(3) It may be taken up by the roots of the vegetation and transpired into the air (excepting the small amount retained by the plant).

(4) It may sink so deeply as to strengthen the underground water.

339. The relative proportions of the rainfall which follow the various alternatives is of the utmost importance. The proportion which runs off is of interest to bridge, road, railway and irrigation engineers, and has long enjoyed their attention. The runoff from a catchment is ascertained by measuring the water flowing past the lowest point of the catchment and, ascertained in this manner, it does not necessarily represent water which will find its way into the sea as, apart from possible use of the water for irrigation and other purposes, further evaporation and absorption will naturally take place.

340. About thirty catchments in the Cape Province, Orange Free State and Transvaal are under observation by the Irrigation Department, and while they are insufficient to enable a precise estimate to be made of the total runoff of the country, they serve as a guide to the specialist and enable him to make a close guess if he knows the country and the nature of the rainfall. Such a " guess " or first approximation has been made by Mr. F. E. Kanthack, M.I.C.E., etc., etc., for many years Director of Irrigation for the Union. He has had exceptional opportunities for carrying out the work, and it is probable that, for a long time to come until our gaugings are more complete, this approximation—partly estimate and partly intelligent guess-work—will be the best available.

341. Runoff varies, not only with the slope of the country, the nature of the soil and its vegetal cover, but, even in one and the same catchment, it varies from year to year in accordance with the incidence of the rainfall. In South Africa the runoff varies from over sixty per cent., in the case of small steep catchments with a high rainfall, to under one-tenth of one per cent. in the case of large, flat and sandy catchments with smaller rainfalls. *The average runoff for the Union and Basutoland is below 4¾ per cent.*, that is, on an average for every hundred gallons which fall at a given spot, 4¾ run off the surface and find their way into the water courses.

342. While 4¾ may be taken as representing the average percentage runoff from all catchments, due regard being paid to area, *this figure does not represent the percentage of the total volume of rain falling in the country* which finds its way into the sea. Taking the estimated annual rainfall in the Union-cum-Basutoland area as just under five hundred million acre feet, the estimated annual run-off of thirty-two and one-third million acre feet is 6½ per cent. of the rainfall.

343. Although it is possible to make an approximation of the runoff, it is very difficult to make any estimate of the remaining alternatives by which rainwater disappears from the spot where it fell. A portion evaporates from the surface, and the amount lost in this manner may be very great, amounting indeed to 100 per cent. when a light shower is followed, as so often happens in the summer rainfall area, by strong sunshine.

344. A portion of the rainfall, however, usually finds its way into the soil, where it may be regarded as behaving in two distinctly different ways. It may pass through the soil, in obedience to the laws of gravity, provided there are—as is usually the case—paths or channels of dimensions sufficient to render the effect of the surface tension negligible, or it may cover the soil particles with a film of water and in this way, in obedience to the laws of surface tension, proceed from point to point. In general both these alternatives proceed simultaneously.

345. The amount of water which a soil can hold in a film covering its particles varies greatly with the nature of the soil. Sandy soils, whose particles are relatively coarse, cannot hold nearly so much as a clayey soil, whose particles are minute in comparison. The water retained by a soil always tends to move in that direction where the film covering the particles is thinnest; but there is a limit beyond which this does not occur, for the film may become so thin as to be ruptured. When the rain has ceased, evaporation commences, the film covering the surface particles is thinned, and a general movement of water takes place in that direction. until the film covering the upper particles is ruptured, and made discontinuous with the film of the lower particles, water will continuously be drawn from below and be evaporated.

346. In this way the expert in dryland farming explains the benefits of the soil mulch in relation to the storage of water in the soil. The loosening of the surface layer results in (*a*) the dissipation of its film moisture and (*b*) in a much less perfect contact between the soil aggregates of the loosened layer as well as of those at the junction of the two layers. Both these results function in preventing the re-establishment of film connection between the lower and upper layers. The dryland farmer therefore deliberately throws away the moisture in the surface layer in order to save that absorbed by the subsurface soil.

347. Now, all soils are to some degree naturally self-mulching, a property highly developed in some cases, especially in those in which the surface soil dries out leaving a more or less loose layer. In this connection it is to be observed that the trampling of stock leads to the removal, by wind or water erosion, of the surface layer of soil which by nature is more self-mulching than that below. It therefore follows that one of the effects of the trampling by

stock is to reduce the natural power of the soil to retain against evaporation the rain it has absorbed.

348. An additional property of soils in relation to the absorption and retention of rainfall against evaporation is the power to pass the rain absorbed by the surface to the subsurface layers. This property usually becomes greatly impaired by the removal of the true surface layer, The deeper and the more expeditiously the rainfall is passed into the soil, the safer it is from dissipation by evaporation at the surface. It therefore comes to this, merely, the trampling of stock, by leading to the removal of the true surface layer of soil, reduces the power of the soil not only to conserve water against evaporation but also—and perhaps more important still—to absorb rainfall and pass it down.

349. The effect of plant life on the removal of water from the soil has been neglected to simplify the discussion. Actually, the soil, even if entirely protected from evaporation at its surface, could not retain all the moisture absorbed so long as it supported growing vegetation. But water removed by vegetation is not wasted but is usefully consumed and is in fact, other things being equal *the* determining factor in the grazing yield. The other factors whether vegetation be present or no, continue to function.

350. Returning now to the rain water which falls on the earth, from the moment it reaches the surface it is subjected to evaporation—nay, even from the moment it leaves the clouds—for many a light shower in the summer is evaporated hundreds of feet up in the air and never reaches the earth at all. The glistening drops on the vegetation, the film on stones, even running water is subjected to the toll of evaporation. What is not removed in the early stages by evaporation or surface flow, sinks in. But it is evident that, other things being equal, the amount which is absorbed by the soil is dependent on evaporation or, in other words, on the state of the atmosphere. Thus, at the very portals of the channels leading to the depths of the soil the question of evaporation must be considered.

351. As has already been explained, the upper layer of soil demands a toll of the water passing through it, the amount retained depending on the degree to which the soil is already saturated which, in its turn, depends on the amount of evaporation which has taken place since the last preceding shower. Here again it is seen the question of evaporation enters, that is, the state of the atmosphere. And further, the percolating water is liable in its journey from the surface to the level of the water table to be taken up by the roots of plants. While the rate of transpiration is susceptible to control by the plant, it is nevertheless more rapid on hot, dry days and is much increased by wind. Here again the factor atmospheric conditions influences percolation to the water table.

352. Perhaps the importance of evaporation in the social economy of the Union has not hitherto been thoroughly realised. Your Commission has therefore thought it advisable to treat the subject in greater detail than was done in paragraphs 100 and 101. The lay mind, estimating the run-off would probably place the figure in the neighbourhood of 90 per cent. of the rainfall. It is with incredulity one hears for the first time that average run-off for South Africa is only about 4¾ per cent. Much has been said about the appalling waste of water running to the sea. This water certainly appears readily to the eye ; but all that enormous volume of water with its large potential value represents only 6½ per cent. of the total rain which falls in the country (see paragraph 342).

353. However great our obligations in connection with the use of the 6½ per cent. may be, it is rank folly to close our eyes to the remaining 93½ per cent. *The 6½ per cent. has long been entrusted to the care of an important technical department ; Parliament has enacted intricate legislation in connection with the use thereof, and special courts have been instituted to interpret the laws ; but up to the present little systematic work has been done in the direction of ensuring the utilisation to the best advantage of the remaining* 93½ *per cent. which does not reach the rivers. The volume of this water amounts to no less than* 494,000,000, *acre feet, a quantity which will appeal more readily to the understanding when it is stated that it is sufficient to cover an area equal to the whole of the Orange Free State to a depth of more than* 15 *feet.*

354. *How much of this water is evaporated needlessly* ? How much of it is wasted, and how much of the waste is preventable ? So little investigation has been carried out in the Union relevant to this subject, that your Commission was unable to obtain the data that would be necessary to make an estimate of evaporation losses analogous to those Mr. Kanthack has computed for run-off. The problem appears to be well-nigh insoluble. It is far more complicated than that of run-off, since it is affected by all of the factors which influence run-off and several others besides. Your Commission is able to do no more than give an idea of the extent to which rainfall is dissipated by evaporation, and this is done in the following paragraphs.

355. The rate of evaporation from a water surface varies according to certain factors, namely :

(i) The temperature of the water,
(ii) The temperature of the air,
(iii) The velocity and duration of the wind,

(iv) The extent to which the air is saturated with water-vapour,
(v) The barometric pressure,
(vi) The amount of rainfall during the period of observation.

If factors (i), (ii) and (iii) are high, and factors (iv) and (v) low, we have ideal conditions for rapid evaporation. On the other hand, low temperatures, calm weather, a moist atmosphere and a high barometric pressure make for low rates of evaporation.

356. Estimates of the losses by evaporation of stored water have frequently to be made by the engineer who for this purpose uses the data furnished by evaporation gauges. Such a gauge usually consists of a small tank or pan fitted with a means for measuring directly the subsidence of the water surface, or with a device which permits of calculating the loss. Such gaugings are all inexact in respect to other water surfaces because it has been found that the area of water surface and the volume of water contained by the gauge materially influence the results. Speaking generally, the smaller the water surface of the gauge, the greater the rate of evaporation from it, a practical point which can be accounted for by a consideration of the temperature and humidity factors. To a considerable extent these objections to evaporation gauges are overcome when the gauge is immersed to a suitable depth in the centre of a large sheet of water. These explanations are necessary to indicate that allowances have to be made when comparing the results obtained by such methods.

Evaporation from a Free Water Surface in Inches per Annum in Various Parts of the World.

Place.	Evaporation.
Kimberley	97
Van Staaden's Dam	97
Johannesburg	75
Lake Nyanza	49
Assouan Dam	104
London (England)	15½
Bombay (India)	85
Ft. Collins (Colorado, U.S.A.)	41

357. In the Union, data regarding evaporation are practically confined to losses from free water surfaces. Therefore, in order to arrive at an estimate of the intensity of evaporation from the soil surface here, we must consider such data as have been accumulated in other countries and see what are their underlying principles. We shall first consider the case of bare soil, that is, soil devoid of vegetation. The amount of evaporation which takes place from such a surface depends on factors similar or identical with those given above for a water surface, namely, the temperature of the soil, the temperature and dryness of the air, the velocity and duration of wind and barometric pressure. In addition, there are other factors such as the amount and distribution of the rainfall and the nature of the soil surface, including its degree of moistness.

358. Regarding these additional factors, it must be observed that it is only so long as the surface is moist that appreciable evaporation takes place from it (see paragraphs 345-7). Therefore a given quantity of rain coming at intervals during, say, a month will usually result in a greater loss by evaporation than if it came all at once, even assuming like percentages of absorption in each case; for where the rain comes all at once, or within a short interval, it penetrates to a greater depth, and is thereby protected against subsequent evaporation (see paragraph 348). Thus one arrives at the conclusion that one good rain is much to be preferred to a similar quantity coming in driblets; provided, of course, the intensity of the single fall is not so great as to lead to very excessive run-off. And what applies to rainfall applies equally well to irrigation.

359. It should be observed that a square yard of soil, no matter how finely granular it be, exposes more than that area of evaporating surface, whereas the evaporating surface of a like area of water is only one square yard. Further, if the soil surface be ploughed or otherwise made undulatory, the exposed surface becomes still greater. These facts furnish one reason why there may be a greater evaporation from a moist soil surface than from a free water surface in the immediate neighbourhood.

360. Further points concerning the nature of the soil in relation to evaporation are its specific heat and its colour. Soil being of lower specific heat than water, the temperature of soil is naturally increased more than that of water by a given quantity of heat; while its usually darker colour leads to a greater absorption of heat. The higher temperature is shared with the moisture in the soil and, as was stated above (paragraph 355), leads to an increased evaporation. This latter, of course, tends to produce an opposite temperature effect which, in hot weather, is always surpassed by the heating effect.

361. So far we have considered the case of a soil surface devoid of vegetation. A new factor is introduced if vegetation be present, for plant growth demands the transpiration through the leaves of moisture which the plant has obtained from the soil. The first effect, therefore, of the presence of a vegetal cover is an increased dissipation of the soil moisture. What this loss amounts to in the case of our indigenous fodder plants is quite unknown ; but it is not a wasteful one : it is one that is vital to plant growth. Without it there could be no grazing yield whatever.

362. The vegetal cover, besides helping to dissipate the moisture in the soil, assists in conserving it. Firstly, it shades the soil surface and thereby tends to prevent its temperature from rising, and in this way minimises the loss of moisture by actual evaporation. Secondly, it shelters the soil surface from wind, besides reducing the wind velocity. This again results in a diminished evaporation from the soil surface. Thus does it appear that vegetation tends to conserve the moisture it requires for its own growth.

363. It has already been pointed out that one of the principal factors in the conservation of rainfall for subsequent use by plants is the penetration of the rain to the sub-surface layers of the soil. The extent to which this takes place depends, not only on the nature of the soil, but also on the presence of root and other channels and on the time of contact between the water and the soil surface. A vigorous vegetal covering means a well developed root system and its quota of channels down which rain finds an easy entry to the soil ; it also means a more efficient obstruction to water flowing over the surface and through that, to an increased time of contact ; and further, the roots of a vigorous vegetal cover certainly lead to a diminished useless evaporation by appropriating moisture that, in absence of such roots, would merely be passed off into the atmosphere by surface evaporation.

364. *One cannot, therefore, escape the conclusion that an efficient vegetal cover makes for efficiency in the use of whatever rain falls on it. Thus again is it apparent that in the preservation of the vegetal cover, through proper grazing methods, is to be found a potent means of reducing the inefficiency of the rainfall* (*see paragraph* 32 (iii).)

365. The following paragraphs (366-382) will serve to indicate quantitatively the effects on evaporation of the several factors mentioned above.

366. How great the effect of exposure may be, is evident from the results of a series of measurements taken near Bloemfontein during the years 1906-1907. They show that there was a difference of 41 per cent. between the amounts of evaporation from the water surface in two similar evaporimeters, one of which was afforded the protection natural to its situation on the banks of the Modder river, while the other was placed in a more exposed situation in the vicinity.

367. The effect of temperature on evavoration is also very marked. Figures No. 3 and 4 show the mean evaporation and mean temperature (i.e. the average of the mean maximum and mean minimum temperatures) month by month throughout the year. The vertical scale on the left shows monthly evaporation in inches, while that on the right indicates temperatures in degrees Fahrenheit, an arrangement which permits of easy comparison between evaporation and thermal conditions. For Cape Town the evaporation data refer to measurements at the Molteno reservoir ; while the temperatures are those taken at the Royal Observatory. The Johannesburg curves embody the data obtained at the Union Observatory there.

368. The figures for Johannesburg give a total evaporation of about 75 inches for the year, and there is a considerable variation in the amount of evaporation from month to month, which is not absolutely proportional to the temperature. One finds that at similar temperatures the evaporation in the Autumn is less than in the Spring. It is probable that this difference is due to the greater prevalence of wind in the Spring, and it may be that the humidity of the atmosphere is less. It may be stated here that it would appear from Dr. Sutton's figures for Kimberley that an increased wind velocity leads to a considerably increased evaporation. The following table indicates approximately the variation in evaporation according to temperature.

JOHANNESBURG.

Temperature, Degrees Fahrenheit.	Evaporation, Inches per month.
50 Degrees	4·5
55 ,,	5·2
60 ,,	6·3
65 ,,	7·5
70 ,,	8·25
75 ,,	12·0

These data are shown graphically in Figure No. 5.

369. The total mean annual evaporation for Kimberley is 97 inches. The figures do not show the same seasonal departure from their mean for a given temperature as do those of Johannesburg. This is perhaps to be expected owing to the smaller humidity there, but still the

difference between the evaporation in Spring and Autumn is strongly marked. The average monthly evaporation at various temperatures is practically the same as that for Johannesburg.

370. The average annual evaporation at the Assouan Dam is 104 inches, the variations throughout the year are indicated in the following table.

ASSOUAN DAM.

Temperature, Degrees Fahrenheit.	Evaporation. Inches per month.
60 Degrees	4·5
65 ,,	5·4
70 ,,	6·6
75 ,,	7·5
80 ,,	8·7
85 ,,	9·9
90 ,,	11·4
95 ,,	13·9

371. From these last four paragraphs it is evident that, not only does evaporation from a free water surface rise very markedly with temperature, but that the higher the temperature the more rapid is the increase in evaporation. For example, the Johannesburg figures show that for an increase of 5 degrees from 50 degrees Fahrenheit the evaporation increases only 0·7 inches per month, whereas for an increase of 5 degrees from 60 degrees Fahrenheit the increased monthly evaporation is 1·2 inches and no less than 3¾ inches for an increase of 5 degrees above 70 degrees Fahrenheit. The Assouan figures tell a similar tale, excepting that both the actual rate of evaporation and rate of increase for a given temperature increment are much lower than the South African figures quoted.

372. In order to lessen the rate of evaporation, it would seem, therefore, that we should attempt to reduce both the temperature and the wind velocity. It is to be observed that even a small reduction of a high temperature, has an appreciable effect in reducing the rate of evaporation. The data quoted above are based on air temperatures, and for the evaporation from a free water surface. Even if it be granted that it is not practicable to reduce the temperature of the air, there remains the very important fact that evaporation from the soil depends to a considerable extent on soil temperature which, it has been shown, an efficient vegetal cover tends to reduce. Vegetation also protects the soil surface from wind action and reduces the velocity of the latter.

373. The African data quoted above all refer to free water surfaces. Similar data for soils are unavailable. Your Commission, therefore, now refer to a series of experiments conducted in California by Dr. Samuel Fortier who measured the evaporation from soil under various conditions.

374. Since the climatic conditions of California bear a resemblance to parts of South Africa, the results of Dr. Fortier's experiments may be taken as an indication of what happens under South African conditions. The experiments were conducted at the following stations :—Chico, Berkeley, Tulare, Pomona and Calexico. The average annual rainfall over the area represented by these stations varies from 25 inches to under 10 inches, conditions typical of much of the Union. The average annual evaporation from a free water surface for the years 1904 and 1905 was as follows :

Chico	53 inches.
Berkeley for 1905 only	42 ,,
Tulare	69 ,,
Pomona	65 ,,
Calexico for 1904	104 ,,
Calexico for 1905	75 ,,

(N.B.—The figures for Johannesburg and Kimberley are 75 and 97 inches respectively.)

The mean temperature for the summer months of June, July, August and September were :

Chico	78 Degrees Fahrenheit.
Berkeley	60 ,, ,,
Tulare	76 ,, ,,
Pomona	74 ,, ,,
Calexico	88 ,, ,,

(N.B.—The figures for Johannesburg, Kimberley and Bloemfontein for the summer months November, December, January and February are 64 degrees, 75 degrees and 71 degrees respectively.)

375 The mean monthly temperatures and the evaporation figures from a free water surface for the five Californian stations are shown graphically on Figure No. 6 (see paragraph 367). The relationship between temperature and evaporation is much the same as that for Johannesburg and Cape Town and, further, the evaporation is more rapid in the early summer than for the period of corresponding temperatures later in the year. Since California is a land of winter rainfall, it would appear that in wind must be sought the reason for increased evaporation of the Spring months.

376. In order to determine the effect of the temperature of water on the evaporation from it, recourse was had to a series of evaporating pans, each member of the series being assigned its own particular temperature, at which it was maintained by artificial means throughout the whole of the period of observation. In this way every pan was subjected simultaneously to identical atmospheric conditions, the only varying factor being the temperature of the water from pan to pan. Such a series of experiments was arranged at each of several places and the results obtained at three of them—Chico, Tulare and Berkeley—are shown graphically in Figure No. 7. The vertical scale measures the average daily evaporation in inches, the horizontal one the temperature in degrees Fahrenheit. It is seen that the average *daily* rate of evaporation increased very nearly one-tenth of an inch for each increase of 5 degrees Fahrenheit of the water between 55 and 90 degrees, the rate of increase being smaller at the lower temperatures. The rapid rate of increase in evaporation which occurs with an increasing air temperature (Paragraph 371 and Figure No. 5), is not so marked here. This is due to the fact that the absorptive power of the air is not measurably increased by heating the water in the pans. When the general temperature is increased, both air and water are raised in temperature, and the rate of evaporation is accelerated by both factors.

377. It has been shown to what extent the rate of evaporation from two water surfaces is accelerated according as the temperature of the water increases, but your Commission has been able to discover data with respect to the rate of evaporation from soil surfaces at different temperatures. It may, however, be assumed that an increase in the temperature of the soil also leads to an increased rate of evaporation of water therefrom. The value of the shade afforded by vegetation in keeping down the temperature of the surface was mentioned in paragraph 362. Figures, indicating the order of differences that may be expected, follow. A series of measurements, taken during the hours of sunshine at Riverside, California, show that the temperature of water in an exposed evaporation tank did not vary much, the mean temperature being about 80 degrees Fahrenheit, and the range about five degrees. The air in the shade averaged 10 degrees above this mean, but the soil in the shade only eight degrees above. The air in the sun was 13 and the soil in the sun 30 degrees Fahrenheit above the mean temperature of the water (see Figure No. 8.)

378. It is obvious that the rate of evaporation from soil in the sun, compared with that from soil in the shade (assuming equally moist soil in both cases) must be large, for not only is the soil in the one case 22 degrees warmer ; but the fact that the air is also warmer (3 degrees) must still further accelerate evaporation. (The experiments described in paragraph 376 showed that, with an increase of 22 degrees Fahrenheit in the temperature of the water, the *daily* increase in evaporation was over four-tenths of an inch).

379. Measurements were also taken at these stations to determine the effect of wind on evaporation, and indicate an undoubted increase in the rate of evaporation, even with a slight increase in wind velocity.

380. In leaving this series of experiments, reference is made to a series of tests which had for their purpose the comparison of the rates of evaporation from a soil, saturated to different degrees with water, with that from a free water surface. The results are tabulated below and they show that the evaporation from a fully saturated soil may exceed that from a free water surface, also that the rate of evaporation varies according to the degree of saturation.

EVAPORATION FROM SOIL AND WATER.

Kind of soil and percentage of free water.	Mean temperature taken morning, noon and evening in degrees Fahrenheit.			Weekly evaporation.			
	Air in shade.	Soil in shade.	Soil in sun.	Moist soil.	Surface of water.	Soil.	Water.
	Degrees Fahrenheit.	Degrees Fahrenheit.	Degrees Fahrenheit.	Degrees Fahrenheit.	Degrees Fahrenheit.	Inches.	Inches.
Sandy loam saturated ..	71	76	95	83	77	4·75	1·88
Sandy loam, 17·5 ..	76	78	106	—	80	1·33	1·94
,, 11·9 ..	76	78	106	—	80	1·13	1·94
,, 8·9 ..	76	78	108	—	80	·88	1·94
,, 4·8 ..	76	78	108	—	80	·25	1·94

This table shows that an amount equal to the annual rainfall of parts of the Union may be evaporated in one week from a moist soil and it suggests that the whole of a good rain may be rapidly dissipated by evaporation unless it sinks well into the soil.

381. In commenting on the results of his experiments, Dr. Fortier says : "*The experiments reported in the preceding pages show that the conditions having the greatest influence on evaporation from soils are the quantity of water in the top soil, the temperature of the soil and water, and the wind movement.*"

382. The increase in evaporation resulting from an increase in temperature, whether of the air or of the soil, should now be clear, and the advantage of shade in keeping down the soil temperature must be apparent ; but there is another point which must be kept in view, and that concerns the way in which the temperature of the air is influenced by the sun. The rays of the sun pass through the atmosphere without warming it greatly, especially if the air be dry. It is only after they have reached the earth and have been changed in character that, by reflection and still more by radiation and conduction, the air becomes heated appreciably. Bare soil becomes much warmer than veld efficiently covered with vegetation. The latter, being cooler, does not heat up the air so readily as the former. Thus vegetation not only directly reduces evaporation losses from the soil by shading it, but also indirectly in that it prevents to some extent the warming of the air by the soil.

383. Having marshalled the principal facts concerning evaporation, and having indicated the magnitude of the losses of soil moisture caused by this factor, your Commission confidently leaves this aspect of drought for your earnest consideration.

384. Your Commission finds that :—

(i) While the State is doing much to encourage the utilisation of that small proportion of the rainwater which runs off, it has done little or nothing to prevent the waste of the remainder, which forms 93½ per cent. of the total.

(ii) Evaporation plays a far greater role in the dissipation of moisture of the soil of arid and semi-arid regions than is generally realised.

(iii) The destruction of the natural vegetal cover tends to increase evaporation.

(iv) The decreased evaporation resulting from an efficient cover will not only result in a more beneficial use of the rainfall ; but will also tend to strengthen the underground water.

(v) These facts afford an additional argument for the prevention of overstocking, overgrazing, and soil erosion.

XXIV. Water Supply for Irrigation, and Analysis of Catchments.

385. In the previous chapter the importance of evaporation was discussed. In this chapter it is proposed to deal with the question of run-off and irrigation in their broadest aspects. Mention was made in the Interim Report of the common belief that our drought losses are due to a diminished rainfall. A belief almost as general, is that it is possible to turn the whole of the Union into a flourishing garden by irrigation, and in that way overcome droughts.

386. The extent to which irrigation development is possible in South Africa is definitely limited by the main factors, rainfall and run-off, and in addition by certain other minor or secondary factors.

387. The run-off from the entire Union, including Basutoland, has been estimated by Mr. Kanthack (see paragraph 340) at 32,000,000 acre feet per annum : that is, sufficient to cover 32,000,000 acres one foot deep. If all this water were available for irrigation, only a little over 6,000,000 acres could be irrigated if it be assumed that an annual depth of five feet is necessary for irrigation—a moderate figure when all losses are allowed for.

388. Three facts must be borne in mind. Firstly, one half of the total run-off is derived from the coastal fringe, the average altitude of which is some two or three thousand feet less than that of the main semi-arid portion. Secondly, the coastal rivers flow through extensive areas where irrigation is either unnecessary, or plays only a very small role in the agriculture of that area. Thirdly, in many parts where irrigation is needed and, topographically speaking, possible, the high cost of the necessary works or the unsuitability of the soil, makes it economically impossible. It is therefore evident that the theoretical maximum of 6,000,000 acres can never be approached in practice. The estimate of approximately 3,000,000 acres, based by Mr. Kanthack on a detailed analysis of the catchments, may be considered, as he himself styles it, "truly optimistic."

389. It may be objected that no account is taken here of seepage water. It is a well established fact in South Africa, as well as in other parts of the world, that some of the water applied to lands, being neither evaporated, transpired, nor stored by the crop, frequently oozes into the water courses below the "lands," where it may be caught up and again used for irrigation. The seepage is sometimes considerable and cases were described to your Commission, where small irrigation works have been established for the utilisation of the permanent stream of water percolating from lands irrigated by the flooding or pumping operations of an

upper neighbour. On the other hand, the seepage water may be highly saline, and for long periods so deleterious as to render useless fresh water in the river below.

390. The total area which could be irrigated with this seepage water is comparatively small, and need not be taken into consideration here; for in any case, as will be apparent below, the omission of this highly problematical supply will not affect the validity of the arguments to be brought forward in this chapter.

391. Three million acres (say one and a half million morgen) or, roughly, 1 per cent. of the Union may therefore be taken as the practical limit to the development of irrigation in South Africa under present conditions, and the roseate dreams of extensive irrigated areas in South Africa can only remain dreams; but the fact that the area is limited in extent, and the run-off forms only a small proportion of the rainfall, does not detract from the importance of irrigation.

392. The above points were raised merely to clear away misunderstanding. Further analysis of the position is now necessary in order that it may be realised what the future may hold in store for irrigation in South Africa. Of the three million acres a little less than one half (41 per cent. or 1,225,000 acres), lies in the Orange-Vaal catchment. That catchment, embracing the basins of the Orange and Vaal Rivers, and all their tributaries, is the most important in South Africa from an irrigation point of view. It is followed in importance by the Limpopo basin, with a total irrigable area of about one-half of the irrigable area of the Orange-Vaal catchment.

393. The estimated total annual run-off for the Orange-Vaal catchment is 7,669,000 acre feet, of which 4,477,000 acre feet, or sixty per cent. is derived from the districts bordering the eastern escarpment, namely, Ermelo, Standerton, Wakkerstroom, Vrede, Frankfort, Harrismith, Bethlehem, Ficksburg, Ladybrand, Wepener, Rouxville, Aliwal North, Herschel, Barkly East and Basutoland. This area represents about 8·4 per cent., or about one-twelfth, of the whole of the Union-cum-Basutoland area.

394. From the last two paragraphs, it would appear that nearly one quarter (60 per cent. of 41 per cent.) of all the water that can be used for irrigation in the Union, comes from this one-twelfth area. *Actually, however, it would seem, on further analysis, that one-third of the total water usable for irrigation is derived from this area.*

395. In order to bring out these relationships more clearly a series of diagrams amd maps have been prepared. Firstly, a map of run-offs (No. XIV) showing the approximate annual run-off in inches for the Union and Basutoland. All points joined by one of these "lines of equal run-off" have the same annual run-off, the magnitude of which is indicated by the number printed on the line. Places between two lines have an annual run-off, whose value lies between those indicated on the two lines.

396. Similar information is given on Map No. XV, but in a manner which appeals more readily to the eye. Here the run-off is not shown as a depth of so many inches, as is usual in the case of rainfall, but in volume. The unit used is the acre-foot, that is, the amount of water which will cover one acre one foot deep. On this map the run-off is indicated by dots, each dot representing an annual run-off of 5,000 acre-feet. The dots are naturally more closely grouped where the run-off is greatest.

397. For the purpose of this chapter, the Union has been divided into groups of river basins shown on Map No. XVI. Group A is the Cape Coast group and comprises the rivers rising on the coastal fringe of the Cape Province, from Clanwilliam to Bathurst. For purposes of reference, the Classification Numbers of the Irrigation Department are quoted: VII, VIII, X, XII and XIV. Group B, Transkei and Natal, comprises all rivers flowing into the ocean on the Transkei and Natal Coasts. The Irrigation Department Classification Numbers are XVI, XVII, XVIII, XIX and XX. Group C, Zululand, comprises all rivers flowing into the ocean on the Zululand Coast. The Classification Number is XXI. Group D, Cape Midlands, comprises the catchments of the rivers Gouritz, Gamtoos, Sundays and Great Fish, and all Union rivers flowing into the Atlantic Ocean, with the exception of the Orange and rivers under Group A. The Classification Numbers are V, VI, IX, XI, XIII, XV. Group E, Quathlamba-Drakensberg, comprises roughly the Klip, Wilge and Upper Vaal Rivers, the Caledon and the Upper Orange Rivers. The Classification Numbers are III 1, IV 1 and IV 2. Group F, Central, comprises the Orange-Vaal basin below the area described as Group E, and above the junction of these two rivers. The Classification Numbers are III, III 3, III 4, III 5, and IV 3. Group G, Cape North-West and Bechuanaland, comprises the remainder of the Orange Basin. The Classification Numbers are IV 4 and IV 5. Group H, Great Olifant and Komati, comprises the basins of the two rivers named. The Classification Numbers are I and II. Group J, Western Transvaal, comprises the remainder of the Transvaal. The Classification Numbers are I 2, I 3, I 4 and I 5.

398. Using Mr. Kanthack's estimates as a basis, Fig. No. 9 has been designed to show relatively the run-off from each group defined in the preceding paragraph. The entire Union-cum-Basutoland area is represented by the length of the base of the diagram, and each group is represented, proportionately to its area, by a portion of that line. The figures below the base-line denote the ratio of the area of each group to that of the whole of the Union-cum-Basutoland area. The area of the rectangles on each base is proportional to the total annual

run-off for the particular group of river basins, and therefore, the height of the rectangle is proportional to the intensity of the run-off.

399. There is, however, a considerable difference between the total run-off and the useful run-off or volume, which may eventually be usefully employed in irrigation. In some instances as has been mentioned before, irrigation may be unnecessary, or impossible. In other cases the run-off may be so extremely variable and uncertain, as to be only partially usable economically. Thus the true value of a catchment for water-supply purposes depends, not on its total yield or run-off, but on its usable or useful yield.

400. Calculated in accordance with this principle, it is found that the relative importance of catchments is quite different from an assessment based on total yield alone. On the same diagram, (Fig. No. 9) is shown, shaded, the useful run-off. The areas of the shaded portions of the rectangles, are proportional to the useful run-off from each group. The figures shown in these shaded portions, indicate the proportion of the total useful water yielded by each group ; and the height of these shaded portions is proportional to the relative intensity of yield. *It is perhaps necessary to state that these calculations refer only to the source of the supply and not to the locality where it is to be used. For instance, water from the Quathlamba-Drakensberg group, may be used for irrigation in the Cape Province.*

401. The diagram makes it quite clear that, while Zululand, Transkei and Natal, and the Great Olifant and Komati groups all show intensities of run-off far exceeding those of the Quathlamba-Drakensberg group, none of them shows even one-third of the intensity of useful yield of the last-named group.

402. The data on which Figs. Nos. 9 and 10 are based, are here tabulated :—

Group.	Name.	Area in square miles.	Total yield in acre feet.	Useful yield in acre feet.	Area in acres irrigable with this water.	Area of group as percentage Unio-cum-Basutoland.	Useful yield as percentage of total useful yield.
A.	Cape Coast	21,428	2,257,900	737,900	286,000	4·4	6·2
B.	Transkei and Natal..	45,381	7,191,247	931,247	133,000	9·3	7·9
C.	Zululand	21,431	6,292,142	555,142	81,000	4·4	4·7
D.	Cape Midlands ..	80,046	1,519,670	1,287,670	532,550	16·4	10·9
E.	Quathlamba-Drakensberg	41,107	4,477,000	3,862,000		8·4	32.8
F.	Central	76,203	2,760,000	2,040,000	1,225,265	15·5	17·3
G.	Cape North-West and Bechuanaland ..	118,400	432,000	292,000		24·2	2·5
H.	Great Olifant and Komati	41,725	5,578,000	1,418,000	473,000	8·6	12·0
J.	Western Transvaal..	43,996	1;858,800	226,000	226,000	8·8	5·7
		489,717	32,366,759	11,797,359	2,956,815	100·0	100·0

403. The relative value of the catchments is so important that it has been deemed advisable to present an additional diagram showing the relative useful run-off from each group of basins. Fig. No. 10 shows very clearly how one-third of the total useful run-off, that is, one-third of all the water potentially usable for irrigation in the Union, comes from the Quathlamba-Drakensberg group. It further shows that one-half of all the usable water of the Union comes from the two Quathlamba-Drakensberg, and Central groups. Commanded by the yield of of these two groups lies 41 per cent. (1,225,000 acres) of the land actually or potentially irrigable (see paragraphs 392 and 402).

404. *Enough has been said to prove the great importance of the areas, described in paragraph 397 as the Quathlamba-Drakensberg and Central groups. If these areas be excluded nearly one-half of the possible irrigation in the Union falls away. Your Commission points out that the value of this area, as a catchment for irrigation water, is deteriorating, and desires to sound a note of warning.*

405. Destruction of vegetation, formation of tracks and grass burning—all tending to greater speed of run-off—are ruining the country. Dongas are being formed and rain, that formerly caused streams to commence running days after it fell, now fills the water courses within a few hours of its fall. Where the stream-beds were formerly covered with a few inches of clear, limpid water, running for weeks, they are now scoured by torrents of muddy water running for hours only. Where water from these streams could formerly be diverted by simple structures and utilised for irrigation, extensive, costly weirs and protective works are now necessary. Where the water was formerly available at any time during the summer, it can now be used for irrigation only at rare intervals ; and, as with the smaller streams and tributaries, so also with the larger tributaries and rivers.

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406. Similar deterioration of catchments, has taken place in many parts of the Union. On the edges of the Upper Plateau, from Pietersburg and Barberton, following the escarpment towards the south and west as far as Worcester, the same complaint was made by witnesses, namely, that in order to provide temporary grazing for a few boer goats, steep mountain slopes covered with a shallow layer of soil, are burnt and the natural covering of bush destroyed. The effect on streams rising in the vicinity and supplying neighbouring farms with water for irrigation, is immediate and disastrous. Within a longer or shorter period the mountain sides become so scoured and eroded that, even for grazing purposes, their usefulness declines.

407. As was to be expected, the complaints of witnesses were loudest in the districts where irrigation has been longest practised, and where crop-raising under irrigation forms the more important part of the agricultural industry of the district. Your Commission was informed at Worcester that the Nuy Irrigation Board had gone so far as to purchase 10,200 morgen of mountain area within the catchment of their water supply merely to be able to control it—to prevent veld-fires and general destruction of vegetation.

408. Your Commission does not desire to belittle the importance of such smaller catchments, nor does your Commission, in mentioning the instance of the Nuy Irrigation Board, desire to convey the impression that, in the case of smaller catchments, their protection should be left to private enterprise or individual effort. It is merely desirous of pointing out that some private citizens have seen the danger and are already, where organised, putting their shoulder to the wheel. It would be possible to multiply instances where the processes described are rapidly making irrigation more and more uncertain and costly. It is sufficient to mention the case of the Nuy Irrigation Board as an instance of a small catchment, and the Quathlamba-Drakensberg and Central groups of river basins as the largest and most important in South Africa.

409. It will be necessary, subsequently, to refer to this question. For the present it will suffice to point out that just as it was necessary for the Nuy Board to take steps to preserve its own catchment, just so necessary is it for the State to take steps to preserve the National Quathlamba-Drakensberg and Central catchments which, together, represent one-half of the irrigation waters of the Union. If, in presenting this the most important case, your Commission has failed to impress the necessity for action, it will be a waste of time and energy to present other less important ones.

410. *We are allowing an invaluable asset of the country to be frittered away.*

411. The conservation of our catchments is a task of such magnitude that one at first cannot decide where to begin. The analysis made in the preceding paragraphs, however, reveals the fact that the yield of useful water from certain catchments is much higher than from others, and that these are therefore of greater national importance. It is to these catchments then that attention must first be directed. The problem, therefore, becomes not so much a general action in connection with all of the catchments of the Union, but rather the taking of steps that will preserve a number of them whose high water-yielding value would become evident as a result of more detailed analysis than that made in this chapter.

412. All the remedial measures already recommended by your Commission were calculated to prevent further deterioration of the vegetal cover of the country and even to restore it. *In this connection your Commission, while emphasising once more the necessity for the education of the public in this direction and for individual action, desires to affirm that success in the preservation of our large catchments can only be attained by systematic work, and that this demands State-direction.*

413. The Union will always remain essentially a stock-raising country. In measure as the population of the world increases, so will more and more of the land, at present used for ranching, but capable of being tilled, be put to crop raising as opposed to stockraising purposes ; and the ranching areas of South Africa will assume greater and greater importance in the trade of the World. Only by the full development of irrigation possibilities can the full capacity of the country for stockraising be attained. *It is the bounden duty of the present generation to guarantee for the days to come, the possibility to irrigate.*

414. Therefore, the need is not to accelerate irrigation development—for much has already been done and steady progress is to be expected in that direction—but to preserve our catchments, a National work that can brook no further delay. Every day permitted to pass without action having been taken, is not only a day of no progress, but one of retrogression.

415. Your Commission finds that :—

(i) While Irrigation Development in South Africa is definitely limited by rainfall and run-off to about one per cent. of the total area, this development is of great importance to the Union which, year by year, will play a larger role as a stock-raising country.

(ii) The various catchments of the Union have greatly different values, when judged by the yield of water usable for irrigation.

(iii) Most of the catchments are decreasing in value owing to deterioration of vegetal cover and to soil erosion.

(iv) While individual action, or the action of a small group, is capable of dealing with the problem in the case of small catchments, State action is needed to preserve the major ones.

(v) One-third of all the actually used and potentially usable irrigation water is derived from one-twelfth of the Union-cum-Basutoland area.

(vi) The fact that relatively small areas have such large water yielding values, renders the problem of preserving them easier to deal with.

(vii) By permitting the deterioration of the catchments to continue, we are irrevocably discarding an invaluable national asset.

(viii) Delay in dealing with the matter, not only means stagnation, but actual retrogression.

XXV. Irrigation and Silting.

416. In previous chapters attention was directed almost entirely to stock-farming, grazing and allied questions. Even irrigation is not a matter entirely divorced from stockfarming because, as has already been mentioned, irrigation is being used to a considerable extent as an adjunct to stockfarming, for the purpose of supplying fodder to lambing ewes, for fattening purposes, for insurance against drought losses, for dairy purposes, and so on. A more general development of the application of irrigation as an aid to stockfarming is highly to be recommended from every point of view. Still, in parts situated far from more favoured districts, where fruit, vegetables, and so on, can be raised readily with the natural rainfall, it will probably always be the practice to apply irrigation in the raising of these crops.

417. Certain problems in irrigation remain the same no matter to what use the water be put. The first obstacle one meets with in almost all irrigation undertakings in South Africa, is the uncertainty of the wide variations in the water supply. There are instances where water is derived from permanent supplies or perennial rivers. But, as a general rule, irrigation schemes in South Africa have, in the past, been designed to obtain water from storage reservoirs built in water courses (which usually carry water immediately after a rain only) or as flood schemes to utilise as much as possible of the water of Karroo rivers during the short and infrequent periods of their flow. Flood schemes have not proved an unqualified success, for reasons which will be advanced later. The tendency of latter years has been in the direction of constructing large reservoirs in the beds of intermittent rivers, for the purpose of storage and for regulating the flow.

418. It has been the experience of the world that the area which any one farmer can efficiently cultivate under irrigation is strictly limited, unless he has a very large amount of capital at his disposal; even then the system of management frequently is such as virtually to divide his irrigated area into several small farms.

419. Frequently witnesses complained about the high cost of irrigation works. While your Commission does not desire to express any opinion concerning costs, it would point out that some witnesses would complain of the magnitude of the water rate, while others, drawing water from the same works, would express their satisfaction therewith. Further inquiry almost invariably elicited the information that the satisfied witness was the owner of a comparatively small holding, while the other was the owner of hundreds of morgen, of which he could cultivate only a portion. Obviously, the rate he had to pay on the large uncultivated area swamped the profit derived from the remainder.

420. The stockfarmer, who has a few morgen under irrigation, is in the position of having two strings to his bow. In a good year the returns from both stock and irrigation will be gratifying, whereas in a year of inadequate water he still has the returns from his stock to fall back upon. Under the larger schemes the tendency will be for irrigation to be practised as the sole business of the small farmer, and a failure for one year will ruin many, if not most, of the irrigators. The flood scheme of a couple of decades ago, is therefore useless for the purpose of closer settlement. Another feature which tells against the flood scheme is the fact that, in the greater part of semi-arid South Africa, rains are plentiful only towards the end of the summer. This means that a large part of the growing season is past before water is available. Several possible cuttings of lucerne are lost, and frequently early frosts interfere with the maturation of crops that are backward, owing to a late commencement of the season.

421. To insure against these failures large storage reservoirs have been built, either to supply water during a dry year, or, in the case of rivers whose total annual flow is fairly certain, to guarantee a supply of water in the spring and early summer. (Compare paragraphs 122 and 123).

422. It would be futile to argue, if the Karroo river had been maintained in its pristine condition of a series of grass-edged pools, as described by old travellers, that these reservoirs would have been unnecessary for the irrigation of the areas at present under cultivation. It is extremely doubtful whether sufficient information could be advanced to prove or refute

such an argument. What, however, is certain is that every few years all previous flood records are eclipsed. This may be due to the fact that old records have not been kept and that what are to-day looked upon as highest floodmarks were actually exceeded fixty years or more ago. It is, however, more probable that the records are actually being exceeded from time to time owing to the increased speed of runoff, due to soil erosion and so on. Each succeeding flood is, therefore, merely another symptom of man's evil-doing, merely another proof of the thoroughness with which he is ruining the country.

423. Each successive flood record imposes additional responsibilities upon the designer of water works, increases the cost of the works and the amount of artificial equalising storage which must be built to regulate the flow of the rivers to guarantee water to the irrigator. Nature has supplied her own regulators in the form of vegetation which, as has been described above, breaks the speed of the run-off and lets the water down into the water courses gradually. The Nuy farmers (see paragraph 407), realising this, decided to purchase the key to their catchment, and allow Nature to regulate their supply, rather than build expensive artificial storage with a limited life.

424. The useful life of a storage reservoir is usually limited merely by the period of effective storage. A reservoir, collecting clear water or a water whose suspended solids do not readily percipitate, will have a long life, but the larger the percentage of readily precipitating suspended solids contained by a water the shorter will be the life of the reservoir. Here again we are confronted by the ever present evils of veld-deterioration and soil-erosion. Water, passing over grassy slopes or well covered veld, is clear or contains but little suspended solids, and these probably of a non-precipitating character ; but water coming over veld, that is bare or cut up by dongas, not only carries in suspension much easily precipitated silt, but also rolls along the bottom of the dongas a very considerable amount of large, heavy particles, none of which can be transported past the reservoir.

425. The probable life of the reservoir is of vital importance to the irrigator in South Africa, a land of characteristically muddy rivers. It is useless to attempt to evade the issue by replying, as was done by some engineer witnesses, that neither plough nor engine lasts for ever and to expect a reservoir to be everlastingly useful is therefore unreasonable. It is not necessary that a reservoir last for ever to be an economic success ; but what an investor should know and must know, unless he is bent on speculation only, is how long the reservoir will be able to function effectively. Will it be fifteen years or fifty ? The designer of the works should be able to furnish reasonably trustworthy information on this point.

426. It is not necessary that the reservoir should have silted up to overflow level for it to fail to function efficiently. A reservoir may have been designed to give three waterings before the January rains come. It would start with an initial capacity of, say, four times the volume needed per watering, the extra one-fourth of its total capacity being needed to provide for evaporation losses. If the capacity of the reservoir become reduced to one-half by silting, the new circumstances do not diminish the evaporation losses, since the water surface exposed to the air will probably not be decreased appreciably. When fifty per cent. of the capacity has been eliminated by silting and twenty-five per cent. of the original capacity removed by evaporation, only twenty-five per cent, that is, enough for one watering, remains. Thus, by having silted up to the extent of one half, the efficiency of the reservoir, for storage purposes, has become reduced to one-third of its original value.

427. If, correspondingly to the diminished storage capacity of the reservoir, the irrigated area be reduced to one-third, the efficiency of the whole undertaking will be diminished by two-thirds. But if, as is often the case, a large number of owners have a call on such a reservoir, and they all demand their share of the water available, they would get one watering only, and this might not be sufficient to produce a crop. In this eventuality the efficiency of the undertaking would approximate to zero. Similarly, a city depending for water on such storage works would, unless good records were kept of silting, wake up some morning and find itself without water. This is, practically, what happened in the case of Bloemfontein in 1919.

428. It is unnecessary to dwell any longer on the general detrimental action of silt on the storage capacity of reservoirs. The preceding paragraphs have indicated its nature sufficiently well. The necessity for studying the silt aspect of our rivers is obvious.

429. The solids, other than those in solution, transported by flowing water may be divided into three groups. Firstly, there are the larger particles, including even boulders, which are carried forward in jerks or rolled along the bed of the water course. Secondly, there are the particles which are carried actually in suspension. The power of water to carry them depends on its velocity. It the velocity of flow diminishes, the largest particles will subside, and if the water comes to rest all the particles of this group of suspended solids will fall to the bottom, given sufficient time to do so. Thirdly, there are particles of much smaller dimensions which are either deposited not at all, or so slowly as to make the water, to all intents and purposes, permanently muddy. While this last group of particles may have a very deleterious effect on the crop it obviously does not enter into the silting of reservoirs. Naturally, there is no well-defined division between these classes of silt ; they fade away gradually, the one into the other.

430. The above facts are presented in order to show the nature of the study required. Each river must be studied separately, due regard being paid to those tributaries which may be feeding the main stream at the time of any observation. The silt content of the water varies with the age of the flood. This means that for good work samples must be taken at intervals during a flood, and the investigation must be continued over long periods.

431. While the content of the third group of solids may be constant throughout the entire cross-section of a stream, the content of group two may be expected to vary as the velocity is increased or decreased, and, therefore, to be the greatest where the velocity is the highest, except in cases where the silt-carrying capacity of the stream is greater than the silt available. For a thorough silt investigation it is necessary therefore to be able to take samples, not only at any point between the banks, but also at any depth below the surface of the river. The measurement of group one—the material which is rolled along the bottom of the river—presents almost insurmountable difficulties.

432. It is evident that an investigation of this kind is beset with many difficulties. Intelligent sample collectors, who can spare the time to take the series of samples required, are essential, as well as bridges and apparatus; and the work must be carried on for several years to yield definite results. Little work of this kind has been done, but probably the most useful is that of Mr. C. Warren, A.M.I.C.E., Circle Engineer of the North Midland Circle of the Irrigation Department, who has several of the Karroo rivers and reservoirs under continuous observation.

433. Observations have also been made by engineers in connection with works supplying towns with water, but the data available are still very scanty. A few observations recently published may be mentioned here. They have little value when removed from their context, but may serve to indicate the relative silt contents of different rivers. It must be remembered that in these readings the group one is not included; nor is it clear from what portion of the streams the samples were drawn.

434. The Great Fish River, at Cradock, gave for the whole year 1919-1920 an average silt content of 2·11 per cent, by weight. For the year 1920-21 the figure was 3·28. The maximum figure of this series was obtained in February, 1921, when the percentage reached 9·87. At Middleton, on the same river, the average for the year 1920-1921 was 4.32 per cent. with a maximum value of 7·98 per cent on December 31st, 1920. Vlekpoort River (probably the heaviest silt bearer in the Union) gave for 1920-1921 a percentage of 5·06, with a maximum of 11·24 in February, 1921. The maximum figure for the silt content of the Vaal River, near Kimberley, for the season 1918-1919 was 0.37 per cent. The Orange River seems to carry more silt than the Vaal; at Kakamas values of over 1 per cent. of silt have been obtained during high floods.

435. Since the proof of the pudding is in the eating, the final criterion is the rate of silt deposition in existing storage works. In certain localities, wire netting stretched across a sloot will hold up debris first, and finally enough silt to fill the sloot. In others, well-packed walls of unwrought stone, have failed in a decade to collect a teaspoonful of silt from a stream of muddy water. Some reservoirs silt up rapidly, others seemingly collect water in which group three silt forms the largest proportion, and they show no diminution of storage capacity. Again, reservoirs which hold up only a small proportion of the water which passes through them, such as, for example, those formed by weirs across rivers, collect deposits from more water than they store, and have therefore short lives; while, other things being equal, reservoirs which seldom overflow, have relatively longer lives.

436. Further investigations may throw additional light on the whole question, but the design of one of the dams being erected by the Irrigation Department is eloquent of the opinion of experts. The dam wall has been so designed that subsequent addition to it will be easy, so that when the present has been so far silted up as to affect its efficiency seriously, the wall may be raised so as to provide its initial storage capacity above the silt deposit.

437. One or two examples of silting, and the danger of trusting to incomplete measurements may be quoted. In March, 1904, the water which feeds the Bongola reservoir was tested and found to contain one-quarter to one per cent. of silt; but in December, 1920, it was found that the capacity of the reservoir dam had decreased 20·8 per cent. in ten years. The thanks of your Commission are due to the Town Engineer of Queenstown for this information.

438. Unfortunately, there are no records of the flow of water during these ten years. The catchment area of the reservoir is 42·8 square miles, the mean annual rainfall 22 inches, and the estimated runoff 10 per cent.; so there are sufficient data to make an estimate of the water which entered the reservoir, the quantity being an annual runoff of just under 219 million cubic feet, or 2,187 million cubic feet for the ten years. The silt caught up in the reservoir in that time is estimated at 51 million cubic feet, or two and one third per cent. of the total volume of water entering the reservoir during the ten years. As a certain amount of silt has passed through the reservoir, either over the spillway or through the outlets, the actual silt content of the water was even higher. No data are available to show what proportion of the water was actually stored during the period; but this is a case in which the mean annual runoff and the storage capacity of the reservoir, approximate to one another

439. Bloemfontein has two storage reservoirs in the bed of the Modder River. Together, their capacity approximates 450 million gallons (say 75 million cubic feet). The silt deposited in these two reservoirs for the year 1921 was about 305,000 cubic yards, (say 8¼ million cubic feet). A total of 4,015 million cubic feet of water is the estimated discharge of the river for that year. The amount of water caught up and stored during the year was approximately 115 million cubic feet. Calculating on the basis of those figures, it would appear that seven and one-sixth per cent, of silt was contained in the water stored. This figure is probably too high, and suggests that these reservoirs also caught up silt from passing flood water. For the period under consideration, the silt caught up represents one-quarter of one per cent. of all the water entering the reservoirs. Thanks are due to the City Engineer of Bloemfontein, who courteously supplied the necessary data.

440. The Stoney roller-sluices erected across the Vaal River by the Rand Water Board should yield valuable information as to the efficiency of that design for keeping the storage area scoured and free from deposit ; but where their use is impossible, it appears that engineers have been obliged to bow to the inevitable.

441. To the engineer, dealing with water which arrived at the boundaries of the area of his work, the problem may be insoluble : the evil done, that is, the contamination of the water, took place in areas outside his control. These areas, however, are under the control of the State, which can do much, along the lines indicated in this report, to encourage the preservation of the veld. An estimate of the total silt annually transported to the sea is given in paragraphs 502 and 504.

442. Your Commission finds that ;—

(i) Since Irrigation can do much to reduce stock losses, and since Flood Irrigation, except as a standby for the stock-farmer, is not usually a success,

(ii) Storage works are necessary to render crop raising under irrgiation certain, either by assuring the volume of water required, or by assuring a supply at times when it is most needed, such as in the early spring.

(iii) The whole question of storage is wrapped up with the question of silting, which shortens the efficient life of the reservoir.

(iv) Owing to the present method of farming, followed as it is by deterioration of the veld and soil erosion, the necessity for storage and the damage done by silt is increasing yearly.

(v) The question of silt, difficult as it is, should be thoroughly investigated.

(vi) To all intents and purposes the prevention of silting has proved to be beyond the powers of the engineer.

(vii) Only by systematic and combined action over a whole catchment can alleviation be obtained, and it devolves on the State to take the necessary steps.

(viii) The recommendations contained in this report in connection with stock farming will, if adopted, do much to reduce silting, and herein lies another reason for their adoption.

XXVI. Economic use of Water in Agriculture.

443. In flood irrigation without storage, it is useless to discuss the economic use of water—that is, the number of waterings, or the number of inches to apply at a watering—not in so far as excessive quantity is concerned. The main essential in flood irrigation is to prepare the lands and the distributary canals in such a manner that the largest area may be irrigated in the shortest time and with least expenditure of labour. The surface of the lands must, of course, be properly graded : if otherwise, uniform wetting is impossible, and non-uniform wetting cannot but be uneconomic. Where, however, storage is provided and a definite amount of water is assured, the problem of the economic use of water assumes an entirely different complexion.

444. In a previous chapter it was shown that the amount of water available for irrigation within the Union is limited, while speaking relatively, the extent of land is infinite. Where the land is limited, and the water unlimited, the problem is : How much water should be applied to produce a maximum crop ? Experiments show that every increase of water up to a certain point, leads to an increase in the yield of the crop, while beyond this point, additional water causes a decreased return. The problem, then, is to ascertain the amount of water needed to produce the maximum crop from a definite area. Owing to the manner in which the crop responds to the application of water, the problem in actual practice is somewhat different. With moderate applications, each slight increase of water produces very nearly a proportional increase in the crop ; but when the waterings approach the amount for maximum effect, a considerable increase of water produces only a slight increase in the crop yield. It is evident, therefore, that it will usually be better not to apply optimum waterings, because the cost of the water and its application at that stage will almost invariably be greater than the value of the increased production. To go beyond optimum waterings is mere folly—not only a waste of water but also a waste of crop.

445. Under South African conditions, the goal should not be maximun yields from unit areas, but rather maximum yields from unit volumes of water. Bearing in mind, however, that the increase of area will increase the cost of production, the object should be to produce per unit of available water the maximum crop economically consistent with the cost of production. The maximum yield depends not only on the volume of water applied, but also on the time of application and the number of applications (see also paragraph 358). At certain stages of growth, crops need water more than at others, so application at the correct times will lead to increased returns. As far as possible advantage should also be taken of any shade which the crop may throw to reduce needless evaporation losses. *The economic use of water is not generally realised by irrigators, who work usually too much by rule of thumb or by no rule at all.*

446. Irrigation would, and should, play a very important part in assisting stock farmers through periods of drought: the higher, therefore, the duty of water achieved, the more important will that part be, for the greater will be the fodder yield. This expression "duty of water" indicates effectiveness of a given volume of water in crop production, thus one speaks of a "high" or a "low" duty as the case may be. It must not be thought that the duty of water is a fixed quantity, for the effectiveness of water in crop production depends on many factors, the most important of which are the skill of the irrigator, the nature of the soil, the kind of water, climatic conditions, and the crop to be raised.

447. While it is not desirable here to enter into a discussion of the principles and practice of irrigation, a good purpose may be served if some of the principal avenues which lead to a diminution in the duty of water, be pointed out. Actual loss of water occurs in two principal ways, namely, by percolation to the water table or by evaporation from the soil surface, neither of which type of loss is wholly preventable, although each is susceptible to considerable reduction if proper methods be employed. For instance, excessive loss through percolation occurs when a porous soil is irrigated too slowly; but if such a soil be flooded rapidly, a considerable amount of air is imprisoned in its pore spaces, and this acts as a buffer preventing the water from sinking in too rapidly or too deeply. If the percolating waters escape by drainage, the loss will be confined to that water, the labour expended in applying it, and the plant food dissolved by the water from the soil; but if drainage is poor, the ground water level will gradually but surely rise until it is sufficiently near the surface to keep the latter more or less permanently wet. In the process the bottom roots of perennial crops will be drowned, the crop killed or rendered unthrifty, and soluble salts, that were formerly distributed throughout the soil, will be brought to the surface by the evaporating waters, to the detriment of crops.

448. If, however, the same method be applied to a fine-grained soil, the pore spaces of which are so fine as to render even air-movement slow and difficult, practically all the air is imprisoned, and the penetration of water so effectively hindered or retarded, that by the time the flowing water has reached the far end of the bed—when it will be turned off to prevent waste—the depth of penetration has been very much short of what is required to give a high duty; and if the crop grows, its root-system will be shallow and, therefore, unable to draw nutriment from the deeper levels of the soil. Further, the surface inches of soil will usually have become so filled with water as to exclude a proper measure of air for the needs of plants and those organisms whose function it is to prepare food substances for the nutrition of the plant. A soil of this type thus watered, remains wet at the surface for an inordinately long period and, as has already been shown, this leads to rapid and considerable losses by evaporation and maybe also to the accumulation, at the surface, of injurious concentrations of soluble salts.

449. Therefore, while a sandy soil sould be flooded as quickly as possible to prevent a loss of water by percolation, and the development of evils which may totally nullify the value of the irrigation works, to irrigate a clayey soil in a similar manner can only lead to much waste of water and poor returns. This, however, is precisely what obtains in local irrigation practice: the two extreme types of soil, as well as those between them, are all irrigated by precisely the same method, excepting perhaps that the beds of the sandier types of soil are given a steeper slope if possible. May be, the universality of the local irrigation practice originated in flood irrigation (the first to be practised on any considerable scale) the main idea in which is to irrigate a field as fast as possible, trusting that the result will be right.

450. It should be obvious, if the foregoing argument is correct, that any method for irrigating fine-grained soils should (*a*) ensure good penetration of the water, and (*b*) obviate as far as possible the lodging of water near the surface. These desiderata cannot be achieved unless the process of irrigating permits of the easy escape of some of the soil air. In practice recourse is often had to a number of furrows, a few feet apart, down which the water is slowly run. The soil surface between the furrows not being wetted by water, provided a path of exit for the soil air and, it should be observed, it serves as a mulch protecting the water which has percolated from the furrows, and in this way reduces evaporation losses. Perhaps best of all is to have the land under-drained, as this induces not only good penetration but efficient aeration.

451. The foregoing points should be sufficient to indicate that correct practice in the field will do much to increase the duty of water; but so far as your Commission has been able to discover, little or nothing is being done by the State to investigate the problems which arise in irrigation, especially in connection with the efficient use of water. *Your Commission is well aware that certain investigations are afoot at the Grootfontein School of Agriculture and, while not desiring to minimise their importance in any way, expresses the opinion that a great deal more irrigation investigation than that projected is required, not only because of the need to make the best use possible of the water available, but also because the State has huge sums of money invested in irrigation undertakings.*

452. Your Commission finds that many irrigators do not choose their crops to the best advantage, but frequently use valuable irrigated lands for crops which could be raised more cheaply in other parts of the country on "dry lands". The market price of such crops is naturally regulated by the cheaper cost of production, and the irrigator suffers financially. Only the more valuable crops should be raised under irrigation.

453. *Obviously, since the dry land farmer and the irrigator are dealing with identically the same materials—vegetation, soil, water and air—the same natural laws apply to the farming of both.* The provision of a good mulch, through the cultivation of the surface soil and the destruction of weeds, will prevent much useless evaporation of soil water, no matter whether it was derived from irrigation or from rainfall. And yet, such is the hard cleavage line that exists between irrigation and dryland farming in South Africa, that even the individual has "water-tight compartments" in his brain, for he treats his "drylands" on the good scientific principles which he does not allow to interfere with his faulty irrigation practice.

454. For instance, an example was brought to the notice of your Commission where the individual had a model "dry-land" orchard, well-tilled and without a weed to be seen; while two hundred yards away was his irrigated orchard with small basins around the tree-trunks, and soil as hard as a paved road. The difference in the yield of these two orchards led the farmer to think that irrigation was a failure.

455. The effectiveness of a mulch in the reduction of evaporation from soils is shown in the accompanying diagram (Fig. No. 11). The height of the various columns is proportional to the evaporation from soils protected by varying thicknesses of mulch. The fractions of an inch, shown at the side, give the evaporation in equivalent depths of water spread over the surface. These diagrams illustrate clearly the benefits of cultivation, and suggest that rain-water saving is a very effective makeshift for rainmaking. The prevention of evaporation, and consequently, the rendering available of larger quantities of water for vegetation, which then grows better than that of the surrounding country, is possibly the origin of the belief that cultivation "attracts" rain. No proof of this belief has yet been submitted: indeed meteorological measurements over long periods fail to show that there is any truth in it at all.

456. The same natural laws govern the activities of both irrigator and dryland farmer, and the operations of the two also overlap. The irrigator practises irrigation in the dormant season for the sole purpose of storing water in the soil, which would otherwise be lost, so also the dryland farmer believes in flooding his lands, if he can, months before seeding them. Your Commission feels that every irrigator should put the principles of dryland farming into effect, in order to enable him to achieve the highest possible duty of water. Business principles would seem to demand that at least as great a care should be taken to guard against the waste of an article that has cost much labour and capital to obtain as is taken in connection with one which drops free from the sky; yet common practice in South Africa would appear to belie this, and the returns from irrigation are much less than they should be.

457. Unless the dryland agriculturist employs scientific methods, he succumbs; but the irrigator puts all his trust in water and tries to wash out the errors of one application with the water of another. No doubt, when he has learned that dry farming methods (such as the storing in the soil, months ahead, of water which would otherwise run to waste) are not to be despised, his returns will have increased.

458. Higher up attention was drawn to the harmful effect of soluble salts when brought up and accumulated in the surface soil (see paragraph 447). The farmer calls a soil, in which the salts are visible or detectable by taste, a brak soil; but less quantities than these may be sufficient to cause considerable damage. It is a matter of history that, as a result of irrigation, much land has already become so brak as to be useless for the growth of ordinary crops. In America the damage due to this cause has been placed at over twelve million pounds sterling, and it is there maintained that, had the necessary precautions been taken, these losses could have been prevented. We are still a young country, as far as irrigation is concerned, and it would seem that we are well on the road to making the same mistakes as irrigators in other countries have done, for on all sides are to be seen the evidence of damage done or threatening.

459. Brak in irrigated lands is the result of incorrect practice. It may be that excessive waterings has brought up the brak ground-water, or that the brak originally distributed throughout a considerable depth of soil, has become concentrated near the surface, which frequently happens when waterings are insufficient or the irrigator takes no steps to prevent evaporation, as by the maintenance of a surface mulch. Poorly graded lands are also a potent

factor leading to the rise of brak. Brak may also be concentrated in soils by the use of slightly, and in itself not injuriously, brak water. This happens it the applications are insufficient to cause drainage, or when there is no sub-soil drainage or lateral movement of the soil water away from the site. Again, irrigated soil containing brak may lose a part of its salts by solution in the water and the subsequent lateral movement of this water under the surface to lower-lying areas, from which there is little or no drainage, may ruin the soil there.

460. Drainage, in fact, is as necessary to success in irrigation as the furrows which convey the water to the lands. It would, therefore, seem desirable that irrigators should enjoy the same privileges in the construction of drainage works as in the construction of supply works ; that is, the irrigator should be able to obtain loans for the construction of drainage works, should be able to obtain a right of way, where necessary, for drainage channels that must pass through properties other than his own, and all owners enjoying actual or potential beneficial use of such works, should be compelled to contribute to their cost, as is the case at present in connection with supply works. Your Commission understands that provision has been made along these lines ; but if farmers are aware thereof, they do not appear to exercise their rights. So important in this matter that, where State monies are advanced, efficient drainage works should be insisted on if the land is not well-drained naturally.

461. Your Commission, for example, noted instances where long depressions running parallel with a river bed, were being ruined by brak, whereas on both sides of these depressions were fertile irrigated lands. These depressions ran through the properties of many owners. To make drains by the shortest path to the river was, owing to the rising ground between the depressions and the river-bank, impracticable. The natural course for drainage was down the depression. A drainage canal, proceeding from the uppermost lands down this "draw" or valley, could be cheaply constructed, and it would take up the surplus brak water, draining from each farm on its route.

462. *Such ruination of fertile soil, ideally situated for irrigation, is not in the interests of the State, and should be prevented.*

463. No summary of the problems concerned with the economic use of water would be complete without reference to the effect of manures. It is an important principle in agriculture not thoroughly realised by the majority of farmers in the Union that the amount of water required to produce a crop is greatly affected by the supply of plant food substances available. Without going into technical details, it may be stated that, other factors being normal, maximum crop yields can be obtained only if a sufficiency of every one of the various plant food substances is present in available form, and provided the relative quantities in which they are present are satisfactory. From this it follows that a crop cannot make the best use of the water supply available to it unless its food supply is in every way satisfactory.

464. The effect of an adequate food supply is well brought out by the experiments of E. G. Montgomery (America) on maize. He found the transpiration ratio, that is, the number of pounds of water transpired by a plant in producing one pound of dry substance, to vary in accordance with the particulars furnished in the following table.

MAIZE.

Type of Soil.	Transpiration Ratio.	
	Manured.	Unmanured.
Poor	350	549
Medium	341	479
Fertile	346	392

465. It will be observed that the figures of the last column (unmanured soil) show that the water cost of the crop is by far the greatest in the case of the poor soil, while those of the second column (manured soil) show that when the soils are manured the water cost of the crop is practically identical in each case. It will perhaps put the matter in a clear light if it be stated that the figures show when the poor soil was manured it required 56 per cent. less water to produce a given crop yield than when unmanured. Manuring soil to insure an adequate food supply for the crop must, therefore, be considered a potent means of economising water supply.

466. The reason why irrigation engineers search for fertile soil for their schemes, and why they condemn so many where other factors are favourable, is now apparent : they consider the water cost of crops on poor soils too great to permit of profitable production. Since fertility depends on several factors other than plant food, and since a deficient plant food supply can be corrected by the application of suitable manures, the engineer will probably be at fault if he condemns a scheme solely on the grounds of deficient plantfood supply. It is

more than likely that a favourable physical constitution of the soil is of much greater importance than its chemical composition, especially in view of the fact that it is not practicable to correct an unfavourable physical make-up while it is an everyday practice to make good the chemical shortcomings of the soil.

467. There are, however, cases in which the physical make-up of the soil remains favourable only so long as the soil gets proper treatment. The question arises, "Does the irrigator till, irrigate and crop his land in such a way as to maintain its original structure unimpaired ?" Your Commissioners are of the opinion that this question cannot be answered in the affirmative except perhaps in a few special cases. Numerous are the cases brought to the notice of your Commissioners in which land, formerly friable and easy to work, has become hard and difficult to till ; and others again in which, after several years, irrigation has resulted in an impaired ability of water to penetrate the soil.

468. These facts clearly point to the physical deterioration of the soil as the result of irrigation, and your Commissioners trust that, if these aspects of irrigation have not already engaged the attention of the government experts, they will do so in the interests of economy in the use of that nationally priceless asset Irrigation Water.

469. What has been urged above in connection with the economic use of water in irrigation also applies, with necessary modification, to the use of rainfall in non-irrigated lands. For example, in the Humansdorp district an application of a phosphatic manure to the soil increases the yield of wheat (and therefore the efficiency of the rainfall) by as much as two hundred per cent. The problems of the dryland farmer have received in the past the undivided attention of agronomists : there is, therefore, not the same need to stress them here as was necessary in the case of irrigation problems.

470. Your Commission finds that :—

(i) The principles governing the economic use of water in irrigation are not generally understood.

(ii) The investigation of problems connected with irrigation deserves the earnest attention of the Government, with a view to ensuring the highest possible effectiveness of a limited water supply.

(iii) Although the problems of dryland farming are better understood than those of irrigators, there should be no relaxation of efforts which have for their object a greater efficiency of the rainfall in crop raising on dry lands.

(iv) The principles enunciated in Chapter XXIII. apply to the efficient use of rainfall in the production of natural grazing.

XXVII. Veldburning.

471. Veldburning is a very deeply rooted practice in South Africa, and as such is extremely difficult to root out. The natural dying down of grass and the decay thereof, returns to the soil the substances which the plant has withdrawn therefrom, and at the same time may enrich the soil with organic matter derived from the air.

472. Veldburning destroys a great deal of the useful covering of the soil. This covering acts in a similar way to the mulch on cultivated land in keeping down the temperature of the soil and excessive evaporation therefrom which, as has been indicated in Chapter XXIII, may assume enormous dimensions. This destruction of soil cover accelerates the speed of run-off, and since the amount of water absorbed depends very largely upon the time of contact between the water and the soil, it is evident that any factor which reduces time of contact also reduces the absorption.

473. The fact that standing grass, and still more, grass standing in an entanglement of its decaying predecessors, acts as a more or less efficient obstruction to run-off is obvious. Several farmer-witnesses, whose reservoirs are filled by run-off, partly from bare and partly from grass-covered veld, gave interesting information as to the relative amount of run-off from the two areas. Unfortunately, since the amounts are only estimates referring to single showers, they are not of general value.

474. A case was actually observed by your Commission, where the veld had been burnt on one side of a small valley, while the grass on the opposite side had been left standing. After a prolonged drought of about seven months a good shower of rain fell. A visit the following day showed that the dongas on the blackened side of the valley had all carried water, while the dongas from the unburned pasture were dry. The area under discussion was not more than a quarter of a square mile, so that there could hardly have been any marked difference in the rate of rainfall over it. The slopes on either side of the valley were gentle and insufficient to affect the relative fall on the two sides.

475. On the whole, grassburning is on the decrease in South Africa, although it is still far too prevalent. In sweet veld it is now indeed exceptional for grass to be burned. The improvement of veld, as a result of grazing control, is now generally recognised and your Commission is certain that the great impetus given to paddocking by the work of your Commission, will greatly reduce veldburning.

476. Over large areas of the Union, however, grassburning is still the rule, because, say the farmers of those parts, that is the only practicable way of getting rid of tne dead innutritious grass of the previous season. To cut the grass with machines may be impossible owing to the nature of the terrein, while to graze it off under present conditions would entail serious overstocking for many months of the year. Even here, however, paddocking would doubtless relieve the situation greatly.

477. In this connection, however, one should not lose sight of the aspect pointed out by Dr. T. R. Sim, the well-known South African forester, who says that grassveld, which grows so vigorously that it cannot be grazed down by full stocking, is naturally tree veld rather than grass veld. If stock-farming is only possible with the aid of grassburning, the question arises whether, in these areas, farms should not be devoted more to timber production than to stock-raising.

478. The timberless condition of South Africa, the enormous depletion of the world's forests to provide timber for structural purposes and for paper, are too well known to necessitate more than brief mention here. Let it suffice to point out that the tendency will be for the price of timber to rise, and that this is a reason for increased development of this branch of agriculture.

479. It is necessary also to refer to Native Reserves in connection with veldburning, which was a native custom before the arrival of the white man. Much damage is still being done by the native, and it is as necessary that he should be discouraged from destroying vegetation as that his neighbour of European descent should cease *his* devastating methods.

480. Whenever your Commission took evidence in the vicinity of a Native Reserve, the same complaint was heard—obviously a case of seeing a mote in the eye of one's neighbour and missing the beam in one's own—European farmers waxing very eloquent on the deterioration of the veld in such reserves. But this does not detract from the damage being done. Bush is being ruthlessly destroyed for the building of huts, for fuel and also to provide from time to time new lands in place of the old which, through continuous cropping without manuring have become impoverished.

481. This destruction of bush has been commented upon, particularly by forestry experts ; but there are obstacles in the way of regulating the cutting down and the burning of bush : the natives cannot understand, and perhaps the native commissioners are occasionally not over sympathetic in the cause of forest conservation. Obstacles of this kind must not however be allowed to balk efforts for improvement in a matter so important that it touches the vitals of our existence.

482. Brief reference is here made to the misdeeds of the native farmer. The evil resulting from the methods of the white farmer have been made sufficiently plain, It is, however, not only the farmer who has occasioned such extensive retrogression : the mines have been a very active cause of destruction. The vicinity of Kimberley and Barberton, in the old days, was denuded of trees for fuel. To-day the alluvial diggings are responsible for the removal of all timber and brushwood, flanking the rivers in the neighbourhood, and the asbestos and diamond mines of Bechuanaland are exacting their toll.

483. Certainly, the destruction caused by fire is now far less than three-quarters of a century ago. The miles and miles of waving grasses are no longer there, or are certainly not continuous. In the old days fires, starting at one spot, would roll on unstopped over areas which to-day are divided into as many as three magisterial districts. One still hears of accidental fires in Bechuanaland roaring their way across some seventy miles of veld before they are stopped, or halt of themselves through lack of fuel. Three-quarters of a century ago, when many of our mountain tops and slopes were covered with primeval forests, veld-fires were accompanied by far greater loss.

484. Your Commission, although of the opinion that veldburning is contrary to the interests of the country as a whole, and to the principles of veld and soil conservation underlying almost all of its recommendations, cannot recommend stringent legislation against veldburning, such as was suggested by certain witnesses. The reluctance to do so is not due to any desire on the part of your Commissioners to permit the continuance of this pernicious practice ; but merely because it would be impossible to enforce such legislation.

485. It may be necessary to explain more fully the position taken up by your Commissioners. Setting fire to veld, of which one is not the owner, is a criminal offence to-day ; yet prosecutions are very few compared with the large amount of arson taking place. More stringent legislation would hardly help, since the number of convictions (which is very small in proportion to the number of instances of veld firing) would probably not increase. If, further, the law be amended so as to make it illegal to burn even one's own veld, human nature being what it is, we may expect cases of alleged " spontaneous combustion " to become extremely common. To make the owner legally responsible for all fires occurring on his property would be contrary to our principles of equity and justice. *Your Commission cannot, therefore, see any hope of eradicating the practice of veldburning, except through the co-operation of the individual. He must be educated to realise that veldburning is not in his country's interest ; or some other means of impressing the fact upon him must be devised.*

486. Your Commission has long cogitated upon this matter. The ultimate goal should be to stop all veld fires. Unfortunately, in a democratic country it is not possible for Governments to introduce measures too far in advance of the wishes of the average voter. At the present stage, therefore, means must be devised to discourage veld fires and encourage tree-planting. Above all must veld fires and destruction of bush be prevented in those comparatively small areas of superlative value as catchments of our irrigation streams.

487. Neglecting for the present the large plateau areas of sour grass veld, let us confine our attention to the steeper mountains of our main catchments, many of which mountains are Crown Lands. As has been explained, it is impossible by legislation to prevent grass-fires, for it is a matter of no great difficulty to arrange devices for setting fire to the grass, hours or even days after one has visited a locality. Detection is practically impossible ; but there is another way. Firing of the grass is not usually done accidently or merely out of wantonness ; *but for the purpose of producing young green veld.* If, therefore, grazing the mountains be prohibited, fires will, *ipso facto*, be greatly reduced in numbers, and may entirely cease.

488. *Your Commission therefore recommends that steps be taken immediately to stop all trespassing on Crown Lands in these localities, and that rights to graze, which are enjoyed by private citizens, be withdrawn as soon as possible.*

Thereafter other areas, forming the headwaters of streams, should, from time to time as may become necessary, be proclaimed reserved areas, on which the grazing of stock is prohibited.

489. This last recommendation will, of course, affect private property, and will interfere with the individual. The matter at stake, however, is of so great importance to the country that, even at the risk of injuring an occasional individual, the State must intervene. It cannot permit of one or two individuals damaging the prospects of perhaps a score of lower owners for the purpose of providing grazing for a few goats.

490. Further, while it is almost impossible to place the responsibility for a veld fire upon the guilty person, anyone who burns, or causes veld to be burned for the purpose of providing grazing, immediately advertises to the world at large by pillar of fire at night and of smoke by day, his intention to graze that veld. With a small police staff arrests for veld fires are almost impossible. but after such an advertisement by a would-be user of the veld, it should be very easy to obtain evidence of subsequent use.

491. Such a law would be easily administered, and naturally is only proposed for selected areas, where the direct effects of veld fires on springs and streams is large. As for the remainder of the Union, it must for the present be treated by the less militant methods described above.

492. In equity, where the privilege of the individual—the right to ruin his own veld—is interfered with for the benefit of the many, it is but right that some recompense be made to him for the curtailment of his destructive activities. To provide this recompense, and at the same time to direct his energies into channels more beneficial to himself and the community, your Commission suggests that the owner of such an area be permitted to reap, free from income tax, for a long period (say fifty years), any timber which he may plant there.

493. Bordering certain of the mountains, which fall under the above mentioned description, are native areas, where increasing population demands more elbow room and endangers certain of our demarcated forest areas. The native custom of looking upon cattle as currency, of using them for barter, or as a criterion of wealth, but not as a direct source of income, results in gross overstocking, Cattle are seldom sold, but kept until they die of old age. If the mountain areas are given over to these natives, not only will the catchment be ruined, but the alleviation of the native's troubles will be purely temporary. After a limited period the increased population would in any case, cause some of them to move elsewhere, or find other means of subsistence. If, those areas, so necessary for the preservation of the flow of our rivers, were put to timber—for which they are better suited than for grazing senile bullocks—an enormous field of industry would be opened to the natives, a field which, added to better methods of cultivating their lands, would probably enable the present area to support the natural increase in population for generations to come.

494. Your Commission finds that :—

(i) Veld burning is still too prevalent and should be discouraged.

(ii) Paddocking will tend to reduce veld burning.

(iii) Much of the veld, at present used for grazing and which can be kept usable for this purpose only by frequent burning, would be far better under timber.

(iv) It cannot recommend direct legislation against veld burning, because such could not be enforced.

(v) State action to prevent or reduce grass burning must therefore, generally, be along the lines of education, of encouraging fencing, and of tree planting.

(vi) Where the right to graze is taken away, the desire to burn automatically ceases.

(vii) In the case of certain mountain-catchments particularly valuable to irrigators below, immediate action should be taken.

(viii) This action should consist in legislation prohibiting the use of certain mountain catchments for grazing.

XXVIII. Afforestation.

495. Your Commission does not think it necessary to enter into a long technical explanation of the relation between forests and rainfall. The generally accepted belief among experts appears to be that, excepting those located in particularly favourable situations, forests do not increase the rainfall in their vicinity. They do undoubtedly reduce the temperature of the air, and may also affect the incidence of the rain, reducing the severity of the storms. But the belief that isolated clumps of trees can "attract" rain is without foundation. On the other hand, many species which transpire much water vapour (as, for instance, certain eucalyptus, pines and wattles) frequently dry up springs in their vicinity, and have been used to dry up swampy ground where drainage is difficult. Cases are on record of springs having ceased to flow, except after very wet years, as a result of plantations of eucalyptus and wattles above them, and subsequently flowing again after the felling of the trees.

496. Your Commission does not desire to leave the impression that forests do not or cannot beneficially affect the rainfall of a country; but merely wishes to point out that to increase rainfall is not the simple operation some forestry enthusiasts consider it to be. Afforestation in South Africa on the largest scale conceivable and most favourable as to the location of the forests, while it might increase the rainfall of a limited area, could not be expected to alter the general character of the climate. Your Commission is, therefore, of the opinion that, if the object were only to increase the rainfall, it would not pay South Africa to carry out any extensive scheme of afforestation.

497. *A programme of extensive afforestation is nevertheless, necessary.*

498. The effect of forests on runoff has often been described. The rain is retarded in its fall to the earth by the leafy canopy, reaches the earth with a decreased velocity, and a reduced destructive force. The trees themselves, the spongelike litter of leaves in all stages of decay lying beneath them, act as obstacles to the rainwater flowing off. The time of contact between the water and the soil is thereby greatly lengthened, and opportunity for soaking into the soil is increased. Useless evaporation is reduced. The underground water, provided the trees do not transpire excessive quantities of water, is strengthened, and the perennial flow of springs assured. The surface water, running off more slowly, causes less soil erosion, and the binding effect of the roots of the trees renders the soil more resistant to the action of running water. Given a more regular flow of rivers, the necessary size of artificial regulators (reservoirs) for irrigation could be reduced. Winter irrigation from streams should become possible, facilitating the growth of winter crops, as well as increasing the possible area of land that could be cultivated. (See paragraphs 456, 457.)

499. South African data showing the effect of afforestation on runoff are unfortunately not available, but innumerable foreign examples could be quoted, showing that the total runoff from forest areas is less than from non-afforested areas. If the runoff for a week or a month be taken it is found, that although the runoff during the rainy season and just after may be greater from nonafforested areas, the runoff from the afforested area soon surpasses that of the other and continues long after it has ceased. The quotation of these foreign figures would, however, probably lead to misunderstanding. Experience in South Africa has sufficiently proved that runoff percentages depend much on local circumstances. Not only the annual rainfall, but also the intensity of the fall, the climatic phenomena of preceding months, and other factors, make the assessment of the runoff, from even one locality, a matter of extreme intricacy. Foreign percentage runoff data are, therefore, liable to mislead when applied to local catchments.

500. In short, afforestation in its effect, is the antithesis of the destruction of vegetal cover, and all of the arguments urged against the destruction of the vegetal cover, may be utilised as reasons for afforestation, provided always that the right type of tree is planted.

501. *Neglecting the reputed beneficial effect of forests on climate, your Commission desires to plead for the adoption of an extensive afforestation scheme on the following grounds, namely, decreased soil erosion and a more economic use of the rainfall; the preservation and improvement of mountain catchment areas; the regulation of the flow of rivers, and the clarification of the waters thereof.*

502. What the actual annual loss of soil to the Union through transport by rivers is is at present unknown. It may, however, serve a useful purpose to make a rough estimate. The following table shows the estimated annual discharge of certain rivers of the Union according to Mr. Kanthack. (See paragraph 341.)

River.	Estimated annual discharge in acre feet.
A.—Orange River and tributaries up to its junction with the Vaal	2,979,000