



Government of Bombay
Public Works Department

Technical Paper No. 24

Report on Land Drainage Experiments at Baramati

BY

C. C. INGLIS, B.A., B.A.I., M.INST.C.E.,
Superintending Engineer, Irrigation Development and Research Circle

WITH

V. K. GOKHALE, B.A.G.,
Deputy Soil Physicist

and the Staff of Baramati Development Subdivision

[Price—Rs. 2 Anna 1 or 4s.]

BOMBAY

PRINTED AT THE GOVERNMENT CENTRAL PRESS

1928

Available from the Superintendent of Government Printing and Stationery,
Bombay; from the High Commissioner for India, 42 Grosvenor Gardens,
S.W.1, London; or through any recognized Bookseller

List of Bombay Public Works Department Technical Papers

Paper No.	Subject	Price	Year of publication	Number of copies in stock (July 1928)
		Ra. a. p.		
1	Reinforced Concrete Flooring in the Hostel for the High School at Satara (Bombay Presidency), by W. L. C. Trench, B.A.I., A.M.I.C.E., Executive Engineer, and T. S. Mirchandani, B.Sc. (Edin), Assistant Engineer.	....	1913	Out of stock.
2	Famine Relief Road Works carried out in the Banda District, United Provinces, in the Famine of 1913-14, by D. R. H. Browne, A.K.C., Executive Engineer.	....	1915	Do.
3	Note on the Lower Ganges Bridge Works at Sara, Bengal, by D. R. H. Browne, A.K.C., Executive Engineer.	....	1916	Do.
4	Report on experiments on Concrete Flooring carried out at Poona (Bombay Presidency), by Conductor T. H. Naughton, Sub-Engineer.	....	1917	Do.
5	Reinforced Concrete Works in the Bombay Presidency by J. C. Gammon, B.Sc., A.C.G.L., late Assistant Engineer, Bombay Public Works Department.	....	1917	Do.
6	Reinforced Concrete Roof Construction for use with ceiling tiles, by J. M. Mackay, A.M.I.C.E., Executive Engineer.	....	1917	Do.
7	Report on the Felling on the Masonry Chimney at Dapuri (Bombay Presidency), by H. W. Oddin-Taylor, A.C.G.L., B.Sc., Executive Engineer.	....	1920	Do.
8	Note on the Tests carried out with Reinforced Concrete Brick Walling loaded as a Beam, by Khan Saheb J. D. Dubash, Assistant Engineer.	....	1920	Do.
9	Note on the Manufacture of Hydraulic Lime in the Nasik and Ahmednagar Districts of the Bombay Presidency, 1920, by Rao Sahab V. K. Chapekar, Temporary Engineer.	....	1921	Do.
10	Glossary of Irrigation Terms applicable to the Deccan Canals.	....	1921	Do.
11	Report on the Malir River Boring Investigations for the Karachi Water Supply by H. O. B. Shoubridge, M.Inst.C.E., Chief Engineer for Irrigation.	....	1925	Do.
12	A Note on the Design, Application and Construction of Masonry Semi Modules as used on the Jamrao Canal, by Mr. Kirkpatrick, Executive Engineer (2nd Edition).	0 12 6	1925	Do.
13	Soil and Subsoil Surveys in the Deccan Canal Areas, by C. C. Inglis, Executive Engineer, and V. K. Gokhale, Deputy Soil Physicist.	0 6 0	1926	Do.
14	A short Note on the Improvement of Damaged Lands in the Canal Irrigated Tracts of the Bombay Deccan, by C. C. Inglis, Executive Engineer.	0 4 6	1927	15
15	Notes on Standing Wave Flumes and Flume Meter Falls, by C. C. Inglis, Executive Engineer, Special Irrigation Division.	....	1928	200
16	Note on Irrigation on the Block System in the Deccan Canal Tracts, by C. C. Inglis, I.S.E., Executive Engineer, Special Irrigation Division.	0 5 0	1927	55
17	Note on the Effluent Farm near Poona (1918-19 to 1925-26), by C. C. Inglis, B.A., B.A.I., M.Inst.C.E., Executive Engineer, Special Irrigation Division.	0 15 0	1927	55
18	Note on the use of Hydro-Electric Power by small Industries in Switzerland, Norway and Sweden, by F. O. J. Roose, M.I.M.E., M.I.E.E., Electrical Engineer to Government.	....	In Press.	....
19	Note on the Design of Distributaries and their Outlets in the Bombay Deccan, by C. C. Inglis, B.A., B.A.I., M.Inst.C.E., Executive Engineer, Special Irrigation Division.	....	1928	100
20	Note dated November 1927 on 'Model experiments to ascertain the effect of partial lining of the Malegaon Cut in miles 39 and 39 of the Nira Left Bank Canal,' by C.C. Inglis, B.A., B.A.I., M.Inst.C.E., Executive Engineer, Special Irrigation Division, and D. V. Joglekar, B.E., Assistant Engineer.	....	1928	200

Paper No.	Subject	Price	Year of publication	Number of copies in stock (July 1928)
		Rs a. p.		
21	Note on the Outturn and Profit from Sugarcane Crops grown in the Deccan Canals tracts, by C. C. Inglis, B.A., B.A.I., M.Inst.C.E., Superintending Engineer, Irrigation Development and Research Circle.	....	1928	100
22	Note on experiments carried out at the Hydraulic Testing Station at Distributary No. 5, Mutha Right Bank Canal near Poona with a Lindley type Standing Wave Flume, by C. C. Inglis, B.A., B.A.I., M.Inst.C.E., Superintending Engineer, Irrigation Development and Research Circle, with the assistance of D. V. Joglekar, B.E., Assistant Engineer.	....	1928	100
23	A Note on Standing Wave Pipe Outlets, by C. C. Inglis, B.A., B.A.I., M.Inst.C.E., Superintending Engineer, Irrigation Development and Research Circle.	....	In Press.	....

Copies obtainable from the Superintendent, Government Printing and Stationery, Bombay, or through any recognised Bookseller.

REPORT ON LAND DRAINAGE EXPERIMENTS AT BARAMATI

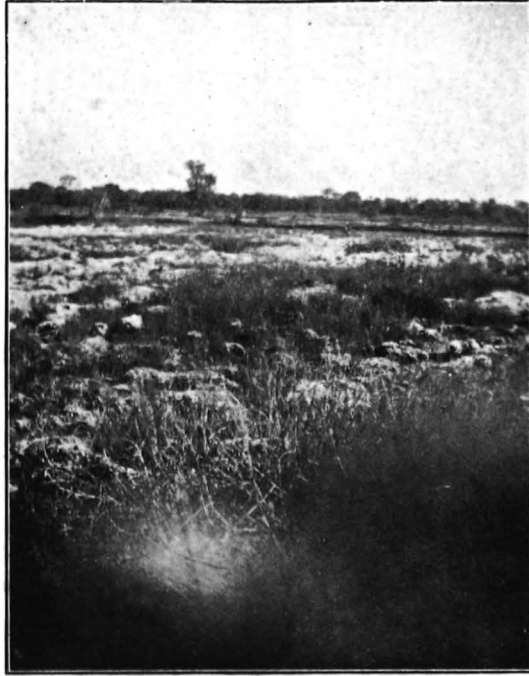
INDEX

PARAS.

1. Damage caused by the introduction of canals.
2. Previous attempts at land drainage in the Nira Left Bank Canal area.
3. Pumping experiment at Baramati.
4. Area selected for the drainage experiments at Baramati.
5. Condition of the area before acquisition in 1915.
6. Early proposals for drainage.
7. Nala trench.
8. Upper Trench.
9. South Trench.
10. Middle Trench.
11. Effect of trenches constructed up to end of April 1916 on water levels.
12. Hydro-isobaths in 1915 and 1916.
13. Water levels and hydro-isobaths of 1917.
14. Small effect of intercepting trench—segregation of area impracticable.
15. Necessity of subsoil surveys—Rendered feasible by post-hole auger.
16. Information obtained from subsoil surveys. Movement of Deccan rivers and nalas.
17. What the data showed.
18. Discharging capacities of various trenches.
19. Lessons learnt from subsoil survey.
20. Work done in 1918-19, based on subsoil survey.
21. Effect of work on water levels.
22. Effect of cross trench.
23. Result of lowering the pipe line of the Middle trench.
24. Effect on the water levels in the adjoining area caused by blocking drainage of the Middle trench.
25. Effect of drainage on land higher up the valley.
26. Deepening of the South trench.
27. Water levels on either side of the South trench before and after excavation.
28. Effect of deepening the South drain.
29. Discharge from the South pipe line.
30. Area between Phaltan and Nira roads.
31. Area above Nira road.
32. Soluble salts contained in the drainage waters from the trenches.
33. Hydro-isobaths.
34. Changes in the salt contents of the subsoil water.
35. Intensity of salt in the soil.
36. Ecology and plant succession.
37. Economic plants and crops.
38. Data obtained from the drainage experiments at Baramati.
39. Relative effectiveness of various trenches.
40. Relationship between cane area in the catchment and total drainage water.
41. Estimated loss of irrigation water through the subsoil.
42. Cane area and damaged area compared.
43. Evaporation of subsoil water through the soil surface of damaged lands.
44. Total quantity of water drained and salts removed during the past ten years.
45. Three zones in the area, showing characteristic grouping of soluble salts.
46. Quality of drainage water from the trenches.
47. Summary of conclusions.

Statements I, II, III and IV.

Figures, 1 to 21.



1. Photo of Plot No. 24 showing salt and *Panicum Fluitans* in foreground.



2. Photo showing salt encrustation in Plot No. 24 of Baramati salt lands. Note match box.



3. Photograph looking across salt land towards Malad from Plot No. 24.



4. EXPERIMENTAL SALT AREA—BARAMATI.—Cane grown by Mr. Shembekar in reclamation plots (1921-22) : outturn 55 pallas of gul.



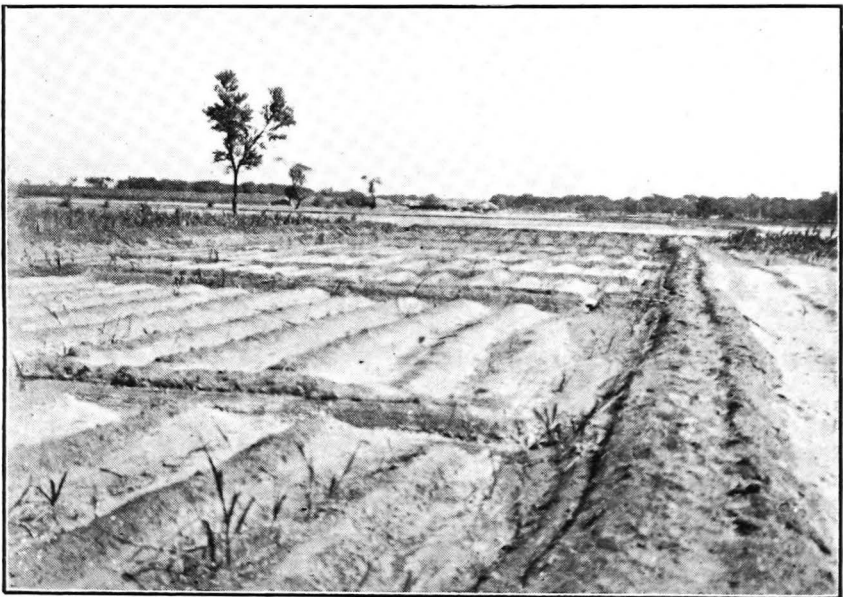
5. S. No. 42 above Nira-Baramati road looking N.E.



6. S. No. 126 looking N.E.



7. S. No. 123 looking W.



8. S. Nos. 122 and 123 looking E.N.E.

REPORT ON

LAND DRAINAGE EXPERIMENTS AT BARAMATI

I. INTRODUCTION

1. *Damage caused by the introduction of canals.*—When the Nira Left Bank Canal was first opened for irrigation in 1885, heavy waterlogging resulted and the damage was so considerable that in 1888 Dr. Ozanne, Director of Agriculture, was asked to carry out an inspection and write a note on the question. Five years later in 1893, Dr. Walter Leather, Agricultural Chemist to the Government of India, did another inspection. It is interesting to note that the areas which were worst damaged at the earlier inspection, had in many cases recovered before the later inspection; whereas in the later inspection some of the worst damage was found in areas which were in good condition at the earlier inspection. Recent work has confirmed these earlier observations and the explanation is that when a Deccan canal is first opened, the percolation is enormous—so that the land in the vicinity of the canal becomes waterlogged—gradually, however, as the percolation decreases,—due to the canal section getting covered with a silt film,—the land near the canal, with a highly porous subsoil, gradually dries out.

While this drying out has been occurring near the canal, the water has been spreading through the deep porous substrata into the valleys, and where the porous substrata have extended up to a deep nala or a river, the water,—after rising to within a few feet of the ground surface,—has reached a maximum level which has been sufficiently far below the surface of the ground to prevent damage resulting, and the excess water has drained away harmlessly.

In deep soil areas, however, the porous layer is replaced by a rocky, non-porous substratum, so that there is no outlet for the excess water. As a consequence, the subsoil water table has gradually risen year after year until it has reached so close to the surface that the excess water has been got rid of by evaporation, leaving behind a deposit of salt.

The Baramati experimental area is of the latter type.

2. *Previous attempts at Land Drainage in the Nira Left Bank Canal area.*—A small drainage scheme was carried out at the instance of the Agricultural Department in Pandhara village, 8 miles from Baramati, in 1908. It was reported to be successful; but though the subsoil water level in the immediate vicinity of the drains may have been temporarily reduced, the drainage was never really successful—in that there was no increase of area under irrigation as a consequence of the work done,—and by 1913, any temporary improvement there may have been, had entirely disappeared.

More ambitious experiments were carried out by the Agricultural Department in Survey No. 123 of Baramati in the year 1909. These experiments have been described in Bulletin No. 39 of 1910 of the Agricultural Department.

It was considered by the writers of the Bulletin that the drainage carried out in this area was successful; but by 1913 the supposedly reclaimed area was covered with a thick layer of salt and was totally unfit for crops. Any improvement there may have been, must have been very shortlived; and the method then followed, which depended on careful maintenance by the cultivators, was clearly foredoomed to failure. We know now that the system then adopted was unsound in general conception and also in detail.

3. *Pumping experiment at Baramati.*—Although the pumping experiment at Baramati forms no part of the Baramati Drainage Scheme, yet it is worth recording the results, because it was carried out in the same area as the later “gravity” scheme, and gave some interesting information.

A pump was set up on a well in Survey No. 48 of Baramati, and a trench was constructed across the valley.

The length of this trench was 1,600 feet and it was 17 feet deep at its deepest point. The longitudinal section is shown in Figures 2, 3 (a) and 1. Figure 3(a).

The idea at the back of this scheme was that if water were pumped daily from the trench, the water table would be reduced,—thus preventing the concentration of salts in the subsoil water—caused by water of dilution evaporating—and it was also expected that where the water in the subsoil was removed it would be replaced by less saline water. It was found, however, that after pumping water almost daily for twelve months there was just as much salt in the water as when the experiment started, and the pumping had had no beneficial effect whatever. The experiment was therefore abandoned. This experiment is quoted in detail in Appendix II of Technical Paper No. 16 of Bombay Public Works Department, entitled "Note on Irrigation on the Block system in the Deccan Canal Tracts."

4. *Area selected for the drainage experiments at Baramati.*—The area chosen for the first drainage experiments at Baramati was selected mainly because it was admittedly the worst salt affected area on any canal in the Deccan, and also because it had once been first class land, so that if reclaimed it might be expected to be very valuable,—especially as it was situated within half a mile of Baramati.

The land lies between the Phaltan-Baramati road and the Karha river, just to the South of the road, and is shown on Figure 1. The area acquired was 54 acres.

Figure 1.

5. *Condition of the area before acquisition in 1915.*—The subsoil water level was at about 2 feet from the surface in the North-west portion of the area; but in most of the area, it was at less than a foot, and in some places was at the surface. As a result, the soil was in such a state that it was not safe to attempt to walk over it.

Figure 14
1915.

The sub-soil water contained salts varying from 200 to 2,000 parts per 100,000,—consisting mainly of sulphates,—and the surface was encrusted with a snow-like sheet of white salts,—as can be seen in photos 1, 2 and 3. The top 6" of the soil contained from 2·5 per cent. to 4 per cent. of salts consisting of about 50 per cent. of sulphates and 23 per cent. of Chloride of sodium.

Figure 16
1915.

The salts decreased with depth as shown by the following figures for soil samples taken from Pit No. 6 of East-West Line No. 2 (North-East corner of Survey No 55):—

Depth of soil sample	0-6"	6-12"	12-18"	18-24"	24-30"	30-36"	36-42"	42-48"
Percentage of salts	2·13	0·82	0·75	0·47	0·45	0·42	0·36	0·37

The area was overgrown with Bulrush (*Typha Angustate*), locally known as *Pánkanis*; and with rushes (*Cyperus laxigatus*), *Pánkunda* (*Panicum fluitans*) was also found in patches. A couple of decrepit *Bábuls* (*Acacia Arabica*) and a few scattered *Tarvads* (*Cassia Auriculata*) completed the vegetation of the area.

6. *Early proposals for drainage.*—The first obvious necessity was to give the area a drainage outfall. This was done by excavating a main drain in the low-lying land,—where there was already a superficial depression which was connected to the Karha river by a cut through the low intervening ridge. Fig. 1A.

Figures 1A, 2 and 4 (c) show the position and longitudinal section of this trench, called the Nála trench. It will be seen that it was excavated through boulders and soft rock for the first 1,500 feet.

Figures 1A, 2 and 4 (c)
1915.

In addition to the Main (Nála) trench, trenches were excavated on all four sides, because it was thought that the whole area could be isolated in this way; but it was soon found that these boundary drains had very little effect on the water levels as will be described hereafter.

7. *The Nála trench.*—Was excavated in June 1915, and the side slopes were dressed subsequently. The average depth of the trench was about 5 feet.

The effect of this drain was ascertained by observing water levels in pits located on two lines at right angles to each other—known as East-West No. 1 and North-South No. 1. The former was approximately at right angles to the Nála trench while the latter ran roughly parallel,—at a distance of about 400 feet.

Figures 5(a) and (b) show 3 sets of water levels :

- Figure 5 (a) and (b). (a) while the work was in progress in May 1915 ;
 (b) just after the trench was completed in June 1915.
 (c) after the monsoon in November 1915.

Figure 5(a) indicates that the effect of the Nála trench was slight and only extended for a distance of about 400 feet.

Figure 5(b) shows that though the Nála trench had little direct effect ; yet as a result of the lowering of the water level in the Feeder trench—which was drained by the Nála trench,—the subsoil water table was reduced as far as pit 3 of North-South line No. 1.

8. *The Upper trench* was commenced on 20th January 1916 and was completed on 20th March 1916. Figure 4 (a) shows the longitudinal section. The length was 1,400 feet and the average depth 4 to 5½ feet.

Throughout almost the whole of its length it cut through massive *kankar*, which is a porous material—known locally as *Mán*—and gave a good discharge of 0·18 cusecs.

9. *The South trench* was completed a month later—on 20th April 1916. The length was 1,400 feet and the average depth 4 to 5½ feet, and it cut through rock, black soil and massive *kankar* (*Mán*).

The discharge of 0·14 cusecs was mainly from the very porous “massive *kankar*” portion in the upper 300 feet.

10. *The Middle trench* and *the Well trench* were also excavated at this time. These were completed immediately after the South trench on 1st May 1916. The longitudinal sections show that no porous substratum was cut and, as a result, very low discharges were obtained from these trenches (0·008 cusecs in each case).

11. *Effect on water levels of trenches, constructed up to end of April 1926.*—Water levels were observed on the North-South and East-West lines. These are shown on graphs and are for selected dates as under :—

20th January 1916.—Water levels when only the Nála trench had been excavated, *i.e.*, before work was started on the Upper, Middle and South trenches ;

20th March 1916.—Water levels after the Upper trench was completed ;

20th May 1916.—Water levels in May 1916, after the South, the Middle and the Well trenches had been excavated.

On comparing the changes in water levels which occurred between 20th January and 20th March, it will be seen from Figure 6 that there was a 2 feet drop in pits 4, 5 and 6 of East-West line No. 1 and a smaller, but still considerable effect right down to the Nála trench.

All pits except No. 5 East-West line No. 2, were affected ; but pits 7 and 8 showed a larger drop than the others. All pits of North-South No. 2 and North-South No. 1 were appreciably affected.

Thus the effect of the Upper trench was most noticeable in pits within 400 feet of it ; but there was a general, but smaller, effect over the rest of the area also.

On comparing the water levels of the two later dates, *i.e.*, 20th March and 20th May, it will be seen that except on North-South No. 1 water levels were only slightly affected. On East-West No. 1 the fall in water levels was negligible except in pit No. 3, which was very near the middle trench ; and on East-West No. 2 there was no effect, except in pits 4 and 5, which were close to a stone drain constructed at that time. North-South No. 2 : No pits were affected. North-South No. 1 : no effect except in pits 4, 5 and 6 which were locally affected by the Well and Middle trenches.

It was therefore concluded that the South, the Middle and the Well trenches (as excavated in 1916) had had very little effect, and the discharges from these trenches, as shown in Statement I, were very small. The reason for this was that the trenches did not cut through the porous substrata.

12. *Hydro-isobaths in 1915 and 1916.*—Figure 14 shows the 3 feet and 4 feet hydro-isobaths in May 1916. On comparing this plan with that for 1915 it will be seen that as a result of drainage the water table had fallen by about 2 feet and the improvement was greatest in Plot Nos. 2, 3, 4, 8, 9, 10, and 11 due to the combined effect of the Upper, the Feeder and the Nala trenches; but the Middle and South trenches had had little effect on the water levels in the South-East corner,—where these trenches were situated.

13. *Water levels and hydro-isobaths of 1917.*—The year 1917 was very suitable for gauging the effectiveness of the trenches excavated in 1916; because:—

- (a) no additional work had been constructed: and
- (b) the rainfall in 1916 was 29·4 inches, which was far in excess of the normal 18 inches.

On comparing the hot weather levels of 1916 with those of 1917, it will be seen that the water levels rose slightly in most of the pits and that the tendency of the subsoil water was to stagnate in the lower part of the area. The water, which had been slightly more than 4 feet below the ground in a considerable part of the area in 1916, rose to less than 4 feet over practically the whole area; and so the 4 feet hydro-isobath disappeared in 1917,—which showed that the drainage was inadequate. It was also noticed that the rise in water levels did not appreciably increase the discharges from the trenches.

14. *Small effect of intercepting trench—segregation of area impracticable.*—Extra pits were excavated in continuation of East-West No. 2 line—to observe water levels on either side of the upper or Intercepting trench. Figure 8 shows observations of 21st March 1917, from which it will be seen that the water levels in pits 8a and 7c—which were only a few feet from the trench,—were some 12 inches higher than the water level in the trench. Bores were then made with a Calyx drill in the bed of the trench, and sub-artesian flow resulted. The 2 inches diameter bore, which gave the strongest flow, discharged 0·004 cusecs (1½ gallons per minute). Later in 1917, when 4 feet deep auger holes were made in Survey No. 56, water rose a foot above the ground (i.e., artesian flow resulted).

It was quite obvious, therefore, that although the Upper (or Intercepting) trench gave a considerable discharge and even had a limited general beneficial effect on the land, yet it was not effective as an intercepting trench,—so that the original idea of segregation of the area by intercepting the flow did not work out in practice and had to be abandoned.

15. *Necessity of subsoil surveys. Rendered feasible by Posthole auger.*—The results obtained up to this time had shown clearly that surface drains could only draw off water from the strata through which they were excavated, and that where there were layers of porous materials at a lower level than the bed of the drains, it was impossible to segregate an area. The next step, therefore, was to investigate the subsoil conditions.

This work was rendered possible by our obtaining a posthole auger, manufactured by Iwan Brothers of Indiana, U.S.A., which made it possible to make bores, and obtain samples, at a fraction of the cost expended where boring machines were used. Later we found that for deep bores, ordinary wood augers were even cheaper than posthole augers though they did not give so much information.

16. *Information obtained from subsoil surveys. Movement of Deccan rivers and nálas.*—The result of the subsoil survey has been shown on the Index plan and cross section. The cross section shows the conditions clearly. It will be seen from this that the Karha river, which at one time flowed in the trough of the valley, subsequently cut a new channel through the rock to the East of the old course, and the old river bed was then covered with layer upon layer of transported materials; grading from boulders, through sand, massive *kankar*, prismoidal *chopan* and *chopan*, to black soil at the surface. It must be pointed out that these strata have not been formed by decomposition 'in situ' but have been washed down from the higher-lying surrounding country, as already explained in Technical Paper No. 13, Bombay

P. W. D. entitled "Soil and Subsoil Surveys in the Deccan Canal Tracts." The boulders and sand were washed down the river bed, and the *chopan* and black soil were rolled down from the ridges and deposited as a colluvial covering.

This section shows clearly why the intercepting trench had so little effect, and why there was artesian flow below it; namely, that as the water in the deep strata was under considerable pressure, the pressure was transmitted through the lower layers of the massive *kankar* and also through the deep sand and boulder layers underlying the massive *kankar*; so that the intercepting trench—which cut only a foot or 2 feet into the massive *kankar*—had only a very local effect. The smallness of the effect was partly due to shallow layers of more clayey material (which were distributed through the more porous layers), cutting off the vertical transmission of pressure.

We have not sufficient data to explain the various stages of the formation of this area in detail; but there is evidence to show that after the Karha river deserted its old bed, the Lendi nála subsequently followed the old course of the river through the experimental area; until it, in its turn, forsook this course and cut its way through into the Karha river above Baramati.

This tendency of Deccan rivers to shift their courses has now been traced in many areas; notably at Vir, where the Vir nála forsook its old bed and cut a new course through half a mile of hard rock.

Another case is at Kopargaon on the Godavari river.

At Kopargaon (which means the village of the elbow) there are several legends which relate that the course of the river was diverted by the elbow of a powerful mythological Being—such as Balráam or Kach.

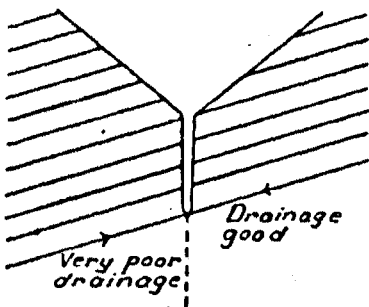
There is ample evidence to show that it is true that the Godavari has shifted its course. So that legend tallies with fact.

The continuous, and in many cases rapid, movement of Deccan rivers and nálas is of paramount importance in connection with drainage, and it was the realisation of this fact which led to a solution of the drainage problem. Without this knowledge, success could not have been achieved.

17. *What the data showed.*—The subsoil data collected at Baramati showed

Figure 3 (b).

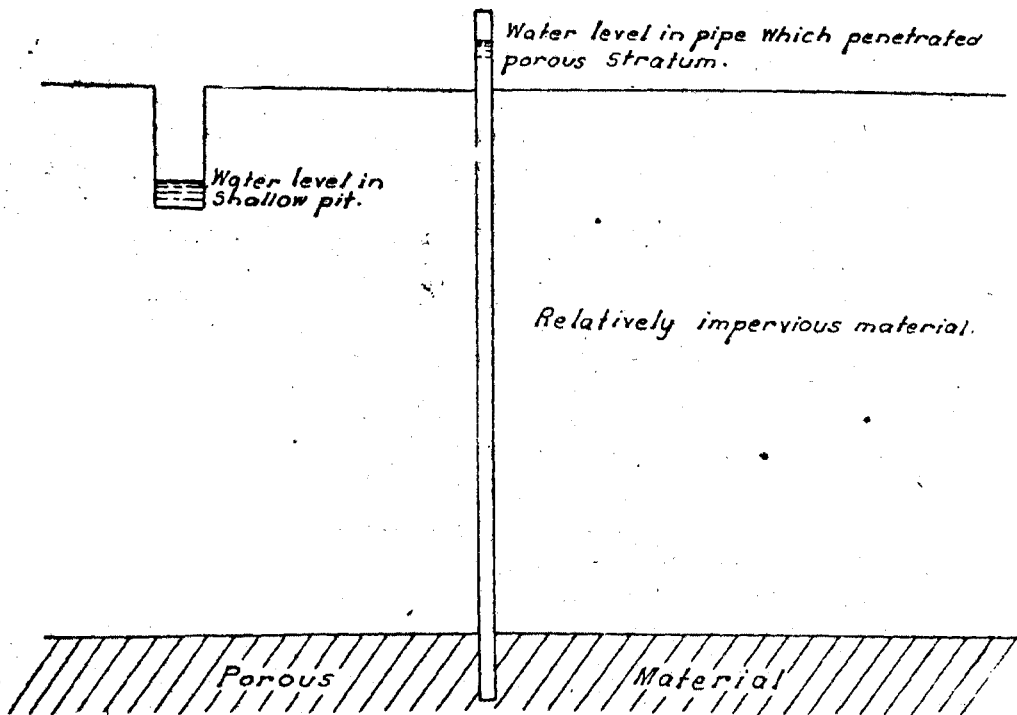
Sketch I



that there was a large volume of subsoil water moving slowly downwards from the ridge—through the porous substrata—towards the experimental area. This subsoil water was due to percolation from the heavily-irrigated fields of cane on the higher-lying lands, and the water had been prevented from reaching the Karha river by a ridge of rock and layers of *chopan* and black soil. The movement of the water was further retarded owing to the stratification of the rock and other material—at the lower side of the area—being counter to the direction of water flow, as shown in sketch I. Water, under pressure, was therefore forced to the surface where the permeable massive *kankar* was confronted by imper-

meable material; and this explained the prevailing artesian conditions, which existed even where the subsoil water level—as observed in shallow bores—was below the ground surface; as shown in sketch II below:

Sketch II



18. *Discharging capacities of various trenches.*—Figure 9 indicates what would be seen if the surface soil of the experimental area were removed.

At the upper side of the area massive *kankar* would be exposed; and at the lower end, impermeable conglomerate and rock would be laid bare. As already explained, the water enters the area from the massive *kankar* substratum at the upper side of the area—particularly through the South-West corner—as is clearly seen from the water contours for 1916 and 1917; and the reason for the wide difference in the discharging capacities of the various trenches is clear from the longitudinal sections of trenches, because some of the trenches cut deep into the porous substratum while others were mostly in soil.

Figures	Trench	Discharge 1916 and 1917 in cusecs	Strata cut
3a	Feeder trench ..	0.10	Partial cutting in massive <i>kankar</i> for 800 feet.
4a	Upper trench ..	0.18	Cut through massive <i>kankar</i> for 1,000 feet.
3d	South trench ..	0.14	Cut through massive <i>kankar</i> for 300 feet.
3b	Middle trench ..	0.008	Cut through black soil and conglomerate.
3c	Well trench ..	0.008	Do. do.
	Total ..	0.43	
4c	Nála trench: Gauge at lower end ..	0.40	Cut through rock and so gave no discharge of its own.

19. *The lessons learnt from the subsoil survey were that—*

- (a) the history of the subsoil formation must be taken into account;
- (b) the first essential of a drainage scheme is an adequate outfall.
- (c) drains should, where possible, be located where they will tap the original subsoil valley; because if constructed in a recent, superficial valley, they will generally be ineffective;
- (d) rivers and *nálas* tend to alter their courses and move from the middle of a valley to the flanks, the main central *nála* frequently being replaced by 2 flank *nálas*;

- (e) drains to be effective must be located in porous material and should cut through it to a considerable depth ;
- (f) drainage takes place along the layers of stratification and in the direction of the 'dip' and only to a very limited extent against the 'dip' ; or normal to the stratification ;
- (g) intercepting drains are only partially effective unless they are taken down to an impervious bed, such as rock. Where the porous stratum is deep, they have little effect—the pressure being transmitted through the deeper layers ;
- (h) drains excavated down the slope are usually much more effective than those excavated normal to the direction of the slope of the ground.
- (i) it is better to overdrain than underdrain an area ; but the cost must be kept down and efficiency balanced against expenditure.

20. *Work done in 1918 and 1919—based on subsoil survey.*—In 1918 the Middle trench was excavated to a depth of about 8 feet, and extended to meet the Upper trench. This is shown on the longitudinal section—
 Figure 3 (b). Figure 3 (b). Pipes were laid in the bed of the trench and above these the trench was refilled with soil.

A cross trench was also excavated (to a depth of 7 feet) along a line where the recuperation coefficients were high ($\frac{x}{A}$ greater than 1.0), where the subsoil water was under considerable pressure—so that it stood more than 1 foot above the ground level in the pipes. It was thought, therefore, that if a pipe line were constructed, it would collect water coming from the massive *kankar* and so reduce waterlogging in plots 18 to 24.
 Figures 4 (b) 8, 9.

In 1919, the last 400 feet length of the Middle trench pipe line (massive *kankar* portion) was further deepened by about 2 feet. Thus the total depth in this portion was 10 feet.
 Figure 3 (b).

21. *Effect of work on water levels.*—Hydro-Isobaths show a fall of about 1 foot in 1918 and $1\frac{1}{2}$ foot in 1919, and the 1919 Hydro-isobaths plan shows that the maximum improvement took place along a line passing through the big trial pit and pit No. 3 of North-South line No. 1. This was along the direction of flow of subsoil water. In this portion water levels in 1919 were more than 6 feet below the ground.
 Figure 14.
 Figure 7.

22. *The effect of the Cross trench, excavated in 1918, was nil ; vide pit 6 of East-West line No. 2.* This result was exceedingly disappointing ; because the coefficients of recuperation and the big head had led us to anticipate a considerable effect. Further investigations, however, showed that the high coefficients of recuperation were due to there being small pockets of porous material surrounded by clayey layers, so that when the water in the sandy pocket was drawn off by the drain, replenishment was exceedingly slow, and was, in fact, negligible.
 Figure 7.

23. *The result of the lowering of the pipe line of the Middle trench was that the subsoil water was drawn down and the Upper trench became dry :—*

Year	Discharge of the Upper trench	Discharge of the Middle trench
1917	0.18	0.008
1918	Nil	0.18
1919	Nil	0.24

The increase in total flow was only 33 per cent. ; but the lowering of the water table, which is the main objective, was considerable—amounting to $2\frac{1}{2}$ feet.

24. *Effect on the water levels in the adjoining area caused by plugging the downstream end of the Middle trench pipe line.*—The end of the Middle trench pipe line was plugged for a few days. The subsoil water was thus artificially headed up. This affected the water levels in adjoining pits as shown on the section North-South line No. 2.
 Figure 3 (b).
 Figure 10.

It is noticeable—on comparing the water levels of 30th June 1919, and after 24 hours—on 1st July—that the water level rose in pit 3, whereas pit 2 was unaffected.

Similarly the rise of water level in pit 3 on 2nd July, 48 hours after the blocking of the pipe, was considerably more than in pit 2, and pit 1 was quite unaffected after 2 days. After 5 days the water levels appeared to have assumed a normal gradient—such as would have been found if no pipe line had been constructed. On the 6th day, *i.e.*, 24 hours after the pipe line was re-opened and allowed to flow free, the water level in pit 2 fell more than in pit 3. Pits 1 and 4 were equidistant from the pipe line, yet it was found that the water level in pit 1 fluctuated considerably whereas that in pit 4 was almost stationary.

It has been shown elsewhere that the direction of flow of the subsoil water in the salt area was from South-South-West to North-North-East, and the foregoing data clearly bears out this fact and explains why pit 1 was affected to a considerable extent while pit 4 was scarcely affected at all.

25. *Effect of drainage on land higher up the valley.*—As a result of the drainage carried out in the experimental area, observations along a line 300 feet above, and parallel to, the Phaltan-Baramati Road showed that the water was almost at ground level in 1915; but that it had fallen to 3 feet below the surface in 1919.

26. *Deepening of the South trench drain.*—As the lowering of the pipe line of the Middle trench was so successful, it was decided in 1920 to lower the South trench pipe line in the same way—with the double object of tapping the subsoil flow of water at the source in the South-West corner and reducing the water levels in plots 18-24, where they had remained persistently high.

In January 1920 a pipe line was constructed to replace the original trench and the alignment was slightly altered to avoid rock at its lower end. The new alignment is shown on Figure 14. This is the deepest and most effective pipe line so far constructed.

Figure 14.

27. *Water levels on either side of the South trench before and after excavation* are shown in Figure 11.

Figure 11.

The reduction of the water levels was very marked at the upper end of the pipe line, due to the pipe line having cut deeply into the massive *kankar* stratum.

28. *Effect of deepening the South drain.*—The general effect of the trench is shown on Figure 7. A marked reduction of water level resulted in bore No. 7 of East-West and bore No. 4 of North-South No. 2, which were close to the South trench; but the effect gradually died away as the distance from the pipe line increased.

Figures 2 and 7.

On comparing the Hydro-isobaths of the year 1919 and 1920, it will be seen that whereas water was within 3 feet of the surface for nearly half the length of the South trench in 1919, in 1920 it was at more than 5 feet—except in a small island in plots Nos. 22 and 23—and it was at more than 6 feet in more than half of the experimental area.

29. *The discharge from the south pipe line was more than doubled.*

Year	Discharge in cusecs of	
	Middle trench	South trench
1919		
June to December	0·20	0·14
1920		
January to June	0·18	0·30
	0·02 decrease	0·16 increase

This increase in the South pipe line discharge did not reduce the discharge from the Middle pipe line appreciably; and not merely did it improve conditions in the experimental area, but it had also an even greater effect on the land lying above the experimental area.

This completed the drainage of the original salt area, the subsoil water level having been reduced below the danger limit over the whole of this part of the experimental area.

30. *Area between Phaltan and Nira Roads.*—Although the drainage already done to the south of the Phaltan road had improved the area to the north of the road, it was still quite unfit for cultivation. It was decided therefore to drain this area according to the knowledge obtained in the previous work; so in 1920 the nála trench was extended for a length of 2,100 feet—almost up to the Nira-Baramati Road. Figure 12 shows a plan of this area and Figure 13 shows the longitudinal section of the open trench. The depth of the trench was 8 to 9 feet.

Figures 12 and 13. Very little water was drained from the lower 1,000 feet; but in the upper half—in S. No. 41—the trench cut through some massive *kankar* and the gravelly bed of the old Lendi nála, and the discharge totalled a third of a cusec.

This drain was exceedingly successful, in that it reduced the water level in its vicinity to a depth of more than 7 feet below ground level, and the level over the whole area lying between the Nira and Phaltan Roads was reduced far below the danger zone.

31. *Area above Nira Road.*—The remainder of the damaged area in the valley lying above the Nira Road consisted of two narrow, salt-affected, hollows; one of which had been denuded of surface soil—leaving *chopan* exposed. Nevertheless it seemed a pity not to complete the work; so the damaged portions were acquired, and two pipe lines known as 1 and 2 were constructed. The lower part, up to the bifurcation, was constructed in 1921; and the two tributary pipes lines in 1923.

Figures 12 and 13.

Pipe line 2 cut through the area on which the Agricultural Department had done their experiments in 1909. Photos 5 to 8 show the condition of the area just after the pipe lines had been completed and before they had had time to affect the conditions appreciably.

The total discharge from the extension above the Phaltan-Baramati Road rose to half a cusec, and the area above the Nira-Baramati Road dried out rapidly, the average depth of water falling to 4 feet below the surface.

Statement II.

Figure 12.

About 99 acres of land were acquired; but a much larger area has benefitted.

32. *Soluble salts contained in the drainage water from the trenches.*—It will be seen on comparing the figures of soluble matter contained in the water of the Middle, the South and the Nala trenches (Statement III) that since 1920—when drainage work in the experimental area was completed—the total salts, except in a few cases, have been decreasing very gradually; but no sudden reduction, such as has sometimes been observed in America, has occurred. The figures for soluble salts were observed each month by means of the Dionic Water Tester (Messrs. Evershed and Vignolles, South Acton, London).

33. *Hydro-isobaths (i.e., lines along which water is at an equal depth below the surface)* are shown on Figures 14 and 15. Detailed fluctuations in these, each year up to 1920, have already been discussed in paragraphs 12, 13, 20 and 27. On comparing the hydro-isobaths for 1920 with those for the following years, it will be noticed that in 1920 water levels were at a maximum depth below the surface. This was because all the drains had been completed; but no cane was planted till the following

Figures 14 and 15.

Figure 15.

year. The yearly hydro-isobath charts show that water levels gradually rose—by about a foot—during the next two years, viz., 1921 and 1922, particularly in the south half of the area. This was due to the plantation of cane in the reclamation plots along the south side of the area. The subsequent two years, viz., 1923 and 1924, showed an improvement, because the cane referred to above was removed. The year 1925 showed a general rise of water levels owing to an extra concentration of cane in the catchment.

The north half of the area was mainly under babuls and so the water levels were not affected locally. The conditions of the year 1925 may be said to represent normal post-drainage conditions in the area.

34. *Changes in the salt content of the subsoil waters in the experimental area shown in Figures 16 and 17.*—The total salts in waters taken from bores were determined each year in the hot weather and lines of equal intensity are marked on the plan. Considerable improvement took place in the pit waters during 1916 to 1918—especially in the lower portion of the area in Plots Nos. 18 to 24. The lines indicating 1,000 and 700 parts of salts per 100,000 dropped out in 1917 and 1918 respectively. This was partly due to drainage and partly due to heavy rains in 1916 and 1917. In 1919 and 1920 the salt content slightly increased as these were very dry years. From 1921 onwards, excluding the minor changes observed in the 600 parts per 100,000 line due to local causes, such as flooding and irrigation of crops, the quantity of salts in the subsoil water remained unchanged.

35. *Intensity of salt in the soil.*—Figures 18 and 19 show the salt content of the soil in 1916, 1920, 1923 and 1927. Contours for 1916 show the condition before drainage. The 1920 contours show that the salts had been reduced to about half the original quantity and the line of 1 per cent. concentration was approximately in the position of the 2 per cent. line of 1916. By 1923 a further reduction to half the 1920 concentrations was observed and the line of 0.5 per cent. concentration was in the position of the one per cent. of 1920 and 2 per cent. of 1916. Improvement was proportionately greater during the three years (1920-1923) than in the preceding five years (1916-1920). This was because drainage was more effective in the latter period and also because the area had been cropped extensively since 1921.

In 1927 a further improvement was observed and the salts in the soil have now been reduced to a safe limit; but the physical state of the soil is still unsatisfactory over part of the area.

The following statement shows the percentage of salts found in soil samples taken from pit No. 6 (East-West) in 1916 and 1925 from various depths:—

Analysis of soil samples from pit 6, East-West line	0-6"	6"-12"	12"-18"	18"-24"	24"-30"	30"-36"	36"-42"	42"-48"
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Percentage in 1916	2.13	0.82	0.75	0.47	0.45	0.42	0.36	0.37
Percentage in 1925	0.35	0.26	0.23	0.40	0.35	0.27	0.29	0.27

The maximum concentration of salts in 1916 was 2.13 per cent. at the surface. By 1925 it was reduced to 0.4 per cent. which was no longer at the surface but between 18" and 24" below the surface.

36. *Ecology and Plant succession* of the natural vegetation in the experimental area is shown in figure 20 for 1916, 1918 and 1920. After 1920 the area was extensively cultivated and so the natural weed colonies could not thereafter be observed. The year 1916 showed conditions just after drainage. *Cyperus laevigatus* (*lavhálá*), a variety of rush, was freely distributed in the lower half of the area where water-logging and saline conditions were predominant; and *Panicum fluitans* (*Pánkundá*) was found growing in patches along the upper part of the area, where the concentration of salts was less and the water level at a little more than one foot below ground level. In 1918, where the water levels were at more than 3', *Cyperus laevigatus* was greatly reduced in extent, and *Panicum fluitans* had spread over almost the whole area; but *babuls* and *Chloris barbata* (*Gonde gavat*) established themselves along the feeder trench, and flourished there, though no seed was planted.

By 1920, the water was at more than 4' depth and *Cyperus laevigatus* had disappeared altogether, while *Panicum fluitans* was replaced to a considerable extent by *Chloris barbata*, and *babuls* were found growing almost everywhere. Thus, there had undoubtedly been a definite plant succession, the dominant factor being the depth to subsoil water.

37. *Economic plants and crops.*—Between 1916 and 1920 reclamation experiments were conducted, and several crops were grown in the salt area on a small

scale. Reclamation plots along the South Trench Plots 11 to 15 and 17 to 25 were levelled, embanked and flooded constantly to a depth of 6" to leach out the salts. This was followed by green manuring with *Sann* hemp or *Shevari*—generally the latter, as it is highly resistant to salt—and before planting cane 20 to 40 cart-loads of manure were added. The results of observations on crop growth are summed up below :—

(a) At first grain crops did not mature. The plants grew well enough, but seed did not form and the husks were empty. At this stage, only fodder crops could be grown satisfactorily, and *Shevari* (*Sesbania aegyptiaca*), *Nilwa* (*Sorghum*) were found to grow best. The former was tried as green manure as *Sann* hemp (*Crotalaria juncea*) would not grow at all at this stage. Barley grew satisfactorily, so did Beetroot and Sunflower (*Helianthus annuus*), but there was no market for them.

(b) *Cane* flourished in some places after the application of heavy doses of farmyard manure. But where the physical state of the soil was badly damaged even heavy applications of farmyard manure did no good. It was found, however, that in such cases, although the application of farmyard manure did not make it possible to grow cane at once, yet crops which were subsequently planted, such as *Chillies*, *Jowar*, *Mug*, etc., grew quite well. This showed that it took a considerable time for the manure to act on the soil. Conditions improved steadily, due to constant cropping with very light irrigation, and one very marked effect was that where trenches had been excavated for pipe lines, and then refilled, crops only grew satisfactorily if the original surface soil was again on top. Where subsoil spoil was left on top the crops either failed or were very poor. This can easily be prevented with a little care.

(c) *Babul* grew immediately after the subsoil water level fell to about 4' below ground level—in spite of a high concentration of salt in the soil.

Shindi (Toddy Palm—*Phoenix sylvestris*), *Nimb* (*Azadirachta indica*), Rain tree (*Pithecolobium saman*) did not die when planted, but they took a long time to develop; *Aloes* (Agave) grew in dry places, along the open trenches. All the above refer to the period 1916 to 1920.

From 1921 onwards more intensive irrigation was adopted, and shallow, temporary drains were opened for leaching out salts. The result was that reclamation was accelerated, and some of the portions—notably plot No. 26 and the reclamation plots—improved enormously. The outturn of *gul* in 1926-27 in some of the reclamation plots was as high as 11,000 lbs. or 46 *pallas*. Plot No. 19 gave 12,175 lbs. or 50 *pallas* of *gul* per acre, and Plot No. 26 yielded 9,413 lbs. or a little less than 40 *pallas* to the acre. There were many other plots which yielded almost as much. The area between the Nira and Sangvi Roads also improved and sugarcane did very well in many of the plots. In 1926-27, the minimum yield of *Pundia* cane was 35 *pallas* per acre and the maximum 49 *pallas*. Other varieties of cane did not, however, do so well as *Pundia*.

The question of reclamation in excessively damaged land—such as this area—has proved very difficult and we have not yet reached finality by any means. Indeed some of the plots and parts of others have so far failed to respond to treatment.

It is, however, much too big a question to deal with in this Paper, so will have to be dealt with in a subsequent note.

38. *Data obtained from the drainage experiments at Baramati: Direction of subsoil flow of water.*—The parallelism of the subsoil water level contours (1916-1920) indicated the general direction of subsoil flow of water and it was noticeable that wherever a drain was excavated; it affected the water table over the whole of the area, though the effect was much more marked in the immediate vicinity of the drain. The maximum draw-down effect of the drainage always occurred on a line passing through pit 5, East-West line No. 1, and pit 3 of North-South line No. 1; and the least effect was always observed in Plots Nos. 22, 23 and 24.

Figures 2 and 14a.

39. The relative effectiveness of various trenches in the drainage scheme is shown by the following statement :—

Trench	Average discharge, 1923-25		Discharge per mile of drain
	Total discharge	Per Chain	
Middle trench (length 10 chains)	0.25	0.025	1½ cusecs.
South trench (length 14 chains)	0.26	0.019	1 cusec.
Open trench, above Phaltan Road (length 22 chains)	0.30	0.0136	7 cusec.
Nira-Baramati Road pipe lines (length 33 chains)	0.25	0.005	½ cusec.
Total drainage : trenches and pipe lines 119 chains	1.07	0.009	½ cusec.

The above figures show that the Middle trench gave the biggest discharge per chain and the Nira-Baramati Road pipe lines the least. The former cuts through massive *kankar* and the latter through prismoidal *chopan*. The figures indicate that massive *kankar* is more than five times as permeable as prismoidal *chopan*. Actually the discharge of the upper 300 feet length of both the Middle and South pipe lines exceeded ¼th of a cusec—or more than half the total discharge of the pipe line.

40. The relationship between the cane area in the catchment and total drainage water can be seen from the figures given below. In the hot weather (i.e., in May) cane is the only crop standing.

Area	Standing cane, acres	1923-25 average Hot weather discharge cusecs	Average discharge from 100 acres of cane in drains
Area between D/24 branch and D/25	133	0.80 total	0.60 cusec

This result may be compared with drainage from irrigation reduced to a cane basis for the whole year.

The average number of acres of various crops for each season in the catchment (Statements Nos. III and IV) during 1923-25 were :—

Serial No.	Season	Crop	Acres	Equivalent to long term cane irrigation	Remarks
i	Hot weather	Overlapping new cane (including extension of cane area).	116	58	Overlapping is usually for 2 months, so water taken is half that for the season of 4 months.
ii	Kharif season	Bajri and other crops	189	47	¼ of the water is required for monsoon seasonal crop.
iii	Rabi season	Jowar	245	90	1/2.7 of the cane water required for Rabi irrigation.
				3) 195 (65*)	

Average seasonal irrigation in terms of cane for the year *65 acres.
Perennial cane 133 acres.

Total average on cane basis .. 198 acres.

The equivalent of 198 acres of cane water gave an average discharge of 1.07 cusecs. ∴ 100 acres of cane gave 0.54 cusecs subsoil drainage.

This is of the same order as the results arrived at previously for the month of May.

No allowance is made for rain water, because the average figure for drainage does not include it. During rainy days, the quantity of water removed is not

measurable, as the gauges are very often submerged under water consequent on torrential rains. The effect of rain lasts for a surprisingly short time in a drained area.

41. *Estimated loss of irrigation water through the subsoil.*—In paragraph 40 it is shown that 100 acres gave $\frac{2}{3}$ of a cusec discharge. Water required at the head of a distributary for irrigating 100 acres of cane (on a 50 duty) would be 2 cusecs. Of this $\frac{2}{3}$ of a cusec or nearly $\frac{1}{3}$ of the irrigation water is lost by percolation.

42. *Cane area and damaged area compared:*—

Total area in the catchment is	..	..	..	500 acres.
Culturable area was	..	..	..	400 acres.
Area fully damaged at the start was	..	..	..	146 acres.
Cane area in the catchment was	..	..	..	133 acres.

Thus for each acre of cane there was a little more than an acre of fully damaged land, which shows how dangerous it is to allow unrestricted cane irrigation without adequate drainage.

43. *Evaporation of subsoil water from the surface of damaged lands.*—Before the construction of the drainage system, practically the whole of the subsoil water evaporated. It can be said, therefore, that the total discharge of 1 cusec draining away to the river at present originally evaporated from 146 acres of damaged land, or 86,400 cft. in 24 hours, or say 600 cft. per acre per day = 0.014 acre feet per day.

This figure agrees closely with losses from lakes and is what might be expected; because though losses from fully water-logged areas may be up to 0.03 ft. per day the loss on the average will be considerably less.

44. *The total quantity of water drained and salts removed during the last ten years* through the whole drainage system is given in Statement No. III.

The figures show that during the four years 1923-26, 3,272 acre feet or 818 acre feet per year of water were drained. This water, if spread over the 400 acres of culturable land, would submerge them to a depth of 2.05 feet per year. In addition, the quantity of salts drained away through the *nala* trench has been enormous. Nearly 10,500 tons were drained away in the three years 1924-26, of which approximately—

2,600 tons were from the South Trench; and
1,500 tons were from the Middle Trench.

45. *Three zones in the area show characteristic groupings of soluble salts.*—The quantity of various salts in the subsoil water in the experimental area was tested in the hot weather each year. The numerous results of chemical analysis of pit waters clearly showed the existence of three zones where particular salts were found (*vide* Figure 21).

Figure 21.

The relative proportions of different salts were found to be as under:—

C (Upper area) Bicarbonate Zone Percentage		B (Middle area) Intermediate Zone Percentage		A (Lower area) Sulphate Zone Percentage	
Ca CO ₃	3.6		3.9		4.8
Mg CO ₃	5.2	Mg CO ₃	2.3	Ca SO ₄	2.1
Na HCO ₃	22.8	Mg SO ₄	5.3	Mg SO ₄	16.7
Na ₂ CO ₃	1.8		0.4		0.7
Na ₂ SO ₄	44.2		68.4		57.0
Na Cl	14.0		13.1		10.7

Leaving out of consideration the artificial grouping of ions into salts, it is quite clear from these figures that the carbonates decreased from the upper to the lower areas, being replaced by sulphates. There are definite reasons for this, which will be dealt with in a separate note on the subject.

It may be stated here that as the concentration of salt increases (as happens in the lower area of the experimental salt lands), solubility of CO_2 decreases, whereas the concentration of Ca and Mg increases; so that more of these ions go into solution.

46. *Quality of drainage water from the trenches.*—Chemical analysis of trench waters from the main trenches in the salt area are given below for comparison. The results are expressed in parts per 100,000 of the trench water. The relative proportion of each salt has also been calculated and represented as a percentage of the salt.

Statement showing chemical analysis of trench waters from salt lands.

Salts	Middle trench		South trench		Nala trench	
	Parts per 100,000	Per cent.	Parts per 100,000	Per cent.	Parts per 100,000	Per cent.
Total salts	184		300		300	..
Ca CO_3	4.0	2.2	13.2	4.4	20.0	6.7
Mg CO_3	6.09	3.3	15.3	5.1	20.88	6.96
Mg SO_4	....	..	....	..	9.41	3.14
Na SO_4	100.86	55.0	194.7	64.9	207.35	69.12
Na HCO_3	44.38	24.2	13.1	4.4	....	..
Na Cl	18.48	10.4	48.1	16.3	35.00	11.66

The middle trench water contains a large proportion of NaHCO_3 . This water is mostly drained from fissures in the massive *kankar* portion and therefore contains a comparatively small quantity of salts. The (CO_3) ion is therefore largely dissolved in that water ($\text{NaHCO}_3=24.2$ per cent.)

The South Trench also receives fissure water from the massive *kankar*; but this water is largely contaminated by other saline springs as the trench flows through a heavily salt-affected area (Survey No. 60, *vide* Figure No. 1). Hence at the outlet the amount of NaHCO_3 is much reduced and is found only in small quantity. The *Nala* trench flows in its whole length in salt-affected land and hence NaHCO_3 is absent, but more of Calcium and Magnesium are present for reasons given in paragraph 45.

47. Summary of conclusions :

- (1) The history of the subsoil formation must be taken into account.
- (2) The first essential of a drainage scheme is an adequate outfall.
- (3) Subsoil water tends to concentrate in the original deep valley and if this is clogged by the deposition of *chopan* and clay soils the water is gradually forced to the surface under pressure, causing waterlogging and salt efflorescence. Consequently, drains should, if possible, be located where they will tap the original subsoil valley; because if constructed in a recent, superficial valley, they will generally be ineffective.
- (4) Rivers and nalas tend to alter their courses and move from the middle of a valley to the flanks, the main central nala frequently being replaced by flank nalas; there is a tendency for nalas to move from West to East.
- (5) Drains to be effective must be located in porous material and should cut through it to a considerable depth.
- (6) Drainage takes place along the layers of stratification and in the direction of the 'dip' and only to a very limited extent against the 'dip'; or normal to the stratification.
- (7) Intercepting drains are only partially effective unless they are taken down to an impervious bed, such as rock. Where the porous stratum is deep, they have little effect—the pressure being transmitted through the deeper layers.
- (8) Drains excavated down the slope are usually much more effective than those excavated normal to the direction of the slope of the ground.
- (9) It is wise to err on the side of overdrainage rather than underdrainage—because once perennial irrigation has become established, it is very costly, and often very difficult, to construct new drains or enlarge old pipe lines.

- (10) Water was found to enter the experimental area from the "massive *Kankar*" at the upper edge of the area, the general direction of flow being from S. S. W. to N.N.E. A drop of water level in one part of the area usually affected the whole area, but by no means evenly. This showed that there was a general water table, but that the drainage effect on different parts of the area varied considerably.
- (11) The total water drained from the catchment amounted to a little more than 1 cusec equivalent to about 818 acre feet per year, or about one-third of the irrigation water applied, the culturable area being about 400 acres and the area irrigated 133 acres of cane, 189 acres of Kharif and 245 acres of Rabi crops.
- (12) The average discharge per mile of drain for the whole scheme was $\frac{1}{2}$ cusec; from prismoidal *chopan* it was $\frac{1}{4}$ cusec; and from massive *Kankar* more than 1 cusec—indeed a single manhole in massive *Kankar* produced $\frac{1}{3}$ th of a cusec from fissures.
- (13) Over 2,000 tons of salts were removed annually by this drainage system (*i.e.*, over 22,000 tons in the past 11 years). The water contains about 300 parts salt per 100,000 and is unfit for irrigation. Though the middle trench water at its upper end contains only about 100 parts per 100,000 of salts, yet as these consist mainly of sodium carbonate and bicarbonate the water is unfit for irrigation. The soluble matter is slowly decreasing; but there is as yet no indication of any large improvement, such as sometimes occurs, quite suddenly, in other countries.
- (14) In 1916, the salt content of the water varied from 100 parts per 100,000 in the western corner to over 1,000 parts in the south-east corner, carbonates being in inverse ratio to the concentration. The salt in the lower portion dropped rapidly from 1,000 parts to 600 parts; but further improvement has been slow.
- (15) In 1915 the soluble salt in the surface soil varied from 1 per cent. to 2 $\frac{1}{2}$ per cent. By 1920 the concentration had fallen to half, and by 1923 to one-quarter. Salt no longer inhibits plant growth; but the physical state of the soil has not yet recovered in parts of the area.
- (16) In this area there was one acre of salt affected unculturable land for each acre of cane grown. In most areas the damaged land is 1 $\frac{1}{2}$ times to twice the cane area and often still more.
- (17) The evaporation from the salt affected area was 0.014 feet per day or approximately the same as from a free water surface.
- (18) A definite succession of plant colonies was observed as the water level fell.
 " *Cyperus laevigatus* " (*Lavhálá*) was replaced by the waterloving " *Panicum fluitans* " (*Pànkundá*) which was succeeded by " *Chloris barbata* " (*Gonde gavat*).
- (19) *Nilva* jowar, *Shevri*, Barley, Beetroot and Sunflower were found to grow satisfactorily even in the damaged state of the soil, and *babul* grew immediately the water level was reduced in spite of salt efflorescence at the surface.
- (20) Where there is a fairly porous substratum, salts can be removed by merely flooding with 6" of water for 3 to 4 months—after shallow drains have been excavated in the vicinity of the flooded plots.
 Where drainage is poor, the addition of one ton per acre of finely ground gypsum before flooding is desirable.
- (21) A *Shalu* crop is a fairly good indicator of improvement of soils. If this does not grow, then further treatment is necessary.
 The *Shalu* crop should be followed by a crop of *Sann* during the ensuing monsoon. If this grows satisfactorily, cane may be planted with safety. Heavy doses of farmyard manure are effective; but the full effect is not produced for 2 to 4 years.

- (22) The experimental area was the worst salt affected land to be found on any canal in the Deccan and the physical state of the soil, after drainage, was so bad that Professor J. B. Knight considered it to be irreclaimable and American physicists told me they did not attempt to reclaim soils of this type ; nevertheless, most of the land has already been reclaimed and has given cane crops producing 30 to 45 *pallas* of 'gul'.
- (23) In the Deccan, drainage is generally possible, and wherever the damaged area is fairly concentrated and there is a reasonably contiguous outfall, the cost of protecting areas does not exceed Rs. 50 per acre. Where the substratum is moderately porous, reclamation is simple. In some places, however, water will not sink into the soil at all. There, reclamation has proved to be difficult ; but a new method of treatment (using chemicals and leaching into shallow drains) which is at present in the experimental stage, gives promise of general success. The question of reclamation will be dealt with fully in a subsequent paper.

I.—Statement showing discharges of trenches in the experimental salt area at Baramati (for positions of trenches see Figure No. 12) 1916-1920

Gauges were fixed at the end of each trench	1916			1917			1918			1919			1920			Remarks
	January-June	July-December	Remarks	January-June	July-December	Remarks	January-June	July-December	Remarks	January-June	July-December	Remarks	January-June	July-December	Remarks	
Nala Trench	0.40	0.40	Discharge from left 8 chains of south Trench (Main portion)=0.08 ca.	0.40	0.40		0.50	0.50		0.50	0.60		0.78	0.90	*South Trench deepened.	
South Trench	0.14	0.14		0.14	0.14		0.14	0.14		0.14	0.14		0.30	0.34*		
Well Trench	0.008	0.008		0.008	0.008		0.008	0.008		0.008	0.008		0.008	....	
Middle Trench	0.008	0.008		0.008	0.008		0.18	0.24	Deepened.	0.23	0.20		0.18	0.23		
Upper Trench	0.18	0.18		0.18	0.18		0.08	Dry	Effect of middle trench.	Dry	Dry		Dry	Dry		
Feeder Trench	0.10	0.10		0.10	0.10		0.10	0.08		0.08	Dry		Dry	Dry		
Total of the above	0.48	0.48		0.48	0.48		0.508	0.468		0.458	0.598		0.488	0.67		
Main Drain above the culvert on Baramati-Sangvi Road.													0.80	0.83	Nala trench extended above Sangvi Road to Nira Road in 1920.	

II.—Statement showing discharges of trenches in the experimental salt area, Baramati (for positions of trenches see Figure No. 12) 1921-1927

Gauges were fixed at the end of each trench	1921		1922			1923			1924			1925			1926			1927		
	January-December	Remarks	January-June	July-December	Remarks	January-June	July-December	Remarks	January-June	July-December	Remarks	January-June	July-December	Remarks	January-June	July-December	Remarks	January-June	July-December	Remarks
I—Nala Trench extension ..	0.36	* Pipe line 1.7 chains constructed.	0.59	0.42		0.46	0.61	* Whole lengths of pipe lines constructed (38 chains).	0.42	0.60		0.53	0.81		0.74	0.87		0.75		
II—Middle Trench	0.21		0.20	0.26	0.25	0.29	0.25		0.25	0.20	0.35		0.24	0.26		0.25				
III—South Trench	0.32		0.23	0.27	0.25	0.29	0.25		0.26	0.22	0.29		0.26	0.27		0.27				
IV—Total of South and Middle Trench.	0.53		0.46	0.53	0.53	0.58	0.50		0.51	0.42	0.54		0.52	0.53		0.52				
V—Nala Trench	0.89		0.77	0.95	0.99	1.19	0.93		1.11	0.95	1.35		1.25	1.4		1.27				

STATEMENT No. III

Statement showing annual average discharge and total salts from important trenches in the Salt Area

Year	Middle Trench			South Trench			Nala Trench Extension			Nala Trench		
	Discharge Cusecs	Soluble matter Parts per 100,000	Remarks	Discharge Cusecs	Soluble matter Parts per 100,000	Remarks	Discharge at Middle Trench	Soluble matter Parts per 100,000 at end of P. L. near Nira Road	Remarks	Discharge Cusecs	Soluble matter Parts per 100,000	Remarks
1916	0.008	....		0.14	300		....	....		0.40	278	
1917	0.008	....		0.14	291		....	....		0.40	292	
1918	0.21	184	Deepened.	0.14	316		....	....		0.50	337	
1919	0.22	240		0.14	309		....	....		0.55	358	
Average 1916-19	0.21	212		0.14	304		....	....		0.46	316	
1920	0.21	230		0.32	368	Deepened.	0.31		Nala Trench extended 362. Construction of Pipe Line across Nira- Baramati Road.	0.84	286	
1921	0.21	210		0.32	360		0.36			0.89	286	
1922	0.23	230		0.27	330		0.36			0.86	290	
Average 1920-21	0.22	223		0.30	359		0.34	....		0.86	287	
1923	0.27	183		0.28	296		0.50	420	Branches 1 and 2 of the P. L. across Nira- Baramati Road.	1.04	273	
1924	0.25	162		0.25	300		0.50	406		1.01	272	
1925	0.23	186		0.25	280		0.67	402	1.15	270		
1926	0.25	158		0.28	241		0.79	317	1.32	242		
1927	0.25	153		0.27	237		0.75	350		1.27	230	January to June.
Average 1923-26	0.25	172		0.27	279		0.61	386		1.13	264	
	Acre feet of water drained	Tons of soluble matter drained		Acre feet of water drained	Tons of soluble matter drained		Acre feet of water drained	Tons of soluble matter drained		Acre feet of water drained	Tons of soluble matter drained	
1916-19	304.0	7,83.5		405.4	1,498		....	....		1,332.2	5,116.7	
1920-22	477.8	1,295.2		651.6	2,843		738.5	3,261		1,867.9	6,516.0	
1923-26	724.0	1,513.6		781.9	2,651		1,766.5	8,288		3,272.5	10,500.9	
Total	1,506.0	3,592.3		1,838.9	6,992		2,505	11,549		6,472.6	22,133.6	

IV.—Statement showing acreage of crops grown in the catchment of Distributary 24 Branch and Distributary 25 Drainage Scheme

Year	D 24 Branch Area				D 25 Area				Total of D 24 Branch and D 25					15
	Cane	Overlapping cane	Kharif	Rabi	Cane	Overlapping cane	Kharif	Rabi	Cane	Overlapping cane	Kharif	Rabi	Rainfall inches	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1916-17	82	30	80	54	53	5	60	39	135	35	140	93	29.37	Cane was not planted as usual due to scarcity of water. New blocks allotted with the help of S. I. D. Rabi maximum on account of famine year.
1917-18	76	30	85	21	49	20	72	52	125	50	157	73	25.17	
1918-19	71	30	98	83	48	20	67	106	119	50	165	189	13.28	
1919-20	N/L.	43 Adsati	92 9	115 *4	N/L.	28 Adsati	126	130	....	71	227	249	20.40
1920-21	68 *1	36	153 *7	219 *7	52	22	87	194	121	58	247	420	8.90	
1921-22	68 *8	12	113 *11	109 *17	52	7	65	115	126	19	189	241	17.26	
1922-23	68 *8	19	95 *44	123 *2	52	27	61	101	128	46	200	226	19.62	
1923-24	68 *16	55	88 *30	100 *15	52	32	69	114	136	87	187	229	9.34	
1924-25	69 *16	63	75 *43	126 *3	46	40	51	103	131	103	169	232	14.76	
1925-26	69 *18	96	103 *44	169 *3	46	55	66	103	133	158	213	275	13.41	
1926-27	69 *17		103 *47	175 *5	46		70	113	132	....	220	293	....

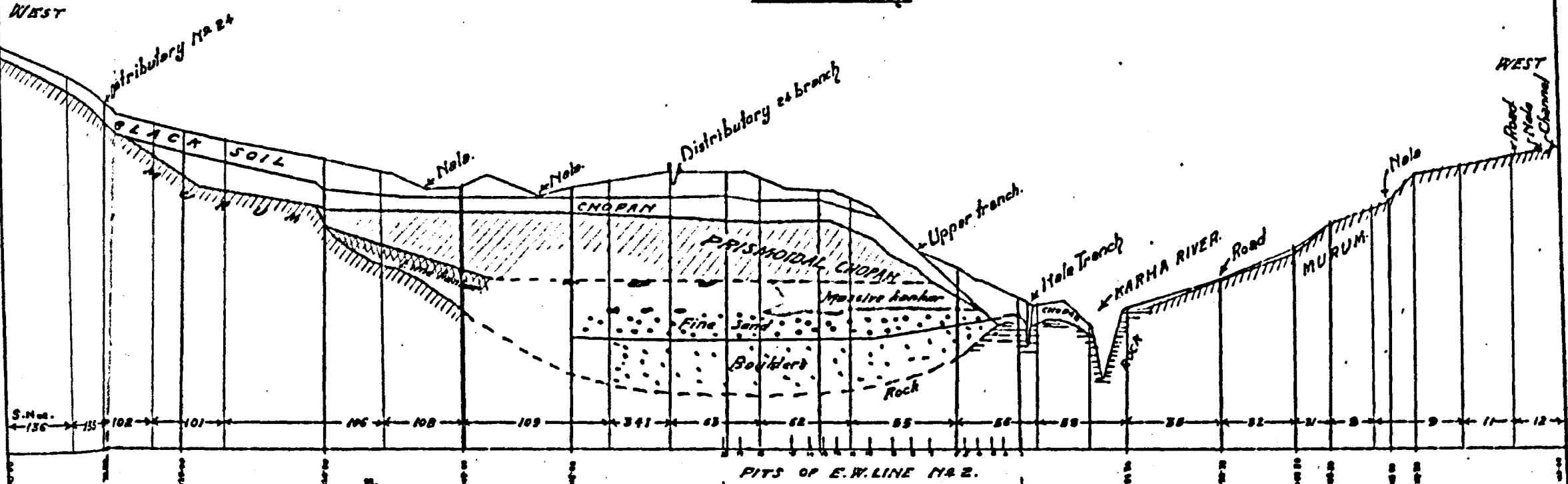
* Crops grown in the experimental salt lands, Baramati.

Special Irrigation Division

NIRA L. B. CANAL

Soil section along the line A B. shown in the Index plan (Fig. 1).

Scale. $\frac{\text{Hori: 1} = \text{1 Mile}}{\text{Vert: 20} = \text{1 Inch}}$



T. H. ...

C. G. ...
ENGINEER, S. I. D.

SPECIAL IRRIGATION DIVISION NIRA L. B. CANAL EXPERIMENTAL SALT AREA BARAMATI

INDEX PLAN

SHOWING SUBSOIL MURUM ISOBATH & CROSS SECTIONAL LINE A.B.

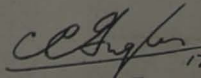
SCALE 4" = 1 MILE



T. BY. BANSAL M.C.

SALT AFFECTED AREA SHOWN THIS [Hatched Box]

EXPT. SALT AREA [Boxed Area]

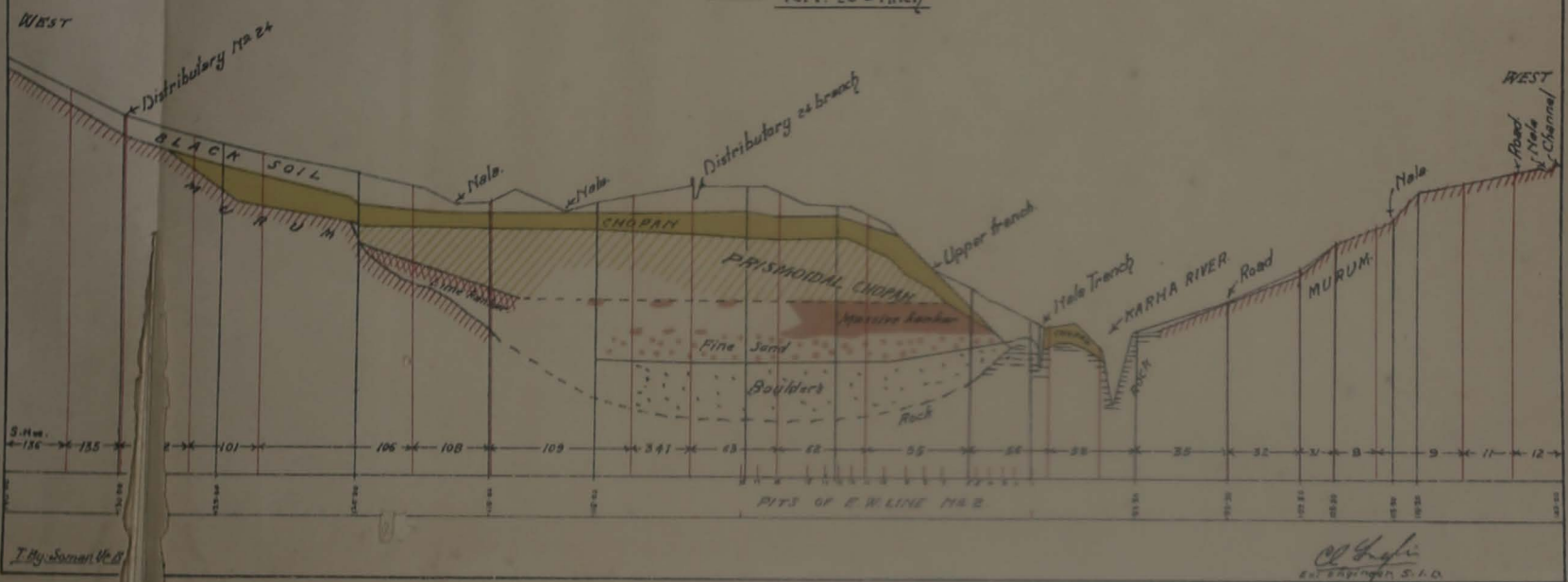

 17/4/28
 EXECUTIVE ENGINEER
 SPECIAL IRRIGATION DIVISION.

Special Irrigation Division

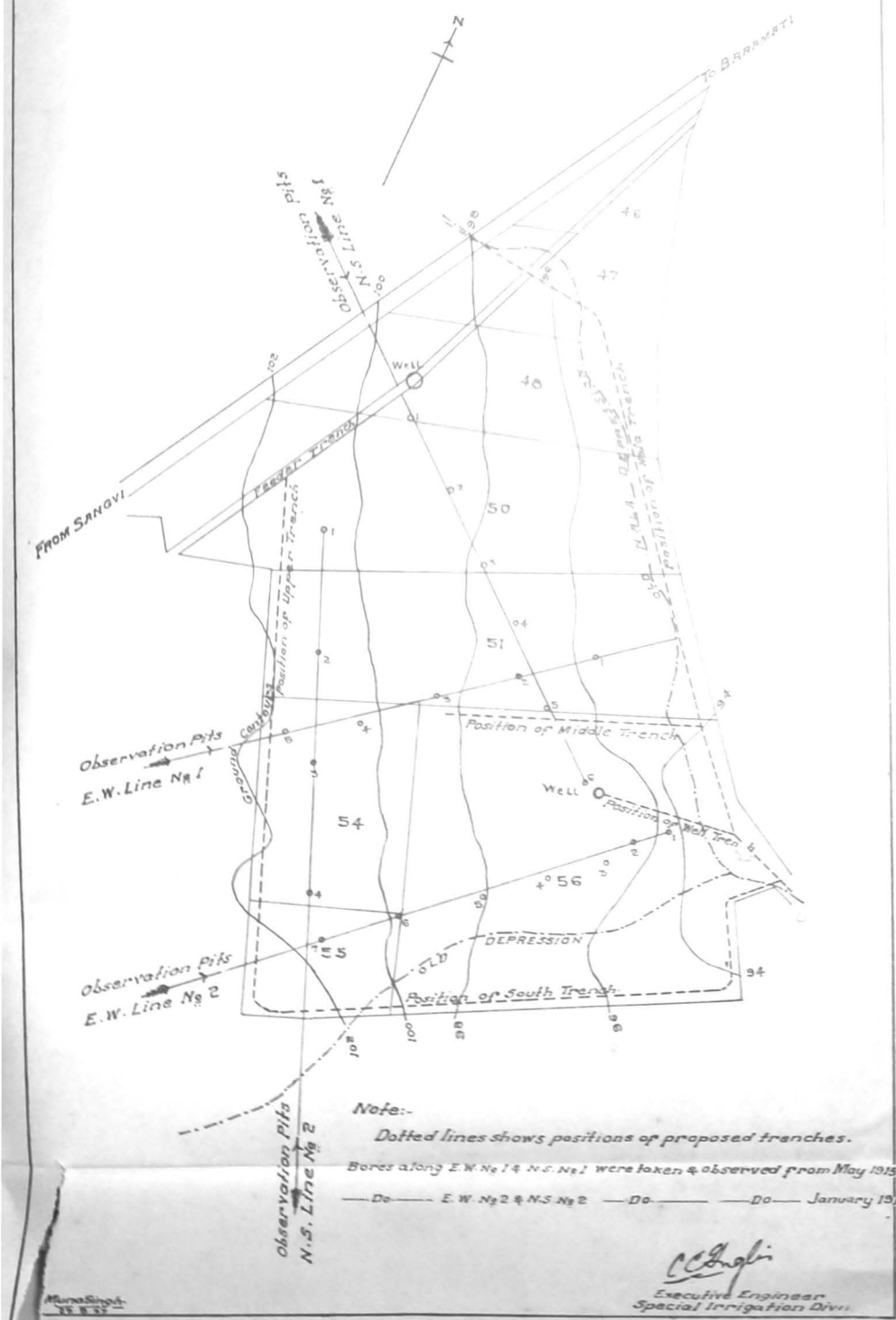
NIRA L. B. CANAL

Soil section along the line A B. shown in the Index plan (Fig: 1).

Scale. $\text{Hori: } 4 = 1 \text{ Mile}$
 $\text{Vert: } 20 = 1 \text{ Inch}$



Special Irrigation Division
Experimental Salt area Baramati.
Plan showing the area acquired
For experimental drainage purposes
Scale:- 297 To 1 Inch



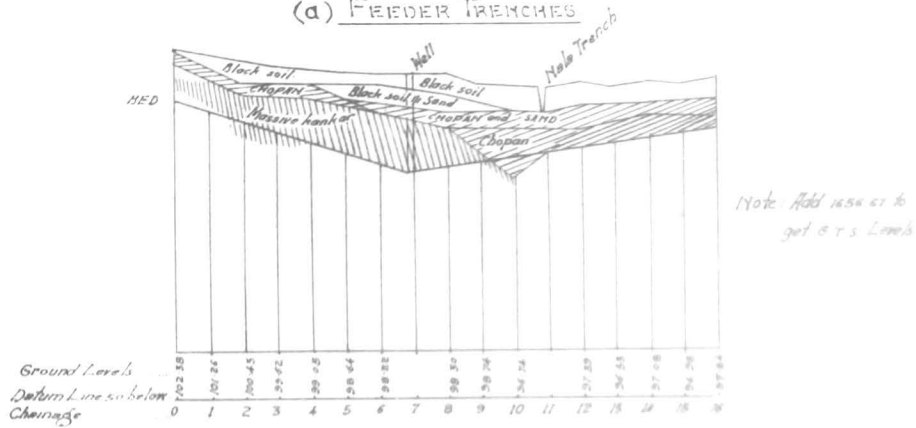
Special Irrigation Division

FIG:3

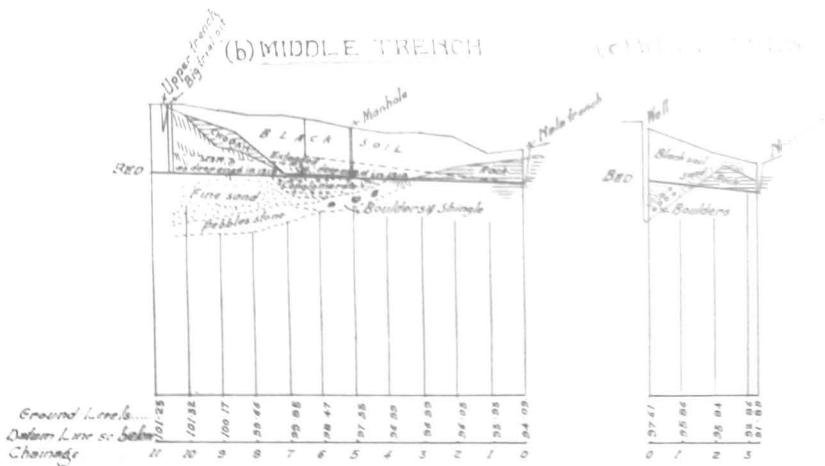
NIRA L.B. CANAL Longitudinal Sections of Trenches.

Scale
Hori: 400 = 1'
Vert: 20' = 1'

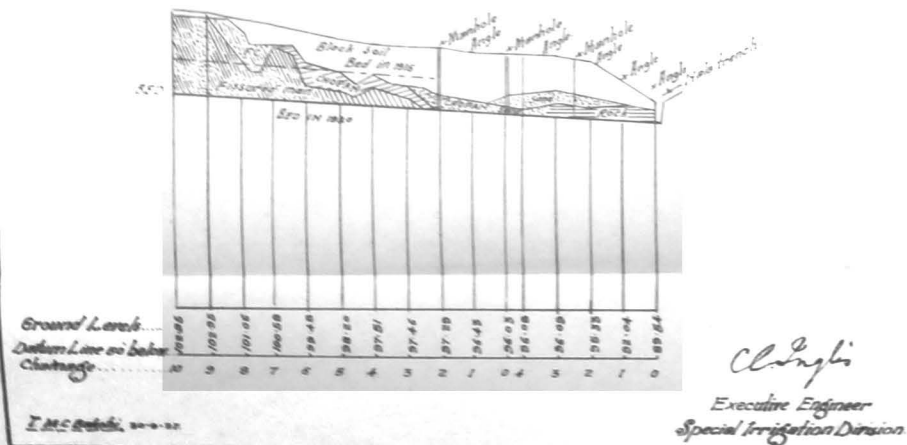
(a) FEEDER TRENCHES



(b) MIDDLE TRENCH



(d) L.S. OF SOUTH TRENCH AFTER DEEPENING.



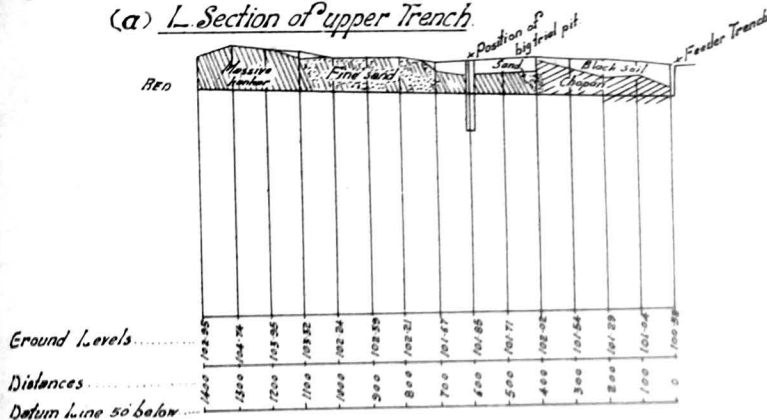
Special Irrigation Division

NIRA L. B. CANAL

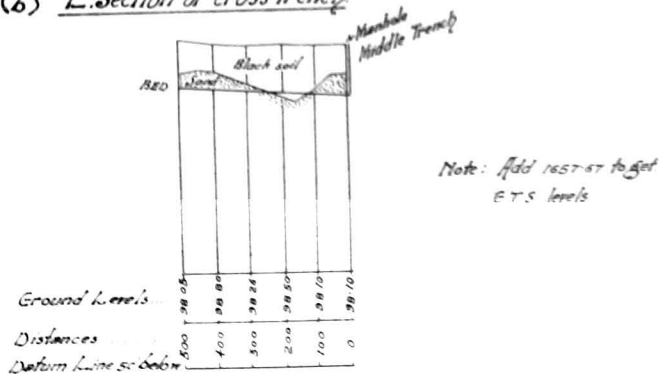
Longitudinal Sections of Trenches.

Scale Hori: 400 = 1'
Vert: 20 = 1'

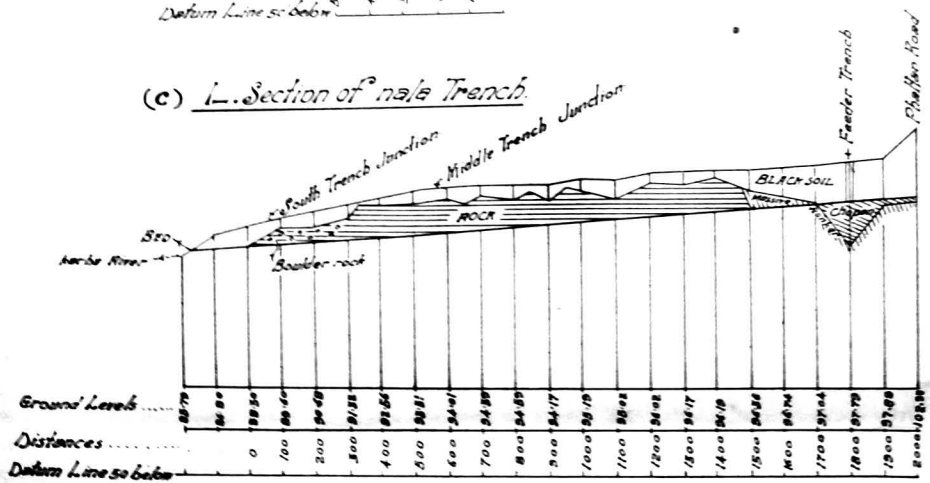
(a) L. Section of upper Trench.



(b) L. Section of cross Trench



(c) L. Section of main Trench



By: MC Bhatia 27-9-27

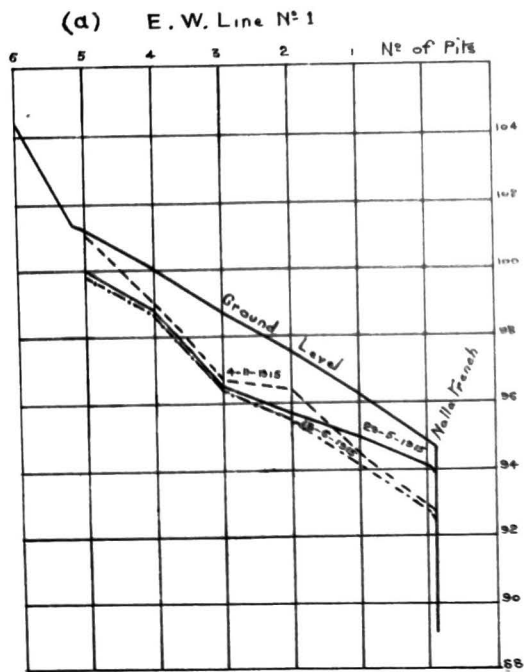
C. Chugh
Executive Engineer
Special Irrigation Division

SPECIAL IRRIGATION DIVISION

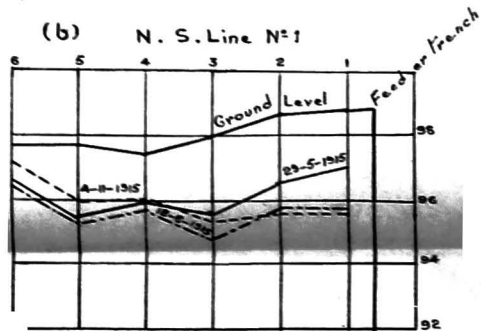
NIRA L. B. CANAL

Experimental Salt Lands at Baramati

Sections showing the effect of the nala Trench on the sub-soil w.L. in Pits of the east west line N^o 1 & N.S. line N^o 1



Note: 23-5-1915 Water levels before the excavation of the Nala Trench.
 18-6-1915 " " after " " " "
 4-11-1915 One month after the last rains of Monsoon (September) were over.



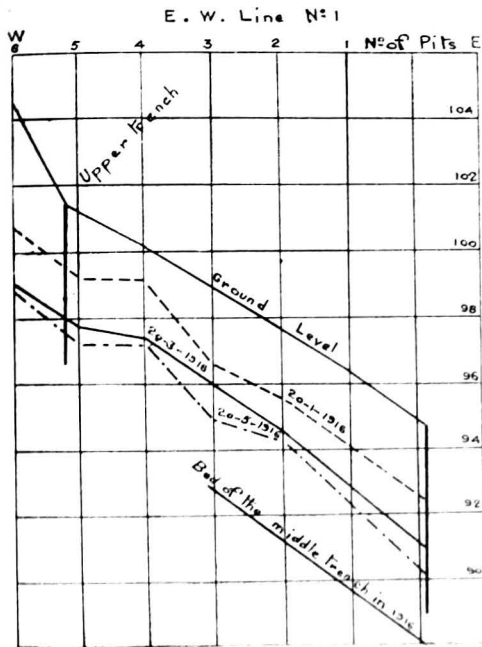
C. S. Singh
 Executive Engineer
 Special Irrigation Division

FIG: 6

SPECIAL IRRIGATION DIVISION

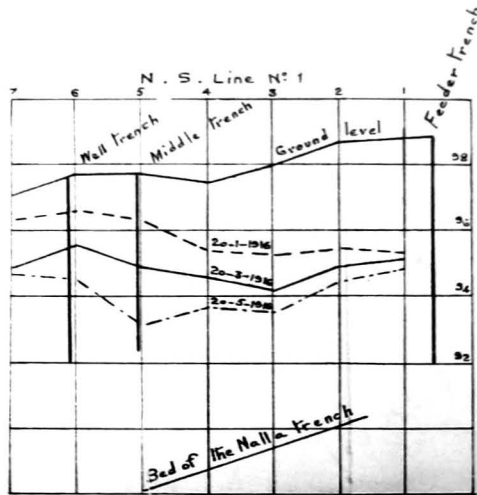
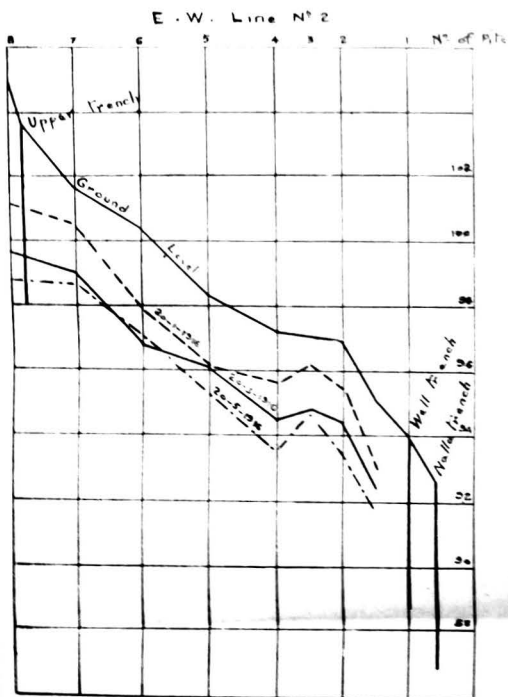
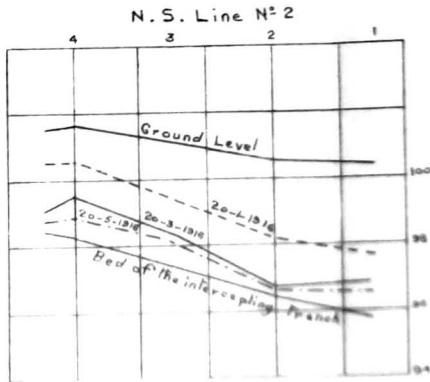
NIRA L. B. CANAL

Fall of water Levels due to Excavation of Trenches
in the Experimental Salt Lands at Baramati.



Note

Fall from January to March was due to the upper or intercepting trench and that from March to May due to the south Middle and well Trenches



C. H. J. S.
Executive Engineer
Special Irrigation Division

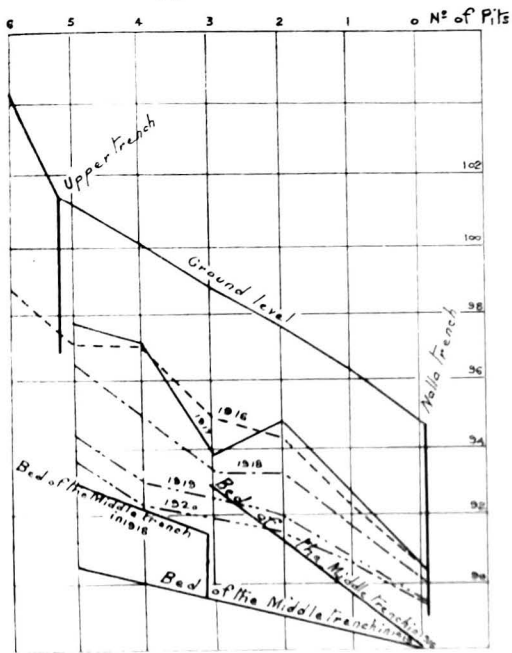
SPECIAL IRRIGATION DIVISION

NIRA L. B. CANAL

Sections showing Hot weather water level from 1916 to 20
in the Experimental Salt Lands at Baramati

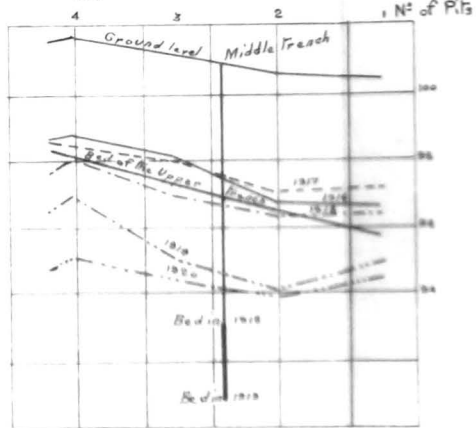
along east west N.S. lines.

(a) E.W. Line N^o 1

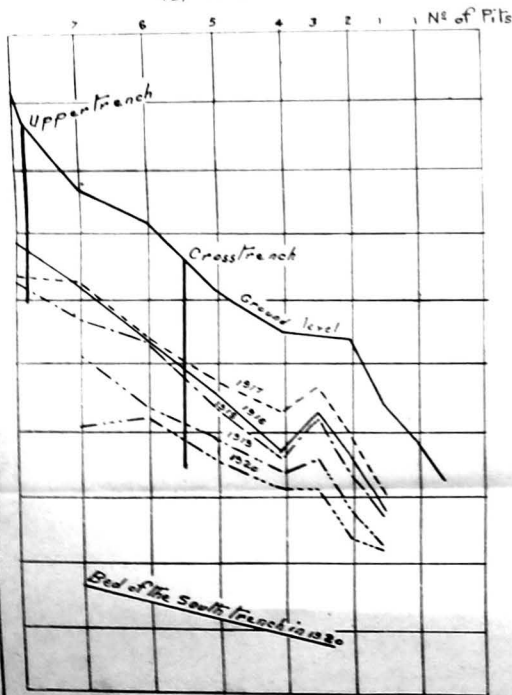


Note: These indicate the effects of the several trenches on the sub-soil water levels in the area.

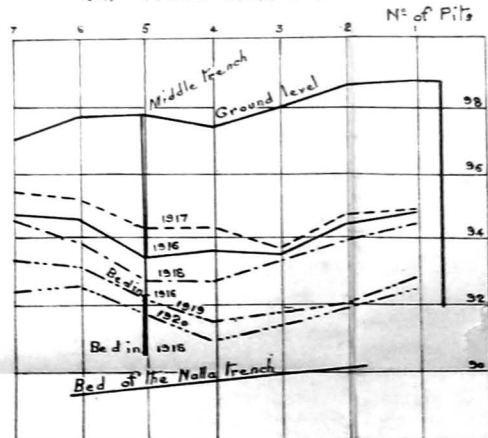
(c) N.S. Line N^o 2



(b) E.W. Line N^o 2



(d) N.S. Line N^o 1



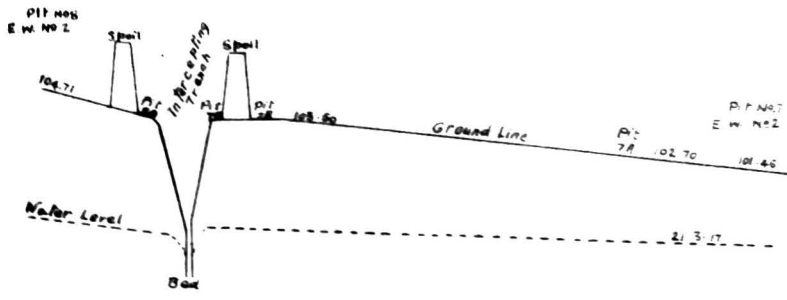
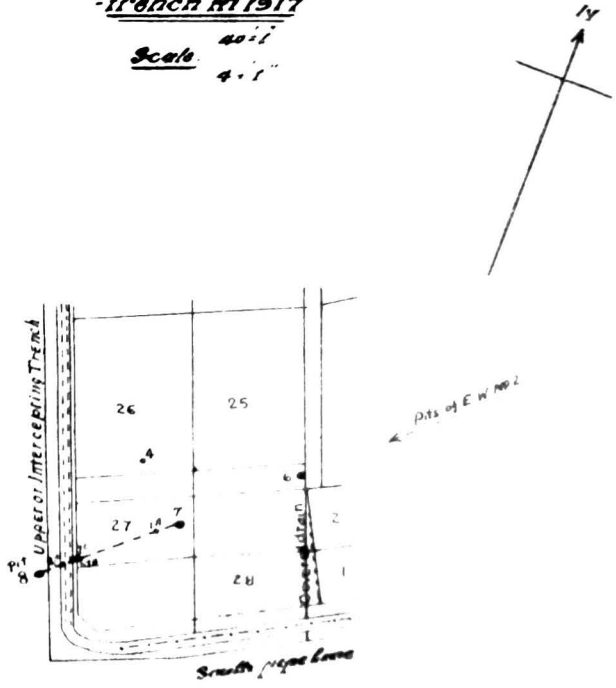
C. S. J. S.
Executive Engineer
Special Irrigation Division

FIG. 8

Special Irrigation Division
Experimental Salt Area Baranmati
Section showing water levels across the upper or intercepting

-trench in 1917

Scale $\frac{400'}{4"}$



W. D. Griffin
Executive Engineer.
Special Irrigation Division.

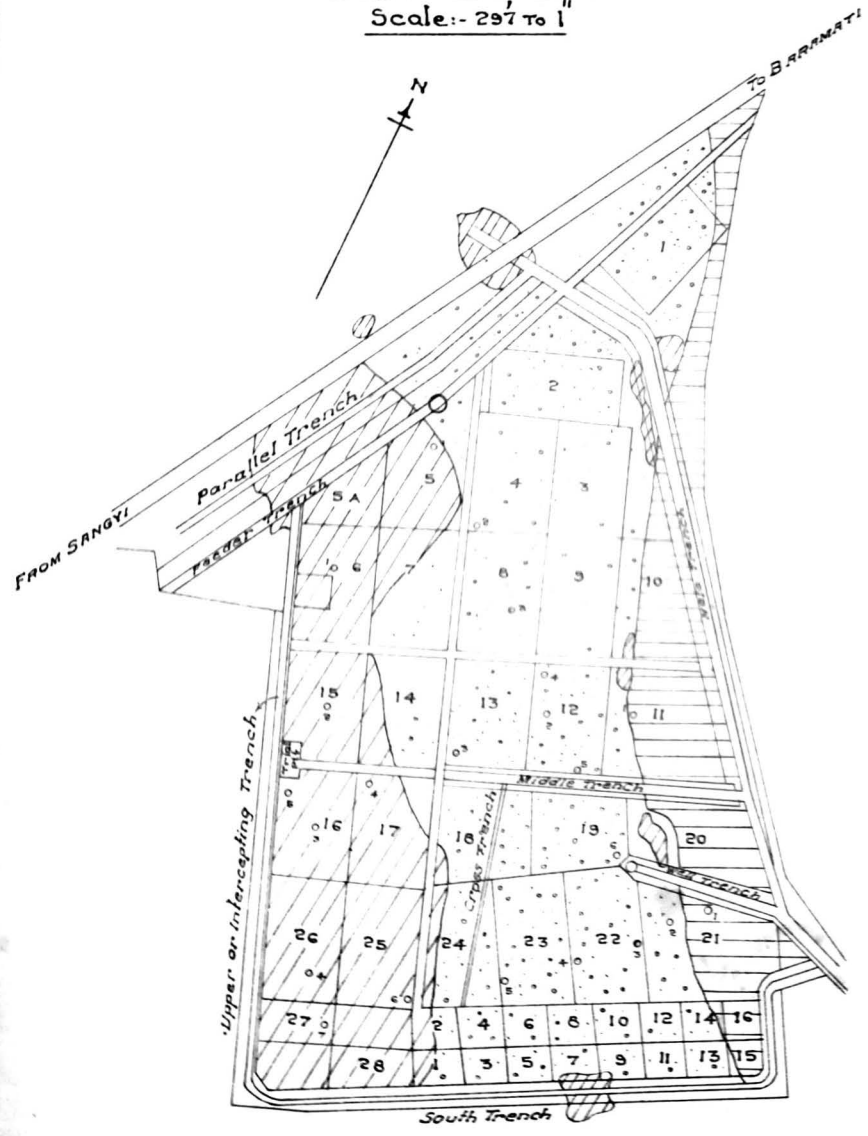
Special Irrigation Division

Experimental Salt area Baramati

Plan showing sub soil assuming the surface soil

layer were removed

Scale:- 297' to 1"



References

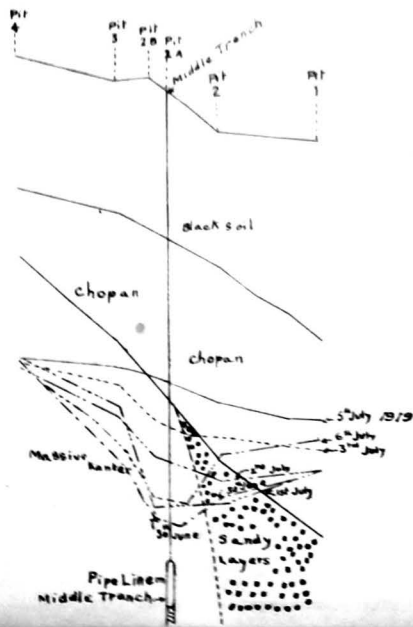
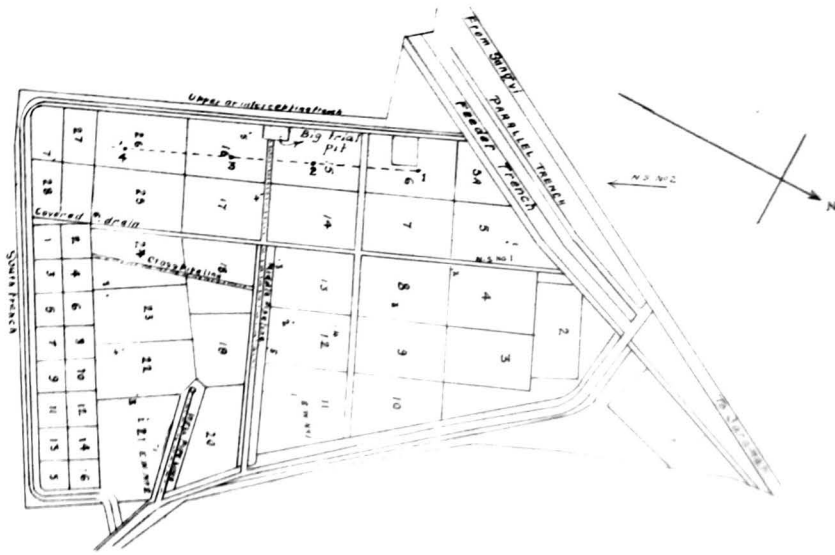
- Massive Granite..... [diagonal hatching]
- Conglomerate..... [stippled pattern]
- Rock..... [horizontal hatching]

Mona Singh
1-10-57

Executive Engineer
Special Irrigation Division

FIG. 10

Special Irrigation Division
Experimental Salt Area Baramati
Blocking of the Middle trench experiment
Scale 396:1"



Section showing the effect of Blocking the middle trench on the sub-soil water level along N.S. line No. 2.

Scale $\frac{400:1}{2:1}$

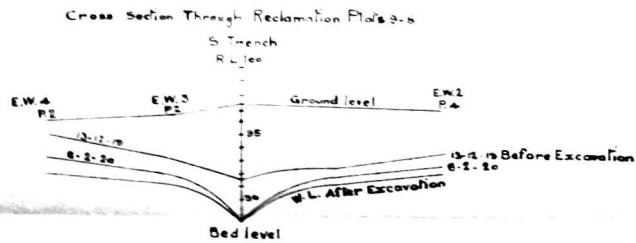
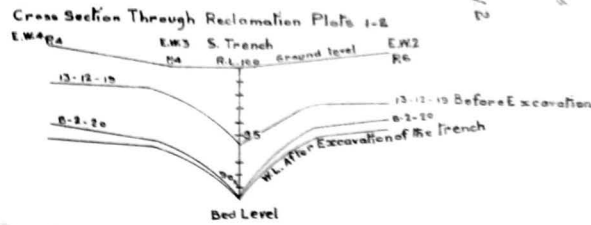
Note 30th June trench blocked
 31st July trench opened

C. G. G. G.
Executive Engineer.
Special Irrigation Division.

FIG:11

Special Irrigation Division
Experimental Salt Area Baranwali
Cross Section showing Water Levels before & After the deepening of
the South Line pipe

Scale 1/8" = 1'
10" = 1'



Chhaji
Executive Engineer
Special Irrigation Division

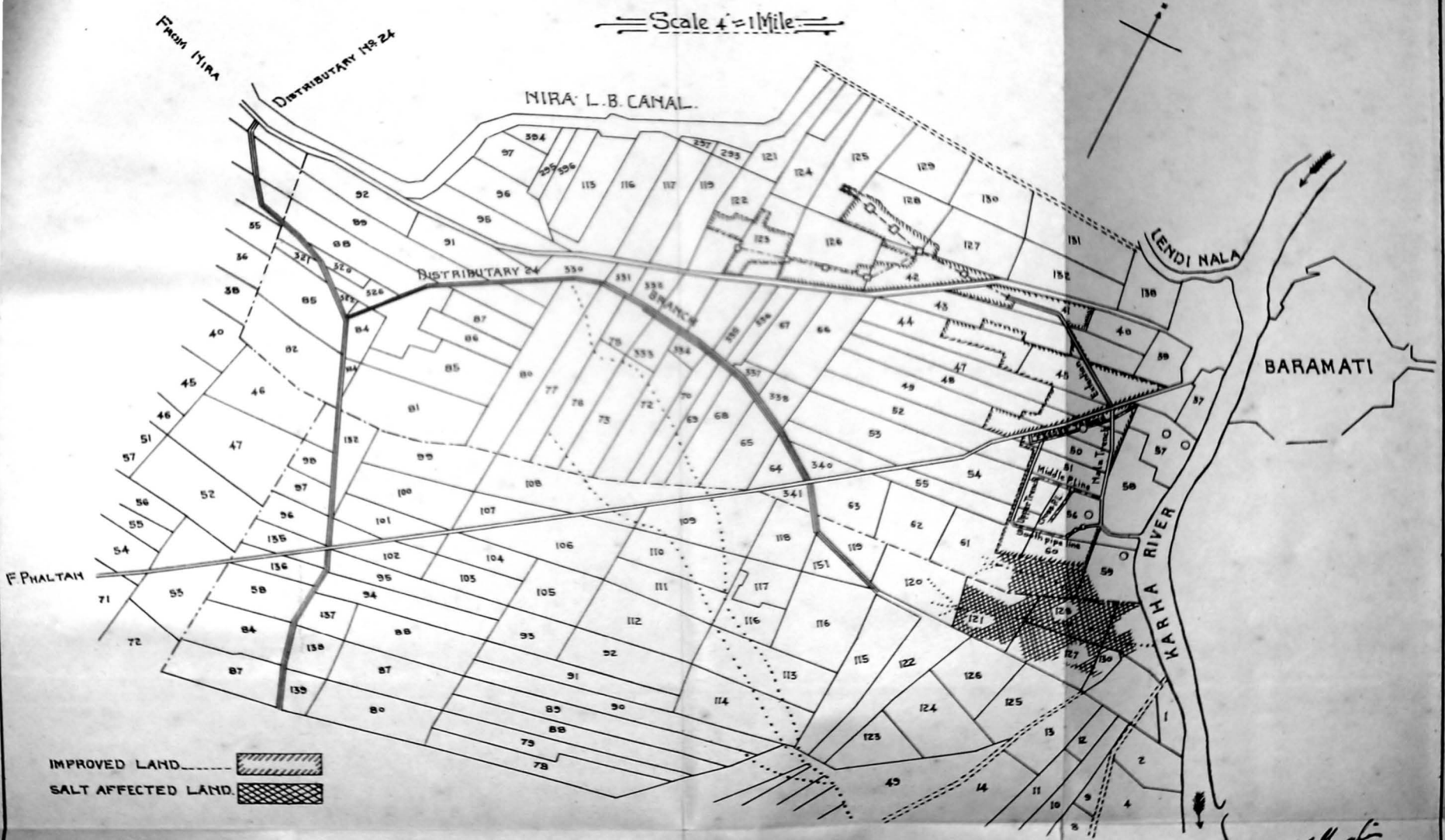
Special Irrigation Division

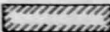
NIRA L.B. CANAL.


Plan showing land improved by the Drainage Scheme between.

distry: No 24 branch & distry: No 25.

Scale 4" = 1 Mile



IMPROVED LAND 

SALT AFFECTED LAND 

Chingli
 Executive Engineer
 Special Irrigation Division

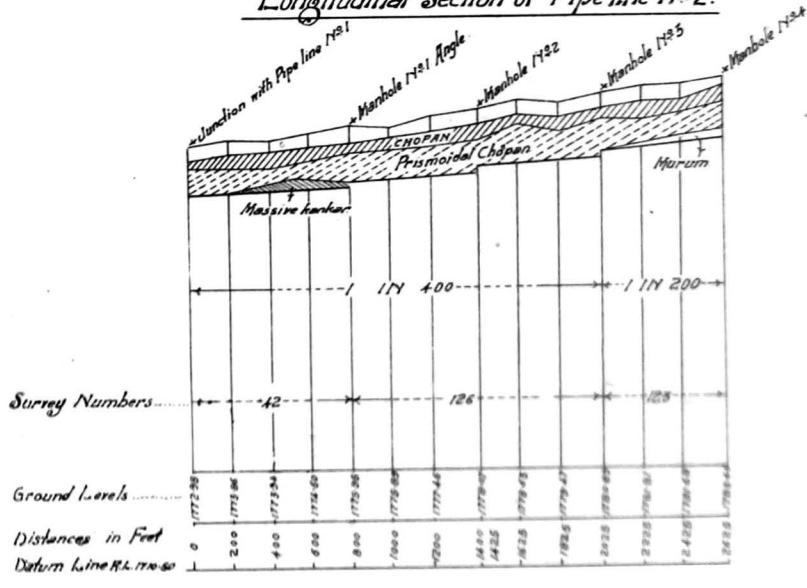
Special Irrigation Division

NIRA L.B. CANAL

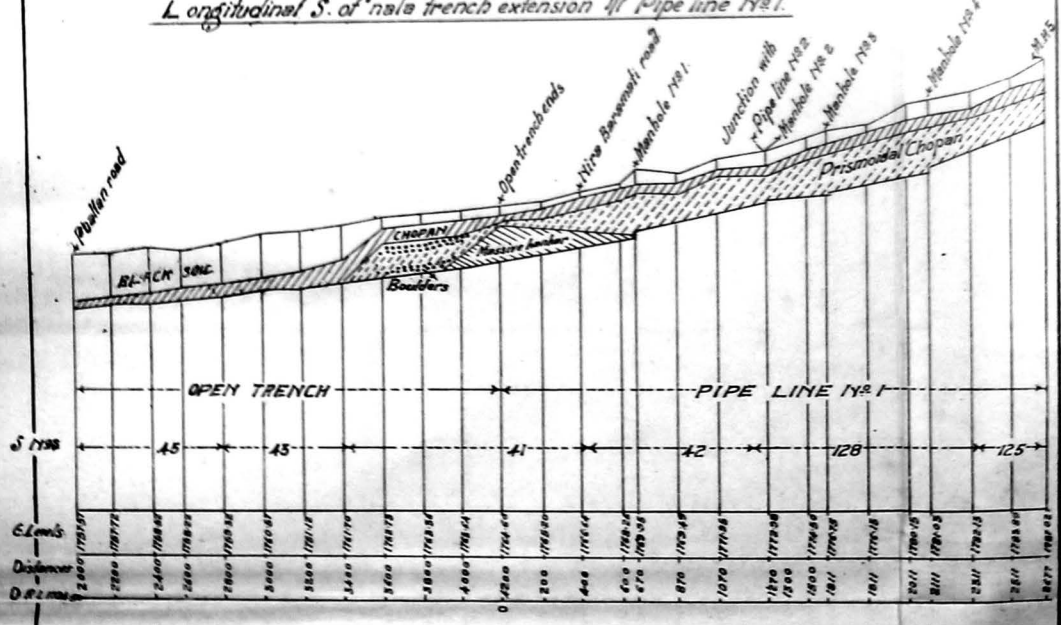
Land drainage of the area between distry: 24 branch of distry: 25.

Scale
 Hori: 660 = 1"
 Vert: 20 = 1"

Longitudinal Section of Pipe line No 2.



Longitudinal S. of nala trench extension of Pipe line No 1.



Trg: M.C. Bantshi 21-2-23

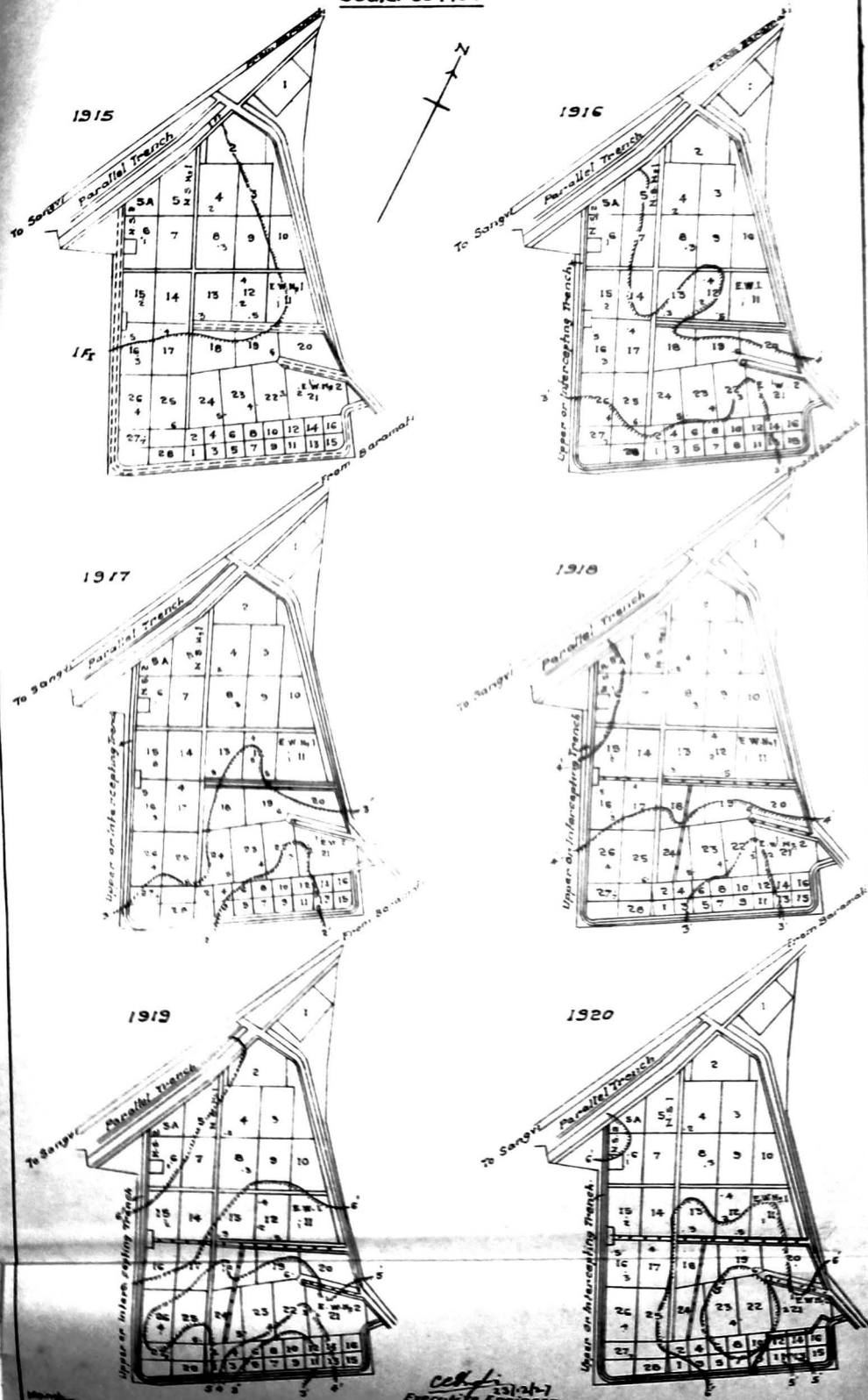
C. Bantshi
 Executive Engineer
 Special Irrigation Division

Special Irrigation Division
Experimental Salt area

FIG. 14

BARAMATI
Scale: 504 to 1

Note: Hydro-isobaths showing depth of sub soil water below ground



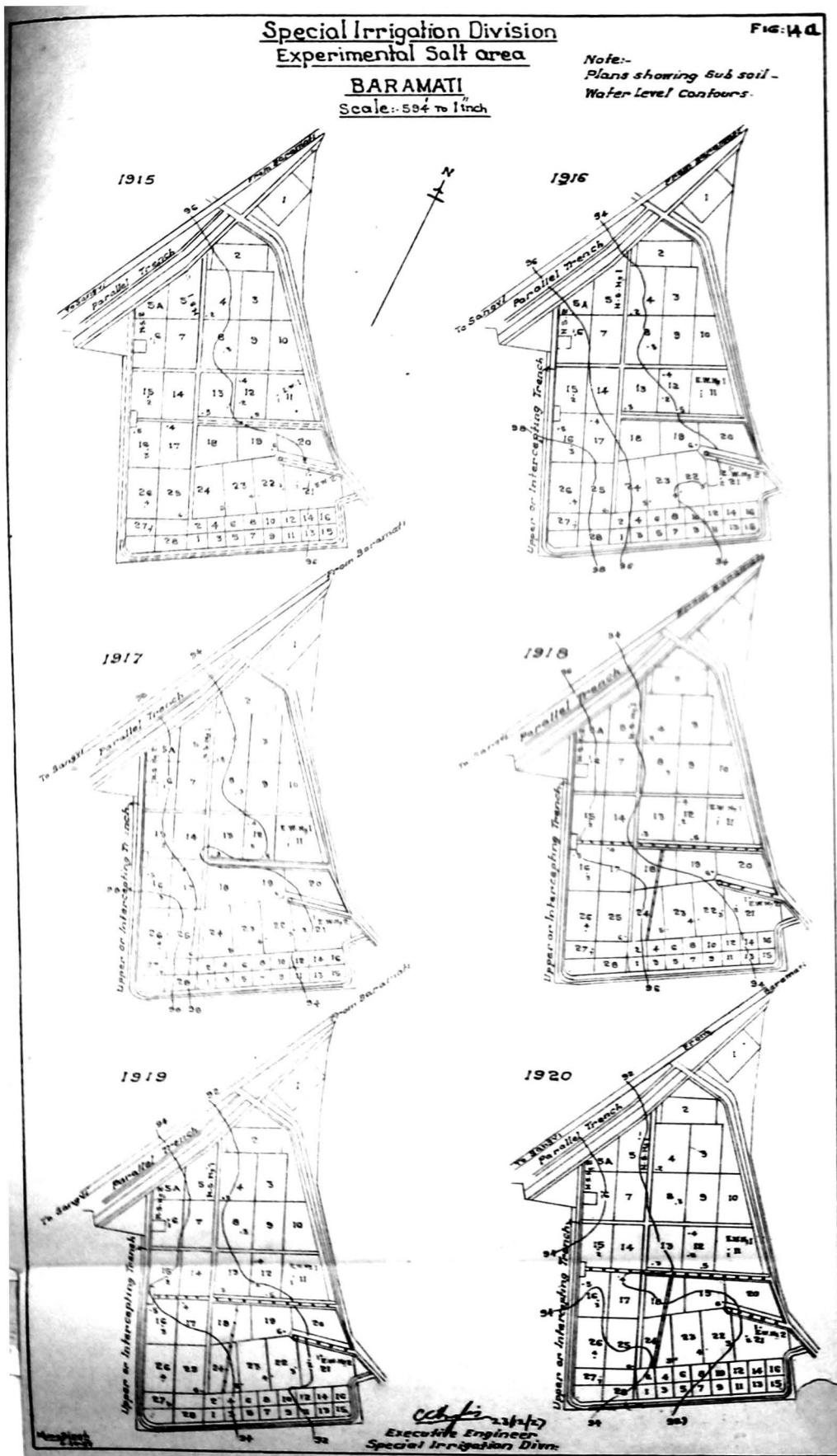
C. K. [Signature]
Engineer
Special Irrigation Divn.

Special Irrigation Division
Experimental Salt area

FIG. 14 D.

BARAMATI
Scale: 5/32 to 1 inch

Note:-
Plans showing Sub soil -
Water Level Contours.

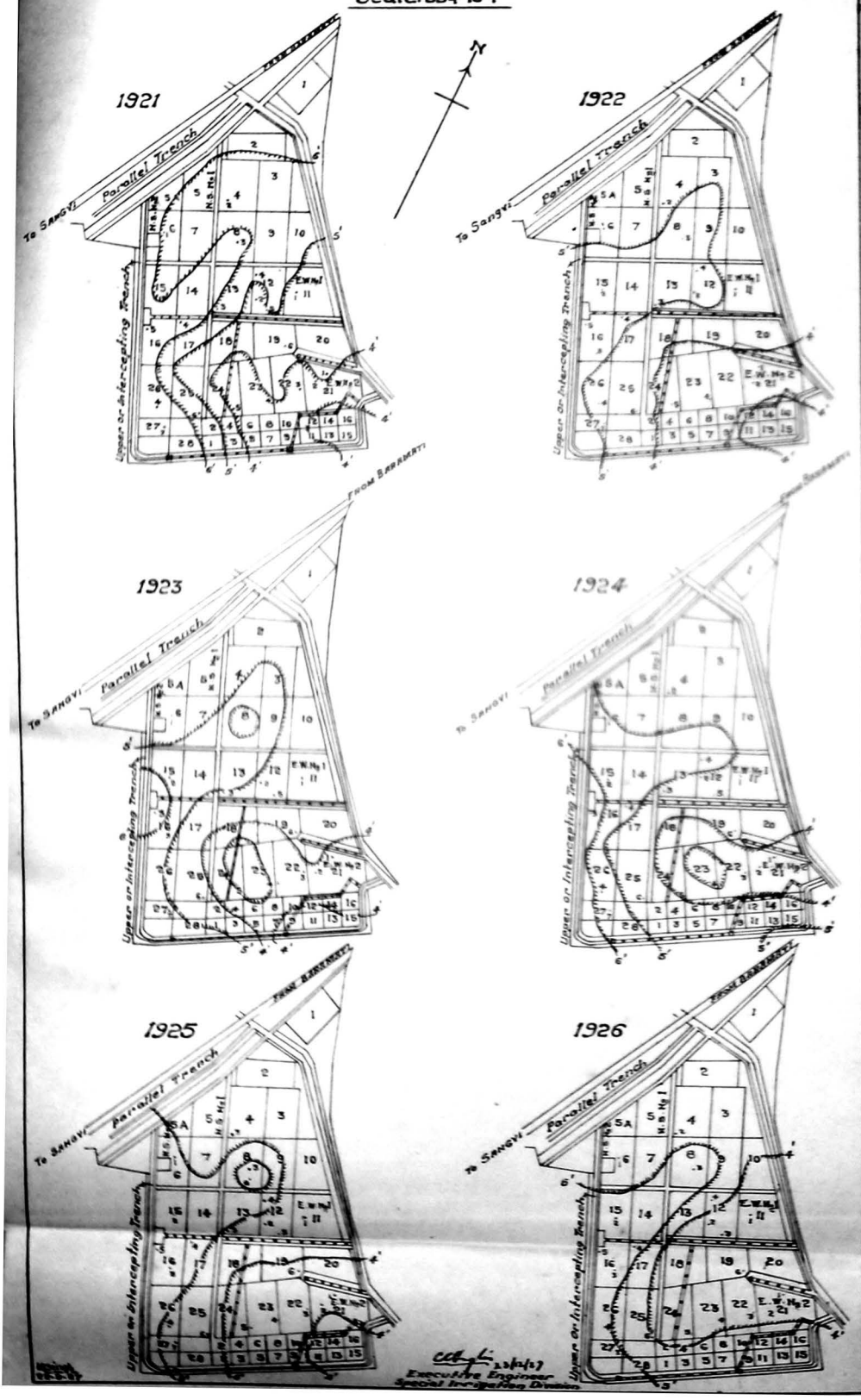


Special Irrigation Division
Experimental salt area

FIG: 15

BARAMATI
Scale: 594 To 1"

NOTE:- Hydro-isobaths
Showing depths of
subsoil water below ground



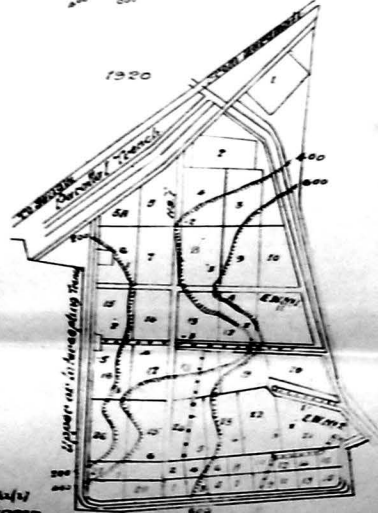
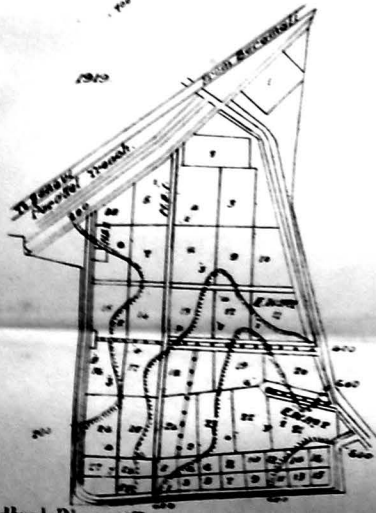
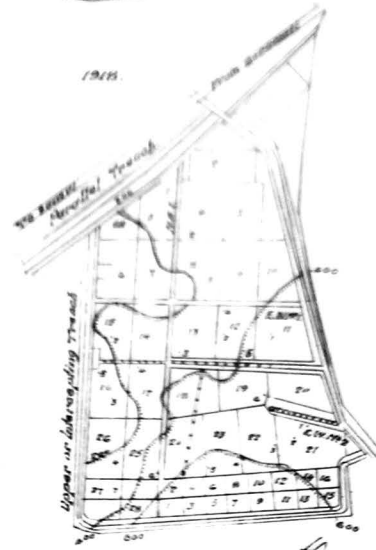
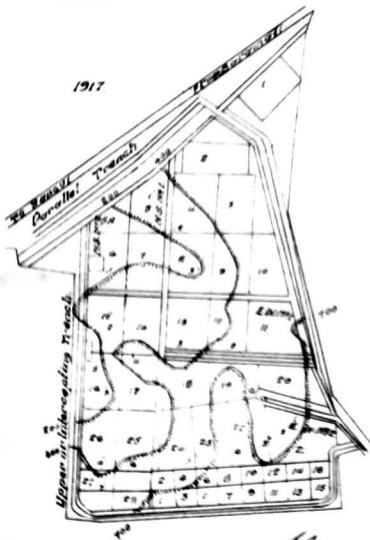
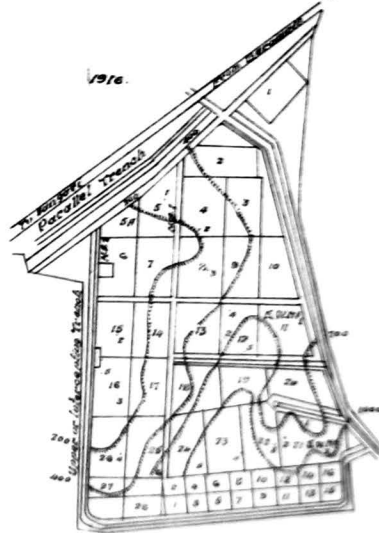
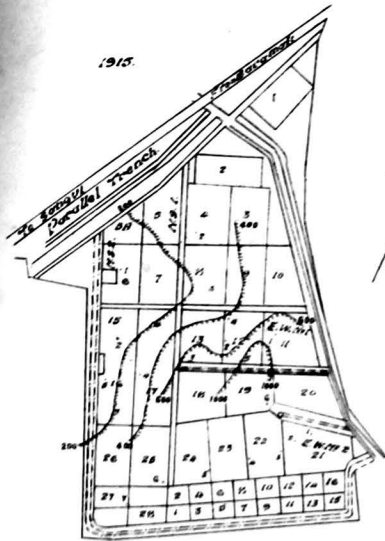
C. L. ...
Executive Engineer
Special Irrigation Division

Special Irrigation Division
 Experimental Salt area

FIG: 16

BARAMATI
 Scale: 504 to 1 inch

Note
 Contours showing concentration
 of soluble salts in sub soil water
 concentration shown in parts per thousand



Traced by: L.P.

ccf
 Executive Engineer
 Special Irrigation Divn

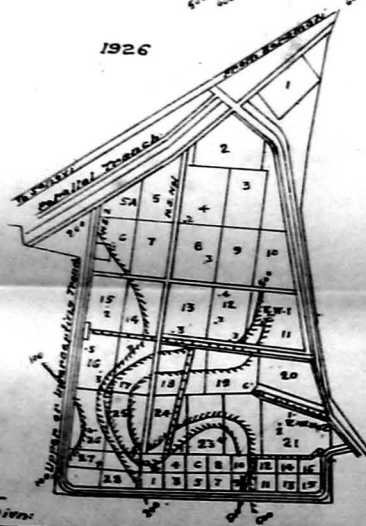
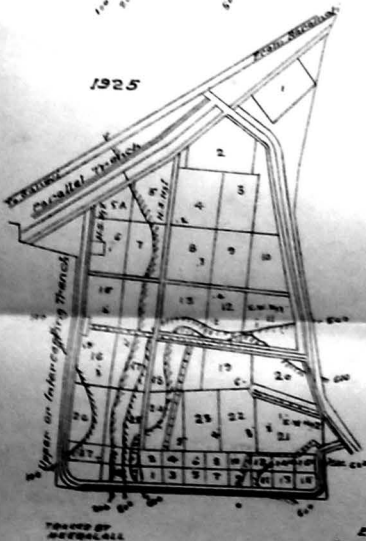
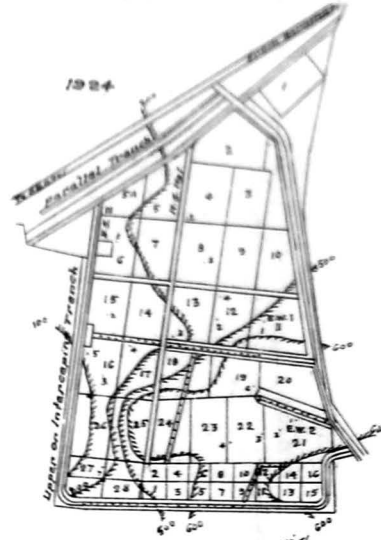
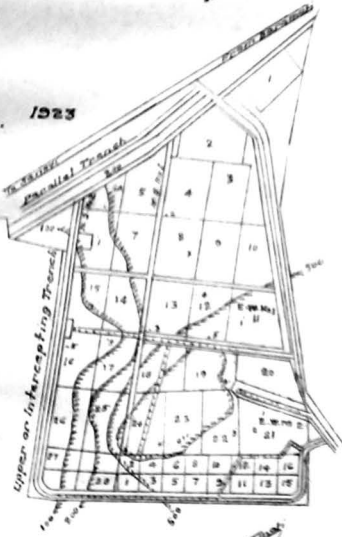
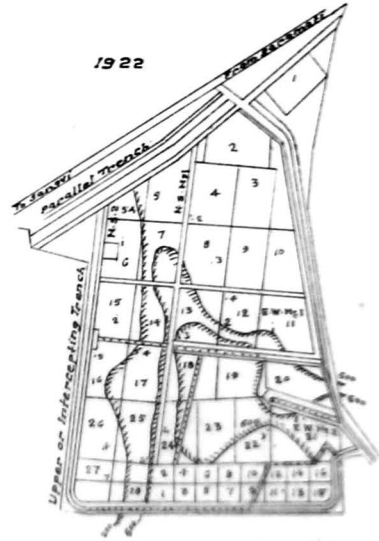
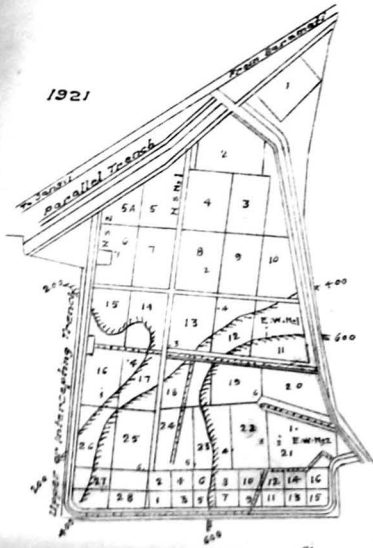
Special Irrigation Division
Experimental Salt Area

FIG:17

BARAMATI

Scale: 594 to 1 inch.

Note:-
Contours showing concentration
of soluble salts in sub soil water
Concentration shown in parts per 1000

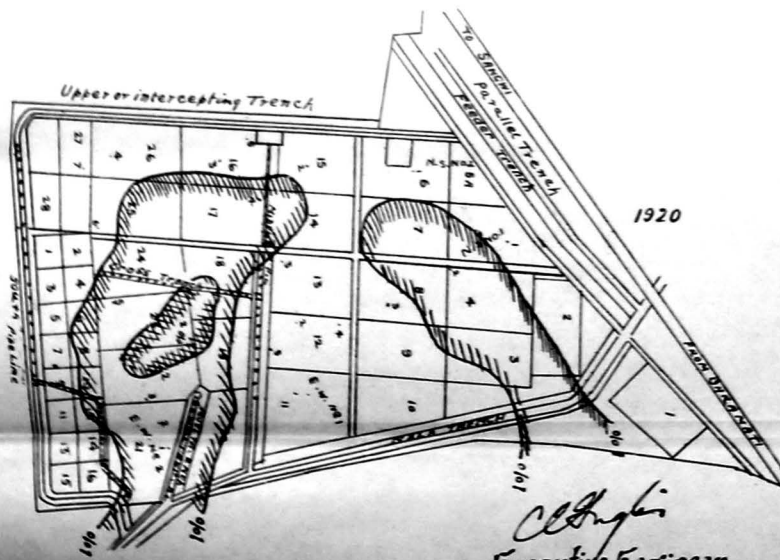
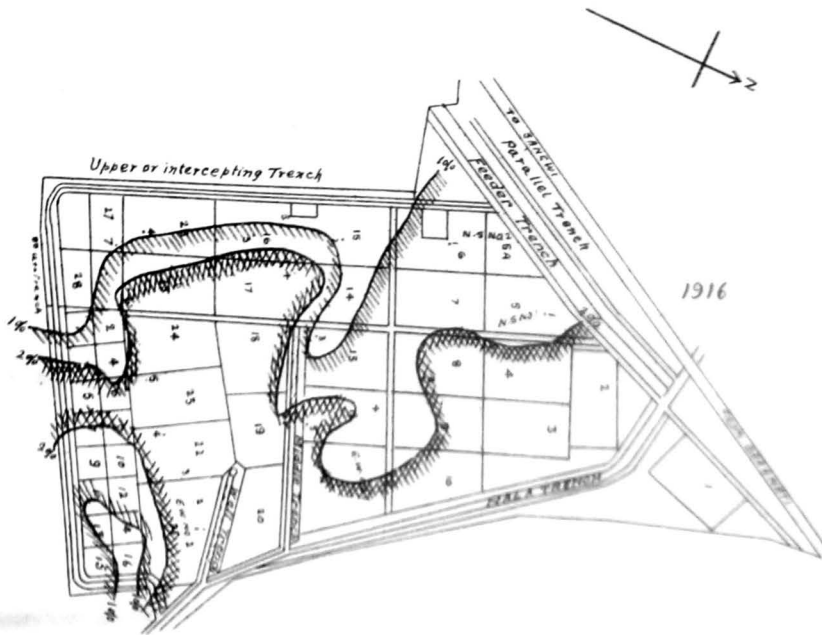


Prepared by
S. S. Kulkarni
Executive Engineer
Special Irrigation Divn.

FIG. 18

Special Irrigation Division
Experimental Salt Area
Baramati
Scale 306:1'

Contours showing concentration of soluble salts in the surface soil. [12"]



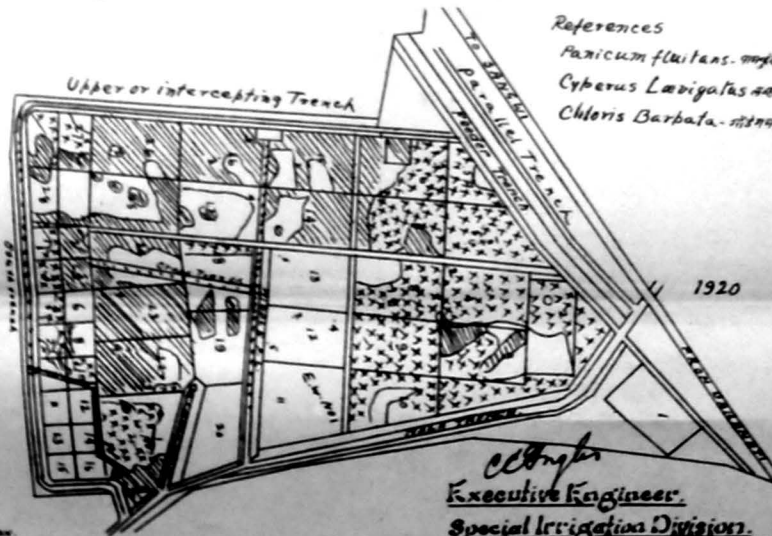
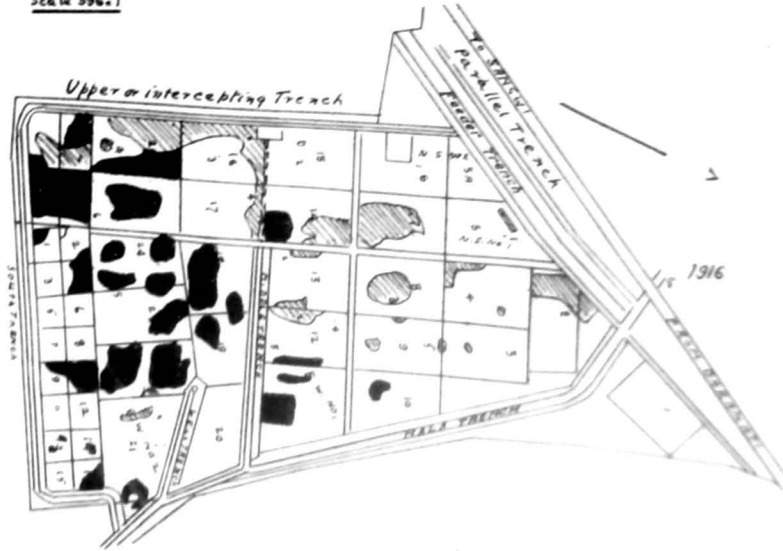
C. D. Inglis
Executive Engineer
Special Irrigation Division

Special Irrigation Division
Experimental Salt Area

Bara matj
 Scale 396:1

FIG 20

Plans showing progressive changes in weed colonies as a result of drainage



References

- Panicum fluitans* - 1910 (diagonal lines)
- Cyperus Laevigatus* - 1918 (solid black)
- Chloris Barbata* - 1920 (stippled)

C. C. Singh
 Executive Engineer,
 Special Irrigation Division.

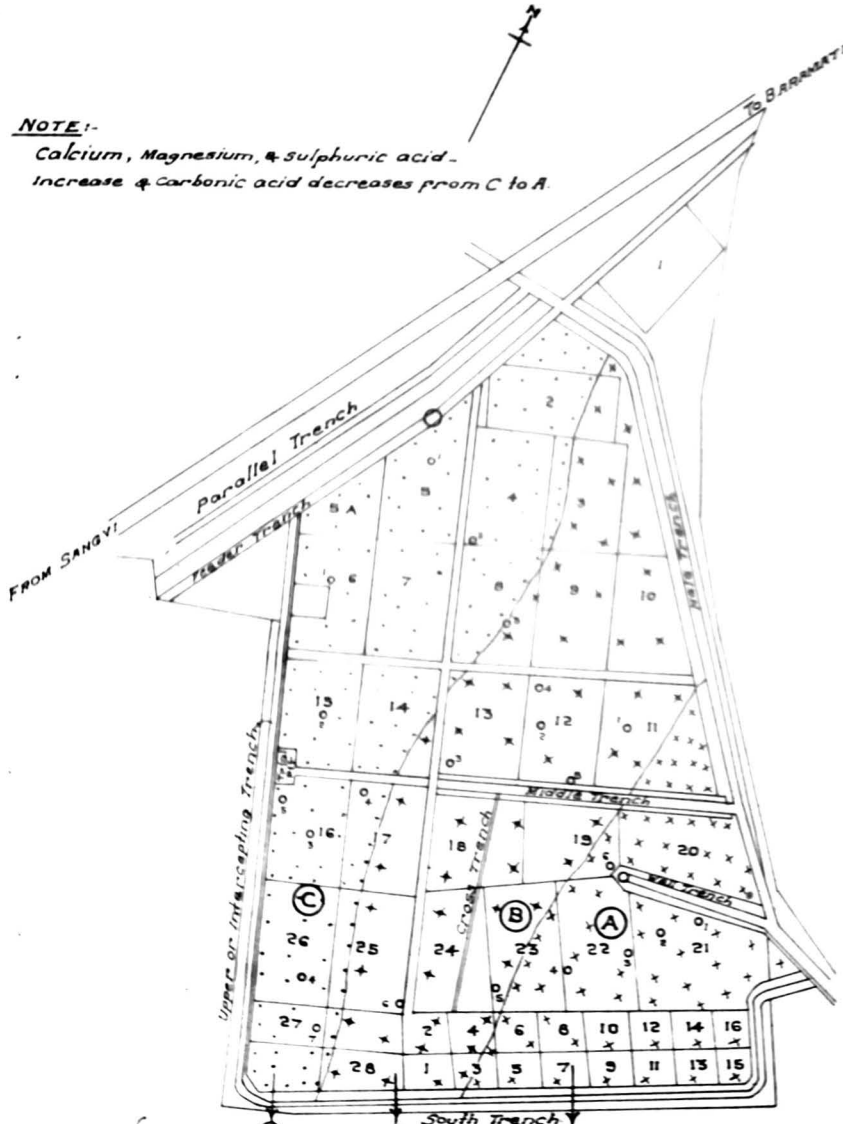
Special Irrigation Division
Experimental Salt area Baramati

Plan showing three portions in the experimental
Salt area where definite proportions of
soluble salts occur in the sub soil water

Scale: 297' to 1 inch

NOTE:-

Calcium, Magnesium, & sulphuric acid -
increase & carbonic acid decreases from C to A.



Composition of Soluble salts	South Trench		
	(C)	(B)	(A)
CaCO ₃	3.6	3.9	4.8
MgCO ₃	5.2	MgCO ₃ 2.3	CaSO ₄ 2.1
NaHCO ₃	22.8	MgSO ₄ 5.3	MgSO ₄ 16.7
Na ₂ CO ₃	1.8	0.4	0.7
Na ₂ SO ₄	44.2	68.4	57.0
Na	14.0	13.1	10.7

M. S. Bhat
1957

M. S. Bhat
Executive Engineer
Special Irrigation Division