UNION OF SOUTH AFRICA

DEPARTMENT OF IRRIGATION

REPORT

OF THE

KALAHARI RECONNAISSANCE

OF 1925

WITH 5 PLATES AND 29 FIGURES

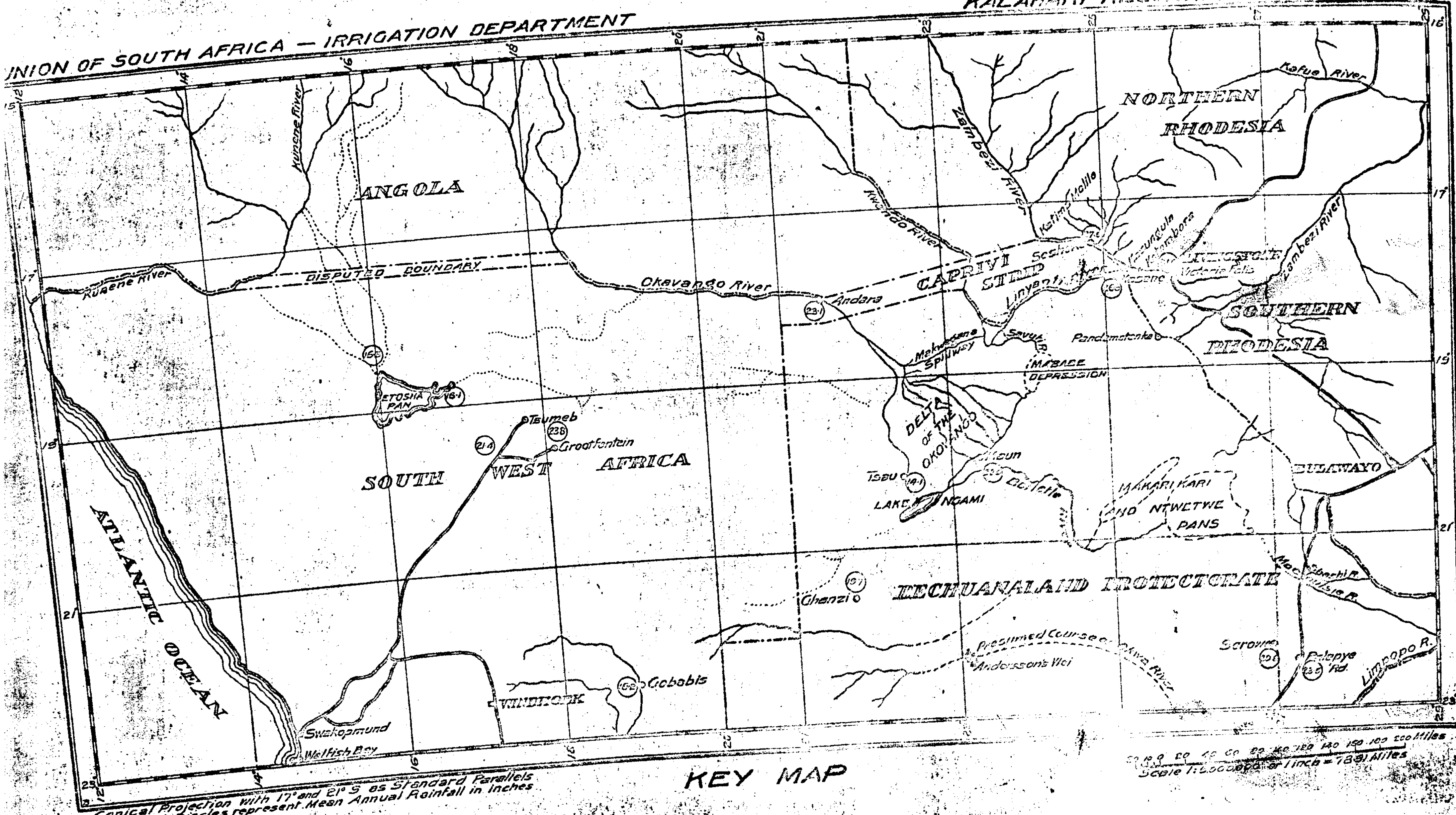
Published by authority of the Honourable the Minister of Justice

Price - - 5s.

PRETORIA
THE GOVERNMENT PRINTING AND STATIONERY OFFICE
1926

KALAHARI RECONNAISSANCE—PLATE I

UNION OF SOUTH AFRICA — IRRIGATION DEPARTMENT



KEY MAP

Conical Projection with 17° and 21° S as Standard Parallels
Figures in circles represent Mean Annual Rainfall in Inches

Scale 1:5,000,000 or 1 inch = 78.91 Miles

	Andara.								Kasane.					Palapye Road.				Maun.									
...	1915	1916	1917	1918	1919	1920	1923	Mean.	1922	1923	1924	1925	Mean.	1923	1924	1925	Mean.	1917	1918	1919	1920	1921	1922	1923	1924	1925	Mean.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
...ary..........	8·71	6·46	2·59	6·89	9·40	6·48	6·65	6·74	2·22	8·58	2·02	10·02	5·71	9·46	0·76	5·04	5·09	3·40	7·95	7·23	5·22	3·95	1·94	1·73	0·56	6·55	4·95
...uary..........	3·54	1·47	7·26	3·64	7·23	11·11	5·41	5·67	7·66	8·92	1·61	9·64	6·96	4·41	3·65	0·73	2·93	4·74	3·46	2·91	9·77	4·47	0·95	4·60	1·86	9·60	4·71
...h..........	0·47	2·30	2·61	4·83	2·34	2·35	6·42	3·05	1·53	5·49	9·35	4·40	5·19	3·95	3·86	8·10	5·30	0·55	11·80	1·56	1·03	6·68	1·87	3·76	7·43	6·24	1·55
...l..........	nil	0·80	4·82	nil	1·57	nil	0·16	1·05	nil	0·16	nil	3·65	0·95	0·08	nil	1·43	0·50	6·07	0·01	1·33	0·11	0·28	nil	0·35	nil	1·90	0·45
....	nil	nil	1·02	nil	nil	nil	nil	0·15	0·11	nil	nil	2·26	0·59	0·10	1·92	3·33	1·78	0·52	nil	0·32	0·22	1·55	0·30	0·49	nil	2·45	0·65
...e..........	nil	nil	nil	nil	nil	nil	nil	0·00	nil	nil	nil	nil	0·00	nil	nil	1·31	0·44	nil	nil	nil	nil	nil	nil	nil	nil	0·06	0·01
...y..........	0·43	nil	nil	nil	nil	nil	nil	0·06	nil	nil	nil	nil	0·00	0·02	nil	nil	0·01	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
...gust..........	nil	nil	nil	nil	nil	nil	nil	0·00	nil	nil	nil	nil	0·00	nil	nil	nil	0·00	nil	0·09	nil	nil	nil	0·13	nil	nil	nil	0·02
...tember..........	0·47	nil	nil	nil	nil	nil	nil	0·07	nil	0·48	nil	0·43	0·23	nil	nil	3·86	1·29	nil	nil	nil	nil	nil	nil	nil	0·12	0·54	0·07
...ober..........	nil	nil	nil	2·46	1·60	0·48	2·78	0·83	1·39	1·10	1·87	0·24	1·15	0·01	2·24	1·12	1·12	0·04	1·18	0·86	0·55	0·69	0·92	0·04	1·77	0·05	0·68
...vember..........	0·72	3·08	1·47	7·49	2·59	1·06	2·17	2·01	1·42	1·97	2·64	1·69	1·93	3·00	2·66	0·73	2·13	2·00	2·19	2·24	0·43	5·17	0·96	1·02	[illegible]	0·38	1·81
...cember..........	1·43	10·39	2·83	8·24	0·84	4·93	0·99	3·52	2·44	0·93	8·17	4·05	3·91	2·92	3·75	1·98	2·88	2·36	2·70	0·56	2·78	3·29	3·88	1·39	[illegible]	3·27	2·66
Total..........	15·77	24·50	22·60	22·52	25·57	26·41	24·58	23·15	16·77	27·68	25·66	36·38	26·62	23·95	18·84	27·63	23·47	13·68	29·38	17·01	20·11	26·18	13·95	16·38	17·30	31·04	20·57

ion..........	Ghanzi.				Serowe.					Tsau.						
....	1923	1924	1925	Mean.	1922	1923	1924	1925	Mean.	1911	1912	1913	1914	1915	1916	Mean.
th—	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
January..........	5·49	1·90	2·61	3·33	1·02	16·23	0·46	7·27	6·24	0·84	5·54	0·36	4·64	5·03	1·39	2·97
February..........	7·12	0·78	5·75	4·55	1·60	3·65	2·79	1·32	2·34	7·15	2·06	3·65	7·14	3·32	1·45	4·13
March..........	3·87	4·49	6·25	4·87	1·43	6·35	6·15	5·77	4·92	3·87	0·41	0·96	1·30	0·47	4·90	1·98
April..........	0·96	nil	4·32	1·76	nil	0·05	nil	2·66	0·68	nil	0·76	2·02	0·06	0·07	nil	0·48
May..........	0·27	nil	0·79	0·35	0·72	0·29	0·72	0·84	0·64	0·80	0·02	0·01	0·04	0·24	nil	0·18
June..........	nil	nil	nil	0·00	nil	nil	nil	nil	0·00	nil	nil	nil	nil	0·03	nil	0·01
July..........	nil	nil	0·36	0·12	nil	0·11	nil	0·15	0·06	0·01	nil	nil	nil	1·90	nil	0·32
August..........	nil	nil	nil	0·00	0·55	nil	nil	nil	0·14	0·02	nil	nil	0·04	nil	nil	0·01
September..........	nil	nil	0·06	0·02	nil	0·20	0·05	2·84	0·77	nil	0·02	nil	nil	0·08	nil	0·02
October..........	0·32	1·71	nil	0·68	1·00	0·02	1·31	0·55	0·72	0·02	0·92	0·22	0·23	0·10	0·46	0·32
November..........	2·39	1·80	2·95	2·38	4·32	0·71	4·00	0·65	2·42	0·62	0·32	0·61	1·67	0·30	0·66	0·70
December..........	0·99	2·89	1·18	1·69	1·01	2·30	2·66	0·59	1·64	0·72	1·69	0·99	8·67	2·47	3·44	3·00
Total..........	21·41	13·57	24·27	19·75	11·65	29·91	18·14	22·64	20·57	14·05	11·74	8·82	23·79	14·01	12·30	14·12

tion............	Livingstone.										Evaporation.	
ar............	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1924	1925
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
onth—	Mean											
January............ 6·80	2·48	0·68	11·10	15·62	5·04	4·68	0·92	8·60	5·15	13·76	n.r.	5·16
February............ 6·80	0·42	1·30	3·28	9·40	15·18	8·96	7·47	8·89	1·95	11·10	7·98	3·65
March............ 4·93	1·67	1·33	6·50	0·75	5·11	7·81	2·57	10·62	6·21	6·70	6·26	5·31
April............ 0·52	0·82	0·55	nil	nil	nil	0·03	nil	0·14	nil	3·65	[illegible]	4·74
May............ 0·48	nil	1·12	nil	nil	0·08	2·22	nil	nil	nil	1·36	6·56	n.r.
June............ 0·00	nil	nil	nil	nil	nil	n.r.	nil	nil	nil	nil	5·73	4·99
July............ 0·01	nil	nil	0·08	nil	nil	n.r.	nil	nil	nil	nil	5·73	4·97
August............ 0·00	nil	nil	nil	nil	nil	n.r.	nil	nil	nil	nil	7·12	6·73
September............ 0·13	0·24	nil	nil	0·17	nil	n.r.	nil	0·36	nil	0·50	9·37	n.r.
October............ 1·09	nil	0·30	nil	1·53	0·65	0·53	4·56	1·19	1·88	0·26	9·97	10·46
November............ 2·60	3·08	2·31	nil	2·60	1·03	4·78	3·90	1·86	5·41	0·98	6·94	8·08
December............ 7·92	5·59	11·09	6·26	11·40	9·31	9·03	7·68	3·24	11·52	4·10	7·18	7·82
Total............ 31·28	14·26	18·68	27·22	41·47	36·40	38·04	27·10	34·90	32·12	42·41	79·96	61·91

The prevailing winds range from E. to E.S.E. and S.S.E., but chiefly the former, which general direction is constant throughout the year. They rarely blow with any great force except for several days just prior to the approach of a rainy spell, when they average about fifteen miles per hour. They then turn round to E.N.E. and N.N.E., also blowing with a force of about fifteen miles per hour for a day or two, whereupon rains may be expected. Immediately the rainy conditions have passed the wind veers round to the prevailing direction and the sky clears.

Clouds.—As cloudy weather is usually only experienced during E.N.E. and N.N.E. winds, and as the prevailing E., E.S.E., and S.S.E. winds as a rule give clear weather, the proportion of cloudy days is not very high. The upper and middle clouds travel invariably from the W.S.W. to the W.N.W., which would appear to be constant throughout the year.

Rainfall.—Nearly all rainfall, the bulk of which falls during the summer months, is connected with thunderstorms approaching from the W.S.W. and W.N.W., principally the W.S.W. Occasionally very light rains are experienced in the form of a drizzle, but such precipitation does not, as a rule, amount to much.

The following *Tables* give the rainfall at various stations in and around the area concerned for so far back as records are available :—

Winds.

Livingstone, 8 a.m.

1924.	N.	N.N.E.	N.E.	E.N.E.	E.	E.S.E.	S.E.	S.S.E.	S.	S.S.W.	S.W.	W.S.W.	W.	W.N.W.	N.W.	N.N.W.	Calm.
January	No records.																
February	1	2	2	1	4	12	2	—	1	—	—	2	—	1	—	1	—
March	—	—	1	6	8	8	1	1	1	1	—	1	1	2	—	—	—
April	1	—	—	1	12	12	2	—	—	—	—	—	—	1	1	—	—
May	—	1	3	5	5	8	—	4	1	—	—	3	—	—	—	—	1
June	—	—	—	1	8	6	2	1	—	—	—	—	3	2	6	1	—
July	—	1	1	6	12	5	1	—	—	—	—	—	—	—	3	—	2
August	—	—	2	3	9	9	3	2	—	—	—	—	—	1	2	—	—
September	—	—	2	3	12	7	1	1	1	—	2	—	1	—	—	—	—
October	3	—	1	2	7	6	3	3	2	—	—	1	—	1	—	2	—
November	1	—	5	2	7	5	2	2	1	—	—	—	1	1	1	2	—
December	—	—	1	7	6	6	1	1	—	1	—	1	—	1	1	5	—
	6	4	18	37	90	84	18	15	7	2	2	8	6	10	14	11	3

1925.	N.	N.N.E.	N.E.	E.N.E.	E.	E.S.E.	S.E.	S.S.E.	S.	S.S.W.	S.W.	W.S.W.	W.	W.N.W.	N.W.	N.N.W.	Calm.
January	—	—	1	3	12	6	—	3	—	—	—	—	—	1	—	3	2
February	—	1	2	5	7	7	1	—	—	—	1	—	—	1	2	1	—
March	—	2	—	8	—	4	14	—	—	—	—	1	—	—	1	1	—
April	—	—	—	2	11	12	3	1	—	—	1	—	—	—	—	—	—
May	—	1	1	4	6	10	4	—	—	—	—	—	1	—	2	—	2
June	—	1	1	2	8	6	4	1	—	—	1	—	2	—	1	3	—
July	—	—	1	3	5	8	1	1	—	—	—	1	—	2	—	2	7
August	—	—	—	3	11	2	—	—	—	—	—	1	—	—	—	—	14
September	—	—	—	3	7	8	1	—	—	—	—	—	—	—	—	—	11
October	—	—	1	5	10	3	1	—	—	—	—	—	—	1	—	—	10
November	—	—	1	1	3	4	1	—	—	—	—	1	—	2	1	1	15
December	1	1	1	9	4	2	—	1	1	—	—	—	—	—	4	4	3
	1	6	9	48	84	72	30	7	1	—	3	4	3	7	11	15	64

APPENDIX IV.

METEOROLOGICAL OBSERVATIONS.

By C. J. L. Stegmann.

The instruments used during the above investigations consisted of an Assmann psychrometer, maximum and minimum thermometers, and a barograph.

As the observations, except for a few occasions, did not extend over more than a couple of days at each place, it is not possible to give more than a summary of the results.

Barometer.—The mean diurnal variation of the barometer is extremely small; it usually amounts to 0·1 and occasionally to 0·15 inches.

Temperature.—The mean maximum, mean minimum, and mean temperatures during July 7th to 30th, Kazungula to Kachikau, were 80°, 45°, and 62°; during August, Kasinka to Sunset Pan, 84°, 42°, and 63°; during September 1st to 24th, Scotchcart Pan to Maun, 86°, 51°, and 68°; and during October 1st to 18th, Bushman Pan to Kabulabula, 97°, 62°, and 80° respectively.

The following are the extremes of temperatures recorded during the above period:—

July	86° on 28th at Kachikau; 34° on 25th at Kachikau.
August	[illegible] at Tsokoro; 27° on 3rd at Goha.
September	95° on 23rd at Maun; 39° on 4th at Eland Pan.
October	100° on 6th near Goha; 58° on 9th at Kasinka.

As standard thermometers were not in use at Kasane and Maun prior to October, the records from these stations previous to that date are not reliable.

1925.	Kasane. Max.	Min.	Mean.	Extreme. Max.	Extreme. Min.	Maun. Max.	Min.	Mean.	Extreme. Max.	Extreme. Min.
October	94°	63°	78°	99°	55°	92°	60°	76°	98°	50°
November	92°	66°	79°	100°	62°	94°	65°	80°	101°	56°
December	89°	66°	78°	98°	63°	88°	66°	77°	100°	61°

Humidity.—The following humidity figures are respectively for areas along the river banks (or swamps) and for areas not in the vicinity of rivers (or swamps). The figures in parenthesis represent the lowest readings recorded.

Along River Banks.—Kazungula to Kachikau and Mogogelo to Maun:—

Hours	8	10	12	14	16	18	20	22
Per cent.	73 (47)	55 (31)	42 (22)	34 (20)	34 (17)	54 (21)	64 (32)	77 (38)

Away from River Banks.—Kasinka to Rakuku:—

Hours	8	10	12	14	16	18	20	22
Per cent.	63 (37)	41 (20)	28 (12)	25 (16)	24 (12)	34 (17)	52 (29)	57 (28)

Maun at 9 a.m.

1925.	Per cent.
October	47
November	55
December	62

Livingstone at 8 a.m.

1924.	Per cent.	1925.	Per cent.
January	55	January	83
February	69	February	88
March	78	March	87
April	65	April	85
May	58	May	76
June	62	June	70
July	59	July	74
August	49	August	57
September	35	September	52
October	42	October	40
November	62	November	52
December	82	December	70
Average	60	Average	70

The efflorescence (sample No. 11) from Kachikau was found to consist almost entirely of sulphates. The figures obtained were—

	Per cent.
Moisture	4·68
Loss on ignition	7·67
Insoluble matter	2·50
Potash	1·17
Magnesia	2·87
Sulphur trioxide	46·67
Phosphoric oxide	Trace
Chlorides	Trace

The material is essentially sulphate of soda, together with small quantities of potassium and magnesium sulphates.

In reporting on the above results, the writer is at the very considerable disadvantage of not having seen the samples *in situ* and in being ignorant of the climatic conditions that obtain.

The colours of the samples require no comment. According to texture, as determined by rubbing the moistened soil between finger and thumb, the soils may be arranged in three groups, i.e.—

(1) Gritty soils—Nos. 1, 2, 8, and 10.
(2) Fine-grained soils—Nos. 6 and 9.
(3) Very fine-grained soils—Nos. 3 and 7.

This classification is corroborated by the mechanical analysis, especially with reference to the gritty soils.

(1) *Gritty Soils.*

	Coarse Sand.	*Fine Sand.*	*Total Sand.*
No. 1	52·5	24·2	76·7
No. 2	74·1	19·0	93·1
No. 8	63·9	28·6	92·5
No. 10	34·0	42·3	76·3

(2) *Fine Soils.*

	Clay.	*Fine Silt.*	*Total.*
No. 6	25·7	26·2	51·9
No. 9			

(3) *Very Fine Soils.*

	Clay.	*Fine Silt.*	*Total.*
No. 3	30·7	27·0	57·7
No. 7	53·9	20·7	73·7

Their behaviour on drying after having been made into a paste is very characteristic and important from an agricultural point of view. Nos. 1, 3, 5, and 7 would prove difficult soils to work under irrigation; the remaining numbers should, however, be easy to till. With the first-mentioned soils trouble is to be expected in connexion with germination. Seeds would experience great difficulty in forcing their shoots through them, if they hardened after being irrigated, or after a heavy fall of rain. This caking would also exclude air.

Of the nine soils, only two are at all rich in organic matter, namely, Nos. 6 and 9. Soil No. 6 is acid, Nos. 1 and 2 slightly so, and the rest alkaline.

Chemically considered, Nos. 1, 2, 8, and 10 (the gritty soils) all consist of upwards of 90 per cent. of matter insoluble in strong boiling hydrochloric acid. Their phosphoric-oxide contents are extremely low, and they are low in potash. The nitrogen contents of Nos. 8 and 10 are very low, of Nos. 1 and 2 quite fair. Of all the remaining soils not one is well supplied with phosphate. They are, however, well supplied with potash, No. 9 containing no less than 2·11 per cent. The amounts of lime and magnesia are also very satisfactory.

With phosphatic manuring Nos. 6 and 9 would probably prove good soils, but on account of physical or chemical drawbacks I would hesitate to recommend any of the others, excepting, perhaps, No. 10, which would require lots of organic matter and phosphates.

Soil No. 1 was examined for waxy materials, with negative results. Its desolate appearance is doubtless due to the fact that it dries to a hard mass.

Notwithstanding anything favourable that may have been said above with respect to any soil, it must be remembered that these remarks may need to be discounted on the score of lack of soil depth or of suitable sub-soil.

The analysis of No. 4 sample (marl) does not appear to call for any special comment.

ANALYTICAL DATA.

(Figures represent percentage of air-dried fine earth.)

Sample Number	1	2	3	4	5	6	7	8	9	10
Colour (dry)	Grey	Black	Grey	White	Grey	Dark Grey	Light grey	Whitish	Very light brown	Very light brown
Colour (wet)	Black	Black	Darker grey	—	Black	Black	Slightly Darker	Slightly Darker	Darker	Darker
Texture	Gritty	Gritty	Very fine	—	Very fine	Fine	Very fine	Gritty	Fine	Gritty
Result of drying after making into stiff paste with water	Very hard mass	Friable mass	Very hard Mass	—	Very hard mass	Cakes, but friable	Very hard mass	Friable mass	Friable mass	Fairly friable mass
(a) *Mechanical Analysis.*										
Fine earth (1 mm.)	100	100	100	100	100	100	100	100	100	100
Moisture	1·46	0·45	6·2	2·4	7·08	4·59	5·93	0·4	6·46	2·04
Loss on ignition	2·95	1·90	6·66	10·29	8·97	12·87	9·05	0·85	13·40	2·8
Solubility in N/5 HCl	1·8	0·90	12·0	—	9·2	6·9	10·0	0·7	8·2	2·9
Reactions to litmus	Slightly acid	Slightly acid	Alk.	Alk.	Alk.	Acid	Alk.	Alk.	—	Alk.
Coarse sand	52·5	74·1	11·5	Not done	0·6	Not done	1·8	63·9	5·4	34·0
Fine sand	24·2	19·0	15·5	Not done	3·9	Not done	8·8	23·6	18·7	42·3
Silt	4·6	1·1	6·2	Not done	5·5	Not done	6·5	1·9	10·8	3·7
Fine silt	10·3	1·9	27·0	Not done	27·9	Not done	20·7	0·9	26·2	6·5
Clay	7·5	3·4	30·7	Not done	55·5	Not done	53·9	3·5	25·7	11·4
(b) *Chemical Analysis.*										
Insoluble inorganic matter	92·33	96·00	70·63	37·2	66·38	71·09	66·37	97·2	58·85	90·4
Iron (Fe_2O_3)	0·80	0·72	4·16	4·02	4·64	2·80	4·24	1·71	20·40	4·4
Alumina (Al_2O_3)	1·80	0·47	6·35		10·82	7·13	10·54			
Lime (CaO)	0·24	0·22	3·90	46·55	1·03	0·94	2·80	0·11	1·29	0·71
Magnesia (MgO)	0·16	0·12	1·07	0·74	0·91	0·46	0·93	0·07	0·29	1·52
Potash (K_2O)	0·09	0·08	0·53	trace	0·66	0·47	0·58	0·08	2·11	0·14
Phosphoric oxide (P_2O_5)	0·02	0·02	0·04	0·084	0·02	0·04	0·03	0·01	0·05	0·01
Nitrogen (N)	0·112	0·084	0·108	0·056	0·118	0·330	0·095	0·02	0·280	0·034

APPENDIX III.

ANALYSES OF SOILS FROM THE KALAHARI

By A. Stead, B.Sc., F.C.S.,

Senior Chemist and Officer in Charge of Soil Survey.

The samples were numbered 1 to 10, and in addition there was a sample (No. 11) of an efflorescence on the soil at Kachikau.

The following is a description of the various samples :—

No. 1.—Mopane soil from pan-strewn area between Sisuma Pan and the Savuti channel.

No. 2.—Mababe Flats : Base Camp on Savuti River.

No. 3.—Mababe Flats : a couple of miles due west of Tonkoro Pan.

No. 4.—Mababe Flats : marls below surface soil on east side near Scotchcart Pan.

No. 5.—Mababe Flats : interior of flats on north-east side towards Scotchcart Pan.

No. 6.—Mababe Flats : in grass plain to south near Noaks's Peg No. 13.

No. 7.—Mababe Flats : soils of grass flat (centre of Noaks's section) between Scotchcart Pan and southern end of hollow.

No. 8.—Extreme south-west edge of Mababe Flats : edge of sand ridge (Douglas's section).

No. 9.—Lake Ngami at Toteñ : upper part, well laminated and overlying No. 10, full of ash.

No. 10.—Lake Ngami at Toteñ : sub-soil of No. 9.

The samples, excepting Nos. 4, 9, and 10, represent the first 12 inches of soil. No. 4 represents the marl below the surface soil, No. 9 the first 9 inches of soil, and No. 10 the next 9 inches. The figures are percentages of air-dried fine earth. None of the samples contained stones.

Owing to the smallness of the samples, it was not possible to determine the "available" plant-food, carbonates, and water-soluble materials. The analytical results are recorded below :—

at a height sufficient to ensure good results, wherefore owing to this and to other causes it was not always possible to pick up the time-signals. Whenever possible, the chronometer error as determined from the Lourenco Marques signals at 9 p.m. was checked by means of the Slangkop signals at 11 p.m.

It might be mentioned that the Lourenco Marques time-signals are spread over a period of three minutes, and it is thus possible to note with considerable accuracy the chronometer time readings at intervals of ten seconds over that period. Mr. Buckland became very expert at synchronizing, and was able to record the error of the chronometer in this way to the nearest fifth of a second with a fair degree of confidence.

As a rule, both latitude and time observations were undertaken on the same night; the necessary computations having been made, suitable stars were selected beforehand. In determining *latitude* circummeridian altitudes were observed and, except when the work was cut short by the presence of clouds, four stars were observed. These were invariably selected in pairs, a star in the north being paired with one at about the corresponding altitude in the south. To each star at least eight, and generally twelve, successive readings were made, approximately half of the readings being on each side of the meridian. From Table I it will be seen that the maximum probable error in the latitude determinations was ± 1·3 second of arc (that is, if any possible local disturbance of gravity or "local attraction" be ignored).

Time was determined by the observation of stellar altitudes on or near the prime vertical. The results were computed from observations to at least four stars. Stars were selected in pairs, east and west, and to each star a series of eight or more readings was taken. Having thus determined the error of the chronometer on local mean time and having also found the error of the chronometer and its rate based on standard time as received by wireless, the computation of longitude could be made. The maximum probable error calculated from the time observation results was ± 0·28 second of time, equivalent to ± 4·2 seconds of arc.

Azimuths were also determined in order to determine the local magnetic variations. As the magnetic meridian was obtained by merely "floating up" the needle of a Trough compass, the accuracy of the results cannot be considered as comparable with those in which some form of magnetometer is used.

The results of the astronomical observations are attached in tabular form (Table I). The degree of accuracy attained is gratifying, and was due in large measure to the expert assistance rendered to the observer by the other members of the party.

Table I.

ASTRONOMICAL OBSERVATIONS—SUMMARY.

Place.	Latitude.				Longitude.								Magnetic Variation.			Total Probable Error, Arc.
					In Time.			Probable Error.		In Arc.						
	°	′	″	Probable Error.	Hrs.	Mins.	Secs.	Time.	Arc.	°	′	″	°	′	″	
				Secs.				Secs.	Secs.							Secs.
Livingstone Observatory...	17	50	24	± 0·16	1	43	25·2	± 0·2	± 3·0	25	51	18	14	04	00	± 3·00
Beacon E 166, near Katombora Camp.........	17	50	52	± 0·9	1	41	36·3	± 0·15	± 2·2	25	24	05	15	09	30	± 2·38
Kabulabula Beacon........	17	49	39	± 0·9	1	39	53·3	± 0·28	± 4·2	24	58	19	15	08	50	± 4·29
Kachikau........	18	08	35	± 0·8	1	37	58·8	± 0·11	± 1·7	24	29	42	14	38	00	± 1·88
Savuti River Camp	18	37	26	± 0·4	1	36	43·6	± 0·16	± 2·4	24	10	54	15	18	30	± 2·43
Wia Pan........	18	45	07	± 1·0	1	37	27·4	± 0·18	± 2·6	24	21	51	15	20	10	± 2·78
Mogogelo Camp..	19	36	00	± 0·1	1	35	08·7	± 0·10	± 1·5	23	47	10	15	18	30	± 1·50
Maun Drift......	19	59	57	± 1·3	1	33	43·2	± 0·12	± 1·8	23	25	48	15	47	00	± 2·24

APPENDIX II.

METHODS AND RESULTS OF SURVEY.

By C. Sholto Douglas.

At an early stage of the investigation it was realized that the feasibility or otherwise of any projects to be entertained would depend almost entirely upon relative levels, and, as the river gradients are flat and the distances considerable, no approximate determinations of altitude by hypsometer or barometer would be of any real value. It was therefore resolved to adopt rigid methods in the determination of relative heights and to regard the fixing of the position of topographical features as of secondary importance.

The usual methods of carrying out a topographical reconnaissance by rapid triangulation or by subtense work were generally impossible owing to the nature of the topography and to the dense bush encountered everywhere except on some open flats in the Mababe depression. The method consequently adopted was to combine compass and stadia reading with ordinary levelling operations, and in this way a complete traverse was made of the routes followed. To provide a framework upon which to base the main traverses, certain points along the latter were selected at which astronomical observations were made for the determination of geographical position.

Subsidiary traverses were run from the main traverse to determine the levels of salient features off the main route. The astronomical stations were marked by means of short lengths of boiler tube sunk into the ground. Sketches have been made and filed with other field records showing the positions of these stations in relation to the surrounding topography or to large blazed trees in the immediate vicinity. The datum adopted for the reduced levels is that of rail-level at Livingstone, taken as 2,977 feet above sea-level. Bench marks were established at frequent intervals. The main level traverse from Livingstone to Maun was check-levelled throughout, but single lines of levels were run in the case of subsidiary traverses. As an extreme degree of precision in levelling was not considered necessary in a reconnaissance of this nature, every effort was made to speed up the work, and sights of from 300 to 400 feet were taken where possible, while operations were also conducted throughout the heat of the day; nevertheless, it is estimated that the error in this work does not exceed that given by the expression $e = \pm 0{\cdot}06 \sqrt{M}$, where e is the error in feet and M the distance in miles. In one case, where a complete circuit of just over 100 miles was made, the error in closure was found to be considerably less than that given by the above expression.

In comparing the results of the traverses with the positions of the selected stations as determined astronomically, the distances between them have been calculated through the traverses and also from the latitudes and longitudes. The average of the proportional relative errors for the six traverses thus compared works out at 1 in 432.

The total distance over which levelling was undertaken by the party was approximately 730 miles; of this, some 320 miles were check-levelled, making the total length of levelling carried out approximately 1,050 miles.

Astronomical Observations.

Stellar observations were carried out by means of a Cooke, Troughton & Simms 5-inch theodolite, of which both circles were read by means of micrometer microscopes. A five-valve wireless set was used for the reception of time-signals from Lourenco Marques and Slangkop, by means of which the chronometer rate was determined from time to time. Explorers have frequently complained of the manner in which chronometer rates vary under conditions of land travel; experience on this reconnaissance proved no exception, and, although the chronometer used had maintained a constant rate whilst stationary, the rate was found to vary widely on the march in spite of the utmost care in transport. So irregular was this variation, that longitude determinations were rejected whenever the wireless time-signals of the same evening could not be clearly distinguished. For the support of the wireless aerial trees were used, and difficulty was frequently encountered in securing this aerial

APPENDIX I.

THE DISCHARGE OF THE ZAMBEZI.

By C. Sholto Douglas.

An estimate of the total volume of water in the Zambezi River likely to be available from year to year is essential in the consideration of any power, storage, or diversion projects on that river.

Records of water levels in the Zambezi have been kept since the year 1906 by the officials of the B. & M. and R. Railways, and a complete record of these levels in graphical form was made available through the courtesy of Mr. Binks, the District Engineer.

A gauge post near the Livingstone Pumping Station was erected in October, 1924, and daily readings are forwarded to the Survey Office in Livingstone. Copies of these levels have been kindly furnished by the Surveyor-General.

An examination of the river section at the Railway Gauge Post, situated three-quarters of a mile above the Falls, showed this site to be inconvenient for current-meter observations, as the river is cut up into several channels by islands and the stream is rapid and turbulent.

The section of the river at the Pumping Station, about 2 miles farther upstream, was also viewed unfavourably on account of the presence of a large island. It was therefore decided to select a more suitable spot for our measurement higher upstream. At Kamajomas, some 14 miles above the Falls, it was found that the river is confined to one channel at all seasons and the flow appeared to be fairly uniform. Gaugings were therefore made at this site in June, the flow of the river being strong at this season of the year. In October a second gauging was carried out at this site, when the river was found to have run down almost to its minimum flow.

Mr. Noaks has analysed the available data with care and has prepared a discharge curve for the river at this section. From the gauge readings of corresponding dates at the other two sites, combined with a single gauging of the river made by Mr. C. L. Robertson, of the Hydrographic Department of Southern Rhodesia, on the 1st to 3rd of October, 1924, and the known high-flood levels at the three sections under consideration, correlations have been established between the various gauges, and from this a *discharge curve* has been deduced for the Railway Gauge Post.

Unfortunately, some inconsistency has been found in the case of the very low readings, but the curve thus obtained has been adopted in the plotting of the *total discharge curves* for each of the eighteen years for which readings are available, and it is considered that these cannot be seriously in error. The mean of these eighteen total discharge curves has been prepared, from which we obtain 27·8 million acre-feet as the mean total annual discharge of the Zambezi. Reckoning the "year" as extending from November to the following October, the *total annual discharges* for the period 1907–25 measured in millions of acre-feet were respectively: 27·2, 36·8, 33·6, 28·0, 28·3, 25·1, 23·7, 16·7, 20·5, 32·1, 31·2, 20·0, 25·7, 28·9, 19·9, 31·0, 20·6, and 37·2. The corresponding *maximum rates of discharge* measured in thousands of cusecs are respectively: 65, 121, 105, 73, 88, 77, 73, 45, 54, 106, 99, 52, 90, 92, 52, 97, 55, and 140, with a mean of 82,000 cusecs. A remarkable feature of the Zambezi River is its seasonal regularity. In the eighteen years under review the peak of the annual flood has on every occasion occurred within the interval between the 30th March and the 19th May, and in eleven of these years the maximum was reached in every case within the last week of April.

Information regarding the catchment area of the Zambezi River and the rainfall in that region is very meagre; existing maps, however, show the drainage area above Katombora to be about 132,000 square miles. On account of its low-lying and sandy nature, a large proportion of this area must have a very small run-off, and it would appear reasonable to assume that the effective catchment is not greater than 110,000 square miles. Over this region the rainfall is said to vary from 30 to over 50 inches per annum.

A total annual discharge of 27·8 million acre-feet represents a run-off of 12 per cent. on a mean rainfall of 40 inches. So little, however, is known of the rainfall and its distribution over the catchment area that it would be dangerous to rely solely upon run-off figures based on such vague information.

The existing [illegible] channel follows a very [illegible] full of trees and in [illegible]

[illegible]

[illegible] per acre [illegible] not much [illegible] than £3 per acre and [illegible] other 5s., the total [illegible] scheme of util[illegible] that provision [illegible] the ground avai[illegible] [illegible] square miles. [illegible] to wh[illegible] that more water [illegible] design, be [illegible]

[illegible] development of the land the [illegible] brown or black soil areas alone cultiv[illegible] [illegible] occupying the north and west [illegible] more difficult to su[illegible] while it [illegible] to exclude the very [illegible] rainfall of [illegible] the grass, [illegible] gravitate [illegible] become [illegible] drainage [illegible] ordinary [illegible] rivers. It is [illegible] dissolved solids, but, as [illegible] in the depression [illegible] therefore, be [illegible] the seepage and [illegible] proportion of the [illegible] compounds [illegible] this expression [illegible] need be app[illegible]

[illegible] can be put forward [illegible] ground that would [illegible] during the summer [illegible] for the cultivation [illegible] for which it would appear to be suited. [illegible] marginal belt of brown [illegible] underlain at a shallow depth by marl would nevertheless be suited for lucerne or tobacco. In deciding upon the nature of the crops to be raised on the remainder of the black soil forming the bulk of the area, there would have to be taken into account the great distance from any market—Livingstone being about 180 miles away—and the fact that transport during both wet and dry seasons would be difficult and costly.

144. The area is entirely waste land and is unoccupied, so that there are no existing rights to be interfered with. It is essential to point out, however, that tsetse fly infests the timber bordering the southern extremity of the Mababe, that this pest

along the gentle hollow lying to the west of the sand ridge, thereby circumventing the Mababe depression and avoiding the enormous losses to be incurred within the latter through storage and evaporation; this last is an eminently important matter.

185. It should once more be pointed out that the projects discussed in this report are of *no direct benefit to the Union*; indeed, the construction of any one of these schemes might have the opposite effect, for it must not be overlooked that the Union has at considerable cost constructed various large irrigation works and that considerable areas of land thereunder are not yet taken up and made use of.

The Union Government could hardly be expected to carry out such additional investigation except with the financial co-operation of the Bechuanaland Administration. The Union Irrigation Department, being in possession of all the available data, might, nevertheless, hold a watching brief and continue the collection, as it is now doing, of hydrographical, meteorological, and other information having a bearing on this problem.

186. While the ambitious ideas of Professor Schwarz are not likely to be realized in practice, it is not improbable that in the future one of these schemes of irrigation formulated above will enable a portion of this waste space in southern Africa to be satisfactorily settled.

(13) The north-western part of the Kalahari was not included in our investigations, but on the assumption that the entire flow of the Cunene River were to be appropriated and permitted to evaporate in the Etosha Pan, the area of water surface thus provided would be less than that represented to-day within the Ngami-Zambezi territory, and by analogy its climatic influence would not be other than trifling.

(14) The detailed project for damming the Zambezi is the only large scheme possible in this region, and its construction would automatically rule out alternative minor works within the Mababe, though not necessarily those within Lake Ngami.

(15) It would seem practicable to irrigate an area of about 125,000 acres within the Mababe depression with water drawn from the Linyanti River by simple diversion via the Savuti channel at a cost of approximately £5 per acre, including distribution.

(16) It would, furthermore, be possible to irrigate the eastern part of the floor of Lake Ngami to the extent of some 30,000 or 40,000 acres with water from the Okavango System alone in one of two ways at a cost of just under £100,000, or approximately £3 per acre, excluding distributaries, or perhaps £6, including distribution.

(17) Not improbably surveys may indicate the feasibility of extending that area by bringing in the Mokolane River on the west, but regarding this auxiliary project no estimates can be submitted.

(18) The Lake itself could be made to serve as a storage basin to hold up water from the Okavango System for subsequent use at some point in the neighbourhood of Rakops on the Botletle River, but the merits of this scheme are not conspicuous and the cost thereof can only in part be determined.

(19) Schemes (15), (16), and (17) are independent of one another, but the adoption of (18) would naturally imply the elimination of (16) and (17).

(20) None of the projects in this region are of direct concern to the Union, but would affect the Bechuanaland Protectorate and its native population almost entirely. The large scheme, (5), would, however, flood a part of the mandated territory of South-West Africa, a part of Northern Rhodesia, and a small corner of Southern Rhodesia.

Recommendations.

182. It does not fall within the scope of a Reconnaissance of this character to discuss, or even to point out, all the various problems and difficulties that would arise under the adoption of any one of the schemes put forward. These would more thoroughly be appreciated and handled by the Governments directly concerned, but for general information it might be remarked that, apart from the purely technical points, there are numerous related questions involved; for example, the problem of white settlement, the transplanting of the native population, transport methods generally and railway communication in particular, the nature of the crops to be produced, the finding of markets for such produce, the possible eradication of the tsetse fly, etc.

183. The further study of the Okavango System, with particular reference to the minor schemes (15), (16), and (17), or any other alternatives, is suggested to the attention of the Bechuanaland Administration, because of their simplicity and moderate cost, though further field investigation in the case of (16) and (17) is advised, with the object of obtaining levels, acreages, gaugings, etc., the figures set down being admittedly based upon limited data and purely provisional. Not improbably the examination of the delta region would disclose other and better schemes of making economic use of the Okavango waters than those suggested.

184. The major scheme, (5), has so far only been proved feasible from the engineering aspect, and it yet remains to investigate the lower reaches of the Botletle in order to determine the area of irrigable land available in that neighbourhood, its agricultural character, and the probable cost of the necessary distribution system. Should it be thought that this report upon the project appears sufficiently encouraging, further investigation should be made, the maximum area to be flooded by the Katombora weir should be determined more accurately, and a chain of levels ought to be run between the mid-Savuti channel and the Kudumane River in order to discover whether the waters from the dam could not perhaps be brought down into the Okavango System

XVII.—SUMMARY AND RECOMMENDATIONS.

180. The conclusions to be drawn from the reconnaissance work can be summarized in comparatively few words, though at times, because of the lack of decisive data, they have to be of a somewhat tentative character. Such an admission must not be taken as implying that this and other kindred problems of the Kalahari are incapable of solution, but rather that further investigations on the lines suggested in the latter part of this section will be required.

It has been our endeavour to investigate these problems in an impartial spirit, and it is considered that the estimates framed are fair and reasonable, and that those based on the less certain factors have not been exaggerated. While the deductions and findings are by no means in accord with the sanguine expectations of Professor Schwarz, it is believed that the evidence on which our conclusions are based, being so largely one of river discharges and of levels, could scarcely be interpreted otherwise in the light of our present knowledge.

181. It is concluded that:—

(1) The idea of a former greater rainfall in the Ngami–Makarikari region in the historic period is based upon a misinterpretation of the facts and of the historic records, and that the climatic conditions do not appear to have altered appreciably within the limited period with which we are particularly concerned.

(2) The facts do not favour Professor Schwarz' conception of an ancient "Greater Ngami," and that the latter cannot therefore be "restored."

(3) Owing to the immense losses through evaporation and absorption within the Okavango delta and the Linyanti swamps, no extensive scheme of flooding either the Ngami or the Makarikari region is possible without including the bulk of the Zambezi flow.

(3) Canalization of the Okavango through the delta would doubtless provide water for the Makarikari region, but, unless such were used for the purpose of irrigation, we should merely be draining one swamp to produce another elsewhere. We are, furthermore, ignorant as to its possible cost.

(5) By damming the Zambezi at Katombora to a height of just over 60 feet, the surplus flow of that river and of the Linyanti could be held up and caused to submerge not only much of the "Caprivi Strip," but also the Mababe depression (and, if necessary, Lake Ngami), the balance passing down via the Thamalakane and the Botletle for use in the Makarikari. A constant discharge down the Zambezi of 18,000 cubic feet per second would be permitted at Katombora in the shape of "compensation water."

(6) By such action and introducing storage, two lakes would be formed having a combined area of about 4,600 square miles, while an amount of water would ultimately become available in the Botletle, probably sufficient, it is thought, to irrigate an area up to approximately half a million acres.

(7) The cost of such diversion would, allowing for interest charges during the early unproductive stage, amount to approximately four millions sterling, exclusive of that for the irrigation canals and distributaries in the Makarikari region, which cannot at present be calculated, but which might perhaps exceed two millions.

(8) It would be possible to obtain up to about 120,000 electrical horse-power at Katombora from the compensation water, which would prevent serious interference with the Victoria Falls.

(9) The area of evaporating surface produced under this scheme would not be more than approximately three times that in existence to-day between Lake Ngami and the Zambezi River.

(10) The influence of the existing huge water and swamp areas on the climate of Ngamiland is, so far as can be observed and inferred, wholly negligible.

(11) The prime object of the Professor's great scheme, the beneficial influence to be expected as the result of increasing such areas even several times by damming the Zambezi, is, as regards the Union, probably insignificant.

(12) All schemes within the north-eastern part of the Kalahari must, therefore, be viewed solely from the irrigational and not from the climatic standpoint.

exceeded the area submerged in normal years by 50 per cent. (and still more that in 1924), yet Ngamiland in the early part of this year (1926) has experienced an unprecedented drought. It is doubtless only coincidence, though certainly curious, that although the Etosha Pan filled in 1903 and again in 1921, the rainfall in the Union during the following years, 1904 and 1922, was deficient over a very considerable area.

175. It has been pointed out that by damming the Zambezi an additional area of 4,600 square miles could be added (from which figure, as a matter of fact, must be deducted some 500 square miles that are at present contributing), and ultimately a subsidiary tract in the Makarikari equivalent to not more than about 500. In addition, Professor Schwarz hopes to obtain another few thousands of square miles by diverting the Cunene River into the Etosha Pan on the west. Taking the mean discharge of that river at 12,000 cusecs as given by him (which is close to the estimate framed by Mr. Kanthack), and assuming that we could take all this flow, thereby depriving the Portuguese of any share, the volume obtained would be equivalent to not more than 2,000 square miles of water surface under the most favourable of circumstances.

176. The total additions that could be obtained from the entire flows of the Zambezi, Linyanti, and Cunene would hence represent an area of 6,600 square miles at the most, as against an existing *mean evaporating area* of 2,500. By bringing in these rivers, therefore, the water and swamp area would, it is seen, be increased about *three and a half times*.

177. Attention should be drawn to the fact that the additional area that could be provided by means of costly diversion works would necessitate bringing in the Zambezi, and yet would be much less than the 15,000 square miles anticipated by Professor Schwarz *without* the assistance of that river. Were the Zambezi to be excluded from this scheme, the Etosha Pan would stand alone on the west, and its influence could, arguing from analogy, be in no way greater than that of the existing Okavango delta, which, as remarked, has yet to be demonstrated and appears to be practically negligible.

Let us assume, however, for the sake of argument, that by these various schemes the water areas could roughly be trebled. With no appreciable results discernible under existing conditions, could one with any degree of confidence be able to presume that the effect would be any more tangible, and could one with reason hope to affect the surrounding country to any considerable distance and induce an increase of rainfall over Bechuanaland, much less the more distantly situated Union?

178. It is, perhaps, not sufficiently appreciated that over the whole of the region concerned the rainfall takes place in the hot summer months, largely in the shape of thunderstorms. Huge volumes of air are induced to ascend rapidly to great heights and thereby become chilled. Sometimes the height is insufficient to cause the saturation point to be reached and drops fail to form; at other times the ascent produces violent precipitation. It cannot even be affirmed that upon the initial humidity of the air would depend the amount or intensity of the rainfall; unless the conditions necessary for bringing about the needed ascent were present, the air could continue humid without any release of moisture in the form of rain. This huge area is practically a plain and there are *no* mountain barriers to deflect the air currents and influence precipitation. Apart from seasonal thunderstorms, which are largely produced by thermal convection, the rains of importance are produced by the more or less conflicting movements of enormous volumes of air, which motions are determined in turn by the atmospheric pressure-distribution over not only the territory in question, but the surrounding regions of land and sea as well. There can be no doubt that the low pressure or cyclonic disturbances tending to bring about precipitation are on a truly huge scale; a constant surging must always be taking place in the atmosphere, and all our efforts to influence these atmospheric motions through the entirely indirect method of altering its humidity must be quite puny as compared with the gigantic operations existing in nature.

179. It must be concluded, therefore, that the hopes of rainmaking on such lines receive practically no support from the study of the data available and obtains scant encouragement from the study of meteorological principles.

water into the atmosphere throughout the year, might, under the hypothesis advanced by Professor Schwarz, appear to be on more or less the required scale, wherefore it becomes our duty to inquire as to the influence that this existing "basin" appears to have on the climate of this region. From that, the next step will be to discuss the expectations on the assumption that this area were to be trebled or even quadrupled.

172. Perhaps one of the most striking features of the region is that one can turn one's back on the swamps or rivers, march a distance of anything from a dozen up to a few hundred yards, and find oneself in typical dry mopane or sand veld, such as stretches away for scores of miles, a waterless country, except for a few pans. Coming from the latter area, there is nothing in the vegetation to mark the proximity to the rivers or swamps until one is almost on the water's edge, where large water-loving trees form a narrow border; indeed, the visitor might well be marching almost within hailing distance of some of the rivers and never suspect their presence. At the Victoria Falls, outside of the insignificant strip bathed by the spray, the aspect of the country is in no whit different to that to be seen miles away from the river. Were the Zambezi to dry up, it could hardly be disputed that, apart from this narrow fringe along its banks being affected, the valley would remain practically unchanged in its appearance.

Right down at the very edge of the water the air instead of being saturated, as might be expected, is singularly dry, as is shown by the fact that even down to October, when hot days were prevalent, dew failed to form at night, and the party was able to sleep in the open on the bank without discomfort. The testimony of the dry and wet bulb thermometers throughout the trip showed that, although the humidity was on an average some 10 per cent. greater than away from the water areas at similar hours, the air was always what could be termed *dry*. Early in the morning the humidity might be as high as 65 per cent., but by 10 a.m. it had dropped to 35 per cent., to rise again at about 6 p.m. Away from the swamps, the corresponding figures were generally 42 per cent. and 25 per cent. It is clear, then, that the moisture evaporated from the water and reed surfaces must ascend rapidly, otherwise the air would soon become saturated, as a short calculation will amply demonstrate. Whatever might happen in the upper air a mile or more in height, we are unable to state, but this much can be affirmed, that the air at ground level on the borders of these swamps is *normally far from saturation point.*

173. The most serious indictment of Professor Schwarz's assumptions is furnished by the rainfall records of Ngamiland and the adjacent territories. The precipitation in this part of Africa is highest in the north and north-east and becomes less and less towards the south-west and south, as is shown by the figures given on the Key Map in this Report. One finds a sudden fall between Livingstone and Sesheke, and Kasane, curiously, too, at the edge of the swamps, after which comes a wide region, right across to Otavi in fact, with a rainfall just over or just under 20 inches, and then most surprising, indeed, the station of Tsau with only 14·1 inches, less even than that in the dry districts of Ghanzi, Gobabis, and Grootfontein to the west. No better spot for a high rainfall under the theory could be found than Tsau, situated as it is on the western side of the Okavango swamps, across which blow the prevailing easterly winds of this region not only in winter, but in summer also; even the occasional northerly winds have to traverse the delta to reach Tsau.

174. We are fortunate in having the continuous wind records of the Livingstone Observatory for some years, and these, supplemented by our own observations and by the information gathered locally, indicate that throughout a great region lying both to east and west of the swamps the winds are remarkably steady *from the east over most of the year*, but that in summer they may veer round suddenly to the north with a tendency to rainy weather. Again, the rainfall at Andara at the opposite corner of the delta is practically the same as that at Grootfontein or Palapye Road, whereas under the hypothesis it ought to be higher. Until more meteorological observations have been made, it would be of little service pursuing this inquiry further, but, so far, then, from the swamps appearing to have any beneficial effect upon the surrounding country, it has reluctantly to be concluded that such an assumption *has not been justified by the facts.*

This is all the more striking because the actual area of water and reed surface embraced in the Okavango delta and Linyanti marshes to-day is so enormous. More extraordinary still is the fact that, while the territory flooded in 1925 appears to have

EXTRA RAIN FROM EVAPORATION, ETC., OVER THE KALAHARI BASIN.

	Million Million Cubic Feet.
Second Year—	
Extra 12 inches from evaporation, etc., over 100,000 square miles..........	2·7
Induced from sea-borne clouds that would otherwise have drifted away..........	2·7
	5·4
Total increment from the Kalahari lakes, second year..........	
Third Year—	
Extra 12 inches from evaporation, etc., over 300,000 square miles..........	7·1
Induced..........	7·1
	14·2
Fourth Year—	
Extra 12 inches from evaporation, etc., over 700,000 square miles..........	18·9
Induced..........	18·9
	37·8"

168. These calculations fairly take one's breath away and make one wonder what would be the state of affairs in another few years' time with storage, evaporation, and precipitation all continuing to increase at compound interest. In what way could this flood be controlled? It will be noticed, however, that several assumptions, some of an outrageous nature, are made: (1) that *all* the water evaporated would fall again over the immediate neighbourhood and so be ready for re-evaporation along with the new supply that had come forward into the lakes. It has been pointed out above that the winter evaporation from the latter would perforce have to be lost, and the same would be the case with the amount transpired from the soil during that period; (2) that such water-vapour, on becoming condensed as rain, would bring down with it *an equal volume* derived from the clouds passing overhead, which is candidly mere speculation; (3) that the flow of the various rivers would thereupon become greater.

169. It has to be remembered in this connexion that the Cunene, Okavango, Linyanti, and Zambezi derive their supply principally from the Angola highlands, *distant from 500 to 900 miles* from the area in question, and that the local contributions are extremely small. This high ground, with its huge annual and very regular rainfall, lies right in the tropical belt, and it yet requires to be shown that its air-borne moisture is derived from the south-east and not from any other quarter of the compass. Still, if we presume, for argument, that such is the case, then the contention that the Union would stand to benefit would obviously be seriously weakened. As a matter of fact, seeing that the rainfall becomes even higher over the great Congo basin further to the north, it would be more reasonable to suppose that Barotseland is merely getting the surplus from the Equatorial belt.

170. All that can be drawn from the above is that the estimates put up by Professor Schwarz, even regarded as approximations, must be greatly exaggerated, though to what extent, if any, an increase of rainfall could be anticipated, it is candidly impossible for any one to say by merely pursuing the above line of argument.

171. Under these circumstances we are compelled to approach the problem from another point of view and attempt to discern any apparent influence exercised by the *existing bodies of water and swamp* upon the climate of the country adjoining. It is a truism that an insignificant lake would exercise no effects whatever, the real question being: "How large an area of evaporating surface would be needed in order to make its presence appreciably felt?"

Basing our calculations upon all the available data, it is estimated that the area permanently swamped under the Okavango, Linyanti, and Zambezi embraces about 1,200 square miles, which in the normal flood season will expand to 4,900 and in exceptional years to 7,200. Taking into account the relative durations of the flood season over each system and making other reasonable allowances, the *mean evaporative area through the year provided by these rivers is estimated at approximately 2,600 square miles for normal years;* abnormal seasons we would naturally ignore. Such a huge tract of open water, reed, grass, timber, and soil, all actively engaged in passing up

165. Let us examine these presumptions more closely. First, even the most casual observation discovers that the "lower air" is not stationary, and that velocities of from 5 to 15 miles per hour are prevalent; only a small proportion of the year is windless. In half a day, therefore, the moisture evaporated may have been carried across the full width of the "evaporating basin;" in a few days' time it may have travelled hundreds of miles, while in a week it might no longer be over the continent even. Again, to presume that the "Upper air" is stationary is wholly contrary to ascertained facts. What guarantee, therefore, have we that such moisture would be precipitated anywhere in the neighbourhood of these lakes or even within the confines of South Africa?

166. For nearly seven months in the year—from April to October—we know that the conditions throughout the great interior region of South Africa are by nature unfavourable for rain, and nothing that we can ever hope to do would be likely to give that territory winter rains. Even Professor Schwarz would scarcely claim that the climate of the interior of South Africa could so radically be altered. These months, then, would remain as before, cold and dry. On the other hand, evaporation does not come to a standstill through that period, though admittedly somewhat less potent; and moisture (to the amount of at least 40 per cent. of the total for the year, as shown by the figures available at Livingstone) is during those months continuously being dissipated into the air, to be carried off to regions unknown and to be lost to the Kalahari, if not to South Africa. Any possible effects from evaporation we therefore see must be cut down by almost *one-half* straightaway, a point overlooked by the Professor.

167. One of the most ingenuous computations in "The Kalahari," it might be remarked, is that propounded to demonstrate this anticipated increase of rainfall and the consequent growth in size and in evaporative capacity of the lakes. Starting out with the assumption that the available flow of the rivers that could be impounded is 2·5 million million cubic feet per annum, the following arguments are given:—

"Table showing Probable Increase of Moisture by Reason of the Evaporation from the Kalahari Lakes.

First year............	2·5 million million cubic feet.
Second year..........	2·5 million million cubic feet engender 2·5 million million cubic feet from transpiration and precipitation of sea-borne clouds; flow of Cunene and Okavango-Chobe Rivers increased 10 per cent. Total for the year: 7·7 million million cubic feet.
Third year............	7·7 million million cubic feet produced 7·7 million million cubic feet extra; flow of rivers, 3. Total: 18·1 million million cubic feet.
Fourth year..........	Total: 36·1 million million cubic feet.
Fifth year............	Total: 75·8 million million cubic feet.
Sixth year............	Total: 155·8 million million cubic feet.

There are too many uncertain factors to be reckoned with to make the calculation of any exactitude, but from the fact that more moisture will remain and circulate the more there are internal sources of supply, this table is more nearly correct than the previous one. What actually will happen is that the whole of the water in the first year will be either evaporated at once from the reservoirs or, if part of the water is short-circuited past the depressions and led on to irrigated land, then the transpiration from the growing crops will give out an equivalent amount of water, the sum total being the same. Suppose the air in the Kalahari at the time has a humidity of 50 per cent., a value which I believe is appropriate, considering the readings of the wet and dry bulb thermometers at Ondongua, then twice the amount of rain will fall that would have done so without the reinforcement, simply from the reprecipitation of the transpired or evaporated moisture. In addition, all the dry thunderstorms that pass over to burst elsewhere will have effect, and the rainfall will be three times the present amount. It has been 9 inches in Ovamboland lately; 27 inches is not too much for this country, and it amounted to 36 inches in 1908–09. Let us take 12 inches for simplicity's sake.

161. In connexion with any scheme of irrigation within the lake, the enormous remoteness of the locality from any large centre, or even from rail, cannot be overlooked, for in this respect it is at a greater disadvantage than the Mababe. Maun is merely a native town having several thousands of inhabitants with a sprinkling of Europeans. Railhead near Gobabis is over 300 miles distant from Ngami, Livingstone is 330 miles away, while Palapye Road is 360 miles therefrom, and on all three routes transport is difficult and costly. Drought and lack of water are the chief troubles, but on the Livingstone route the summer rains hamper progress and the tsetse fly takes its toll of oxen; consequently transport charges are excessive.

The nature of the crops to be grown and their profitable disposal therefore form the problem that requires solution. Whether the planting of cotton, or, as suggested in the case of the Mababe, of rice, could be made a profitable proposition would depend upon the opinions of experts in those branches of agriculture.

162. The merit of Scheme C lies in its aparent cheapness, in view of which it would probably be worth while carrying out further surveys and gaugings to determine the possibilities of irrigation in this region. It might be pointed out that the lake floor is at present waste land, which is only being used intermittently for grazing purposes, that the areas planned to be submerged are almost unoccupied, and that there would be but little interference with the established rights of the small population around Ngami.

XVI.—THE CLIMATIC EXPECTATIONS OF THE SCHEME.

163. One of the main objects of Professor Schwarz' proposals, indeed the *only one of direct concern to the Union,* is the anticipated increase in the rainfall over the surrounding country as the result of the evaporation of the waters impounded in the Kalahari with their subsequent recondensation from the atmosphere. Various critics have, from time to time, expressed their doubts regarding such expectations, and the general attitude in the scientific world has been that the magnitude and consequences of such action have been grossly over-estimated by the Professor.

We shall, therefore, proceed to consider this side of the problem, since the farming community in South Africa, because of this propaganda, have come to have great expectations from the scheme and have hailed it as the solution of one of their greatest handicaps, a normal deficiency in the rainfall.

164. It is, therefore, the more regrettable that Professor Schwarz has nowhere discussed the phenomena in any but the vaguest manner, and we are left merely with a statement that, if the interior depressions were to be refilled, the rainfall would be strengthened and the Union, as well as Bechuanaland, would vastly benefit. A mere assurance from any scientist, no matter his eminence, is hardly enough for the interested inquirer, who desires that the grounds for such an opinion be disclosed, that the physical basis of rainfall be discussed and explained, that figures be quoted to show the probability or possibility of such action, and that other cases of a similar or comparable nature should be cited.

Instead of that, we merely find the allegation unsupported, however, by any figures or rainfall-charts, that without the Central African lakes the region embracing them would be a desert, while only a few elementary meteorological truisms are set down. Nothing is said as to the atmospheric distribution, the directions or intensity of the prevailing winds, the humidity of the air near by and away from these lakes; nothing, indeed, which could be of any assistance towards the arguments that these bodies of water must beneficially be affecting the climate of the adjacent country.

Similarly, the absence of detail of such a kind regarding the Kalahari is one of the most exasperating features of the Professor's writings. Throughout them there would appear to be the implication that the air above such a large water area would remain more or less stationary, that the layer in contact with the surface would thereupon become saturated, and that on ascending it would increase the vapour-content of the atmosphere higher up, and thus facilitate precipitation from the latter when the conditions favouring rainfall are present.

The irrigation of a great flat may consequently become all but impracticable owing to the impossibility of obtaining full command of the land. We are so accustomed to our schemes in the Union with their relatively rapid slopes that the drawbacks introduced by the level character of country of this kind are apt to be lost sight of. In the case of the Ngami depression such inherent difficulties must very definitely be pointed out so that the reasons for having to cut down the irrigable area on the lake floor may be properly appreciated.

157. After these preliminary explanations, two alternatives for irrigating such restricted sections of the lake from Toteñ onwards can be considered—Scheme C involving the Kunyere, and Scheme D the Mokolane River.

It must be pointed out that in either case very little real *storage* would be obtainable above the diversion works, and that these would actually be flood schemes, although differing considerably from those of the Union, in that the flows of the rivers would be more regular in their incidence, the rise and fall much more gradual, and the period of flooding one to be reckoned in weeks instead of in days. As in all flood schemes, the irrigable area would have to be based upon the assumption of a period of three successive minimum years, and not simply upon an average year alone.

158. *Scheme C.*—In its simplest form the Thamalakane would be excluded and the Lake River dammed by an earthen bank at a cost of approximately £10,000. The diversion weir would be built across the Kunyere just above its junction with the Lake River, where it enters the head of the Ngami depression, and the two main canals would take out at a full supply level of about 3,068, such implying a drop of only 6 feet in the 35-mile section from Gwangis close to Maun.

The left-bank canals would be cut in moderately porous soil, but the right would traverse very porous sand in which seepage losses would be high. On various assumptions as to the slope of the ground, the loss of head in the canals, etc., which need not be detailed here, it is considered that the water might be taken to a distance of perhaps as much as 12 or 15 miles from Toteñ, which would give an irrigable area of possibly between 30,000 and 40,000 acres, for which from 180,000 to 240,000 acre-feet of water would be required.

Beyond this point the canals would probably sink beneath the ground surface, so that the water could no longer be led out on to the lands. This compulsory limitation of the area has nevertheless one advantage, namely, the exclusion from cultivation of the very lowest part of the depression, towards which the salts in the soil would naturally gravitate.

The figures given above are admittedly only a first approximation, for, until definite figures are obtained for the gradients of the Kunyere and for the lake floor, the size of the area that could be irrigated, and hence the cost of the canal system, must remain uncertain.

159. It is not at all unlikely that the Kunyere would be competent to furnish the quantity required for the area in question, while by blocking the cross-connexions with the Thamalakane and by dredging the Kunyere channel, a great improvement could doubtless be effected in the discharge of that river. It may nevertheless be necessary to reduce the irrigable area to somewhat below the figures given. The cost of this project can be estimated as follows: Regulator on the Kunyere, £20,000; bank across the Lake River, £10,000; main canal system—two branches, each 15 miles in length, £50,000; improvements along the upper part of the Kunyere, £15,000; total, £95,000, *exclusive of distributaries*, working out at the sum of between £2. 7s. 6d. and £3. 3s. per acre, which is somewhat higher than the similar scheme in the Mababe; including distribution, this figure would have to be raised to perhaps £6.

160. *Scheme D.*—The otherwise unreachable western side of the lake could doubtless be satisfactorily watered from the Mokolane were the channel of that river to be restored, but as to the cost of such a work, the height to which the water could be dammed at the diversion weir, the length of canals, and the size of the irrigable area, it would be idle to speculate in the absence of any surveys. Consequently no figures can be submitted that would not be other than mere guesses. The scheme, however, would have the merit of being quite *independent of C*, and naturally would not be undertaken until the successful operation of the latter had been amply demonstrated.

151. As in Scheme A, the cost would depend very largely upon the diversion works required in the lower part of the Botletle River, and complete estimates cannot, therefore, be given; nevertheless, it might be noted that this project would eliminate any uncertainty as to the cost of restoring the Mokolane channel, although at an increase of £10,000 in the construction of the regulator.

(2) *The Lake itself as an Irrigation Project.*

152. From the way in which the grass and reeds spring up on the floor after heavy rains or floods, it would seem that the soil must have a respectable value agriculturally. The natives grow mealies in the darker soils of the old and normally dry channels and depressions, and also cultivate patches on the lower slopes along the south-eastern shore of the lake, and are said to raise fairly good crops on them. It is accordingly worth inquiring whether irrigation of the lake floor from Toteñ onwards (see paragraph 76) might not be a feasible proposition.

153. The criticisms upon the Mababe, through being an area of internal drainage, would apply here, and with not less force, for one cannot overlook the remarks by Livingstone (in 1849) as to the brackish character of the water when low, nor those of Andersson (in 1853) that the water was bitter and disagreeable. If such were the case when fresh water was able to enter from the north and the surplus to escape into the Botletle, it must be concluded that the situation cannot have improved in the interim, during which the periodical inflow from the east has been wholly evaporated, leaving in the soil any salts thus brought in. Not improbably, the ash formed from the systematic burning of the reeds has been responsible for a good deal of this saline matter in this hollow.

One is therefore led to doubt whether under irrigation these salts would not tend to be brought to the surface; considerable skill would probably be needed in dealing with such an area, necessitating restricted applications and frequent cultivation. Professor Schwarz' warnings on this question are worthy of study ("The Kalahari," pp. 33–36).

Unfortunately, from the observation that the ground is often highly porous, a high consumption of water would seem inevitable, and, with the low rainfall—from 14 to 19 inches annually—and high temperature, it is doubtful whether more than 120 acres could properly be watered from 1 cusec.

154. While the total area of the lake floor is at most about 250 square miles, or 160,000 acres, and while the necessary water therefor, amounting, as will be seen, to about 1,300 cusecs, could doubtless be obtained from the Okavango System, it by no means follows that the whole of that surface could be brought under irrigation for the following reasons.

155. Until levels have been run across the lake, one cannot act on the assumption that its centre is more than only a few feet below the inlet at Toteñ (although such may well be the case), while the fact that the Dautsa Flats are not known to have been submerged within the past thirty years at least, would rather imply that the floor beyond the road at Bodibeñ is rising towards the south-west.

The lake is fully 36 miles long, and it would be necessary to construct two main canals branching out near Toteñ—one on either shore; these would have to be graded at not less than 1 in 10,000, which would require a fall in that distance of not less than 19 feet. Decidedly that would not be possible, for by pushing up the intake level to about 12 feet opposite Haka, both the Thamalakane and Kunyere would become diverted back into the Mogogelo River; it is, of course, assumed that a regulator has been built on either the Botletle or the Kunyere.

156. It is perhaps inadequately realized, as seems to be the case with Professor Schwarz and with those who have advocated irrigation in this flat portion of South Africa, that the rivers are here moving upon extremely flat gradients, and consequently with low velocities, and that their slopes cannot be reduced much more without influencing their speed and discharge very appreciably. Even with a channel a couple of hundred yards wide, a gradient of not less than 1 *foot in 5 miles is an essential* if an adequate flow has to be maintained therein and the growth of the aquatic plants kept in check, and hence it would become necessary to go for miles up the river before it would be possible to turn out the flow by means of a weir. After that, again, come the loss of head in the main canals, probably half a foot a mile, and the still greater drops in the smaller distributaries, ranging from 1 to 5 feet per mile.

(7) This water would be released through the regulator during the months of September–May and allowed to flow down the Botletle River. There being, however, so far as we are able to gather, no large extent of irrigable land until close to Rakops, a channel with a length of fully 120 miles and a breadth of from 100 to 400 yards would have to be kept supplied with water. Since this would doubtless be during the warmest months of the year, the losses therein would be considerable. Even at a conservative estimate, taking a mean width of 220 yards and evaporation and absorption at 8 feet per annum (not too high because of the dry climate, the abundance of reeds, and the numerous hollows and lagoons), the consumption from these causes would, perhaps, be 77,000 acre-feet per annum, or equivalent to 106 cusecs, leaving from 400 to 650 cusecs (300,000 to 476,000 acre-feet per annum) available for irrigation at Rakops, only about three times the designed capacity of the Hartebeestpoort Dam.

(8) A diversion weir would be required to turn out the water from the Botletle, together with the necessary canals and distributaries.

148. Under liberal assumptions the scheme might irrigate from 60,000 to 100,000 acres, but it is clear that with such great losses under storage and en route everything would depend upon the quantity entering the lake. The considerable loss in transferring irrigation water down a river bed in large schemes should be remembered in this connexion. Furthermore, storage in the lake would be at the expense of the Thamalakane–Botletle System, and our measurements make it certain that in normal and bad years the flow of the latter river would, under this scheme, be wholly insufficient to bring water to Mokalamabedi, which is about the limit reached in average seasons at the present day. On the other hand—and this would apply equally to Scheme B—the claims of the large indigenous native population along the Botletle, particularly in its lower reaches, cannot be overlooked, for by thus intercepting its supply, material injury might be done. It is nevertheless true that the amount of the "returned seepage" from any extensive area of irrigated lands is after some years of operation by no means insignificant. Not improbably, in the initial stages at least, the passing down throughout the year of a certain volume of compensation water would be necessary, 200 cusecs being perhaps the minimum required to enable a constant flow to be maintained, failing which the channel would be converted into a chain of waterholes.

149. The cost of the project would depend very largely upon the work required to restore the Mokolane channel, the nature of the diversion works required in the Botletle, and the distance of these headworks from the land to be irrigated. In the entire absence of any data, no estimate can be given beyond the cost of the regulator in the Lake River at Haka, which, as stated above, is reckoned at £30,000, but, undoubtedly, this figure is only a fraction of the total sum that would be required.

150. *Scheme B, excluding the Mokolane River.*—The alternative can be suggested of leaving the dry Mokolane channel untouched and bringing in the Thamalakane instead. This would require:—

(1) *A dam and regulator* across the head of the Botletle River which would divert the flow of the Thamalakane into Lake Ngami, with the Kunyere functioning as well. Such a structure, as shown by measurements at the junction (Fig. 29), would have to be 1,500 feet long and 27 feet in maximum height, with gates to take a flood of 5,000 cusecs, the cost being estimated at £40,000.

(2) Storage could, theoretically, be carried up to 3,073, beyond which the Thamalakane would overflow by means of the Mogogelo River into the Mababe Flats; the swamps around Maun and those as far up as the Gomoti River would be flooded.

(3) The same storage would be obtainable in the lake as under Scheme A, namely, some 1,600,000 acre-feet, for the rocky bar at Haka would naturally determine the minimum level within the reservoir.

(4) It is just possible that more water could be intercepted and stored than under Scheme A, since the flow otherwise passing down the Botletle in the flood season would be held up by the regulator in addition to that provided by the Kunyere, but further gaugings are desirable to settle this point.

As the flood is already very much delayed in this part of the world, it is questionable whether much advantage would accrue in holding up the water in the reservoir for merely an additional short period before releasing it for use down the Botletle; paragraph 129 should be read in this connexion.

The existing Savuti channel follows a very winding course, and is in places very constricted and sometimes full of trees, and in view of the porous nature of the bed, a considerable amount of rectification as well as widening of the channel would become imperative. It is roughly estimated that this improvement would involve the removal of nearly ten million cubic yards of spoil at a cost of about £150,000. In the absence of detailed surveys, the cost of distribution is a matter of conjecture only, but for preliminary purposes such may be assumed at not less than £3 per acre to be irrigated.

140. So far the presence of the Mababe River entering on the south has been ignored, but it is manifest that its waters would have to be controlled or else prevented from flooding the depression during the winter months. The first-named policy involves certain engineering difficulties, though it is just possible that the flow could be made use of to supplement that from the Linyanti. On the other hand, it might be necessary to divert the water at a point some 50 miles up the Kudumane River, so as to make it join the streams flowing southwards into the Thamalakane.

141. It will thus be seen that water could be made available for irrigating an area of perhaps about 200 square miles, or 125,000 acres, forming part of the floor of the Mababe depression, at an approximate cost of £175,000, which works out at the modest figure of about £1. 8s. per acre. Assuming that the cost of distribution would be not much more than £3 per acre and that the diversion of the Kudumane would not add more than another 5s., the total cost per acre would probably not exceed £5, *decidedly lower* than in any scheme of utilizing the Zambezi flow.

It will be observed, too, that provision is only being made for dealing with 200 square miles of land, although the ground available, excluding the area of poor grey sandy soil, probably exceeds 300 square miles. This conservative attitude is considered necessary, since it is not known to what extent the Linyanti could be drawn upon. Should, however, it be found that more water were available, the scheme could, without any serious modification in design, be correspondingly enlarged.

142. In the development of the land the mopane-clad ground would be excluded and the brown or black soil areas alone cultivated, particularly the slightly higher-lying portions occupying the north and west of the depression. The southern and eastern portions would be more difficult to supply with water, while it would be of advantage, furthermore, to exclude the very lowest part of the flats.

This region possesses a rainfall of probably over 20 inches and the run-off from the hard clay flats bordering the grassy area would doubtless be quite considerable. These waters would naturally gravitate towards the lowest part of the depression and the latter might, therefore, become submerged in the wet season. The area is peculiar in being one of "internal drainage," and consequently all the saline matters dissolved in the water or brought up to the surface under irrigation must remain in the hollow and cannot, as in ordinary schemes, be carried out by means of drains and passed away down the rivers. It is fortunate that the Linyanti water is clear and manifestly low in dissolved solids, but, as stated in Section VII, there is reason to believe that the sub-soil in the depression may be carrying salts detrimental to agriculture. The policy would, therefore, be to exclude from cultivation the lowest part of the flats, towards which the seepage and excess irrigation water would gradually drain, taking with them a proportion of the injurious saline compounds. Investigations may, however, show that this expression of opinion is unduly alarming and that but little danger from brackness need be apprehended.

143. The suggestion can be put forward that the lower-lying ground that would be liable to water-logging during the summer rains might be used for the cultivation of rice, for which it would appear to be fitted. The narrow marginal belt of brown loam underlain at a shallow depth by marl would doubtless be suited for lucerne or tobacco. In deciding upon the nature of the crops to be raised on the remainder of the black soil forming the bulk of the area, there would have to be taken into account the great distance from any market—Livingstone being about 180 miles away—and the fact that transport during both wet and dry seasons would be difficult and costly.

144. The area is entirely waste land and is unoccupied, so that there are no existing rights to be interfered with. It is essential to point out, however, that tsetse fly infests the timber bordering the southern extremity of the Mababe, that this pest

exists along the upper and mid-Savuti, and that a few individuals are on occasions to be caught in the neighbourhood of the Gubatsa Hills. This menace to cattle cannot be ignored.

XV.—SCHEMES EMBRACING LAKE NGAMI.

145. Apart from merely refilling the lake and producing thereby an evaporating basin, as proposed by Professor Schwarz—a course which, as will be seen from Section XVI, is *not* being recommended—it would be possible to make more serviceable use of the water in one of several ways, namely, in *Irrigation*. Either (1) a part of the Okavango flood could be diverted into the lake and stored there, to be released later and utilized along the lower reaches of the Botletle many miles distant, or (2) the inflow could be employed towards the cultivation of the actual floor of the depression during the winter season. The Zambezi would be *excluded*.

(1) *The Lake as a Storage Project.*

146. *Scheme A, involving the Mokolane and Kunyere Rivers.*—In order to maintain the lake at its maximum, that is to say, with an area of 250 square miles, it would be necessary to supply sufficient water to make good the losses by absorption and evaporation, equivalent to the depth of not less than *seven feet per annum*—possibly more—representing a continuous inflow at the rate of 1,500 *cubic feet per second*. Now, the combined flow of the Lake and Kunyere Rivers into Ngami was in September, 1925, 1,160 cusecs, and, while the maximum entering during that winter may have been not far from double that amount, such discharge could not have lasted for more than a short period; furthermore, it must not be lost sight of that this was during an *exceptional year*. It is clear, therefore, that the lake could not be filled or kept full by means of these two rivers entering at Toteñ, and it would be necessary, therefore, to restore the Mokolane branch in the west to provide the additional water required.

147. Assuming that such were done and that the lake had to be converted into a *storage basin*, certain essentials have to be pointed out:—

(1) A *dam and regulator* would be necessary to furnish storage above spillway level on the Lake River, founded preferably on the quartzite bar at Haka, which would appear to be the highest point along the bed of this 40-mile channel. It would take the form of a battery of sluice gates 20 feet high, set between concrete piers and having a total length of opening of 100 feet, the flanks being protected by earthen embankments across the valley, which is here approximately 1,200 feet wide. The cost of this regulator is estimated at £30,000.

(2) The height to which full supply could be brought would be dependent upon the gradient of the Kunyere River up to its cross-connexions with the Thamalakane at Gwangis and again behind Maun. Such could not be made higher than 3,073 without pushing back the water into the Thamalakane.

(3) The contents of the lake below the sill-level of the regulator, that is to say, approximately the 3,063-foot contour, would be dead water and, therefore, unavailable for withdrawal down the Botletle River.

(4) The effective storage would be very roughly 160,000 acre-feet per foot of rise above this sill-level, or 1,600,000 acre-feet at its maximum height of 10 feet.

(5) The volume thus stored would, however, be dependent on the combined flows of the Mokolane and the Kunyere, since the presence of the barrage at Haka would obviously exclude any flow from the Thamalakane via the Lake River, the latter having a lower level.

(6) We have no idea as to what amount the Mokolane River would yield, it being obvious that by thus tapping its feeder, the Taoge, the Thamalakane, and Kunyere would actually be deprived of a certain volume of their water, wherefore we are led to doubt whether the maximum quantity obtainable would exceed, say, 2,000 cusecs, except during good seasons. Until gaugings have been taken along those branches, all suggestions must be merely tentative, but it would serve our purpose to assume that an average inflow of between 2,000 and 2,250 cusecs might in this way be obtained. From this figure a loss through evaporation amounting to 1,500 cusecs would need to be deducted, leaving only from 500 to 750 cusecs available for distribution—from 362,000 to 543,000 acre-feet per annum.

could not be appreciably decreased owing to the drop in the power output through such loss in head. Making allowance for such modification, it can be remarked that a charge of between £12 and £15 would probably have to be added to the capital cost of each electrical horse-power produced at Katombora as compared with an installation at the Falls.

136. It is true that at the present moment there are no industrial developments in the immediate neighbourhood making any demand for power, and that consequently, any scheme for weiring up the Zambezi would, under present conditions, have to depend for its construction entirely *on its irrigational merits*. Still the vast strides lately taken by the mining industry at Broken Hill and beyond open out great possibilities in the supply of electrical energy for metallurgical and for power purposes, which cannot be ignored.

XIV.—THE IRRIGATION OF THE MABABE.

137. Though not considered by Professor Schwarz in his Scheme, it would be quite possible to irrigate this large depression from either the Savuti or the Mababe River, or from both, though preferably from the former alone. We have seen that there are falls in the two branches of the Savuti towards their junction at C amounting to 23 feet and 22 feet respectively, with a further drop to the Base Camp, F, within the depression of 48 feet. These grades are sufficient to ensure the required flow from the Linyanti River. In the main channel the growth of reeds has apparently hampered the flow to such an extent, that the amount reaching the point E, nine miles from its intake, was in August, 1925, quite small, while the rapid drop in the level of the water surface towards its end demonstrated the highly absorbent nature of the ground and the great loss from such a cause, for there were no other hindrances to the advance of the river. At the intake of the eastern branch the gradient of the porous bed for the first few miles was, on the other hand, too small to permit of any flow from the swamps.

138. In order to make use of the Savuti, the following would have to be done: (1) Deepening of the intake; (2) rectification and regrading of the winding channel; (3) building headworks to control the inflow; (4) providing a regulator and bank across the channel at a point near the entrance to the Mababe depression; and (5) constructing two main canals taking out above the regulator to run along the western and northern sides of the depression, as well as various distributaries.

In this scheme the Linyanti level would *not be raised*, since the swamps extend for many miles to the north and north-east, and for various reasons it is not recommended that a mole be thrown out into the latter for the purpose of intercepting water that would otherwise be passing down between the reeds towards Kasane. It is considered that possibly up to 1,000 cusecs could be obtained even in the low-water period by merely drawing off from the Linyanti down to about 7 feet below its existing level, for, in addition to the flow in the open channels, there is a vast amount of water stored up among the reeds. The autumn floods would tend to replenish the swamps, while in favourable years the contribution from the Makwegana could also be reckoned on. We are of opinion that, after paying due regard to the large losses that would necessarily have to be incurred in its distribution, it would be possible to obtain sufficient water for the irrigation of a considerable part, though not the whole, of the Mababe, that is to say, of perhaps about 200 square miles of the open country possessing a black or brown soil. It might, however, be necessary to open up one or more channels in the reeds in order to promote a flow towards the intake.

139. The western or main branch, although involving a greater length of canalized channel, is considered as more suited for regulation than the eastern one. A simple type of regulator could be built, consisting of a series of concrete piers supporting steel sluice gates of suitable design to discharge a flow of some 2,000 cubic feet per second under a small head. In the absence of rock foundations the whole structure would have to be founded upon a solid concrete floor with cut-off walls. The cost thereof is estimated at £15,000. In addition a certain amount of banking would be necessary for the flank protection of the regulator and for the closure of any depressions through which water might possibly overflow from the Linyanti during high floods. An allowance of £10,000 would probably be sufficient for this work.

sterling, which would work out at £4 per acre, a figure which, as will be seen from paragraph 116, would have to be practically doubled when interest over the early stages is taken into account. This is for delivering the water only and does not include the costs of distribution. For comparison attention might be drawn to the costs per acre in the minor schemes detailed in Sections XIV and XV.

Irrigational Possibilities.

131. A striking feature is the relatively small volume available at the Botletle intake as compared with the huge quantity to be held up by the Katombora weir. On the other hand, we can ignore the further losses down the Botletle, which may be considered as probably offset by contributions from the Kudum[illegible] and Mogogelo, which would otherwise be lost in the Mababe.

Part of this water could be used in Lake Ngami, as detailed in Section XV under Scheme C, but, since a sufficiency for that purpose could [illegible] obtained at a moderate cost from the Okavango System direct, *it would be a sound policy to employ the whole stream in the neighbourhood of Rakops,* provided that sufficient irrigable land is to be found in that quarter. The remarks under Section XV should be referred to in this connexion, but since the water would *probably be sufficient to irrigate an area of about* 500,000 *acres,* it would be essential to determine whether so large a tract is available there having a soil of suitable character, possessed of grades fitted for the construction of canals, etc. Surveys would be needed to decide these points, to determine the best site for diversion from the Botletle channel, the cost of that structure therein and that of the main feeders to the lands, etc.

132. Until such have been carried out, it is impossible to make any statement as to the economic practicability of such proposed irrigation, and this suggested great scheme of Zambezi diversion will unfortunately therefore have to await the outcome of such surveys. As mentioned earlier, the cost of merely delivering this water in the Makarikari region, reckoning interest as well as capital charges, would be in the neighbourhood of *four millions sterling,* without including the expenditure involved in its distribution. In the absence of data on practically every point of vital importance regarding the latter, estimates of such additional costs cannot be submitted, but from our knowledge of existing irrigation schemes it can hardly be doubted that a couple of millions might be needed for that purpose.

133. As will be seen from a study of Section XVI, the climatic expectations from this scheme are not viewed with any favour, and, *if such a weir be built, it would have to be constructed purely with the object of providing irrigation and possibly power, and not with any idea of increasing the rainfall of the country.*

Power Possibilities.

134. An attractive feature in this scheme is the possibility which it affords of obtaining additional electrical power on a fairly large scale at Katombora. It has already been mentioned that the Victoria Falls Power Company are to-day the holders of a concession valid until 1981, enabling them to obtain up to 250,000 electrical horse-power and granting them exclusive rights within a radius of five miles of the Falls.

So far from adversely affecting the situation downstream, the building of the Katombora weir might be a decided advantage, while it would also permit of power being obtained either without the harnessing of the Falls or else independently of any installation at the latter spot.

At Katombora 18,000 cusecs could be constantly available under a head of about 62 feet (from 3,020 to 3,082), which would represent about 90,000 electrical horse-power. Were arrangements to be made for the turbines to be placed at the foot of the rapids with discharge at about 3,002, this figure could be raised to close on 120,000 electrical horse-power. In a straight line this spot is 31 miles from the Victoria Falls and somwehat less from Livingstone. In the building of the weir all the power required could, of course, be generated electrically at the existing rapids.

135. It ought to be pointed out that, if the intention were merely the obtaining of power to the exclusion of irrigation, the scheme would be modified, in that the gap in the sand ridge occupied by the Savuti would be closed and the Mababe depression excluded, thus reducing the evaporation losses in the basin by roughly one-fourth and rendering a corresponding volume available at Katombora. The height of the weir

Since, however, we are faced with the (at the moment) insuperable obstacle introduced by these particular vested interests, it is impossible for us to ignore them and work out the details for various otherwise feasible alternatives of a decidedly more favourable character, for of every additional thousand cusecs that could be impounded above the figure given, from 300 to 400 would become available in the Thamalakane, the prime cost of diversion remaining practically unchanged. In no small degree, therefore, the feasibility of this scheme would appear to hinge upon the attitude taken up by the Company, and a lot would depend upon its willingness to modify its claim to the Zambezi flow. Under the latter contingency it would then become possible to reconsider the scheme in a much more favourable light, and to obtain additional data thereon.

128. The preceding discussion has shown that at the cost of over *two-fifths of the flow* in the Zambezi—after providing for power at the Falls and for the maintenance of the latter—only about one-tenth can be diverted south-westwards into the Kalahari, and that with fluctuations ranging from a minimum of 400 cusecs to over 6,000 cusecs. With such variations in prospect, it would be rash to design any settled scheme of irrigation based on a flow of *more than 1,000 cusecs without storage*, so that of the one-tenth diverted about three-fourths would not be permanently available, that is to say, assured for irrigation. This flow would join the water from the Okavango, it is true, but as the latter only on rare occasions reaches so far as Rakops on the Botletle, we could only rely on the quantity obtainable from the Zambezi for any irrigation scheme, that is to say the discharge of about 1,000 cusecs, only sufficient to irrigate about 150,000 acres. The cost of such would, therefore, amount to about £13 *per acre* for diversion from the Zambezi alone without reckoning that of distribution, interest, etc.

Diversion with Storage.

129. There is no doubt that by means of suitable regulation a more constant supply could be furnished to the Thamalakane than under a scheme involving merely a free discharge from the basin. Indeed, in the above estimates provision has actually been made for a regulator in the gap in the sand ridge between the Zambezi Basin and that of the Mababe, which would not only prove of advantage during the early stages of infilling, but which would be shut when the Zambezi level dropped below that in the Mababe, as calculations showed would be the case in certain years for a short period until the level in the former was restored.

Owing to the absence of any rock upon which this regulator could be founded, and to the fact that its height would exceed 35 feet, the cost of this structure is a serious item and is estimated at £120,000.

The main regulation would be provided at the critical point on the Thamalakane, preferably quite close to Mogogelo, where an earthen bank would have to be carried north-westwards into the Okavango delta and sluice gates provided to control the outflow from the Mababe at a cost of, perhaps, £100,000, though not improbably much less. In this way some of the flood water of good years could be held up and released for irrigation just when desired, instead of allowing it to escape without control into the Thamalakane. At the same time it should be pointed out that within the Zambesi Basin the losses would increase at a tremendous rate with progressive rise in its level, and that any additional water held up for more than a short period might very largely be lost as the result of this extra absorption and evaporation at full supply.

130. The calculations were not made in great detail for such conditions, but, inasmuch as in the computation shown graphically in Plate IV at *no period* was the inflow of the Zambezi sufficient to cause the Katombora weir to overflow, it follows that the *total volume available annually* at the critical point would probably be slightly less through such storage and regulation, though the monthly quota would be not so subject to fluctuation.

There is no reason to believe, therefore, that an average flow of nearly 4,000 cusecs would be reached, though the monthly minimum rate would be raised and the maximum diminished. Supposing that we can assume that a constant flow of about 3,000 cusecs could be reckoned upon, this would probably be sufficient to irrigate permanently an area of some half-million acres. The cost merely of constructing the works to deliver this quantity of water into the Thamalakane would roughly be just over *two million pounds*

Water Discharged from Basin without Provision of Storage.

122. So far from the problem of the discharge into the Thamalakane being a straightforward and simple one, as might at first sight appear, it is really an extremely complicated one for the following reasons :—

Assuming that the basin has become filled and that water is now passing down over the spillway at the critical point into the Thamalakane, it will be seen that the incoming Zambezi flood would in part raise the level in the Zambezi Basin and in part pass therefrom into the Mababe Basin. The former action would incidentally increase the water area, whereby the evaporation loss would become temporarily greater. In turn the water level in the Mababe would be raised, thereby increasing the discharge into the Thamalakane, an action set off, however, by the losses due to evaporation.

Over quite a portion of the year the inflow would manifestly be insufficient to balance the evaporation, which over the two basins would generally amount to some 12,000,000 acre-feet per annum, or at a mean rate of over 16,000 cusecs; nevertheless, a flow would be maintained over the spillway at the critical point because of the huge area of the basin and its very slow discharge.

123. These intricate fluctuations have been calculated in detail by Mr. Buckland for each month over a period of eighteen years, as is indicated graphically in Plate IV, and a study of this diagram will serve to bring out the variations in the discharge into the Thamalakane from month to month and from year to year, based on certain necessary assumptions, such as the rate of evaporation (5 feet per annum), etc.

In this particular lengthy computation it is assumed that a *constant discharge is being maintained down the Zambezi of* 18,000 *cusecs*, of which 8,000 are intended for power purposes and 10,000 for the maintenance of the Falls.

124. From this it is reckoned that there would become available in the Thamalakane a volume ranging from a maximum of 5·62 to a minimum of 0·49 millions of acre-feet per annum, with a mean of 2·81, which latter would correspond with a flow of almost 4,000 cubic feet per second. As shown on the diagram, the overflow would during bad seasons be disappointingly low, as, for example, in the case of the two successive years of 1915–16, when the figures work out at 0·49 and 0·80 respectively, or 700 and 1,100 cusecs only; during certain critical months the volume actually drops to 400 cusecs.

It might, perhaps, be arranged that some temporary abatement in the quantity of compensation water be permitted, so as to tide over the situation and maintain an average flow in the Thamalakane. On the other hand, during good years the volume to be anticipated would be very much greater.

125. As an alternative, calculations on similar lines have been made, based on the assumption that 8,000 cusecs were passed down throughout the year for power purposes and 20,000 cusecs in addition thereto, though only during the months April to September, under which the Victoria Falls would be displayed in more spectacular fashion, though for half of the year only. Although the mean outflow works out at 2·33 million acre-feet per annum and rises in certain years to over 5, yet it drops during two successive years to the insignificant amount of only 0·15 and 0·24 million respectively, or to only a few hundred of cusecs, scarcely sufficient to keep the Botletle channel filled even.

126. A feature brought out by these computations is the exceedingly slow response of the Thamalakane to the variations of the Zambezi System, due to the immense volume stored in the basins and to other causes. It is, nevertheless, clear that under the first-mentioned proposal a mean discharge amounting to somewhere about 4,000 cusecs could be anticipated at the head of the Botletle *in normal years*, but that during a spell of low rainfall much less than this would be available if the full demands for power purposes were to be provided for.

127. If, on the other hand, the Victoria Falls Power Company were prepared to waive a portion of its rights and be contented with a lesser volume, or, alternatively, if it were to develop a part of its power from a separate installation at Katombora, as discussed below, then the situation would be much improved and more water could be diverted into the Kalahari during dry years.

by evaporation and absorption. Based on the meagre data available, it has been estimated that this period would not be far short of *ten years*, the total capacity of the main basin and the Mababe depression having been taken at 80 million acre-feet. The area of water surface so produced is reckoned at about 1,600 square miles (Plate V, inset), of which the Mababe would contribute 1,190; over much of the latter the water would be over 50 feet in depth.

The Volume of the Compensation Water.

119. In determining the proportion of the Zambezi flow that it would be possible to divert, full cognizance has to be taken of the existing "power rights" at the Victoria Falls, while in addition sentimental and other reasons render it essential that the beauty of the latter should be interfered with as little as possible. Could such limitations be disregarded, a much larger volume could naturally be made available in the Kalahari, but, circumstances being what they are, that region would perforce have to be content with only a fraction of the total Zambezi discharge, the evaporation losses being so considerable.

120. The agreement between the African Concessions Syndicate and the Victoria Falls Power Company gives the latter the full right until 1981 to develop up to 250,000 electrical horse-power. The agreement between the Chartered Company and the African Concessions Syndicate gives the latter the additional right to all above the 250,000 electrical horse-power granted to the Victoria Falls Power Company, subject to the maintenance of the "natural beauty and characteristics" of the Falls, and, furthermore, the permission to store water within a distance of thirty miles from the Falls. As there is no suitable site for this, chiefly owing to the considerable fall in the river and also the general narrowness of the valley, such a concession has no actual value; moreover, it is difficult to see how the Falls could be maintained as specified were even the Victoria Falls Power Company to exercise its unqualified rights.

The maximum steady output of power at the Falls would be dependent upon two factors: (1) the minimum flow of the river, and (2) the height to which the flood will rise in the gorge below the bridge during the early autumn. The control of the Zambezi at Katombora would, by reducing (2), augment the available head from 315 feet to 355 feet approximately, and so actually *increase* the power obtainable under minimum flow. Even with this greater head, somewhere about 8,000 cusecs would be needed for the production of 250,000 electrical horse-power, which is about equal to the lowest recorded discharge of the river. It is true that the lowest gaugings are all in the region of 10,000 cusecs, but the railway gauge has recorded lower stages still, in part, no doubt, because of its situation, wherefore the absolute minimum is somewhat in doubt, though fortunately the period of such very low flow is quite brief, and the discharge during this time is quite small as compared with that during the rest of the year. Nevertheless, it is apparent that were the Victoria Falls Power Company to take *all the power to which it is legally entitled*, the waterfall would be reduced to an absolute trickle in the spring during most years. With control, however, the situation could be distinctly bettered during that critical period of the year.

121. It must be made clear that these conflicting interests, namely, the power rights and the preservation of the Falls, strongly clash with any project for diversion, and consequently render it difficult to formulate any satisfactory scheme under which a reasonable proportion of the volume could be made available in the Kalahari. At the present day the Falls are not be seen at their best during the last few months of the year since the volume is really too small, but, on the other hand, during the flood season in the early autumn the gorge loses much of its impressive character by reason of the clouds of spray. It may be taken that a flow of about 20,000 cusecs would display this wonder of the world to its fullest advantage; for power rights an additional amount of about 8,000 cusecs would have to be reserved, or 28,000 cusecs in all. Now the mean flow of the Zambezi is only 38,200 cusecs, whereas the mean evaporation losses in the storage basin are computed to be some 16,000 cusecs, thus leaving nothing at all for diversion. Obviously the total amount of such compensation water would have to be cut down to some 18,000 or 20,000 cusecs, which is about the bare minimum possible to enable these limiting conditions to be satisfied, though one under which the *Falls would still exist—after satisfying the demands for power—in the same state as under their present low-flow conditions.*

115. The estimate is as follows:—

Foundations	£48,000
Masonry in weir, 580,000 cubic yards at 50s.	1,450,000
Concrete protection to toe of weir, 28,000 cubic yards at 60s.	84,000
Sluice gates and lifting gear	28,000
TOTAL	£1,610,000
Engineering and Administration charges, 12 per cent. (approximately)	193,000
TOTAL	£1,803,000

Added to this is a provision against the cost of removal of the natives from the area to be submerged, for the dismantling and removal of the magisterial stations at Sesheke and Kasane, for compensation to various missionary societies and traders, for the construction of a new wagon route from Katombora to Maun, and for the removal and reconstruction of portion of the Zambezi Sawmills Railway, etc. The cost of these items is not likely to fall short of £40,000.

116. It will thus be seen that the total cost of merely diverting the surplus flow of the Zambezi and Linyanti and delivering it beyond the critical point into the Thamalakane may not be less than £1,843,000. To this total, however, must be added the interest on the capital during the unproductive periods, not only of construction of the dam, but of infilling of the "basin," which in about thirteen years at current rates of interest would *not far from double this amount.* It should further be made clear that in the estimate submitted we have taken up throughout a viewpoint favourable to the scheme, and that the amounts set down for the more or less well-assured items are regarded as being not at all excessive.

The Basin in Operation.

117. In the weir provision is made for passing down to the Falls during the construction period and thereafter a volume of up to 20,000 cubic feet per second, but for reasons to be set forth below (paragraph 121) the estimate on which the working scheme is based allows for a constant discharge down the river of 18,000 cusecs, or nearly double the present mean minimum flow of the Zambezi.

If the weir is built high enough, no flood will go over it, and the balance of the flow, less the evaporation losses, will pass into the Thamalakane, but it is estimated that if the height be taken up to not more than 3,086, only very occasionally could any water go over its crest to pass down to the ocean.

It has already been explained in paragraph 51 that, if the water surface be raised to over 3,072, water would begin to flow in the old flood channels south of Kachikau through the Savuti gap in the Sand Ridge into the Mababe depression. Merely to get the flood water to pass the critical point it is estimated that the normal water level would be about 3,082 in the main basin and about 3,078 in the Mababe, several feet of head being required to cause the necessary movement of the water through the shallow and irregular tree-strewn connexions between Kasinka and the Savuti, and between the Mababe and the Thamalakane Rivers respectively. Obviously there would have to be an appreciable fall in the water surface through these two restricted sections; improvements within the latter could, however, be obtained by means of dredging, while possibly erosion during the period of infilling might enlarge the channel leading into the Mababe.

118. The basin thus formed would be so large that a very considerable period would elapse before the level at which diversion would take place could be attained. While the lines of levelling that have been run along the Zambezi and Linyanti and through the Mababe have made it possible to form a very approximate estimate of the total area to be submerged at diversion level, more detailed surveys are required before a table of capacities could be prepared, based upon which it would alone become possible to determine the period needed for the flood waters of the two rivers to fill these basins up to the levels of 3,082 and 3,078 respectively, due allowance being made for losses

The line adopted crosses the Linyanti at the upper limit of the rapids in a section 430 yards wide, traverses with several bends the undulating strip between the two rivers nearly 3,000 yards wide (which is intersected by one curious narrow channel), extends across the main Zambezi Rapids, which average 800 yards broad, and then takes advantage of the very northern or Mambova channel beyond that, and the gentle ascent situated about a mile to the south of Mambova Village.

Basalt is exposed in the rapids and over considerable lengths of this line, though the rock is often much weathered; indeed, in the central part the formation is in places deeply hidden by brown or black clayey soil, a matter of prime importance when regarded from the viewpoint of foundations. Assuming that the weir is carried to the height of about 3,086 feet, the total length of the wall would be 24,200 feet or $4\frac{1}{2}$ miles; it would have a maximum height of about 60 feet and the wide central section would generally range from 12 to 36 feet in height.

Estimates were taken out for such a structure to be built either in masonry or concrete, but, as they gave much greater quantities than the dam at Katombora, no detailed designs were prepared.

The lesser height of the structure is more than counterbalanced by the greater length, which, by increasing the distance through which the materials have to be conveyed, would add to the cost of construction. It is, again, certain that in places in the central section a large overburden of unsound rock would have to be removed.

On the other hand the divided channel would have been a great convenience during building operations.

The Katombora Site.

113. As shown in Plate III, the Zambezi makes a fine sweep on approaching Katombora, the stretch of smooth water averaging 350 yards in width, and having a wooded basalt slope on the right and a flood plain on the left. Curiously, the waters spill over the rapids in a direction almost at right angles to the general course of the stream, rippling over ledges of basalt forming the main passage 650 yards wide and several gaps beyond made by two large and some small islands, the stream thereafter being broken up by a multitude of islets and rocky points. The length of rapids is one and a third miles and the total drop therein 29 feet. Higher ground borders the river and thereby provides an admirable site for a regulating dam, the most suitable location being that indicated in Plate III, where gentle spurs jut out on either side towards the river, and where such an alignment would place the wall very close to the crest of the rapids. The bed-rock, basalt, is excellently exposed when the river is low, making flattish surfaces, though channelled here and there, and altogether the rock appears to be of quite a satisfactory nature for the foundations, and only a moderate amount of excavation is accordingly anticipated. The wooded islands crossed by the line of section appear to be mere superficial accumulations of sand, bound together by vegetation, that rest on this rock platform. On the flanks the basalts are exposed to a height of over 150 feet above the river, though superficially decomposed as a rule. The advantages of this site over that above Kazangula are the straight alignment across the rapids, the even and more satisfactory foundation, the shorter crest-line, and the lesser distance from Livingstone and from the railway in the Mpanda Valley belonging to the Zambezi Sawmills Company, against which has to be set the greater height.

The Katombora Dam.

114. The type of structure proposed for this site is a masonry overspill weir having its crest-level at 3,086, giving a crest length of 9,600 feet and foundation length of 6,340. On the right a battery of eleven Stoney sluice gates would be introduced, each 10 feet wide and 20 feet high, with sill-level at 3,030, for passing 18,000 cusecs down to the Falls. Owing to the inaccessibility of portions of the channel and to the limited time available, detailed soundings to obtain the depth of the rock foundation were not everywhere possible, but the attached longitudinal section (Plate III) is sufficiently accurate for obtaining a fairly close estimate of the cost of the structure. At its maximum cross-section the weir would possess a height from foundation level of 66 feet, with a base width of 53 feet, crest width of 12 feet; and crest length of 9,600 feet; its contents would represent 580,000 cubic yards of material.

Now, the efficacy of Professor Schwarz' "scheme" is absolutely dependent upon the magnitude of such evaporation, and, therefore, these minor projects cannot be placed in the same category with the larger one, the possible influence of which will be found discussed in Section XVI.

XIII.—THE ZAMBEZI DIVERSION AND STORAGE.

Schwarz' Idea of Diverting the Linyanti.

107. Professor Schwarz has suggested that it might be possible to dam this river at some point in the neighbourhood of Ngoma, some distance above Kabulabula, by means of a simple earthern bank, and thereby throw its waters into the Thamalakane. Our reconnaissance showed that Ngoma was situated on the seasonally flooded plain, and that any scheme of diversion close by was impracticable, but it was discovered that some distance higher up, just above Kanguma, the swamp narrowed to a width of only 2,100 feet. Accordingly, following along a line that from the air appeared to be the highest ground, levels were carried northwards from this point for 5 miles through gently undulating bush country with only a slight general rise in that direction to the maximum of 3,060 feet.

108. It must be realized that, in any diversion scheme from the Linyanti towards the Kalahari, the water must be raised in level sufficient to enable it to pass over the watershed. At the critical point south of the Mababe depression the level at this spot is, as we have seen, 3,076, so that any dam across the Linyanti or Zambezi must be taken up well above that level, to 3,084 at least, to which must be added a further amount of 10 feet for freeboard. This would mean that at Kanguma the bank would have to be 50 feet high at least.

After a distance of 5 miles it would still have to be over 30 feet in height, and, while it is just possible, though somewhat doubtful, that the wooded ground to the north may rise to as much as 3,090 in places, we certainly have in this distance of 25 miles between the Linyanti and the Zambezi the Lilonga depression, as well as certain broad hollows not far from the latter river. The dam would be an enormously long one, and would have to be composed of porous sandy soil.

109. *A simple low bank anywhere near Ngoma as contemplated by Professor Schwarz can therefore be definitely ruled out of consideration.*

110. It might be possible to go much higher up the Linyanti, to the neighbourhood of the Savuti intake, and there divert all the water of the Linyanti southwards, but from our gaugings of this river, and from other considerations, it is doubtful whether its whole flow would suffice even to fill the Mababe depression. The conclusion was, therefore, reached that the only hope of any practical scheme of diversion of a large volume of water south-westwards into the Kalahari was *to utilize the Zambezi itself.*

Diversion of the Zambezi.

111. Though apparently not known by the Professor, we found that this could effectively be done by means of a dam at one of two points, either just above or just below the junction of the Linyanti with the Zambezi, various considerations favouring the lower site at Katombora, though it would be well to give a short account of the upper one for purposes of record.

The Kasane–Mambova Site.

112. The ledges of rock cropping out in the rapids of the two rivers determine the location of such an impounding structure, which, taking advantage of the gently rising ground in their fork, would have to be of very considerable length. The surface is thickly bushed and great difficulty was experienced in carrying the lines of levelling from one side to the other along what appeared to be the most economical profile.

101. *With regret, it has to be announced that the diversion of the Linyanti by itself for use in the Makarikari is not feasible, and it thereby follows that Professor Schwarz' sanguine expectations in regard to this river as well as to the Okavango cannot be attained in practice. Under these circumstances the impounding of part or the whole of the Zambezi flood would become inevitable, if anything on the scale conceived by the Professor had to be presented for serious consideration, since, in order to provide the enormous quantity required for storage, evaporation, and irrigation, only a river of the size of the Zambezi would be of any use.*

102. Most unfortunately it happens that under such a scheme it becomes necessary to raise the level for diversion to a height far above anything expected by Professor Schwarz. Instead of there being a shallow gradient through from Ngoma to the Thamalakane, as he appears to have anticipated, our surveys show that there is actually a surprisingly great rise in the level of the Linyanti from Ngoma to the Savuti intake, an even larger drop into the Mababe, and a considerable rise thereafter to a point a little south of Mogogelo. The latter spot forms the critical point in such a scheme, for the water of the Zambezi would obviously have to be raised to this height before any of it could pass into the Thamalakane. Indeed, it would be necessary to raise the level of diversion several feet *above that of this faint "water-parting"* in order to promote the required discharge. It is for these reasons, therefore, that a low-level weir becomes an impossibility and that diversion has had to be taken up to the 3,084-foot contour.

103. Accordingly, estimates have been taken out for the cost of a storage dam across the Zambezi, which of necessity would impound the Linyanti as well, and which, while passing a certain minimum amount downstream, would enable the remainder to be diverted through the Mababe into the Thamalakane and so towards the Makarikari. Since two lakes several thousands of square miles in total extent would thereby be produced, high losses would be experienced under such a project, as will be realized when it is remarked that this basin is calculated to take about *nine years to fill*. By this means it would, nevertheless, be feasible to deliver water in the Makarikari region sufficient in amount to irrigate a tract some hundreds of square miles in extent, yet undoubtedly falling far short of the huge area so confidently anticipated by Professor Schwarz. The cost of this great scheme would naturally run into millions sterling, but, provided that there is sufficient irrigable land along the lower reaches of the Botletle River, which we are informed is the case, the probable charge per acre would not appear to be excessive, though there are many essential factors concerning which we have no data whatever. One important advantage arising out of this scheme is the possibility of obtaining *electrical energy* from the surplus water passing over the dam, thus obviating interference with the Victoria Falls, or else supplementing the power obtainable from the latter.

104. In addition, some much smaller schemes involving *storage within Lake Ngami*, and alternatively *the direct irrigation of that hollow and also of the Mababe*, by means of the flood waters of the Okavango and Linyanti respectively, have been duly considered and are detailed below. The relative merits and approximate costs of these projects are duly set forth in Sections XIII, XIV, and XV.

105. There would be no object in criticizing from the geographical side, as one might, Professor Schwarz' view that there is a belt running from the Makarikari southwards to the Molopo River within which extensive irrigation could be carried out, nor that there is another similar strip in the west stretching south-eastwards to the Nossob River, since the *total volume of water that could be diverted under any scheme for such a purpose is absolutely inadequate*. He has certainly failed to realize the enormous quantities that would be needed for the irrigation of these extensive areas of ground.

106. It will be observed that only in the case of the Zambezi scheme could any considerable volume of water—which would otherwise pass on to the ocean—be diverted towards the central Kalahari region, there to be evaporated ; in the case of the others we should merely be utilizing waters that would normally soon vanish into the atmosphere near by.

Consequently only in the *first named* could there be brought about any appreciable increase in the amount of moisture constantly being yielded up to the atmosphere.

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97. To reproduce in any degree the conditions prior to the interference with the drainage system would necessitate the dredging of large channels, for example, one following more or less the course of the Boro, thus enabling the Okavango waters to reach the Thamalakane-Botletle System with freedom. As to the feasibility, the cost thereof, and the benefits to the country further down from the irrigational standpoint as against the losses to the natives of the Batawana Reserve, we are not in a position to express any opinions; such would form a problem of future investigation.

98. Arising out of the above hypothesis, which seems to be a reasonable explanation of all the facts, follows the logical conclusion that the ancient Makarikari "Lake" has been deprived of its waters by the claims of the growing Okavango delta. If this be admitted, then one must deduce that, if "Greater Ngami" ever came into being, it did so at the *expense of the Makarikari*, and for the consequences therefore, climatic and other, which, as Professor Schwarz alleges, followed the drying up of the latter, "Greater Ngami" would have to be blamed. It is not intended to pursue this question further, but the reasonings are set down here to show that a totally opposite conclusion to that of the Professor is to be reached by arguments not less plausible than those advanced by him. Put briefly, this means that the flow of the Okavango would have been insufficient in the past to have kept *both the Makarikari and Ngami-Mababe Lakes supplied*, and presumably, therefore, it would not be able *to do so to-day*. Not improbably about the same quantity of water is being evaporated to-day as formerly, though slightly further towards the north-west instead.

XII.—DIVERSION, IRRIGATION, AND POWER POSSIBILITIES.

99. Having thus discussed the geographical and hydrographical features of the several sections of the region, we are now in a position to enter into the consideration of certain possible engineering schemes under which water could be diverted or stored and ultimately made use of in irrigation. On this question the optimism of Professor Schwarz is surprising. While regretting that the Zambezi could not be brought into his scheme for sentimental and other reasons, he nevertheless considers that sufficient water could be obtained from the Okavango and Linyanti (Chobe) to fill the Makarikari; arrived there, this water would be evaporated to fall as rain during the next year, and so on, until in time all the Kalahari rivers would start running, while ultimately it would become possible to irrigate an enormous area in the eastern Kalahari, shown on his map as forming two broad belts stretching from below Rakops down to the Molopo on the Union border.

100. It has, however, been pointed out that only in exceptionally wet years does any of the Okavango water escape by way of the Makwegana spillway to the Linyanti, and we have no special reasons for believing that this amount is particularly great. The remainder of this large river, and *in normal years its entire discharge*, is lost in the Okavango delta and in feeding the Botletle over only a short distance, while the Makarikari has lamentably to go without a share. Short of canalizing the river right through the delta, no other reasonable plan for getting its waters to the Makarikari suggests itself. The Linyanti, on the contrary, has been shown to be a smaller river which loses great volumes in the extensive swamps between the Portuguese border and Kabulabula. We could readily turn much of its flow down the Savuti into the Mababe, but we could not hope thereby to fill the latter and divert any surplus down the Thamalakane, since, before the requisite level could be attained, the water would be spreading out over the Kasinka–Kachikau Flats to return to the Linyanti lower down. Moreover, a little calculation will show that, even supposing a low dam were possible here to prevent such an escape north-eastwards, the evaporation from the Mababe Lake alone, with its surface of no less then 1,190 square miles, would demand an inflow equivalent to at least 6,500 cubic feet per second. One has grave doubts as to whether the Linyanti could provide so great a flow.

On considering a dam across the river at Kanguma, as detailed below, it is found that an enormously long earthern bank would be necessary, which would have to be carried to an impracticable height for the flow to be diverted westwards (paragraph 108).

size through the progressive removal of the sand hemming it in can hardly be doubted, and the probability is all in favour of the stream responsible therefor being the Makwegana-Savuti branch of the Okavango, the waters of which ultimately escaped into the Thamalakane; but since then the Linyanti has possibly "captured" the waters of the Makwegana and so robbed the Savuti of its limited flow. A river such as this could not, of course, excavate well below the levels of the adjacent river systems, and it accordingly becomes necessary to invoke an actual *sinking of the crust of the earth* in this region to explain the abnormal depth as well as position of this hollow. Once this has to be admitted the probable explanation of the Okavango delta is forthcoming, and further investigation on these lines brings out many facts favouring such an hypothesis. The gigantic series of fractures that affected the Tanganyika and Nyasaland regions, leading to the production of these great troughs known comprehensively as the "Great Rift Valley" of Central Africa, could quite possibly have in mild form extended further towards the south-west. The enormous fault-trough of the Loangwa Valley in Northern and that of Wankie in Southern Rhodesia have probably to be connected with the initial efforts of these tremendous earth movements, and it is not unlikely that a repetition of sinking in such or in adjacent belts of country took place in geologically recent times.

95. The great but very shallow hollow made by the drainage systems of this particular region trends most suggestively in a north-easterly direction, parallel to the important lines of trough-faulting in Rhodesia. It is instructive to find the solid formations exposed on the opposed margins of this "depression," namely, at the Ngambwe and Mpandwe Falls on the Zambezi and Popa Falls on the Okavango, and again from Mambova to Kachikau and along the south-eastern shore of Ngami. In addition the "surface quartzites" overlying the basalts actually dip beneath the flood plain at Kätima Molilo on the one side and in the stretch between Kasane and Simuantha's on the other.

But see Rogers S. Afric. Geo. (1936) p. 73

Furthermore, a couple of miles to the south-east of Kanguma outcrops were discovered in the "sand veld," indicating, so far as could be judged, an actual faulting of these geologically recent quartzites along a line striking north-eastwards with downthrow on the Linyanti side. Another small fact is the lower level of the sand ridge forming the western rim of the Mababe as compared with that of the terrace to the east and north. All these suggest an actual sagging of the crust over an area fully 100 miles broad at the most and with a length of at least 300, though apparently much greater, bounded partly by bendings and partly by fractures; the depth of the sinking would probably vary from point to point, just as is so conspicuous a feature in the Rift Valley zone. Within this considerable area of presumed subsidence and warping, the original red surface sand would naturally have been worked over and over by the rivers, and its bright colour removed through wear and bleaching, wherefore the absence of red coloration from the soils within the depressions.

96. Granting a movement of this kind, it can then be deduced that prior thereto the big rivers flowed across the plain of Kalahari sand, each in a well-defined single channel, the Okavango straight across to the Botletle and thence through the Makarikari to the Limpopo by way of the Macloutsie River, the Zambezi straight across to Mambova, and the Linyanti perhaps following rather closely its present course. The "delta" not having yet come into existence, the Makarikari could well have been an immense lake, as is so generally assumed. With sinking of the crust athwart this drainage system, the flow of the rivers would have been intercepted and the Makarikari *deprived of its supply*. Each of the three rivers would then have started to develop a delta where it entered this shallow depression; branches would have been formed, to alter their positions as sand was brought down from Angola and Barotseland, and spread out over the low ground, just as happens in present-day deltas. On the further side of the depression, where the supply of silt would have been less abundant, bodies of open water would have remained down to a late period, whence the Mababe and Ngami hollows, these having so far escaped being completely silted up, perhaps mainly because they lay furthest from the "axis" of the delta which the Ngoga River appears to follow. The rivers to-day appear to be doing their best to fill the hollow and get back to single blessedness; the Zambezi has been the most successful, the Linyanti is yet encased in swamps, but the Okavango is still wasting its waters in a network of shallow channels, and has but little flow left where these unite to form the Botletle.

It might be remarked that there are differences of opinion as to the "outlet" to this depression, which could only be settled by actual levelling, though it is worth recording that, according to Colonel Daniel, the late Chief Khama stated that the waters formerly used to escape at the south-eastern corner of the Makarikari into the valley of the Macloutsie and so into the Limpopo.

XI.—"GREATER NGAMI."

91. A few remarks on this subject may not be out of place in view of the importance attached by Professor Schwarz to the alleged immensely greater size during the past of the lake system of this region.

The deposits laid down in lakes being very different to those formed by rivers, it should be possible by a study of the formations exposed within the basins of the Okavango and Zambezi to obtain an idea of the approximate limits of such former bodies of water. There ought, for example, to be traces of beaches or shore lines somewhere and, perhaps, fossiliferous deposits as are to be found along the margin of the lakes of Central Africa. Save for the manifestly lacustrine marls of the Mababe, there are no evidences of widespread lake deposits, the country being covered by sands—the reddish or greyish "Kalahari Sand" on the higher ground (of aeolian origin for the most part), and the fine grey-white river-distributed sands of the lower-lying regions, bound together in depth by the addition of calcareous matter to make white or yellowish calcareous sandstones of different degrees of hardness. Fresh-water shells are occasionally to be found in the soil or soft sandstone, it is true, but, inasmuch as they belong to species still living in the rivers, their presence is no decisive indication of lacustrine conditions. The entire lower-lying and well-timbered region between the Zambezi and the Okavango shows in the clearest manner that its surface has been moulded by running water, as can well be studied in the area west of Kasinka or in the belt several miles in breadth bordering the south-eastern side of the Thamalakane (and adjoining the terrace of Kalahari sand), within which last area altitudes of as much as 25 feet above the present river have been measured.

92. The existence of many large trees—mopane, baobab, camel thorn, etc.—speak eloquently of the great age of this "delta landscape." Whatever may have been the state of affairs quite long ago—such as only borings could decide—there is no decisive evidence that any time within the past few centuries the region concerned was other than a series of sandy river-flats just like those of to-day, excepting that the Ngami and Mababe may then have been permanent lakes. Lyons has satisfactorily disposed of similar arguments in respect to a suggested lacustrine origin for the great Sadd Region of the Upper Nile.

So far as this problem is concerned, the idea of a "Greater Ngami" has nothing very concrete to support it, the phenomena finding their explanation in a more simple and reasonable manner. The arrangement of the drainages is, however, most peculiar, and, since the origin of the remarkable depression of the Mababe is intimately connected therewith, a few remarks thereon would not be superfluous even at the risk of some speculation.

Origin of the Okavangó-Mababe-Zambezi Depression.

93. The surprising thing about the Mababe is the fact that, with the exception of its north-eastern side, most of its floor lies at a *lower level* than the Okavango and Linyanti Systems, part of it lower even than the Katombora Rapids. The drop down into it from Mogogelo is about 60 feet and from the intake of the Savuti almost 80 feet. It is, moreover, hemmed in on the west as well as north-east and south-east by the terrace of Kalahari Sand.

94. Geological evidence is pretty conclusive that this widespread deposit of sand has a considerable age, and that the various rivers bordering and occasionally traversing the Kalahari have gradually been deepening and widening their channels in this reddish medium-grained sand, quite soft at the surface, but becoming compacted into sandstone or even into hard quartzite in depth. In places the underlying solid formations—basalt or porphyry—have been exposed as the result of such long-continued erosion. That the Mababe hollow must gradually have become enlarged to its present

Lake Kumadau, which he described as only a small lake 3 to 4 miles broad and 12 long He talks of the arid salt plains, and speaks feelingly, as he well had reason to do, of the parched nature of the country in February, 1853, due to the delay of the rainy season.

87. Taking all these statements into consideration, we are, therefore, led to doubt whether the country has changed so radically as Professor Schwarz would apparently want to make out.

X.—THE BOTLETLE RIVER.

88. This artery through the heart of the north-eastern Kalahari, about 160 mile in length, is customarily taken to begin at the junction of the Thamalakane with the Lake River (Fig. 29). It flows generally eastwards for a distance of about 90 miles with a couple of wide bends, in the first of which Mokalamabedi is situated, but at Kwaraga, as shown on Professor Schwarz' map, it turns abruptly southwards to Rakops, a stretch of nearly 40 miles. Throughout this upper section of its course the Botletle is, according to Passarge, our principal authority, from 100 to 500 yards in breadth, well sunk beneath the level of the sandy Kalahari Plain and in places bounded by steep banks of white limestone (like that pictured in Fig. 26) up to as much as 60 feet in height—though generally attaining to only half that value—and with occasional bars of surface quartzite across the floor of its channel. The Botletle could not be embraced in the party's programme, and no remarks can, therefore, be made regarding its character from the engineering aspect, but in connexion with any irrigation scheme there would doubtless be found one or more spots, where the channel narrows and the hard rock closes in, suitable for building the necessary regulating or diversion works.

Some 8 miles above Rakops the high ground retreats, the river enters the great flat of the Makarikari, and with low wooded banks, winds its way towards Mopepi through an immense grass-clad plain dotted with thorn-trees growing in a humus and calcareous soil. The plain is bounded by abruptly rising ground on the west, south-west, and south, but its limits on the north-east are not known with certainty, though Passarge, following Baines' account, shows it as sweeping far in that direction; the eastern margin is ill-defined, but lies approximately 50 miles to the west of Francistown. Within this huge and relatively faint depression is set the hollow called "Kumadow" by Livingstone, with the great bare saline pans of the Makarikari to the east and north-east of Mopepi—an uninviting region. It is highly doubtful whether, as shown on Professor Schwarz' maps, any important channel takes out from this depression in a southerly or south-westerly direction connecting with either the Molopo or Nossob, upon the presence of which he appears to set great store, but in the absence of positive evidence thereon this point will not be stressed, since, as will be indicated in Section XIII, the volume of water that could be diverted down to Rakops would be disappointingly small.

89. From various accounts it would appear that from Rakops downwards, but more particularly on the left side of the river, there are very considerable areas of dark soil that could be irrigated. Surveys would, however, be needed to confirm this assumption and to investigate other points vital to any scheme, chief of which would be the delimitation of the areas occupied by the salt pans of this region, the character of the soil, and its liability to "brack."

Such being the case, we are unable to make any pronouncement upon the possibilities of this part of the Kalahari, though, from the scattered accounts given by various travellers, there would appear to be a considerable tract which, perhaps, could be brought under water, possibly large enough to take all the flow that could be obtained from the Zambezi.

90. Opinion is general that in normal years the Botletle does not run much further than Makalamabedi. Only now and again, as, for example, in 1912–14, does the water reach Rakops, while only in exceptional seasons do the Makarikari salt pans receive any flood from this river, as happened in 1899 and 1925. On the north-east there enters the Nata River, which, originating on the rising margin of the Matabeleland plateau, often brings much water into these depressions during the summer.

dried out, so that only a small amount was discharged by the Kunyere that season. In 1925, the swamps in the north were still fairly wet when the Okavango came down, and not only the Kunyere, but also the Lake River flowed strongly, the waters in Ngami at the end of August reaching the Bodibeñ–Mochabeñ Road. In September that year the party went down by boat and advanced into the lake for a distance of eight miles from Toteñ, where the waters were found spreading out to the south-west so far as the eye could see (Figs. 27 and 28), while, as already remarked, at the end of January, 1926, there was still an inflow, an event unprecedented in recent years.

The Cause of the Drying Up.

84. Reviewing the situation, one cannot arrive at any other conclusion but that the prime cause must have been the cutting off of that highly important feeder from the north, the Mokolane River. From information given by various persons acquainted with that branch, it would appear that the flow therein is to-day prevented by patches of sand, according to one account washed down into the channel, according to another tramped down by the movements of cattle. With the course thus blocked it is likely that the Taoge to the north is, to-day, much shallower, due to the growth of reeds, the accumulating of silt between the roots of the latter, and other causes, as would naturally be expected. Attention should also be directed to the story relating how some forty years ago the Chief Moremi intentionally and in self protection dammed the flow of the Mokolane in order to deprive the hostile natives occupying the southern shore of Lake Ngami of their water supply. Passarge, again, states that the natives have ascribed this stoppage to the blocking of shallow channels by papyrus rafts, abandoned by the natives, descending the Taoge, the possibility of which is admitted by Stigand.

Without wishing to connect the two cases, some reference might be made to the extraordinarily rapid growth of a tree known as the "Gomoti" in certain of the rivers, leading to the rapid blocking of the channel with clumps of a dense vegetation. A patch of it is restricting the Thamalakane a few miles above the Botletle junction, while higher up on the Gomoti River the channel has been blocked up for miles by these curious trees.

85. Various persons have informed us that it would be possible to clear the Mokolane channel without much difficulty, but, until actual surveys have been carried out, no definite pronouncement can be made on this point, nor as to the approximate cost of the work, though from experience of the similar abandoned channel of the Savuti it is not improbable that that figure would be quite a moderate one.

It is most suggestive that on the several recorded occasions when Ngami became filled, its waters should in every case have reached to about the Bodibeñ–Mochabeñ Road; the same condition we have seen can be presumed to have occurred in 1853. Apparently, then, this limit must be somewhere not far from its normal maximum and hence approximately the same as in Livingstone's time, for there is no historic record of the Dautsa Flats having ever been covered. Given an exceptionally good year, or more properly two particularly good years in succession, we see that the lake would fill sufficiently to bring the waters in the Lake River to a standstill at the close of the flood season—the Botletle being the only natural outlet from the lake—and there seems no reason to doubt that such will continue to be the case in the near future.

When this aspect is carefully considered, the doubt is at once raised as to the necessity for invoking a decrease of rainfall to explain the phenomena recorded, when a simpler and more reasonable and less revolutionary interpretation is at hand, quite in harmony with the facts. The reader of Professor Schwarz' works will doubtless be left with the impression that in Livingstone's time the river systems of the Kalahari were amply supplied with water, and that in the succeeding three-quarters of a century this region has practically dried up. A more careful study of the writings of these early explorers will serve, however, to modify this impression. Except for the fact that the Taoge no longer flows into Lake Ngami and that the latter therefore can only occasionally get filled through the medium of the Thamalakane, those early descriptions could to-day be applied almost *in toto*. Livingstone mentions the shallow character of the lake (p. 66), more particularly in the months preceding the annual influx, when it was with difficulty that cattle could approach the water because of the boggy, reedy banks. On the Makarikari region he comments in 1849 that only when the supply to the Zouga (the Botletle) was more than usually abundant did the water flow beyond

77. The chemical analyses (Appendix III) show the upper loamy soil (No. 9) as being surprisingly high in potash, clearly due to the ash present, with adequate lime, still rather low in phosphoric acid, though high in organic matter, but the sub-soil (No. 10) is less well supplied with plant foods and is extremely low in phosphoric acid. As soils go in this part of southern Africa, it is an example well above the average.

Passarge reports that boreholes were put down in this end of the lake floor and that the depth to rock was anything up to 60 feet, though generally from 10 to 20, mainly calcareous sands or sandy limestones with small fragments of diabase. He gives (p. 753) an analysis of the lake mud, which shows 46·[illegible] per cent. of silica, 14·92 per cent. of alumina, 5·69 per cent. of ferric oxide, 3·83 per cent. of lime, 13·01 per cent. of carbonic acid, and 12·92 per cent. of moisture and organic matter, the proportion of the latter being high. In the neighbourhood of the wells at Mochabeñ, Passarge records beneath the sand a layer of sandy marls impregnated with salts, though occupying only a limited area. Saline incrustations were also observed by him along the southern side of the lake.

Drainages.

78. Coming down from the north, the Taoge branch of the Okavango splits at Tsau, and the two channels continue southwards—the Mokolane to the west and the Maputle to the east—uniting just before reaching the northern side of Ngami, close to Mochabeñ. Up to the seventies the Mokolane (referred to as the Teoughe, Teouge, or Teoge) flowed into the lake, a river apparently about as large as the Thamalakane is to-day, nowhere, according to Andersson, exceeding 40 yards in width in 1853, very winding in its course, but deep in the flood season, hardly anywhere less than 3 feet deep, but with a bar where it reached the lake—statements generally confirmed by Chapman. According to Stigand, it began to dry up about 1883, and ceased to flow seasonally after 1887. In 1910, the Mokolane only reached the lone palms at Makukun, while in 1925 it only extended a short distance beyond that spot, 17 miles short of Ngami. So far as can be gathered, the Maputle branch has not functioned for as many years.

79. At the eastern end of the depression enter the combined Kunyere and the Lake or Ngami River, the former fed from the Okavango in the north and the latter contributing the surplus flow from the Thamalakane-Botletle system in the north-east. In normal years the Kunyere discharges its waters into Ngami, and in September, 1925, was damming back the Lake River for nearly a mile to the north-east.

According to Stigand, the presence of a bar close to Toteñ raised the level of the Kunyere on occasions sufficiently to enable its waters to pass along the Lake River into the Botletle, though such would not at first sight appear to be probable. It is striking, however, to find both Livingstone in 1849 and Andersson in 1853 commenting on the lack of any perceptible movement in the waters of the lake River near Toteñ, which would indicate that the height within the lake itself was then sufficient to pond back the flows of the Kunyere and of the Thamalakane.

When measured in September, 1925, the Kunyere was discharging 610 cubic feet per second, its maximum flow for that season being close on 800 cusecs, though the high-flood mark was not as sharply defined as one could desire.

Ordinarily, in the winter flood season, the water from the Kunyere makes its way past Toteñ, enters the depression in a defined channel about 60 yards wide, and begins to spread out over the lake floor a few miles below that place, to saturate the surface and to be evaporated in the spring.

80. The bulk of the Thamalakane flood passes down the Botletle, and it is only *in exceptional seasons* that the level at the junction is raised so much that some of the water is forced to flow along the Lake River into Ngami; there is nothing in the descriptions of the pioneers to show that there has been any appreciable change in this respect. The Lake River during recent years has generally not flowed south-westwards beyond the quartzite ledges at Haka, about half-way to the lake, and even up to that point it commonly has consisted of a series of large lagoons separated by dry stretches. The level of this particular reef is estimated to be about 3,063, based on the known gradient of the Thamalakane after making certain reasonable assumptions. Since 1910, the Lake River had not flowed into the lake until 1925, its discharge in September that year being gauged at 550 cubic feet per second, with its maximum for the season somewhere in the neighbourhood of 750.

influence of vegetation, it will have to be conceded that the actual losses annually through the progressive wetting, submerging, and drying out of the great delta cannot be small, and that the figure of eight feet (of river water) used below is probably by no means too high.

74. We may assume, therefore, on this conservative basis that the *mean average loss in the delta* could be somewhere between 16,000 and 21,000 cusecs, that is to say, equivalent to approximately half the flow of the Zambezi; the estimate given by Professor Schwarz for the flow of the Okavango is admittedly only a very rough one, being based on various assumptions, and is obviously too high. Should future measurements show that the Okavango possesses a greater flow than we have assumed, the losses in the delta through these various causes would be even larger than those suggested.

Although no detailed study of the Okavango system has been made by the party, the above discussion has been introduced in order to emphasize the important points about the system, namely, that the bulk of the considerable flow is, to-day, evaporated in the area proposed as an "evaporating basin" by Professor Schwarz, and that the amount of the evaporation so taking place under natural conditions is tremendous. Its possible effect upon the climate and rainfall will be considered in Section XVI.

IX.—LAKE NGAMI.

Physical Features.

75. This flat hollow, trending north-east to south-west, covers an area given by Passarge as 240 square miles, and estimated from Stigand's map at 250, the perimeter being nearly 90 miles in length. Its south-eastern margin is rather even, the north-western more wavy; the eastern end is somewhat pointed, the western bluntly curved.

Its borders are generally defined by ground sloping upwards to a height of between 30 and 50 feet above its margin. Along the south this rise makes a well-timbered belt from 1 to 2 miles wide, in which outcrops of various hard formations appear from beneath a covering of light drab soil, embracing what is called by Passarge the "younger and older alluvium," beyond which stretches the terrace of scrub-clad Kalahari sand. On the north, the flat sandy margin is bare and treeless for a breadth of from half to a mile wide, after which an abundance of timber is found, the soil being a deep porous grey sand. On the north-east, Stigand reports an old marginal terrace made of this sand, while in the west, according to Passarge, a similar feature is formed by the limestone of the Matanya area, which occurs also to the west of Mochabeñ (Maschabing).

From all accounts the limits set to the lake are fairly well defined, by which it should be understood that its area would not become increased very appreciably beyond the figures given above were the maximum depth of water as recorded by various travellers to be somewhat exceeded. The problem of the origin of this feature and the possible existence of an ancient "Greater Ngami," as postulated by Professor Schwarz, will be reviewed later in Section XI.

Soils.

76. While the "shores" are formed by porous, medium-grained greyish soils more calcareous on the south and more siliceous on the north, the floor is occupied by a loamy or even a clayey soil, hard and often powdery in the dry season, but dark and tenacious when wet. Flooding brings about an extraordinarily rapid growth of vegetation, which on the drying up of the lake leads to great areas of dead reeds. All authorities agree in their statements that over the floor, away from the margins, there is a good depth of loamy or clayey soil full of ash from the periodic burning out of the reeds. Indeed, there is so much vegetable matter in the soil that once the latter takes fire it is said to smoulder for months to depths of several feet below the surface, leaving a porous ashy mass over which it may be dangerous to walk. In the neighbourhood of Toteñ, the pits which we dug showed a few inches of loamy soil, then anything up to eighteen inches of laminated greyish material extremely light in weight and full of roots, stem-casts, and ash, resting upon a drab clayey sand.

The annual losses of water in these swamps must be enormous, but must vary a great deal from year to year. Thus the high-flood level at Andara in 1924 was higher even than in 1925, yet the flood at Maun was only an average one. This was because 1923 was a very dry year; but in 1925, since the swamps had been thoroughly soaked during the previous season, the flood-level at Maun surpassed all previous records.

Late in September the road along the Botletle was in places still submerged, while at the beginning of October many of the mealie lands along it and the Thamalakane and Lake Rivers were still under water, and the natives were engaged in preparing portions of the sandy slopes for cultivation. Even at the end of January, 1926, the river at Maun had not fallen to normal, and in April was rising again.

71. In the absence of precise gaugings the volume of the Okavango at Andara can only be guessed at. Professor Schwarz has reckoned the mean annual discharge at that point at 1·4 million million cubic feet, which would be at *the mean rate of 44,000 cubic feet per second, and the bulk of this must be lost in the swamps.* This figure may provisionally be taken as a basis on which to work, though probably far too high.

In 1925, an exceptional year, the maximum rate of flow of the combined Botletle, Lake, and Kunyere Rivers could not have exceeded 4,000 cusecs as indicated by our gaugings; such would apply only to a short period and would diminish to a thousand or so at the end of the year; we may assume, therefore, an *average* of no more than 2,000 cusecs throughout the year at Maun. The flow of the Makwegana is unknown, but for our purpose it would perhaps suffice to assume a similar average rate of 2,000 cusecs, although only in abnormal years would this spillway function. By subtraction we discover therefore on the above basis that the *mean rate of loss* in the Okavango Delta would be equivalent to the amazing figure of somewhere *about* 40,000 *cusecs!* This is probably too high, though the following rough calculation will show that the loss must be at least nearly half that amount.

72. Measuring on Stigand's maps, the areas periodically submerged, exclusive of the lower Makwegana, the Mababe, Ngami, and those sections not known to have been flooded in recent years, we obtain the figure of 3,875 square miles for an average year and 5,335 square miles for an abnormal one, the region permanently inundated being 750 square miles. The *mean size of the area* flooded during the year could hence be taken to range between about 2,300 and 3,000 square miles. Admittedly, those areas would include innumerable islets, but, since the latter are closely wooded, the margins of the swamps, and particularly the shallow creeks, are crowded with reeds or papyrus, and the lagoons are thickly sown with the broad leaves of handsome water lilies, the losses due to transpiration by all this vegetation must undoubtedly be great. Professor Schwarz, indeed, has given a table ("The Kalahari," p. 30) of the transpiration losses of various plants, which serves to bring out the importance of such an action, that would naturally be greater in this warmer and drier climate than in Europe. It is noteworthy that an astonishingly close parallel to this remarkable country is to be found in the vast "Sadd" or "Sudd" region of the Sudan, which is responsible for such an appreciable reduction in the flow of the White Nile, and the accounts thereof by Willcocks ("The Nile Projects," 1919), Lyons ("The Physiography of the River Nile and its Basin," 1906), and others make most instructive reading. Although the annual rainfall over those swamps is fully 30 inches, which is sufficient wholly to set off the loss by evaporation alone over the wet season, the mean annual loss from that cause after making allowance therefor is, nevertheless, estimated by Lyons as about 80 inches and by Keeling at 72 inches.

73. Applying the lower figure to our case, the Okavango Delta could be reckoned to have *mean losses* equivalent at the least to from 12,100 cusecs in normal years up to 16,000 in abnormal ones, due to the active evaporation from the *free water surface alone.* Now it is imperative not to overlook the fact that when the land gets flooded the porous grey sandy soil has first of all to absorb a considerable amount of water, which after the floods have abated is soon transpired and lost to the atmosphere. The magnitude of this action we are unable to gauge precisely, but it must certainly be equivalent to at least a couple of feet of water and not improbably may be much more. We have observed that in the swamp area the invading water passes freely along the burrows of rodents to ooze out and saturate the ground far in advance of the lagoon-edge, and the effect of capillarity and transpiration must hence be considerable around the margins of the numerous creeks and islets. When to this must be added the

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VIII.—THE OKAVANGO SYSTEM.

66. The Okavango is undoubtedly the most remarkable river in South Africa. Entering mandated territory just above Andara (Libebe's) in one strong stream, which is said to be, during the winter season, 650 yards broad and 16 feet deep, it passes down over the Popa Falls made by reefs of ancient quartzites, and shortly afterwards begins to overflow its banks and spread out within a well-defined valley, which soon acquires and then maintains a width of nearly 7 miles, so far as the "head" of the so-called "*delta*," 90 miles below Andara. By this time the channel has broken up into a number of widely diverging branches, which wander peacefully through vast areas of swamp and patches of forest, a picturesque country teeming with game and only sparsely inhabited. The chief branches, which are perennial, are (1) the Taoge, which hugs the sand ridge of the western Kalahari for considerable distances and courses southwards to Tsau, but formerly discharged into Lake Ngami; (2) the Kwapa (Siroe) and Boro, which pass on either side of Maun; (3) the Ngoga with its peculiar bifurcation into the Gomoti and the Mogogelo, a feature of more than usual interest; (4) the Mochaba or Kudumane flowing in an easterly direction: and (5) the Makwegana or Selinda connecting with the Linyanti.

67. In extraordinary fashion all these, except the last named, reunite along a single curving front made by the Lake-Thamalakane-Mogogelo drainage, forming a nearly perfect arc trending north-eastwards with a length of 140 miles. Where the Mogogelo and the Gomoti meet the arc, the latter is standing at *its greatest height*, and curving away in opposite directions these rivers drain off respectively into the depressions of the Mababe to the north-east and the Ngami to the south-west; the surplus is removed by the Botletle taking out almost at right angles. The origin of this "delta region" will be considered in Section XI.

Levels.

68. Levelling has only been done along the delta "fringe," which, as stated, proves the highest point of its water surface to be situated between the Mogogelo and Gomoti Rivers, where the channel is quite shallow (at about 3,076 feet in October, 1925); this is the *Critical Point* in connexion with the Zambezi project. It naturally follows from the existence of the Makwegana connexion that the head of the delta must exceed 3,103 feet (Section V). Various references to the appreciable currents in the more important channels make it probable that their intake could not stand at less than 3,110 feet. On the other hand, the lowest point in the Mababe is only 3,020, while the Ngami at Toteñ will probably not be more than about 3,061 feet.

Hydrography.

69. At Andara the river, which has a drainage area of approximately 70,000 square miles and an "effective catchment" of about 48,000 square miles, and hence less than that of the Zambezi, usually commences to rise about January, and attains its maximum at the end of March or beginning of April, but as the water passes down it has to spread out, saturate and fill the huge flat and swampy area made by the delta, and consequently it so happens that the rise of the Thamalakane and Mogogelo is normally delayed for *several months*, and this despite the local summer rainfall, which must amount to a considerable part of the annual precipitation of from 12 to 20 inches. In the south, therefore, the waters do not start rising until about July and do not recede until late in September or even early in October, by which time the early rains are just about due in Angola.

Losses in the Delta.

70. Stigand, to whom we owe much for his laborious geographical and hydrographical investigations in this region, has separately distinguished on his maps the areas that become submerged under normal and abnormal floods. Owing to the extreme flatness of the ground, the irregularities in size and length of the various reed-margined channels, and the great absorption by the sand, the waters in the cross-connexions move slowly first in one direction and then in another as the depressions gradually fill and then dry up. Slow changes also occur in the growth of swamp vegetation, leading to the permanent restriction or even a blocking of a channel, as, for example, along the Gomoti branch.

markedly deficient in plant food, but the grey mopane soil (No. 1) is much better, the potash and lime being fairly high. The dark soils from the open flats (Nos. 3–7) are tolerably well supplied with potash, lime, and, in one instance, nitrogen, but their phosphoric-oxide content is surprisingly low, which is decidedly unfortunate.

61. The area occupied by the dark "turf" soils is probably more than 300 square miles in extent, but lack of time prevented its western boundary from being explored. The strip occupied by brown "transition soil" is narrow, and the total extent of the latter probably small. The remainder, amounting to fully 600 square miles, is formed by greyish sand or dark mopane soil. According to information given us, the latter is useless for agriculture, but whether such be actually the case or not, there can be no doubt that the mature mopane has managed to oust all rival vegetation, and the bare ground between the stems only rarely carries any useful growth of grass.

62. The marls beneath the black soil have been sectioned beneath grey sands in an old well on the road to Maun (now fallen in), and range from a porous cindery material to well-laminated hard white clays and marls, in which are occasional bands rich in gypsum. Fresh-water shells can occasionally be found in the spoil thrown out from burrows and help to show that these deposits are of lacustrine origin.

The water at this well, it might be noted, was salt, and the same was the case in a shallow pit sunk in the Savuti bed at the road drift near the Gubatsa Hills on the north-west, observations which raise the vital question as to the suitability of the Mababe as an agricultural proposition.

63. That a lake formerly extended over this flat receives support from the occurrence, at the base of certain of the porphyry hills within it, of boulders of that rock, the smaller of which show marked rounding, a character such as might have been developed in beach material had these kopjes been forming rocky islands within the lake, while the solid rock near by sometimes exhibits smoothing and polishing of a kind different to that resulting from sand-blast. Such boulders can, for instance, be seen in the northernmost part of the Gubatsa Hills at an approximate level of 3,046 feet.

64. The remoteness of this period is shown by the depth of grey sand that overlies the marls in the well referred to—representing material brought down by the rains on to the old lake-floor from the rising sand-covered ground to the east. Not improbably, the northern half of the depression is also underlain by these marls concealed by pale sand, like that swept in periodically by the Ngwezumba River, and also brought down formerly by the Savuti; such a view would, furthermore, explain the greater altitude of the floor in those quarters. The Ngwezumba came down in flood in April, 1925, to a depth of nine feet over a width of about seventy-five yards (Fig. 24), and spread out across the main road in a sheet a couple of feet deep and several miles across, bringing along much white sand derived from the Sand Ridge.

Drainage.

65. In the wet season the run-off from the hard mopane soil must be considerable, the rush of the waters being marked out by lines of drifted débris and in the lower parts of the hollow by ripple-marked and sun-cracked clay surfaces. The only other river bringing in water periodically is the Mababe, for the Savuti has not functioned for many years now, but even the Mababe River is erratic in its contribution, being dependent in its turn on the flow of the Kudumane and of the Mogogelo. It was surprising to find that in October, 1925, the waters of the latter had not yet met (though just about to do so) those of the Kudumane, which was then the only contributor to the Mababe River. In other and more normal years, however, plenty of water had passed down by this route into the depression by the beginning of the spring. Chapman, reaching the western side of the flats in October. 1853, was disappointed at not being able to travel by boat up the Mababe River to the Thamalakane, remarking that when the rivers came down the flats would be flooded far to the east, forming a sheet of water nearly twenty miles broad, where at other seasons not a drop could be found. The testimony of other travellers is corroborative, so that there can hardly be any doubt that for three-quarters of a century at least the Mababe has been in more or less the same state as it is to-day—only intermittently flooded. It may, however, be conceded that the incursion of sand on the north and north-east has during that period led to the gradual encroaching of the mopane and thorn-bush upon the open grassland.