Hydraulic Laboratories of the West, Their Technique and Equipments.

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IN the West hydraulic experiments have come to be recognised as the first essentials before a hydraulic construction of any magnitude is undertaken. Though the laws concerning hydraulic similitude are still in the making it is admitted on all hands that hydraulic model experiments conducted on proper lines can show up all the intricacies of movement inside the water medium which our present knowledge of mathematics and hydrodynamics cannot follow. It is therefore one of those cases that crop up very often in modern sciences where experiments come to the help of mathematics to establish a theory. This intimate interplay of theory and practice makes Hydraulics one of the most difficult of sciences. A number of careful experiments were conducted in the 19th century on various hydraulic problems. "Of these experimentalists perhaps Mariotte, Bernoulli and D'Alembert with Poiseuille, Darcy and Bazin in France, Rankine, Froude, Reynolds and James Thomson in England, Eytelwein, Weisbach and Hagen in Germany, Venturi in Italy with Francis and Hamilton Smith in America are most worthy of note.

"In spite, however, of all the work which has been so ably accomplished by these and other observers, Hydraulics cannot yet be classed as an exact science. The laws governing many of its phenomena are still imperfectly understood."[1] It had continued like this for some time till it was recognised that these laws had very serious limitations. Hydraulic structures based on Bligh's theory were found to be very unsafe[2], canals designed on Kennedy's theory very seldom ran smoothly.[3] Hydraulics was at this stage when it was felt that something more than empirical laws was necessary if we wanted to control nature—a deeper insight into the workings of nature. A scientific and not only practical handling of the problems was felt imperative. It was felt that these problems must be tackled more scientifically always with an eye to their practical applications. This new recognition has given rise to three distinct classes of Hydraulic Laboratories. The first are the purely scientific laboratories generally called Hydrodynamic Laboratories. These extend their fields of activities not only to Hydraulics but to Aeronautics and Meteorology as well. The second class are purely practical and are strictly confined to the practical solution of definite problems. The third class are a combination of the above two and have the most difficult and most useful career before them. I shall take a typical case from each of these classes and show their workings.

Of the first class the best that I have visited is that of Prof. L. Prandtl of the University of Göttingen. It is called Der Kaiser Wilhelm Institute fur Stromungsforschung—the Research Institute for Fluid Movement. It has got four laboratories—one for hydrodynamical research, another for aerodynamics, third for turbine and the fourth for research by students. As I was concerned mostly with the first laboratory I shall describe briefly some of the experiments that were being carried on there at the time of my visit. The experiments that have made Prandtl's Laboratory famous throughout the scientific and engineering world are varied. I shall concentrate mainly on Turbulence that has direct bearings on Irrigation Problems. Prof. Prandtl's laws of turbulent flow[4] in pipes have shown how even for high Reynolds' number the friction loss in pipes is dependent on this number. At present experiments are in progress that will show where this influence ceases. This fact that even in the turbulent region, unless the Reynolds' number is very high, friction loss due to turbulence depends on this number, is very important for model experiments and limits very seriously the dimensions of the model. It is well to point out here that the loss of energy due to turbulent friction is much more, sometimes even a thousand times more than that due to viscous friction. Prandtl's theoretical

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[1] *Hydraulics and Its Application*, Prof. Gibson.

[2] E. Mckenzie Taylor, *Curr. Sci.*, 1934, **2**, 367.

[3] G. Lacey, "Uniform flow in alluvial rivers and canals," *Proc. Inst. Civil Engineers*, Session 1933-34, **23**.

[4] "Neue Ergebnisse der Turbulenz-forschung," Prof. L. Prandtl. *Zeitschrift des Vereines Deutscher Inginieur*, 1933.

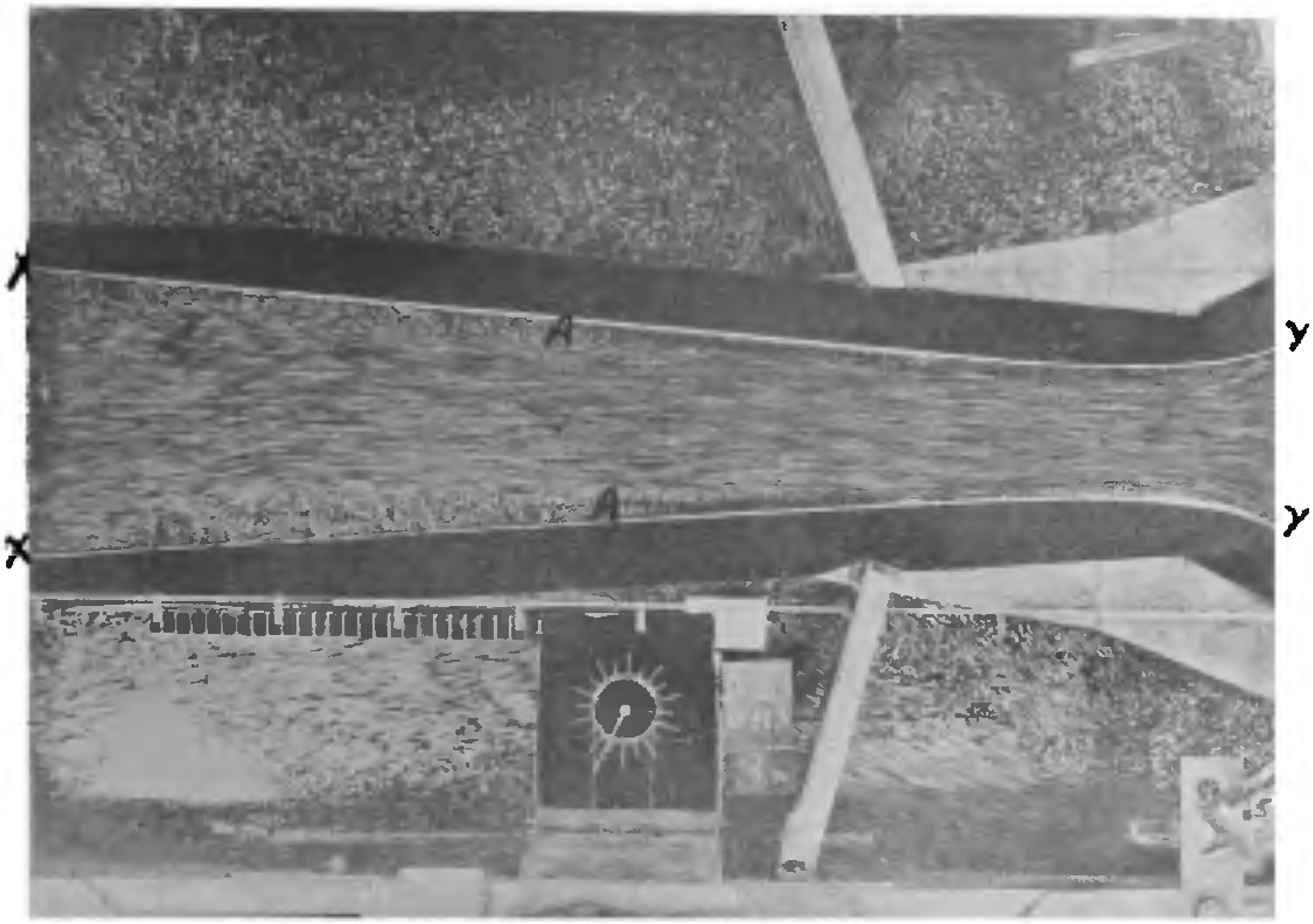

Fig. 1.

Refers to a series of experiments mentioned on page 4 in Prof. Prandtl's Laboratory at Göttingen.

Illustrates beautifully at A and A the side scour on the downstream end of an apron—XAY and XAY are the sides of the apron. The clock work with the scale enables the velocity of flow to be recorded automatically.

deductions from these experiments and G. I. Taylor's[5] mathematical analysis of Townsend and Fage's experiments have to a certain extent cleared our ideas about turbulence and will in future help us to tackle the problem of silt-control in rivers and canals. There is another class of problems that are being tackled in this laboratory that have direct bearing on some of our irrigation problems. It is well known that when water flows along a fixed surface there is a retarded layer of water between the fixed surface and the free fluid. This retarded layer called the boundary layer under certain circumstances leaves the fixed surface and generates a series of vortices between the fixed surface and the free fluid. These vortices generally scour away the fixed surface. It will be seen that we have the same phenomenon occurring at the downstream end of the wing walls of a fall or a weir. This problem is being attacked theoretically and experimentally in his laboratory.

[5] "The Transport of Vorticity and Heat through fluids in Turbulent Motion," Prof. G. I. Taylor. *Proceedings of the Royal Society*, Series A, 1932, **135**.

Of the second class the best I think is at Carlsruhe under the direction of Prof. Rehbock. Though Rehbock started his hydraulic research with his well-known formula for the discharge over a rectangular weir, of late years he has been mostly busy with experiments on river control and harbour reconstruction. His work on Zudar See was directed principally with an eye to immediate application; and in his present work on the Rhine, all his energy has been directed to the practical solution of the problem. His conception of 3 or 4 variables and treating them as independent has been more than justified by success. In dealing with river problems or scour and silting problems he is not at all conventional but strikes out a path which is novel and very often not approved of by the leading hydraulicians. I shall describe in detail only one of the various experiments that are in progress in his laboratory. The general principles of river experiments are as follows: When it is decided to do model experiments on a stretch of a river a long stretch of the river is taken and 2 or 3 different models with different scale ratios are constructed, say 200: 1, 160: 1, 150: 1, the length ratio and the depth ratio are the same. Having thus fixed 'n' the discharge is consequently fixed. The river is then built with its levée that has remained stationary for a considerable length of time. The bed of the model which has a different slope steeper than that of the river is filled uniformly with brown-coal—very light chips of coal about 1 to 1·5 mm. in size and density about 1·4—to a certain depth. A certain discharge is allowed to pass over the model for different lengths of time and the contours traced out by the water are photographed by a camera that travels on two rails at a height of about 2 to 3 m. above the model, the rail is kept parallel to the water surface so that photographs of the same size are obtained every time. These contours are then obtained for different discharges and then compared to the actual contours of the river bed: by this means a time factor for each experiment is obtained which is different for different rivers. This time factor depends on the slope and the quality of the silt used. For a stretch of the Rhine they have found that for the scale ratio 160:1, the time factor 61 is nearly correct, so that a change that took 2 years in the Rhine to take place will require less than one day in the model. This makes his experiment quick and has been more than justified in practice.

Of the third class of laboratories I think that of Prof. Meyer Peters at Zurich is by far the best. Though built only three years

Fig. 2.

Shows a corner of Prof. Meyer Peters' Laboratory.

A marks the big flume referred to on page 6.
B marks the moveable inlet arrangement
referred to on page 7.

ago one could easily see that it has got a most useful career before it. In equipment and arrangement I think it is the best and being the youngest it has profited by all the experiences of its predecessors. A series of experiments that are being carried on there will show clearly how Prof. Meyer Peters is trying to combine theoretical and practical aspects of a problem in these experiments. I found his assistant Einstein, son of the world-famous scientist, busy in finding the model rules for experiments with silt. This is in connection with some Rhine experiments in which it is proposed to investigate the silt carrying capacity of the Rhine. At present there are two similar experiments on the same line—one with pebbles about the size of 3 to 4 cm. and the other with ·5 to ·8 mm. The central idea in these experiments is the following:—In the experiments on the bigger scale which is supposed to be the prototype, of the 4 variables Q the quantity of water, q the quantity of pebbles introduced per second, i the slope and t the depth of water, only the quantity q is variable, all the other quantities are kept constant. It is found that for each Q and q, the slope i and the depth t adjust themselves, so that by changing q, the slope and depths can be varied. Corresponding to this big scale experiment a model experiment on a small scale about 20:1, is being carried on in a small flume, so that for each Q there corresponds a Q', for i a i', t a t' and q a q'. This is being done in the two flumes simultaneously with corresponding Q and Q'. It will be seen that of these two experiments that on the big scale one is directed to a practical purpose whereas the small scale one serves the purpose of establishing the theory of model experiment for silt.

The equipments of these laboratories have been more or less standardised in the course of the last few decades. With the exception of a few arrangements that might be required to meet the special needs of any particular set of experiments or sometimes the special bias of the man in charge, the hydraulic laboratories are coming to be built more or less on the same lines. There are a few well-recognised principles :—

1. There should be as few fixtures in the hall as possible. With the exception of the High Level Reservoir no arrangement is fixed in the laboratory—even this exception Prof. Seifert of the Prussian Government Laboratory at Charlottenburg thinks unnecessary. This is found to add considerably to the flexibility of a laboratory and to its capacity to accommodate different experiments specially on river-control at the same time. The latest laboratory of Prof.

Meyer Peters is built on this type and has been found to work quite satisfactorily. In his laboratory there are a number of moveable inlet arrangements provided with graduated rectangular weir. These inlets can be joined to the high-level reservoir, connections from which run all over the laboratory floor; and they can be coupled with any experiment that wants the required discharge, so that it is possible to build the model at any part of the floor of the laboratory hall.

2. The High Level Reservoir is regarded as the soul of the Laboratory. Much depends on the way this behaves. A steady supply of water is found to be the first essential of all hydraulic experiments. The type at Carlsruhe has become the model for almost all the laboratories. It has the overflow capacity of six litres per meter length of the spillway. This is found to be more than ample—sometimes we can do with less. Of course opinions differ about the most suitable height for these reservoirs. Rehbock thinks they should not be higher than 2 to 3 m., whereas that one at Prag is as high as 9 m. On discussion with Prof. Smetana, Director of the Prag Laboratory, I found that the experiments that are usually carried on in his Laboratory require very high heads and he wants to have as much head as possible available. It is well to remember that Prof. Smetana's Laboratory has been built to meet the special problems of Czechoslovakia, that found herself after the War separated from Germany and Austria faced with the necessity of generating power without coal or petroleum. She turned to her only river Moldava and started harnessing it for power generation. This laboratory has been built to control the river with a certain degree of security.

3. A general concurrence of opinion appeared to be that it is much better to measure the water surface in an experiment directly by means of a pointer from above than to take it in a side vessel connected with the main flow by means of a pipe. Of course the latter method has got this advantage that once the water surface is to be measured in a side vessel where the movement of the level is negligible, highly accurate technique can be applied. In spite of this advantage it is coming to be recognised that bore holes for the gauge wells can never be accurately placed and if the streamlines are not exactly perpendicular to the bore which is very unlikely in turbulent flow, there is a danger of false reading. Hence water-levels are read in the open by pointers every 10 sec. about 20 times continuously and then averaged out. It is found that this gives better level than the gauge well readings.

There are a number of special problems that are coming to be recognised as being amenable to model experiments. Mention has already been made about one of these, movement of silt in canals and rivers. Another is the problem of seepage in a porous medium such as the sand. It was Darcy who first derived the empirical law of flow associated with his name; but it was Forchheimer[6] who first attacked this problem theoretically and showed how the movement in such a medium follows some well-known definite laws. Forchheimer's deduction is based on the assumption that the movement of water in a porous medium is capillary. Experiments have not been conducted to prove this. The series of experiments that are at present being carried on in the Punjab Irrigation Research Institute will prove or disprove this definitely. However the argument of the Vienna School is something like this. It having been established that movement in such a medium is laminar experiments on models follow as a matter of course. In Prof. Schaffernak's Laboratory at Vienna such model experiments are done now more or less as a routine work; and Prof. Schaffernak thinks that with the theoretical treatment of these problems on the lines suggested by Prof. Forchheimer and with the experimental simplification arrived at by him in his laboratory," it is possible to calculate the probable seepage from a dam or a canal, the expected safety of a weir or dam foundations against blowing up. Model results in this field have come to be recognised here as reliable as those in any other cases of hydraulic experiments: and the model laws in this case being better known and understood it is possible to transfer all model results to the full-scale structures, with a greater degree of confidence than in any other fields of hydraulics. Prof. Schaffernak and his assistant Dr. Dachler have reduced the whole thing to such a state that they can predict the safety of a dam or a weir, or the seepage from a canal with a fair amount

[6] "Zur Grundwasserbrurgung nach Isothermischen Kurvenscharen, Prof. Phillip Forchheimer, *Wien*, 1917.

of accuracy. Whenever a problem is referred to them they put the model (generally to a scale of 25 : 1) in a sand tank and run the experiments for a certain length of time and photograph a few streamlines with colouring dyes. This photograph with a few certain other data of the experiment is analysed in a very ingenious way[7] and they know how the prototype is going to behave under similar conditions. Of course the porosity of the soil below the prototype forms an important factor in this behaviour. In river constructions particularly it is known that the soil medium is stratified. This stratification alters the course of streamlines and pressure gradients in a very marked way. This has also been tackled by the Vienna School. How to take account of the heterogeneity of the soil has been considered by Prof. Terzaghi and forms an interesting chapter in his book "Erdbaumechanick". So between Forchheimer, Schaffernak and Terzaghi they claim to have solved this problem of seepage and safety of dams more or less completely and they claim very close agreement. It will be seen that their whole claim rests on the assumption of Forchheimer which if not supported by experiments the whole superstructure falls.

The above is a very short account of my experience during my last visit to the principal hydraulic laboratories of the West. I am afraid some of the points require amplification and it is hoped to deal with them more at length in some future issue.

[7] "Versuchstechnische Lösung von Grundwasserproblemen". Prof. F. Schaffernak and Dr. R. Dachler, *Die Wasserwirtschaft Jahrgang*, 1931, heft 1 and 3.

The Study of Plant Tissue Fluids. A Critical Review.

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PLANT physiologists have interested themselves in the study of saps which represent the nearest phytological analogue of blood. The great success achieved by physiologists in the field of clinical chemistry, has stimulated the investigation of tissue fluids which regulate all the principal metabolic processes in plants. A study of the sap should give a closer insight into the metabolic changes in the plant than that obtained by an investigation of the whole tissue which includes the static reserves and the physiologically inert structural units comprising the plant organism.

Tissue fluid studies have proved useful in elucidating the nature of the physiological changes accompanying the (*a*) various phases of growth, (*b*) changes of environment and season, (*c*) manuring, and (*d*) onset of diseases. Valuable information has been obtained with regard to the suitability of a particular soil for the cultivation of a given crop. The fact that the fluid of the tea leaf has a pH value of 4·3—4·5, is an indication that the crop prefers an acid soil and instances are known where liming of tea soils and attendant reduction in acidity, has proved detrimental to tea growth.[1] The analysis of indigenous plants has provided significant indication regarding the suitability or otherwise of the area for the introduction of related exotics.[2] Tissue fluid studies have been employed with more or less success for obtaining information regarding the biogenics of essential constituents of plants; establishing varietal differences of crops [3-7] for elucidating the nature of drought [8-13]

[1] Cooper, *Ind. Tea Ass. Sci. Dept. Quart. J.*, 1925, pt. iv, p. 130.

[2] Harris *et al*, *J. Agr. Res.*, 1924, **27**, 893.

[3] Balls, *Proc. Camb. Phil. Soc.*, 1914, **17**, 467.

[4] Harris, Gortner and Lawrence, *J. Phys. Chem.*, 1921, **25**, 122.

[5] Harris, Gortner and Lawrence, *J. Gen. Physiol.*, 1921, **3**, 343.

[6] Harris and Popenoe, *J. Agr. Res.*, 1916, **7**, 261.

[7] Newton and Martin, *Can. J. Agr. Res.*, 1930, **3**, 336.

[8] Gortner, Hiffman and Newton, *C.A.*, 1924, **18**, 2543.

[9] Pantanelli, *C.A.*, 1919, **13**, 1602.

[10] Harvey, *J. Agr. Res.*, 1918, **15**, 83.

[11] Dexter, Tottingham and Graber, *Plant Physiol.*, 1932, **7**, 63.

[12] Salmon and Fleming, *J. Agr. Res.*, 1918, **13**, 497.

[13] Maximov, *Protoplasma*, 1929, **7**, 259.