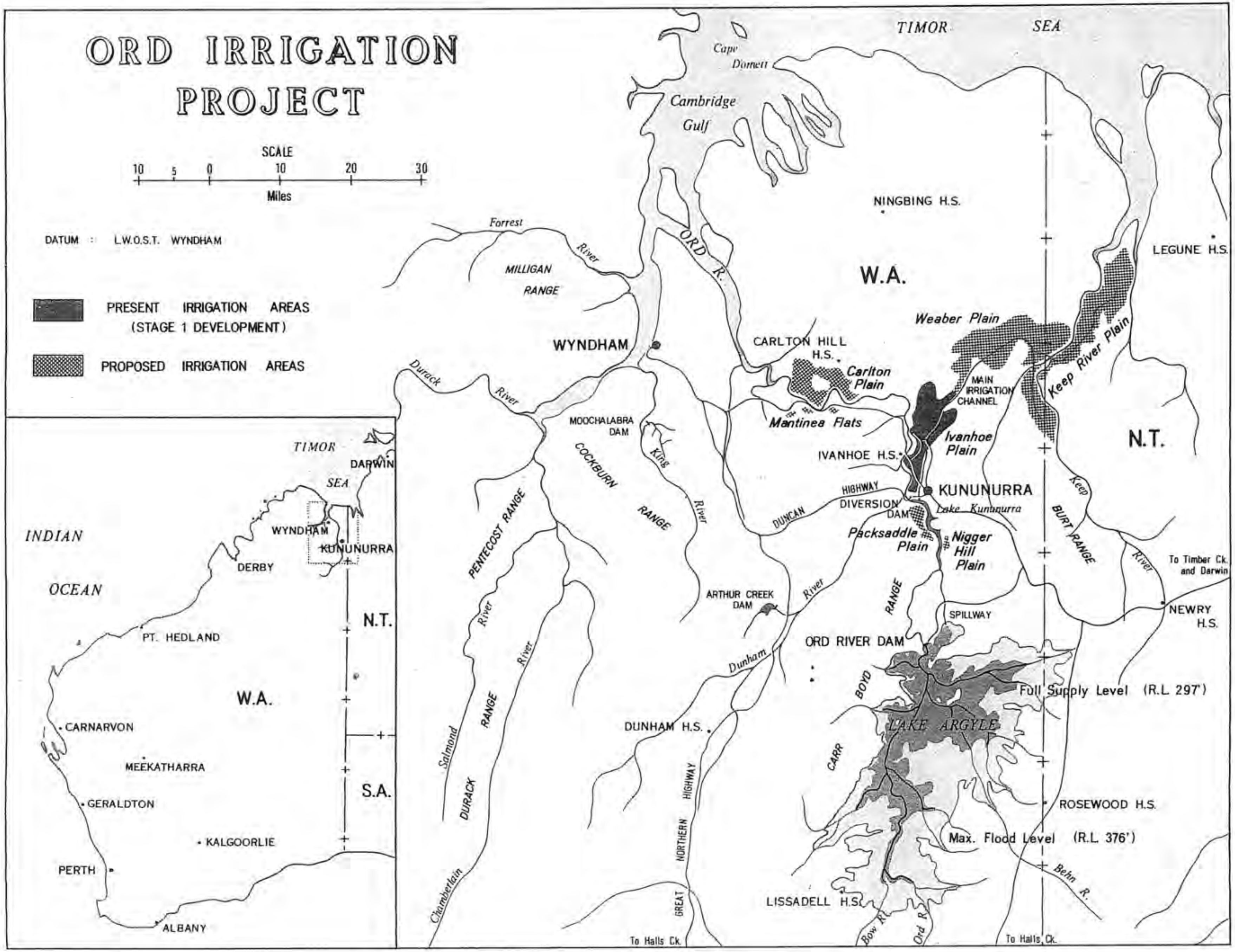
(e) The provision of townships and the ancillary development of community services.

The Project was planned to be developed in three stages:

Stage 1 involved the construction of the Kununurra Diversion Dam, the development of 30,000 acres of irrigable land on the Ivanhoe Plain plus the establishment of the township of Kununurra. In 1959 the Commonwealth Government approved that portion of the funds required for Stage 1 of the Ord Irrigation Project as part of a grant of $10,000,000 made available to the Western Australian Government to promote development above the 20th parallel of south latitude. Stage 1 was officially opened in 1963 by the then Prime Minister, Sir Robert Menzies. The final farms were allocated in 1965.

Stage 2 covers the construction of the major storage reservoir and the development of the remaining irrigation areas in Western Australia with additional townsites and community facilities. Grants and loans totalling $48,180,000 for Stage 2 of the Project were approved by the Commonwealth Government in October 1967. The Ord River Dam provides the major storage reservoir and its construction marks the commencement of Stage 2 of the Project.

Stage 3, which is not yet approved, involves the construction of a 30,000 kW hydro-electric power station and the reticulation of power.


ORD IRRIGATION PROJECT
SCALE
10 5 0 10 20 30
Miles
DATUM : L.W.O.S.T. WYNDHAM
PRESENT IRRIGATION AREAS (STAGE 1 DEVELOPMENT)
PROPOSED IRRIGATION AREAS
TIMOR SEA
Cape Domett
Cambridge Gulf
NINGBING H.S.
LEGUNE H.S.
W.A.
N.T.
ORD R.
Forrest River
MILLIGAN RANGE
WYNDHAM
Weaber Plain
Keep River Plain
CARLTON HILL H.S.
Carlton Plain
MAIN IRRIGATION CHANNEL
Mantinea Flats
Ivanhoe Plain
IVANHOE H.S.
KUNUNURRA
Lake Kununurra
HIGHWAY
DIVERSION DAM
DUNCAN
Packsaddle Plain
Nigger Hill Plain
Durack River
MOOCHALABRA DAM
COCKBURN RANGE
King River
PENTECOST RANGE
BURT RANGE
Keep River
To Timber Ck. and Darwin
NEWRY H.S.
ARTHUR CREEK DAM
RANGE
SPILLWAY
ORD RIVER DAM
Dunham River
BOYD
Full Supply Level (R.L. 297')
LAKE ARGYLE
DUNHAM H.S.
CARR
ROSEWOOD H.S.
Max. Flood Level (R.L. 376')
Salmond River
DURACK RANGE
Chamberlain River
GREAT NORTHERN HIGHWAY
Behn R.
LISSADELL H.S.
Bow R.
Ord R.
To Halls Ck.
To Halls Ck.
TIMOR SEA
DARWIN
INDIAN OCEAN
WYNDHAM
KUNUNURRA
DERBY
N.T.
PT. HEDLAND
W.A.
CARNARVON
MEEKATHARRA
GERALDTON
S.A.
KALGOORLIE
PERTH
ALBANY

ORD RIVER DAM

During a reconnaissance made in 1941, the Director of Works, Mr. R. J. (now Sir Russell) Dumas, and the Government Geologist, Mr. F. Foreman, six possible damsites were identified in Carlton Gorge where the Ord River cuts through the Carr-Boyd Ranges. The most southerly site (known as No. 1 Site) was the narrowest and the first to be investigated. It was surveyed in 1942 and 1943 while a limited amount of diamond drilling of both abutments was carried out from 1945 to 1947.

The first flow measurement of the Ord River was carried out during the wet season of 1944-45. In the early stages of the investigations, the magnitude of the Ord River floods were not fully appreciated, but by 1956 a discharge of one million cubic feet per second had been recorded.

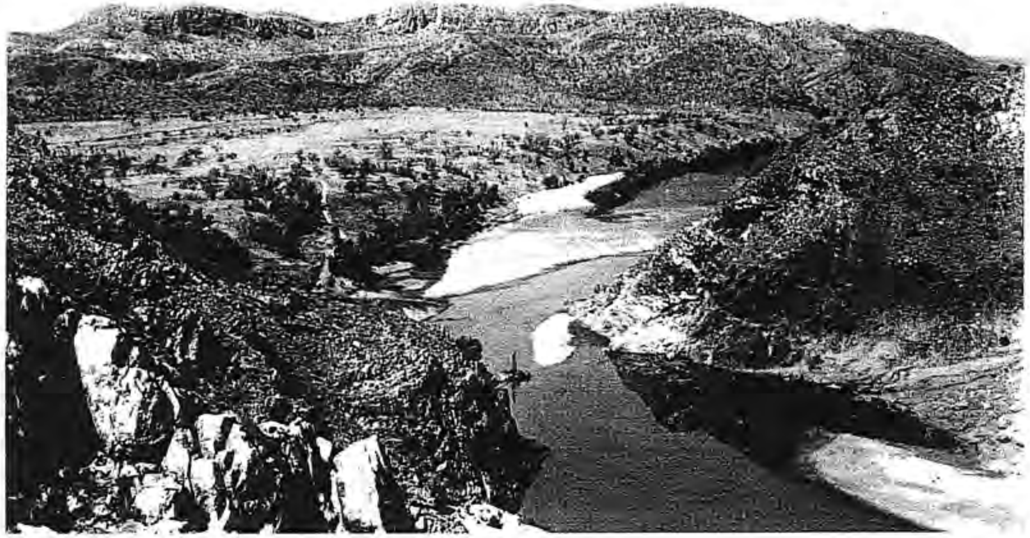
In 1960, due to foundation problems and spillway considerations, Dumas' No. 1 Site was abandoned and investigations were subsequently concentrated on his No. 2 Site, some ¾ of a mile downstream. This site was finally adopted.

During the early investigations the construction of a mass gravity concrete dam was envisaged, and the large floods were to have been passed over the structure. However, later investigations revealed that a rockfill embankment with a thin impervious core was the most practical and economic structure.

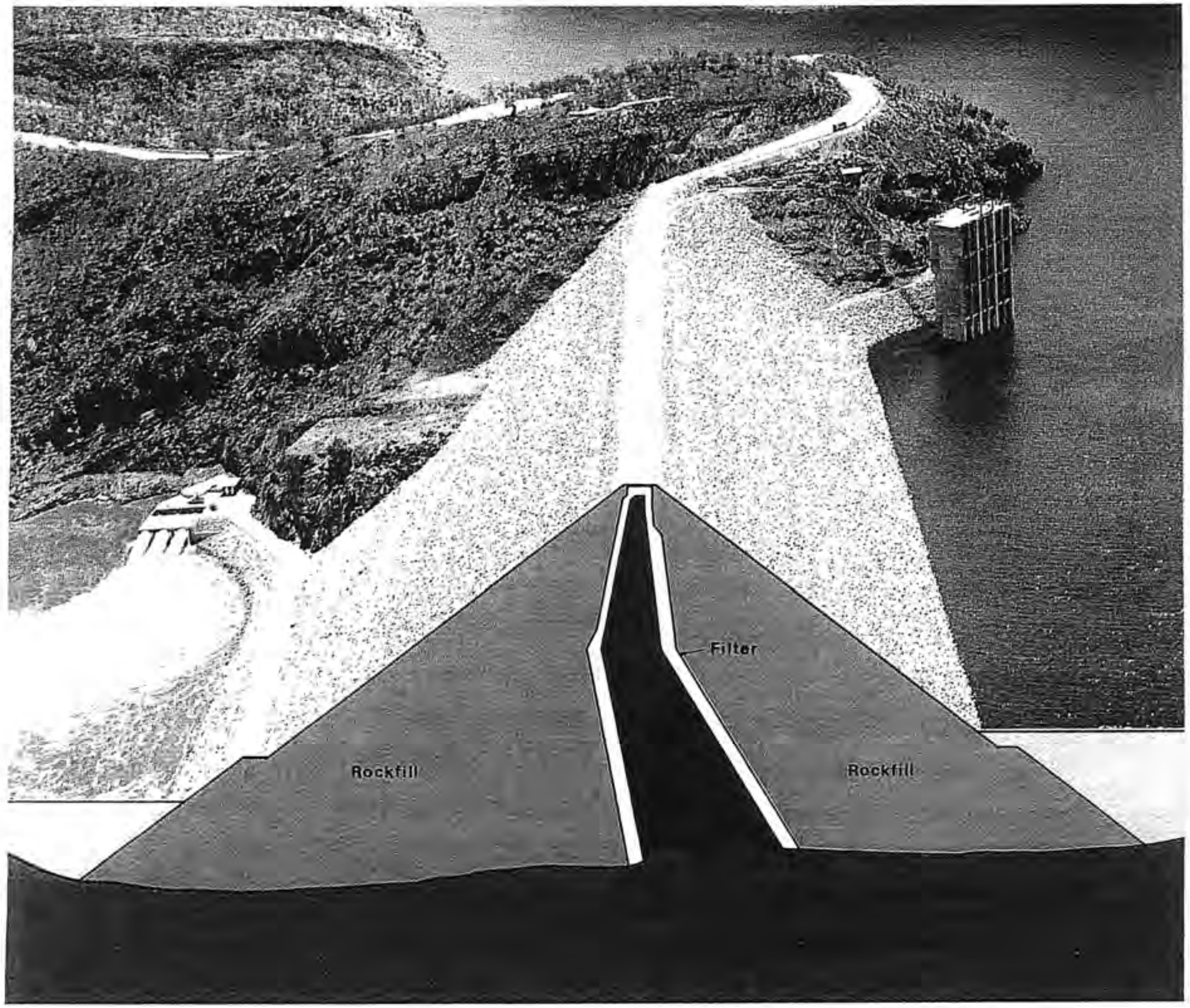
The initial designs for the rock fill dam provided for a concrete lined spillway cut through a saddle just downstream of the right abutment of the dam. The decision to locate the spillway some 5 miles to the north-east of the embankment was influenced by economic and technical advantages.

Two 14 feet 6 inches diameter tunnels convey water from a 190 feet high intake structure through the right abutment to the outlet valves. These provide for a discharge of up to 4,500 cubic feet per second of water for irrigation purposes and a supply to the future hydro-electric power station.

The Ord River Dam has been constructed at a cost of approximately $21.5 million utilising funds granted by the Commonwealth Government under the provisions of the Western Australian Agreement (Ord River Irrigation) Act, 1968.



Above: The damsite viewed from downstream prior to construction *Below: The completed embankment*



A cut-away view of the Ord River Dam showing the arrangement of the zones of materials incorporated in the design.

PRINCIPAL STATISTICS

EMBANKMENT

Type	Rockfill with thin impervious core
Height above lowest foundation	323 feet
Height above original river level	222 feet
Crest level	380 feet above low water, Wyndham
Crest length	1,100 feet
Crest width	23 feet
Upstream and downstream slopes	Mainly 1.6:1
Volume of rockfill	2,030,000 cubic yards
Volume of impervious core (clay)	318,000 cubic yards
Volume of filters	143,000 cubic yards
Volume of excavation for foundations	574,000 cubic yards

INTAKE STRUCTURE

Height (lowest foundation to bridge level)	190 feet
Span of access bridge	168 feet

OUTLET TUNNELS

Number	Two
Combined length	2,019 feet
Diameter	14 feet 6 inches
Volume of excavation	22,000 cubic yards
Volume of concrete lining	8,120 cubic yards

OUTLET VALVES

Guard valves	Three 96 inch diameter butterfly type
Regulating valves	Three 78 inch hooded Howell Bunger type
Maximum discharge	1,500 cubic feet per second from each of the 3 outlets

SPILLWAY

Type	Unlined channel excavated in granite
Length of cut	7,200 feet
Bottom width	40 feet
Invert level	297 feet above low water, Wyndham
Depth of maximum excavation	90 feet
Volume of excavation	640,000 cubic yards
Maximum discharge	125,000 cubic feet per second or 781,250 gallons per second

RESERVOIR (LAKE ARGYLE)

Capacity at full supply level	4,600,000 acre-feet or 1,250,000 million gallons
Capacity of flood storage	28,000,000 acre-feet or 7,623,000 million gallons
Area at full supply level	286 square miles
Area at maximum flood level	800 square miles

CONSTRUCTING THE DAM

Approval to proceed with Stage 2 of the Ord Irrigation Project was given by the Commonwealth Government in October 1967.

The Public Works Department of Western Australia, as the constructing authority, immediately moved to complete the drawings and specification for the construction of the Ord River Dam.

Applications from contractors for registration as tenderers for the construction of the dam were called in March 1968 on a world-wide basis. Documents were issued to the selected tenderers early in July 1968 and tenders were closed on October 15, 1968.

On November 19, 1968 a contract for the construction of the Ord River Dam was awarded to Dravo Pty Ltd, the Australian subsidiary of the Dravo Corporation of the United States of America.

By the end of 1968 the Department had established the construction village and all services were in operation. Some accommodation buildings had been provided for the Contractor and by using these and other departmental facilities he was able to station men on site and commence establishment work early in 1969.

In April 1969 the Contractor's major equipment arrived from America in a specially chartered vessel and work under the contract commenced almost immediately.

Due to the extent and complexity of the work, completion of the contract had to be spread over three dry seasons. (April to November).

The essential feature of the 1969 construction programme was the completion of the diversion tunnel which was to pass the dry season flow of 1970 and 1971 while work on the embankment was in progress. In addition the Contractor carried out the excavation of the second tunnel (the outlet for irrigation water), the excavation of the embankment foundations on the left abutment above the river level and the excavation of the spillway.

During the 1969-70 wet season the preparation of the foundations on the upper levels of the right abutment was carried out by a small team.

Early in April 1970 coffer dams were constructed and the flow of the Ord River was by-passed through the diversion tunnel. This enabled the dewatering of the damsite to begin and the deposits of sand and silt were quickly removed to expose the required foundation of solid rock. In June the placing of rockfill commenced, and by the end of October 1970 the embankment had been constructed back to normal river level. The exposed surface of the embankment was covered with a layer of selected rock armouring, while the downstream slope was additionally secured by a layer of steel mesh. The rock armouring and steel mesh were designed, following extensive model testing, to protect the embankment from damage by the river flows which were to pass over it during the 1970-71 wet season.

Also during 1970 the irrigation outlet tunnel was concrete lined and a start was made on the construction of the intake structure.

The river flows during the 1970-71 wet season were generally moderate but the rock armouring was thoroughly, and successfully, tested by a flow of 200,000 cubic feet per second (35 feet deep) in March 1971. Such is the erratic nature of the Ord River that, within three weeks of this peak flood, the flow had reduced to less than 3,000 cubic feet per second and was passed through the diversion tunnel. This was early in April 1971, and after the surface of the embankment was cleaned down the race to complete the embankment commenced. In the next six months 1,900,000 cubic yards of material were placed and on November 13, 1971 the diversion tunnel was plugged and the dam commenced to store water.

The 1971 dry season also saw the completion of the intake structure, the installation of the outlet valves and the construction of the concrete bridge on the main access road just downstream of the spillway.

At the end of the 1971-72 wet season 1,500,000 acre-feet of water were stored in the reservoir and the depth adjacent to the dam was 112 feet. Lake Argyle then covered an area of 125 square miles.

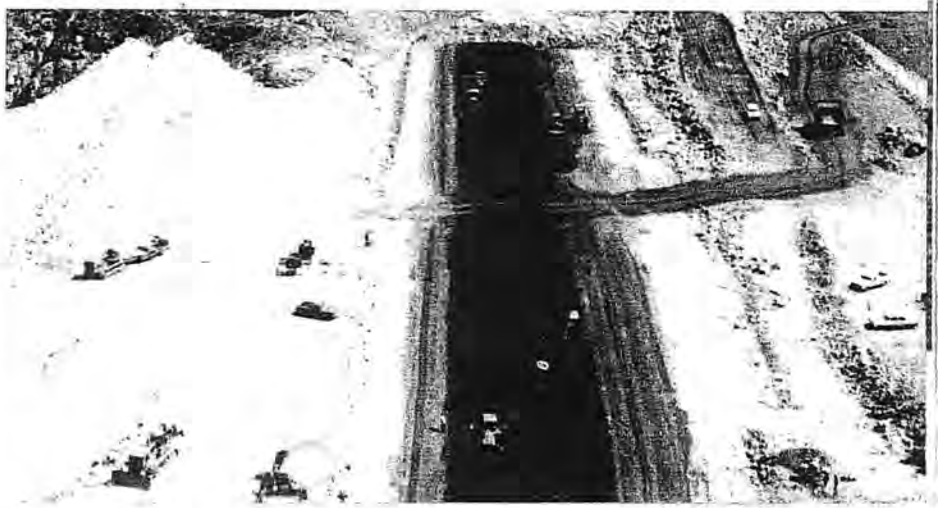
Foundation excavation nearing completion, June 1970

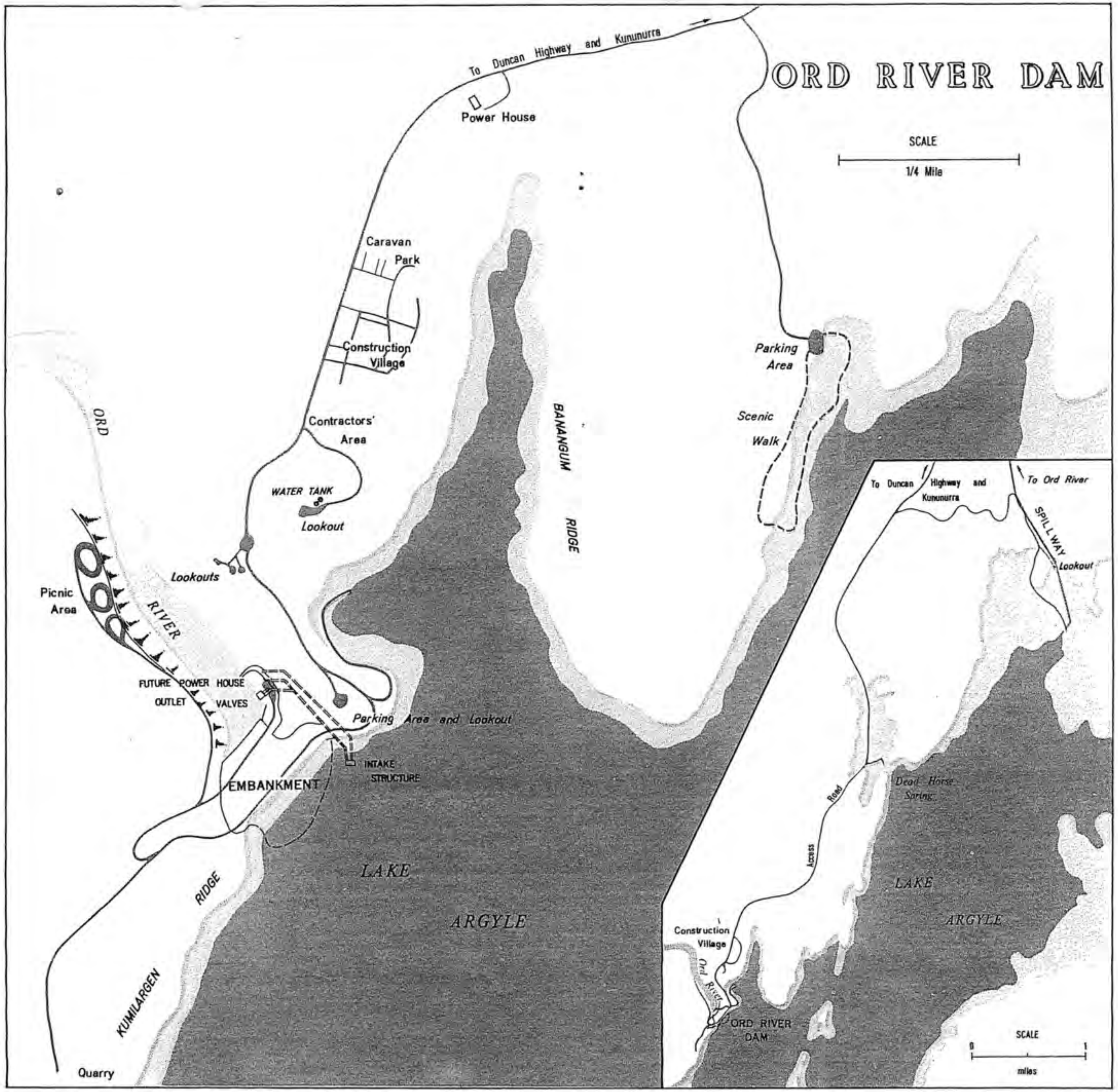
Placing clay core in foundations, September 1970

Left abutment of damsite before commencement of construction

Ord River flowing over partly completed embankment during 1970-71 wet season

Partly completed embankment, August 1971. Rockfill zones are clearly shown on both sides of the central clay core




ORD RIVER DAM
SCALE
1/4 Mile
To Duncan Highway and Kununurra
Power House
Caravan Park
Construction Village
Contractors' Area
WATER TANK
Lookout
Lookouts
Picnic Area
ORD RIVER
FUTURE POWER HOUSE
OUTLET VALVES
Parking Area and Lookout
INTAKE STRUCTURE
EMBANKMENT
BANANGUM RIDGE
Parking Area
Scenic Walk
KUMILARGEN RIDGE
Quarry
LAKE ARGYLE
To Duncan Highway and Kununurra
To Ord River
SPILLWAY
Lookout
Dead Horse Spring
Access Road
Construction Village
Ord River
ORD RIVER DAM
LAKE ARGYLE
SCALE
0
1
miles

HYDROLOGY AND SPILLWAY CONCEPT

The climate of the Kimberley Region is divided into two distinct seasons, a 'wet' and a 'dry'. Rainfall is received from cyclonic depressions and thunderstorms which occur erratically throughout the December to April wet season. The storms are quite intense and are generally interspersed with periods of fine hot weather.

The reservoir has a catchment of 17,800 square miles which extends east into the Northern Territory and as far south as Halls Creek. The annual rainfall varies from 25 inches in the north to 18 inches in the south and the annual evaporation approximates 100 inches.

The cyclonic storms can lead to very large floods and in 1956, 1959 and 1966 flows of approximately 1,000,000 cubic feet per second were recorded.

Droughts in the East Kimberley are infrequent. Nevertheless, the wet season rainfall pattern is erratic and run off varies considerably from year to year. Since 1944 the recorded annual flows in the Ord River at the damsite have ranged between a low of 214,000 acre-feet in the 1963-64 wet season and a maximum of 10,200,000 acre-feet in the 1958-59 wet season. The mean annual flow is 3,500,000 acre-feet.

For design purposes the maximum flood which may enter the reservoir has been assessed at 2,500,000 cubic feet per second with a volume of 15,000,000 acre-feet.

Two alternative concepts for passing flood flows at the Ord River Dam were investigated in detail. The first design concept involved a conventional type of spillway where individual floods are passed through the reservoir and spillway within a relatively short time after their occurrence. A very large concrete lined spillway would have been required to pass the design flood.

The adopted design is more economical and involves a relatively small spillway excavation and a higher dam. The immense flood storage is designed to hold seasonal flows and discharge them slowly over extended periods.

The spillway is an excavated channel some 5 miles from the embankment with a capacity of 125,000 cubic feet per second.

Statistical studies of reservoir behaviour show that for only one year in ten will water fail to pass through the spillway and that during the last 62 years there would have been a 25 year sequence of continuous overflow.

Natural saddles provide secondary spillways which will only come into operation during very infrequent periods of extremely high inflows.

Spillway Channel viewed from upstream

CONSTRUCTION VILLAGE

The initial task associated with the Project was to establish a township with modern facilities in order to provide accommodation for both the Department's and Contractor's workers and their families.

The departmental buildings, comprising 10 houses, 12 single staff units (each of 4 rooms) a mess and recreation hall, an office and nursing post were completed during 1968. Also completed at the same time were the essential services such as water supply, sewerage, power supply, access road (from the Duncan Highway) and communication facilities. In order to assist the Contractor with his initial establishment, the Department provided accommodation units for 48 men.

The Contractor, Dravo Pty Ltd, extended these services and erected accommodation, office and mess buildings by May 1969.

The village, when completed, contained a total of 29 houses for staff personnel and single quarters for a further 300 people. The Contractor also established a caravan park which accommodated 40 families. At its peak in 1970 the population of the village was 540 persons.

The Medical Department staffed the nursing post with a full time nursing sister and regular visits were made by the doctor and infant health sister from Kununurra. When necessary patients were transported to either Kununurra or Wyndham hospitals in the Contractor's ambulance, and the nursing sister had radio contact with the Flying Doctor Service at Wyndham.

A two-room primary school was installed by the Public Works Department and staffed by the Education Department.

The Contractor constructed a wet canteen and nearby an open air cinema and a flood-lit tennis/basketball court were provided.

A police constable was stationed on site and had the use of a transportable police station building.

The Public Works Department arranged the installation of modern telephone and telex equipment for use by both the Department and the Contractor. Sophisticated carrier equipment enabled six telephone and two telex channels to be connected into the P.M.G. system at Kununurra and operate simultaneously through a single pair aerial line.

The P.M.G. Department arranged for the operation of a money order post office with full banking facilities and a multi-coin public telephone in the village.

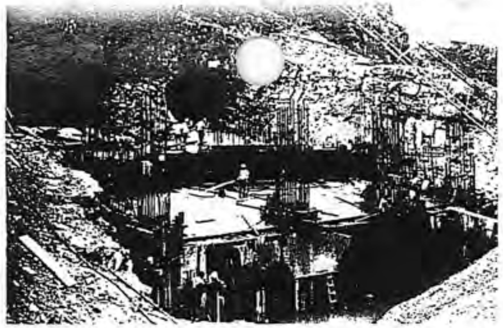
The Contractor constructed an airstrip and used his private aircraft for transporting key personnel as well as urgent supplies and materials. The airstrip was available for use by other aircraft including those of the Flying Doctor Service. The airstrip was located on the flats upstream of the dam and has now been flooded by the rising waters of Lake Argyle.

With the completion of the dam, the Commonwealth Government has agreed that the departmental single staff quarters and associated mess and recreational hall be retained at the Ord River Dam to promote tourism. These facilities will soon be handed over to the Western Australian Tourist Development Authority which has called tenders for the operation of a tourist complex. This complex will include the caravan park which has been purchased from the Contractor.

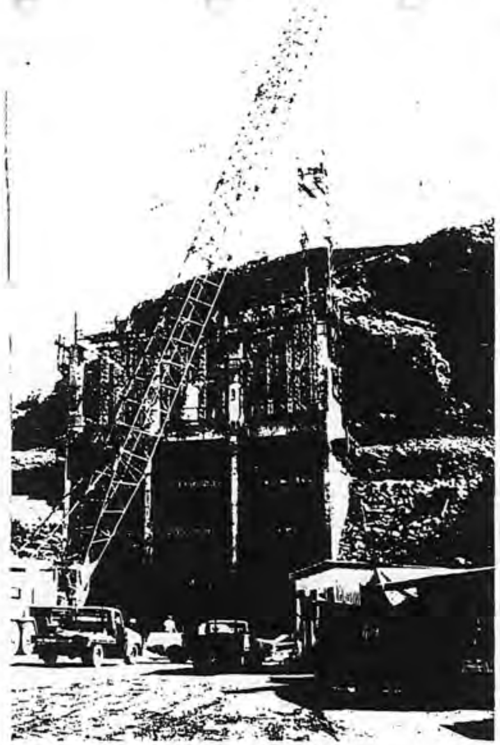
The Contractor's housing

Above: A Public Works Department house

Below: Departmental buildings



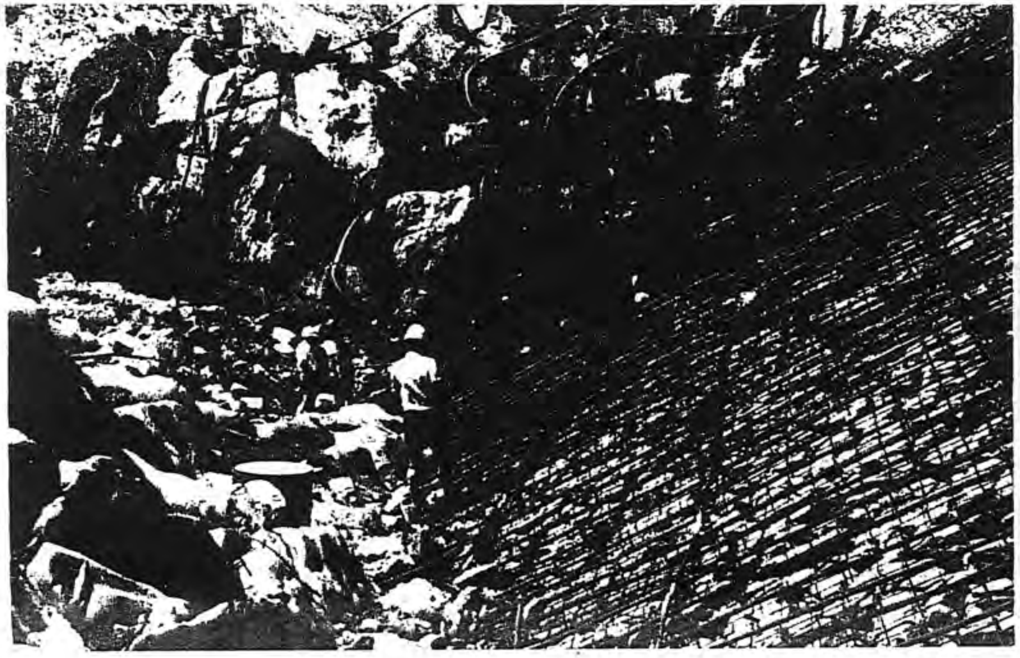
Concrete foundations of intake structure with tunnel portals in background



Intake structure in early stage of construction

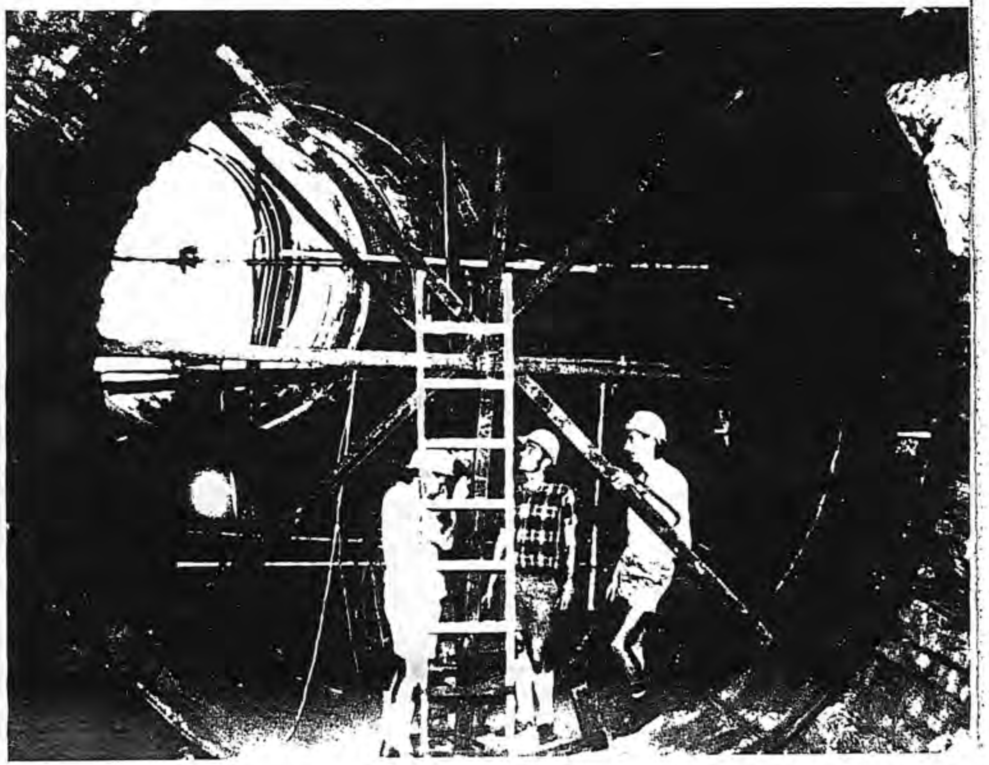
Installation of outlet valves, August 1971

Protective steel mesh at downstream toe of the embankment



Bridge over Spillway Creek on main access road from Kununurra

Steel liner being installed near outlet end of irrigation offtake tunnel



ORGANISATION OF THE PROJECT

The Constructing Authority for the Ord River Dam was the Public Works Department of Western Australia. Since approval for the dam was given in 1967, the position of Director of Engineering has been held by Mr. J. E. Parker (until September 1969), Mr. D. C. Munro (from September 1969 to November 1971) and Mr. R. M. Hillman (since January 1972). The detailed work was principally co-ordinated by Mr. D. C. Munro who was Chief Engineer until September 1969.

The investigations and design of the dam were carried out by the Planning Design and Investigation Branch of the Public Works Department headed by Mr. K. C. Webster. The work was under the supervision of Mr. W. J. Wilkin with Mr. R. J. Wark responsible for the detailed design.

The geological investigations were carried out under the direction of the Government Geologist, Mr. J. H. Lord. The field investigations were supervised by Mr. F. R. Gordon.

The construction of the dam was undertaken by the Construction Branch of the Public Works Department headed by Mr. K. J. Kelsall (until June 1970) and Mr. W. S. Shelton (since that date). Mr. Kelsall was responsible for the administration of the Contract. Resident Engineer was Mr. B. E. Gale and Messrs. P. J. Shaw, R. J. Perkins, and A. Bacon were his senior site engineers and Mr. P. J. Burgess was the site geologist. Landscape work at the dam was planned by Mr. J. B. Oldham.

The Mechanical and Plant Engineer's Branch of the Public Works Department headed by Mr. J. McBurney, carried out the electrical design and assisted with the inspection of the mechanical and electrical equipment. This work was under the general supervision of Mr. D. Rickman.

During the design and construction phases of the work specialised technical services and general supervisory assistance were received from the Snowy Mountains Hydro-Electric Authority (now the Snowy Mountains Engineering Corporation).

The activities of the main contractor were under the general direction of Mr. G. M. Shupe, Vice President of the Dravo Corporation of the United States of America, Mr. G. V. Reid was Project Manager for the Contractor while Messrs J. L. Jordan and A. N. Ahles were his senior engineers.

The provision of access roads for the project was directed by the Commissioner of Main Roads, Mr. D. H. Aitken. The field work was carried out by the Kimberley Divisional Engineer of the Main Roads Department and supervised by Mr. J. D. Butorac.

The group which attended the signing of the Contract on December 16, 1968:

Left to Right: Mr. J. F. D. Keet, Secretary and Director, Dravo Pty Ltd; Mr. J. McConnell, Under Secretary for Works; Mr. J. E. Parker, Director of Engineering; Mr. G. V. Reid, Contractor's Project Manager; Hon. Ross Hutchinson, Minister for Works; Mr. K. J. Kelsall, Construction Engineer, P.W.D.; Mr. G. E. Marley, Managing Director, Dravo Pty Ltd; Mr. D. C. Munro, Chief Engineer, P.W.D.

ORD RIVER DAM

CONSTRUCTING AUTHORITY

Public Works Department of Western Australia

PRIME CONTRACTORS

Ord River Dam and Appurtenant Works	:	Dravo Pty Ltd
Outlet Valves	:	Boving & Co (ANZ) Pty Ltd
Fixed Wheel Gates in Intake Structure	:	Evans Deakin Industries Limited
Frames, Tracks and Guides for Fixed Wheel Gates	:	Murray Autoclaves Pty Limited
Hoists and Stem Handling Equipment for Fixed Wheel Gates	:	Marfleet & Weight (Sales) Pty Ltd
Controls for Fixed Wheel Gates	:	Steel Construction Co. Pty Ltd
Gantry Crane	:	Combined Engineering Services Pty Ltd

PRINCIPAL SUB-CONTRACTORS OF DRAVO PTY LTD

Fabricated Steelwork	:	Electric Power Transmission Pty Ltd
Cement Grouting	:	Monier Grouting Company
Electrical Equipment	:	Rileys Pty Ltd
Protective Coatings	:	Dimet (WA) Pty Ltd
Pneumatically Applied Mortar	:	Specialized Processes Pty Ltd