The relative magnitude of the quantity of water contributed by each of these various agencies is of considerable moment, and it will be of interest to attempt to estimate, from such scanty data as are available, how far each is responsible for the rise of spring level.

The first may be at once dismissed from consideration: firstly because it is quite impossible to estimate it, and, secondly, because it is not of much importance, since, in the nature of things, it can never cause a rise of spring level above river level, which, as a rule, will be too far below ground surface to be able to cause water-logging. Percolation from the rivers will cease, therefore, before water-logging appears, and this is probably by far the most important part of this source of ground water.

The five remaining agencies are the important ones, since they all add water to the subsoil from above ground level, and so are capable of causing a rise of the water-table which may reach that level.

The calculations in Appendix I, based on the average results of ten years' working of the Lower Chenab Canal, form an attempt to estimate the relative importance of these different agencies. From this the volume of water contributed to the soil, expressed in feet depth spread over the whole area included between the rivers and the uppermost part of the canal, is as follows :—

	Feet.
(1) Rainfall	1·10
(2) Percolation, main and branch canals ...	0·25
(3) Percolation, distributaries	0·13
(4) Percolation, watercourses	0·30
(5) Spread on fields	0·90
Total ...	2·68

It is evident that Nos. (2), (3) and (4), go direct into the subsoil, but this is not the case with Nos. (1) and (5), in regard to which it is necessary to make corrections.

A proportion of No. (1) escapes by surface drainage to the rivers, and never enters the sub-soil, but what proportion thus runs off is not known with any certainty. The Indian Irrigation Commission of 1902-1903 arrived at the conclusion that over the whole of India, 35 per cent. of the rainfall ran off in this way, but this is very evidently too high a figure for the fairly flat cultivated lands which are mostly under irrigation, and probably in such areas it will not be safe to take more than 10 per

cent. as doing so. This will leave a balance of 0·99 foot depth which enters the soil, or say 1·0 foot, and in addition to this 1·0 foot of rainfall over the whole area which must be absorbed into the soil or evaporated, there is also 0·90 foot of canal water over the whole area which is similarly disposed of, but the latter is actually spread over only about 2,250,000 acres, of which 750,000 acres is in the kharif season, and, 1,500,000 acres in the rabi season. It is necessary to form some idea how this water, aggregating 1·90 feet depth, is disposed of.

Experiments made at Lee Bridge and at Rothamstead, in England, which extended over a period of twenty years in each case, have shewn that in the former case 73 per cent. and in the latter case 55 per cent. of the rainfall not removed by surface drainage was evaporated, an average of 64·5 per cent. Similar experiments made at Nash Mills, differentiating between winter and summer, shewed that in winter 60 per cent. and in summer 88 per cent. is evaporated. In India the climatic conditions are far more favourable to evaporation than they are, in summer even in England, so that, but for the protection afforded by vegetation, it would seem to be quite reasonable to assume even 90 per cent. evaporation in India. This, however, would not take into consideration the fact that evaporation is most rapid when there is no rainfall, and that in India rainfall is more concentrated into a few very heavy falls, and is not well distributed throughout the year as it is in England, so that the conditions in India after rainfall are, owing to the humidity of the atmosphere, relatively unfavourable to evaporation, and therefore favourable to a higher percentage of absorption.

As regards rainfall, therefore, it will probably be reasonable to assume that where vegetation has little effect, 65 per cent. of the rainfall is evaporated. On the uncropped area, therefore, this figure will be taken, that is, on 1,880,000 acres (in round figures) the depth of rainfall finally absorbed will be 0·35 foot. Of the remaining area 1,500,000 acres is cropped in rabi, and 750,000 acres in kharif, that is, 750,000 acres is continuously under crop throughout the year, and 750,000 acres during the rabi only. Where a crop is grown, although the crop checks direct evaporation from the soil, it very much increases the total evaporation by means of transpiration and evaporation from the leaves of the vegetation, and in an area of such scanty rainfall it will probably be quite safe to consider that 90 per cent. of the rainfall is evaporated from cropped land. That is to say, on 750,000 acres there will be finally absorbed only 0·1 foot

of rainfall. On the remaining 750,000 acres, which is only under crop during the rabi season, the depth will be different. Roughly two-thirds of the rainfall occurs in the kharif season, and one-third in the rabi, so that on this area the depth absorbed will be—

$$\frac{35}{100} \times \frac{2 \times 1}{3} + \frac{10}{100} \times \frac{1 \times 1}{3} = 0{\cdot}26 \text{ foot.}$$

The depth of rainfall which will be finally absorbed will thus be—0·35 foot over 1,880,000 acres, 0·10 foot over 750,000 acres, and 0·26 foot over 7,50,000 acres, which reduces to an average of 0·28 foot over the whole area.

There remains the question of the canal water, equivalent to 0·90 foot over the whole area. The consumption per unit area is roughly twice as much in kharif as in rabi, but the ratio of areas is reversed, so it will be sufficiently correct to assume uniform consumption throughout the year, taking no account of changes of season. Canal water is applied more particularly when evaporation is high, and should, ideally be supplied in only just sufficient quantity to supply the needs of the crop, so that, apart from the first watering, part of which may be absorbed finally, the whole of the canal water ought to be evaporated. This ideal has not been reached, but, as methods of applying water improve, a high degree of economy may be looked for, and it should be safe to assume that not more than 10 per cent. of the canal water which is spread over the fields, will be finally absorbed into the subsoil, that is to say, an average depth over the whole area of 0·09 foot. In practice a certain amount of extra water is needed in order to carry away the salts which are contained in the canal water, but this 10 per cent. which is considered to be absorbed, added to the rainfall, should amply ensure this.

On the assumptions and results above considered, the final account of all water, both rainfall and canal water, which ultimately percolates into the subsoil will be—

(1) Rainfall	(*a*) ...	0·14		
	(*b*) ...	0·14	...	0·28 foot
(2) Main and branch canals			...	0·26 ,,
(3) Distributaries ...			...	0·13 ,,
(4) Watercourses ...			...	0·30 ,,
(5) Canal water on fields			...	0·09 ,,
	Total		...	1·06 feet

No. (1) has been divided into two parts, because the water added to the subsoil by the rainfall is very largely increased, perhaps more than doubled, when a tract is brought under cultivation, for the proportion of the rainfall which runs off by surface drainage will be much reduced when the tract is brought under cultivation. For this there is no practicable cure. From these figures it appears that in the Lower Chenab tract the canal is responsible for an increase of nearly 600 per cent. in the volume of water which enters the subsoil, out of which percolation from the main canal and its branches is responsible for about 200 per cent. while the water spread on the fields is the least serious offender, accounting for only about a 60 per cent. increase, and less than 10 per cent. of the total quantity which is now added to the subsoil. No great accuracy can be claimed for these figures, but they probably represent a very fair idea of the relative importance of the different elements in contributing to the rise of spring level and water-logging in the tract to which they refer. The figures relating to rainfall will vary from district to district, while those relating to canal water are of fairly general applicability only where the intensity of irrigation is about the same, but, until further research and observation can provide something better, they may serve. For the "Colony" canals of the Punjab they may, until superseded, be taken to apply throughout, for conditions as to rainfall, etc., are much the same on all those canals.

Earlier Methods of Prevention of Water-logging.

It is perhaps because little attempt has been made in the past to analyse the sources of subsoil water that the idea became current, and is still to some extent prevalent, that water-logging arises principally from the water which is spread on to the fields, an idea which was perhaps responsible for the now obsolete "water-logging rules" of 1901. To this, too, may perhaps be attributed the complicated systems of varying the intensity of irrigation in "zones," determined by the depth to spring level prior to the opening of the canal concerned, a means of determining intensities of irrigation which is completely stultified within a very few years of a canal being opened, owing to the rapid rise of spring level which follows.

When water-logging appeared, as it first did some sixty or more years ago, the most obvious apparent remedy, in the absence of any very extensive knowledge of the subject, was drainage; and accordingly it is found that drainage has been resorted to from time to time without any very striking success. In the

absence of knowledge of the extent to which the water spread on the fields was the cause of the trouble, the next easiest and most obvious course was restriction of irrigation, and it is perhaps in no small measure due to undue faith having been placed in this as a preventive of water-logging that only spasmodic, and, up to date, unsuccessful attempts have been made to find a more radical cure.

Restriction of irrigation is not without value for the purpose of checking, or at least, of delaying, water-logging. When it takes the form of restriction to irrigation in the kharif season it has this most useful result, that all forms of percolation from all parts of the canal are stopped for half the year, which, besides reducing the quantity of water which is added to the subsoil, gives the accumulated ground water an opportunity to drain off, and may at the same time facilitate such drainage by removing temporarily percolation cones which obstruct subsoil flow when the canal is open.

Reduction of the intensity of irrigation is also to a slight extent useful as a check to water-logging, because it reduces the quantity of water which is added to the subsoil. But the reduction in quantity of water added to the soil will not be proportionally so great as will be the reduction of irrigation, and is seldom likely to be sufficient seriously to affect the question of water-logging. The watercourses, according to the figures tabulated on page 44, are responsible for only about 30 per cent. of the water which reaches the subsoil, and it seems unlikely that this can be reduced to less than 20 per cent., if any useful percentage of irrigation is to be retained. Such reduction, moreover, is most difficult to put into effect, owing to the vested interests which are concerned to get as much canal water as possible.

Drainage.

Up to date, apart from restriction of irrigation, and a few desultory and incomplete attempts to line canal channels with a more or less waterproof material, the only means which have been tried for the alleviation of water-logging is drainage, a means which, in the opinion of some, is highly efficacious, while others, among whom is included the present writer, consider that it offers little prospect of success and at best is a mere palliative of a disease, for which it is most necessary to find a radical cure. It is perhaps in deference to the former opinion that it has, of recent years, been customary when constructing a new canal, to mark out and reserve strips of land along all the main lines of surface drainage, ostensibly for the purpose of dealing with water-logging, should it arise. In the writer's opinion this course

is entirely useless for that purpose, though it is certainly a wise proceeding from the point of view of preventing surface flooding by ensuring good surface drainage. Such divergent views as are held regarding the value of drainage as a remedy for water-logging can hardly both be correct, and for the purpose of justifying his own somewhat unorthodox opinion the writer will now indicate the way in which drains may be supposed to work.

In Fig. (18), G G is ground level in water-logged ground, and S S immediately beneath it is the spring level which it is desired to reduce.

Before operations are commenced there will be a state of equilibrium, but as soon as the seepage drain D is dug this

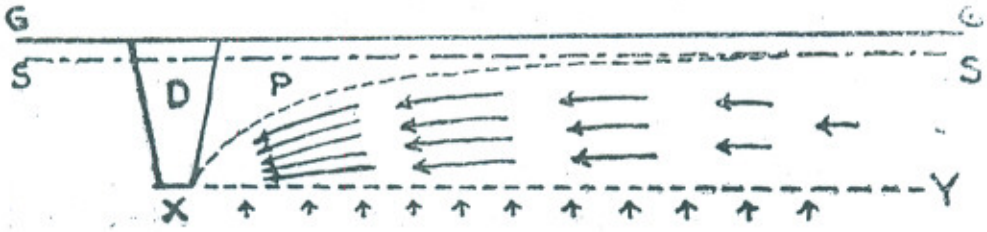


FIG. 18

equilibrium will be disturbed. Water will flow into the drain, and the spring level will be lowered. As a result of the lowering of the spring level there will be an upward flow of subsoil water throughout the whole width X Y affected by the drain, as shewn by the small arrow heads in Fig. (18), and the water which thus rises above the line X Y will be removed by flow towards the drain through the soil lying above the line X Y. It is evident that this flow towards the drain is such that the discharge constantly increases and the area constantly decreases on approaching the drain, so that the velocity must increase very rapidly towards the drain, and in order to maintain it the slope of the subsoil water surface must get steeper and steeper as it gets near the drain. What this amounts to is that the new spring level line will be a parabola X P S, having its axis horizontal and its apex in the drain, while it will be asymptotic to the original spring level line. Careful and reliable observations of spring level in such circumstances are wanting up to date, but the cone of depression of a well is an analogous case, and supports the very crude reasoning above given. As a consequence of the spring level line taking this curved shape, the effect of a seepage drain will be purely local, just as the effect of pumping

from a well is found to be so, but the effect of a drain will be even less extensive, because the head causing flow will be very much smaller. There is little information available as to the actual dimensions of the spring level curve in the neighbourhood of a seepage drain, but in one example seen by the writer a drain 100 feet wide and extending down to 5·3 feet below spring level had no effect at all at a distance greater than 200 feet from the drain, so it can be judged that its useful effect must have been limited to a distance considerably less than this. The effect can be extended to a greater distance only by making the drain deeper, and there is a limit to the extent to which this can be done, for, the deeper the drain, the greater will be the velocity of seepage inflow into it, and, unless the drain is protected by revetments, it will not be long before the velocity attains a value which causes the sides of the drain to slough in.

It has yet to be decided what constitutes water-logging. By some it is held to occur only when spring level reaches ground surface, while others consider, and in the writer's opinion more correctly, that water-logging should be defined as being a rise of spring level to a distance so little below the ground surface as to cause soil deterioration or damage to public health. What depth this definition calls for is not yet known with any certainty, and is a matter for research by sanitary and agricultural experts. The opinion has been expressed in India that a depth of ten feet is required, while in Egypt a depth of $1\frac{1}{2}$ to 2 metres, or say 5 to $6\frac{1}{2}$ feet has been quoted as being necessary for agricultural purposes. The writer's view has been expressed earlier in this paper, and is that the spring level should be at such a depth that the zone of capillary moisture which overlies the water-table should ordinarily not come higher than say within one foot from ground surface. This condition will require a different depth for every class of soil, which depth can be determined only by experiment.

Reclamation of land naturally water-logged has been effected both in Egypt and in Italy by means of drainage, and it is interesting to see how this has been done. The plan in Fig. (19) will give a good idea of the measures which are necessary, and of what drainage for the alleviation of water-logging means. It is a plan of a typical block of land, about three-quarters of a square mile in extent, at Lake Aboukir in Egypt, which has been reclaimed by drainage, and it shews the system of drains which has been found necessary for the purpose of keeping the and sufficiently dry for cultivation. The plan speaks for itself

and suggests that if such an elaborate system of drains is found to be necessary in other countries, the rudimentary systems of drains which have been made in the Punjab are mere toying with the subject, and can neither have had nor be expected to have any appreciable effect on water-logging. Such drains as have been dug, ostensibly as a cure for water-logging, are for the most part mere surface drains, and are at such distances apart that even had they been deep enough to act as seepage drains, they could have had only the most local effect.

The examples of Egypt and Italy, in which latter country very similar systems of drains are in use, shew conclusively that water-logged soil can be rendered fit for cultivation by means of drainage, but only by a system of drainage of great elaboration and costliness, both for initial cost and for upkeep. For the system of drains shewn in Fig. (19) it is calculated that the cost in the Punjab would be as below ; it requiring no less than 400 lineal feet of drain per acre.

	Rs.	a.	p.
Excavation	8	0	0
Land occupied	7	8	0
Maintenance (capitalised) ...	50	0	0
Total, per acre protected ...	65	8	0

These figures make no provision for pumping, which might become necessary were no suitable gravity outfall available for the main drain. The proper maintenance of such a system of drains would be a matter of constant and grave concern, for failure to maintain them in good order would render them completely useless. Such a system would then be both very costly and very troublesome, and before embarking on such schemes it is necessary to be very sure that no more satisfactory cure is available at a cost which shall make it financially practicable. The cost of such a system of drains increases rapidly as the depth to which spring level must be reduced increases, and were a depth of about six feet required, the cost per acre protected would be about treble the figure above arrived at.

Attempts have been made to intercept the percolation water from large canals by means of seepage drains parallel to and close along side the canal. This is a seepage drain having a different function, which, at first glance, might seem to have more to recommend it, and is therefore deserving of some consideration.

Such a drain might be expected to ensure that spring level in the soil beyond it should not rise to a height greater than the level of the water in the drain, and if correctly proportione , it will perhaps do this. The effectiveness of such a drain will be determined not by its depth alone, nor by its capacity to carry off water, but principally by the extent of its seepage area, that is, by the quantity of water which can percolate into it per lineal foot of drain. If this quantity is not less than the quantity which percolates out of the canal per foot run, the drain will probably intercept the whole of the percolation water, and prevent spring level outside it rising above the desired height. Failing this, percolation flow will continue to take place beneath the drain, and the spring level outside it will rise, the only effect being a purely local reduction of level on each side of the drain.



FIG. 20

In Fig. (20), suppose C is a canal which is causing water-logging, and that the water-table resulting from its presence is S S S. Now let a seepage drain D be dug to some depth below S S S for the purpose of intercepting flow from the canal, and let W W be the water level in the drain. It is clear that seepage will commence through the sides and bed of the drain at a rate which will be due to the head "h," the intercept between spring-level and water-level in the drain.

In the canal it may be assumed that percolation takes place under a head H, the depth from water surface in the canal to the point at which the water-table curve attains a fairly uniform gradient. Considering only one half of the canal, it follows that the percolation flow from it will be equal to $V = K\frac{B}{2}\phi H$, where B is the wetted perimeter, while seepage into the drain will amount to $V' = K\, b\phi h$, where b is the seeping perimeter of the drain. In order that flow under the drain may cease entirely, and seepage from the canal be cut off, it is clearly necessary that $V = V'$, or that $\frac{B}{2} H = b\, h$. The value of H will seldom be less than 5 feet for any large canal, and even if the depth of the drain is made such that h also is 5 feet, it follows that b, the seeping perimeter of the drain, must be

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equal to half the wetted perimeter of the canal. The conditions assumed in the foregoing calculation are that a high spring level already exists and has to be reduced. After it has been reduced the conditions will be altered for the worse even, for the seepage head at the side of the drain remote from the canal will then become nil, and the average head will therefore be less than the value h, assumed above, so that the seepage per unit area will be less and a still greater seeping perimeter will be necessary. In practice, unless heavy revetments are put into the bed and sides of the drain, it is unlikely that h can be made as great as 5 feet.

An intercepting drain of this nature will, then, need to be either extremely wide, or very deep and protected by revetments, and in either case its cost will be immense, while it is at the same time subject to the drawback that it will actually increase the volume of percolation from the canal by providing an easier path for percolation flow. Such a drain, therefore, has little to recommend it, and is not likely ever to be a satisfactory solution of the problem of water-logging by percolation from canals.

It is sometimes stated that the very rudimentary systems of drains which have been constructed on some of the older canals of the Punjab have in fact cured water-logging, and it is a fact that some improvement has followed the construction of some of these drains, but it would not be safe to conclude that this improvement has been a consequence of the construction of the drains. In nearly all, if not in all, such cases of apparent cure by drains, it will be found that other influences have also been at work which may well have had more effect than the drains, and, in the writer's opinion, the improvement is not at all likely to have been caused by the drains, which have been for the most part mere surface drains. There seems to be only one way in which such drains could have any influence on water-logging, and that is by increasing locally the percentage of runoff from rainfall, whereby seasonal fluctnations of spring level would be somewhat reduced, and seasonal water-logging thus become slightly less frequent.

Drainage, then, would not seem to be a very promising means of combating the evil of water-logging caused by canals; a view which is by no means new or original, for as long ago as 1857 Colonel Baird Smith, then Superintendent-General of Irrigation, wrote as follows:—

"———. No measures, dealing only with the effects of percolation, as drainage works must necessarily do, can effectually

remove the evil. To trust to them would be like trying to cu an organic disease by treating its symptoms and leaving its sour untouched. I am, therefore, strongly of the opinion that, a radical removal of the effects of percolation is desired, remedi measures must be directed to the canal itself, and not to th country outside it."

Again, in 1862, Colonel R. Maclagan, then Secretar to Government, Punjab, P. W. D., wrote as follows :—

"Drainage is, however, a remedial measure of only secondary value. Unless the levels of some part of the surround ing country are favourable, it cannot be carried out, and, in any case, drainage even where most fully practicable, as a remedy for an evil which continues to be produced, and to require this provision for meeting it, must be looked on as a measure of very inferior efficacy and worth, to noe which strikes at the root of the evil and aims at prevention instead of cure."

These opinions remain as true to-day as they were the day they were written, and it is indeed remarkable that in the sixty years which have since passed, although the water-logging trouble has constantly recurred, no real advance has been made in its treatment. It is, however a problem which now calls urgently for solution, for, with the recent and projected increases in the number of large canals, and with the increase in age of those already working, the evil is likely to become far more serious and widespread, as witness the steady rise of spring level in the Lower Chenab Canal tract, which as yet shews no signs of coming to an end. That a state of equilibrium will some day be reached admits of no doubt, and, in fact, on the oldest canals and in some parts of the newer ones, a careful and complete examination of the subject might shew that it has already been reached, but there is evidence that, in some areas, at any rate, very considerable areas of land are likely to be ruined before that condition is arrived at. It behoves irrigation engineers, therefore, to thresh out the subject energetically and thoroughly in order that effective prevention may be made possible before serious damage is done.

Lining Canal Channels.

The only other means of dealing with water-logging which suggests itself is the lining of canal channels with some water-proof material. The figures on page 44, shew that if all canal

channels, from main canals to watercourses, were lined with a really waterproof material, canal water would cause an increase in the water added to the subsoil equivalent to 0·09 foot depth over the whole area only, while such lining would completely prevent obstruction of subsoil drainage, so that, although the bringing of the land under cultivation has probably increased the quantity of rainwater which enters the subsoil by 100 per cent. since subsoil drainage would be unobstructed, the increased quantity would drain off without causing a dangerous rise in the level of the water-table. From the figures given on page 44, it is seen that the quantity of water added to the subsoil has been increased on the Lower Chenab Canal from the equivalent of 0·14 foot to the equivalent of 1·06 feet, that is, by nearly 650 per cent. and the point for determination is how much of this increase can be tolerated in order that the whole amount may still drain off by subsoil flow without causing water-logging. This is a question to which, in the present state of knowledge, no reply can be given, and until far more careful and extensive observations have been made of the rise of spring level, and the phenomena of subsoil flow have been more closely investigated than has yet been done, it is only possible to make speculations on the subject.

It would at present be quite impracticable to line the whole of the canal channels with waterproof material, and, if a selection is to be made for lining parts of them only, it is clear that distributaries should be left out of the question and attention concentrated on the watercourses and on the main and branch canals. The stoppage of percolation from main canals and from watercourses by means of waterproof lining has this further advantage, that it renders available more water for application to the fields, so that expenditure on the lining of channels, besides being of use for the prevention of water-logging, will also be to some extent remunerative to the State, both directly, from the additional sum recovered in charges for water and for land revenue, and indirectly in increasing the productivity of the land ; for were percolation from watercourses stopped there would no longer be any point in restricting the intensity of irrigation, and without making any extension of canals a very much larger area of crops could be matured.

The advantages of waterproofing watercourses were realised twenty years ago, by the late Mr. R. G. Kennedy, and under his instructions a series of experiments on waterproof linings was carried out, but, unfortunately, did not result in the

discovery of any suitable material, so that the experiments proved abortive. The effect of such a lining in checking the rise of spring level does not seem at that time to have been considered at all ; had it been, perhaps instead of the matter lying dormant for fifteen years, this added incentive would have resulted in greater persistence in carrying out experiments, and the discovery of a lining suitable both for watercourses and for main canals.

Financial Aspect of Lining.

At that time it was calculated that from Rs. 2,000 to Rs. 4,000 per mile of watercourse could be expended without absorbing the whole advantage of the water saved, but these figures now seem to need revision, and may be recalculated. The figures given in Appendix I, shew that only 75 per cent. of the water which enters the canal head reaches the outlets and passes into the watercourses. They shew also that 25 per cent. of the outlet discharge is lost by absorption in the watercourses, and, were the latter loss prevented, the area of irrigation could be increased by 33 per cent.

Taking the Lower Chenab Canal as an example, it appears from the figures given in Appendix II, that on the average of the past ten years working, every cusec which enters an outlet has irrigated 390 acres of crops annually, so that an average watercourse, having a discharge of two cusecs at outlet, would irrigate 780 acres of crops in each year. The revenue derived from this, including both direct water-rate and enhancement of land revenue, has averaged about Rs. 6-12 per acre, so that the total receipts from an average watercourse have averaged Rs. 5,265 annually. If the area irrigated were increased by 33 per cent., by preventing loss of water by percolation, the increase of revenue would, on this basis, be Rs. 1,755 per annum, which, capitalised at 5 per cent., amounts to Rs. 35,400 for an average watercourse as the amount which could reasonably be spent on waterproof lining. The length of an average watercourse is three miles, and in order to line it completely it requires 15 square feet of lining per lineal foot, or a total area of 225,000 square feet. Thus the increased revenue resulting from such lining would balance an expenditure of $\frac{35,400}{2,250}$ = Rs. 15-12-0 per hundred square feet of lining even at the low pitch of water-rates now cnrrent, while the true value of the water would justify at least 50 per cent. more expenditure. Thus a really effective and durable waterproof lining for watercourses would cost the State nothing even though

a sum of Rs. 24 per hundred square feet were spent on it, and, up to this limit, on this canal, its further service as a precaution against water-logging would be obtained for nothing. This figure will of course vary from canal to canal according to the local conditions of average discharge, duty, water-rate, etc.

So much for the financial aspect of the lining of water-courses. As regards the lining of large canals, similar calculations can be made. Thus suppose a main canal loses by percolation 12 cusecs per mile, and has a wetted area of 250 square feet per lineal foot. The value of the water lost will be, in this case, $12 \times 290 \times 6{\cdot}75 =$ Rs. 23,490 per annum per mile, representing a capital cost of Rs. 469,800 per mile, or nearly Rs. 38 per hundred square feet of perimeter, which, at the present standard of water-rates, would be the limit of expenditure on lining, which would pay for itself in extra revenue from water saved. This figure will also vary from place to place, and must be separately calculated in each case, but it shews that with water-proof linings much can be done to prevent water-logging without any real expense to the State, a respect in which such linings are far superior to any system of drainage which can be devised.

Thus the financial aspect of waterproof linings as a cure for water-logging, whether applied to watercourses or to main canals, is most encouraging. Expenditure on them would be immense, but it would be productive expenditure, even apart from its value as a safeguard against water-logging. It would not, probably, be necessary to line the whole of the main and branch canals of a system, and local lining in carefully selected reaches might be expected to suffice, so some special cases may now be examined to gauge the probable effect of linings in large canals.

Probable effect of Lining certain Lower Chenab Canal Channels.

Reverting to Fig. (12), the probable effect of lining the main canal and the Kot Nikka and Gugera Branches may be considered. In this cross section the spring levels suggest that percolation from the main canal passes away in two directions to each side of the channel. That passing off to the left seems to be obstructed by the percolation cone of the Gugera Branch, so that water-logging between the main canal and this branch seems inevitable unless some remedy is applied, and percolation from the Gugera Branch itself is also helping to fill up this area. A waterproof lining in the Gugera Branch, besides reducing the volume of water added to the subsoil, would do away with the percolation cone of that Branch and would thus remove obstruction

to subsoil flow beneath it, permitting the percolation water from the area between the Gugera Branch and the main canal to pass off beneath the Gugera Branch, as is at present the case in Fig. (13).

On the right of the main canal the Kot Nikka Branch does not seem to cause any obstruction to subsoil flow, perhaps because its head seven miles has already a concrete lining. Percolation water here comes almost entirely from the main canal and its branches, for there is not much irrigation in this area and so not many watercourses. Hence, if both the main canal and the Kot Nikka Branch were lined, not only would the volume of percolation water be much reduced, but obstruction to subsoil flow by the percolation cone of the main canal would cease, and percolation from watercourses, etc., in the area between the main canal and the Gugera Branch could find a second outlet in this direction. The net result would be that no water-logging would be likely to occur in this area.

Coming now to Fig. (13) once more, there is here some water-logging on the right of the Jhang Branch, which must be due principally to percolation from that branch, and a water-proof lining should cause considerable improvement. On the left side the Gugera Branch does not seem to be causing any obstruction to subsoil flow, and it would at present serve no useful purpose to line it. There is, however, a disquieting rise of spring level here, which has so far been steady, and shews no sign of coming to an end, and this is likely, in course of time, to result in the water-table rising into the "solid" portion of the percolation cone of the Gugera Branch. It may be observed that, at present, probably the greater part of the percolation water from the channels and fields lying between the Jhang and Gugera Branches, and also a part of that from the Jhang Branch itself, has to pass away beneath the Gugera Branch, the remainder escaping longitudinally down the *doab*. Were the Jhang Branch lined, there would be no percolation from it and no obstruction to flow under it, with the result that part of the percolation water from the area between the two branches would find a new and shorter route for escape under the Jhang Branch, reducing the volume of flow and rate of rise of spring level under the Gugera Branch. Thus a lining put into the Jhang Branch would be likely not only to check water-logging, but also to render lining unnecessary in the Gugera Branch.

The waterproofing of the upper portions of a canal must also have a marked effect on the rate of rise of spring level in

the lower portions, for, of the whole volume of percolation flow from main and branch canals, by far the greater part occurs in the upper reaches of the canal, and, besides causing a very intense rise of spring level in the immediate neighbourhood, a considerable part of this water travels parallel to the canal and contributes to the rise of spring level in the lower parts of the area.

It may be here noted that while the lining of watercourses will certainly do much to reduce the rate of rise of spring level in the lower portions of the canal area, where percolation from watercourses is relatively far more important than would appear from the figures on page 44, it is of very little use in the upper reaches, where the watercourses have much less, and the main canal much more, influence than would appear from the figures given on that page, so that in such places the lining of main canals is all important. The same is also to some extent true of places where water-logging is threatened from geological causes, and it is therefore most essential to determine the precise cause of water-logging in every case before attempting a remedy.

The two examples given will suffice for the purpose of shewing how, in tracts where the soil is reasonably homogeneous, a careful study of spring levels in their relation to the canal system and to the contours of the ground surface and position and levels of the rivers, can be made to shew where lining would be useful, and where it is not likely to be needed. Where the soil is not fairly homogeneous, a geological survey will also be needed, for where there exists an impermeable stratum lying beneath the canal, unless it is at a very considerable depth, water-logging can only be prevented by lining the canal with a water-proof material. The water proof lining of water courses and of main and branch canals in selected places promises, then, to be by far the cheapest and most effective means of preventing water-logging, but, having arrived at this conclusion, there remains the problem of how to line the channels, and it must be admitted that up to date no really efficient means of so doing has been discovered.

Lining Material.

A certain amount of experimental lining has been done on the Punjab canals, mostly with puddle or cement linings, but both have proved costly and neither is entirely satisfactory. Good puddle clay is not at all common, is very laborious to lay, and is liable to crack and become useless, while, cement is costly,

difficult to lay, and also liable to crack, while at best it is doubtful how far either of these materials is really impermeable. Neither, therefore, offers much ope of success.

What is wanted is a lining which shall be practically, if not completely, impermeable ; shall be easy to lay, so that the work can be carried out during short closures of the canal, and shall be durable and not liable to crack.

It may here be remarked that the application of linings to canals presents two different aspects. When a new canal is to be lined at the time of construction, the work can be done easily and it may be possible to economize in the section of the canal owing to the lesser roughness of the lining as compared with an earth channel, and to the lining having greater power of resistance to erosion than an earthen channel has. On an old canal this is not possible, for the cost of reducing the section of the canal would outweigh all the advantage of the reduced section, so that in this case cheapness and ease of application become of prime importance. It is not necessary that a waterproof lining should have much mechanical strength, for it can be laid below bed level and protected by a layer of earth. On one canal in the Punjab a lining of oiled paper was experimented with over a short length, being buried under a protective layer of earth. Just at first this proved to be very successful, but it lost its impermeability very quickly and soon became useless, owing, no doubt, to the oil, itself a fluid, flowing away and leaving the paper in its natural absorptive state. This experiment suggests, however, that thin films of waterproof sheeting, if of suitable material, might prove to be a solution of the problem on old canals, and the writer would suggest that asphaltic or bituminous sheetings should be experimented with, since these are not substances that will flow, are flexible, and so will not crack, and may be expected to prove to be completely waterproof. Provided that the joints offer no serious difficulties such sheeting would be very quickly and easily laid, and thus, if it can be done at a reasonable cost, it may well turn out to be a most effective means of lining old canals.

Once the difficulty of finding a suitable material for lining canals is overcome, so that it becomes possible to line channels quickly and at reasonable cost, the spectre of water-logging will be in a fair way to being laid for ever, and the productivity of the canal-irrigated areas would be much increased without danger of ruining large areas of land by water-logging.

Conclusions.

The general conclusions which may be drawn, then, from such information as is at present available in regard to water-logging as a consequence of the introduction of canal irrigation may be summed up as follows :—

(1) A canal crossing a surface drainage line does not have any influence on subsoil flow, so that, provided proper surface drainage crossings are provided to obviate accumulations of water on the surface, there is no objection to a canal alignment crossing surface drainages.

(2) The form of the water-table prior to the introduction of canal irrigation is of little account. What needs to be studied is the form of the water-table which is likely to result from the construction of the canal, and canal alignment should be selected as far as possible so that their percolation cones shall not obstruct subsoil flow beneath them. It will in practice seldom be possible to take this into consideration when designing canals, since surface considerations will generally make alignments compulsory which are often the worst possible from the point of view of subsoil drainage.

(3) Careful inspection of cross sections of ground surface will generally make it possible to determine places at which water-logging is liable to occur. Water-logging arising from the presence of an impermeable stratum beneath the canal cannot be foreseen by this means, but a study of geological sections will reveal danger spots due to this cause also.

(4) There is no reason to suppose that any of the drainage works so far carried out in the Punjab have had or ever can have the slightest effect as a remedy for water-logging. To be of use for this purpose a most intricate system of drains is needed, such as has never yet been attempted anywhere in the Punjab. Such a system would be very costly, most troublesome to maintain, and at best would be only a palliative of a trouble which it could never cure.

(5) The introduction of canal irrigation causes an increase in the quantity of water added to the subsoil of 200 to 600 per cent. according to the rainfall and the intensity of irrigation, and of this by far the greater part is contributed in nearly equal parts by the main canals and by the watercourses. Other parts of the canal system have relatively little effect.

(6) The action most likely to lead to extensive and dangerous water-logging is the obstruction of subsoil drainage by the percolation cones of the larger canal channels, and this can be prevented only by waterproofing the bed and sides of such channels. The lining of all such channels would probably not be necessary, provided that they were lined in suitable selected reaches, mainly at and near bifurcations of large channels.

(7) Before more precise conclusions regarding the obstruction of subsoil flow by percolation cones can be arrived at, observations of a much more careful and detailed character than have hitherto been made are needed, and these should be made in wells or bore holes sunk specially for that purpose. But, so far as information is at present available, it is probable that there is little danger of such obstruction being caused by channels of moderate size, such as large distrbutaries, unless spring level is already very near the ground surface.

(8) Water-logging which becomes apparent only after rainfall is not necessarily the result of that rainfall, but may really be due to a permanent rise in spring level having followed the introduction of canal irrigation. For the purpose of distinguishing the cause of water-logging in such cases a record of spring levels prior to the construction of the canal is necessary, and a spring level survey should, therefore, always form part of the project survey of a canal.

(9) Where, as on the main line of the Lower Chenab Canal, water-logging has appeared as a consequence of the very large amount of water percolating from

the canal needing a steep gradient to carry it away, lining will be the best remedy.

(10) No entirely satisfactory means of lining canals with waterproof material has yet been evolved, and further experiment thereon is most essential.

(11) The waterproof lining of canals and watercourses, besides offering the best protection against the water-logging danger, may also prove to be actually remunerative owing to the revenue which will be obtained from the water which will be saved, while it will also increase the general productivity and resources of the country. No effort should therefore be spared in order to arrive at a satisfactory means of effecting it.

With these general conclusions the subject may be left for consideration and discussion. The author has, in this paper, brought out little or nothing that is original or new, but he has endeavoured to review the whole subject of percolation and water-logging from canals on a broad basis, and to focus attention on some aspects of the question which seem in danger of being forgotten.

Much further investigation and research is needed in order that the subject may be adequately dealt with, and the author has endeavoured to suggest directions in which further enquiry seems to be more particularly called for. The subject of percolation from canals is a vast one, and one on which reliable information of a sufficiently detailed character is conspicuously lacking. It offers, therefore, a most promising field for research which, while being itself full of interest, is likely at the same time to be fruitful of results beneficial to the country and creditable to the science of irrigation engineering, which the present backward state of the subject certainly is not.

APPENDIX I.

Rainfall and Absorption on the Lower Chenab Canal.

Year.	Mean Rainfall.	Canal Head Discharge less Escapage.	Distributary Head Discharge.	Loss in Main Canal and Branches.
	Inches.	Cusec days.	Cusec days.	Cusec days.
1909-10 ...	14·7	2,745,076	2,171,494	573,582
1910-11 ...	15·6	2,632,214	2,161,819	470,395
1911-12 ...	5·0	2,889,775	2,356,999	532,776
1912-13 ...	11·5	2,801,316	2,293,311	508,005
1913-14 ...	14·0	2,647,129	2,156,420	490,709
1914-15 ...	17·9	2,786,152	2,363,268	422,884
1915-16 ...	3·25	2,733,714	2,393,872	339,842
1916-17 ...	15·0	2,523,549	2,082,789	440,760
1917-18 ...	27·0	2,330,329	2,019,001	311,328
1918-19 ...	8·21	2,908,166	2,476,156	432,010
Total ...	132·16	...	22,575,130	4,522,291
Average ...	13·21	...	2,257,513	452,229

Total volume of water lost annually in main canal and branches $= 60 \times 60 \times 24 \times 452{,}229 = 39{,}552{,}585{,}600$ cubic feet.

Area of water surface.

$40 \times 5{,}280 \times 280 = 59{,}136{,}000$ square feet.

$387 \times 5{,}280 \times 100 = 204{,}336{,}000$ „

Total $= 262{,}472{,}000$

Volume evaporated $6 \times 262{,}472{,}000 = 1{,}574{,}832{,}000$ cubic feet.

Volume absorbed $(39{,}552{,}585 - 1{,}574{,}832) \times 2 = 37{,}977{,}753{,}000$ cubic feet.

This volume, spread over 3,385,000 acres, is equivalent to a depth of 0·26 foot over the whole area.